Striped Bass (*Morone saxatilis*) Year Class Strength in Relation to River Flow in the Sacramento-San Joaquin Estuary, California[1]

DONALD E. STEVENS

Bay-Delta Fishery Project, California Department of Fish and Game
Stockton, California 95205

ABSTRACT

Striped bass, *Morone saxatilis*, abundance indices were developed from two analyses of sportfishing party boat catch statistics for the Sacramento-San Joaquin Estuary. These analyses cover the periods 1938–1954 and 1958–1972. The abundance indices provided evidence that the size of the fishable population fluctuated by a factor of 3.7 during the latter period and that river flows in the first summer of life affected recruitment during both periods.

In the Sacramento-San Joaquin Estuary, annual indices of young striped bass abundance are highly correlated with the logarithm of river outflow during all combinations of months from April to July (Turner and Chadwick 1972). The best relationship is described by a second degree polynomial equation which indicates young bass survival increases rapidly as mean June–July outflows increase from 57 to 285 m^3/s, but changes little at higher flows. This finding is important as water development is reducing flows. However, management implications depend on subsequent recruitment to the sportfishery also being related to flow. My objective is to document such a relationship.

STUDY AREA AND FISHERY

The Sacramento-San Joaquin river system forms a tidal estuary. The salinity gradient generally is about 80 km long extending from San Pablo Bay to the western delta (Fig. 1). River flows into the delta are quite variable and are partially controlled by upstream reservoirs. Inflows peak in winter and spring. Delta outflow depends on river inflow and amount of water diverted in the delta for local agriculture and federal and state water project exports. Kelley (1966) describes this region in detail.

Striped bass utilize the entire estuary and adjacent coastal area. They spend most of the year in saltwater, but in winter and spring migrate to the delta and rivers upstream for spawning (Chadwick 1967). The young bass nursery is from the delta downstream to eastern San Pablo Bay (Turner and Chadwick 1972).

Bass anglers fish from the Pacific Ocean near San Francisco to the rivers above the delta. Only sportfishing is legal. In 1956, minimum legal size became 40.6 cm total length. Previously, it was 30.5 cm. Daily bag limit was five bass until it was reduced to four in 1955, and three in 1956.

Many bass are caught on party boats. Operators of these boats take anglers fishing for a fee. They fished primarily from San Pablo Bay to the delta until the late 1950s (Chadwick 1962). Afterwards, small boat ownership increased, resulting in diminished demand for party fishing upstream from Carquinez Strait. New fishing techniques resulted in San Francisco Bay becoming the dominant area (McKechnie and Miller 1971). This fishery is seasonal. Catches are low in late winter and spring when weather is poor and most bass are in freshwater. Catches increase in early summer as bass move downstream and usually peak in late summer and fall.

Since 1938 party boat operators have been required to report catches to the California Department of Fish and Game. These reports are the best long-term striped bass catch records available.

METHODS

Standard correlation and regression procedures (Steel and Torrie 1960) were used to

[1] Funds for this investigation were provided by Dingell-Johnson Project California F9R, a study of sturgeon and striped bass, and by the California Department of Water Resources in cooperation with the California Department of Fish and Game.

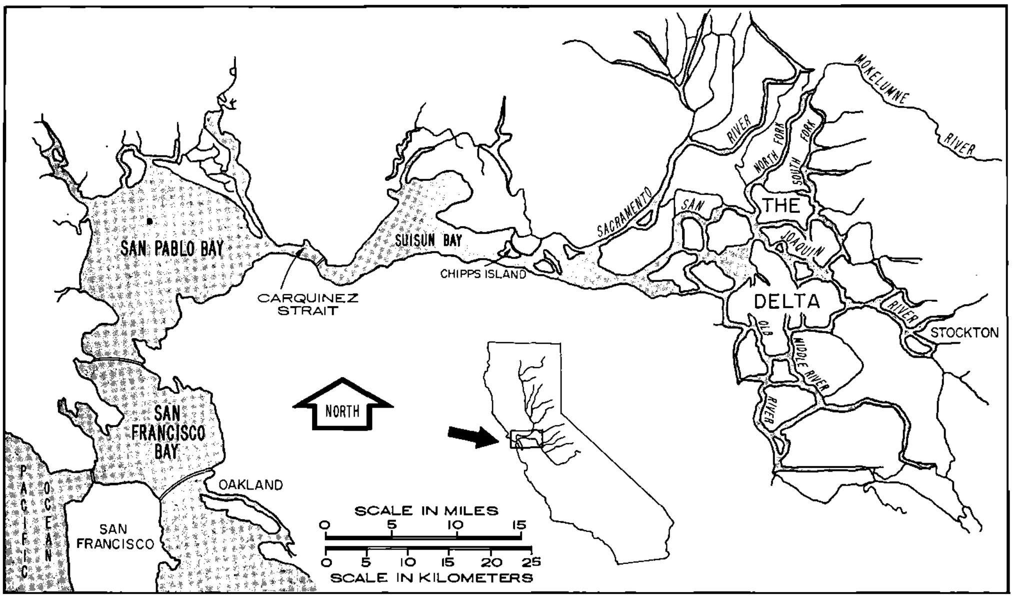

FIGURE 1.—*Sacramento-San Joaquin Estuary.*

relate recruitment indices developed from party boat catch records to the logarithm of delta outflow[2] during the first summer of life. *F* tests determined statistical significance of the regressions.

