REPRINT FROM
Calif. Fish and Game, 66(4) 210-219. 1980.

Calif. Fish and Game 66(4): 210–219

RECENT TRENDS IN THE WHITE STURGEON POPULATION IN CALIFORNIA'S SACRAMENTO-SAN JOAQUIN ESTUARY [1]

DAVID W. KOHLHORST
California Department of Fish and Game
Bay-Delta Fishery Project
4001 North Wilson Way
Stockton, CA 95205

Recent trends in the white sturgeon, *Acipenser transmontanus,* population in the Sacramento-San Joaquin Estuary were evaluated from commercial passenger fishing boat (CPFB) and tagging records. Total catch and catch/angler h on CPFB's declined from 1967 to 1974. Catch/angler h increased from 1974 to 1978, while total catch continued to decrease through 1977. Population estimates suggested that a decrease in abundance occurred between 1967 and 1974 and that abundance increased between 1974 and 1979. Mean size of sturgeon caught on CPFB's increased from 1964 to 1973 or 1974, then decreased through 1978. Annual survival rate changed little over the period examined. The population decline was likely due to poor recruitment from year classes produced after the mid-1950's. Possible causes of low recruitment are discussed.

INTRODUCTION

This report analyzes trends in the white sturgeon, *Acipenser transmontanus,* population in the Sacramento-San Joaquin Estuary from 1964 to 1979. This species is a native anadromous fish in the Sacramento-San Joaquin Estuary and is the object of a small but important sport fishery. Another species, the green sturgeon, *A. medirostris,* is much less common and legal-sized ($\geq$ 101.6 cm total length) fish are seldom caught.

Sturgeon are long-lived, late-maturing fish (Roussow 1957; California Department of Fish and Game, unpublished), some living over 50 yr and most maturing at 10 to 15 yr. Fishes with this type of life history normally exhibit long-term population stability and a slow response to environmental vicissitudes (Goodman 1975). Hence, sturgeon populations are vulnerable to overharvest and subsequent decline (Bajkov 1949; Dees 1961) because they cannot rapidly compensate for unusually high mortality.

Historical accounts indicate that a commercial fishery substantially reduced the Sacramento-San Joaquin Estuary white sturgeon population in the late 1800's (Skinner 1962). After a complete fishing closure in 1917, the sport fishery was reopened in 1954. Through 1963 the only catches were generally incidental to the striped bass, *Morone saxatilis,* fishery. Fishing success improved dramatically in 1964 when shrimps, *Crangon* spp. and *Palaemon macrodactylus,* first became popular as bait. Estimated annual harvest rates have been low: at least 2% in 1954 (Chadwick 1959), 7.3% in 1967, 6.5% in 1968 (Miller 1972), and 5.6% in 1974 (Kohlhorst 1979).

Changes in abundance, catch, mean size, and survival may provide clues to factors affecting the sturgeon resource and influence management of the fishery. Over-exploitation is normally characterized by decreasing catch/unit effort and

[1] Accepted for publication May 1980.

declining mean size of fish in the catch (Gulland 1971). Reduced recruitment also causes decreasing catch per unit effort, but mean size increases. The former would suggest that harvest should be restricted, while the latter requires investigation of the causes of poor recruitment. Stable or increasing abundance measurements would suggest a healthy population.

METHODS

White sturgeon population trends were interpreted from catch, effort, and size data reported by commercial passenger fishing boat (CPFB) operators and from catch/effort, size, and absolute abundance estimated from tagging studies. Since variations in annual survival might have caused fluctuations in abundance, I evaluated survival rates from the only data available. These data provided estimates of survival in 1967 from tag returns and average annual survival over several years from a catch curve.

The CPFB reports were compiled annually from 1964 to 1978 for trips when sturgeon were caught to determine trends in total catch and catch/angler h. Operators of CPFB's are required to furnish the Department with daily logs listing species, number, and sizes of fishes caught, number of anglers, and time spent fishing.

Catch/net h during tagging in San Pablo Bay was available for fall 1967, 1968, 1974, and 1979. This catch/effort index was based on trammel netting in similar areas and months in all 4 yr.

Trends in size of sturgeon were determined from: (i) annual mean lengths and weights calculated from information on logs submitted by the CPFB operators (operators chose to report either length or weight; they seldom reported both), and (ii) mean lengths of white sturgeon tagged in 1967, 1968, 1974, and 1979.

