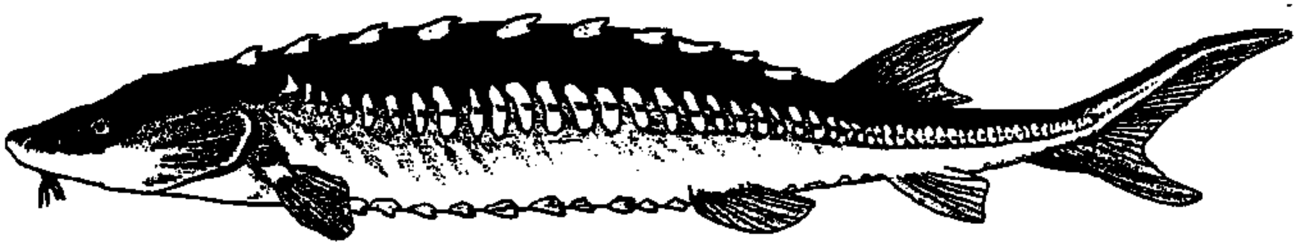
WRINT-DFG-Exhibit 28

STURGEON IN RELATION TO WATER DEVELOPMENT IN THE SACRAMENTO-SAN JOAQUIN ESTUARY



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INTRODUCTION

Two species of sturgeon inhabit the Sacramento-San Joaquin Estuary, the white sturgeon and the green sturgeon. Both of these native species are anadromous, spending most of their lives in brackish or salt water and returning to fresh water to spawn. Sturgeon are important sport fish in the estuary and have become more popular in the last decade as populations of other sport fish have declined and as more effective fishing techniques have been developed.

LIFE HISTORY

Green Sturgeon

Green sturgeon are found around the rim of the North Pacific Ocean, from Monterey, California to Japan, but are less abundant in North America than white sturgeon. In the Sacramento-San Joaquin system, ratios of adult green:white sturgeon during tagging studies have ranged from 1:50 to 1:100 (CDFG, unpublished). Hence, green sturgeon are a minor component of the sport fishery here.

Little is known about green sturgeon life history. They make extensive ocean migrations, so that most recoveries of individuals tagged in San Pablo Bay have come from the ocean and from rivers and estuaries in Washington and Oregon (CDFG, unpublished). Collection of juvenile fish in the Sacramento River near Hamilton City (CDFG, unpublished) and in the delta and bays and observations of adults near Red Bluff Diversion Dam in late winter and early spring (J. Smith, U.S. Fish and Wildlife Service, pers. comm.) demonstrate that green sturgeon spawn in the Sacramento River. Juveniles inhabit the estuary until they are about 4-6 years old, when they migrate to the ocean (CDFG, unpublished).

<u>White Sturgeon</u>

White sturgeon is the predominant sturgeon species in the Sacramento-San Joaquin Estuary and is the object of an important sport fishery. It occurs along the west coast of North America from Monterey, California to southern Alaska, but is most abundant in large river systems such as the Fraser, Columbia, and Sacramento-San Joaquin. It apparently makes less extensive ocean migrations than the green sturgeon, spending most of its life in the river and estuarine environment; landlocked populations exist in the Columbia and Snake rivers and previously existed in Shasta Lake. There is limited interchange of fish among rivers of the west coast; less than 1% of the recoveries of fish tagged in San Pablo Bay have come from other rivers in Washington and Oregon and no fish tagged in the Columbia River in recent years have been recaptured in California (Kohlhorst et al. 1990).

White sturgeon are long-lived and late-maturing. Their longevity allows them to reach a large size, reportedly as large as 1,300 pounds at over 100 years of age. The California sport fishing record is a 468-pound fish that was probably 40-50 years old when caught in the mid-1980s. Most females spawn for the first time at about age 15 and may spawn as infrequently as every 5 years thereafter. Males probably mature at a somewhat younger age than females and spawn more frequently.

