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THE FISHERIES OF SAN FRANCISCO BAY:
PAST, PRESENT AND FUTURE

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The character of the important fisheries of San Francisco Bay (chinook salmon, striped bass, sturgeon, shad, Pacific herring, northern anchovy, starry flounder, surfperch, elasmobranchs, bay shrimp, and bivalves) has changed dramatically over the past century. Many commercial fisheries that were once important to the Bay Area economy have disappeared (e.g., the river fishery for chinook salmon and the extensive clam and oyster industries), and although other commercial fisheries have been revived in recent years (e.g., herring, bay shrimp), there has been an overall change in emphasis from commercial to recreational fishing. This has been largely due to legislation restricting the commercial harvest of anadromous species such as salmon, striped bass and sturgeon.

Man-induced changes in the environment are implicated in the decline of certain fishery resources. Water storage and diversion projects have affected the distribution and abundance of salmon and striped bass, and land reclamation and domestic sewage pollution essentially eliminated the clam and oyster industries. Fishing pressure has also been linked with the decline of the bay shrimp and sturgeon fisheries.

The San Francisco Bay-Delta region (Fig. 1) was once the foremost fishing center on the West Coast but has long since relinquished this position. Extensive land reclamation, dredging, water pollution, and water development projects have taken a great toll on the habitat, and over-fishing can also be blamed for much of the decline. Fishery resources came under heavy exploitation between 1870 and 1915, and many fishery products from within the Bay began to decline even before the turn of the century (Skinner 1962). Introduction of new species has mitigated part of the damage, although the full ecological effects of these introductions are not known.

On the positive side, public concern and subsequent investigations by the California Department of Fish and Game (DFG) and other state and federal conservation agencies have led to restrictions which have at least slowed the destruction of habitat and fishery resources. These resources include a wide variety of fish and shellfish, some important to recreational interests, others valuable as commercial products, and still others waiting for the right circumstances to be utilized. Over 100 species of elasmobranchs and fishes, some 70 bivalves and 30 decapods have been recorded in the rich fauna of the Bay-Delta region (Painter 1966; Messersmith 1966; Aplin 1967; Green 1975; Eldridge 1977; unpublished catalog of invertebrates, Calif. Acad. of Sci., San Francisco).

The following sections describe the history and current status of the commercial and sport fisheries that have existed within the San Francisco Bay-Delta complex. Emphasis is placed on the changing nature of the fisheries—how they have been affected by demand, resource availability, regulations, and in particular, alteration of the environment by man. Species life history information, where pertinent, is also presented. Those covered are native and naturalized exotic species—we have not attempted to cover the extensive oyster industry which existed from 1870 to the late 1930's, mainly because the species that largely supported the industry, the eastern oyster
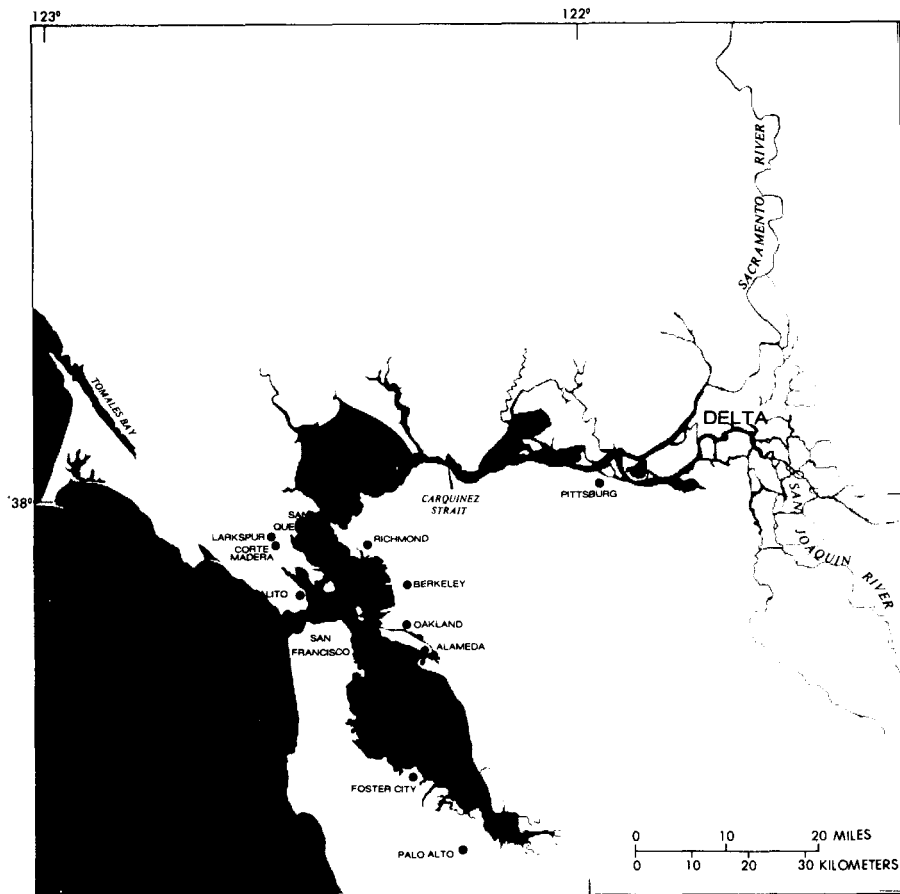
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Fig. 1. Index map of the San Francisco Bay-Delta and environs.

(*Crassostrea virginica*), was imported for seed culture or holding only and never became success-fully established in the Bay. It should be mentioned, however, that the San Francisco Bay oyster industry was at one time the single most valuable fishery in the state; it declined rapidly after the turn of the century as water quality deteriorated and conditions became unsuitable for oyster cul-ture. The market crab (*Cancer magister*) also supported a valuable fishery in the San Francisco area, but is not covered here because of the lack of quantitative information on the early fishery inside the Bay prior to the time when crabbing operations moved outside the Golden Gate. The Bay, however, is an important nursery area for this species (see Tasto 1979).

Skinner (1962, 1972a, b) has provided excellent reviews of the history and current status of the fisheries of San Francisco Bay area. This chapter summarizes and updates these and other works and provides additional insight as to the possible fate of the fisheries resources in the future.

CHINOOK SALMON

The chinook salmon, *Oncorhynchus tshawytscha*, is an extremely valuable food and game

resource in the Bay area and along the entire northern California coast. About 80% of all California's chinook salmon landings originate from stocks in the Sacramento-San Joaquin river systems (Skinner 1962). Most recreational fishing and all commercial fishing for chinook salmon now takes place outside the Golden Gate.

The chinook salmon attains a length of 147 cm and a weight of 57 kg, and its ocean range extends from San Diego, California, north to the Bering Sea and south along the Asiatic Coast to northern Japan (Fry 1973).

The species is anadromous, passing through the Bay and ascending rivers (Fig. 2) to spawn in cool, fresh-water streams over clean gravelly substrate (Fry 1973). Like all Pacific salmon, the
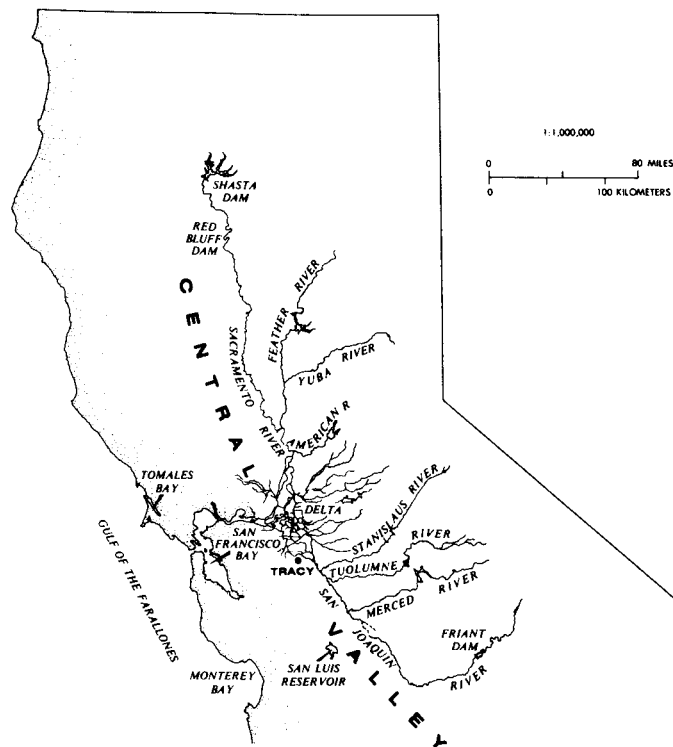
Fig. 2. The drainage basin of the San Francisco Bay-Delta system.

adults die after spawning. Eggs hatch in 50 to 60 days, and about a month later the young emerge from the gravel (Fry 1973). Peak downstream migration of young occurs in the spring and to a lesser extent in the fall. Fingerlings from 2 months to 1 year old move downstream through the estuary into the ocean, where they remain from 1 to 4 years (usually 3) to grow and mature before returning to native spawning streams (Heubach 1968).

