Age and Growth of Klamath River Green Sturgeon (*Acipenser medirostris*)

Rodney J. Nakamoto
U. S. Forest Service
Redwood Sciences Laboratory
1700 Bayview Drive
Arcata, California 95521

Tom T. Kisanuki
Greg H. Goldsmith
U. S. Fish and Wildlife Service
Coastal California Fish and Wildlife Office
1125 16th Street
Arcata, California 95521

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U.S. Fish and Wildlife Service
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INTRODUCTION

During 1992, the U.S. Fish and Wildlife Service, Coastal California Fish and Wildlife Office (CCFWO), and the U.S. Forest Service, Redwood Science Laboratory (RSL) were jointly funded through the Klamath River Basin Fisheries Task Force to conduct an age and growth investigation on green sturgeon (*Acipenser medirostris*) from the Klamath River. This Task Force was created under the provision of the passage of the 1986 Klamath River basin Conservation Area Fishery Restoration Program (P.L. 99-552). This public law was initiated to restore the anadromous fish stocks of the Klamath River basin, and to offset the effects of dams, floods, timber harvest, mining, and other detrimental impacts (Klamath River Basin Fisheries Task Force 1991).

Within California, green sturgeon have been reported in the Sacramento, Eel, Klamath and Trinity river systems. Presently, green sturgeon have disappeared from the Eel River. Green sturgeon tend to spend much of their life in the ocean (Chadwick 1959, Miller 1972), returning to freshwater streams to spawn. Tagging information suggests that there is significant interchange among green sturgeon populations along the Pacific Coast (Chadwick 1959). Klamath and Trinity river green sturgeon are unique in that they represent the only California population which migrate significant distances upstream (Fry 1973). Currently, information pertaining to green sturgeon biology is scarce (Houston 1988). The USFWS has identified green sturgeon as one of five stocks of special concern due to their depressed stock status (USFWS 1988). Further, Moyle (1989) identified green sturgeon in California as a species of uncertain status needing additional investigation.

Basic information pertaining to the ecology of any fishery population is essential for effective management. The scarcity of information pertaining to green sturgeon ecology is a significant barrier to developing an effective management plan for this species. The objectives of this study were to:

1. Define the age composition of sturgeon harvested in the 1990-1993 Klamath River gill net fishery.

2. Define the age composition of green sturgeon captured incidentally in CCFWO's 1989-1990 beach seining project in the Klamath River estuary.

3. Provide descriptive growth data on Klamath River green sturgeon.

4. Determine the utility of pectoral fin ray sections in estimating the age of green sturgeon.

5. Examine the utility of using Optical Pattern Recognition System (OPRS) for age and growth interpretation work of green sturgeon.

6. Expand the current biological database on green sturgeon.

STUDY AREA

The Klamath River originates in Oregon and flows in a southwesterly direction into California. The Klamath River drains approximately 14,400 square kilometers (km^2) and 26,000 km^2 in Oregon and California, respectively. Iron Gate Dam on the Klamath River at river kilometer (rkm) 306, and Lewiston Dam on the Trinity River (rkm 179) represent the upper limits of anadromous salmonid migration in these basins.

The Klamath River has historically supported large runs of anadromous fish such as chinook salmon (<u>Oncorhynchus</u> <u>tshawytscha</u>), steelhead trout (<u>O.</u> <u>mykiss</u>), eulachon (<u>Thaleichthys</u> <u>pacificus</u>), Pacific lamprey (<u>Entosphenus</u> <u>tridentata</u>), and smaller runs of coho salmon (<u>O.</u> <u>kisutch</u>) and green sturgeon (<u>Acipenser</u> <u>medirostris</u>). These fisheries have significantly contributed to subsistence, sport, and commercial fisheries in California. Generations of Native Americans have utilized fishing grounds in the Klamath River basin. Salmon, steelhead, and sturgeon have historically provided the mainstay of the Native American economy and culture in the area (Bearss, 1981).

METHODS

Field Procedures

Sturgeon data and biological samples were collected from the mouth of the Klamath River, upstream 70 rkm to the river's confluence with the Trinity River, at Weitchpec, CA. The Klamath River flows through the Yurok Indian Reservation throughout this distance (Figure 1). The data and samples were collected in conjunction with the Native American gill net harvest monitoring and beach seining activities conducted by the CCFWO, Arcata, California, during the 1990-1993 seasons.

<u>Beach Seining</u>. The beach seining program in the Klamath River estuary was conducted to target the adult run of fall chinook salmon. This program was terminated after the 1990 season. During the 1990 season the sampling period extended from July 23 to October 2. Seining times for the 1990 season varied daily to target the tidal period from before slack low tide to immediately after the slack low tide. Seining schedules were conducted during daylight hours. Sturgeon catch during the beach seining operation was

