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Anadromous Fish Conservation Act

Project AFS-17
American Shad Study

FINAL REPORT
JOB NUMBER 5
AMERICAN SHAD MANAGEMENT PLAN FOR THE SACRAMENTO RIVER DRAINAGE

BACKGROUND

History of American Shad in California

American shad (Alosa sapidissima) were first introduced into California by Seth Green in 1871; at that time about 10,000 fry were transported from New York and released in the Sacramento River near Tehama. The shad population developed quickly and by 1879 they were appearing in San Francisco markets. The commercial fishery in the Sacramento-San Joaquin Estuary continued to grow, and from 1900 to 1945 catches regularly ran over a million pounds. The largest catch recorded was 5,675,509 lb and was made in 1917. Catches rarely exceeded one million lb after 1945, and in 1957 legislative action terminated the fishery.

Although American shad were taken by commercial gill netters in the Sacramento-San Joaquin Estuary as early as 1879, there is no clear record when sport angling began. Some shad angling occurred in the 1930's (Nidever 1936) and in the 1940's (McCully 1949) but enthusiasm for the fishery did not develop until the 50's (Warner 1956). Once established, the popularity of shad fishing grew and by the mid-60's an estimated 100,000 angler days were being fished (California 1965). A more recent study, however, indicats that angler interest has declined to between 35,000 and 55,000 angler days per year (Meinz 1979). Popular shad angling areas in central California are the Sacramento, American, Feather and Yuba rivers with a small scattered and inconsistent fishery in tributaries of the San Joaquin River.

A unique method for catching shad in California is called "bumping", which is done primarily at night in the Sacramento-San Joaquin Delta (McCully 1949, Warner 1956, Ruch 1963, Radovich 1970). 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 the fish into the boat. Essentially all shad caught are male and it is not unusual to get more than one at a time.

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Habitat and Life History

This section is included for the future manager in California who may need a ready reference to pertinent facets of American shad ecology.

Shad in the Ocean
(Distribution, temperature effects)

We know little about adult shad on the Pacific Coast. Since their introduction to the west coast in 1971, shad have been found in coastal waters from Todos Santos Bay, Baja California, Mexico, northward and westward to Karluk, Kodiac Island, Alaska. At present, shad fishing is found in coastal streams in British Columbia, Washington, Oregon and California (Welander 1940, Clausen 1959, Turner 1962).

Talbot and Sykes (1958) were the first to describe the oceanic migrations of shad in the Atlantic Ocean. They were able to show that shad from all the major Atlantic Coast rivers congregate in the Gulf of Maine in the summer and fall. This group of shad included immature fish from all streams and survivors of spawning from streams north of Chesapeake Bay. They further believed that the shad moved south to waters off the middle Atlantic states in the winter. If mature in the spring, the shad move either north or south to their home streams to spawn. The shad runs in southern streams occur early in the spring and progressively later northward. Confirmation of these conclusions came from Walburg and Nichols (1967) and Leggett and Whitney (1972). Leggett and Whitney (1972) found these north-south movements to be associated with the 13.0-18.0 degrees C isotherms. These annual cycles of ocean warming were noted on the Pacific Coast. From known ocean temperatures and the range of migration taking place on the Pacific Coast, by circumstantial evidence, these workers hypothesized a similar migration pattern for the Pacific Ocean shad.

We noted some ocean migration during our studies. Three adult shad tagged at Collinsville, on the Sacramento River, were caught in the ocean by bottom-fish drag boats (Monterey, Fort Bragg and Eureka).

Spawning Migration
(Homing, temperature, time of, age at)

When shad become sexually mature they return to their natal river to spawn (Hollis 1948, Vladykov 1950, Walburg and Nichols 1967, Carscadden and Leggett 1975a 1975b).

The timing of these migrations appears regulated by water tmperatures both at sea and in the home river (Leggett and Whitney 1972). They found the peak of spawning runs into rivers at various latitudes on the Atlantic and Pacific coasts of North America takes place when water temperatures are near 18.5 degrees C. They noted that at Bonneville Dam, Columbia River, Washington, 90% of the run took place when river temperatures were between 16.0 degrees and 19.5 degrees C. During our 1976 and 1977 investigations, the peak of adult shad tagging in the western Sacramento-San Joaquin Delta occurred within a 14.0 degrees to 19.0 degrees C range (Painter 1979).