There are at present three different stocks in chinook salmon in the Central Valley; these stocks are named for the time each enters spawning streams—spring-run, fall-run, and winter-run fish (Jensen 1972). A fourth group (late fall-run) has been identified (Hallock 1977), but we have included this group in the fall-run category. Most spring-run fish spend the summer in deep pools

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and do not spawn until the fall. Fall-run fish spawn soon after their arrival on the spawning grounds, and winter-run fish spawn in late spring and early summer (Hallock 1977; Jensen 1972).

Fall-run salmon are by far the most numerous and support the bulk of ocean sport and commercial fisheries. These fish spawn predominantly in the Sacramento and its tributaries, though some enter San Joaquin tributaries such as the Stanislaus, Merced, and Tuolumne rivers (Fig. 2). According to Jensen (1972), winter-run fish, which ascend the Sacramento system, have in recent years become the second most numerous group. Slater (cited by Heubach 1968) believes these fish are descendants of a small run that spawned in the McCloud River, a tributary of the Sacramento that was blocked off to spawners after construction of Shasta Dam. The spring run, which was apparently quite extensive prior to the construction of Shasta and Friant dams, is now the least numerous variety (Jensen 1972). Many spring-run fish formerly spawned in the San Joaquin River system, but due to inadequate flow caused by dam construction and other water projects, the Sacramento system now supports most of what remains of the spring run.

History of the Fisheries

Clark (1929), Skinner (1962) and Scofield (1956) provide good background information on the history of the salmon fishery. According to these authors, commercial fishermen began fishing for salmon around 1850 using gill nets and seines in the Sacramento and San Joaquin rivers and in parts of Suisun and San Pablo bays.

The first salmon cannery started operation on the Sacramento River in 1854. The industry grew rapidly, stimulating the early growth of the fishery. In 1864 one cannery packed 2,000 cases of salmon, each case containing 48 one-pound (0.45 kg) cans (Clark 1929). By 1882, 200,000 cases were produced by a total of 19 canneries operating on the rivers. After that year the industry began a gradual decline and ceased operations in 1916.

Records of the total river catch (Fig. 3A), which became available after 1874, give a better indication of the magnitude of the early salmon harvest. During the ten-year period between 1874 and 1884, an average of 3,220 t (metric tonnes) was landed annually, with a peak harvest of 4,900 t in 1880—the highest catch ever recorded. Ocean trolling for salmon, later to replace the river fishery, increased steadily after the late 1890's when gasoline boat engines were introduced (Scofield 1956). The major shift to ocean fishing, which took place from the late 1920's to the early 1940's, was largely augmented by legislative restrictions that curtailed river netting, such as stream closures, closed seasons and gear restrictions (Scofield 1956). In 1957, the year of the lowest river catch on record (146 t), legislative action eliminated all commercial salmon fishing inside the Golden Gate, making the ocean troll fishery the only legal commercial salmon fishery in California.

After World War II, sport trolling for salmon came into prominence, and the San Francisco area now produces the most consistent ocean sportfishing for salmon in the state (Squire and Smith 1977). About 45% of the chinook salmon taken near San Francisco are landed by recreational fishermen (P. O'Brien pers. comm.).

Environmental Problems

It is beyond the scope of this report to enumerate all of the many man-made changes that have affected salmon populations in the Central Valley. Readers are advised to refer to Clark (1929), Skinner (1962, 1972a), Kelley (1966), Heubach (1968), and Jensen (1972) for more detailed information.

Spawning streams were already being destroyed as early as the Gold Rush days by hydraulic gold mining, railroad construction and lumbering operations. These activities left many streams badly silted or blocked by debris (Gilbert 1917). Water development, particularly storage and

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diversion projects, had an immense effect on salmon stocks by blocking access to spawning areas above dams, reducing flow and altering temperature regimes below dams, diverting fish into irrigation channels, altering the natural condition of spawning streams, and, in the case of water transport projects, changing the hydrography of the Delta itself.

In 1928, before many of the major dams had been constructed, and before the advent of the federal Central Valley Project (CVP) and State Water Project (SWP), an estimated 80% of the original Sacramento-San Joaquin salmon spawning grounds had already been cut off by obstructions (Clark 1929). The construction of Shasta Dam in 1944 eliminated approximately 50% of the available spawning area of that river (Skinner 1962). Completion of Friant Dam on the San Joaquin River in the mid-1940's essentially eliminated salmon runs in the main stem of that river (Menchen 1977). Dam construction and water diversions on other rivers and streams have also blocked valuable spawning areas, or reduced flows to the extent that either the adults can not or
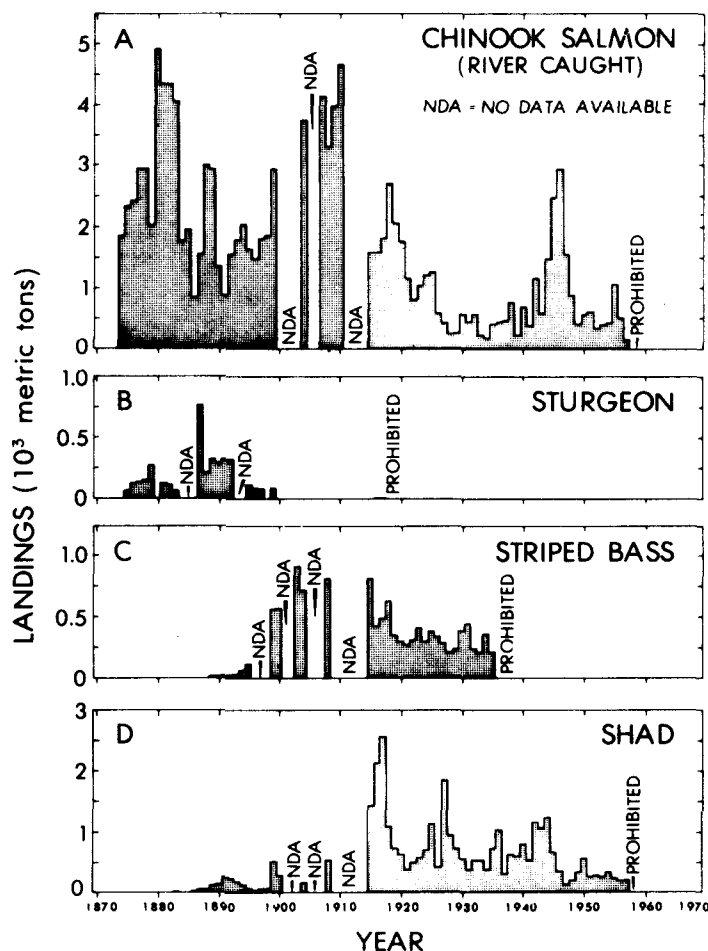

Fig. 3. Commercial fish catches of the Bay-Delta and adjacent tributary streams: (A) Salmon (1874-1957) in the Sacramento-San Joaquin rivers; (B) Sturgeon (1875-1917) in the Bay-Delta; (C) Striped bass (1889-1935) in the Bay-Delta; (D) Shad (1884-1957) in the Bay-Delta.

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will not ascend spawning streams, or the young are unable to pass downstream during their seaward migration in spring. Hatcheries have been built to replace some of the major spawning areas lost to water development.