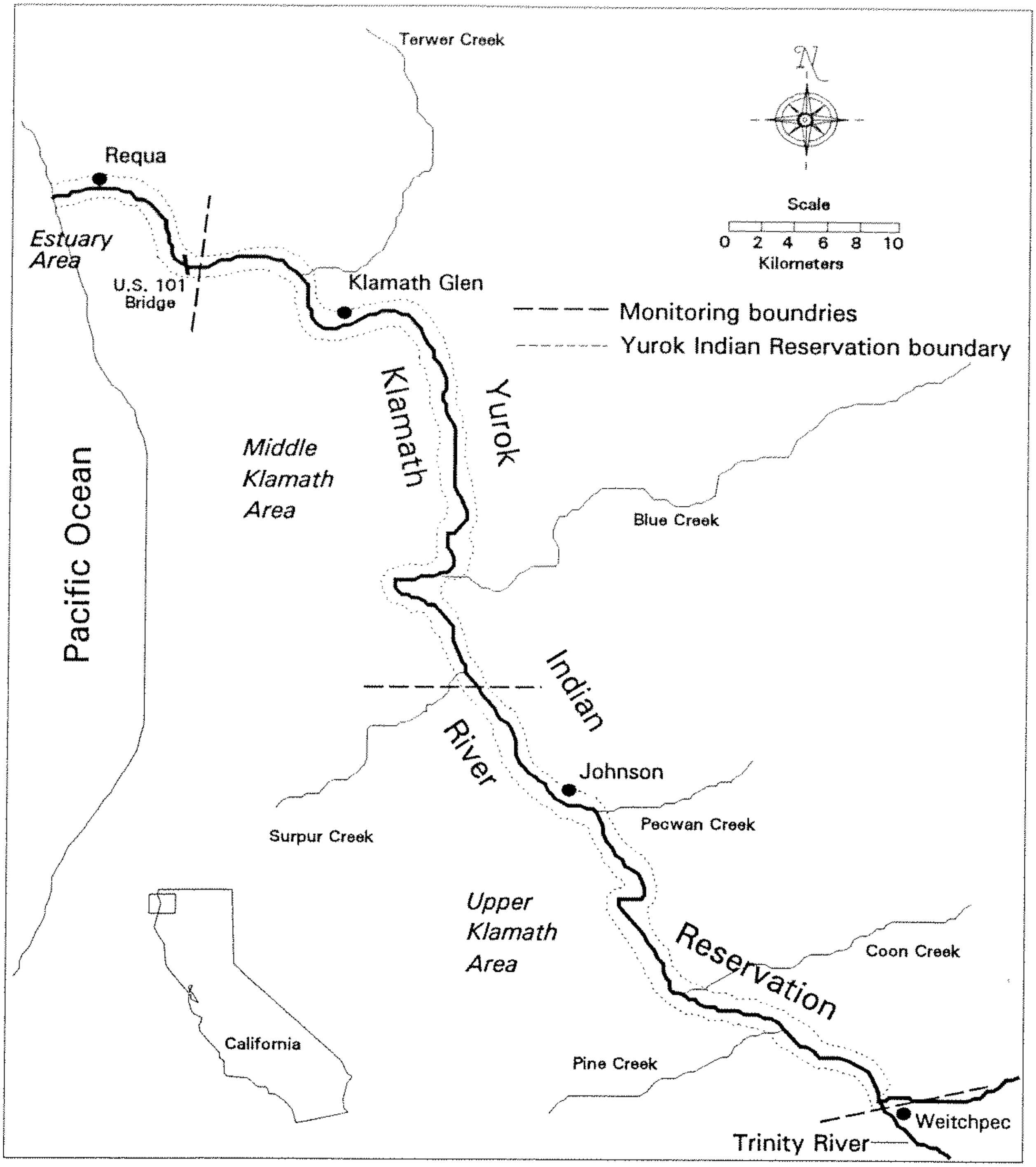

Figure 1. Map of the Klamath River and Yurok Indian Reservation depicting sampling reaches.

largely dependent on the physical characteristics of the seining site. Those sites which were characterized as off-channel, slow-water habitats favored sturgeon capture. A 150 meter (m) x 6 m beach seine net with a 5.4 cm bar mesh bag section was deployed with a jet boat, and retrieved to shore using gas-powered winches. Eight net sets were made each sampling day. Captured sturgeon were identified to species, measured for fork and total length, weighed, tagged with a Peterson disc tag, and a pectoral fin was excised prior to release. Fins were stored in plastic bags and frozen prior to conducting laboratory processing and analyses.

Net Harvest Monitoring. Coastal California Fish and Wildlife Office staff monitored the spring and fall Native American gill net fishery which target anadromous salmonids and sturgeon in the Klamath River. Detailed descriptions of the monitoring methodology are available in USFWS (1992). The spring monitoring period generally begins in early April, and concludes in mid-July. The number of sturgeon captured was generally dependent on spring flows. High spring flows hamper the operation of the Native American gill nets resulting in lower harvest rates and therefore fewer sturgeon available to measure. The fall fishery monitoring begins in mid-July, and usually ends in latter September, although in some years, dependent upon fishing quotas, has extended into October and November. Gill net harvest information was collected by CCFWO crews from three contiguous areas (estuary, middle Klamath, and upper Klamath) of the Klamath River on the Yurok Indian Reservation (Figure 1). The estuary area was defined as the lower 6 rkm, from the mouth to the U.S. Highway 101 bridge. The middle Klamath area is from the 101 bridge to Surpur Creek, a distance of 27 rkm. The upper Klamath area constitutes the final 33 rkm, beginning at Surpur Creek and ending at the confluence with the Trinity River, at Weitchpec, CA.

During periods of allowed fishing, CCFWO crews surveyed gill net fishermen in the estuary at two hour intervals. Native American fishers were interviewed during each time stratum to obtain information on the number of each fish species caught, the type and number of nets fished, and the number of hours fished. Those fishes made available by the fishers for examination were identified to species, measured, weighed, examined for identification characteristics (fin-clips, tags, etc), and sampled for scales (salmonids) or pectoral fin rays (sturgeon). The fins were transported to the laboratory and frozen until processing. Sex determinations were made based on examination of gonads. In those cases when the gonads were not available for examination the sex was listed as unknown.

The fishery was monitored four to five days per week in the middle and upper Klamath areas during the allowed fishing period. CCFWO crews interviewed Native American fishers for netting effort and biological information, in the manner previous described.

Laboratory Procedures

Frozen pectoral fin rays were thawed in boiling water, and defleshed with a stiff brush. The leading fin ray was isolated, and allowed to air dry. The fin rays were mounted on plywood strips and thin-sectioned using a lapidary saw (Raytec, Jem Saw Model 45), in accordance to methods described by Brennan and Cailliet (1989). The fin ray sections were then adhered to a glass microscope slide using clear nail polish.

