Exhibit 23, entered by the California Department of Fish and Game for the State Water Resources Control Board 1987 Water Quality/ Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta.

REQUIREMENTS OF AMERICAN SHAD (*Alosa sapidissima*) IN THE SACRAMENTO-SAN JOAQUIN RIVER SYSTEM

PREFACE

Interagency staff representing the California Department of Fish and Game had lead responsibility in preparing this report. Drafts have been reviewed by members of the fisheries/water quality committee of the Interagency Ecological Studies Program for the Sacramento-San Joaquin estuary.

The report reflects the fisheries/water quality committee members' agreement on most points. Committee members will provide direct testimony on areas of disagreement.

Agency management was not part of the review process and may differ on how study results can be used in managing American Shad resources.

American shad (Alosa sapidissima) were first introduced into the Sacramento-San Joaquin River system in 1871 when it was still largely unchanged by man. Initially, about 10,000 young-of-the-year were transported from New York and released into the Sacramento River near Tehama. An additional 819,000 young fish were stocked from 1873 to 1881 (Skinner 1962).

The American shad population exploded and soon supported a major commercial gill net fishery in the estuary during the spawning runs. American shad were sold in San Francisco markets by 1879. Catches regularly exceeded 1 million lbs. from 1900 to 1945, with about 5.6 million lbs. taken in 1917. After 1945 the fishery diminished, and in 1957 it was terminated by legislation due to public concerns about the impact of the gill nets on striped bass (Morone saxatilis) (Skinner 1962).

Although American shad were commercially important, enthusiasm for sport fishing did not begin until the 1950s when anglers began fishing the spawning grounds in the upper Sacramento and San Joaquin River systems, particularly the mainstem Sacramento and the American, Feather and Yuba rivers. Once established, the popularity of shad fishing grew and by the mid-1960s an estimated 100,000 angler days were expended (California Fish and Game 1965). However, more recent surveys in 1977 and 1978 indicate about 35,000 and 55,000 angler days were expended to catch 79,000 and 140,000 shad, respectively (Meinz 1981). The present bag limit is 25 fish per day, but most anglers typically release all or most of their catch.

Additional sport fishing effort occurs in the "bump net" fishery in the delta at night. A long-handled chicken-wire dip net is fished in the prop-wash of a slow moving boat and when a shad bumps the net, the "bumper" quickly attempts to flip it on board. Essentially all fish caught are males which apparently are attracted to the prop-wash as they would be to a spawning female.

SPAWNING

Table 1 provides a general description of the life history of shad in the Sacramento-San Joaquin system. Much of our information on shad comes from a study conducted from 1975-1978. Other information has been derived from general surveys or collected incidentally during studies of other species.

From 1975 to 1978, based on analysis of scales, 92% of the male American shad spawned for the first time in the Sacramento-San Joaquin River system as three-or four-year-olds and 79% of the females initially spawned as four-or five-year-olds (Wixom 1981). For both sexes, spawning appeared to occur for the first time as early as age 2 and as late as age 7. Once a fish spawned, it continued to do so annually.

Historically, shad spawned throughout delta tidal fresh waters upstream into both the Sacramento and San Joaquin rivers (Nidever 1916, Hatton 1940) but spawning has declined in the San Joaquin system leaving the north Delta and Sacramento system upstream from Hood the primary spawning areas (Stevens 1966, Painter et al. 1977).

TABLE 1. Life history strategy of American shad in the Sacramento-San Joaquin River system.

Annual migration to fresh water	March-May
Major spawning locations	Upper Sacramento River & major tributaries
Secondary spawning locations	North Delta & Old River
Major spawning period	May-early July
Temperatures during peak spawning	63-75 F
Major Nursery Areas of young fish	Lower Feather River, Lower American River, Sacramento River from Colusa downstream, Delta
Usual environment after first year	Ocean, but a few fish remain in the estuary

Adults returning from the ocean begin passing through the Delta in late March or April (Stevens 1966). In fyke traps (Hallock et al. 1957) set in the Sacramento River at Clarksburg, American shad catches increase substantially through April and peak during May (Table 2). River temperatures during May generally range from about 57^{o}F to 75^{o}C.