Mark-recapture estimates of legal-size white sturgeon abundance were available from tagging studies in 1954 (Pycha 1956) and 1967 (Miller 1972). Pycha's estimate was derived from a multiple census technique and Miller's was a Petersen estimate. For comparison, I estimated abundance from tagging studies in San Pablo Bay in 1967, 1968, 1974, and 1979 (Miller 1972; Kohlhorst 1979) using the multiple census technique of Shumacher and Eschmeyer (Ricker 1975), where:

$$N = \frac{\Sigma\ (C_t M_t^2)}{\Sigma\ (M_t R_t)}$$

and: N = estimated population
M_t = total tagged fish at large at the start of the t^{th} day
C_t = total fish caught on day t
R_t = number of recaptures in the sample C_t.

All the multiple census abundance estimates likely are biased downward as tagged fish probably did not mix randomly with the untagged population during the 2-month tagging season. Sturgeon not in San Pablo Bay were neither subject to tagging nor recapture. Hence, overall, tagged fish would have been more vulnerable to recapture than untagged fish to initial capture. This differential vulnerability, plus effects of immigration to and emigration from San Pablo Bay, make determining the proportion of the entire sturgeon population represented by the abundance estimates impossible. Despite the bias, the abundance estimates probably reflect major trends. However, due to their imprecision, my intent is to present them as supplementary to the other data.

I estimated average annual survival rate from a catch curve (Ricker 1975) using age frequencies of sturgeon collected mostly during tagging in 1974 and on CPFB's in 1973–1976. Aging was as described by Kohlhorst, Miller, and Orsi (1980). The slope of the descending right limb of the curve was estimated using a least squares fit of the linear regression equation: $\log_{10}$ (number of fish) = a + b (age). The antilog_{10} of the slope (b) is an estimate of survival.

Miller (1972) estimated first year survival of sturgeon using 2 yr of returns from tagging in 1967 and 1968. I re-estimated this survival rate and its confidence interval with 6 yr of returns using a bias-adjusted maximum likelihood equation (Model 1 of Brownie et al. 1978):

$$S_1 = \frac{R_1(T_1 - C_1)(N_2+1)}{N_1 T_1 (R_2+1)}$$

where: S_1 = survival rate in 1st yr after 1967 tagging
R_1 = total returns from 1967 tagging
R_2 = total returns from 1968 tagging
T_1 = R_1
C_1 = returns in 1st recovery year
N_1 = number of fish tagged in 1st yr
N_2 = number of fish tagged in 2nd yr

Confidence limits for S_1 were calculated as $S_1 \pm 1.96SE(S_1)$, where:

$$SE(S_1) = \sqrt{S_1^2\left(\frac{1}{R_1} - \frac{1}{N_1} + \frac{1}{R_2} - \frac{1}{N_2} + \frac{1}{T_2 - R_2} - \frac{1}{T_1}\right)}$$

and $T_2 = R_2 + T_1 - C_1$. The other elements are the same as above.

RESULTS

Catch Data

Fishing success declined during much of the period examined. Sturgeon catch reported by CPFB's declined from a peak of 2,272 fish in 1967 to a low of 327 fish in 1977 (Figure 1). Catch/angler h on CPFB's decreased from 0.052 in 1964 to 0.028 in 1974 and then increased to 0.039 in 1978 (Figure 1). Negative linear trend lines for both catch (1967–1978) and catch/angler h (1964–1974) were significantly different from zero ($p < 0.0005$). The positive trend in catch/angler h from 1974 to 1978 was not significantly different from zero ($p \cong 0.10$).

Legal-sized white sturgeon also were more difficult to catch with trammel nets in San Pablo Bay in 1974 than in 1967, 1968, or 1979. Catch/net h during tagging was 15.3 in 1967, 19.5 in 1968, 3.7 in 1974, and 8.4 in 1979. Hence, catch rate in 1974 was 79% lower than the 1967–1968 mean and 56% lower than in 1979.

Mean length of sturgeon reported by CPFB's increased from 124 cm in 1964 to 134 cm in 1974 (Figure 2). Sample sizes were too small from 1975 to 1978 (only 1 to 11 fish) to calculate reliable mean lengths. Mean weight increased from 13.8 kg in 1964 to 19.0 kg in 1973 and then decreased to 14.9 kg in 1978. Positive linear regression slopes of trends in both mean length from 1964 to 1974 and mean weight from 1964 to 1973 were significantly different from zero

($p < 0.0005$). The negative trend in mean weight from 1973 to 1978 was also statistically significant ($p < 0.0005$).