The fin ray sections were examined with a microfiche reader equipped with a 30X lens. Banding patterns on the fin ray sections were interpreted in accordance to criteria outlined by Brennan and Cailliet (1989). It was assumed that the combination of one translucent (formed during the summer) and one opaque (formed during the winter) band represented a single years growth. The authors examined the fin sections independently and assigned numerical values to indicate the number of summer growth (annular) bands for each individual fish.

A Optical Pattern Resolution System™ (OPRS, BioSonics 1985) was employed to determine the feasibility and utility of this system in interpreting green sturgeon fin ray sections. This system utilizes a Ikegami (model ICD-4422) video camera linked to a Olympic BH2 microscope via a Olympic MTV-3 coupler. The camera interfaces with Biosonics OPRS software based on a 386 micro-computer. Prepared fin ray sections were placed in the microscope and the image was projected onto a video monitor. A reference line was drawn from the center to the posterio-lateral margin of the fin ray section and the software was allowed to select annular locations based on differential light transmission between winter and summer growth bands. The locations of each of the selected annuli were evaluated by the operator. All measurements for a particular fin ray were stored as records in a computer file.

RESULTS

Between 1990 and 1993, 243 sturgeon were measured as part of the Native American gill net harvest monitoring program and 30 sturgeon were measured as part of the beach seining program on the Klamath River. Regression equations were developed for the relationship between fork length and total length for males, females, and males and females combined (Table 1). Examination of F statistics and correlation coefficients for the equations suggested that the combined male and female equation best explained this relationship.

The leading pectoral fin ray from 154 of the 243 sturgeon collected between 1990 and 1993 was prepared for age and growth assessment. Ages were assigned to 148 sturgeon by two independent readers. Thirty-four percent of the two age estimates differed by less than two years. Sixty-six percent of

Table 1. Regression equations developed for the relationship between fork length (fl, cm) and total length (tl, cm) of green sturgeon (Acipenser medirostris, Ayers) measured from the Klamath River, 1990-1993.

Sex	n	Model	r^2	p
Male	58	tl = -2.0878 + 1.1202(fl)	0.99	0.0001
Female	33	tl = -8.3060 + 1.1597(fl)	0.95	0.0001
Combined[1]	91	tl = -4.6131 + 1.1374(fl)	0.98	0.0001

[1] Pooled males and females.

the age estimates differed by less than 5 years. The average difference between age assignments was 4 years (range 0-19 years). The mean of readings assigned by reader 1 (21 years, range 1-45 years) was 1 year greater than the mean of readings assigned by reader 2 (22 years, range 2-54 years).

Age assignments for 115 of the 148 sturgeon were also made using the OPRS system. The average age assigned by the OPRS system was 29 years (range 1-72 years). Age assignments by the OPRS system were consistently older than the age assignments using the microfiche reader. OPRS age assignments averaged 8 years greater than the average age assignment using the microfiche reader. Total length variation within a given age was greater for those sturgeon aged using the OPRS system compared to those aged using the microfiche (Figure 2). In addition, the OPRS results suggested that between ages 1-9 total length (tl) remains nearly static. Greater magnification, image clarity, and the computer enhanced ability of the OPRS system to differentiate between light and dark banding patterns may have resulted in the counting of false or incomplete annuli which resulted in the greater variability in the length-age relationship. Due to the greater variability in the data noted for the OPRS readings and the poor relationship at young ages, the average of the two microfiche readings will be used for further discussions of age.

Weight information was collected in conjunction with fork length (fl) data for 56 males, 31 females and 23 individuals of undetermined sex. Male sturgeon averaged 58 kilograms (kg) (range 20-112 kg) while female sturgeon averaged 94 kg (range 29-148 kg). The relationship between fork length and weight, and total length and weight were described by:

$$\text{weight} = -27.9907 + 0.0039(\text{fork length}^2)$$

$n = 90$
$r^2 = .85$
$p < 0.0001$

$$\text{weight} = -20.0434 + 0.0027(\text{total length}^2)$$

$n = 110$
$r^2 = .58$
$p < 0.0001$

Sex was determined for 165 individuals between 1990-1993. Female sturgeon were less abundant, older, and significantly longer than male sturgeon (Figures 3, 4). Female sturgeon averaged 32 years old (range 22-46 years) while males averaged 23 years old (range 9-45 years).

Sturgeon <60 mm tl were collected primarily during the beach seining operations within the Klamath River estuary. The beach seining operation was discontinued after the 1990 season. During 1990, 27 small green sturgeon were captured. These fish averaged 52 mm tl (range 32-66 mm tl). Age estimates for these individuals indicated that these individuals averaged 3 years old (range 1-4 years old). Previous years' data indicate that within the

