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AGE AND GROWTH OF WHITE STURGEON COLLECTED IN THE SACRAMENTO-SAN JOAQUIN ESTUARY, CALIFORNIA: 1965–1970 AND 1973–1976 [1]

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Ages of white sturgeon, *Acipenser transmontanus,* collected in the Sacramento-San Joaquin Estuary from 1965 to 1970 and from 1973 to 1976 were estimated from transverse sections of pectoral fin rays. Sturgeon were difficult to age and there was considerable disagreement between individuals interpreting ages. Estimates of male and female growth rates were not significantly different. A von Bertalanffy growth curve was calculated for ages 0–21 from the 1973–1976 collection. A length-weight relationship was estimated from 1965–1970 data. Estimated growth rate was similar in 1965–1970 and 1973–1976, but was lower than in 1954. It was not possible to determine if a recent decrease in growth rate was real or was due to different aging techniques. Possible causes of reduced growth are discussed.

INTRODUCTION

White sturgeon occur mainly in estuaries and rivers along the Pacific Coast of North America. Presently they support a small but important sport fishery in the Sacramento-San Joaquin Estuary and its tributaries. Sturgeon were common here in the mid-1800's but commercial exploitation severely reduced the population by 1900. Sturgeon fishing was prohibited from 1901 to 1910 and from 1917 to 1954, when sport fishing was again permitted. The sport fishery expanded with the discovery in 1964 that shrimp (*Crangon* spp. and *Palaemon macrodactylus)* were effective bait. Both catch and effort peaked in 1967 and have generally declined since (unpublished data).

Initiation of the sport fishery in 1954 stimulated investigations of sturgeon biology to provide information to manage the fishery. Pycha (1956) reported on sturgeon age, growth, size composition, migrations, and abundance. Chadwick (1959) and Miller (1972*a*, 1972*b*) estimated harvest rates and described migrations. Young (Schreiber 1962) and adult (McKechnie and Fenner 1971) sturgeon food habits also were described. Stevens and Miller (1970) and Kohlhorst (1976) determined time and location of spawning.

This report presents new information about white sturgeon age composition and growth from 1965–1970 and 1973–1976 and compares the recent growth rate to that estimated by Pycha (1956).

METHODS

Data were gathered during two collection periods: by the junior authors from spring 1965 to spring 1970 and by the senior author from spring 1973 to summer 1976. Samples from the two periods were analyzed separately since we wanted to compare growth rates between periods. In general, sampling was not systematic; we examined most available fish.

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In any age group, some fish in our samples may have as much as one more season's growth than others, increasing the variability in length at each age. This problem was most significant in the 1965–1970 data. It was minimized in the 1973–1976 data because about two-thirds of the sample was collected from September to March after the growing season (June through October) was essentially complete.

Transverse sections of the first ray of the pectoral fin were used for age determination. Although pectoral fins were obtained from several sources, most samples were collected from the sport fishery, particularly commercial passenger fishing boats (CPFB's), and from sturgeon captured in trammel nets during tagging in fall 1974 (Table 1). All samples obtained from CPFB's in 1965–1970 and from creel censuses in both periods were $\geq$101.6 cm total length (TL), the minimum legal size for sturgeon. Fin rays from sturgeon of all sizes were collected by a Department of Fish and Game employee riding on CPFB's in 1975–1976.

TABLE 1. White Sturgeon Collection Methods in the Sacramento-San Joaquin Estuary.

Collection method	*Collection period*	*Number of sturgeon*
Sport angling		
Commercial passenger fishing boat	1965–70	579 [1]
	1975–76	502
Creel census	1967, 1969–70	48 [1]
	1973–75	346
Trammel net	1974	422
Gill net	1966	1
	1973–76	145
Surface trawl	1975–76	111
Beam trawl	1974–75	32
Otter trawl	1975	4
Fish screens at U. S. Bureau of Reclamation Tracy Pumping Plant	1965	4
Fyke trap	1970	1
	1973	2
Unknown	1969–70	6
Total	1965–70	639
	1973–76	1,564

[1] Only legal-sized fish (101.6 cm TL) were collected.

Methods of removing fin rays varied. Some fish were subsequently released alive; on those, the first ray was severed near its proximal end with a fine-toothed saw or heavy-duty wire cutter and then cut from the rest of the fin. The entire fin was removed from dead fish. Both fin rays and whole fins were thoroughly air-dried before sectioning.

Two 7.6-cm diameter diamond lapidary saw blades mounted 0.9 mm apart in 1965–1970 and 0.5 mm apart in 1973–1976 were used to section the rays. The water cooled saw operated at about 5000 rpm. Two to four transverse sections were cut between 1.3 and 2.5 cm from the proximal end of the ray. Age is most easily differentiated in this region and loss of early annuli is minimized (Sunde 1961). In 1965–1970 sections were polished with fine sandpaper and mounted on microscope slides with clear fingernail polish. In 1973–1976 the narrower spacing of the saw blades eliminated the need to sand the sections before mounting.