River flow may affect the distribution of American shad on their initial spawning runs in the Sacramento River system (Painter et al. 1980). This hypothesis is supported by measures of the distribution of virgin spawners in the American, Yuba, and mainstem Sacramento rivers. These measurements indicate the percentage of the runs formed by virgins tends to increase with the contribution of a stream to the flow immediately downstream from its confluence with adjacent river branches (Wixom, 1981; Fig. 1). Similar results were not obtained for the Feather River, however. This may reflect either a longer residence period for young fish in that tributary allowing them to become imprinted for homing on their maiden runs or aberrant results for 1977. Sampling with beach seines reveals that many young-of-the-year American shad remain in the Feather River through summer, while few reside in the Sacramento River above Colusa or in the Yuba and American rivers (Table 3).

Obviously, the shad fishery is affected by the distribution of adult fish. Hence, low spring flows in the most accessible tributaries, the American, Feather and Yuba rivers, not only reduce the shad runs, but also angling opportunity.

TABLE 2. Catch of adult American shad in fyke traps set in the Sacramento River at Clarksburg. NS means not sampled.[a]

Period	1974	1975	1976	1979	1980	1982	1983	1984	$\bar{X}$
March 21-31	0	0	7	10	7	1	NS	2	3.9
April 1-10	0	8	8	62	16	3	NS	7	14.9
11-20	50	38	65	56	19	NS	NS	29	42.8
21-30	380	174	59	213	30	153	120	68	149.6
May 1-10	594	264	133	181	20	303	NS	178	239.0
11-20	389	427	168	220	122	356	NS	92	253.4
21-30	433	498	28	105	32	197	582	151	253.2
May 31-June 9	137	109	30	14	3	149	538	23	125.4
June 10-19	116	38	4	2	4	6	96	20	35.8
20-29	16	2	NS	NS	NS	NS	41	NS	19.7

a/ We terminated sampling in mid June during years when catch trends indicated future catches would be insignificant. During 1982 and 1983, we were unable to fish during the early spring when riverflows exceeded 40,000 cfs, the maximum flow at which we could safely fish our gear.