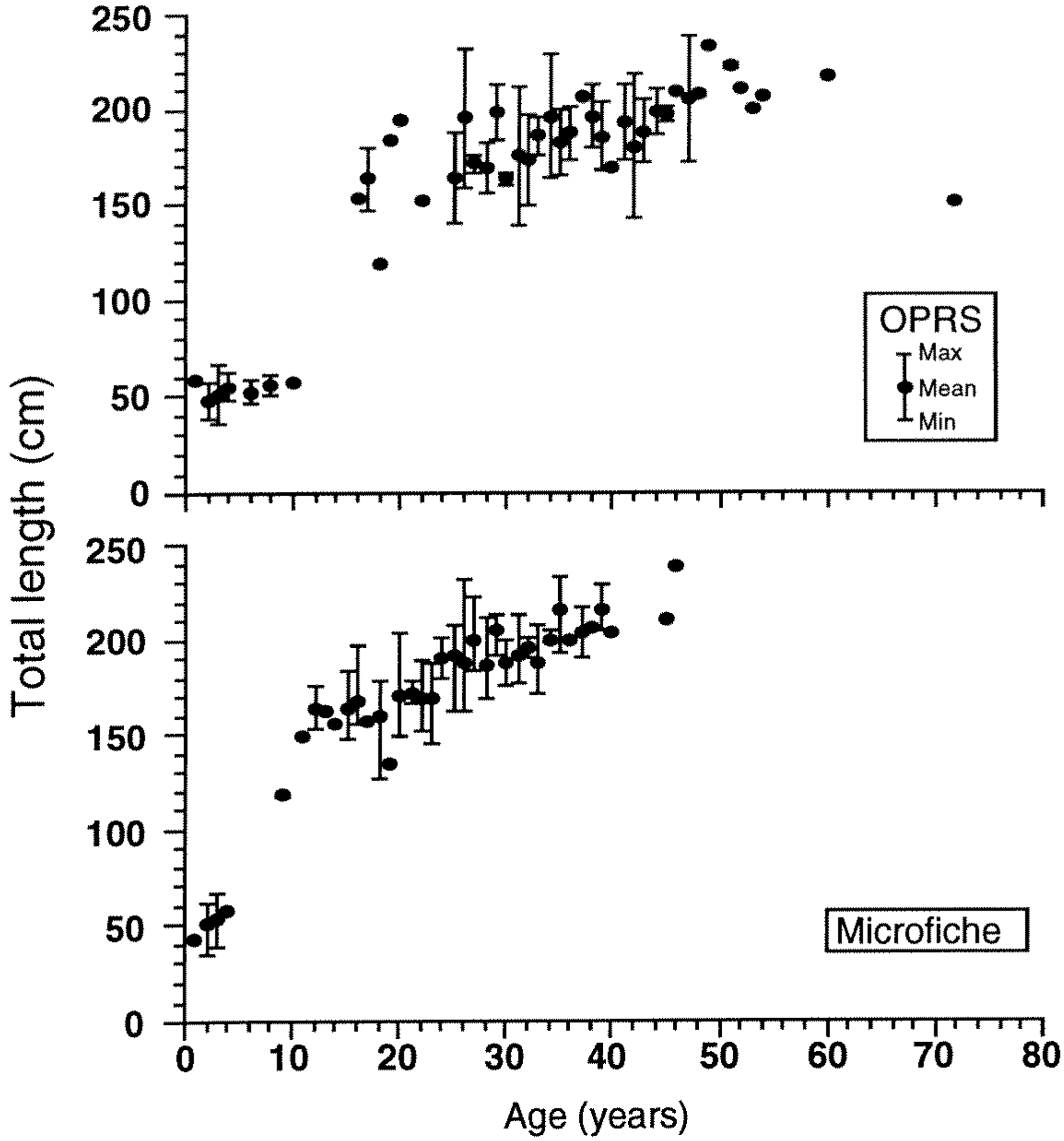

Figure 2. Mean and range of length at age for sturgeon aged using the Optical Pattern Resolution System (OPRS) and microfiche reader. Estimates using the microfiche reader are the average of two independent readings.