Development of Abundance Indices, 1938–1954

Striped bass age-length relationships (Robinson 1960; Miller and Orsi 1969) indicate that before the minimum legal length increase in 1956 most bass were 2 years old when recruited. Age and length statistics are not available for pre-1956 catches, but considering Calhoun's (1949) description of the fishery in Suisun Bay and the consistently small mean weights reported, it seems probable that 2-year-old bass dominated that fishery. Party boat logs reveal that best fishing in Suisun Bay was from August to November; hence, I used mean August–November catch per angler day in that area to index 2-year-old bass abundance from 1938–1954. No indices were calculated for 1950–1952 or 1955 as little angling was reported (fewer than 50 angler days per year).

Other factors affecting fishing success obviously bias these indices. These factors probably include: (1) outflow during the fishing period—when freshwater flows are low, less turbid seawater intrudes into Suisun Bay probably enhancing the ability of bass to find bait or lures; and (2) ocean temperature—from 1938 to 1959 there was a high correlation between Radovich's (1963) seaward migration index and ocean temperature, so, numbers of bass inhabiting Suisun Bay may have varied with temperature. The effect of these factors on the catch per day-summer outflow regression was assessed through a multiple regression analysis.

Development of Abundance Indices, 1958–1972

After 1954, catch per angler day is not an appropriate index of recruit abundance as few party boats have fished Suisun Bay and fish size varies too much elsewhere. However, I devised a different method to index recruitment.

First, an index of total population abundance was calculated for each year from 1958–

[2] Delta outflow is the mean calculated daily outflow past Chipps Island during June and July. These data were obtained from California Department of Water Resources, Water Supervision, and Water Flow bulletins.

TABLE 1.—*Striped bass catch, mortality, and outflow statistics for the Sacramento-San Joaquin Estuary, 1958–1972.*

Year (beginning May 1)	Catch on party boats	Fraction of population harvested[a]	Population index	Fraction of population surviving[a]	Recruitment index	Mean weight of bass in party boat catch (kg)	Outflow[b]
1958	51,768	0.372	139,160	0.319			
1959	47,390	0.247	191,860	0.534	147,470	2.11	633.8
1960	53,127	0.243	218,630	0.601	116,180	2.50	252.9
1961	61,227	0.190	322,250	0.662	190,850	2.55	886.4
1962	57,491	0.200	287,460	0.592	74,130	2.78	41.3
1963	66,553	0.281	236,840	0.511	66,670	3.38	72.8
1964	29,662	0.235	126,220	0.557	6,190	3.74	58.9
1965	18,120	0.142	127,610	0.655	57,300	5.03	173.9
1966	44,381	0.179	247,940	0.628	164,360	4.38	314.0
1967	23,838	0.160	148,990	0.647	−6,720	4.89	109.0
1968	22,644	0.120	188,700	0.687	92,310	4.28	304.4
1969	20,146	0.174	115,780	0.647	−13,860	4.77	62.3
1970	14,554	0.116	125,470	0.515	50,560	4.26	1205.3
1971	13,850	0.161	86,020	0.695	21,410	4.39	96.0
1972	30,994	0.153	202,580		142,790	4.41	830.3

[a] Calculated from tag returns. Methods described by Chadwick (1968). 1958–1964 estimates from Chadwick (1968), 1965–1968 estimates from Miller (1974), and 1969–1972 estimates based on unpublished data.
[b] Mean calculated daily outflow past Chipps Island during June and July 3 years earlier in cubic meters per second. From California Department of Water Resources, Water Supervision, and Water Flow bulletins.

1972. The concept is $N_t = C_t \div u_t$, where N_t = legal (≥40.6 cm) bass population size at start of year t; C_t = total catch during year t of those bass that were legal at the start of the year; u_t = fraction of the legal population harvested during year t.

Total catches (C_t) are unknown, so I assumed reported catches on party boats were a constant fraction of the total catches and used them as annual catch indices (K_t). Annual estimates of the fraction of the population harvested (u^*_t) are available from tag returns (Table 1). Hence, my population indices: $(P_t) = K_t \div u^*_t$.

