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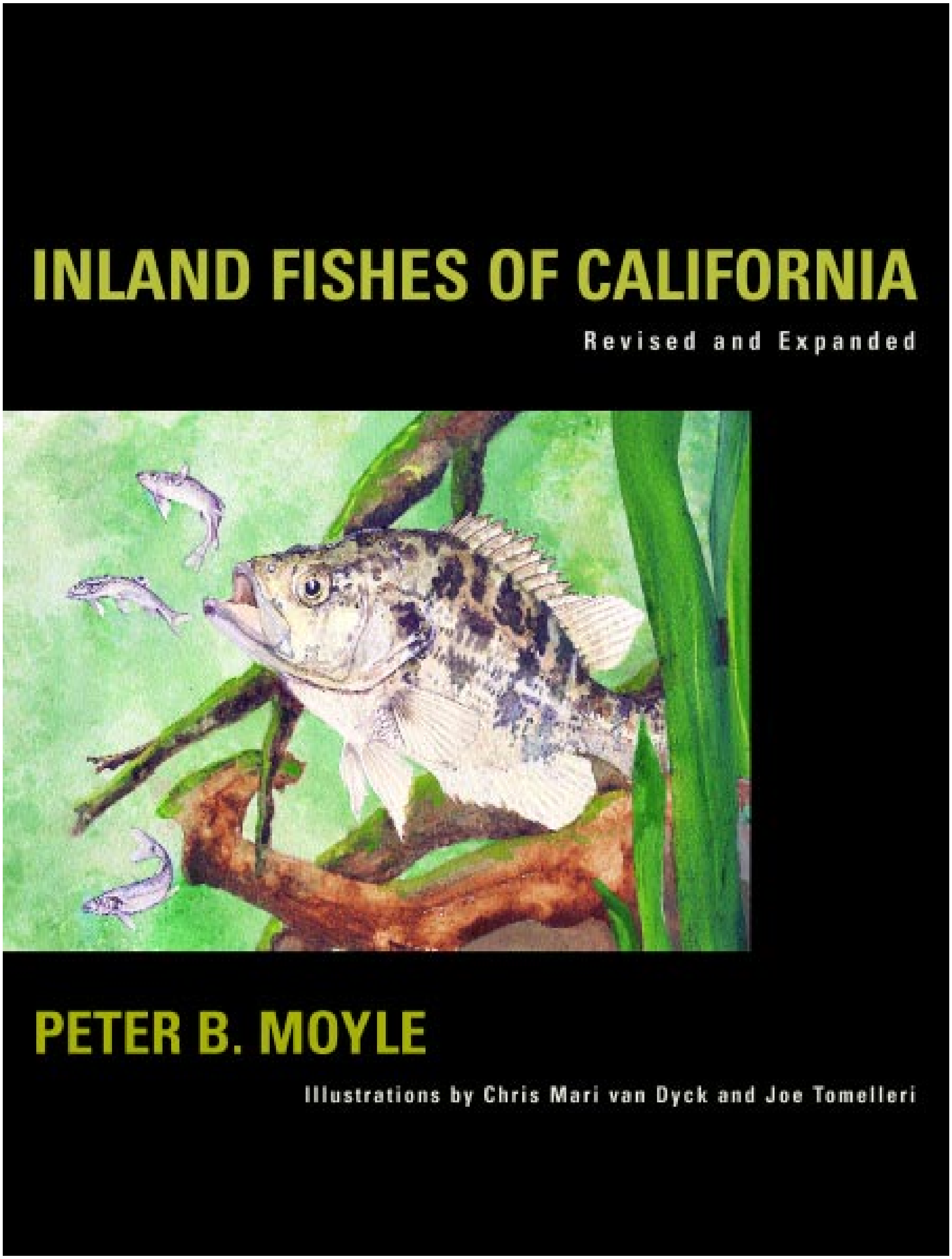

Herrings, Clupeidae

If sheer number of individuals is the criterion for success, herrings are one of the most successful families of fishes in the world. Early in the history of teleost evolution, they achieved plankton-feeding specializations that have allowed them to remain abundant. Herrings have highly protractile jaws and long, fine gill rakers for picking and filtering plankton. Their scales are cycloid, deciduous, and silvery, reflecting light like miniature mirrors to confuse predators. Their bodies are muscular yet deepened by a sharp keel on the belly. The keel eliminates the faint belly shadow most fishes have when seen from below, thus increasing the difficulty predators have in picking out individuals from a shoal. Indeed, most morphological specializations of the Clupeidae enable them to function in the huge schools in which they are typically found.