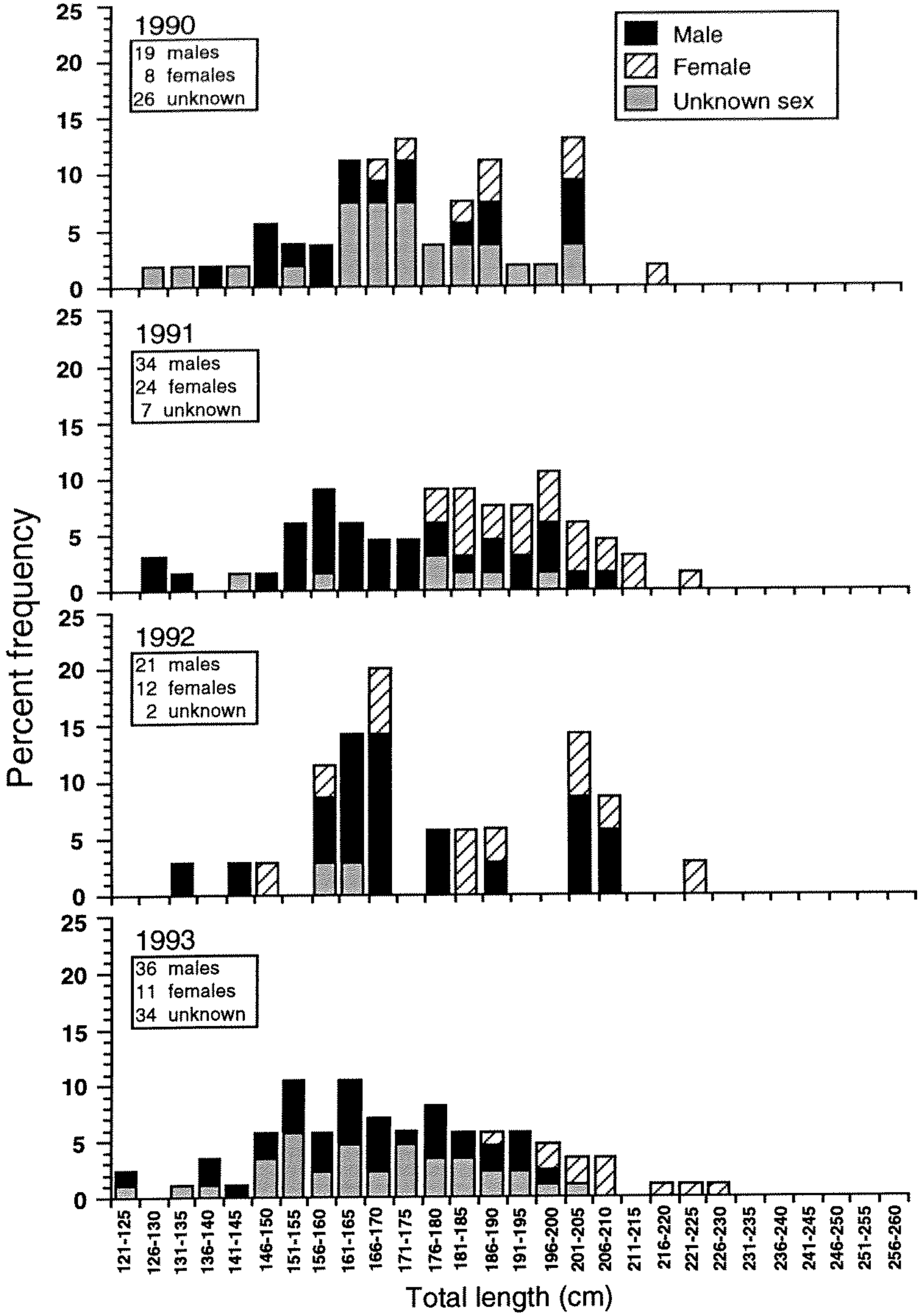

Figure 3. Length-frequency distribution (5 cm groupings) for male, female, and unknown sex green sturgeon measured from the Klamath River, California, 1990-1993.

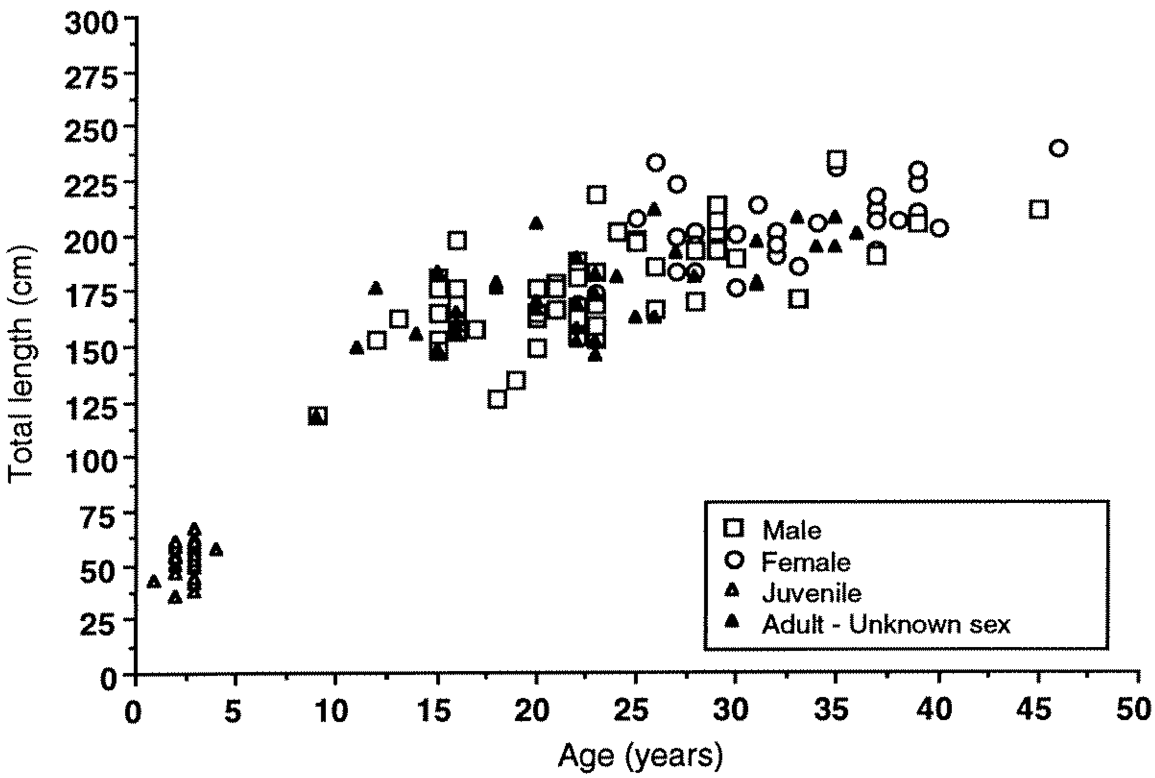

Figure 4. Length-age relationship for male, female, juvenile, and unknown sex green sturgeon measured from the Klamath River, California, 1990 - 1993.

Klamath River estuary the abundance of these small sturgeon peaks between July and September. Juveniles generally spend up to 3 years in freshwater prior to migrating to sea, primarily during the summer-fall period (Emmett et al. 1991, USFWS 1982).

A conspicuous lack of individuals measuring between 71-115 mm was observed in the length-frequency distribution for sturgeon collected between 1990 and 1993 (Figure 5). Similar length-frequency distributions were obtained by the USFWS (1982, Figure 5). Previously published information suggests that individuals within this size range are migratory marine residents and seldom venture into freshwater.

We further examined data collected on 610 green sturgeon measured in the Klamath River between 1980 and 1993. Previously published information indicates that green sturgeon can reach 230 cm fl (256 cm tl) and 159 kg (Moyle 1976). However, they seldom exceed 130 cm fl (144 cm tl) and 45 kg (Skinner 1962). Within this study, 431 of the 610 individuals exceeded 130 cm fl (mean 160 cm, range 132-233 cm).

We compared the lengths of male and female sturgeon measured between 1980-1982 to those measured between 1990-1993 (Figure 6). The results demonstrate that the patterns noted between 1990-1993 were similar to those noted between 1980-1982. Female sturgeon were generally larger and less numerous than male sturgeon.

