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TR EL-82-4

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest)

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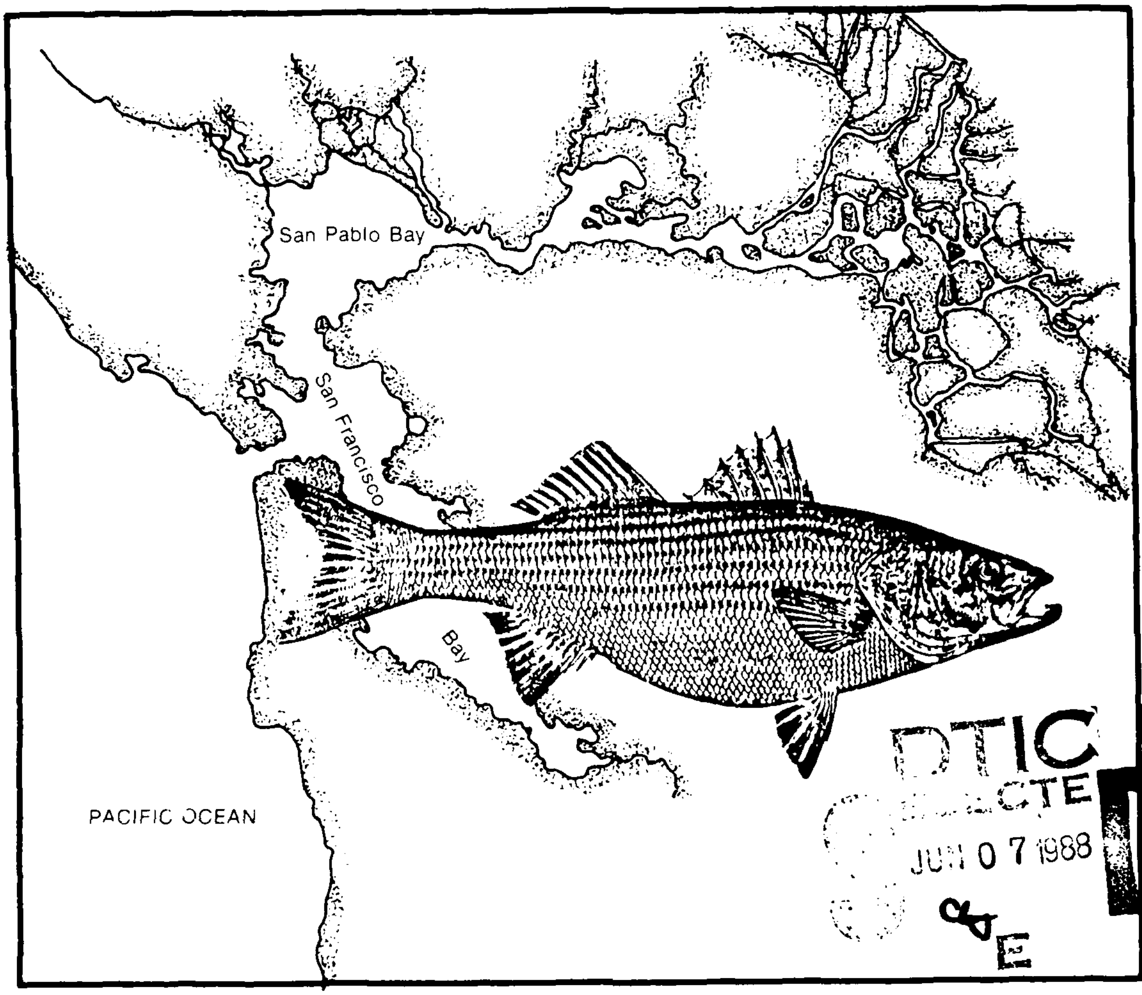

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

Fish and Wildlife Service
U.S. Department of the Interior

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest)

STRIPED BASS

by

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Coastal Ecology Group
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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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Vicksburg, MS 39180

CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees

CONTENTS

ACKNOWLEDGMENTS

I am grateful for reviews by Serge Doroshev, University of California at Davis, and Maxwell Eldridge, National Marine Fisheries Service, Tiburon, California.