The sections were examined under a binocular dissecting microscope using transmitted light. Annuli were visible as narrow light or translucent bands (Figure 1). Periods of more rapid growth appeared dark or opaque.

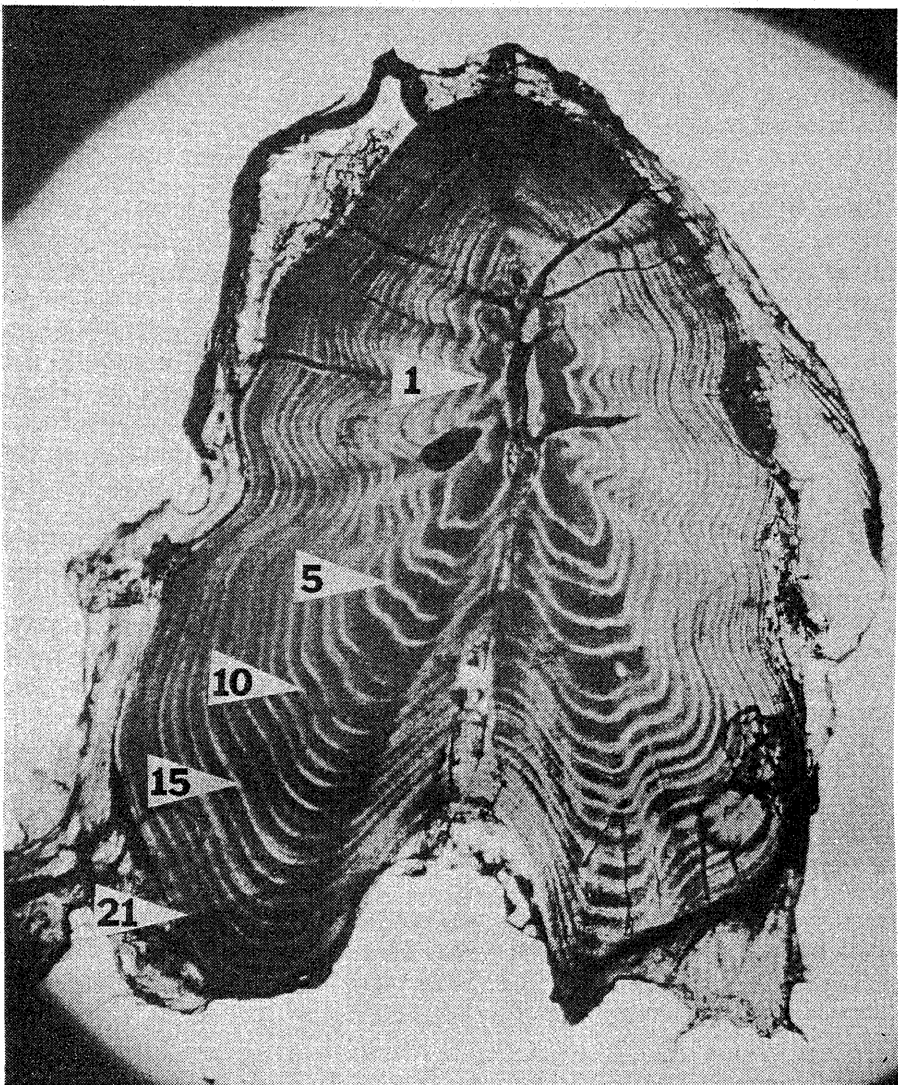

FIGURE 1. Cross-section of the first pectoral fin ray of a 21-yr-old white sturgeon collected in October 1974 from the Sacramento-San Joaquin Estuary. Five of the annuli are numbered for reference.

Sturgeon are difficult to age because they live long, annuli often are difficult to interpret, and known age fish are lacking for validation of aging technique. To assess the reliability of aging white sturgeon, five individuals familiar with fish aging techniques (but not necessarily with sturgeon aging) independently and without training or guidelines interpreted 40 fin rays randomly selected from the 1965–1970 collection. There were many disagreements (see Results).

We established two criteria in an attempt to increase consistency: (1) Only annuli that were distinct in the lobes of the rays and also in the dorsal and ventral portions were counted. Often, annular rings were very closely spaced in the lobes and did not appear in the other areas. Our criterion was intended to eliminate the possibility that some readers would interpret them as false annuli while other readers would interpret them as true annuli with little growth between. (2) A marginal annulus was assigned if one was not visible between 1 April, approximately the midpoint of the spawning season (Kohlhorst 1976), and 1 July. By 1 July that year's annulus was usually visible near the edge of the section and no additional annulus was assigned. This criterion was necessary because annuli were formed in spring but were not usually apparent until more rapid growth resumed.