Although usually thought of as marine, herrings are also successful as anadromous and freshwater fishes. Thanks to humans, the ranges of some forms have been greatly extended, especially in North America, with results ranging from beneficial to disastrous. Small freshwater shads of the genus *Dorosoma* have long been regarded as ideal forage fish in reservoirs and large lakes, and consequently have been distributed throughout the United States. Unfortunately, most of these introductions took place before it was realized that plankton-feeding fishes can alter lake ecosystems by changing the zooplankton community, causing clear lakes to become green with algae and reducing the amount of food available to the young of game fishes. Often shad introduced as forage fish cause declines in the very predatory fishes whose populations they were supposed to enhance (DeVries and Stein 1990).

Only two clupeid species are regularly found in California's fresh waters, threadfin shad and American shad. Both were introduced with greater success than was perhaps ever imagined. In addition, Pacific herring (*Clupea harengeus*) occasionally wander into fresh water when they move into estuaries to spawn. Northern anchovy (*Engraulis mordax*), in the closely related family Engraulidae, wander into brackish water on occasion, usually as juveniles.

Threadfin Shad, *Dorosoma petenense* (Günther)

Identification Threadfin shad are small (rarely longer than 10 cm TL in California) with the typical deciduous scales, flattened bodies, and sawtooth bellies of most herrings. They are distinguished by the long, threadlike final ray of the dorsal fin and by the single dark spot behind the operculum. The mouth is oblique, small, and toothless. The upper jaw is longer than the lower. The dorsal fin (11–17 rays, usually 14–15) is falcate. Anal fin rays number 17–27; scales in the lateral series, 40–48; belly scutes (scales), 15–18 before the bases of the pelvic fins and 8–12 behind them. The intestine is long and convoluted, with a gizzardlike stomach. The gill covers are smooth or have a few faint striations. The overall color is silvery, although the back frequently has a black or bluish hue.

Taxonomy The subspecies of threadfin shad introduced into California is *D. p. atchafalayae* (after the Atchafalaya River, Louisiana), although subspecies designations may have little validity (1).

Names *Doro-soma* means lance-body, referring to the eel-like larvae. *Petenense* is after Lake Petén, Guatemala, from which the first specimens were described. *Threadfin* refers to the distinctive dorsal fin. *Shad* is apparently derived from the ancient Celtic name for herring.

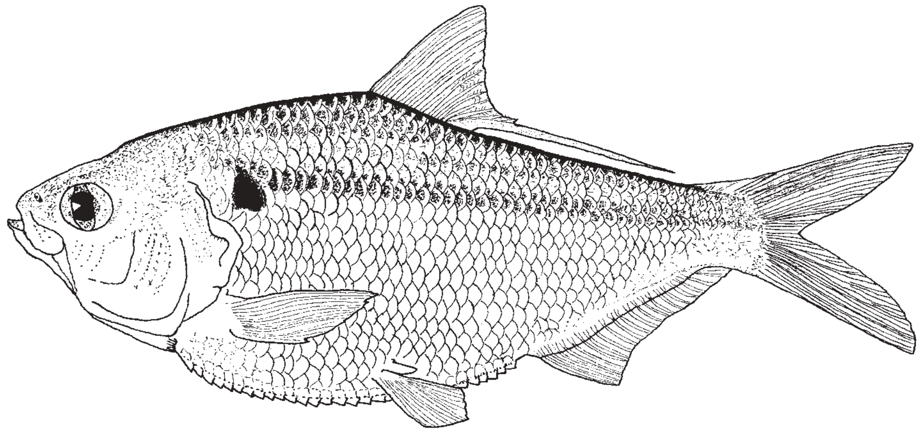

Figure 40. Threadfin shad, 10 cm SL, Sacramento–San Joaquin Delta. Drawing by A. Marciochi.