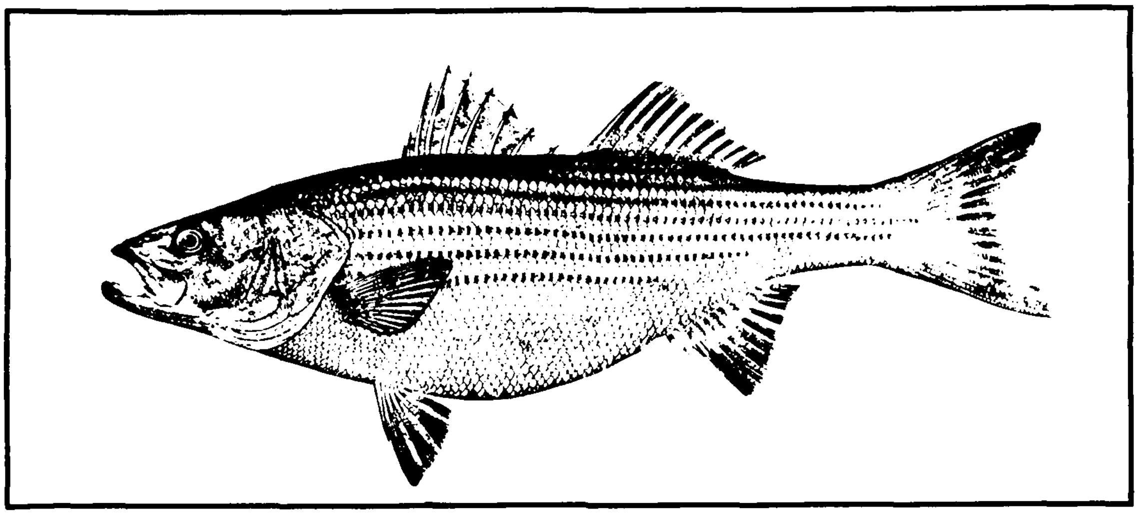

Figure 1. Striped bass.

STRIPED BASS

NOMENCLATURE/TAXONOMY/RANGE

Scientific name . . . . *Morone saxatilis*
Preferred common name . . . . striped bass (Figure 1)
Other common names . . . . striper, rockfish
Class . . . . Osteichthyes
Order . . . . Perciformes
Family . . . . Percichthyidae

Geographic range: Atlantic coast from the St. Lawrence River, Canada (Magnin and Beaulieu 1967), west to Montreal (Vladykov and McAllister 1961), and south to the St. Johns River, Florida (McLane 1955). Gulf of Mexico from west Florida coast to Louisiana (McIlwain 1968). Introduced into the lower Sacramento River, California in 1879 (Scofield and Bryant 1926). Now extend from Barkley Sound, British Columbia south to Ensenada, Mexico (Radovich 1961; Forrester et al. 1972; Miller and Lea 1972). Introduced into waters of the Soviet Union (Doroshev 1970) and France and Portugal (Setzler et al. 1980). Landlocked form has been successfully introduced into freshwater impoundments in North America (Figure 2 is map of distribution in the Pacific Southwest Region; distribution of fish that live only in freshwater is not included).

MORPHOLOGY AND IDENTIFICATION AIDS

Meristic Characters: dorsal IX + I-II, 12, anal III, 9-11, pectoral 16-17; lateral line scales 57-67; gill rakers 8-11 + 14-17; vertebrae 25 (Miller and Lea 1972). Two dorsal fins, one spiny and one soft, separated at base and about equal in