Annual harvest rates (u^*_t) were derived from numbers of tags recaptured within one year of release. May 1 was about the midpoint of the approximate two-month tagging period; therefore, the "harvest rate year" was roughly May 1 to the next April 30. Catches (K_t) were tabulated from May 1 to April 30 so they and the harvest rates pertained to the same periods.

The annual index of recruit abundance (R_t) was calculated assuming all recruitment occurred on May 1. The formula used was $R_t = P_t - P_{t-1}\, s_{t-1}$, where: s_{t-1} = estimated survival rate in year $t-1$.

Since 1956, most recruits have been 3 years old (Robinson 1960; Miller and Orsi 1969); therefore, I assumed this index measured 3-year-old bass abundance.

These population and recruitment indices are imprecise as several biases exist. The most important of these biases follow.

(1) The party boat catch does not form the same fraction of the total catch each year. This fraction was estimated from angler surveys in 1956 (Skinner 1962) and 1969–72 (unpublished). Estimates varied from 10.1 to 17.4%.

(2) The fraction of the party boat catch that is reported varies annually. Studies in 1950 (Johnson 1951), 1959 (Chadwick 1962), and 1969 (unpublished) indicate an average of about one-quarter of the trips are unreported. The fraction unreported depends on attitudes of individual operators. In San Pablo Bay the proportion of trips unreported was remarkably constant (18%, 20%, 19%) during the three studies, but similar estimates for San Francisco Bay which were made only in 1959 (45%) and 1969 (30%) varied more. Catches from reported trips generally are within 5% of true catches (Johnson 1951; Chadwick 1962).

(3) Recruitment does not consist entirely of 3-year-old fish and does not occur instantaneously at the start of the year (May 1). It occurs throughout the year and some 2-year-old fish are involved. The typical recruitment-fishery sequence follows.

(a) Initial recruitment from a year class consists of 2-year-old fish and occurs primarily from September to November, which is the latter half of the peak fishing season (Fig. 2). Roughly 24% of the fish attain legal size then. Some of these early recruits are caught before the next May and contribute to the population and recruitment indices one year too early.

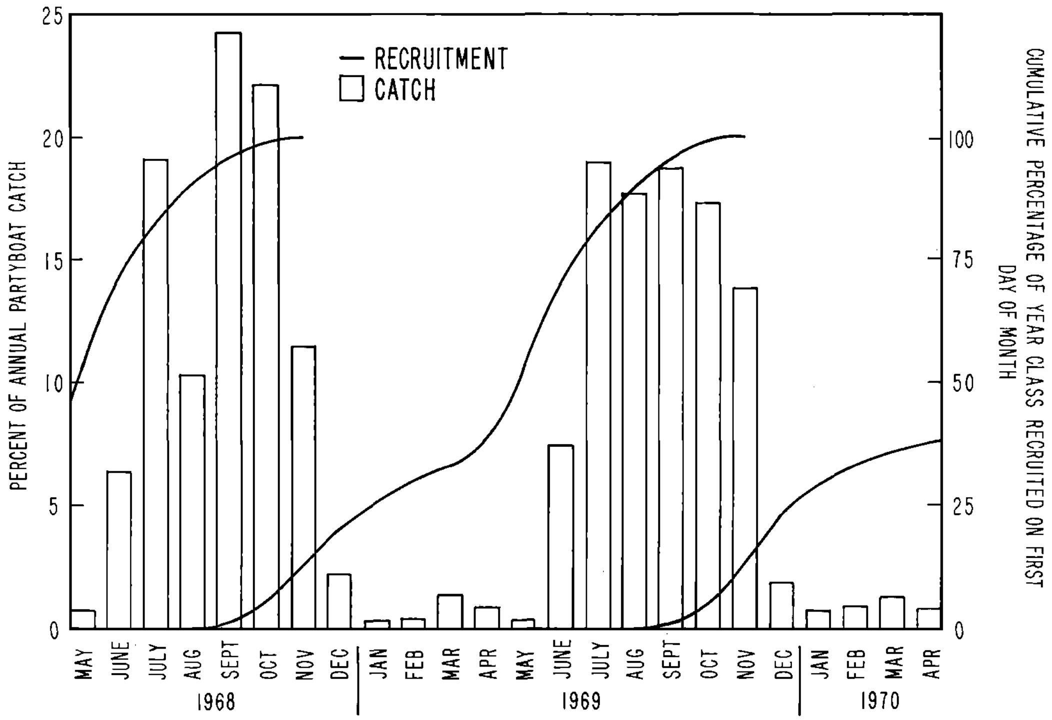

FIGURE 2.—*Relationship between striped bass party boat catches from May 1968 to April 1970 and the "typical" monthly recruitment (bass growing past 40.6 cm) distribution of a year class (unpublished growth rate data).*

(b) The bulk (57%) of the year class is recruited between December and July. Fishing is poor during this period, so these fish essentially are unutilized until they are in the "proper year."