Distribution Threadfin shad are native to streams flowing into the Gulf of Mexico, south to Belize. In the Mississippi River and its tributaries they are found as far north as southern Indiana and Illinois (1). Shad from the Tennessee River at Watts Bar, Tennessee, were introduced into ponds in San Diego County in 1953 by CDFG (2). In 1954 fish from these ponds were introduced into San Vincente Reservoir, San Diego County, and Havasu Reservoir on the Colorado River. About 1,000 shad were planted in Havasu, and within a year they numbered in the millions and quickly spread downstream (2). In subsequent years they were planted by CDFG in reservoirs throughout the state, with the Sacramento–San Joaquin drainage planted in 1959 (3). From these transplants they have become established in the Sacramento–San Joaquin River system and its estuary, as well as in most of the lower Colorado River and the canals and drains of the Salton Sea region. Unauthorized plants have further expanded the range to more isolated lakes and reservoirs, such as Pillsbury Reservoir and Clear Lake, Lake County. They are occasionally taken in salt water from Long Beach to Yaquina Bay, Oregon (1, 4). Besides California, threadfin shad have been planted successfully in suitable waters throughout much of the United States, including Hawaii.

Life History Threadfin shad inhabit open waters of reservoirs, lakes, and large ponds as well as sluggish backwaters of rivers. In reservoirs they often congregate near inlets of small streams or along steep surfaces of dams. They prefer well-lighted surface waters and are seldom found below depths of 18 m (3). The best growth and survival occur in waters in which summer temperatures exceed 22–24°C and that do not become colder than 7–9°C in winter. Threadfin shad apparently cannot withstand water colder than 4°C for long (5). A sudden drop in temperature also causes high mortalities, as do prolonged periods of cold water. The population in the Sacramento–San Joaquin Delta experiences heavy die-offs every winter when the water cools to 6–8°C (6). In Clear Lake threadfin shad became abundant in 1985, but they were apparently extirpated during the exceptionally cold winter of 1990–1991. They reappeared in 1997, perhaps as the result of an illegal reintroduction (18).

Threadfin shad live mainly in fresh water and become progressively less abundant as salinity increases. Nevertheless, they can survive and grow in sea water (4). Salt water apparently inhibits reproduction: shad in the Salton Sea have failed to reproduce despite continuous recruitment from inflowing canals (7).

Threadfin shad form schools segregated by size and hence by age. Although shad concentrate in surface waters, young-of-year tend to be found in deeper water than adults, especially at night (8). When attacked by predatory fish such as striped bass, a school of shad will close together and hug the water surface, with some individuals leaping from the water at each attack. At such times they also are vulnerable to terns and other fish-eating birds.

Like all clupeids, threadfin shad are plankton feeders. They use their gill rakers to strain small (<1 mm) zooplankton, phytoplankton, and detritus particles from the water but feed individually on larger organisms, mostly zooplankton (9). This ability to feed by both filtering and picking allows for broad diets. Planktonic organisms often occur in their digestive tracts in roughly the same proportion as in the water during the day. At night, however, phytoplankton and detritus predominate in the stomachs, because low light levels restrict the ability of shad to feed by picking (9). Although shad can grow and reproduce on filtered prey alone, larger zooplankters, such as cladocerans and copepods, appear to be preferred (19). Large shad populations can virtually eliminate larger zooplankton species from lakes (10).

Threadfin shad are fast growing but short lived. Under optimal conditions they can increase in length 1–3 cm per month during the first summer of life, reaching 10–13 cm TL by the end of summer. Normally they reach only 4–6 cm TL by the end of their first year and 6–10 cm TL by the end of their second. Few live longer than 2 years or achieve more than 10 cm TL, although rare individuals may live as long as 4 years (8) and achieve lengths of 33 cm TL (11). The largest threadfin shad recorded from California was 22 cm TL, from the Salton Sea (7). Fish from nonreproducing saltwater populations frequently achieve larger sizes than are normal for fresh water (8). In fresh water one of the main factors limiting growth seems to be interspecific competition for food and space (8). Thus shad newly established in reservoirs tend to grow larger during their first year than their counterparts in more established populations.

Threadfin shad may spawn at the end of their first summer but usually wait until their second (8). Spawning takes place in California in April through August, peaking in June and July when water temperatures exceed 20°C (12). Spawning, however, has been observed at 14–18°C (13). Despite a protracted spawning period, each shad apparently spawns once a summer (8). Spawning is most often at dawn and centers around floating or partially submerged objects, such as logs, brush, aquatic plants, and gill nets. Small, compact groups of shad swimming close to the surface approach such objects rapidly, turning away just prior to collision. As they turn, eggs and sperm are released (14). The fertilized eggs stick to surfaces. Spawning is usually accompanied by splashing and leaping from the water. Females produce 900 to 21,000 eggs, the number increasing sharply with the size of the fish (8). The ability of threadfin shad to deposit eggs on floating objects may help account for their success in reservoirs, in which fluctuating water levels frequently expose embryos attached to fixed objects (12).