Since the 1950's flow reversals caused by the pumping of huge volumes of Sacramento River water across the Delta to export pumps to the south near Tracy have also created problems for chinook salmon, which depend on their olfactory senses in homing to spawning areas. During periods of reduced flows and high pumping rates, Sacramento fish are attracted to the central and southern Delta by Sacramento River water present there, and are thus delayed in their spawning migration. At the same time, San Joaquin fish have to negotiate the barrier of Sacramento River water to reach their native San Joaquin water—most of which is being delivered away from the Delta to CVP and SWP transport pumps upstream (Jensen 1972; Skinner 1972b). Screens at the pumping station are fairly efficient, but large numbers of fingerling chinooks from the San Joaquin are still lost at those sites.

It has been suggested that construction of the proposed Peripheral Canal will resolve or minimize many of these problems (see for example Gill et al. 1971); however, with or without the Canal, water demands will continue to grow in California, and careful management and control of future development in the Central Valley will play an essential part in protecting the future of this important fishery resource.

STRIPED BASS

The striped bass, *Morone saxatilis*, was first introduced to the San Francisco Bay system in 1879 when 132 juveniles, taken from a small New Jersey estuary, were shipped across country by rail and released into Carquinez Strait (Skinner, 1962). A second plant of 300 fish was made in 1882 in lower Suisun Bay. Conditions in the Sacramento-San Joaquin estuary were obviously ideal, for the species flourished beyond all expectations and now supports a valuable recreational fishery within the Bay.

Today the bulk of west coast striped bass production occurs in the San Francisco Bay estuary. The species is anadromous, migrating in winter and spring to the Delta and upstream to spawn. Information on the biology of the striped bass, population size, and environmental factors affecting the species is presented by Stevens (1979).

History of the Commercial and Sport Fisheries

Ten years after its first introduction and for 46 years thereafter the striped bass supported an important commercial fishery in the Delta area. Fish were taken with gill and trammel nets, primarily in the San Joaquin River (Skinner 1962). Between 1889 and 1915 the catch usually exceeded 454 t (10^6 lb) annually, but catches subsequently dropped and for 20 years thereafter only twice exceeded 454 t (Fig. 3C). Growing interest in sportfishing for striped bass led to increased efforts toward conservation of the species. Finally in 1935 commercial fishing was prohibited and the resource reserved exclusively for sport use.

Until the late 1950's most angling effort took place from San Pablo Bay to the Delta, but as new fishing techniques developed and partyboat fishing upstream of Carquinez Strait diminished, San Francisco Bay proper became the major fishing area (Stevens 1977). Prior to this time most fish were caught by bait-fishing and some by surface trolling; however, it was discovered that bass could be readily taken from partyboats in north San Francisco Bay trolling deep with heavy sinkers. In addition, a winter-spring fishery developed during the herring spawning runs (Chadwick 1962). In the early 1960's another major change occurred in partyboat fishing methods with the

introduction of deep drifting with live anchovies. Today this is the primary method used by San Francisco Bay partyboats during the height of the season in summer and fall.

Impact of Water Development

Water development in the Delta has created a variety of problems for the striped bass. Water diversions have led to loss of eggs, larvae and young fish into export canals; salinity intrusion, caused by low rainfall and increased water export, has affected spawning in the San Joaquin River; and subsequent low river flows through and out of the Delta have been associated with poor year-class survival and later recruitment to the fishery (Stevens 1979).

AMERICAN SHAD

The American shad, *Alosa sapidissima,* is another transplant from the Atlantic Coast, and like the striped bass, became firmly established within the San Francisco Bay system soon after its introduction. Shad reach a length of 76 cm and become mature at 3 to 5 years (Fry 1973; Stevens 1972).

The species is anadromous, spending most of its life at sea, the adults using the Bay only as a migratory pathway enroute from the ocean to upstream spawning areas. Most shad spawn from April to June primarily in the Sacramento River system (Stevens 1972). Formerly, shad ascended the Sacramento for 300 miles or more (Nidever 1916), but since construction of the Red Bluff Dam in 1967 (Fig. 2), most runs stop at that point (Fry 1973). Unlike salmon and trout, shad do poorly at ascending fishways, especially the more common weir and orifice type (W. Leet pers. comm.).

Stevens (1972), summarizing the work of others, reports that spawning shad appear to require fresh water, a good current, and relatively warm water temperatures between 16° to 21°C. Many adult shad die after spawning. The eggs are slightly heavier than water and are carried near the bottom by river currents until hatched. Most of the young then move downstream, leaving the Delta and passing through San Pablo Bay from September to November. Young shad feed on zooplankton, primarily cladocerans and copepods. The principal food of the adults in the Delta is the opossum shrimp, though cladocerans and copepods are also eaten. Apparently nothing is known about young shad once they enter the ocean, and little is known of the oceanic habits of Pacific Coast adult shad.

Shad are extremely delicate fish, and the slightest physical injury proves fatal. Because of their fragile nature, shad young may be less apt to survive contact with fish screening devices otherwise suitable for hardier species such as young striped bass and salmon (W. Leet pers. comm.; Kelley 1968a).

History of the Commercial Fishery

Shad were first brought to the West Coast in 1871, when 10,000 fry were introduced into the Sacramento River (Nidever 1916). Between 1873 and 1880 several additional plants were made. As early as 1879, large numbers of shad started to appear in the San Francisco market. When the first few fish began to appear, some curious customers paid as much as $10 to $15 for a single fish, and many shad brought from $1 to $1.50 per pound (0.454 kg). The novelty soon wore off, however, as shad continued to increase in numbers and began to glut the market. By 1894 the price had plummeted to 2 cents per pound. Until 1912 shad were utilized entirely by the fresh fish trade, but later a salt shad market was established in China, and practically all fish were shipped there. Shad roe was salted and either canned and shipped to the east or sold in local markets.

During this time practically all shad were caught in drift gill nets in upper San Francisco Bay and in the Delta.

The shad catch reached a peak of 2,540 t in 1917 (Fig. 3C), but afterward landings declined. In 1958 legislation was enacted that prohibited gill netting in inland waters and the shad fishery was eliminated. The action was taken primarily to protect salmon and striped bass caught incidentally in netting operations and not because the shad population was endangered. It would appear that since the turn of the century the commercial fishery was, for the most part, limited not by population size but by lack of demand. Even though shad has an excellent flavor and is a popular food fish on the east coast, it is not sought after to any extent in California, except by recreational fishermen.

The Sport Fishery

Recreational fishing for shad started to become popular around 1950, and since then the sport has grown considerably. In 1963 DFG estimated that 100,000 angler days were spent by fishermen seeking shad on the Yuba, American, and Feather rivers (Kelley 1968a). In recent years the main stem of the Sacramento River has become the most important fishing area (D. Painter pers. comm.).

In addition, a small "bump net" sport fishery exists in the Delta area where upstream migrants are caught in large, long-handled dip nets made of chicken wire held in the wake of an outboard motor. For some reason, only male fish are caught by this method (Stevens 1972).

No quantitative information is available on the size of the adult shad population, but it is thought to be large. At the present time DFG is undertaking tagging studies to obtain population estimates. Factors influencing the survival from egg to adult are thought to be similar to those of striped bass, although predation on shad appears to be lighter (Kelley 1968a). Maintenance of *Neomysis* sp. populations in the Delta, upon which shad depend, may be an important factor in the future as increased water demands and diversions lead to reduced outflow through the Delta, increasing the duration of salinity intrusion and altering the habitat and distribution of *Neomysis* sp. especially during dry years (Orsi and Knutson 1979).

STURGEON

Two species of sturgeon occur in the San Francisco Bay estuary, the white sturgeon, *Acipenser transmontanus,* and the green sturgeon, *A. medirostris.* The largest white sturgeon taken along the Pacific Coast was reported to be about 610 cm long, weighing 817 kg. The smaller and less common green sturgeon reaches about 213 cm and a weight of about 159 kg, but most of those that are caught are considerably smaller (Squire and Smith 1977). Female sturgeon reach maturity when they are about 12 to 15 years old, or approximately 125-140 cm in length. Males apparently mature earlier, at 10 to 12 years of age and about 112-125 cm in length (D. Kohlhorst pers. comm.).