The mean length of sturgeon captured for tagging also increased from the late 1960's to 1974, then declined substantially between 1974 and 1979 (Figure 2).

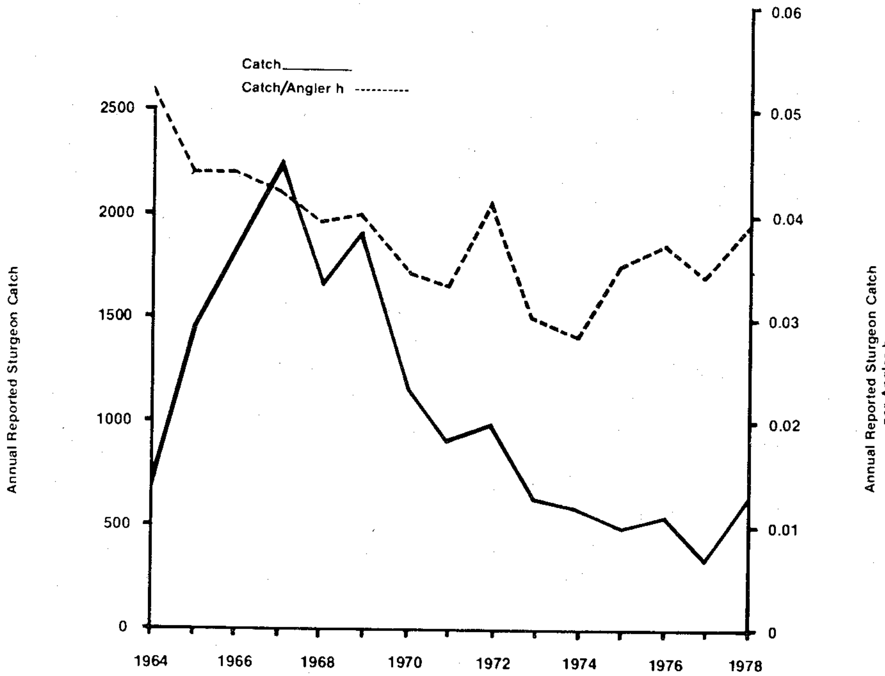

FIGURE 1. Annual reported sturgeon catch and catch/angler h by commercial passenger fishing boats in the Sacramento-San Joaquin Estuary.

Mark-Recapture Estimates

From 1967 to 1974, trends in the mark-recapture abundance estimates (Table 1) were about the same as those demonstrated by the CPFB and netting data. Specifically, the estimate for 1974 was lower than those for 1967 and 1968 and the estimate for 1979 suggested abundance increased after 1974. My 1967 estimate was similar to Miller's (1972) for the same year, but a major inconsistency is that the estimate for 1968 is lower relative to 1967 and 1979 than would be expected from the other data. Presumably, this reflects the previously mentioned imprecision in the multiple census data. The 1954 estimate is lower than any of the more recent estimates suggesting abundance was relatively low then.

Survival Estimates

The slope of the righthand limb (age 9–20) of the catch curve for white sturgeon collected in 1973–1976 was −0.0569 (Figure 3). Estimated mean annual survival (antilog $_{10}$ −0.0569) was 0.878 (95% CI = 0.818, 0.941). The scatter and moderate nonlinearity of points in the righthand limb suggest that survival and/or recruitment were variable over the 12-yr period represented by those ages.