The embryos hatch in 3–6 days and larvae immediately assume a planktonic existence. They are weak swimmers and so are susceptible to entrainment in water diversions and power plant intakes. However, they are capable of some vertical migration, preferring surface waters during the day and deeper waters at night (12). The length of the planktonic life stage is not known exactly, but it is probably 2–3 weeks depending on temperature. Larvae metamorphose into juveniles at about 2 cm TL. Juveniles form dense schools and, in estuaries, are found in water of all salinities, although they are most abundant in fresh water (12).

Status IIE. Threadfin shad were brought into California in 1953 on the optimistic assumption that they were ideal forage fish for reservoirs that should greatly improve the growth rates of game fishes. Their desirability stemmed from their small size, high reproductive rate, and ability to occupy open waters presumed to be unexploited fish habitat. In many reservoirs managed for trout, especially those receiving large plants of catchable-size fish, the growth of trout larger than 28 cm FL can be extremely rapid when they feed on shad. The success of striped bass in Millerton Reservoir, Fresno and Madera Counties, is probably due largely to their diet of shad. In other reservoirs, large-size largemouth bass, black and white crappie, and white catfish also utilize threadfin shad. Unfortunately, shad are largely unavailable to small warmwater game fishes. Because the young of many centrarchids live in open water for extended periods of time, feeding on plankton, shad may actually compete with them by reducing plankton populations. In particular, threadfin shad may eliminate large species of planktonic crustaceans important in the diets of larval fishes (10). Thus, in some California reservoirs, growth and survival of young centrarchids, including largemouth bass, decreased after introduction of shad (15). In Clear Lake the establishment of shad was followed by the crash of *Daphnia* populations, decreased survival of juvenile largemouth bass, and huge increases in the numbers of piscivorous birds (e.g., western grebes, double-crested cormorants, white pelicans) (18). When the shad population collapsed in 1990, bass, bird, and zooplankton populations returned to preintroduction levels. When shad became reestablished (1998), *Daphnia* collapsed again and the birds returned (18). The increase was also accompanied by a huge die-off of shad in 1999, littering beaches with dead fish.

Mixed success with shad introductions has been experienced elsewhere, leading to attempts to eradicate them from some waters (16, 17). Unfortunately, although fisheries managers may have adopted a more cautious attitude toward threadfin shad introductions, enthusiasm for this fish still persists among some anglers, resulting in unauthorized introductions.

The ability of shad populations to increase explosively has allowed them to spread rapidly by "natural" means far beyond original introduction sites. The thousand shad introduced into Havasu Reservoir managed to provide enough offspring to colonize the entire lower Colorado River and Salton Sea basin in less than 18 months (3). In the Sacramento–San Joaquin drainage they quickly established populations downstream from reservoirs and then spread throughout the California Aqueduct system. In most areas they colonized, their effect—especially on native fishes with planktonic larvae and on young centrarchids—is unknown. In the Sacramento–San Joaquin Delta shad are a major item in the diet of striped bass and other piscivorous fishes, but their role in the ecosystem is poorly understood. Numbers in the Delta have gradually declined since the late 1970s, reflecting a general decline of planktonic fishes in the estuary.

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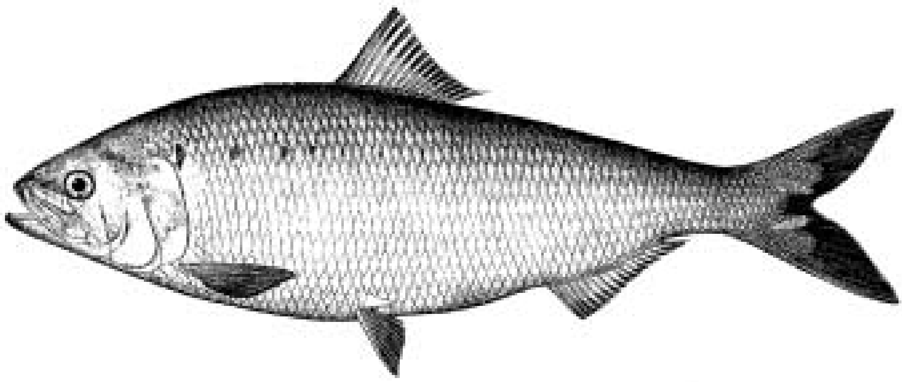
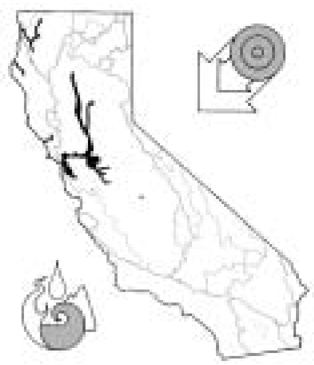