Spawning occurs in both the Sacramento and San Joaquin rivers, but tag returns suggest that about ten times more white sturgeon spawn in the Sacramento River as in the San Joaquin (Kohlhorst et al. 1990). In the Sacramento River, the spawning season extends from late February through May, but most spawning occurs in March and April at water temperatures of 46-64 F (Kohlhorst 1976). Tagging with radiotransmitters indicates that females move deliberately upstream as much as 7-10 miles per day until they reach the primary spawning area near Colusa; however, some spawning occurs at least as far upstream as Red Bluff Diversion Dam. Increasing flows (freshets) appear to trigger spawning (Schaffter 1990). The eggs sink to the bottom and adhere to solid substrate until they hatch in 5-10 days, depending on water temperature. Larval movement and dispersal is dependent on river flows: in high flow years, many larvae are found in the Delta and upper bays, but in dry years most larvae remain in the rivers (Stevens and Miller 1970). Thus, the location of the nursery area for most young-of-the-year fish appears to move farther downstream as flows increase (Kohlhorst 1976).

Young white sturgeon grow rapidly, reaching 12 inches at age 1 and 18 inches at age 2; they attain the minimum legal size for the sport fishery (presently 46 inches) at age 11 (Kohlhorst et al. 1980).

Food habits vary with size. White sturgeon younger than one year old feed primarily on small benthic invertebrates such as *Neomysis* and *Corophium* (Schreiber 1962). As they grow, their diet becomes more diverse and includes clams, shrimp, crabs, polychaetes, and fish and fish eggs (Radtke 1966; McKechnie and Fenner 1971).

As mentioned earlier, the white sturgeon is the object of an important sport fishery in the Sacramento-San Joaquin Estuary. This fishery gained substantially in popularity in the 1980s as sturgeon increased in abundance and other species declined. This increased fishing pressure and the development of more effective angling techniques caused harvest to exceed 10,000 fish annually in the mid-1980s. To protect the sturgeon population from the overharvest to which it is readily susceptible, a series of angling regulation changes have been instituted to raise the minimum size limit from 40 inches to 46 inches in 2-inch annual increments and to establish a maximum size limit of 72 inches.

FACTORS AFFECTING WHITE STURGEON YEAR CLASS STRENGTH

An index of white sturgeon year class strength was developed from catches of young-of-the-year (age 0) and juvenile (ages 1-5) fish in otter and midwater trawls fished once monthly by the San Francisco Bay Outflow Study at 35 locations from southern San Francisco Bay to the western delta from January 1980 to August 1989 and from February to September 1990. All white sturgeon caught were measured to the nearest millimeter fork length. Approximate age was assigned using the Von Bertalanffy growth curve for white sturgeon (Kohlhorst et al. 1980) after first converting fork length to total length by multiplying by 1.08.

An index of year class strength for year i was calculated as:

$YCI_i = N_o/y$, where

y = number of years in which fish of year class i were available to the sampling gear at ages 0-5, and

$N_o = N_t/e^{-Zt}$, where

t = age at capture,

N_t = number captured at age t,

Z = assumed instantaneous mortality rate of 0.2877 (equivalent to annual survival rate of 0.75), and

N_o = backcalculated catch at age 0 that would be the equivalent of N_t.

With this method, the more ages at which each year class is sampled, the more reliable the estimate of YCI.

Associations between YCI and hydrologic variables (mean daily freshwater outflow from the estuary, mean daily freshwater diversions from the delta, and mean daily percent of inflow diverted) were explored with correlation analysis. These environmental variables were chosen because they affect the production of young by other anadromous fishes in the estuary (Turner and Chadwick 1972; Stevens 1977; Stevens and Miller 1983; Stevens et al. 1985).

A total of 495 white sturgeon was captured in otter and midwater trawls from 1980 to 1990. These fish ranged from 31 to

1,441 mm total length (Figure 1), but fish greater than age 5 (approximately 815 mm) were omitted when indexing year class strength for 1975 to 1990 because the trawls were inefficient for large fish. Estimated production from the 1982 and 1983 year classes was substantially greater than for other years in this period (Figures 1 and 2), while production in 1987-1990 appears almost nonexistent. Both 1982 and 1983 were years of very high spring and early summer freshwater outflow from the estuary, but 1987-1990 were drought years with very low outflow. The years 1982 and 1983 are primarily responsible for the strong correlation between year class index and outflow in all months from April to July (Table 1, Figure 3). These correlations with mean daily flow decreased slightly from April to July, suggesting spring flow affects production more than summer flow.