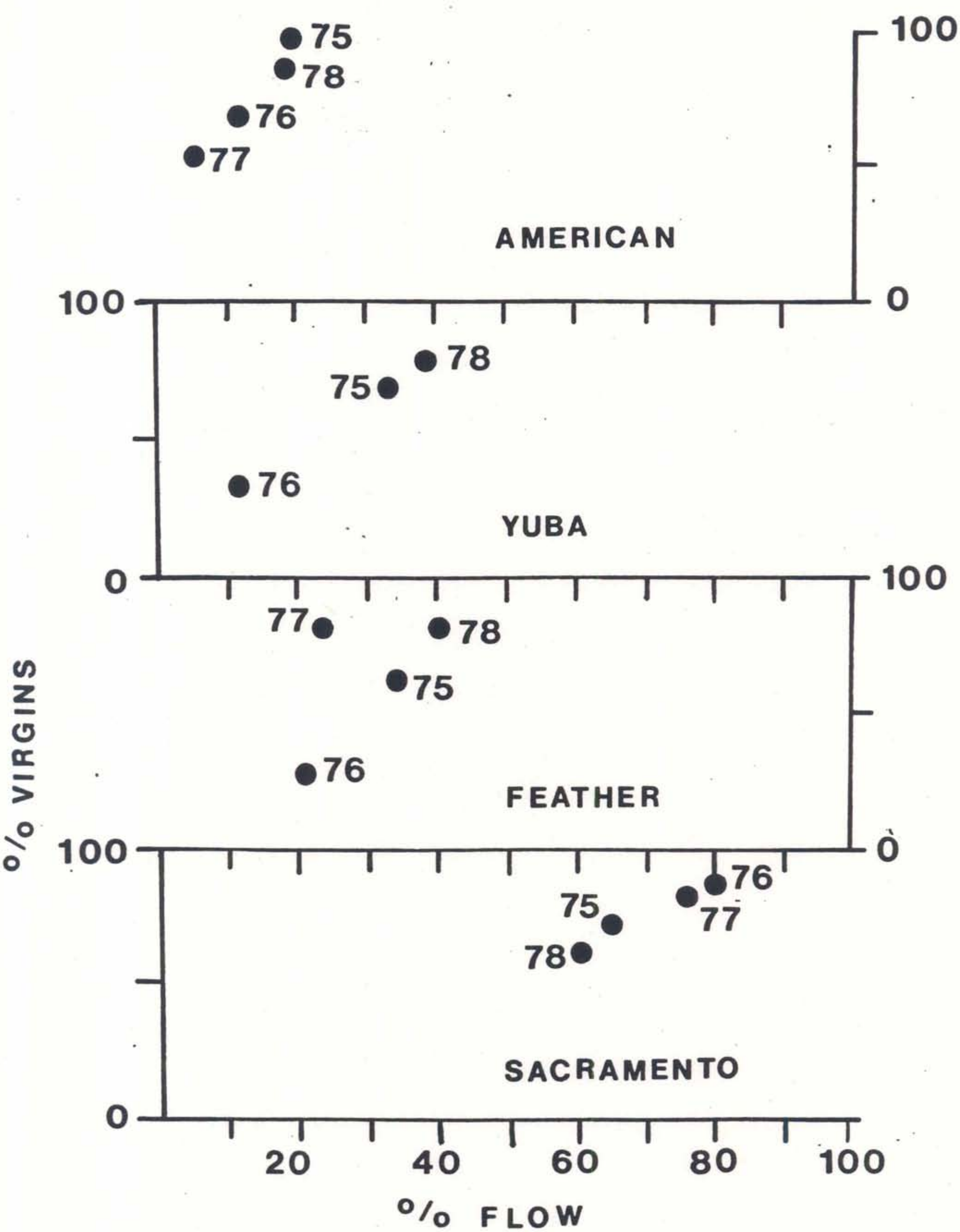

Figure 1. Percentage of American shad spawning runs formed by virgins and percentage contribution of streams in the Sacramento River system to the flow downstream from their confluence with adjacent river branches.

TABLE 3. Mean catch-per-seine-haul of young American shad in the Sacramento-San Joaquin River system. Sampling was approximately weekly from July through September. Number of samples in parentheses.[a]

	Year		
Area	1976	1977	1978
Sacramento River above Colusa	0.0(18)	0.1(38)	0.1(12)
Feather River above Yuba River	0.0(9)	0.0(8)	(0)
Feather River below Yuba River	7.7(18)	7.2(26)	7.2(8)
Yuba River	1.1(18)	0.4(15)	0.0(8)
Sacramento River from Colusa to Sacramento	8.6(15)	3.6(37)	0.7(13)
American River	(0)	0.1(11)	3.9(12)
North Delta[b]	3.0(62)	1.9(43)	8.5(30)
South Delta[c]	0.2(13)	0.0(10)	0.0(10)

a/ Data from Michael Meinz, California Department of Fish and Game.

b/ Rivers and sloughs north from San Joaquin River upstream to Sacramento.

c/ San Joaquin River and rivers and sloughs to the south.

Most repeat spawners in the Sacramento River system probably home to the tributary where they have spawned previously. During 1978 about 6,000 American shad were tagged on the spawning grounds. During subsequent years, 12 tags were returned from these fish. Nine of these returns were from the river of tag origin. Of the remainder, only one was an obvious stray from routes that led to the river where the fish were tagged (Table 4).

Sampling of American shad eggs with nets set in the Feather River indicates that spawning occurs predominantly from May to July at temperatures of 63°F to 75°F (Painter, et al. 1977).

NURSERY

The location of the summer nursery of American shad may be discerned from a combination of seine surveys, trawling in the delta, and catches at the fish screens in front of the SWP diversion in the southern delta. The flow in most of the spawning areas is swift enough that the eggs are washed downstream before hatching. During the seine surveys, few young American shad were ever captured in the Sacramento River above Colusa, the Feather River above the Yuba River, the Yuba River, the American River except at its mouth in 1978, and in the south Delta (Table 3). Young American shad were more numerous in the Feather River below the mouth of the Yuba River, the Sacramento River from Colusa to Sacramento and the north Delta. Despite the virtual absence of fish in the south Delta seine hauls, bimodal recoveries

TABLE 4. Distribution of tag recoveries during 1979 and subsequent years for American shad that were tagged while on their spawning grounds in the Sacramento River system in 1978.

	Spawning Ground 1978			
Recovery Location	American River	Feather River	Yuba River	Upper Sacramento River
Delta and Sacramento River below American River	0	1	0	1
American River	0	1[a]	0	0
Feather River above Yuba River	0	2	0	0
Sacramento River above Feather River	0	0	0	7
Total Recoveries	0	4	0	8
Number Tagged	312	1,211	199	4,242

a/ Obvious stray from route back to 1978 spawning ground.

at the SWP fish screens (Fig. 2) reveal the presence of both young shad spawned within or near the Delta and the outmigration of shad spawned in upriver areas. Peak summer recoveries include newly metamorphosed fish less than 1 inch long, originating from spawning near or within the Delta; fall recoveries reflect fish from upriver areas which do not enter the Delta until their outmigration. Thus the main summer nursery of American shad appears to extend from Colusa on the Sacramento River to the north delta,including the lower Feather River with some numbers of fish also using the south Delta.