After we defined these criteria, three new readers estimated ages of the same 40 randomly selected fish. Their performance was only slightly better than that of the first group of individuals, but for consistency we still adopted the criteria.

Subsequently, three trained readers independently examined all ray sections. If at least two age determinations agreed, that was accepted as the true age and was used in our age-growth analysis. If all three disagreed, the sample was omitted.

Length, to the nearest 2.5 cm in 1965–1970 and to the nearest centimetre in 1973–1976, and capture date were recorded when fins were collected. Sex was recorded when dissection was practical.

All lengths reported are total lengths (TL). However, only fork length (FL) was measured on 68 fish. These were converted to TL using the geometric mean functional relationship (Ricker 1973) $TL = 5.06 + 1.08\ FL$ ($r^2 = 0.98$, $n = 366$) that we obtained from sturgeon on which both TL and FL were measured.

In 1965–1970 age-length data from many of the youngest and oldest age groups were either biased by gear selectivity or unreliable due to small sample sizes. Therefore, growth was estimated only for ages 11–17. The data were fit to the linear equation:

$$l_t = a + bt$$

where: l_t = centimetres TL at age t
t = age in years

using the method of least squares.

Growth of sturgeon collected in 1973–1976 was adequately described by fitting all age-length data to the von Bertalanffy growth curve:

$$l_t = L_\infty[1\text{-}e^{-K(t-t_0)}]$$

where: l_t = centimetres TL at age t
L_∞ = asymptotic TL in centimetres
K = constant determining the rate of decrease in growth
t = age in years
t_0 = hypothetical age at 0 length

using the least squares computer program BGC-2 (Tomlinson and Abramson 1961, Abramson 1971).

A separate sample of sturgeon collected in 1965–1970 was measured and weighed to the nearest 0.2 kg. The length-weight relationship was estimated by fitting the equation:

$$\log w = \log a + b(\log l)$$

where: w = kilogram weight
l = centimetre TL

using a geometric mean functional regression (Ricker 1973).

RESULTS

Evaluation of Aging Technique

Before we adopted specific aging criteria, we did not obtain complete agreement among the five technicians on the age of any of the 40 randomly selected fin ray samples. Agreement between pairs of readers 1, 3, 4, and 5 averaged 12.5 specimens (Table 2). Reader 2 averaged only 2.5 agreements with the other readers. Readers 1, 3, 4, and 5 disagreed mostly by 1 or 2 yr. Reader 2 often disagreed by 3 yr or more. Reader 2 generally assigned younger ages by ignoring annuli which he considered false.

TABLE 2. Variation Among Readers in Age Determination of 40 Randomly Selected Sturgeon Fin Rays Collected in the Sacramento-San Joaquin Estuary in 1965–70.

Readers compared	*Agreement*	*Disagreement (number of years)* 1	2	3	4	5	*Total disagreements*
1 & 2	3	2	6	9	10	10	37
1 & 3	13	12	6	4	3	2	27
1 & 4	11	17	7	2	2	1	29
1 & 5	10	16	8	2	2	2	30
2 & 3	5	10	5	9	7	4	35
2 & 4	1	5	7	12	8	7	39
2 & 5	1	3	7	12	4	13	39
3 & 4	15	14	7	4	0	0	25
3 & 5	12	14	9	2	1	2	28
4 & 5	14	16	7	1	2	0	26
Mean 1–5	8.5	10.9	6.9	5.7	3.9	4.1	31.5
Mean 1, 3, 4, 5 with each other	12.5	14.8	7.3	2.5	1.7	1.2	27.5
Mean of 2 with 1, 3, 4, 5	2.5	5.0	6.3	10.5	7.3	8.5	37.5

The specific criteria for identifying annuli did not have much effect on results (Table 3). Agreement between pairs of readers averaged 12.7 specimens. However, two of the three readers agreed on ages of 26 of the 40 sturgeon, meaning that ages could be assigned to 65% of these fish.

TABLE 3. Variation Among Trained Readers in Age Determination of 40 Randomly Selected Sturgeon Fin Rays Collected in the Sacramento-San Joaquin Estuary in 1965–70.

Readers compared	*Agreement*	*Disagreement (number of years)* 1	2	3	4	*Total disagreements*
1 & 2	6	22	9	2	1	34
1 & 3	16	12	11	0	1	24
2 & 3	16	16	6	2	0	24
Mean 1–3	12.7	16.7	8.7	1.3	0.7	27.3

In the 1965–1970 sample, 15–19 yr old sturgeon were the most troublesome group, two of three readers agreed on the age of only 56% of them (Table 4). Agreement in other age groups, from 0–4 yr to ≥20 yr was consistent, ranging from 65 to 67%.