Figure 41. American shad, male, 38 cm SL, Norfolk, Virginia, 1878. USNM 25096. Drawing by H. L. Todd.



American Shad, *Alosa sapidissima* (Wilson)

Identification American shad are large (to 75 cm FL) clupeids with thin, deciduous scales, compressed bodies, and a sawtooth keel on their bellies. The mouth is terminal, and the upper and lower jaws are about equal in size, the lower fitting into the central notch of the upper (but sometimes projecting slightly). The dorsal fin (15–19 rays, usually 17–18) is short and straight edged, without the greatly elongated last ray characteristic of threadfin shad. Anal fin rays number 18–24 (usually 20–22); scales in the lateral series, about 50–55 (the lateral line is poorly developed); belly scutes (scales), 19–23 (usually 22–23) before the bases of the pelvic fins and 12–19 (usually 15–17) behind them (1). Gill rakers are long and slender, with 59–73 below the sharp bend on the first arch. The opercula have coarse, fanlike striations on their surfaces. Live fish tend to be steely blue on the back and silvery on the sides. They are distinguished by a row of 4–6 black spots that starts on the back just behind the operculum. The first spot is larger than the rest.

Taxonomy American shad show biochemical, meristic, and life history differences among watersheds in their native range along the Atlantic coast, but these differences are clinal, so no subspecies are recognized (10, 11, 24).

Names *Alosa* is derived from the old Saxon name for European shad (*Alosa alosa*); *sapidissima* means "most delicious," a fitting name for the most edible of the North American shads. American shad are often referred to as common or white shad.

Distribution American shad are native to the Atlantic coast from Labrador to the St. Johns River, Florida (1, 2). Between 1871 and 1881, more than 800,000 fry were caught in New York and planted in the Sacramento River (3, 18). By 1879 they were abundant. As a result of the California plants, they are now found from Todos Santos Bay in Mexico to Cook Inlet, Alaska, and a population has established itself as well in the Kamchatka Peninsula in Russia. Plants of shad were also made in the Columbia River in 1885 and 1886, although shad from California had already colonized the area by that time (18). They spawn in major rivers from the Sacramento drainage north to British Columbia.

The main shad runs in California are in the Sacramento River up to Red Bluff and in the lower reaches of its major tributaries (particularly the American, Feather, and Yuba Rivers), with smaller runs in the Mokelumne, Cosumnes, and Stanislaus Rivers as well as the north Delta and Old River in the south Delta. Small runs enter the Klamath, Russian River, and Eel Rivers. Apparently the only landlocked population of American shad in existence is in Millerton Reservoir, Fresno and Madera Counties, where they were accidentally introduced with striped bass between 1955 and 1957 (4, 5).

Life History Because of the importance of the species as a sport fish, American shad have been the subject of investigations by CDFG. Unless otherwise indicated, this account is based on summaries provided by Skinner (3), Stevens (6), Painter et al. (7), and Stevens et al. (8).

American shad, with the exception of the Millerton Reservoir population, are found in fresh water only when adults move up into rivers to spawn and when juveniles use rivers as nursery areas for the first year or two of life. What happens during the 3–5 years between emigration to sea and return for spawning is largely unknown, although shad tagged in the Sacramento River have been recovered from Monterey to Eureka. In their native Atlantic they make extensive movements up and down the coast from Florida to New Brunswick (9). The wide distribution of shad along the Pacific coast indicates that similar movements take place here as well, albeit mainly in years when oceanic conditions are favorable.