In 1978, a wet year, the seine catches were notably lower in the Sacramento River and higher in the northern Delta than in 1976 and 1977 which were dry years. This difference probably reflects the transport of young fish by river flow, and suggests that annual flow differences cause the precise location of major concentrations of fish to vary.

During their outmigration, young American shad typically range in fork length from about 2 to 6 inches (Stevens 1966).

Most young American shad leave the estuary by year's end (Ganssle 1966, Stevens 1966); however, some remain for more than 1 year and perhaps do not go to sea. Ganssle (1966) reported catching American shad in their second year of life in trawl tows in San Francisco, San Pablo and Suisun bays. More recently, California Department of Fish and Game biologists have captured some yearling (about 20 to 30 cm fork length) American shad in these areas during trawl surveys in the spring and fall (1967 to

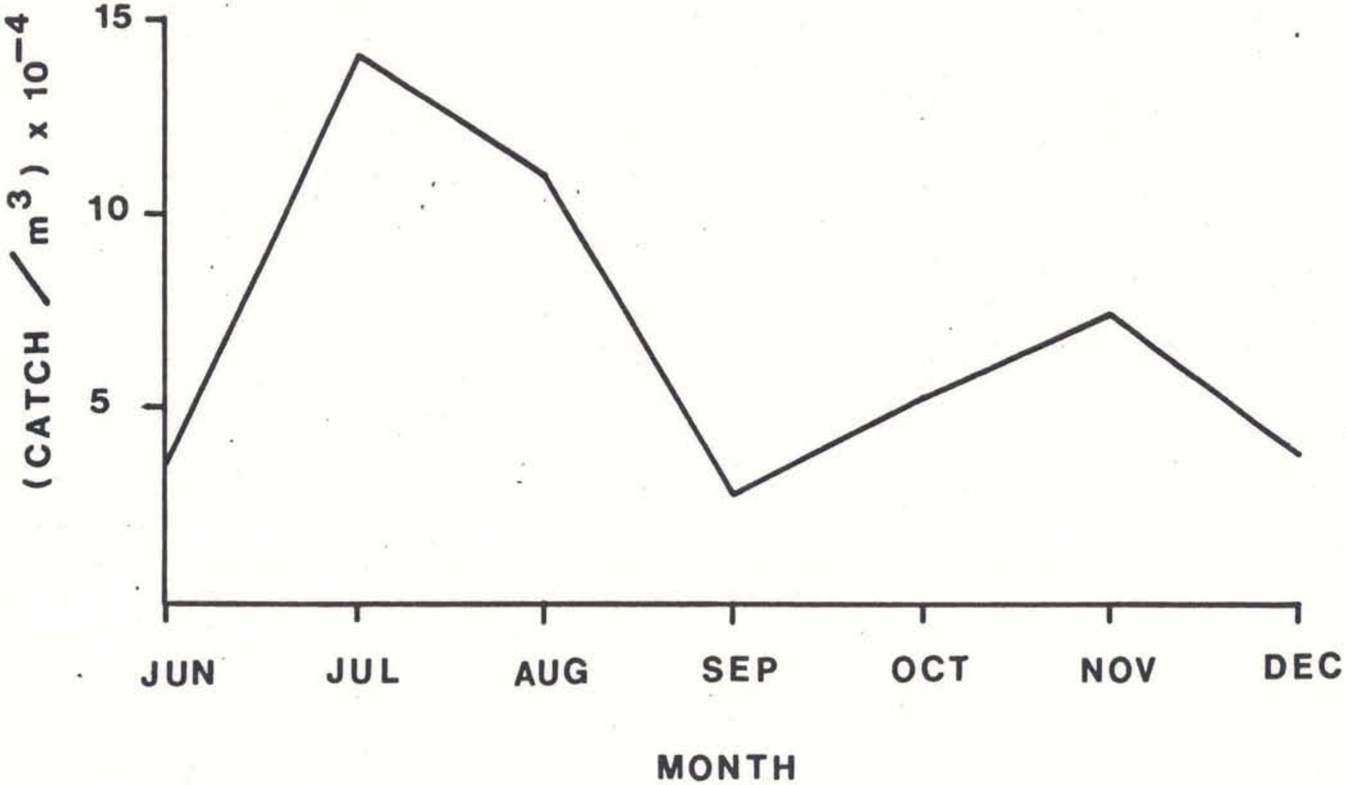

Figure 2. Mean monthly catch of young American shad at the State Water project fish screens in the Sacramento-San Joaquin Delta 1968-1980 (Bay-Delta Fishery Project 1981).