TABLE 4. Effect of Age on the Rate of Age Agreement Between Two of Three Trained Readers for White Sturgeon Collected in the Sacramento-San Joaquin Estuary in 1965–70 and 1973–76.

			1965–1970	
Age	*Agree*	*Disagree*	*Total*	*% agreement*
0–4	2	1	3	67
5–9	56	30	86	65
10–14	282	152	434	65
15–19	58	46	104	56
≥20	8	4	12	67
Total	406	233	639	64
			1973–1976	
Age	*Agree*	*Disagree*	*Total*	*% agreement*
0–4	286	9	295	97
5–9	525	92	617	85
10–14	234	90	324	72
15–19	147	119	266	55
≥20	32	30	62	52
Total	1224	340	1564	78

In the 1973–1976 sample aging difficulty increased with age. At least two readers agreed on the age of 97% of 0–4-yr-old fish and agreement consistently decreased to 52% for fish ≥ 20 yr (Table 4).

Age-Length Frequency

We examined fin rays from 639 white sturgeon collected from 1965 to 1970 (Table 1) and assigned ages to 406 of them. They ranged from 2 to 27 yr and from 44 to 203 cm TL.

From 1973 to 1976, 1,564 white sturgeon were examined (Table 1). We assigned ages to 1,224 of these fish. They ranged from 0 to 24 yr and from 24 to 201 cm TL.

Age frequencies and length frequencies for combined 1965–1970 and 1973–1976 data both have two prominent modes. Two and 9-yr old fish dominated the collections, as did 50–54-cm and 100–104-cm length groups (Figure 2). Mean lengths of these modal ages, 54 cm and 103 cm, respectively, fall within the modal length groups, suggesting that age interpretation was reasonably consistent throughout the sample processing.

Growth Rate

Growth rates of the two sexes were compared to determine if they could be combined for an unbiased estimate of average growth. In making this comparison, only part of the available age range was used because: (1) sample sizes were small (≤4) at ages ≥18 in 1965–1970; (2) in both samples, sexed sturgeon were obtained primarily from the sport fishery which has a minimum legal TL of 101.6 cm, and data from sport caught fish are biased by selection for the fastest growing individuals among the partially recruited age groups. This bias is apparent in the length-age relationship for all ages (Figure 3).