(c) The remaining 19% of the fish are recruited during the peak fishing months, July through November. They are not fully vulnerable for the entire fishing season, so they are not fully represented by the population and recruitment indices.

Hence, the indices certainly are affected by annual variations in recruitment and catch patterns. Underestimates caused by category (3c) fish are offset to varying degrees by category (3a) fish, presumably resulting in overestimated recruitment of year classes which are followed by larger year classes and underestimates for year classes followed by smaller year classes.

There is no way to evaluate the overall impact of these biases quantitatively. A qualitative evaluation was made by comparing recruitment index trends with trends in annual mean weights of bass in the party boat catch. The premise was that weights and recruit indices would fluctuate inversely if the index trends were valid.

RESULTS

Indices from 1938 to 1954

From 1938 to 1954, catch per angler day in Suisun Bay averaged about 2.51 bass and ranged from 1.16 bass in 1953 to 4.17 bass in 1939 (Table 2). When 1941 is omitted, a linear relationship is evident between catch per day and the logarithm of mean June–July delta outflow, up to 1,444 m^3/s, 2 years earlier ($F = 18.51$; $P < 0.005$) (Fig. 3). The regression accounts for 63% of the variation in catch per day.

The 1941 point can be explained by two other factors suspected to affect fishing—outflow during the fishing period and ocean temperature. A multiple regression of catch per angler day on the logarithm of mean June–

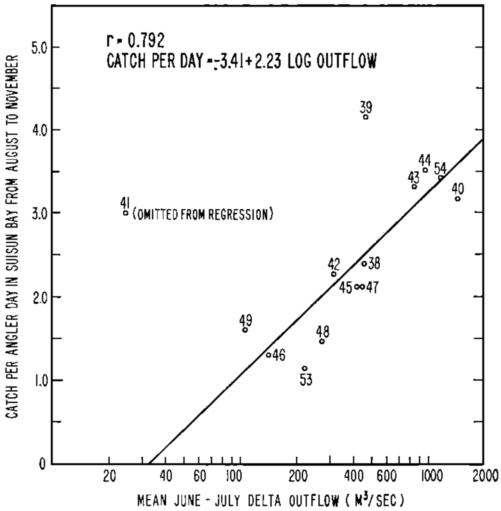

FIGURE 3.—*Relationship between fishing success on party boats in Suisun Bay and mean June–July outflow from the delta 2 years earlier. Numbers on figure designate fishing year.*

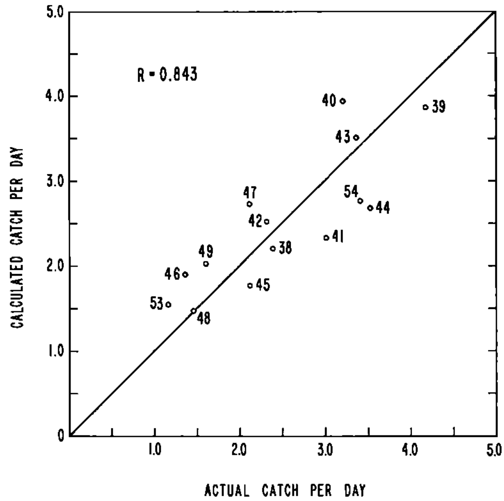

FIGURE 4.—*Predicted versus actual fishing success on party boats in Suisun Bay. Calculated catch per day = –13.11 + 0.91*X_1 *– 0.0069*X_2 *+ 0.88*X_3 *when* X_1 *= log mean June–July delta outflow 2 years earlier,* X_2 *= mean monthly delta outflow during the August–November fishing period, and* X_3 *= mean annual sea temperature at La Jolla. Outflow measured in* m^3/s *and temperature in Celsius. Numbers on figure designate fishing year.*

July outflow 2 years earlier, outflow during the fishing season, and ocean temperature accounts for 71% of the variation in catch rate for all years ($F = 8.17, P < 0.01$) (Fig. 4).

Indices from 1958 to 1972

The striped bass population index (P_t) fluctuated by a factor of about 3.7 from 1958–1972 (Fig. 5). It increased annually and more than doubled from 1958 to 1961. After 1961, the index fluctuated irregularly with a downward trend.