1985) and in gill nets fished in Suisun Bay (fall 1973) and the tidal sloughs of the Suisun Marsh (February, June and October 1977 and 1978). In the Suisun Marsh more than 30 of these fish (22 to 35 cm fork length) were taken during February when they were almost 2 years old.

Little is known about American shad at sea on the Pacific Coast. The recapture of three of our tags by commercial bottom fish trawlers from 1975 to 1977 has revealed that some Sacramento-San Joaquin fish inhabit the ocean off the northern California Coast.

FOOD HABITS

Adult shad actively feed in both brackish and fresh water during their spawning migration provided that larger zooplankton (Neomysis, and Cladocerans) are present (Stevens, 1966), but are not deterred from entering otherwise suitable spawning waters if the zooplankters are absent (Hatton, 1940). It is probable that shad can successfully spawn without eating in fresh water but it is not known if total 'fasting' during the spawning migration has any affect on postspawning survival.

Food habits of juvenile American shad in California are not well known. Ganssle (1966) reported, in order of occurrence, Neomysis, copepods, larval fish and Corophium sp. were the primary stomach contents of 59 young of the year shad captured in the west delta. No similar information is available from fish rearing in either the central Delta or or the the upper Sacramento River and tributaries.

Studies in East Coast rivers found young shad eating a wide variety of insects and zooplankton (copepods and cladocerans) with the diet of a particular population dependent on the prey items available (Walburg 1957, Massman 1963).

It is likely that shad in California have a similar flexible feeding strategy. Shad, during the time they are rearing in zooplankton poor areas upstream of the Delta (Turner 1966), probably depend primarily on insects originating in the wooded areas surrounding the Sacramento River and its tributaries. Shad rearing in or moving through the more open water areas of the Delta and west Delta would feed on zooplankton originating in the Delta waters.

Both sources of juvenile American shad food are threatened by human development. Continued removal of riparian and streamside vegetation in the Sacramento system upstream from the delta potentially reduces the amount of insect drop supporting young shad in those regions. Water development has reduced abundance of zooplankton in the delta, primarly because the use of Delta channels as conduits to carry water south to the CVP and SWP pumps has increased flow velocities, has reduced water residence times, and brings large volumes of zooplankton-deficient Sacramento River water into the central and south Delta (Turner 1966, Turner and Heubach 1966, Heubach 1969, Knutson and Orsi 1983, Orsi and Mecum 1986).

ABUNDANCE

We estimated adult American shad abundance in 1976 and 1977 from mark-recapture data. Fish were captured in gill nets in the Delta downstream from the sportfishing areas. Only those fish that appeared in good condition were tagged. Floy anchor tags (Dell 1968) were inserted into the musculature below the dorsal fin so the tag became anchored behind the neural spines of the vertebrae and pterygiophores that support the fin rays. About half of the tags offered a $5 reward. Each fish was categorized as a male or female by presence or absence of milt when finger pressure was applied in a squeezing motion near the urogenital area.

We did not observe many tags during sampling for recaptures. Thus, instead of the usual Petersen method, we estimated population size by dividing annual estimates of catch by estimates of exploitation rates. Catches were estimated by multiplying estimates of angler effort based on instantaneous use counts by catch-per-unit-effort (Meinz 1981). These catch estimates were stratified according to sex ratios observed during Meinz's creel census. Mailed tag returns corrected for non-response were used to estimate exploitation rates (Table 5).

The tags were conspicuous and the program was well publicized; therefore, we believe that tag recognition was high and tag returns accurately depicted the fraction of the population caught by anglers.

TABLE 5. American shad mark-recapture, catch, and abundance estimates for the Sacramento-San Joaquin River system.