DISCUSSION

Significant difficulties were encountered in aging the pectoral fin ray sections. The annular patterns consisted of alternating dark and translucent bands. The wide dark bands result from the abundant formation of connective tissue during the summer, converted later to bone tissue; the narrow translucent bands correspond to the period of metabolic inactivity during the winter (Brennan and Cailliet 1991). Examination of the prepared fin ray sections using a microfiche reader revealed that annular patterns within the sections were extremely difficult to differentiate. The irregular shape of the fin ray combined with close spacing and discontinuity of the circuli and incorporation of secondary fin rays made confident age assessment difficult. These difficulties have been encountered by other researchers (Roussow 1957, USFWS 1983, Brennan and Cailliet 1989). The observed variability in sturgeon size at each age appears to be characteristic of sturgeon studies (Semakula and Larkin 1968, Kolhorst et al. 1980, USFWS 1983). Kolhorst et al. (1980) suggested that size variation at each age may be real. The reduced growth rates of older fish and prespawning age fish, formation of spawning checks, long migrations or adverse environmental conditions may contribute to decreased ability to accurately assess age from pectoral fin ray sections

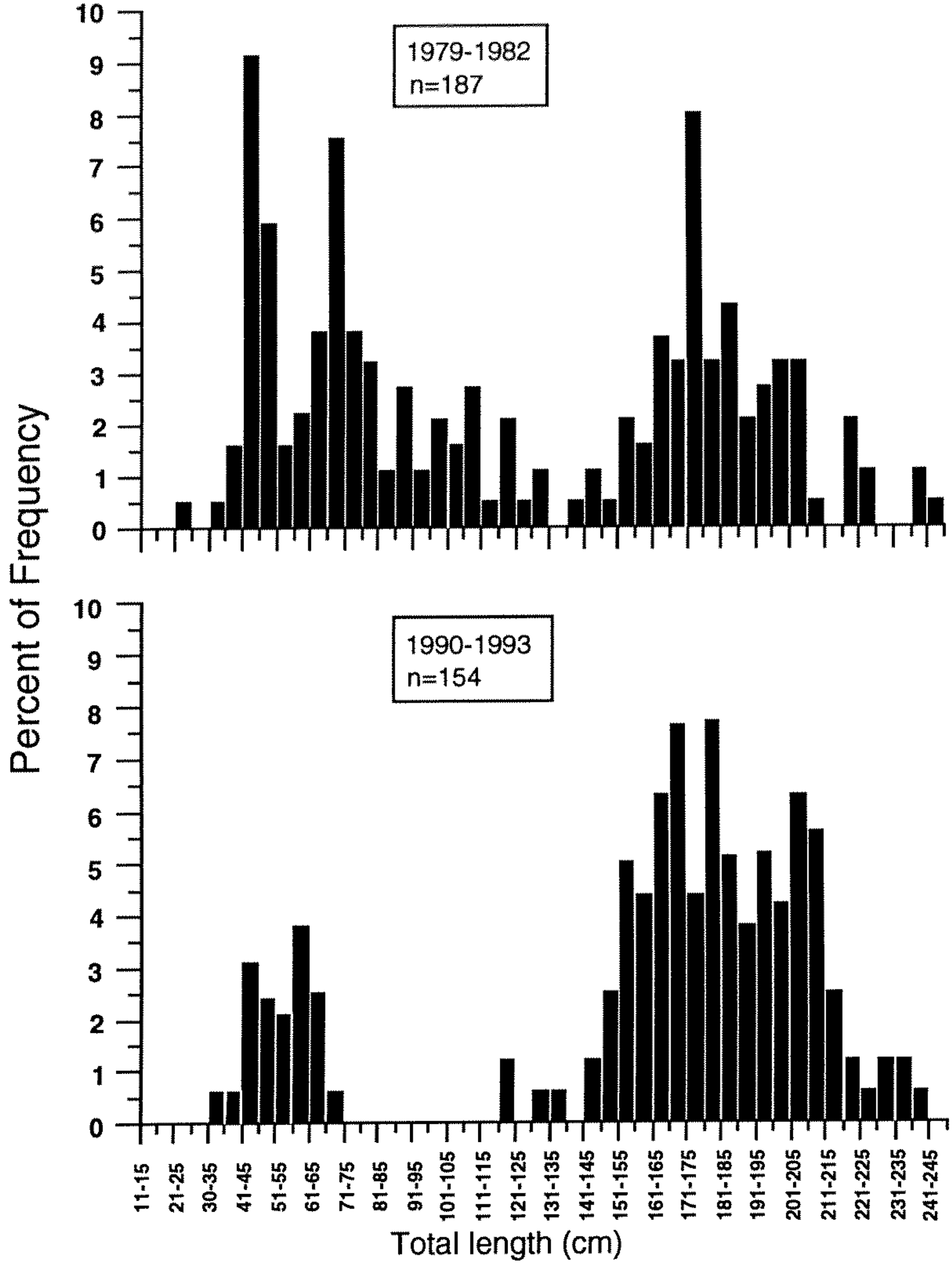

Figure 5. Length-frequency distributions of green sturgeon measured as part of the beach seining and Native American net harvest monitoring monitoring activities conducted by the U.S. Fish and Wildlife Service, Arcata, California, in the Klamath River for periods 1979-1982 and 1990-1993.