The population decline after 1961 appar-

TABLE 2.—*Relationship between striped bass catch per angler day in Suisun Bay and various environmental factors.*

Year	No. angler days[a]	Catch per angler day[b]	Mean June–July outflow[c]	Mean August–November outflow[d]	Ocean temperature[e]
1938	589	2.39	465.5	249.6	16.6
1939	2,289	4.17	474.4	84.1	17.2
1940	1,776	3.20	1443.9	164.0	17.4
1941	1,042	3.00	25.0	190.8	17.6
1942	284	2.31	317.8	233.6	17.0
1943	392	3.37	854.2	160.4	17.0
1944	298	3.51	975.6	194.4	16.4
1945	171	2.12	414.4	305.4	16.6
1946	267	1.35	143.9	251.7	16.8
1947	598	2.12	441.6	208.6	16.9
1948	191	1.45	274.7	248.3	16.0
1949	108	1.60	107.8	181.2	16.5
1953	163	1.16	221.3	263.9	16.3
1954	67	3.40	1176.7	246.2	16.8

[a] Total angler days reported on party boats from August 1 to November 30.
[b] Mean catch per angler day on party boats from August 1 to November 30.
[c] Mean calculated daily outflow past Chipps Island during June and July 2 years earlier in cubic meters per second. From California Department of Water Resources, Water Supervision, and Water Flow bulletins. Correlation coefficient is calculated from log of outflow. Outflow value for 1939 (line for 1941) was given as –17.8 in the bulletin; however a recent computation for the U.S. Bureau of Reclamation (Hugo Fischer 1974, unpublished report) indicates that it should be about +25. Hence, that value was used for the calculations in this paper.
[d] Mean calculated daily outflow past Chipps Island from August 1 to November 30 in cubic meters per second. From Water Supervision and Water Flow bulletins.
[e] Mean annual ocean temperature Scripps Institute pier at La Jolla in degrees Celsius. This station is on the southern California coast, but Radovich (1963) used these temperatures in analyzing bass migrations because central California temperatures were not available for his whole study period, and the two correlated well when temperatures were available from both areas.

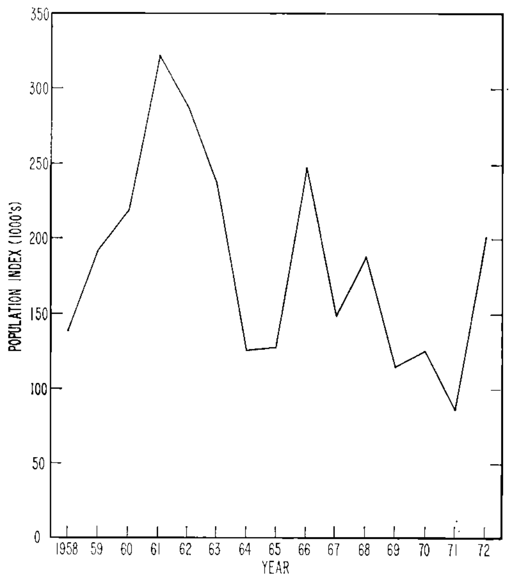

FIGURE 5.—*Trends in striped bass population indices derived from sportfishing party boat catch statistics.*

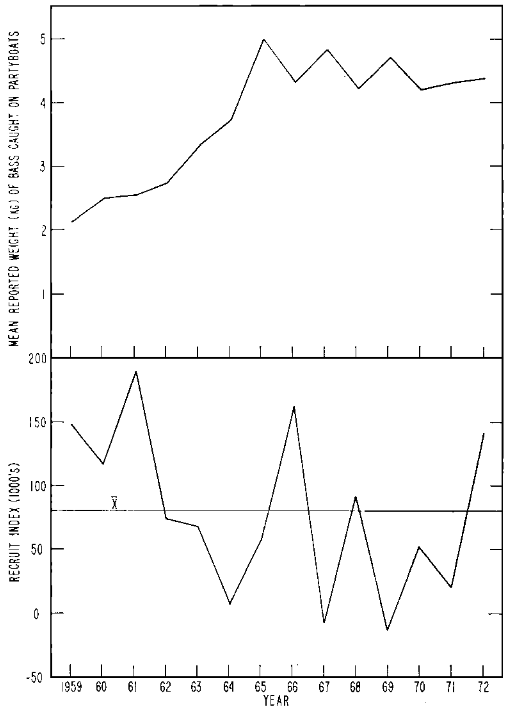

FIGURE 6.—*Trends in recruit indices derived from sportfishing party boat catch statistics and weights reported for bass caught on party boats. Both measurements are based on data from May 1 to April 30 of the following year.*

ently was due to relatively poor recruitment (Fig. 6). Recruit indices (R_t) declined every year from 1962 to 1964. They were particularly low during 1964, 1967, and 1969. After 1961, recruit indices were above average only in 3 years.

Mean weights reported for bass caught on party boats tended to fluctuate inversely from the recruit indices (Fig. 6), providing evidence that the recruitment trends are valid.