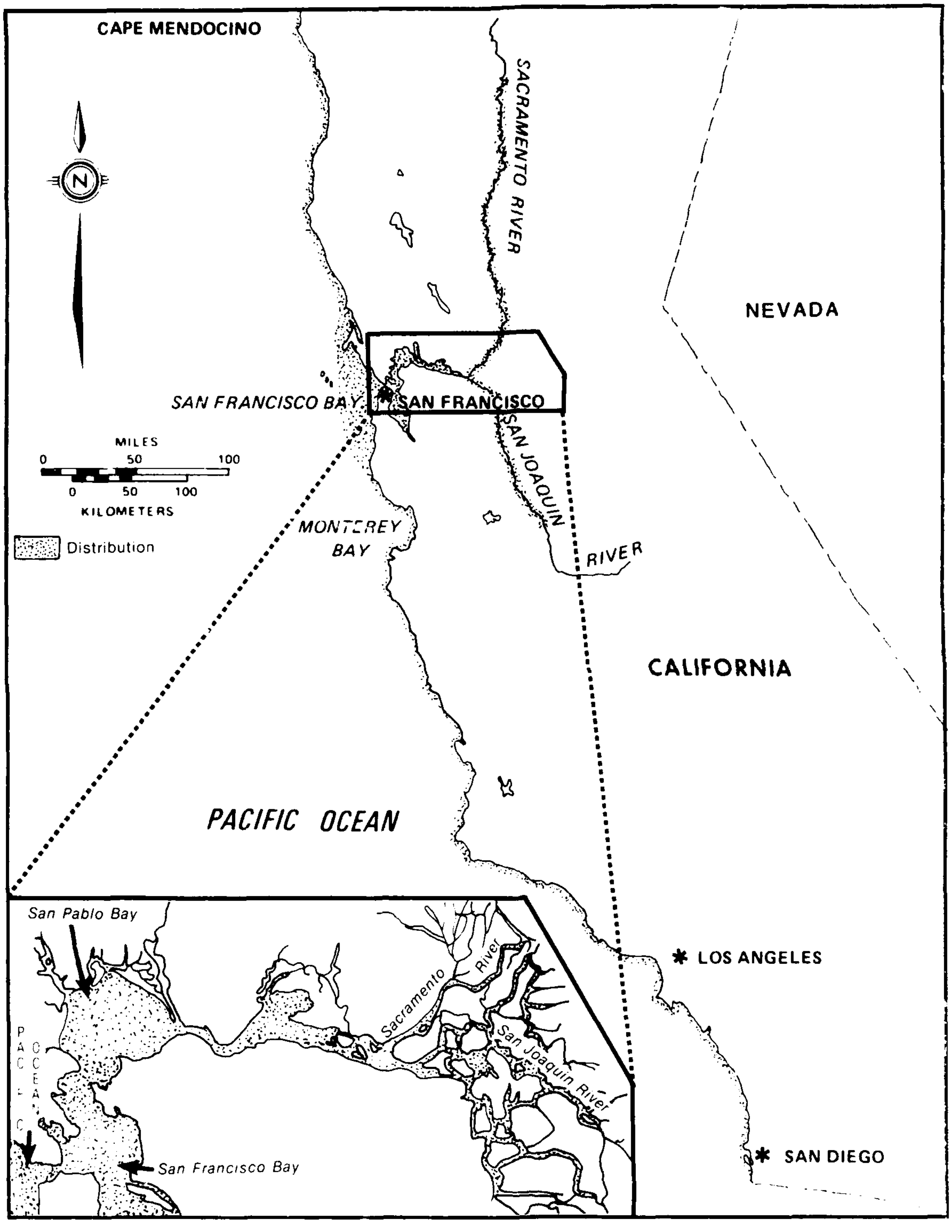

Figure 2. Pacific Southwest distribution of striped bass.

length; operculum with two spines on posterior edge (Fay et al. 1983). Mouth large, but maxilla does not reach past the hind margin of the eye; two distinct patches of teeth at base of tongue (Moyle 1976). Eye small, less than one-fourth of head length; pectoral fins do not reach back beyond tips of pelvics (Roedel 1953).

Body elongated, with 6-9 dark, usually broken but sometimes continuous, horizontal stripes (Miller and Lea 1972), one follows lateral line and three are below (Fay et al. 1983). Color: steel blue to olive-green above becoming silvery on sides and belly, with brassy iridescence (Roedel 1953).

REASONS FOR INCLUSION IN SERIES

The striped bass supports one of the most important sport fisheries in the Pacific Southwest Region. It is one of California's top ranking sport fishes and is the dominant sport fish in the Sacramento-San Joaquin Estuary (Figure 2). The only populations of striped bass of consequence in the Pacific Southwest are in this Estuary and in the Pacific Ocean within 40 km of the estuary (Chadwick et al. 1977; Stevens 1979, 1980; Stevens et al. 1985). The fishery extends from the Pacific Ocean near San Francisco, upstream throughout San Francisco, San Pablo, and Suisun Bays, the Delta and more than 200 km into the Sacramento and San Joaquin Rivers (Figure 2). The striped bass is anadromous and occupies many different types of habitat from freshwater to coastal ocean waters. Freshwater spawning areas and estuarine nursery areas appear to be the most critical habitat requirement for striped bass.

The Sacramento and San Joaquin Rivers, the Delta, and Suisun Bay are the major spawning and nursery grounds for striped bass in the Pacific Southwest. These areas are greatly influenced by environmental factors and water management. A decline in abundance of striped bass in recent years in the Delta and adjacent bays is believed to be associated with decreased water quality and increased water management in the Sacramento and San Joaquin Rivers and Delta (Stevens et al. 1985).