The first mature shad of each year's run appear in autumn in the lower portions of the estuaries, where they gradually adjust to low salinities. They do not move into fresh water until March–May, when water temperatures exceed 14°C. Peak runs and spawning usually occur at higher temperatures, 17–24°C in the Sacramento River. This means the first shad, usually unripe males, appear in late March or early April, but large runs are not seen until late May or early June. The runs become smaller again when water temperatures exceed 20°C, and few adults are seen after the first week of July. In the landlocked Millerton Reservoir population, mature shad start appearing in the San Joaquin River in late April, but some spawning occurs as late as early September (5); peak spawning occurs from mid-June to mid-July at water temperatures of 11–17°C (5). In their native range homing of shad to their natal streams is well documented (10). Shad have remarkable abilities to navigate and to detect minor changes in their environment (11). In the Sacramento River and its tributaries homing is generally assumed, although there is some evidence that numbers of fish spawning in major tributaries are proportional to flows of each river at the time the shad arrive. They are also capable of adjusting the timing of their runs to the timing of river outflows (24). However, spawning fish tagged in one year are most likely to turn up in the same river in following years if they are repeat spawners (19).

In the Sacramento River, most males spawn for the first time at 3–4 years, and most females spawn at 4–5. Thereafter, fish may spawn every year, as shown by checks on their scales, with the oldest being 7 years. However, 70 percent of the run is made up of fish that have not spawned before.

Adult shad in the Delta feed in fresh water, unlike their counterparts on the Atlantic coast. This is likely a result of the abundance of large zooplankters in the Delta, as opposed to their scarcity and small size in most Atlantic spawning streams. Even in the Delta, however, the percentage of shad with empty stomachs is high, and feeding virtually ceases once main rivers are entered. The most abundant organism in their stomachs while they are in the Delta is mysid shrimp, followed by copepods, cladocerans, amphipods, clams, and fish larvae. On occasion they will eat other fishes. In Millerton Reservoir they prey on threadfin shad (5), and in the Sacramento River below Red Bluff Diversion Dam they occasionally prey on small chinook salmon (25).

Spawning takes place mostly in main channels of rivers over a wide variety of substrates, although sand and gravel are usual. Depth of the water ranges from 1 to 10 m, usually less than 3 m (1). Currents are typically 31–91 cm/sec (13), but shad at Millerton Reservoir spawn in currents of 20–60 cm/sec (5). Dissolved oxygen levels must be above 5 mg/liter (13, 21).

Spawning is a mass affair that peaks after dark and seems stimulated by falling light levels (1). In the San Joaquin River above Millerton Reservoir, all spawning takes place between 2100 and 0700 hr, with peaks between 2300 and 0400 hr (5). Each act is initiated when one or more males press alongside a female. The fish swim rapidly in a circle, side by side, releasing eggs and sperm. Other groups of shad usually spawn at the same time. During the spawning act, dorsal and upper caudal fins of spawning groups often break the surface, making distinctive splashing sounds. The higher the intensity of splashing, the more eggs are found in the water column (5). Each fish spawns repeatedly over a number of days, until the females have released all their eggs. Numbers of eggs produced by California shad have been determined only for the Millerton Reservoir population, where shad fecundities range from 98,600 to 225,600 (5). On the East Coast, average fecundity varies with geographic locality, and shad from New York (the source of California shad) produce 116,000–468,000 eggs, depending on the size of the female, with a mean around 250,000 (1). One reason for such high fecundities is that fertilization rates may be exceptionally low. In Millerton Reservoir only 2 percent of eggs collected had been fertilized (5).

Shad embryos are only slightly heavier than water, so they stay suspended in the current, gradually drifting downstream. They can be found at almost any depth during peak spawning season but are most numerous near the bottom. Hatching takes 8–12 days at 11–15°C, 6–8 days at 17°C (considered to be the optimal developmental temperature), and 3 days at 24°C (1). More rapid development at higher temperatures seems to be countered by lower survival rates of embryos.