		Number Tags Released		Number Tags Recaptured				
Year	Sex	Reward	Non Reward	Reward[a]	Non Reward[b]	Exploitation Rate[c]	Catch[d]	Abundance Estimate (10)[e]
1976	Male	1,789	1,904	69	74	0.039	56,165	1.44
	Fem.	939	937	15	15	0.016	25,562	1.60
1977	Male	2,437	2,226	95	91	0.040	49,853	1.25
	Fem.	1,305	1,260	27	22	0.019	29,325	1.54

a/ Mailed tag returns corrected for non-response. Response rate = 0.59 based on return of 10 of 17 $5 reward tags observed during 1976-1977 creel census.

b/ Mailed tag returns corrected for non-response. Response rate = 0.40 based on overall 1976-1977 non-reward tag return rate (.013) ÷ reward tag return rate (.019) x reward tag response rate (0.59).

c/ Total tags recaptured ÷ total tags released.

d/ From Meinz (1981).

e/ Catch ÷ exploitation rate.

Due to the "catch and release" nature of the fishery, some fish in the catches were potentially recounted which would lead to overestimates of abundance, but since anglers only caught about 1 to 4% of the population this bias was inconsequential.

The American shad run in 1976 was estimated to be 3.04 million fish, consisting of 1.44 million males and 1.60 million females (Table 5). In 1977 the population estimate was 2.79 million fish and consisted of 1.25 million males and 1.54 million females.

Numbers of spawners may be somewhat less than our estimates of the total runs. Scale analyses suggest not all American shad in the Delta migrate upstream to spawn or enter the fishery. A small sample of 15 shad was recovered in 1977 after being tagged in 1976. Six of those fish lacked spawning checks on their scales.

While our data indicate that American shad are abundant, past populations probably were larger. We speculate that in 1917, at an average weight of 3 lbs. per shad, almost 2 million fish were caught in the 5.8 million lb. commercial fishery. While we do not know the efficiency of the early fishery, it is reasonable to speculate that the total shad population was several times the number landed, and perhaps two to three times greater than current runs.

Abundance of young American shad in the Sacramento-San Joaquin Estuary varies annually by more than an order of magnitude, and the strongest year classes occur in the years with the highest river flows during the spawning and nursery period (Stevens and Miller 1983). The most reliable estimate of juvenile abundance is an index based on catches of outmigrants during a fall midwater trawl survey at 87 sampling stations scattered from San Pablo Bay through the Delta (1967 to 1985, except 1974 and 1979). Correlations between $\log_{10}$ of the indices obtained by trawling and Delta inflow are statistically significant for all 15 combinations of months from April through August (Table 6) but the highest correlations are for flows during May, April-May and April-June (Figure 3). These were however, only slightly higher than the correlation coefficients for several other combinations of months. In general, the coefficients decrease as flows from the later months are included although all correlations containing April and/or May flows are high.

The value of the correlations between young American shad abundance and river flow would be enhanced if a similar correlation existed between the year class strength of adult American shad and flow in the natal year. We intended to look for such a correlation, using catches of adult American shad in striped bass fyke traps set in the Sacramento River, but found that the fishing efficiency of these traps was so affected by flow during the trapping period that the catches did not adequately reflect shad abundance.

We also examined catches of adult American shad from the commercial fishery that was in the estuary until 1957. Catches

TABLE 6. Correlation coefficients between $\log_{10}$ index of young American shad abundance (measured by midwater trawl survey) and $\log_{10}$ inflow to the Sacramento-San Joaquin Delta, 1967-1985 (no date for 1974 or 1979). Coefficients are for the entire period between corresponding months on the two axes. For example, 0.77 is the correlation coefficient between abundance and mean flow for all months from May to August.

	Apr	May	Jun	Jul	Aug
Apr	0.82**				
May	0.83**	0.83**			
Jun	0.83**	0.81**	0.74**		
Jul	0.82**	0.79**	0.73**	0.64**	
Aug	0.81**	0.77**	0.71**	0.62**	0.56*