Correlations of the year class index with the mean daily volume of diversions by the State and Federal water projects and delta agriculture were low, but the negative correlations with the percent of inflow diverted were moderate and increased from March to July. The latter correlations may reflect cause and effect or they may simply be the result of an inverse relationship between percent diverted and outflow.

Other evidence also is available that annual production of young sturgeon in the estuary is dependent on spring outflow. Analysis of Skinner Fish Facility data from 1968 to 1987 indicated that young sturgeon salvage per acre-foot of water exported was associated with spring outflows, especially in the months of April and May (CDWR 1990)(Figure 4).

CONCLUSIONS

Legal-sized white sturgeon abundance in the Sacramento-San Joaquin Estuary has varied dramatically in the last 35 years, while their total mortality rates during much of that period have been relatively stable (Kohlhorst 1980; Kohlhorst et al. 1990).

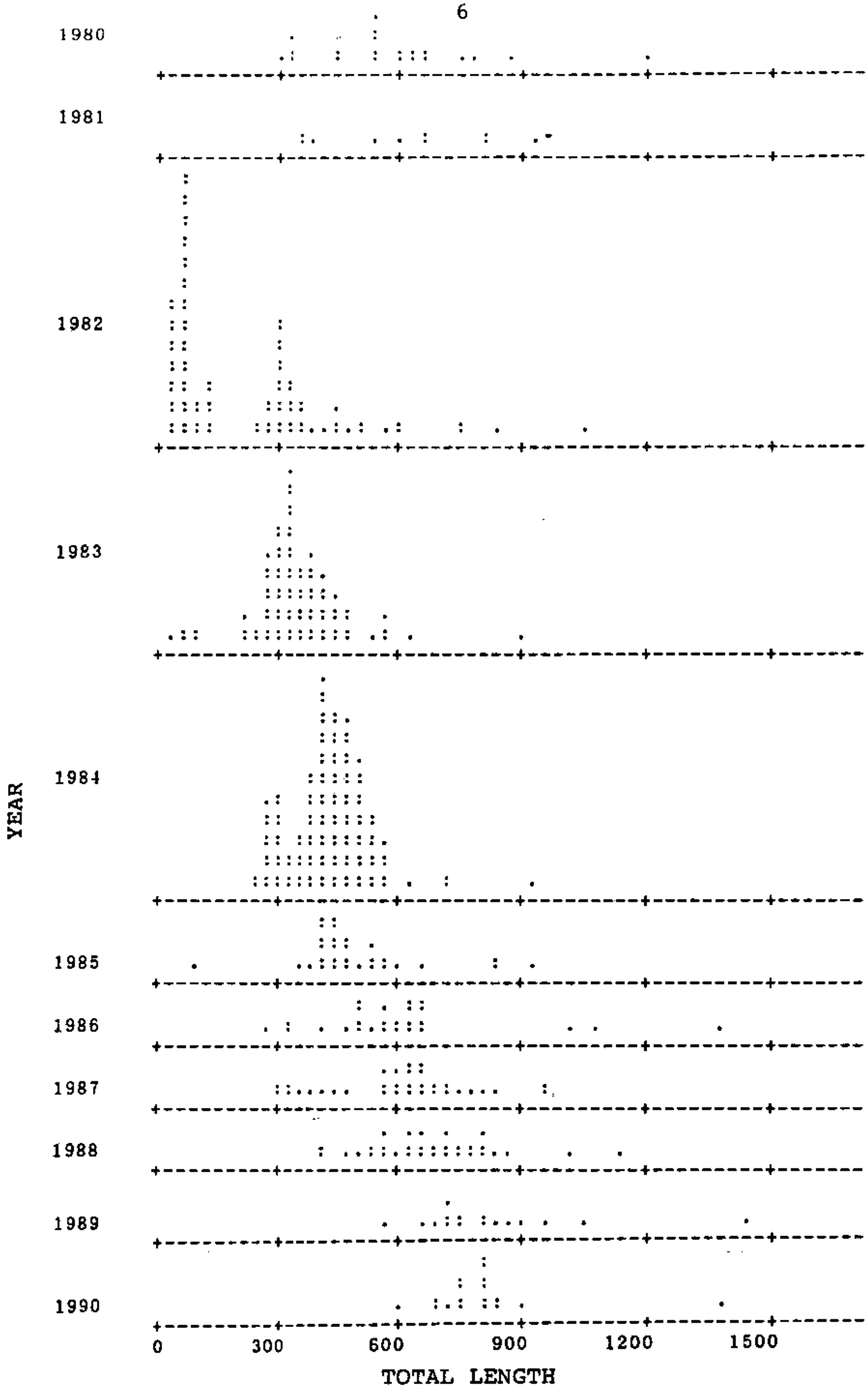

Figure 1. Annual length frequencies of white sturgeon caught in otter and midwater trawls in the Sacramento-San Joaquin Estuary from 1980 to 1990.