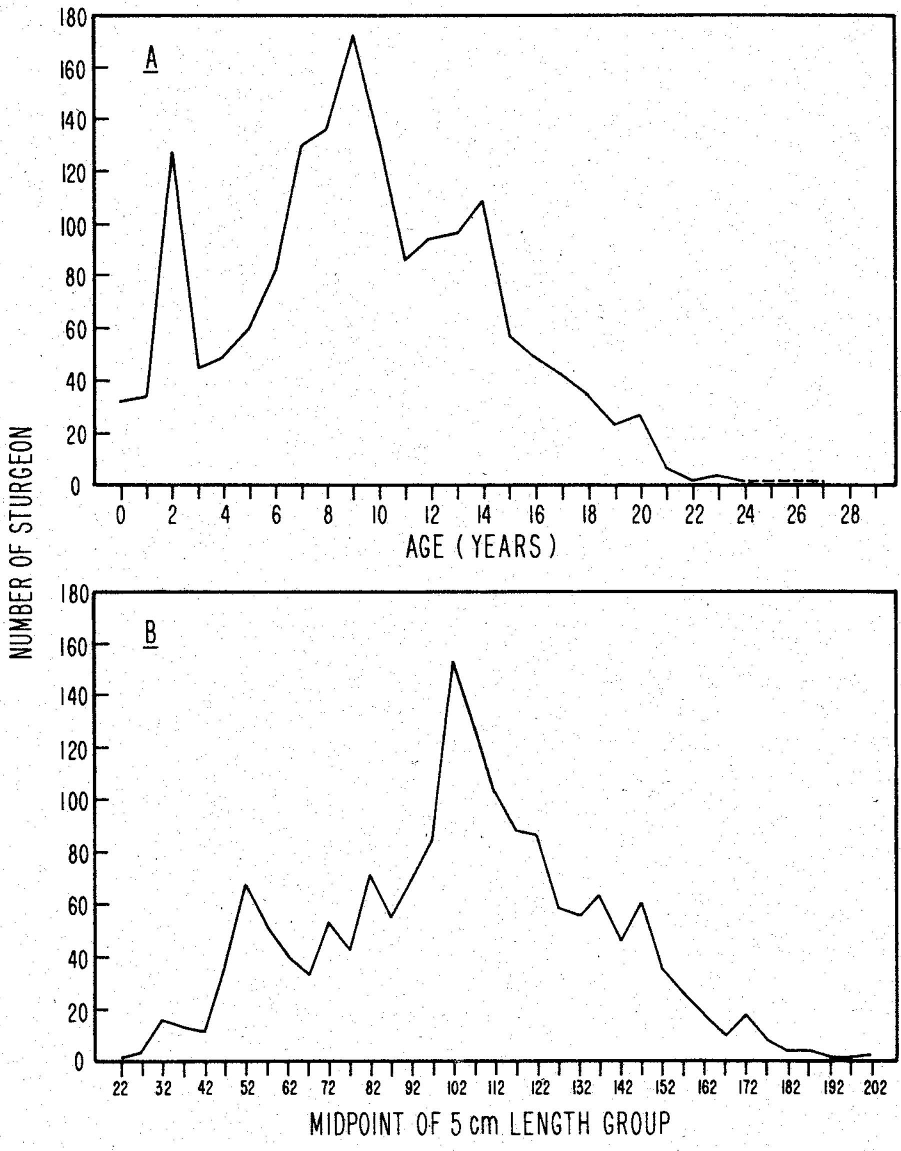

FIGURE 2. Age and length frequency distributions of white sturgeon collected in the Sacramento-San Joaquin Estuary in 1965–1970 and 1973–1976 combined. (A) Age distribution. (B) Length frequency grouped in 5-cm increments.

Growth rate was estimated separately for each sex for ages 11–17 in 1965–1970 and ages 10–20 in 1973–1976. In these age groups, linear regression coefficients for males and females were not significantly different in 1965–1970 ($t = 1.29$, $P = 0.20$) or 1973–1976 ($t = -0.34$, $P = 0.50$) (Figure 3). Therefore, in subsequent analyses we combined the data.

The following linear growth equation describes the 1965–1970 growth data from ages 11–17:

$$l_t = 44.86 + 6.212t$$

Length and age data from age 0–21 generated the following von Bertalanffy growth equation for the 1973–1976 data:

$$l_t = 261.2 \, [l\text{-}e^{-0.04027(t + 3.638)}]$$

The von Bertalanffy curve agrees well with mean lengths calculated for each age; therefore, it appears to provide a good description of overall white sturgeon growth (Figure 4). The curve probably overestimates first year growth (35.6 cm) very slightly. Mean length of fish collected after one growing season (33.2 cm) is probably the best estimate. Subsequently growth estimates slowly declined, from 8.9 cm during the second growing season to 4.0 cm during the 22nd growing season. Length increased from 44.5 cm at age 1 to 164.4 cm at age 21 (Figure 4B).

Length-Weight Relationship

We determined both length and weight of 209 sturgeon collected in 1965–1970; the sex of 77 of these was known. Since the length-weight relationships for males and females were not significantly different ($t = 0.52$, $P > 0.50$), all data were combined to determine the functional relationship $\log W = 3.348 \log L - 5.927$ (Figure 5). Weight increased from 6.2 kg at 101.6 cm to 50.4 kg at 190 cm.

DISCUSSION

Estimates of sturgeon size varied considerably at each age. This finding is characteristic of sturgeon growth studies (Magnin 1964, Cuerrier 1966, Semakula and Larkin 1968). Aging inaccuracies are a factor, but size variation at each age may actually be large.

The validity of age determinations from sturgeon pectoral fin rays has been discussed by several authors, including Cuerrier (1951), Roussow (1957), and Sunde (1961). However, they did not determine consistency in age interpretation among several readers. In our analysis, two of three trained readers agreed on the age of 64% of the fish in the 1965–1970 sample and 78% in the 1973–1976 sample. In 1973–1976, agreement decreased with age, indicating increased difficulty in interpreting fin ray sections with age.

The growth rate calculated for age 11–17 sturgeon in 1965–1970 was similar to the rate for that age range in the 1973–1976 sample. The rates were not compared statistically because different methods were used to estimate growth in the two samples. A comparison over a wider age range was not possible because of weaknesses inherent in the 1965–1970 data, specifically: (1) Mean lengths from age 6 to at least age 10 are overestimated since essentially the entire sample consisted of fish larger than the minimum legal length (101.6 cm) in the sport fishery. Hence, the fastest growing individuals from these younger, partly recruited age groups were unavoidably selected. (2) The data for ages > 17 may not be representative because of small sample sizes.

We could not identify any important biases affecting the 1973–1976 data since sample sizes generally were adequate and fish were collected by a variety of methods. Hence, we believe that the 1973–1976 data adequately represent recent white sturgeon growth in the Sacramento-San Joaquin Estuary.