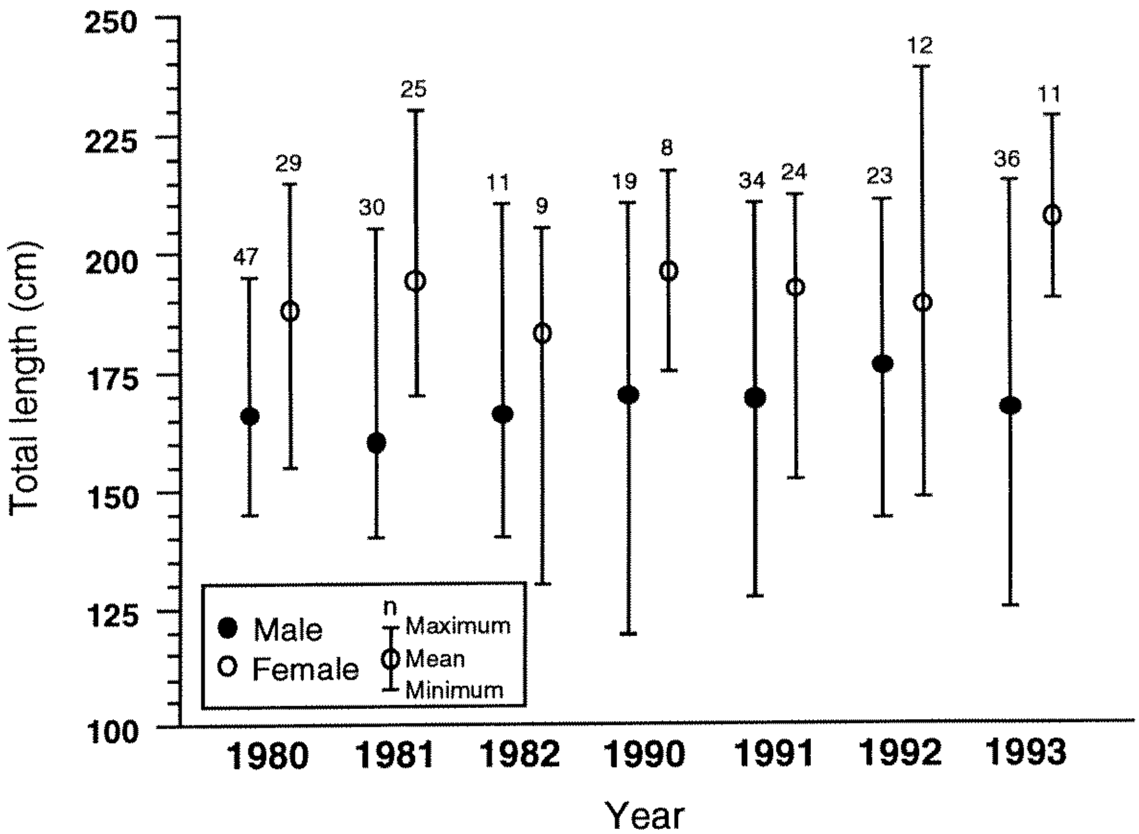

Figure 6. Mean, range, and sample size for total lengths of male and female green sturgeon measured in the Klamath River, California, 1980-1982 and 1990-1993.

(Roussow 1957, Sokolov and Malyutin 1978, Kolhorst et al. 1980, Keenlyne and Jenkins 1993, Rein and Beamesderfer 1994).

The relative rarity of males between ages 3-9 years and females between the ages of 3-13 years suggests that these individuals spend relatively little time in freshwater. Within the Klamath River these individuals are usually observed between July and October (USFWS 1982, 1983, 1992). Previous reports have documented the marine migratory behavior of subadult and adult green sturgeon. Green sturgeon tagged in San Pablo Bay were recovered as far north as Gray's Harbor and as far south as Santa Cruz (Chadwick 1959; Miller 1972). Roedel (1941) reported the capture of a green sturgeon weighing 3.3 kg offshore between the towns of Huntington Beach and Newport, CA. Chadwick (1959) concluded that there is considerable interchange between green sturgeon populations along the Pacific Coast.

Females under 145 cm tl did not appear in the record. The smallest female sturgeon sampled between 1990 and 1993 was 148 cm tl. Size selectivity of the gill net would not preclude capture of females smaller than 145 cm tl as individuals under this size are commonly caught. The absence of small females in the harvest suggests that either prior to reaching 145 cm tl gonadal development was insufficient to determine sex or that females return to freshwater sometime after reaching 145 cm tl. This length would correspond to an age of about 13 years old. Males generally appeared in the harvest record after reaching 120 cm tl (8 years old). The size at which males mature is questionable as the gill net sampling efficiency is biased toward individuals greater than 120 cm tl. In addition, sex determination was based on gonadal observations. In many cases individual sturgeon less than 120 cm tl may have been caught but due to their small size they were released. In these cases, the observers would not have been able to determine sex. Although the length frequency distribution suggests that male sturgeon may begin spawning sometime after reaching 120 cm tl, this conclusion is tentative; male sturgeon may become reproductively active prior to reaching 120 cm tl.

The data suggests that male green sturgeon may become reproductively mature at a younger age than female green sturgeon. Differences in age at first spawning between sexes have been noted for other sturgeon species. Semakula and Larkin (1968) noted that the age at first spawning for white sturgeon (<u>Acipenser</u> <u>transmontanus</u>) from the Frasier River is 11-22 years (81-137 cm tl) for males and 11-34 years (81-231 cm tl) for females. Roussow (1957) reported age at first spawning for lake sturgeon (<u>Acipenser</u> <u>fulvescens</u>) in Canada varied between 12-19 years and 14-23 years for males and females, respectively. Keenlyn and Jenkins (1993) reported that male pallid sturgeon mature at ages 5-7 years while females may begin spawning sometime after 17 years old.

The use of pectoral fin rays for estimating the age of sturgeon was not a precise method. However, these results do not totally discount the utility of this method. Comparison of the length-age relationship reported by the USFWS (1983) to the relationship obtained in the herein reveals that the relationships are very similar (Figure 7). The similarity in the relationships adds some strength to the utility of pectoral fin ray analysis. The pectoral fin ray analysis offers a simple and practical tool for fisheries managers. The pectoral fin rays can be obtained without sacrificing the sturgeon. Green sturgeon are a long-lived species, with a life span of several decades. Age estimates for nearly 70% of the individuals differed by less than 5 years. The results of this study and previously published information suggest that green sturgeon life history can be divided into three general phases: 1) freshwater juveniles ($\leq$3 years old), 2) coastal marine migrants (3-9 years for males, 3-13 years for females) and 3) adults. Further research aimed at investigating spawning periodicity, fecundity, survival, and the degree to which adults may use rivers other than their natal rivers for reproduction is needed in order to effectively manage this long-lived species.