INTRODUCTION OF STRIPED BASS

The striped bass was introduced into California in the late 1870's. In 1879, 135 yearlings from the Navesink River, New Jersey, were released in the Carquinez Strait at Martinez, California, and in 1882, 300 yearlings from the Shrewsbury River, New Jersey, were released in Suisun Bay near Army Point (Scofield and Bryant 1926). Striped bass increased rapidly and were offered for sale on the California market only 10 years after their first introduction (Craig 1928). The only other populations of striped bass of significance along the west coast are in the Coos and Umpqua Rivers, Oregon (Parks 1978).

ESTUARY

The Sacramento-San Joaquin Estuary, the most important striped bass nursery area in the Pacific Southwest Region, includes the Delta and Suisun, San Pablo, and San Francisco Bays (Figure 2). The Delta is a reclaimed tidal marsh where the Sacramento and San Joaquin Rivers join before flowing into Suisun Bay. The Delta consists of 298,300 ha, with more than 40 large farmed islands protected by levees and surrounded by 1,130 km of channels (Kelley and Turner 1966; Chadwick et al. 1977; Arthur and Ball 1978). A salinity gradient extends from the western Delta to San Pablo Bay (80 km) and sometimes to San Francisco Bay. Freshwater outflows from the Delta range from 1,500-4,500 m^3/s in winter to 100 m^3/s in summer (Stevens et al. 1985). The historical mean freshwater outflow to the ocean

(1,100 m^3/s) has been reduced by about 50% as the result of consumptive water use upstream and water diversions from the Delta (Chadwick et al. 1977).

The San Joaquin system has been developed for upstream water use and the Sacramento system for transport of water through the Delta for use in southern California. Water is exported by two large pumping plants in the southern Delta. Export rates from these plants exceed the flow of the San Joaquin River, and most water must come from the Sacramento River. About the first 100 m^3/s of exported water from the Sacramento River crosses the Delta through channels upstream from the mouth of the San Joaquin River; at higher export rates (>100 m^3/s), water is drawn up the San Joaquin River from its confluence with the Sacramento River. Flow reversals in the San Joaquin River are typical in spring, except in wet years, and in summer and fall in all years (Chadwick et al. 1977).

LIFE HISTORY

Reproductive Physiology and Strategy

Striped bass are dioecious, though hermaphroditism has been reported (Morgan and Gerlach 1950; Westin 1978). Females grow more rapidly and to a larger size than males (Scofield 1931; Collins 1982). In the Estuary, males begin to mature at ages II or III, and all are mature at age V; some females mature at age IV and all are mature at age VII and older (Scofield 1931; Stevens 1979).

Striped bass are polygamous; the eggs are broadcast into the water column, where they are fertilized (Woodhull 1947; Miller and McKechnie 1968). Fecundity is related to age, length, and weight (Westin and Rogers 1978). Mean fecundity of females from the Sacramento-San Joaquin Estuary ranges from 243,000 eggs for fish of age IV to 1.4 million for fish of age VIII and older (Stevens et al. 1985).

Spawning

Adult striped bass are anadromous and migrate to fresh or nearly fresh water to spawn. In the Sacramento-San Joaquin Estuary most spawning occurred from mid-April to mid-June (Turner 1976). The principal spawning areas in the Pacific Southwest are the Sacramento River and Delta (Calhoun et al. 1950; Farley 1966; Turner 1976). More than 83% of the spawning in the Sacramento River (1963, 1964, 1966, 1972) occurred between river miles 40 and 140 (Figure 3). Over 90% of the spawning in the Delta (1966-72) occurred between river miles 10 and 40. In 1968, some spawning occurred in the San Joaquin River between the mouths of the Stanislaus and Merced Rivers (Turner 1976). Farley (1966) estimated that 66% of the striped bass spawning was in the Sacramento River and 34% in the Delta in 1964, and Turner (1976) estimated that 55% was in the Sacramento River and 45% in the Delta in 1972.

In the Estuary, spawning occurred at water temperatures of 14.0 to 23.9 °C and peaked at 16 to 20 °C (Scofield 1931; Farley 1966; Turner 1976; Wang 1981). In the Delta, most spawning occurred at salinities (total dissolved solids, or TDS) of $\leq$ 200 ppm in 1964-71 and at $\leq$ 200 to 1500 ppm in 1972 (Turner 1976).