Except for the 1967 year class index, the recruit indices are related linearly to the logarithm of mean June–July delta outflow 3 years earlier ($F = 25.06$, $P < 0.005$) (Fig. 7). The regression accounts for 69% of the variation in the indices. Hence, the 1959–1961 bass population increase is attributable to excellent survival associated with high flows in 3 consecutive years—1956, 1957, 1958, and the subsequent population decrease is associated with lower flows in most years since 1959.

Ten of the recruitment indices are for year classes for which Turner and Chadwick measured young-of-the-year abundance. There was a positive trend between the two indices (Fig. 8), but the regression was not significant ($F = 1.07$, $P > 0.10$). This lack of significance presumably is due to variations in mortality between the young and recruit stages and/or error in the indices.

DISCUSSION

Turner and Chadwick (1972) demonstrate conclusively that in the Sacramento-San Joaquin System the survival of young bass up to 3.8 cm long is related to summer river flow through the delta. My analyses of sportfishing party boat catch statistics provide evidence that these flows impact recruitment to the fishery several years later and are largely responsible for the population abundance fluctuations.

A basic difference between the relationships is that Turner and Chadwick found young bass survival does not increase at delta outflows greater than 285 m^3/s; whereas, my data suggest that survival increases at flows up to at least 900 m^3/s. The survival limit demon-

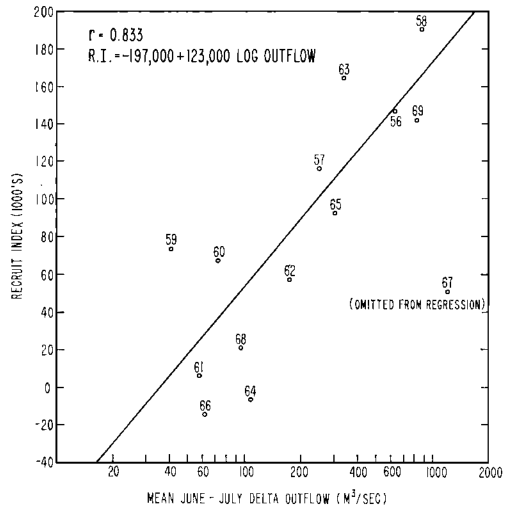

FIGURE 7.—*Relationship between recruit indices derived from sportfishing party boat catch statistics and delta outflow during June and July 3 years earlier. Numbers on figure designate year classes.*

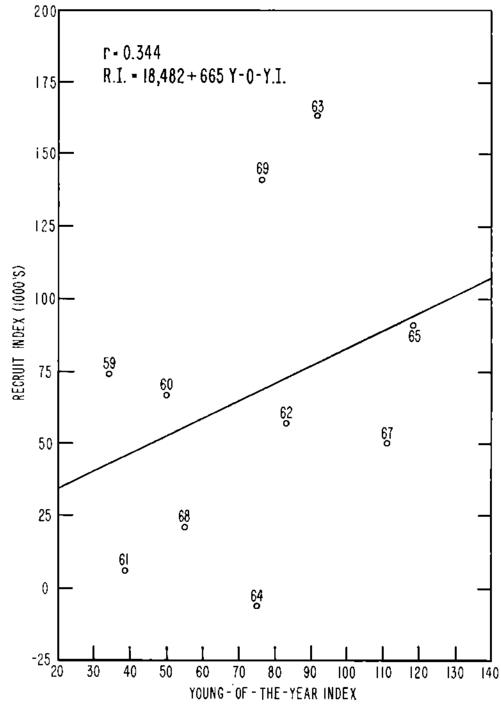

FIGURE 8.—*Relationship between recruit indices derived from sportfishing party boat catch statistics and Turner and Chadwick's young-of-the-year index 3 years earlier. Numbers on figure designate year classes.*

strated by Turner and Chadwick may be artificial. Many post-larval bass are flushed to San Pablo and San Francisco bays by high flows (unpublished data). Turner and Chadwick had only one sampling site west of Carquinez Strait. Catches were small there (Chadwick 1964), suggesting bass were scarce. However, the tow net may have been ineffective because saltwater in the bays is clearer than the fresher water in the upstream nursery areas. Large catches of young bass in seines and chinese shrimp nets (Scofield and Bryant 1926) are evidence that the western bays were at least formerly an important part of the striped bass nursery.

A survey of summer bass abundance in Chesapeake Bay spawning areas suggests young bass survival is affected by flow during or shortly after spawning in part of that estuary too. This survey by the Maryland Department of Natural Resources began in 1954, although in 1961 it was revised to improve coverage. Since that revision, the mean catch per seine haul in the Potomac River has been highly correlated with mean April–May flow in the Potomac (r = 0.865 for 1961–1971; Joseph Boone, personal communication). However, similar relationships were not found for other parts of Chesapeake Bay and bass catches in the Potomac River were not highly correlated with June–July flow (r = 0.059).