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About three months (March, April and May) are needed for most of the upstram migrating shad to pass through the Sacramento-San Joaquin River Estuary (Hatton 1940, Skinner 1955, Stevens 1966, Painter 1979).

Leim (1924) believed that spawning began at four or five years of age in Canadian waters off the east coast. La Point (1957) found that a few shad on the east coast spawned at three years of age, but the majority spawned at four and five years. In California, Wixom (1979) found 92% of the males sampled were spawning for the first time as three- and four-year-olds and 79% of the females were four- and five-year-olds. He also states that adult shad were found to spawn for the first time as early as age two and as old as age seven, once a fish spawned it continued to do so annually, and total age at capture ranged from two to 11 years. Data collected by Mullen (1972) in Oregon's commercial shad fishery, Sanford (1975) in 1969 from Yuba River samples, and Shoubridge and Leggett (1976) from five Pacific Coast rivers support Wixom's findings.

Spawning
(Temperature; spawning sites; water depth; water velocity).

Water temperature appears to be the most important factor that determines the time of shad spawning. Shad are reported to spawn at water temperatures from 8 degrees to 26 degrees C (Walburg and Nichols 1967). Massmann (1952) states that spawned eggs were not abundant until 12 degrees C was reached in Virginia rivers. Leim (1924) concluded that a temperature of about 12 degrees C was necessary in Canadian rivers along the east coast before much spawning activity was displayed. Optimum temperatures for spawning in the Feather River were found to be between 15.6 degrees and 21.1 degrees C (Painter, Wixom and Taylor 1977). 60 70

Shad spawn only in freshwater (Leim 1924, Massmann 1952, Walburg 1960) but there does not appear to be any required distance above brackish water (Massmann 1952). Shad prefer areas dominated by broad flats or shallow water with moderate currents (Bigelow and Welsh 1924, Massmann 1952, Marcy 1967, Walburg and Nichols 1967). Walburg and Nichols (1967) determined shad spawning grounds in selected east coast rivers by the location of relative numbers of eggs collected in plankton nets. They state, "The bottom was generally sand, gravel or a combination of both...water depth was three to 30 feet but ranged up to 40 feet...the current ranged from one to three f.p.s....in some streams, river flow in spawning areas was always downstream but in others it was affected by tide and current moving both upstream and downstream during the tidal cycle...water conditions varied from clear to very turbid."

Generally, spawning areas on the east coast occur from 25 to 100 miles inland from the limit of brackish water (Walburg and Nichols 1967). In the upper San Joaquin Delta region Hatton (1940) observed shad spawning near the limit of the tidal basin on into fresh water. He also observed spawning throughout the length of the Sacramento River from Hood upstream. Spawning was also observed in the Feather, American and Yuba rivers, and other tributaries. He felt the San Joaquin River was not used extensively as a spawning place. Based on sexual maturity of migrating shad, Stevens (1966) believed a portion of the spawning took place in the San Joaquin portion of the Sacramento-San Joaquin Delta.

Eggs and Larvae

(Description, egg drift, oxygen levels, pH, time to hatchery, food habits)

Female shad deposit eggs in open water, near the surface, where they are fertilized by one or more males (Leim 1924, Leach 1925, Massmann 1952, Walburg and Nichols 1967). When deposited, the eggs are transparent spheres, pale amber or pink, and about 0.05 in. in diameter. Immediately after fertilization, they absorb water and increase to a diameter of about 0.1 to 0.15 in. The eggs are carried by the currents and, being slightly heavier than water, gradually sink. The distance that eggs drift is apparently dependent upon water velocity; Marcy (1976), sampling in water velocities from 0.15 to 0.6 m/s determined that most eggs had traveled only 1.6 to 6.4 km from where they had been spawned. Whitworth and Bennett (1970) followed the movement of shad eggs from the time that they were broadcast until they sank or were lodged on the bottom and found this occurred about 5 to 35 m downstream.

Marcy (1976) found no shad eggs in water with dissolved oxygen concentrations of less than 5 ppm. The LD50 value of dissolved oxygen for Columbia River eggs was 3.5 ppm and was between 2.0 and 2.5 ppm for Connecticut River eggs (Bradford et al 1968). A good hatch with a high percentage of normal appearing larvae occurred at 4.0 ppm.

Shad eggs developed satisfactorily at pH 6.0 to 9.4 (Bradford et al 1968). All died below pH 5.2. The LD50 for low range of pH was 5.5 and was above 9.5 pH in the high range.