**P<0.05 *P<0.01

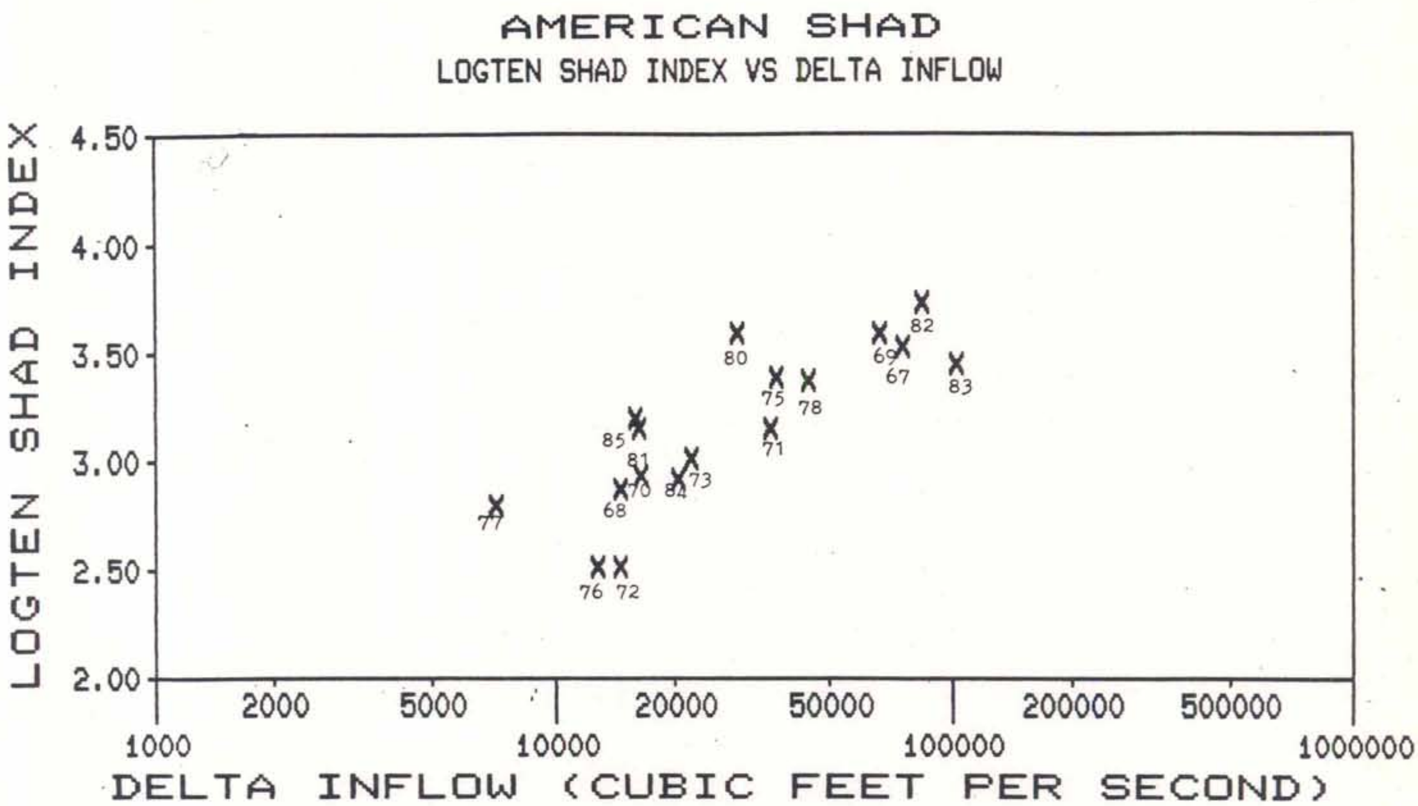

Figure 3. Relationship between young American abundance and the average daily April-June inflow to the Sacramento-San Joaquin Delta, 1967-1985 (excluding 1974 and 1979). Abundance was measured by midwater trawl surveys in the Estuary during the fall.

were available from 1916 to 1957. We correlated $\log_{10}$ of these catches against total inflow to the Delta in May using 3, 4, 5, 3-4, 4-5, and 3-5 year lags. All of these correlations were low (correlation coefficients range from -0.013 to 0.127) indicating that other factors had more effect on the catches. One such factor is that commercial catches are not a strict measure of shad abundance as fishing effort was strongly affected by market demand (Skinner 1962). Thus the low correlations do not necessarily indicate that flow did not affect the shad runs.

AMERICAN SHAD AND WATER DIVERSIONS

Young American shad are vulnerable to diversion by the state and federal pumping plants in the south Delta. Juvenile shad spawned in the south Delta and Mokelumne river channels would be drawn to the pumps as larvae and newly metamorphosed small fish while Sacramento system juveniles tend to be drawn through the delta cross channel and across the Delta during their downstream migration. From 1968 through 1985, American shad have been the third most common fish at the SWP screen with annual recoveries as high as 3 million fish. In 1967 CVP recoveries exceeded 8 million fish (Table 7).