RECOMMENDATIONS

The OPRS system may be a valuable tool for green sturgeon age assessment. The computer assisted technology offers a fast and precise means of fin ray interpretations. In contrast to the microfiche, the OPRS may over-estimate the age of sturgeon. This was attributed to the acute discriminatory abilities of the OPRS system. Additional experimentation and calibration may be necessary to fully utilize this technology for age analyses of sturgeon fin rays. The utility of this system should be further explored.

The use of pectoral fin rays in this study for estimating the age of sturgeon was not a precise method. However, the observed variability between age estimates does not totally discount the utility of this method. The use of fin rays offers a simple and practical tool for fishery managers. The fin rays can be obtained without sacrificing the sturgeon. The fin rays are readily sectioned, and most managers possess the skills necessary to perform the age interpretation work. Green sturgeon are long-lived, with a life span of several decades. Age determination increased in difficulty with increased age of the sturgeon. At present, fin ray analysis is the most readily available method of estimating sturgeon age. This method in conjunction with biological data is extremely useful for estimating the age at which these fish become reproductively mature.

The use of a high quality lapidary saw with a micro-adjustable feed ramp is imperative for producing precise, thin cross sections. The saw utilized in this study was marginal, and had to be modified with a "home-made" feed

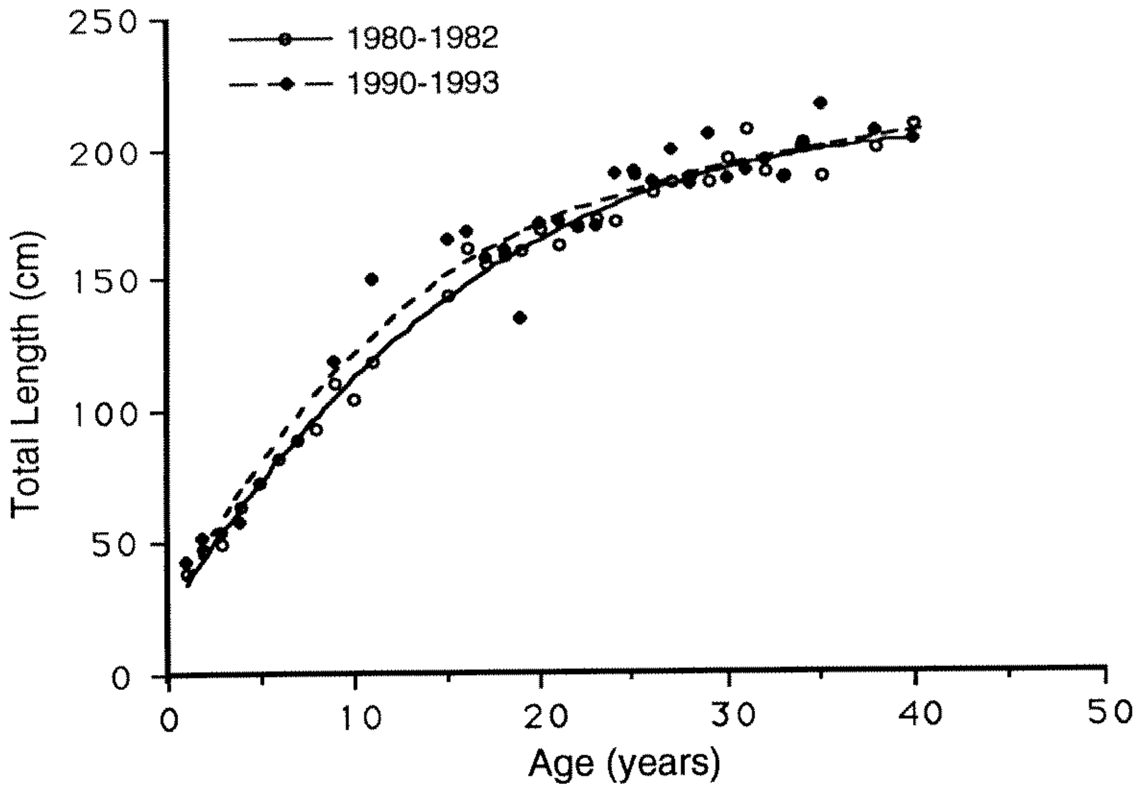

Figure 7. Mean length at age for green sturgeon sampled from the Klamath River, California, between 1980-1982 and 1990-1993.

mechanism. We found it difficult to produce consistent cross sections, thus necessitating repeated efforts. The inability of the operator to smoothly feed the fin rays stemmed from the inferior mechanism.

Initiation of sturgeon tagging programs in order to provide validation for aging techniques, and information pertaining to the recurrence of spawning and dispersion along the Pacific coast would be helpful. Application of external tags in conjunction with biological markers (such as tetracycline) would allow age validation, and provide empirical information on growth rates, and migration characteristics. The external tags would help identify whether sturgeon tagged in the Klamath River basin are utilizing other Pacific coast rivers and bays, and whether green sturgeon utilize multiple natal waters.

Continuation of data collection in conjunction with the Native American gill net fishery is recommended. On-going data needs include collection of length-weight data, sex ratios, and gonadal development and fecundity. This long-term information is necessary to monitor any potential changes in the sturgeon age and size composition, and sex ratio. Consideration of the timing of collection of fin ray samples may increase the accuracy of age estimation. Rein and Beamesderfer (1994) noted that within the Columbia River system, fin rays should be collected either before May or after July in order to better ensure that annular formation was complete.

In conjunction with age and growth assessment work, conducting genetic stock identification work on green sturgeon would be very helpful towards the defining potentially distinct Pacific coast populations. Green sturgeon are assumed to be highly migratory, are they utilizing multiple natal streams? Are there distinct populations of green sturgeon, or one common gene pool? Answers to these questions would have profound implications for the future of sturgeon management.

There is considerable need to understand the biology of green sturgeon, yet most government agencies are constrained by budgetary and personnel limitations. We recommend that fishery managers coordinate, and utilize an integrated approach to share research needs and costs. This coordination would prevent work duplication and promote comparable data.

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