In general, shad eggs hatch in 4 to 6 days at about 15 degrees to 18 degrees C (Walburg and Nichols 1967). Time required for hatching was measured by various workers who reared eggs under artificial conditions. Massmann (1962) found eggs to hatch in 96 hours at 16 degrees to 17 degrees C; Leach (1925) found the optimum period of incubation to be 6 to 12 days at 11 degrees to 1,815 degrees C, but healthy larvae were not produced at 10 degrees or 24 degrees C; Leim (1924), Leach (1925), Mansueti and Kolb (1953) and Bradford et al 1968) reported that temperatures below approximately 16 degrees C prolonged the period of development and reduced survival; Leim (1924) states that at 12 degrees C, hatching occurred in from 12 to 15 days and at 17 degrees C in from 6 to 8 days; Marcy (1976) stated that at 13.8 degrees to 23.0 degrees C it took 71 to 86 hours for eggs to hatch. Watson (1968) provided a regression equation for the number of hours required for hatching. Where Y equals the number of hours required for hatchery, and X equals the mean temperature for development in degrees F, $Y = 729.06-8,75X$ ($r = 0.93$).

The appearance of the newly hatched larvae and stages of development are described by Leim (1924) and Leach (1925). The larvae are about 9 to 10 mm long at hatching, the body quite slender with a large yolk sac. Growth is rapid and transformation to adult form is completed at 24 to 28 mm in 30 to 40 days. Maxfield (1953) found that after 53 days from hatching transformed shad averaged 27.5 mm.

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Immediately upon hatching, shad placed in a hatchery pond subsisted entirely upon their yolk sac (Maxfield 1953). These larvae consumed zooplankters 4 to 5 days later, and prior to adsorption of the entire yolk sac. The food of early transforming shad was made up entirely of cladocerans. Ostracods, insects, insect larvae, and copepods became major food items along with cladocerans as transformation of young shad progressed. No significant change in food habits of these young shad was found following transformation, 53 to 121 days following hatching. The absence of algae in the digestive tracts of his specimens suggests that larvae seek out zooplankton in preference to phytoplankton as food.

Atlantic Coast studies on wild young shad food habits (Walburg 1956, Massmann 1963, Levesque and Reed 1972) have shown that small crustaceans and insects are the common foods. Massmann stated further that the most important food source did not originate in the rivers, but in the wooded areas bordering them. Maxfield (1953), Walburg (1956), and Levesque and Reed (1972) thought young shad utilized those food items which were most readily available.

Downstream Migration
(Time of, temperature, size at)

In the Atlantic states young shad remain in the rivers until the cool weather of fall comes. By the last of November all have passed out to the ocean or bays until they return 3 and 4 years later (Leach 1925, Walburg and Nichols 1967). During their river residence, the young fish tend to disperse throughout the area, and juveniles nearest the spawning area are smaller on the average than those below the tidal stretches of the river (Leim 1924, Walburg and Nichols 1967).

Hatton (1940) provided evidence of a seaward migration of young-of-the year shad down the Sacramento River past Hood from July to mid-December with the peak in late August and September. These shad averaged 20 mm during late June and by the end of October averaged 80 mm total length. Meinz (1979) found the Sacramento River upstream of Knights Landing, the Feather River upstream of Yuba City, and the entire American and Yuba rivers were not season-long nursery areas for young shad. Stevens (1966) concluded that the seaward migration of young shad through the Sacramento-San Joaquin Delta starts in late June and extends through November. In July these juvenile shad average 55 mm and by November they averaged about 105 mm in fork length. Messersmith (1966) and Ganssle (1966) caught large numbers of young shad apparently moving through Suisun Bay, Carquinez Straits and San Pablo Bay in the fall and only a few into the winter and following spring.

Several workers have researched the effects of water temperature upon the downstream movement of young shad. Leach (1925) states that"...they leave the Potomac River when the water temperature falls to about 40 degrees F (4.5 degrees C)." Sykes and Lehman (1957), Walburg and Nichols (1967), and Leggett and Whitney (1972) found this movement from the east coast rivers usually began after the water temperatures decreased to less than 25.5 degrees C. However, contrary to these findings, studies in the Feather River show that few young shad were sampled after river temperatures dropped to 15.5 degrees C (Painter and Wixom, unpublished). Again, on the

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east coast, temperature decreases to not far above the lower lethal limit (4-6 degrees C, Chittenden 1972) trigger the final movement of juvenile shad from fresh water while factors associated with fish size appear to initiate the earlier stages of seaward emigration (Marcy 1976).