Benthic invertebrates such as clams, small crabs and bay shrimp predominate in the diet of sturgeon; however, during the winter herring spawning runs, herring eggs are reported to account for 20 to 80% of their food. Fish, such as striped bass, herring, staghorn sculpin, and anchovy are eaten in lesser numbers (Miller 1972a; McKechnie and Fenner 1971). The opossum shrimp and the amphipod *Corophium* sp. make up the bulk of the diet of young-of-the-year sturgeon (Miller 1972a).

Tagging studies indicate that white sturgeon confine their movements primarily to the estuary, spending summer, fall and winter in the lower bays and Delta, and migrating upstream

primarily in early spring. Green sturgeon appear to spend more time in the ocean and move considerable distances along the coast (Miller 1972b).

Environmental conditions necessary for successful migration and reproduction of sturgeon are not known, and to our knowledge, spawning and embryology of California sturgeon have not been described. Sturgeon larvae have been taken by DFG in the Delta and in the Sacramento River upstream to Hamilton City (rkm 330) from March to mid-June (Kohlhorst 1976; Stevens and Miller 1970). Apparently most, if not all, of these larvae were spawned in the Sacramento River above the Delta. Catches by nets set at different depths indicate larvae are demersal.

There is concern that yolk-sac larvae coming down from the Sacramento River in spring will be vulnerable to water diversions. Recommendations have been made to prevent their being diverted with the water by providing efficient screening facilities and/or pumping curtailment (Miller 1972a). Kelley (1968b) predicted that increased net velocities in Delta channels resulting from increased water transport to the south may reduce populations of *Corophium* and *Neomysis* spp., which are important foods of sturgeon. Also, proposed reclamation or bay fill may have a detrimental effect on both juveniles and adults which feed on benthic organisms over the shallow flats of San Pablo and Suisun bays.

History of the Fishery

Before the 1870's, the sturgeon resource in the estuary was virtually untapped. Only the Chinese considered them of value, but they often utilized only the gelatinous notochord (Skinner 1962). A demand for sturgeon apparently came about when "Easterners" with a taste for sturgeon and caviar migrated to the Pacific Coast. Around the same time, the Atlantic coast supply had diminished (Skinner 1962). Furthermore, great quantities of sturgeon were in demand to feed ranch hands and labor gangs prior to 1895 (Scofield 1957).

The fishery only lasted about 30 years, but within that time the resource was heavily exploited. Initially, most fishing was conducted by the Chinese, who snagged the fish using heavy setlines with unbaited barbless hooks (Fry 1973). Gill and trammel nets took many, but such catches were usually made while fishing for other species. Green sturgeon, considered inferior as a food fish, was not sought after and brought only half the market price of white sturgeon (Smith 1895). From 1875 to 1892, landings averaged 227 t annually, while between 1892 and 1901 they ranged from about 45 to 91 t (Fig. 3B). In 1895, a law was passed protecting sturgeon during part of the spawning season, and Chinese setlining was prohibited (Scofield 1957). In 1901 the State Legislature temporarily abolished the fishery, claiming the white sturgeon to be on the verge of extinction. The fishery remained closed until 1910, when it was reopened to a limited extent but then finally abolished completely in 1917.

Kelley (1968b) suggested that hydraulic mining operations in the Sacramento system may have had as much influence on the decline of the sturgeon as did overfishing. Between 1860 and 1914 tremendous loads of mining debris flowed through the river system to the sea, affecting the benthos and probably sturgeon as well. The decline in the fishery from 1875 to 1900 occurred after 15 years of rapid and heavy bed load movement of debris down the Sacramento and accumulation in Suisun and San Pablo Bays, principal feeding areas of sturgeon. This debris passed out of Suisun Bay by 1930 and out of San Pablo Bay by 1950 (see also Krone 1979).

The taking or possession of sturgeon was prohibited until 1954, at which time DFG felt the population had sufficiently recovered to recommend opening the fishery for sportfishing only. Initially, snagging seemed to be the only effective fishing method, but this was prohibited in 1956 (Miller 1972b). Very few fish were taken until about 1964 when it was discovered that bay shrimp (*Crangon* sp.) could be used successfully as bait. Afterwards, partyboat catches jumped from three

sturgeon in 1963 to 2,400 fish in 1967 (McKechnie and Fenner 1971).

In recent years sturgeon angling has become increasingly popular. Although they are caught throughout the year in the upper bays and Delta, best fishing is from fall through early spring when the biggest fish are taken. There is a one-fish bag limit and 102-cm minimum size. Much of the angling takes place from boats in San Pablo and Suisun bays, where anglers stillfish on the bottom using shrimp for bait. During the herring spawning runs from about January to March, sturgeon also congregate around Sausalito and the Tiburon Peninsula, where, during the height of the runs, they are caught by shore and boat anglers using herring fillets or herring roe for bait. A modest fishery exists in South Bay where anglers use methods similar to those used in San Pablo Bay.

PACIFIC HERRING

Although Pacific herring, *Clupea harengus pallasi,* are distributed along the entire U.S. west coast, they are uncommon in southern California. Within the range there are a series of intergrading populations which spawn in specific areas; tagging experiments give evidence of only limited interchange among populations (Hart 1973). Major spawning areas in California are Tomales and San Francisco bays.

Each year from about November to March large schools of herring enter San Francisco Bay to spawn, principally along the shores of Sausalito and the Tiburon Peninsula. Most herring spawn when they are two years old and about 25 cm long (J. Spratt pers. comm.). Pacific herring spawn intertidally and subtidally down to 7.6 m or more (Eldridge and Kaill 1973). They appear to prefer substrates covered with seaweed, eelgrass, or rock upon which to deposit their adhesive eggs although the eggs commonly blanket every available surface during the height of spawning activity. Fecundity is 18,600 eggs for females averaging 192-mm standard length, and 29,500 eggs for females of 223 mm (Hart and Tester 1934). Most spawning occurs at night, although fish have been observed to spawn during the day as well, and at all tidal stages. The eggs range between 1.3 to 1.7 mm in diameter and are usually deposited one or two eggs thick, but can be in layers up to 51 mm deep (Miller and Schmidtke 1956). Eldridge and Kaill (1973) found that when heavy "clumping" of eggs occurs, survival is poor among all but the outlying eggs.

During and after spawning, adult fishes and eggs are subjected to heavy predation from the many sea birds, fishes and sea lions that gather at the spawning grounds. Mortality of eggs may range from less than 5% in deep water to 99% or more for intertidal spawning where eggs are available to a variety of predators, particularly gulls (Eldridge and Kaill 1973). After leaving the Bay, postspawning adults and juveniles are thought to disperse along the coast (J. Spratt pers. comm.) and a significant number apparently migrate to Monterey Bay where the commercial fishery regularly lands nonspawning herring.

History of the Fishery

Immigrant Italian fishermen started fishing for herring about 1850, and by 1888, 35 to 40 boats were engaged in the fishery which was centered in Richardson Bay (Skinner 1962). There was also limited fishing over the shallows on the eastern side of San Francisco Bay south of Alameda and off Point Richmond. Fishermen used gill nets, beach seines, and later paranzella nets. The bulk of the landings was sold in the fresh fish markets, but when abundant and cheap, part of the catch was salted and sold for bait as well as for human consumption. According to Collins (1892) herring landings in 1888 amounted to 1,200 t.