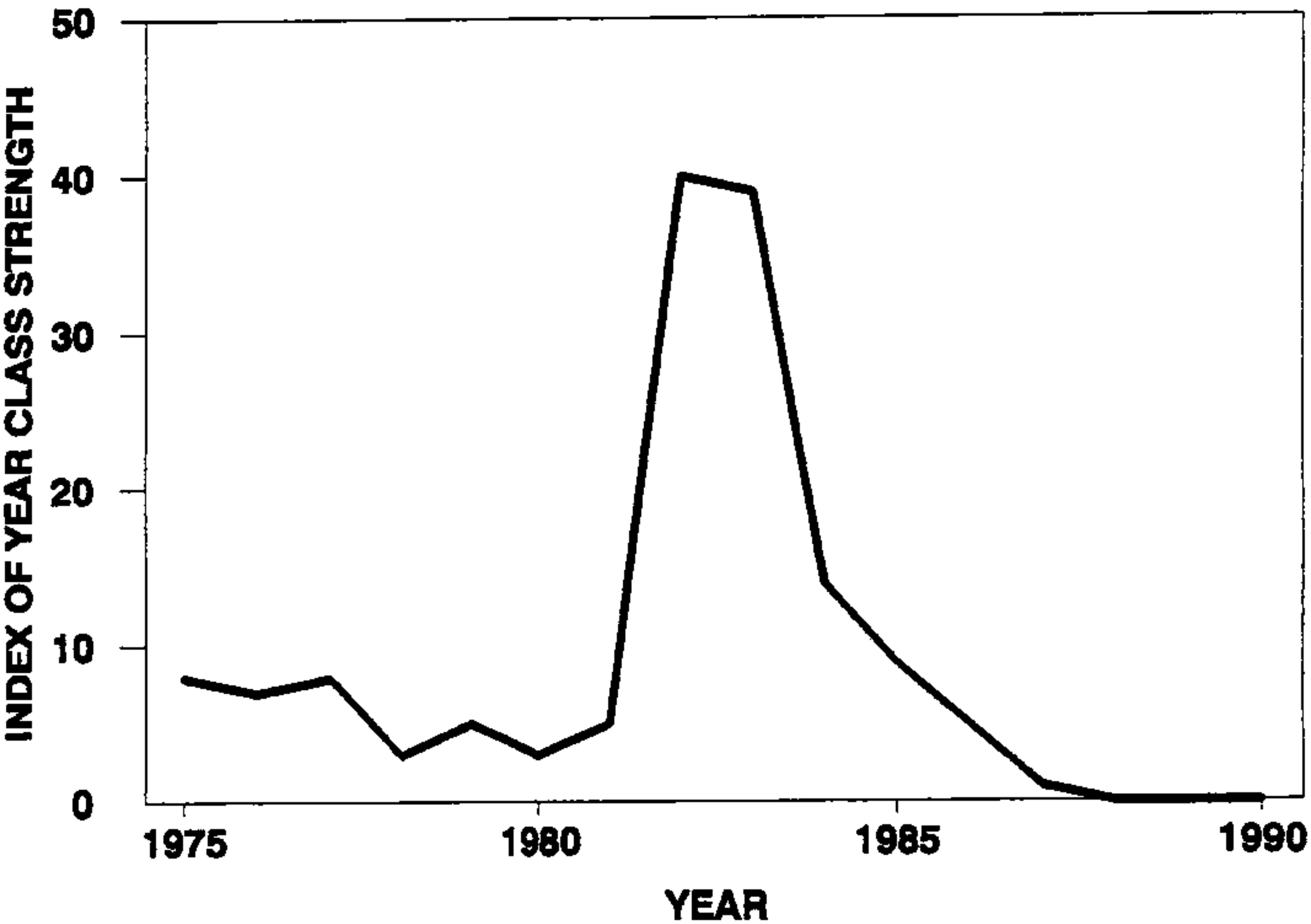

Figure 2. Trend in white sturgeon year class indices for the Sacramento-San Joaquin Estuary developed from trawl catches by the San Francisco Bay Outflow Study.

Table 1. Correlation coefficients between the Bay Study white sturgeon year class index and hydrologic variables in the Sacramento-San Joaquin Estuary for the years 1975-1990. Mean daily values are used for all hydrologic variables.

Variable	Correlation with Year Class Index
March Outflow	0.583
April Outflow	0.869
May Outflow	0.831
June Outflow	0.813
July Outflow	0.813
April-May Outflow	0.874
May-June Outflow	0.834
June-July Outflow	0.816
April-May-June Outflow	0.881
May-June-July Outflow	0.826
April to July Outflow	0.884
March Diversions	0.119
April Diversions	-0.044
May Diversions	-0.071
June Diversions	-0.155
July Diversions	-0.388
March % of Inflow Diverted	-0.335
April % of Inflow Diverted	-0.500
May % of Inflow Diverted	-0.512
June % of Inflow Diverted	-0.696
July % of Inflow Diverted	-0.857