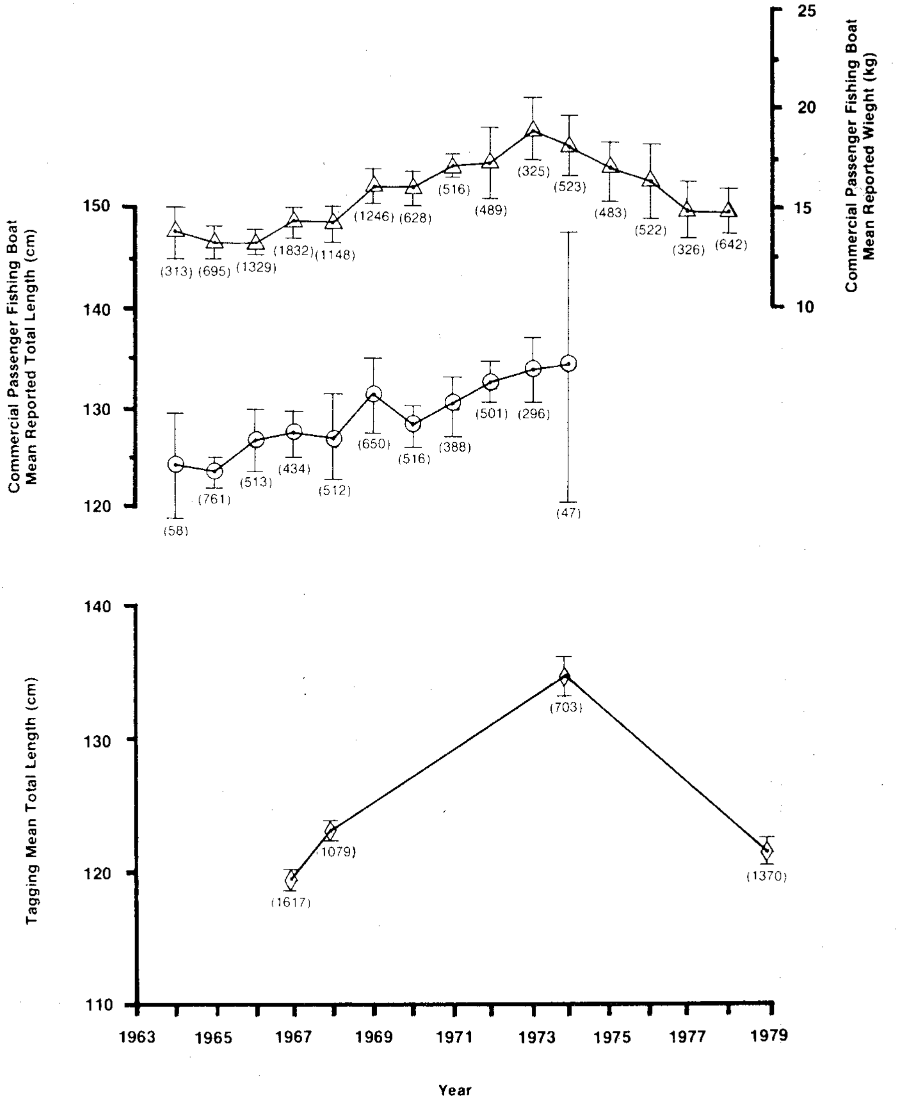

FIGURE 2. Annual mean weight and total length reported by commercial passenger fishing boats and mean total length during tagging of sturgeon in the Sacramento-San Joaquin Estuary. Bars are 95% confidence intervals and numbers in parentheses are sample sizes.

Six years of returns from tagging in 1967–1968 (Table 2) yielded an estimated survival rate of 0.841 (95% CI = 0.648, 1.03) for the first year after tagging in 1967. The similarity of these two estimates suggests that changes in survival rate were not large enough to cause the observed fluctuations in abundance.