The Maryland survey also provides evidence that early survival determines numbers of bass available to the fishery several years later. Schaefer (1972) worked with the data from all Chesapeake Bay seining sites starting in 1954, and assumed that the New York commercial fishery relies on fish produced in Chesapeake Bay. He found a significant correlation (r = 0.85) between the commercial landings from 1960–1971 and 4-year running averages of the young-of-the-year catches 3 to 6 years earlier.

Commercial striped bass catches in Chesapeake Bay (United States Bureau of Fisheries 1932–1941; United States Bureau of Commercial Fisheries 1942–1971; Koo 1970) are largely 2-year-old fish (Vladykov and Wallace 1952; Koo 1970), but I was unable to establish a significant relationship between them and flows 2 years earlier in the Susquehanna River, the largest tributary of Chesapeake Bay. Contrary to the survival-flow relationship, the dominant 1934 year class (Merriman 1941; Vladykov and Wallace 1952) was produced when mean April–July flows were about 40% below average at Conowingo (Susquehanna Electric Company data).

Turner and Chadwick advanced several hypotheses to explain the bass survival-flow relationship. They believed that food availability was determined by the way that flow affected bass distribution, nutrient input, and spawning time. They also discussed the possibilities that flow might have affected young bass abundance by diluting toxic effluents, controlling predation by maintaining turbidity, and controlling numbers of young bass lost to water project diversions.

The latter mechanism was considered possible because there was an almost perfect inverse correlation ($r = -0.997$ for 1959–1970) between logarithm of delta outflow and the proportion of delta inflow (and presumably numbers of young bass) removed by diversions. Subsequent evidence indicates that loss to diversions is a major factor controlling bass survival (California Department of Fish and Game et al. 1975). However, my correlation between recruitment in Suisun Bay and flow occurred largely before major water project diversions operated suggesting diversions alone do not cause the relationships.

When one considers the rapid population growth following the original introduction of striped bass into the Sacramento-San Joaquin Estuary (Scofield 1931) and the abundance-flow correlations, it seems probable that the population presently is density limited in a restricted environment, with the carrying capacity of the estuary increasing with late spring and early summer flow. Such an increase could be due to high flows increasing available habitat by dispersing eggs and young over a greater area.

George (1972) and Sutcliffe (1972, 1973) have demonstrated relationships between catches in several other fisheries and river discharge. They suggest nutrient input and/or recirculation as the cause. In this regard, Turner and Chadwick's hypothesis that high flows enhance the food supply of young bass seems reasonable; yet, measurements of standing crops for the various levels in the striped bass food chain do not support their hypothesis. Summer standing crops of algae apparently are inversely related to outflow (M. Ball, U.S. Bureau of Reclamation, unpublished data) and no secondary production-outflow relationship has been found.

In summary, my analysis of Sacramento-San Joaquin striped bass party boat catch statistics and Schaefer's (1972) analysis of Atlantic Coast data indicate that the number of bass available to the fishery is largely a function of survival early in life. In the Sacramento-San Joaquin Estuary, there is firm evidence that high survival coincides with moderately high river flows. Recent data from part of the Chesapeake Bay system indicate a similar relationship; however, strong year classes have also been produced there under low flows and such a relationship does not exist in all parts of Chesapeake Bay. Hence, a better understanding of the mechanism(s) responsible for these relationships is necessary to interpret their significance fully.

ACKNOWLEDGMENTS

I thank Harold Chadwick, Edward Huntley, Lee Miller, James Orsi, and John Radovich for making suggestions that improved the manuscript. Nanci Dong drew the figures. Joseph Boone kindly granted permission to cite the abundance-flow relationship in the Potomac River. The idea for deriving the population and recruit indices from 1958–1972 and correlating recruitment to outflow is my own. In 1971 I discussed the concept with Gerald Paulik (deceased) and provided the basic data so he and Prichar Sommani could develop a more intricate approach, designed largely to divide recruitment between 2- and 3-year-old bass. Sommani used that approach in developing a striped bass population model for his doctoral thesis at the University of Washington (1972). Although Paulik and Sommani's version was analytically more sophisticated than mine, it required additional tenuous assumptions and did not substantially alter results; therefore, I utilized my original approach in preparing this analysis.

LITERATURE CITED

CALHOUN, A. J. 1949. California striped bass catch records from the party boat fishery: 1938–1948. Calif. Fish Game 35(4): 221–253.

CALIFORNIA DEPARTMENT OF FISH AND GAME, CALIFORNIA DEPARTMENT OF WATER RESOURCES, U.S. FISH AND WILDLIFE SERVICE, AND U.S. BUREAU OF RECLAMATION. 1975. Interagency ecological study program for the Sacramento-San Joaquin Estuary. Ann. Rept. No. 4. 121 pp.