Special Habitat Requirements

Water temperature and river flow are the most obvious environmental factors affecting shad.

Water Temperature

In the review of Habitat and Life History, water temperature was shown to be relevant in all phases of the shad life cycle. Spawning migrations elsewhere, as well as in California, began when the lower reaches of the spawning rivers approached 14-18 degrees C. Temperatures during spawning were well documented to occur between 8 and 26 degrees C, with most spawning in the range 14-21 degrees C. Egg survival was shown to be lower below 16 degrees C and above 21 degrees C. Of course the rate of egg development was associted with ambient water temperature. In some localities downstream migration of young shad was demonstrated to be associated to 16 degrees C. Even adult and subadult migrations at sea could be related to a known temperature cline.

Any proposal for shad management must contain safeguards to assure maintenance of water temperatures suitable for shad survival.

Flow vs. Virgin Shad

Flow is regulated in every river in the Sacramento watershed. Shasta Dam on the main stem Sacramento, Oroville Dam on the Feather, Englebright Dam and Daguerre Point Diversion on the Yuba, and Folsom Dam on the American all operate to control flow into the Sacramento system (Figure 1).

Shad runs in central California are composed mostly of virgin fish (Wixom 1979). Over the 4 years of his study, virgins made up 67% of the males and 72% of the females sampled. For determinations here it is assumed that the Virgin Recruitment Ratio (VRR) is 70/30, or 70%.

That shad exhibit a tendency to return to the stream where they were spawned has been implied or demonstrated many times on the east coast (Hildebrand and Schroeder 1928, Vladykov and Wallace 1938, Hammer 1942, Warfel and Olsen 1947, Hollis 1948, Freden 1954, Talbot 1954, Talbot and Sykes 1958, Fischler 1959, Hill 1959, Nichols 1961, Nichols 1966, Carscadden and Leggett 1975, Leggett and Carscadden 1978). In at least three tributaries in the Sacramento River watershed, however, river flow, and not homing, appears to determine the distribution of spawning virgin shad.

From 1975-1978 data we correlated the percentage virgins in each river with the percentage flow that each river was of the river it immediately joined in the watershed. Except for the Feather River, the resulting coefficients of correlation were all above 0.99 (Table 1).