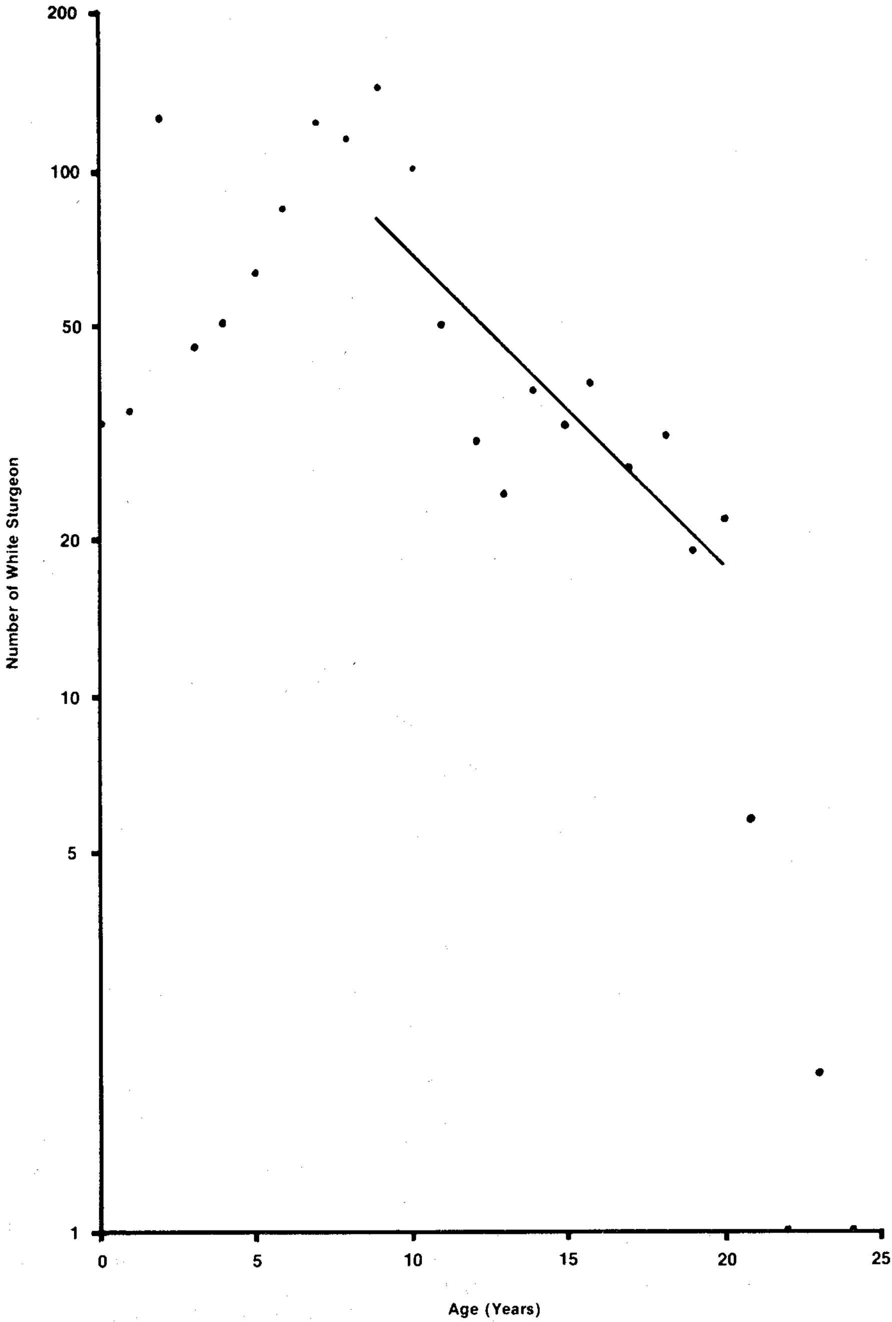

FIGURE 3. Catch curve of white sturgeon collected from 1973 to 1976 in the Sacramento-San Joaquin Estuary. Annual survival of 0.878 for age 9–20 fish was estimated from the antilog_{10} of the slope (−0.0569) of the line.

TABLE 1. Population Estimates for Legal-Sized (≥ 101.6 cm TL) White Sturgeon in the Sacramento-San Joaquin Estuary. Numbers in Parentheses Are the Number of Recaptures on Which the Estimates Are Based.

Year	*Population estimate*
1954	11,154 (45) [1]
1967	114,667 (14) [2]
	110,500 (10)
1968	40,000 (12)
1974	20,700 (12)
1979	74,500 (13)

[1] Pycha 1956
[2] Miller 1972

TABLE 2. Six Years of Tag Return Data from 1967 and 1968 White Sturgeon Tagging in the Sacramento-San Joaquin Estuary Used to Estimate Survival in the First Year After 1967 Tagging.

Year tagged	*Number tagged*	*Year of recovery* 1	2	3	4	5	6	*Total recoveries*
1967	1,212	87	73	34	18	11	7	230
1968	819		53	22	14	14	11	114

DISCUSSION

My analysis of trends in the sturgeon fishery depends greatly on unsupervised reporting by CPFB operators. The long-term reliability of sturgeon CPFB logs is unknown, but striped bass logs do adequately reflect catch trends in that fishery (Grant 1977), and sturgeon size and catch trends developed from the log data agree reasonably well with trends apparent from our own measurements suggesting that the log data are adequate for my purpose.

Trends in catch/effort during tagging and by CPFBs, total CPFB catch, and population estimates all indicate that white sturgeon abundance declined in the Sacramento-San Joaquin Estuary between 1967 and 1974, and, possibly, since at least 1964. After 1974, CPFB reports and the 1979 population estimate suggest that abundance increased.