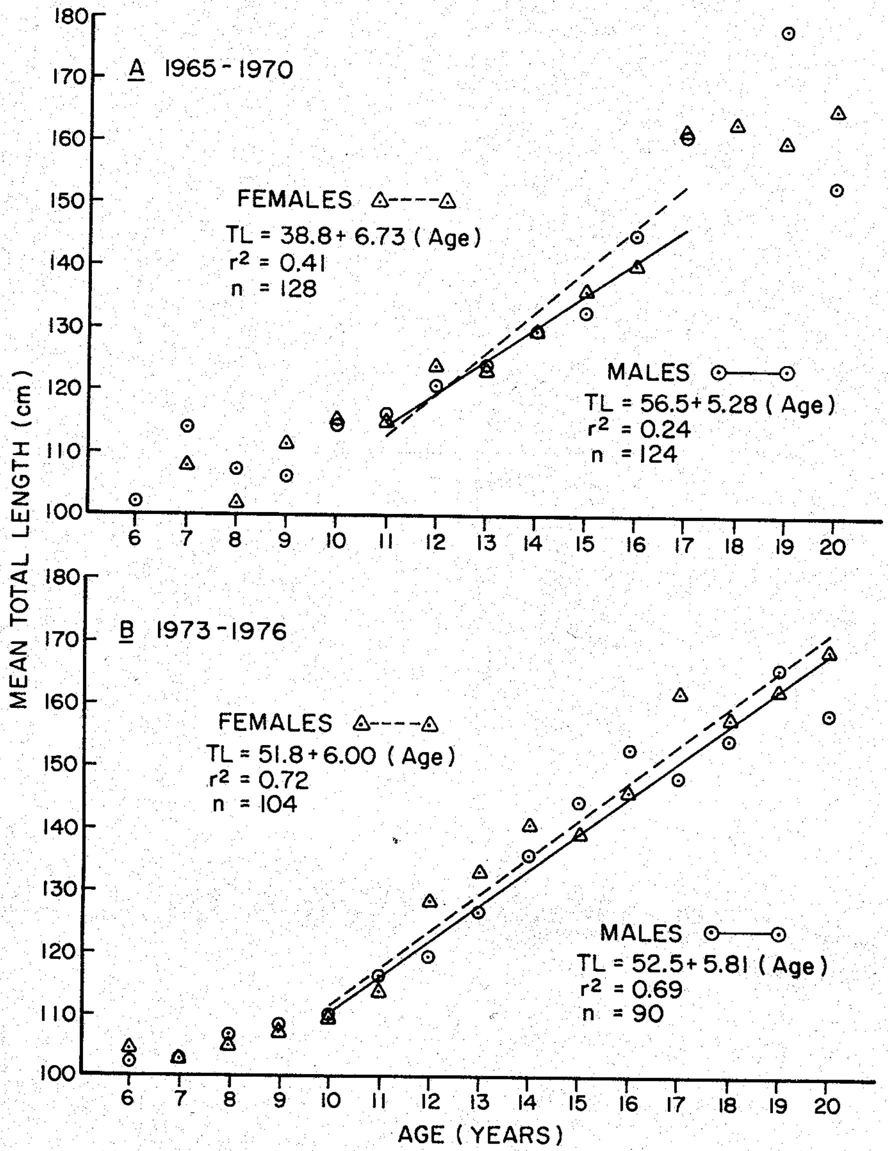

FIGURE 3. Growth rates of male and female white sturgeon from the Sacramento-San Joaquin Estuary. Lines are least squares linear regressions. (A) 1965–1970. (B) 1973–1976.

Assuming that Pycha (1956) used aging criteria similar to ours, it appears that white sturgeon growth has decreased since 1954 (Figure 6). However, growth here apparently is still more rapid than in the Fraser River, British Columbia (Semakula and Larkin 1968). Lower water temperatures and a shorter growing season in the Fraser River due to a 12° difference in latitude probably account for the difference.