Eggs

Fertilized striped bass eggs are spherical, nonadhesive, semibuoyant, and nearly transparent when first spawned. As they develop, they become almost invisible (Hardy 1978; Wang 1981; Fay et al. 1983). Usually eggs have a single oil globule (sometimes also small ones), and a wide perivitelline space. The eggs are high in energy content (7,808 cal/g dry weight) and exceed the caloric

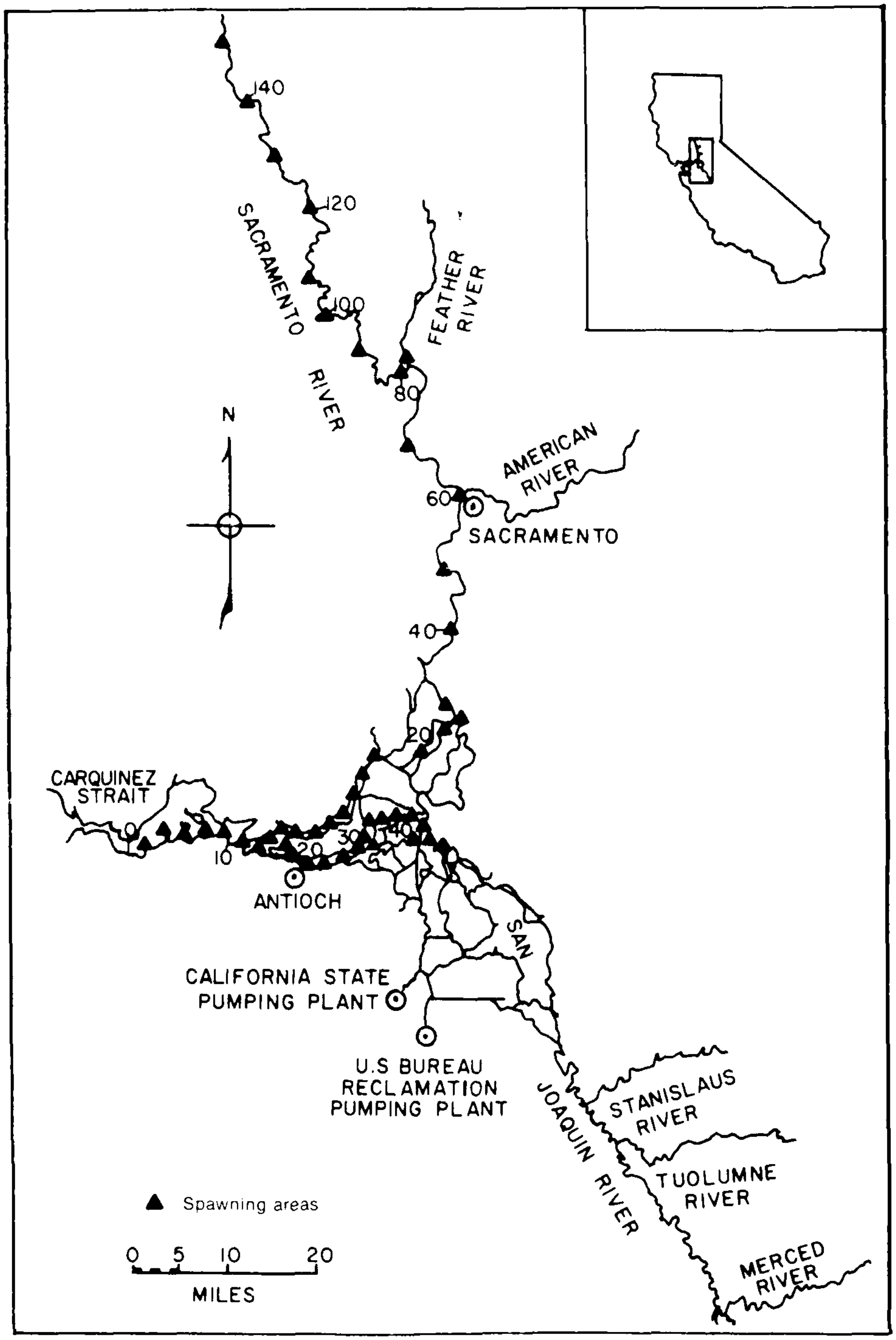

Figure 3. Map of striped bass spawning areas by river mile for the Delta upstream from Martinez, and for the Sacramento River upstream from its confluence with the San Joaquin River (from Turner 1976).

values of eggs from many freshwater, anadromous, and marine fishes (Eldridge et al. 1982).