Mean size increased as abundance decreased, suggesting that the population decline between 1967 and 1974 was not due to overexploitation. Reductions in fish populations due to exploitation are normally accompanied by decreases in mean size of fish in the catch (Gulland 1971), assuming growth does not increase concurrently.

The survival rate apparently changed little and exploitation was low during the period examined. Annual survival of 84–88% and harvest rates of 6–7% intuitively appear adequate to maintain a stable population.

Hence, the trends in abundance and size most likely resulted from low recruitment from 1967 to 1974. Since white sturgeon reach legal size at age 6–12 (Kohlhorst, Miller, and Orsi 1980), the weak year classes would have to be produced starting as early as the mid-1950's or as late as the early 1960's.

The three most likely causes of poor recruitment are: (i) Degradation of juvenile habitat. Survival of juveniles of other anadromous species in the Sacramento-San Joaquin System, such as striped bass, American shad, *Alosa sapidissima,* chinook salmon, *Oncorhynchus tshawytscha,* and longfin smelt, *Spirinchus thaleichthys,* is reduced by low freshwater flows and high water diversion rates during the spawning and nursery periods (Turner and Chadwick 1972; Chadwick, Stevens, and Miller 1977; Stevens and Miller, unpubl. data). Low freshwater flows apparently impact juveniles of these species by restricting available habitat or reducing food supplies. Water diversions reduce survival by directly removing fish or by changing flow patterns to disrupt migrations.

Freshwater outflow from the Sacramento-San Joaquin Delta in late spring and summer, the period that might be critical for sturgeon, was low from 1959 to 1962 and in alternate years thereafter through 1972. During this period, flows were highest in 1967 and 1969. Also, the percent of inflow diverted from the Delta increased substantially after 1958. For example, the mean percent of May–June inflow diverted was 5.1% from 1951 to 1958 and 19.7% from 1959 to 1968. Since sturgeon are recruited between ages 6 and 12 (Kohlhorst, Miller, and Orsi 1980), flow and/or diversion conditions during a period as brief as 1959–1962 could have depressed recruitment from 1965 to 1974, while high flows in 1967 and 1969 may explain increased abundance since 1974. As partial corroboration of the latter, the 1969 year class comprised 19.1% of the sturgeon tagged in 1979 and was the most abundant age group in the sample. However, the next most abundant year class was from 1970 (17.6%), a relatively low flow year.

The effect of flow on recruitment also may be reflected in Pycha's (1956) data which suggested that dominant year classes were produced in 1938 and 1948. Late spring and early summer flows were high in both of those years, particularly in 1938.

(ii) Environmental contaminants. Polychlorinated biphenyls (PCB's) are of special concern. Samples of legal-sized sturgeon collected in San Pablo and Suisun bays in 1975 contained mean gonadal PCB concentrations of (mean $\pm$ SD) 49.3 $\pm$ 24.8 ppm in males and 23.7 $\pm$ 27.8 ppm in females (California Department of Fish and Game, unpublished). A concentration of 7.0 ppm of PCB in eggs of the sheepshead minnow, *Cyprinodon variegatus,* caused mortality in the fry (Hansen, Schimmel, and Forester 1974). Hogan and Brauhn (1975) found that 60–70% of rainbow trout, *Salmo gairdneri,* fry were deformed 30 d after hatching due to PCB levels of 2.7 ppm in the eggs. Mortalities were also increased by PCB's in the first 30 d after hatching.

These studies suggest that PCB's may reduce survival of larval sturgeon and subsequent recruitment. They gained wide use in late 1930's and early 1940's (Walker 1976), so sturgeon probably have been accumulating them for many years. Unfortunately, long term information on PCB concentrations in white sturgeon is not available to indicate whether PCB's actually could account for recent changes in sturgeon abundance.

(iii) Spawning stock size. Declining abundance of sturgeon between 1967 and 1974 and the apparent increase thereafter may be caused by fluctuations in abundance of mature spawners. Preliminary analysis of age composition data collected in 1954, 1965–1970, and 1973–1976 suggests that, since 1932, there has been about a 14-yr periodicity in year class strength. Fourteen years is approximately the age of first spawning of female white sturgeon (California Department of Fish and Game, unpublished). Perhaps, strong year classes produce large numbers of young when they mature and weak year classes, few young.