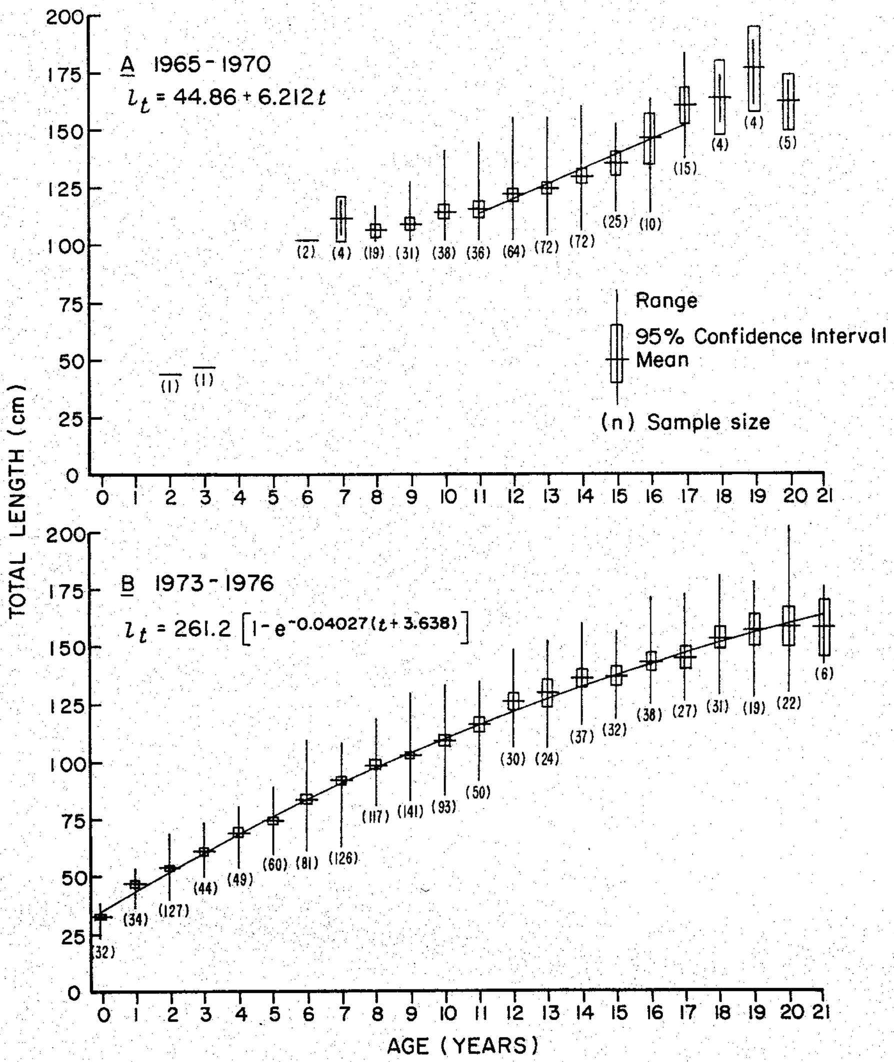

FIGURE 4. Growth curves fitted by the method of least squares for white sturgeon collected in the Sacramento-San Joaquin Estuary. Mean total lengths, confidence intervals, and length ranges are shown for comparison. Sample sizes are given in parentheses. (A) Linear growth between ages 11 and 17 of fish collected in 1965–1970. (B) Von Bertalanffy growth curve for age 0–21 fish collected in 1973–1976.

The apparent reduction in growth rate since 1954 has several possible explanations:

(1) *Genetic*—Presently, the fastest growing individuals are vulnerable to the sport fishery (which started in 1954) at a younger age and for a longer period than slower growing sturgeon. Hence, proportionately more slow growing fish remain in the population and cause an apparent reduction in population growth rate when sampled by nonselective methods.

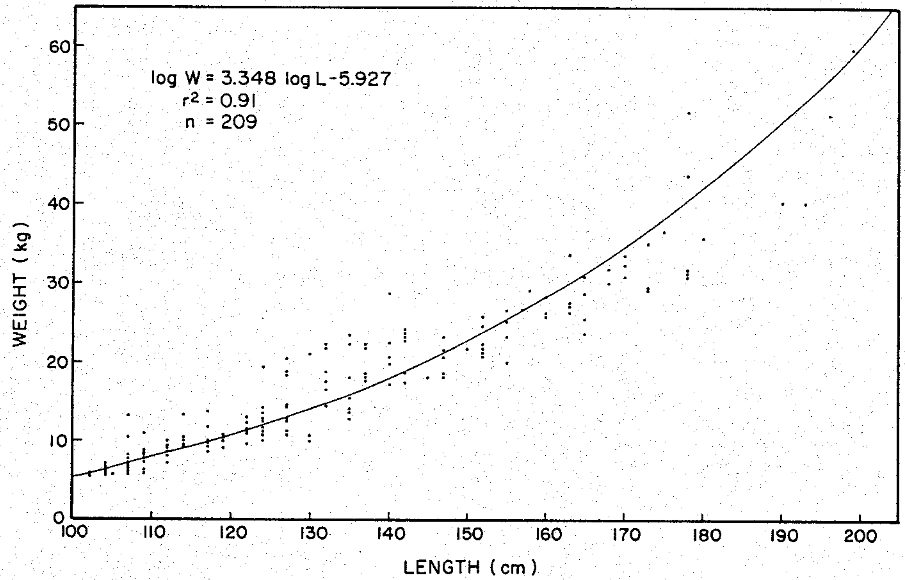

FIGURE 5. Length-weight relationship of white sturgeon collected in the Sacramento-San Joaquin Estuary from 1965 to 1970. The curve is a geometric mean functional regression.