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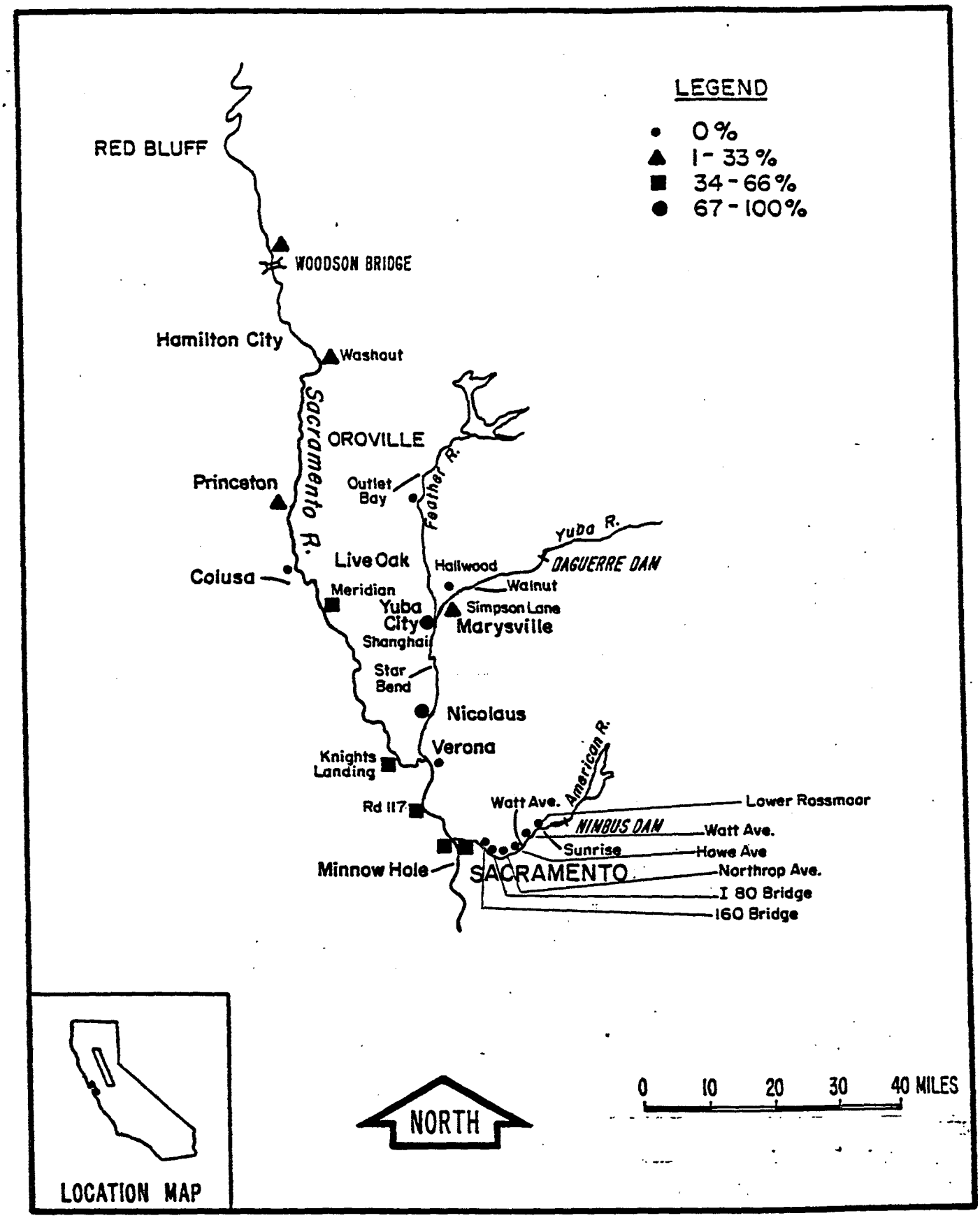

FIGURE 1. Sacramento River system showing sample sites and percentage of sample days in which shad were captured, 1976-78.

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Table 1. Percentage Flow and Virgin Shad in the Upper Sacramento, Feather, Yuba, and American Rivers, 1975-1978, with Coefficient of Correlation (R), for Each River

Year	Upper Sacramento		Feather		Yuba		American	
	%Q[2]	%V	%Q[3]	%V	%Q[4]	%V	%Q[5]	%V
1975	65.8	72.7	34.2	62.7	33.8	70.45	19.0	96.8
1976	79.5	90.8	21.5	29.0	10.3	32.61	10.5	71.7
1977	76.8	85.4	23.2	82.2		N.A.	5.4	58.8
1978	60.1	63.9	39.9	80.1	38.9	80.06	18.2	91.9
Coefficient of correlation	0.9971		0.5020		0.9997		0.9978	

[1] % virgins each year from Wixom (1979), %Q based on mean May-June flows, USGS data.
[2] % upper Sacramento of upper Sacramento + Feather River flow.
[3] % Feather River of Feather River + upper Sacramento.
[4] % Yuba of Yuba River + Feather River at Yuba City.
[5] % American River of Sacramento River at Sacramento.

The Feather River was also the only tributary where young-of-the-year shad were seined almost every week during outmigrant shad studies (Meinz 1979). Young shad were rarely captured in the upper Sacramento, Yuba and American rivers.

When or at what age young shad are imprinted with information that enables the homing phenomenon to occur is unknown. We believe, however, that Feather River young shad reside in their natal steam long enough to be imprinted while young shad in the other mentioned rivers do not.

Shad in the latter rivers may be swept out of each tributary as eggs or small fish that have not formed an attachment to their "home" stream. When these unimprinted shad return as virgins to spawn they do not necessarily enter their natal streams but are distributed to tributaries in proportion to the amount of flow from each tributary. As evidence we submit that at least 99% of the variation in percentage of virgins in the three tributaries is associated with variation in the percentage of stream flow. Therefore, how flows from the tributaries are regulated has a great effect upon the distribution of the majority of shad in each run.

To determine what flows are necessary to ensure that each tributary gets its "fair share" of virgin shad, we calculated, from the predictive equations developed during correlation analysis, the percentage flow in each river that would produce a 70% VRR. These are similar to the mean percentage flows from 1968 to 1977 for these rivers (Table 2), as we would expect them to be. However, the recommended 70% VRR flows should be considered minimum flows required to maintain present shad population distributions and not an average level.