Dry weights, volumes, and caloric contents of striped bass eggs and egg components at time of fertilization, and oxygen consumption of eggs after fertilization, were determined by Eldridge et al. (1982). Mean egg diameter of recently spawned eggs collected in the Delta ranged from 1.78 mm (not water-hardened) to 3.30 mm 1 hour later (Woodhull 1947). Diameters of eggs collected in Sacramento-San Joaquin Rivers were reported by Albrecht (1964) to range from 2.5 to 4.4 mm (mean 3.8 mm). Mean weight of artificially fertilized eggs was 285 µg (Eldridge et al. 1981).

Striped bass eggs hatch 29 to 80 hours after fertilization, depending on water temperature (Setzler et al. 1980). Hardy (1978) summarized incubation times at different water temperatures, and Polgar et al. (1976) expressed the relation between water temperature and hatching time as $I = -4.60\ T + 131.6$, where I = development time to hatching in hours and T = temperature in Celsius degrees.

Larvae

Year-class strength of striped bass in the Sacramento-San Joaquin Estuary has been correlated with survival and growth during the first 60 days after hatching. The abundance of young striped bass (mean fork length [FL] 38 mm) was correlated positively with freshwater outflow from the Delta and negatively with the percent of the river inflow diverted from Delta channels during spring and early summer by Federal and State water projects (Stevens et al. 1985). Thus year-class size, which is related to larval survival, is greatly affected by water diversions from the Delta and the Sacramento and San Joaquin Rivers.

At hatching, striped bass larvae were 3.0 to 4.0 mm in total length (TL) in the Estuary (Wang 1981) and 3.3 to 4.5 mm FL in the laboratory (Eldridge et al. 1982). Yolk sac absorption time varied from 3 to 9 days, depending on water temperature (Albrecht 1964; Rogers et al. 1977; Eldridge et al. 1982); total absorption of the nutrients in the yolk sac often takes longer (Maxwell Eldridge, National Marine Fisheries Service, pers. comm.). Larvae began feeding actively 5 days after hatching (7 days after fertilization) at 18 °C. Yolk-sac larvae maintain a surface position by swimming, but sink if swimming ceases (Fay et al. 1983). Larvae sink in the water column faster than eggs the first 15 hours after hatching (Meinz and Heubach 1978). The newly-hatched larvae actively swim off the bottom, essentially staying in suspension. Larvae are free swimming 100 hours after hatching. If larvae sink to the bottom and remain, high mortality may occur (Pearson 1938; Raney 1952; Setzler et al. 1980). Most larvae inflate their swim bladders 5-10 days after hatching, and thus acquire hydrostatic regulation (Doroshev et al. 1981).

The vertical and lateral distribution of eggs and larvae in the Sacramento-San Joaquin Estuary are associated with river flow. The distribution in the Estuary has been described by Albrecht (1964), Sasaki (1966), Turner and Chadwick (1972), Turner (1976) and Stevens et al. (1985). In the Sacramento River, virtually all larvae caught were near the bottom in mid-channel; few were at the surface in mid-channel or near shore. In low-flow years, virtually all striped bass eggs and larvae were in the Delta. Eggs and larvae began entering Suisun Bay in higher flow years and most were in Suisun Bay in the highest flow years.

Detailed descriptions and drawings of early developmental stages of striped bass were published by

Pearson (1938), Mansueti (1958), Hardy (1978), and Wang (1981). The duration of the larval stage ranged from 68 days at 15 ^{o}C to 23 days at 24 ^{o}C (Rogers et al. 1977). The larvae became adult-like (juveniles) at 20-36 mm TL, depending on water temperature and food availability (Hardy 1978; Wang 1981).

Juveniles

The juvenile stage lasts from metamorphosis to sexual maturity; duration varies with sex. In the Pacific Southwest Region, males 25 to about 320 mm FL and females 25 to about 534 mm FL are considered juveniles. Males mature at ages II or III and females at ages IV or V (Scofield 1931; Stevens 1979).

In the Estuary, juvenile striped bass abundance is highest in the convergence zone, where fresh and salt water meet. Plankton populations are dense in this zone and its location is important to juveniles (Massman 1971; Turner and Chadwick 1972; Arthur and Ball 1979; Orsi and Knutson 1979). The zone is downstream (usually in Suisun Bay) when river outflows are high, and upstream (in the western Delta) when outflows are low; plankton production is much greater when the zone is in Suisun Bay (Stevens et al. 1985). Generally, the principal food organisms of young bass are concentrated in or near this zone.

During their second year, many striped bass still live in the Delta and Suisun Bay, but others move upstream into the rivers above the Delta and downstream into San Pablo Bay (Sasaki 1966; Stevens 1979).