Attempts to establish export markets failed because Pacific herring did not measure up to the quality of Atlantic herring. Bay fish were particularly unsuitable because of their small size,
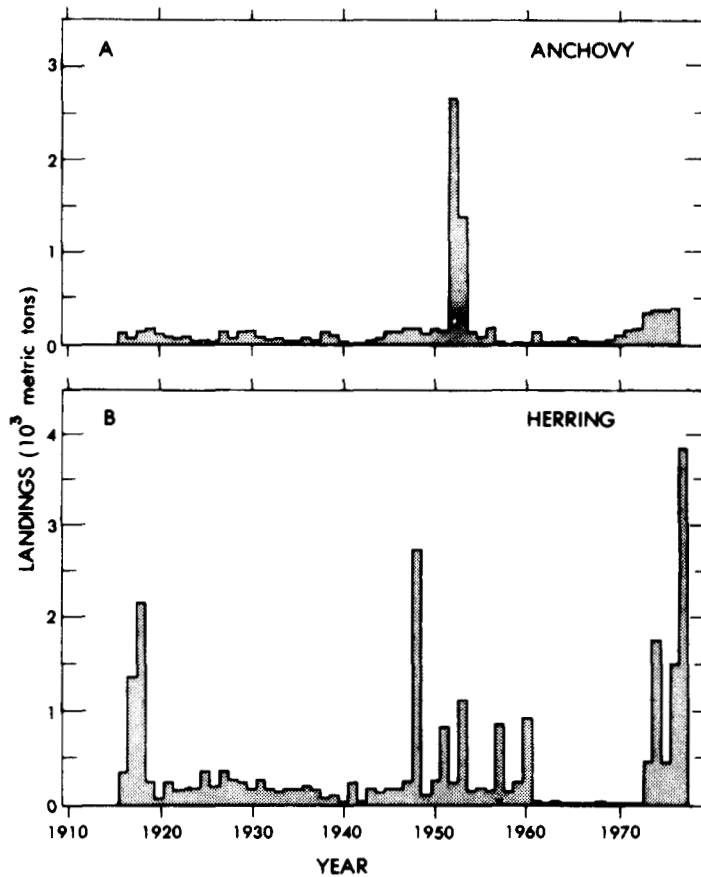
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Fig. 4. Commercial fish catches in the Bay: (A) Anchovy (1916-1976); (B) Herring (1916-1976/77 season).

and because gill netters and seiners took only spawning fish that were not in prime condition for salting and smoking (Scofield 1918). Some salted herring was shipped to the Orient, however.

Demand for herring increased as food came into short supply during World War I. In 1917 a canning and reduction plant was established at Pittsburg, California, supplied by fish from San Francisco and Tomales bays, particularly the latter, because the fish were fatter and longer (Scofield 1918). Although the San Francisco Bay catch rose to nearly 2,150 t in 1918 (Fig. 4B), the fishery was short-lived. In 1921 the State Reduction Act was enacted, limiting reduction of fish to fish meal. Canning operations closed and from 1920 through 1946 only small quantities were landed for fresh consumption, bait, and for smoking (Frey 1971; Miller and Schmidtke 1956).

The fishery had a brief revival after the end of World War II when herring was tried as a substitute for the vanishing sardine, but the attempt was unsuccessful. Thereafter only a small pet-food market continued to provide a limited demand, but even this market did not hold (Eldridge and Kaill 1973).

In the mid-1960's, a specialized fishery began for herring eggs, utilized in Japan in two forms: "kazunoko" and "kazunoko-kombu." Kazunoko consists of the ovaries taken from ripe

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herring. Fish are taken by lampara nets, gill nets, and purse seines. Kazunoko-kombu refers to herring eggs-on-kelp, which is gathered by divers in subtidal areas. Both products are expensive gourmet items in Japan.

As fishing effort intensified in both Tomales and San Francisco bays, public concern mounted over the fate of the herring resource, and emergency legislation was passed in 1973 that instituted a permit and quota system for the herring fishery. In San Francisco Bay, the present (1977-1978) quota for adult herring is 4,558 t; the quota for eggs-on-kelp is 4.5 t, including plant material. The commercial season extends from December 14 through March 31 with different starting dates for the various fishing methods.

The 1976-77 herring spawning population in San Francisco Bay was estimated at 24,489 t (J. Spratt pers. comm.).

NORTHERN ANCHOVY

Probably the most abundant species of fish in the Bay, the northern anchovy, *Engraulis mordax*, supports a modest commercial fishery and is important in the food web. The anchovy is a short-lived species, attaining a probable maximum of seven years, although rarely exceeding four years of age and a length of 18 cm (Frey 1971). Sexual maturity is reached by the end of two years at a length of about 13 cm (Frey 1971).

Anchovy are found in the Bay throughout the year, but a large influx occurs in May, and an elevated abundance persists through September (Aplin 1967). Commercial landings also coincide with this period, but high catches extend into October and sometimes into November (DFG Catch Bulletins). Many small anchovy can be found during this period, indicating that the species probably spawns in the Bay. Eldridge (1977) found the greatest number of larval anchovy during December, however.

Many species of fish feed on anchovy of appropriate size, including downstream migrant salmon (Heubach 1968), jacksmelt (Boothe 1967) and striped bass (Johnson and Calhoun 1952). Indeed, because of its abundance and small size the anchovy is probably the most important forage fish in the Bay.

The Fishery

From 1916 through 1951, annual landings of anchovy in the Bay Area (Fig. 4A) amounted to less than 180 t (Skinner 1962). In 1952 the catch increased suddenly to 2646 t due to the need for a substitute for the failing sardine industry. Because of low consumer acceptance of canned anchovies, and rigid state laws governing reduction of fish into fish meal, catches in subsequent years declined considerably. Recently, however, the landings have started to increase again, and the commercial catch has stabilized at around 385 t (M. Oliphant pers. comm.).

Practically the entire reported catch is now preserved and packed as frozen bait for recreational fisheries. An additional unrecorded amount, perhaps as much as 25% of the "dead bait" landings, is taken for use as live bait, primarily for use in the sport fishery for striped bass. In some years both live and dead anchovy are also used as bait in the commercial albacore tuna fishery. The landed value of the 1974 "dead bait" catch was $73,344 (McAllister 1976).

Although anchovy for the bait industry are normally caught within the Bay, in some years about 10% are caught outside the Golden Gate (W. Millazzo, Meatball Bait Co., Sausalito; and W. Beckett, bait dealer, Oakland, pers. comms.). We have no estimates of the tonnage caught outside the Bay during the two years of greatest landings (1952 and 1953).

Anchovy are caught in the Bay exclusively with a roundhaul seine called a "lampara" net.

When the anchovy are to be kept alive the fish are dip-netted from the seine into holding tanks aboard the fishing vessel. At times the entire net with the encircled school of anchovy is towed to a moored bait receiver.

No estimates are available on the abundance of anchovy in the Bay. Since the greatest bulk of anchovy are seasonal migrants, it seems unlikely that the stocks in the Bay can be imperiled by the present fishery.

STARRY FLOUNDER

The starry flounder (*Platichthys stellatus*) is one of the most important sport-caught flat-fishes along the Pacific Coast (Squire and Smith 1977). It is euryhaline, commonly occurring in estuarine areas, and sometimes in full fresh water and appears to prefer a soft sand habitat (Orcutt 1950). The main spawning period is December-January, when mature starry flounder apparently migrate to shallower waters (Orcutt 1950). Average size of individuals taken during a bottom trawl survey in San Francisco Bay was 41 cm, with a range of 24-63 cm (Boothe 1967). According to Orcutt (1950) a 41-cm fish weighs about 1.5 kg and would be sexually mature. Lockington (cited by Orcutt 1950) reported in 1880 that large starry flounder from 3.6 to 5.4 kg occurred in San Francisco Bay. Fish of this size are rarely encountered today.

Although mature starry flounder are common and some spawning would be expected to occur within the Bay, only few eggs, larvae, and juveniles have been taken in surveys (Green 1975; Eldridge 1977). Ganssle (1966) found that size of starry flounder decreased with distance up-stream from San Francisco Bay. D. Stevens (pers. comm.) reports that few starry flounder are found in the Delta, but large ones are commonly caught in San Luis Reservoir, suggesting that the young are carried from the Delta to the Reservoir via the aqueduct. Food of starry flounder in San Francisco Bay consists primarily of polychaete worms, small bivalves, siphons of larger clams, and small crabs (Boothe 1967).

The Fishery

The starry flounder is an important species to anglers in the Bay as it is an excellent food fish. Bottom fishing from anchored or drifting boats in San Pablo and Suisun bays probably produces the best catches, although this species is also common in the shore catch. The commercial fishery for starry flounder is conducted almost exclusively by bottom trawl in offshore coastal waters; no commercial fishing occurs in San Francisco Bay. No data are available on the abundance of starry flounder in the Bay. Sampling with a bottom trawl disclosed its presence at all stations, from Palo Alto to Richmond, and although it ranked 16th in total numbers captured (Aplin 1967), its large size should relegate it to a higher position in terms of biomass.