CHADWICK, H. K. 1962. Catch records from the striped bass sport fishery in California. Calif. Fish Game 48(3): 153–177.

———. 1964. Annual abundance of young striped bass (*Roccus saxatilis*) in the Sacramento-San Joaquin Delta, California. Calif. Fish Game 50 (2): 69–99.

———. 1967. Recent migrations of the Sacramento-San Joaquin River striped bass population. Trans. Am. Fish. Soc. 96(3): 327–342.

———. 1968. Mortality rates in the California striped bass population. Calif. Fish Game 54(4): 228–246.

GEORGE, C. J. 1972. The role of the Aswan high dam in changing the fisheries of the southeastern Mediterranean. Pages 159–178 *in* Farver, M. T., and J. P. Miltoz, eds. The careless technology. Natural History Press, New York. 1030 pp.

JOHNSON, W. C. 1951. The reliability of the striped bass party boat catch records. Rept. to Bur. Fish. Cons. Calif. Div. Fish Game 51-1: 1–14 (typewritten).

KELLEY, D. W. 1966. Description of the Sacramento-San Joaquin Estuary. Calif. Fish Game Fish. Bull. 133: 8–17.

KOO, T. S. Y. 1970. The striped bass fishery in the Atlantic states. Chesapeake Sci. 11(2): 73–93.

MCKECHNIE, R. J., AND L. W. MILLER. 1971. The striped bass party boat fishery: 1960–1968. Calif. Fish Game 57(1): 4–16.

MERRIMAN, D. 1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic Coast. U.S. Fish Wildl. Serv. Fish. Bull. 50: 1–77.

MILLER, L. W. 1974. Mortality rates for California striped bass (*Morone saxatilis*) from 1965–1971. Calif. Fish Game 60(4): 157–171.

———, AND J. J. ORSI. 1969. Growth of striped bass, *Morone saxatilis*, in the Sacramento-San Joaquin Estuary, 1961–1965. Calif. Fish Game, Anad. Fish. Admin. Rept. 69-6: 1–7.

RADOVICH, J. 1963. Effect of ocean temperature on the seaward movements of striped bass, *Roccus saxatilis*, on the Pacific Coast. Calif. Fish Game 49(3): 191–206.

ROBINSON, J. B. 1960. The age and growth of striped bass (*Roccus saxatilis*) in California. Calif. Fish Game 46(3): 279–290.

SCHAEFER, R. H. 1972. A short range forecast function for predicting the relative abundance of striped bass in Long Island waters. N.Y. Fish Game J. 19(2): 178–181.

SCOFIELD, E. C. 1931. The striped bass of California (*Roccus saxatilis*). Calif. Fish Game Fish. Bull. 29. 84 pp.

SCOFIELD, N. B., AND H. C. BRYANT. 1926. The striped bass in California. Calif. Fish Game 12 (2): 55–74.

SKINNER, J. E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay Area. Calif. Dep. Fish Game Water Proj. Br. Rept. (1). 226 pp.

SOMMANI, P. 1972. A study on the population dynamics of striped bass (*Morone saxatilis* Walbaum) in the San Francisco Bay Estuary. Ph.D. Thesis. University of Washington. 133 pp.

STEEL, R. G. D., AND J. H. TORRIE. 1960. Principles and procedures of statistics. McGraw-Hill Co. 481 pp.

SUTCLIFFE, W. H., JR. 1972. Some relations of land drainage, nutrients, particulate material, and fish catch in two eastern Canadian bays. J. Fish. Res. Board Can. 29(4): 357–362.

———. 1973. Correlations between seasonal river discharge and local landings of American lobster (*Homarus americanus*) and Atlantic halibut (*Hippoglossus hippoglossus*) in the Gulf of St. Lawrence. J. Fish. Res. Board Can. 30(6): 856–859.

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. Trans. Am. Fish. Soc. 101(3): 442–452.

UNITED STATES BUREAU OF COMMERCIAL FISHERIES. 1942–71. Fisheries statistics of the United States, 1939–1968. Statistical digests nos. 1, 4, 7, 11, 14, 16, 18, 19, 21, 22, 25, 27, 30, 34, 36, 39, 41, 43–44, 49, 51, 53–54, 56–62.

UNITED STATES BUREAU OF FISHERIES. 1932–41. Fishery industries of the United States, 1930–1939. Comm. Fish., Ann. Repts. 1931–1939. (Admin. Rept. Ser., nos. 3, 8, 13, 15, 20, 24, 27, 32, 37, 41.)

VLADYKOV, V. D., AND D. H. WALLACE. 1952. Studies of the striped bass, *Roccus saxatilis* (Walbaum), with special reference to the Chesapeake Bay region during 1936–1938. Bull. Bingham Oceanogr. Collect. 14: 132–177.