Newly hatched shad are 6–10 mm TL and 9–12 mm TL when the yolk sac is finally absorbed and feeding begins (1, 12). At this point, if larvae do not feed within 2 days their survival may be severely depressed (19), demonstrating the need to reach a food-rich area at the appropriate time. Larval shad are planktonic for about 4 weeks. At this stage they cannot survive in salt water, although once they metamorphose into actively swimming juveniles (>25 mm TL) they can tolerate an abrupt switch to sea water (22). The first several months are usually spent in fresh water, but small shad can live in salinities of up to 20 ppt (20). They seem to prefer temperatures of 17–25°C (23). In the Sacramento River the main summer nursery areas are lower Feather River, Sacramento River from Colusa to the north Delta, and, to a lesser extent, the south Delta (8). During this period, they are extremely vulnerable to entrainment in agricultural diversions in the Delta, power plant cooling water diversions, and especially pumps of the State Water Project and Central Valley Project in the south Delta. Abundance indexes of juvenile shad have strong positive correlations with Delta outflows as a result of complex interactions among entrainment, larval feeding, and timing of spawning.

As the season progresses, the center of juvenile shad abundance moves closer to salt water. Entry into salt water takes place in September, October, and November, but it may start as early as late June, especially in wet years when outflows are high. Outmigrating shad are 5–15 cm FL. Most go out to sea, but some remain in the estuary for 1–2 years (8). In the Eel River juvenile shad spend their first summer in large schools in deep pools of the lower river. What they feed on is a mystery, but they may serve as food for adult shad trapped in the pools after spring flows drop.

While in the San Francisco Estuary, young shad feed on zooplankton, especially mysid shrimp, copepods, and amphipods. Although they feed primarily in the water column, they are opportunistic and will also take abundant bottom organisms (such as chironomid midge larvae) and surface insects (14). Most feeding takes place during the day, reflecting a reliance on vision for prey capture. The presence of summer concentrations of young shad in dead-end sloughs, where zooplankton are abundant, indicates that they will seek concentrations of food off migration pathways.

Growth of American shad varies with rearing environment and is probably related to a combination of temperature and availability of food. In Millerton Reservoir, where appropriate foods are relatively scarce, growth is slow compared with that in populations that go out to sea. At the end of the first year they average about 8 cm FL; second year, 16 cm; third year, 24 cm; fourth year, 30 cm; fifth year, 37 cm; sixth year, 39 cm; and seventh year, 42 cm (5). This is roughly comparable to the growth rates of males from the Yuba River, but females typically reach 42 cm FL by the end of their third year and 48 cm during their seventh year (5, 15). The largest fish in any year class are invariably virgin spawners, because repeat spawners have less energy to devote to somatic growth. There are no records of shad from California living longer than 7 years, although in their native range they live 11 years and reach 58 cm FL (1).

Status IID. The introduction of American shad into California was extraordinarily successful. By 1879, 8 years after the first introduction, a commercial fishery had developed (3). The fishery peaked in 1917 when 5.7 million lb were landed, representing about 2 million fish. Between 1918 and 1945 the catch ranged annually from 0.8 to 4.1 million lb. Much of this catch was canned. Between 1945 and 1957, the catch exceeded 1 million lb only once. Despite their reputation on the East Coast as an excellent food fish, American shad have never been particularly popular on the West Coast. Thus the commercial fishery was never very valuable, despite its size. Female shad, from which roe was removed for shipment to Asia, fetched $0.06–0.08 a pound in 1957; males brought less than $0.01 a pound.

In 1957 the inland commercial fishery was banned in favor of the sport fishery, mainly as a means to protect striped bass caught incidentally in gill nets set for shad (18). As a result, when shad migrate upstream today, especially in the Yuba, Feather, and American Rivers, anglers line the stream banks, often standing shoulder to shoulder when fishing is good. Spawning shad readily take a fly, jig, or small spinner and put up spectacular fights on light tackle. Ripe males are also caught at night by "bumping," a technique in which a long-handled dipnet is held vertically from the stern or side of a slowly moving boat. When a shad hits the net, it is twisted and lifted, and the shad is flipped into the boat. Some shad are also caught by dipnetting from banks. The present fishery seems to be mostly for sport, and a good many of the fish caught are either discarded or returned to the water.

Despite their popularity, American shad have been declining. In 1976 and 1977 the total spawner population was estimated at around 3 million fish, perhaps one-third the number that existed 60 years earlier (8). Although population estimates have not been made since 1977, indexes of juvenile shad abundance have declined steadily since then (16), and sport fishing catches appear down. The major cause in recent years is most likely the increased diversion of water from the rivers and the Delta, combined with changing conditions in the ocean, although pesticide affects on larvae and other factors may also be contributing. The shortage of adequate attraction flows in major spawning tributaries, such as the American River, may also have played a role in the decline (17).

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