SURFPERCH

About a dozen species of surfperch (family Embiotocidae) occur in San Francisco Bay, the most common being the pile (*Damalichthys vacca*), black (*Embiotoca jacksoni*), shiner (*Cymato-gaster aggregata*), walleye (*Hyperprosopon argenteum*), white (*Phanerodon furcatus*), rubberlip (*Rhacochilus toxotes*), striped (*Embiotoca lateralis*) and rainbow (*Hypsurus caryi*) surfperches (Wooster 1968a; Squire and Smith 1977). Surfperch are relatively small coastal marine fishes, although the larger species, such as the pile and rubberlip, are known to reach lengths of 44 and 47 cm, respectively (Miller and Lea 1972).

All embiotocids are viviparous—a reproductive process rare among marine teleosts. Breeding habits have been described for some surfperch species (Eigenmann 1894; Wales 1929; Rechnitzer

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and Limbaugh 1952; Engen 1968; Wares 1971; and others). In general, mating usually takes place shortly after a previous brood has been released and the sperm may be carried for months by the female before the eggs are fertilized. The embryos develop in membranous sacs and receive nourishment from the surrounding ovarian fluid. The young are well developed and independent at birth (Wares 1971; Frey 1971). It appears that many Bay surfperch release their young in spring and early summer, judging from the occurrence of term females in the sport catch at that time (W. Dahlstrom pers. comm.). To our knowledge, nothing has been published on movements and breeding habits of Bay surfperch, and in general, information on other life history aspects is lacking. Boothe (1967) found that shiner surfperch fed predominately on benthic invertebrates such as gammarid amphipods and cumaceans, and to a lesser extent on clams and polychaetes. Adams (unpublished)[1] found gammarid and caprellid amphipods were the most important food of black surfperch; other small crustaceans, tanaids and isopods were also important, as were polychaete worms and bryozoans. The diets of striped and rainbow surfperch were similar, but for pile perch, large crustaceans, hard-shelled molluscs and barnacles were much more important in the diet.

Because they occur and are caught in nearshore locations, often adjacent to highly populated and industrialized areas, surfperch and the organisms upon which they feed may be exposed to higher concentrations of pollutants than species inhabiting the deeper waters of the Bay where tidal action and outflow flushing aid in dispersal of these materials. Earnest and Benville (1971) found DDT levels to be higher in surfperch than in the flatfish, sculpin and crabs they sampled in the Bay.

The Fishery

Surfperch form an integral part of the marine sport catch in San Francisco Bay, and are frequently taken by pier and wharf anglers (Wooster 1968a; Squire and Smith 1977). Shiner perch is also a popular live bait for striped bass. Winter and spring are the best fishing times, when larger individuals are usually taken (Wooster 1968a).

Members of this family are of minor commercial importance locally, although some do occasionally appear in local markets. Before the turn of the century, however, surfperch were apparently quite common in San Francisco fresh fish markets (Eigenmann 1894, citing Lord). Judging from some of the early accounts (Wilcox 1898), most were taken with beach seines.

ELASMOBRANCHS (SHARKS AND RAYS)

Of the species of elasmobranchs occurring in San Francisco Bay, the most abundant is the brown smoothhound, *Mustelus henlei* (Herald and Ripley 1951; Russo and Herald 1968). The leopard shark (*Triakis semifasciata*), soupfin (*Galeorhinus zyopterus*), dogfish (*Squalus acanthias*), sevengill shark (*Notorhynchus maculatus*), and the bat stingray (*Myliobatis californica*) are all fairly common. The largest shark caught in the Bay was a rare sixgill shark (*Hexanchus griseus*) which measured about 3.3 m and weighed 210 kg (Herald and Ripley 1951). Total biomass of these species is unknown but may be considerable. One study using bottom longline gear produced a catch rate of 15 sharks per 100 hooks (Herald and Ripley 1951), which is an exceptionally high catch rate for any commercial longline fishery.

South Bay apparently harbors more sharks than the central and northern reaches (Herald and Ripley 1951). The brown smoothhound and leopard sharks apparently prefer shallower waters, while the sevengill is usually found in waters deeper than 6 m. The Bay may be a nursery ground for some sharks, as evidenced by the predominance of juveniles in the catch. Soupfin gives birth to pups in the Bay (Herald and Ripley 1951), and we have caught many pregnant brown smoothhounds with near-term pups.

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[1] "Resource partitioning among members of a model fishery." NMFS, Tiburon Lab., Tiburon, CA 94920.

Food habits of leopard sharks and brown smoothhounds have been extensively studied by Russo (1975) who found that both were essentially benthic feeders. Disturbingly, he also found polychlorinated biphenyl (PCB) levels of 22-47 ppm in the liver, and total identifiable chlorinated hydrocarbon levels of 37 and 108 ppm respectively for smoothhound and leopard sharks. Among the important food elements (over 15% frequency of occurrence in stomachs of sharks caught in San Francisco Bay) were shrimps, crabs, herring eggs, and the fat innkeeper worm (Russo 1975).

The bottom-feeding mode of these two species apparently was connected to a case of mass mortality recorded in 1967 (Russo and Herald 1968). During a period of 33 days, more than 725 elasmobranchs were found dead along the banks of the eastern shore of San Francisco Bay. Of this total 492 were brown smoothhounds. Leopard sharks and bat stingrays, presumably a bottom feeder also, made up the rest of the total killed, except for a solitary sevengill shark. The cause of death was not determined.

History of the Fishery

Presently no commercial fishery exists in San Francisco Bay for elasmobranchs. During the celebrated "boom" of shark liver oil that lasted from 1937 through the early 1950's, an intensive fishery was conducted throughout the state for soupfin and spiny dogfish (Ripley 1946; Frey 1971). The livers of these species, particularly the soupfin, are rich in Vitamin A. During this period landings of sharks from the San Francisco Bay region constituted over 40% of the total for the state (Ripley 1946). Between 1937 and 1945, annual landings of all sharks in the San Francisco Bay area averaged 870 t, with a high of 2,243 t in 1940.

Ripley's (1946) figures indicate that during 1941-44, soupfin constituted 16% of the total shark landings in the San Francisco region. Presumably most of the remainder were spiny dogfish, much of which were caught by bottom trawl gear outside the Bay. Byers (1940) indicates that a large proportion of the soupfin landed in the San Francisco region were caught by hook and line within the Bay.

Shark and ray fishing is popular with many Bay anglers, and although most people disdain the thought of eating sharks, some species are considered desirable and are commonly eaten. In fact, all the species found in San Francisco Bay have been found in the market (Frey 1971). The leopard shark and soupfin are particularly desired for their substantial amounts of firm white flesh, and many anglers in San Francisco Bay undoubtedly consume these species regularly. A further use of shark, one heartily recommended by gourmets, is the Chinese sharkfin soup.

CLAMS, OYSTERS, AND MUSSELS

San Francisco Bay contains large numbers of shellfish species, some of which have known potential commercial and recreational value such as the soft-shell clam, Japanese littleneck, mussels, and the native oyster (see also Carlton 1979 and Nichols 1979). Although considerable progress has been made in improving water quality in the Bay in recent years, shoreline waters are apparently not yet free enough of sewage contamination for the State Public Health Department to sanction harvesting of Bay shellfish for consumption.

History of the Fisheries

San Francisco Bay was one of the major landing areas in the State for oysters and clams, but these fisheries declined steadily after 1900, with the oyster industry collapsing in the late 1930's, and the soft-shell clam industry in the late 1940's (Skinner 1962; Jones and Stokes 1977). By and large, introduced species have been the most important commercially.

Oysters: Three species of oysters were harvested from San Francisco Bay in the past: the native oyster *(Ostrea lurida),* the eastern oyster *(Crassostrea virginica),* and the Pacific or Japanese oyster *(C. gigas).* The latter two species are exotics introduced for holding and fattening or seed culture—neither have reproduced sufficiently in the Bay for commercial exploitation (Jones and Stokes 1977). Information on these oyster fisheries can be obtained from Bonnot (1935), Skinner (1962), and Wooster (1968c).