However, all females from a year class do not mature at the same time and many live long enough to spawn more than once. These older fish have higher fecundity than first-time spawners. These facts suggest the explanation is more complicated than a simple 14-yr cycle.

Exploration of factors possibly affecting sturgeon recruitment is continuing. If recruitment is affected by controllable factors, these could be manipulated to increase sturgeon abundance.

ACKNOWLEDGMENTS

I wish to thank D. Ramczyk for first bringing to my attention the decline in catch and increase in size of white sturgeon reported by CPFB's. Many other Department employees assisted me in both the field and laboratory. D. Stevens and H. Chadwick critically reviewed the manuscript. A. Conner drafted the figures. This work was performed as part of Dingell-Johnson Project California F-9-R, "A Study of Sturgeon, Striped Bass, and Resident Fishes", supported by Federal Aid to Fish Restoration funds.

REFERENCES

Bajkov, A. D. 1949. A preliminary report on the Columbia River sturgeon. Oregon Fish. Comm. Res. Briefs 2:3–10.

Brownie, C., D. R. Anderson, K. P. Burnham, and D. S. Robson. 1978. Statistical inference from band recovery data—a handbook. U.S. Dept. Interior, Fish Wildl. Serv. Resource Publ. 131:1–212.

Chadwick, H. K. 1959. California sturgeon tagging studies. Calif. Fish Game, 45(4):297–301.

Chadwick, H. K., D. E. Stevens, and L. W. Miller. 1977. Some factors regulating the striped bass population in the Sacramento-San Joaquin Estuary, California. Pages 18–35. *In:* W. Van Winkle, ed. Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations. Pergamon Press, New York. 380 p.

Dees, L. T. 1961. Sturgeons. U.S. Fish Wildl. Serv., Bur. Comm. Fish., Fish. Leaflet 526:1–8.

Goodman, D. 1975. The theory of diversity-stability relationships in ecology. Quart. Rev. Biol., 50(3):237–266.

Grant, J. J. 1977. Evaluation of striped bass party boat log reporting for the Sacramento-San Joaquin Estuary from 1969 to 1974. Calif. Dept. Fish and Game, Anad. Fish. Br. Admin. Rept. 77-8:1–21. (Mimeo).

Gulland, J. A. 1971. Appraisal of a fishery. Pages 259–269. *In:* W. E. Ricker, ed. Methods for assessment of fish production in fresh waters. Internat. Biol. Programme Handbook No. 3. Blackwell Scientific Publications, Oxford. 348 p.

Hansen, D. J., S. C. Schimmel, and J. Forester. 1974. Aroclor 1254 in eggs of sheepshead minnows: effects on fertilization success and survival of embryos and fry. Southeastern Assoc. Game Fish Comm., Proc. 27th Ann. Conf., p. 420–426.

Hogan, J. W., and J. L. Brauhn. 1975. Abnormal rainbow trout fry from eggs containing high residues of PCB (Aroclor 1242). Prog. Fish. Cult., 37(4):229–230.

Kohlhorst, D. W. 1979. Effect of first pectoral fin ray removal on survival and estimated harvest rate of white sturgeon in the Sacramento-San Joaquin Estuary. Calif. Fish Game, 65(3):173–177.

Kohlhorst, D. W., L. W. Miller, and J. J. Orsi. 1980. Age and growth of white sturgeon collected in the Sacramento-San Joaquin Estuary, California, 1965–1970 and 1973–1976. Calif. Fish Game, 66(2):83–95.

Miller, L. W. 1972. White sturgeon population characteristics in the Sacramento-San Joaquin Estuary as measured by tagging. Calif. Fish Game, 58(2):94–101.

Pycha, R. L. 1956. Progress report on white sturgeon studies. Calif. Fish Game, 42(1):23–35.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Can., Fish. Res. Bd., Bull. 191:1–382.

Roussow, G. 1957. Some considerations concerning sturgeon spawning periodicity. Can., Fish. Res. Bd., J., 14(4):553–572.

Skinner, J. E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. Calif. Dept. Fish and Game, Water Proj. Br. Rept. 1:1–226.

Turner, J. L., and H. K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, *Morone saxatilis,* in relation to river flow in the Sacramento-San Joaquin Estuary. Am. Fish. Soc., Trans., 101(3):442–452.

Walker, C. R. 1976. Polychlorinated biphenyl compounds (PCB's) and fishery resources. Fisheries (Bull. Am. Fish. Soc.), 1(4):19–22.