(2) *Intraspecific competition for food*—There is evidence that sturgeon abundance increased between 1954 and 1967 (Miller 1972*a*), and that it declined between 1967 and 1974 (unpublished data). Increased abundance may decrease growth by intensifying intraspecific competition for a limited food supply. If food is limiting, effects of competition between 1954 and 1967 may still be apparent in our data since age-length relationships determined from a discrete sample reflect growth conditions over a number of previous years. Improved growth due to less competition more recently may not be detected for several years.

(3) *Decreased food supply*—White sturgeon feed primarily on benthic invertebrates in the San Francisco Bay area (McKechnie and Fenner 1971). One of these, the bay shrimp, is fished commercially and California Department of Fish and Game records indicate a substantial decrease in mean annual landings from 307,320 kg in the 1940's to 34,940 kg in the 1970's. Market demands and processing costs account for part of this change, but the magnitude of the reduction suggests that shrimp abundance actually decreased. Factors affecting shrimp abundance may have caused undocumented decreases in populations of other benthic organisms also.

(4) *Effects of environmental contaminants*—White sturgeon in the estuary accumulate polycholorinated biphenyls (PCB's) in their tissues. Means levels in muscle tissues of legal-sized fish collected in San Pablo and Suisun bays in 1975 were 2.0 ppm (SD = 2.5, n = 10) in males and 3.5 ppm (SD = 5.0, n = 12) in females. Concentrations in the gonads were much higher, 49.3 ppm (SD = 24.8, n = 8) in males and 23.7 ppm (SD = 27.8, n = 12) in females. Sublethal levels of PCB's inhibit growth in channel catfish, *Ictalurus punctatus* (Hansen, Wiekhorst, and Simon 1976) and might affect sturgeon in the same manner.

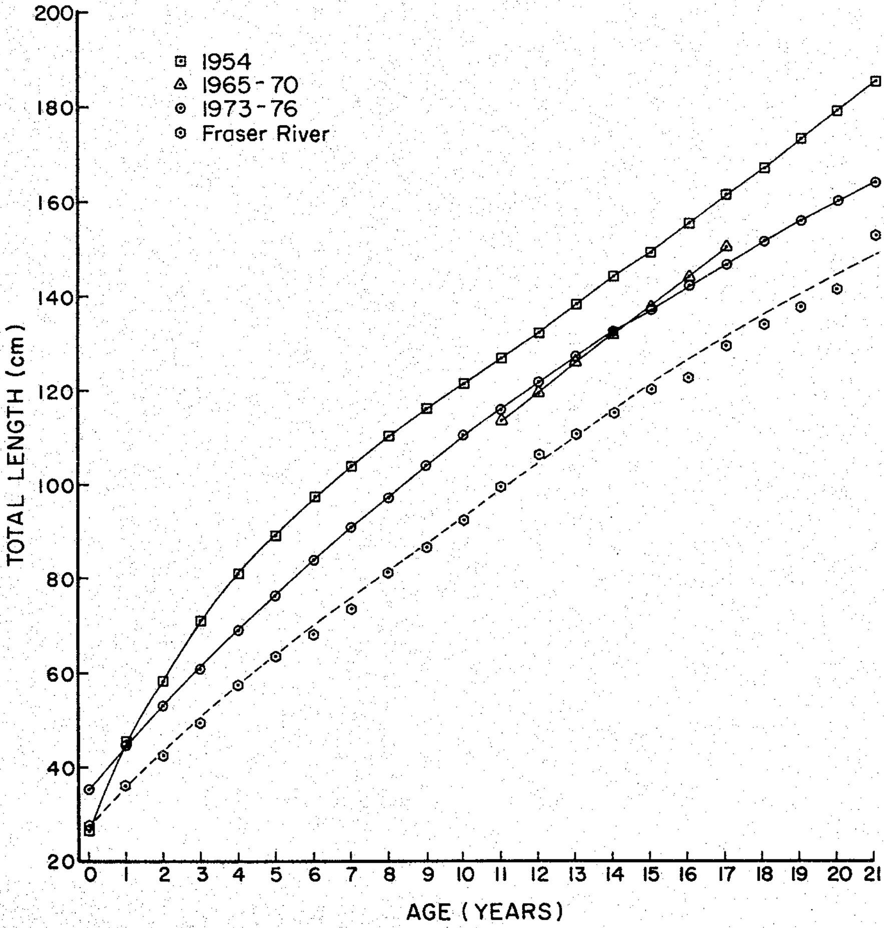

FIGURE 6. Growth of white sturgeon collected in the Sacramento-San Joaquin Estuary in 1954, 1965–1970, and 1973–1976, and in the Fraser River, British Columbia. Fraser River fish ages are adjusted to our method of age designation (age 0 is the youngest age class).

Facts are not available to evaluate the relative significance of the various potential causes of reduced growth.

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