The native oyster was once extremely abundant in many parts of the Bay (Townsend 1893). This species was harvested centuries ago by local Indian populations and briefly for the restaurant trade during and after the Gold Rush days (Wooster 1968b; Jones and Stokes 1977). It could not compete with the larger, more desirable eastern oyster after the latter was introduced, however. Apparently no attempts have been made to culture the native oyster in the Bay, and although at least five large native oyster beds still exist (Wooster 1968b), the species is much less abundant than it was before the turn of the century. The decline in native oyster populations is thought to be the result of predation by the eastern oyster drill which was introduced with the first eastern oyster shipments from the Atlantic Coast, and the silting in of much of the suitable substrate that once existed (Bonnot 1938; Wooster 1968b).

Clams and Mussels: Three of the most abundant species of bivalves are not native to the Bay, and all were accidental introductions. These are the soft-shell clam *(Mya arenaria);* the ribbed or horse mussel *(Ischadium demissum);* and the Japanese littleneck *(Tapes japonica).* The bay mussel *(Mytilis edulis)* is considered indigenous to this coast; however, some populations may represent exotic stocks introduced by way of ship fouling (D. Chivers pers. comm.; Carlton 1979).

The soft-shell clam was introduced into California with shipments of eastern oysters in 1869 or 1870 and first detected in 1874 (Fitch 1953). It became abundant and widely distributed in the Bay in the late 1880's and soon formed the bulk of the clam trade in San Francisco (Wooster 1968b). Apparently *Mya arenaria* largely displaced native clams in the Bay, especially the bent-nose clam *(Macoma nasuta)* in the South Bay, where prior to 1876, large numbers were harvested by Chinese fishermen (Skinner 1962; Weymouth 1920). According to Wilcox (1895), from 1889 to 1892, between 500 and 900 t of soft-shell clams were taken in the Bay each year (Fig. 5A). In 1899 Bay landings amounted to 695 t valued at $21,908 (Wilcox 1902).
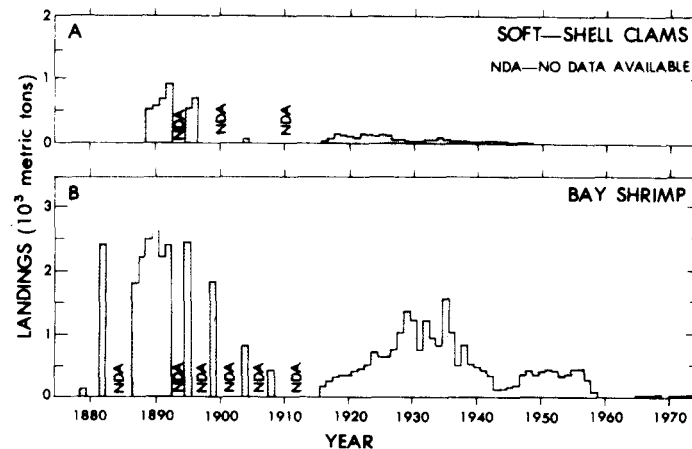

Fig. 5. Shell-fish commercial catches in San Francisco Bay: (A) Soft-shell clams (1889-1948); (B) Bay shrimp (1879-1974).

After the turn of the century, landings dropped considerably. In 1916 only 245 t were sold, and by 1927 the take had declined to 68 t (Wooster 1968b). By the early 1930's several beds had been destroyed or abandoned due to expiring leases and pollution (Bonnot 1932). The commercial fishery for soft-shell clams had disappeared by 1949. Its decline has been attributed to a variety of factors; domestic and industrial waste pollution, bay filling and construction; overharvesting; the high cost of manual labor required to dig the clams; and State allocation of some of the better clam beds for recreational use only (Bonnot 1932; Skinner 1962; Wooster 1968b).

During the time the soft-shell clam industry was collapsing, another exotic food clam, the Japanese littleneck (*Tapes japonica*) was becoming established. It was apparently introduced with shipments of Pacific oyster seed during the early 1930's, and since that time it appears to have taken over much of the habitat formerly occupied by the native littleneck or rock cockle, *Protothaca stamina* (Jones and Stokes 1977; Ricketts and Calvin 1968).

Soft-shell clam and Japanese littleneck are presently abundant in the Bay, and although subjected to intensive sport clamming in such areas as Foster City and Berkeley (despite warnings of the Public Health Department), these resources remain essentially unused (Jones and Stokes 1977; W. Dahlstrom pers. comm.).

The soft-shell clam prefers sheltered bays and a heavy mud substrate where there is some mixing of fresh and salt water (Fitch 1953). Heavy wave action is detrimental to the species (Matthiessen 1960). Recently over 1 million clams were destroyed in the Corte Madera-San Quentin area, possibly the result of wave scouring caused by the new Larkspur commuter ferry (R. McAllister pers. comm.).

The Japanese littleneck apparently can survive within a wide salinity range. It adapts well to extreme saline conditions and has also been found in the estuary where salinities were as low as 16 °/oo (Wooster 1968b). The species appears to prefer gravel bottom, and does not develop on substrates where no attachment is possible or where the young may be subjected to gill clogging (Filice 1958; Wooster 1968b).

The bay mussel, *Mytilis edulis*, like the soft-shell clam, contributed substantially to the Bay shellfish harvest in times past, especially prior to 1895. Between 1889 and 1892, San Francisco Bay mussel landings fluctuated between 950 and 1300 t per year (Wilcox 1895). Soon afterward the fishery suffered a severe decline which was attributed to reports of people becoming ill from eating bay mussels. At the present time it is utilized mostly for bait and occasionally for food. Although considered a delicacy in Europe where it is cultured commercially, it is not much sought after locally (Fitch 1953).

The ribbed mussel, *Ischadium demissum*, is another abundant mytilid in the Bay. It was apparently introduced with oyster shipments in the 1870's, and though it has occurred in San Francisco markets in the past, it has never been an important food item (Jones and Stokes 1977). Because of its high Vitamin D content, a proposal was made in the early 1960's to harvest *I. demissum* for use in freeze-dried form as a food additive, but the venture fell through because of Public Health restrictions (Aplin 1967; Jones and Stokes 1977).

The ribbed mussel lives in the high intertidal zone, most often in association with the native cord grass (*Spartina foliosa*), and the species is capable of filtering out great quantities of suspended matter from the water (Aplin 1967). The continual sedimentation effected by mussels may play a large part in salt-marsh development and mussel populations may also be important in the estuarine phosphate cycle by furnishing raw materials to deposit feeders which in turn regenerate the phosphate (Kuenzler 1961).

Paralytic shellfish poisoning (PSP) is commonly associated with mussels and results from the consumption of shellfish that have been feeding on toxin-producing dinoflagellates of the genus *Gonyaulax* (Ricketts and Calvin 1968). Most, if not all, cases of PSP in California are probably

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associated with the sea mussel, *Mytilis californianus*, not the ribbed or bay mussels; however, all mussels are under State quarantine from May through October, when blooms of *Gonyaulax* are known to occur (Jones and Stokes 1977).

Public Health Problems and the Future

The combination of rapid population growth and industrialization since 1900 has undeniably affected shellfish resouces in San Francisco Bay. Skinner (1962) points out that even before the turn of the century, pollution, siltation and ship wastes were hastening the decline of the fisheries in the Bay, and that shellfish were particularly vulnerable. He cites an 1878-79 Board of Fish Commissioners report by W. N. Lockington, who attributed the decline not just to overfishing and increased boat traffic, but in particular, to the "constant fouling of the waters and destruction of life by the foetid inpourings of our sewers . . ."

In 1932, bacterial levels in the Bay were so high that the State Board of Health passed a resolution establishing a general permanent quarantine on shellfishing in San Francisco Bay, but this quarantine was rescinded in 1953 (Jones and Stokes 1977).

No comprehensive sanitary survey has been conducted in the Bay although bacterial surveys are made at irregular intervals at various locations by certain governmental agencies. These surveys have revealed a significant improvement in water quality over the past 10 years (California Water Quality Control Board 1976); however, Jones and Stokes (1977) point out that results obtained during the past two drought years may be misleading due to the reduction of urban runoff, a significant contributor to high bacterial levels. Even if bacterial quality reaches acceptable levels, other problems still need to be resolved such as uncontrolled urban run-off during storms, presence of harmful viruses, uptake and concentration of harmful trace metals and other toxic substances; and sport-commercial allocation of the resource.