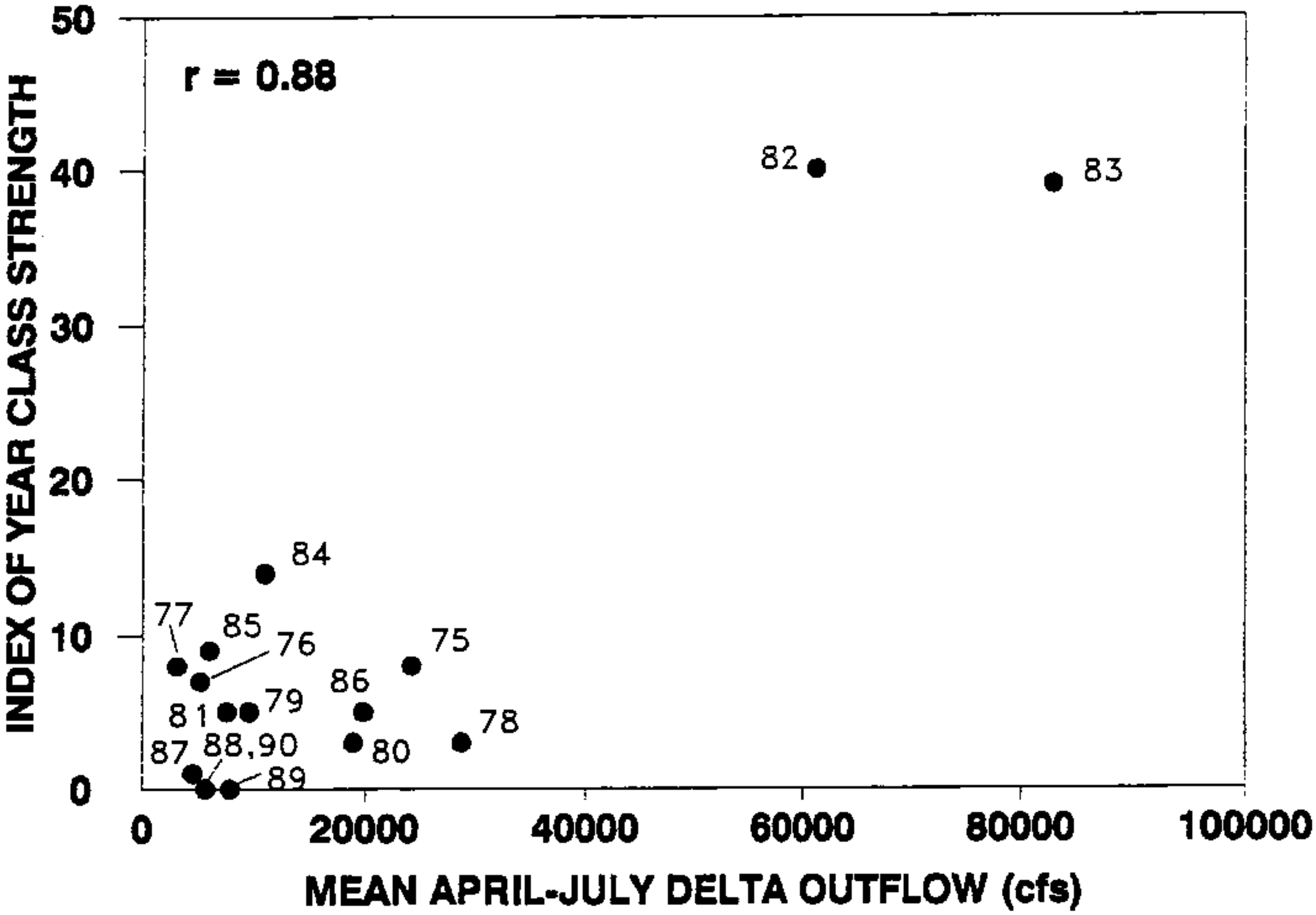

Figure 3. Scatterplot of white sturgeon year class index from trawl catches versus mean daily outflow for April to July in the Sacramento-San Joaquin Estuary. Numbers adjacent to points designate year classes.