Adults

Distribution and migration patterns of adult striped bass in the Sacramento-San Joaquin Estuary have been determined by tagging studies. Adults move to freshwater (into the Delta and upstream in the Sacramento River) to spawn in the spring. After spawning, most return to San Pablo and San Francisco Bays and to the Pacific Ocean within about 40 km of the Golden Gate Bridge, where they spend the summer. In fall, adults move from the ocean into the bays; some migrate to the Delta. During the winter, adult bass are spread from San Francisco Bay to the Delta (Calhoun 1952; Chadwick 1967; Orsi 1971; Stevens 1979; Stevens et al. 1985). Adult bass spend about 6 to 9 months annually in San Francisco and San Pablo Bays. Immature fish do not participate in the spring spawning migration.

Striped bass tagged at different locations and at different times in the Delta and Sacramento River migrated similarly. A major difference was that migration to the Delta was distinctive, in that bass tended to return to the tagging area a year after they were tagged there (Chadwick 1967). Large adults migrated further downstream than smaller ones and only medium-sized and large fish went to the ocean. Fish length seemed to influence migration pattern more than sex did.

Striped bass reported from the Estuary have included females up to 16 years old and 1080 mm FL by Scofield (1931), fish (probably females) up to 20 years old and 1170 mm FL by Clark (1938), and fish weighing up to 37.2 kg by Scofield and Bryant (1926). The oldest reported male bass from the Estuary was age XI (Miller and Orsi 1969). Older and larger striped bass have been reported from other areas (Fay et al. 1983).

GROWTH CHARACTERISTICS

Growth

The growth for striped bass up to 70 cm long from the Sacramento-San Joaquin Estuary can be calculated from scales by the formula:

$$Y = (L-1)(R/S) + 1$$

where Y = back-calculated total length (at time of formation of annulus in question) in centimeters, L = current total length of fish in centimeters, R = radius of annulus in question, and S = total scale radius; R and S should be in the same (arbitrary) units (Scofield 1931). Robinson (1960) calculated growth by using a direct proportion nomograph corrected for the Y axis intercept that was determined from body length-scale radius relations for striped bass from San Pablo Bay and the Delta. Other body length-scale radius relations and conversion factors were reviewed by Fay et al. (1983).

Growth rates for young-of-the-year (YOY) striped bass from the Sacramento-San Joaquin Estuary have been determined daily and seasonally. Turner and Chadwick (1972) estimated daily growth (June-August, 1960-70) of 0.544 to 1.016 mm per day. The rate was calculated by determining the time in days required for the mean length of the bass in the population to increase from 25 to 41 mm FL. Chadwick (1964) reported 2-week growth increments (June-August, 1959-62) of 7.62 to 17.78 mm. Collins (1982) reported daily growth (July-October, 1967-75) of 0.58 mm. Growth rates were based on mean length change from the time when the bass reached 25 mm FL through mid-October. Young striped bass reach 25 mm FL by 1 July (Chadwick 1966) and average 105 mm FL at the end of the first growing season (Scofield 1931; Robinson 1960).

Size differentials established in YOY striped bass during different years in the Estuary are maintained throughout life. Collins (1982) found that although striped bass of the 1970 and later year classes in the Estuary averaged 2 cm smaller than the 1965 to 1969 year classes, the actual growth rates of adult fish had not changed. The size reduction was due to slower growth during the first year of life of the 1970 and later year classes.

Striped bass eggs, yolk and oil volume, and feeding, growth, and energy conversion of artificially fertilized eggs from the Sacramento River were studied in the laboratory by Eldridge et al. (1982). Eggs were incubated at 18 °C and hatched 2 days after fertilization. Yolk sac lengths were 3.9 ± 0.6 mm standard length (SL) at hatching and 5.8 ± 0.3 mm SL at first feeding, 7 days after fertilization. Embryos and larvae consumed the yolk linearly, and growth after hatching was directly related to food concentration. The 58% of the yolk energy that remained at hatching was used by days 6 to 7, the time when active feeding began. The 86% of egg oil energy that remained at hatching was completely used by days 20 to 29. The rate of embryo growth in weight (Gw) from fertilization to hatching (Gw=1.872) was three times that to feeding age (Gw=0.647). Larvae were 11 mm SL 29 days after fertilization, when the experiments were terminated (Eldridge et al. 1982).