The assumptions necessary for the minimum flows above to be valid recommendations are that the watershed wide population level does not fluctuate much from year to year (1.4 to 2.3 million; Painter 1979) that the mortality rates for virgin and nonvirgin shad are similar (69%; Painter, Pibid.), and that repeat spawners do home to rivers where they previously spawned (homing references cited earlier). The weakest assumption is the first; based upon only two population measurements. Additional population estimates are needed to strengthen this hypothesis.

Flow vs. Young-of-the-year Abundance

Environmental conditions in 1976 and 1977 produced 2 years of severe drought in California. All rivers in the watershed had low flows during the spring shad spawning season. While our seine catches of outmigrants are more qualitative than quantitative they do indicate that many more young shad were taken during 1975 and 1978 than were captured during the 1976-77 drought years (Meinz 1979).

Inference that flow somehow affects young shad abundance was made by the Bay-Delta Study, California Department of Fish and Game (Lee Miller, personal communication, 1976). From analysis of 1967-1975 midwater trawl catches of young shad in the Sacramento-San Joaquin Delta, Miller correlated shad abundance and log10 of June inflow to the Delta. He found these were positively correlated; $r = 0.948$.

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Table 2. Predictive Equations (Y = Percentage Flow. X = Percentage Virgins) at 70% VRR, and Mean Percentage Flow for Four Rivers in Central California

River	Predictive equation	%Q[1/] for 70% virgins	Mean %Q[2/] 1968-1977
Upper Sacramento	Y = 1.3284x - 15.5171	64[3/]	59
Feather	Y = 1.3991X + 21.9482	34[4/]	41
Yuba	Y = 1.6440X + 15.5572	33[5/]	31
American	Y = 2.7208X + 43.6819	10[6/]	15

1/ Computed from predictive equation.
2/ From USGS (year).
3/ Percentage upper Sacramento River of upper Sacramento + Feather flow.
4/ Percentage Feather River of upper Sacramento + Feather River.
5/ Percentage Yuba River of Yuba River + Feather River at Yuba City.
6/ Percentage American River of Sacramento River at Sacramento.

Just what biological and/or environmental mechanisms cause survival to be directly related to flow have not been verified. Unfortunately, during the present contract, we were unable to conduct egg and larval investigations that may have helped explain some of these unknowns.

THE MANAGEMENT PLAN

Objectives

Our principle management objective is to maintain and enhance the present adult shad population so that anglers can continue to enjoy this outstanding resource. Other objectives are: 1) identify factors affecting survival of juvenile shad from spawning through downstream migration, 2) determine the role and relative importance of the lower Sacramento-San Joaquin Delta and bay in the growth of subadult shad and the maintenance of adult shad populations, 3) develop and implement methods for reducing losses of juvenile shad in water diversions, and 4) plan and implemented studies to periodically monitor shad population sizes and angler utilization rates.

Problems

The biggest problem facing American shad is maintenance of habitat. Of prime importance is the preservation of sufficient volume of flow within a suitable range of water temperature.

An obvious weakness in the management plan is the deemphasis of, and lack of recommendations for, enhancement. While our study on the distribution of adult shad in response to river flow suggests a possible enhancement tool, we have made no judgements here to enhance one river reach or tributary at the expense of another. In the future this may be a valid management decision. For instance, many people in the metropolitan Sacramento area angle for shad in the American River. They literally fish in their own backyards. It might be argued that the present 2% angling mortality rate is very low. A more efficient use of the resource could be made if more virgin shad were diverted into the American River. There are potentially more anglers to harvest shad there than if the fish were distributed elsewhere in the watershed. However, because we still lack information needed for management (specifically, knowledge in those areas cited in the management Objectives), no proposals for enhancement have been made.

Recommendations

1. Maintain at the highest practicable level of activities and studies to preserve and maintain shad habitat and implement program objectives.

2. Maintain a normal distribution of adult shad to tributaries in the watershed. The May-June flow of the:

   a) Feather River should be not less than 34% of the Sacramento River,
   b) Yuba River should be not less than 33% of the Feather River, and
   c) American River should be not less than 10% of the Sacramento River at Sacramento.

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3. Keep water temperatures during May and June between 16 degrees and 21 degrees C in upper Sacramento, Feather, Yuba and American rivers.

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