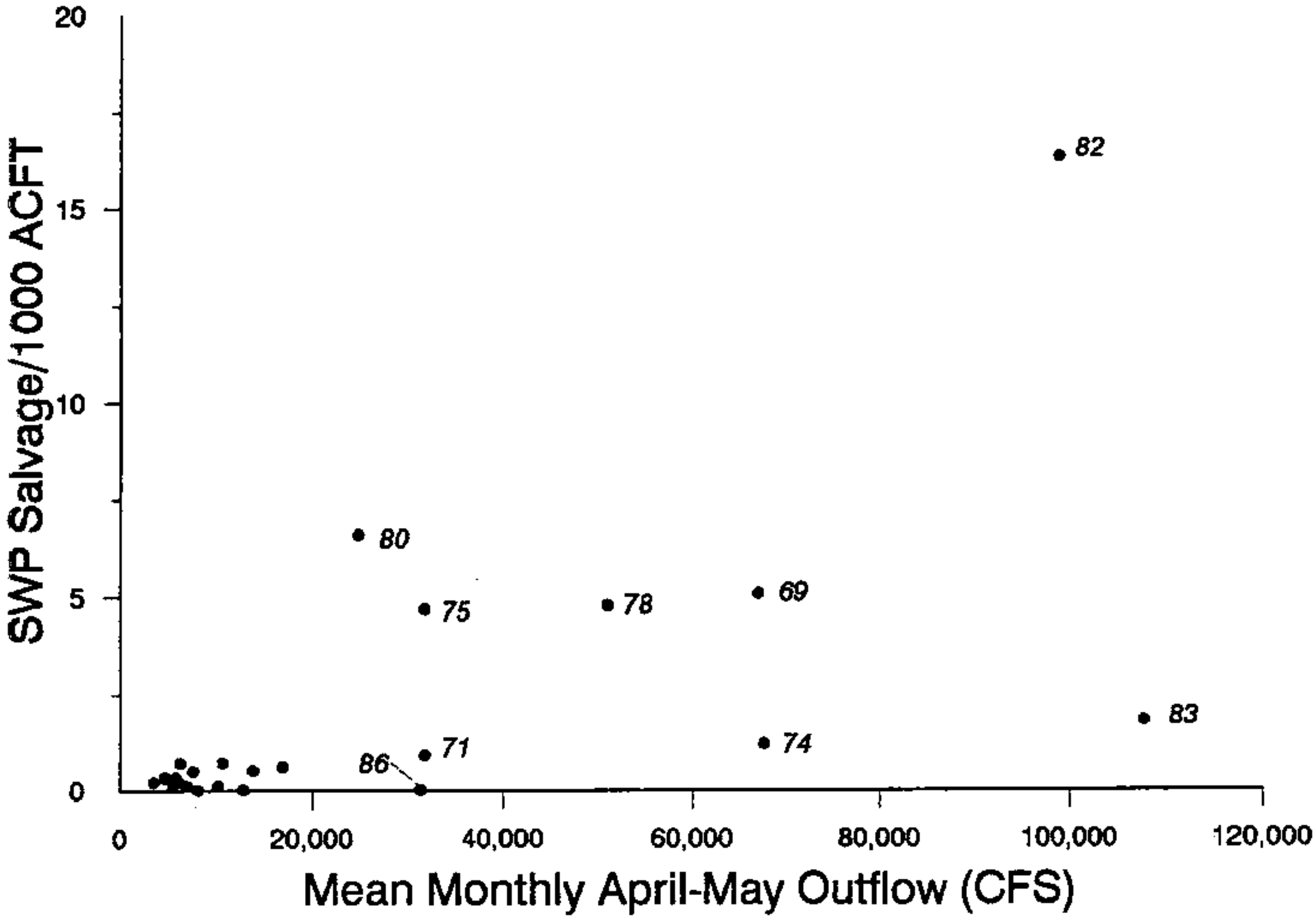

Figure 4. Scatterplot of white sturgeon year class index from salvage at the Skinner Fish Facilities versus mean daily outflow for April to May in the Sacramento-San Joaquin Estuary, 1968-1987. Years are shown adjacent to points for higher flow years. Adapted from CDWR (1990).

This suggests that the abundance of legal-sized sturgeon has been controlled primarily by variations in recruitment. If, like many other fishes, white sturgeon year class strength is set early in life, then recruitment is directly related to previous production of young fish.

The available evidence indicates that the production of young sturgeon is associated with freshwater outflow from the estuary; in years with very high outflow in spring and early summer, more young-of-the-year sturgeon are produced. Year class strength may also be weakly associated with the fraction of freshwater inflow to the estuary that is diverted in the delta, but this may be the result of an inverse relationship between percent diverted and outflow.

The dependence of the association between the Bay Study year class index and outflow on two very wet years, 1982 and 1983, does not allow specification of outflow necessary for good sturgeon production. The salvage data, however, suggest that there is a threshold of about 20,000 cfs of mean April-May outflow necessary for the production of good year classes (Figure 3).

The association of sturgeon year class strength with outflow is consistent with relationships observed for several other anadromous species inhabiting the estuary, specifically striped bass (Morone saxatilis) (Turner and Chadwick 1972; Stevens et al. 1985), chinook salmon (Onchorynchus tshawytscha), American shad (Alosa sapidissima), and longfin smelt (Spirinchus thaleichthys) (Stevens and Miller 1983). High flows may improve young sturgeon survival by transporting larvae to areas of greater food availability, by dispersing larvae over a wide area of the rivers and estuary to take advantage of all available habitat, by quickly moving larvae downstream of any influence of water diversions in the delta, or by enhancing productivity in the nursery area by increasing the nutrient supply. Additionally, adults may experience a stronger attraction to upstream spawning areas in high flow years and spawn in greater numbers.

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