Evaluations of screening efficiency comparable to studies for striped bass and salmon have not been made for American shad, but we believe larger fish in the fall are screened fairly efficiently. Conversely, based on results for other species, we

TABLE 7. Annual recoveries of American shad at the John E. Skinner fish facility[a], SWP, and the CVP Tracy fish Facility.

Year	SWP recoveries (1000,s)	CVP recoveries (1000,s)
1966	-	875.8
1967	-	8,366.8
1968	118.3	2,056.8
1969	64.6	728.7
1970	140.4	201.8
1971	448.5	631.5
1972	302.4	386.4
1973	494.9	280.0
1974	2,378.2	871.4
1975	3,049.5	1,434.0
1976	380.5	323.1
1977	300.9	133.6
1978	125.9	1,164.8
1979	885.4	551.6
1980	619.2	552.9
1981	896.6	579.6
1982	848.6	590.1
1983	76.2	379.4
1984	418.8	507.1
1985	273.8	285.4

a/ No SWP operation until 1968.

suspect that screening efficiencies for newly metamorphosed juveniles in the late spring and early summer are quite low. Without estimates of screening efficiency rates, we are unable to estimate total entrainment losses.

American shad are notoriously intolerant of handling and, we do have rough estimates of handling and trucking losses at the SWP fish facility. Tests have shown that losses of American shad that were successfully screened exceeded 50 percent during summer months with slightly lower mortalities during the cooler fall months. These high handlng mortalities suggest the only practical strategy for reducing losses may be pumping schedules that minimize shad entrainment.

SUMMARY AND CONCLUSIONS

The explosion and spread of the population of American shad shortly after its stocking reveals that environmental conditions formerly were near ideal for this species in the Sacramento-San Joaquin River system. At the time of the introductions, although the rivers and Delta were largely leveed off, the rest of the system was relatively undeveloped by man. There were hundreds of miles of rivers suitable for spawning with no major dams to block the runs and reduce the freshwater flows that disperse the young. California agriculture and industry were just beginning, so losses of young fish to water diversions and toxic wastes would have been minimal. Also, the native fish fauna contained few top predators in the major nursery areas.

The American shad population has declined since the early 1900s. Available evidence indicates that the population has not been overfished, but there is substantial evidence that the favorable environment experienced by this species, initially, has become less friendly due to human activities. The most obvious of these have been the construction of dams in the upper reaches of the rivers; water diversions by water projects, power plants and farms along the rivers and in the Delta; and discharges and accidental spills of toxic substances by municipalities, industry, and agriculture.

Specifically, these perturbations have had the following adverse effects:

1) Reduced river flow. Year class strength correlates positively with river flow during the spawning and nursery period. Flows must be ample to attract American shad spawners into Sacramento River tributaries, transport and disperse the young fish to suitable nursery habitat, and reduce the probability of entrainment of young fish and their food organisms in water diversions. Water development has reduced flows during the spring and early summer periods which are most critical in this respect (Table 8).

2) Reduced food supplies for young fish. An adequate supply of zooplankton must be available at the time and place that the young fish initially feed. Water diversions have been implicated in reducing the quantity of zooplankton available to young shad in the Delta. Again, spring and summer are the time impacts are greatest.

TABLE 8. Mean April-June inflow (CFS) to the Sacramento-San Joaquin Delta 1978-1982. Unimpaired flow estimates from California Department of Water Resources Statewide Planning Branch.

Year	Actual	Unimpaired	% Reduction
1978	43480	87581	50
1979	19690	57761	66
1980	28945	63237	54
1981	16216	34025	52
1982	83221	122016	32

3) Losses of fish entrained in water diversions. Shad both reside in and migrate through the Delta and are vulnerable to entrainment in water diversions. At the CVP and SWP high handling losses occur in the recovery facilities. At present, the only practical means of reducing these losses are pumping schedules that would reduce entrainment.

Hence, to maintain the American shad resource suitable river flows are essential during the spawning season and young and adult outmigrants need to be protected against losses caused by water diversions. Both young and adult shad feed while migrating through the Delta, so food sources such as copepods, cladocerans, and Neomysis also require protection.

Each of the effects enumerated above should be considered in selecting measures to protect beneficial uses in the Sacramento-San Joaquin Estuary.

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