BAY SHRIMP

Three species of native shrimp occur in San Francisco Bay: *Crangon franciscorum, C. nigricauda,* and *C. nigromaculata.* The Korean shrimp, *Palaemon macrodactylus,* which was introduced accidentally in the early 1950's, has also become established in brackish waters of the Bay system (Ricketts and Calvin 1968). Of the crangonids, the largest and most abundant is *C. franciscorum,* followed by *C. nigricauda. C. nigromaculata* is far less numerous and is not considered in this chapter.

Bay shrimp are important forage for sport and market fishes. In the Bay they occur frequently in the diet of sturgeon (McKechnie and Fenner 1971) and striped bass (Johnson and Calhoun 1952). Moulting by bay shrimp and agitation of bottom sediments in their search for food and protection may also contribute to the cycling of nutrients (Krygier and Horton 1975).

Much of the life histories of *C. franciscorum* and *C. nigricauda* are similar (Israel 1936). Both species breed at the end of their first year. Females attain a larger size than males, and at maturity measure approximately 37 mm TL (*C. nigricauda*) and 53 mm TL (*C. franciscorum*). The eggs hatch in water of high salinity. Larval stages are planktonic until reaching 6 to 7 mm in length, at which time they settle to the bottom and move toward shallow water of reduced salinity. The earliest postlarval shrimp are found in brackish or nearly fresh waters of tidal flats or sloughs. As the shrimp develop and spawning season approaches, they move back into deeper, cooler, and more saline water.

Ovigerous females occur throughout the year, but Israel (1936) found that major spawning occurred from December to May or June for *C. franciscorum* and from April to September for *C.*

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nigricauda. Krieger and Horton (1975), however, found a bimodal spawning pattern for the same species in Yaquina Bay, Oregon. Ganssle (1966) observed ovigerous *P. macrodactylus* in Suisun Bay during fall sampling.

Of the crangonids, *C. franciscorum* is the more tolerant of fresh water and has been found far up into the Delta, while the upper limit of *C. nigricauda* is in Suisun Bay, and then only in the fall with intrusion of salt water (Skinner 1962). This difference may be an important factor separating the two species and limiting competition, although it is possible that this balance may have been disrupted in some way with the introduction of the Korean shrimp.

Little data are available on the population size and species distribution in the Bay, although the present bait fishery appears to be far from utilizing the full potential of the resource (Frey 1971). Because bay shrimp are short-lived there may be large fluctuations in abundance from year to year, and, for the same reason, shrimp populations would be particularly sensitive to the effects of short-term pollution in the environment (Frey 1971).

History of the Fishery

Scofield (1919), Israel (1936), and Skinner (1962) have provided summaries of the development of the bay shrimp fishery. According to these authors, shrimp fishing in California was started in 1869 by Italian fishermen who employed 18 m long seines and sold their limited catch to local fish markets. The Chinese entered the fishery in 1871 with the far more efficient Chinese shrimp net or "bag net," which greatly increased the catch and promptly put the Italian fishermen out of business. The Chinese nets were funnel-shaped stationary traps, 9 m across, 12 m long and operated by tidal action. The local demand for shrimp was not great, but a profitable export trade was built up from the dried product which was shipped to the Orient. An estimated 1,500 Chinese were engaged in the fishery in 1875. Between 1882 and 1892, yearly catches averaged 2,270 t (Fig. 5B). In 1897, 26 Chinese shrimp camps were established at various locations around San Francisco Bay. This number was reduced to 19 camps by 1910.

The use of Chinese shrimp nets met with opposition from the beginning, because many juvenile food fishes were allegedly destroyed incidental to the shrimp catch, and later because it appeared that the shrimp resource was being rapidly depleted. Thus a series of laws was passed from 1910 to 1919 involving closed seasons, gear restrictions and processing limitations. After 1915 Chinese nets were allowed only in South Bay, while beam trawls were used elsewhere.

In following years the number of shrimp camps diminished, but the catch rose steadily until 1929, then fluctuated around 1000 t between 1930 and 1936, after which landings decreased steadily due to lack of a market for dried shrimp (Frey 1971).

In 1965 the fishery was revived to supply bait for striped bass and sturgeon sportfishing. Today there are about 15 boats in the fishery, and all but a few fish with beam trawls. Most fishing takes place in San Pablo and Suisun bays, and to a limited extent in South Bay. Although the size of the fishery is small, the business can be lucrative, as bait shrimp brings a price of $2.00 to $2.50 per pound (0.45 kg) to the fisherman. It is sold both frozen and live, the latter being in the most demand and bringing the highest price. The small size of bay shrimp appears to be the major factor limiting the demand for them as food, and at this time it does not appear that they can be processed economically for sale on a large scale.

DISCUSSION

The foregoing account illustrates the changing fortunes of the fishery resources of San Francisco Bay. The commercial landings, affected by regulations and environmental changes as

well as market demand and resource availability, have undergone drastic changes not only in quantity but also in the kinds of fishery resources harvested from the Bay. Formerly, bivalves, shrimp, salmon, and sturgeon, as well as a number of other finfishes, provided a substantial income to Bay Area fishermen. Now the only remaining commercial fisheries of note within the Bay are those for herring, anchovy and bay shrimp, and the latter two are used almost exclusively as bait.

Recreational fisheries, alternatively, have fared somewhat better, due primarily to legislation which has restricted commercial fishing for certain species and outlawed some fishing gear detrimental to stocks of incidentally caught fishes. Striped bass and sturgeon are now reserved exclusively for the sport fishery, as is chinook salmon fishing within the Bay.

Human activity is clearly implicated in the decline of much of the fishery resources of San Francisco Bay. Although the full effects of dumping, dredging and filling are not clear, we can safely surmise that filling of shallow mud flats around the perimeter of the Bay has drastically reduced the amount of suitable habitat for such forms as oyster, clams, and bay shrimp. Pollution has degraded the purity of water to the extent that even now after considerable effort to improve water quality, commercial and recreational use of molluscs is still hazardous and by and large discouraged or disallowed. In past years intensive harvesting also contributed to the decline of many Bay fisheries.

Anadromous fishes have suffered from the damming and diversion of rivers which resulted in elimination or alteration of spawning and nursery habitats. Changes in the hydrography of the Delta caused by diversions, and pollution from industrial, agricultural, and municipal waste discharges may not only affect these fishes directly but may also affect the distribution and abundance of forage species upon which they depend.

Research Needs

A review of the literature discloses that except for bivalves and a few finfish (striped bass, herring, sturgeon, salmon) little quantitative data are available on the fishery resources of San Francisco Bay. Neither is there much information on the life history of most of the animals which reside in the Bay, whether they be seasonal migrants or residents. There is also a need to study trophic relationships and interspecific interactions in order to better gauge the effects of changes in the environment.

The Future

It is likely that reduction in duration and frequency of fresh-water flows into and out of the Delta, caused by increasing demands for water for agricultural, industrial and domestic use, will further affect anadromous fish stocks unless steps are taken to prevent or replace losses caused by reduced flows. The gradual decline in the amount of fresh-water flow out of the Delta will probably alter salinity regimes in the Bay, which may change the distribution of certain species and possibly the migratory habits of anadromous fishes and invertebrates such as the salinity-regulated crangonids.

The full effects of the recent drought (1976-77) on anadromous fishes is not known, and may not be felt for years to come when the fish spawned during the past few years begin to enter the fisheries. There may be a severe decline in the population resulting from poor spawning and year-class survival.

On the positive side, if water quality continues to improve in San Francisco Bay proper as it has over the past 10 years, we may see increased shellfishing in the Bay and perhaps the opening up of certain clamming areas that are now considered restricted by the California Department of Public Health.

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Prediction of what will happen in the future is difficult if not impossible, not only because of the complexity of the estuary itself and lack of knowledge of environmental requirements of many Bay species, but also because the San Francisco Bay estuary is obviously no longer a natural system. Factors such as water quality, water flow and habitat conditions are now largely under human control. Resource-related decisions made now and in the future will ultimately determine the fate of the Bay's fisheries. The value of these resources, perhaps now more than ever, will have to be weighed carefully against land and water use demands.

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