Growth and survival of striped bass larvae fed different rations were studied by Daniel (1976). Survival of larvae increased with the number of brine shrimp nauplii (Artemia salina) consumed. Mean daily length increase after 10 days was 0.04 mm for larvae fed no nauplii and 0.27 mm for larvae fed 30,000 nauplii/m^3 of water.

The mean lengths for male and female striped bass of ages I to XIII collected during different years from the Sacramento-San Joaquin Estuary are shown in Table 1. Males and females grew at the same rate until age IV, when females began to mature and grow faster (Scofield 1931; Robinson 1960). Growth occurred primarily between May and November but some growth occurred in winter among females of ages III to V (Collins 1982). The von Bertalanffy growth equation described the growth of adult striped bass well, but underestimated the length of longer fish (Figure 4). The correlation coefficients between

Table 1. Mean fork lengths (mm) for male and female striped bass from Sacramento-San Joaquin Estuary in different years (M = male, F = female).

	Years of Collection									
	1925-1928[a]				1957-1958[b]		1961-1965[c]		1969-1978[d]	
Age	M	F	M[e]	F[e]	M[e]	F[e]	M	F	M	F
I	98	97	106	106	104	104				
II	286	264	251	247	249	249				
III	373	346	371	370	386	289	414[f]	424	429[f]	
IV	463	458	445	460	493	500	485	523	504	539
V	499	535	516	542	566	594	572	650	578	637
VI	541	605	563	612	622	683	643	693	649	709
VII	610	686	612	680	671	747	711	752	706	768
VIII	685	777			716	800	739	803	751	816
IX	805	795			762	836	565	841	785	853
X	785	870					785	876		
XI		947					864			
XII		990								
XIII		980						991		
XIV		1030								
XV		1050								
XVI		1080								

[a]Scofield 1931.
[b]Robinson 1960.
[c]Miller and Orsi 1969.
[d]Collins 1982.
[e]Calculated lengths at age.
[f]Biased high due to sampling program.

observed lengths and those predicted from the von Bertalanffy equation were 0.998 for males and 0.996 for females (Collins 1982). Males grew from about 400 mm at age III to about 860 mm at age XII, and females from about 400 mm at age III to about 960 mm at age XII.

Length-Weight Relations

Length-weight relations of striped bass have been developed for larvae in the laboratory and for juveniles and adults combined from the Sacramento-San Joaquin Estuary. Larval length-weight relation was exponential and described by the equation:

$$Y = 0.0028787e^{0.631929X}$$

where Y = dry weight mg and X = SL mm (Eldridge et al. 1982). The length-weight relation of male and female striped bass from the Estuary commercial catch (March-April 1927) was presented graphically and described by the equation $W=FL^{x}$ (units = pounds and cm FL; Scofield 1931). Robinson (1960) described the length

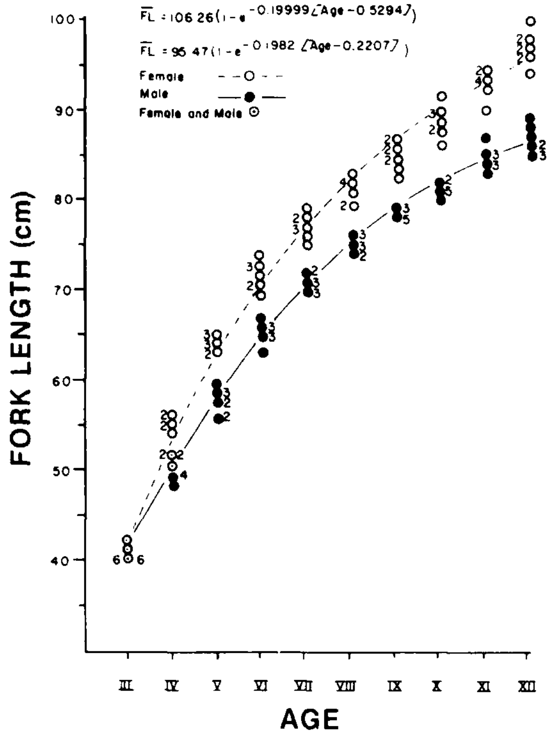

Figure 4. Von Bertalanffy growth curves for striped bass sampled during spring (1969-76) in the Sacramento-San Joaquin Estuary. Numbers next to data points indicate number of overlapping points (from Collins 1982).

weight relation of bass from the Estuary by the equation:

$$\log W = -2.1393 + 3.0038 \log L$$

where W = pounds and L = inches FL.

THE FISHERY

Commercial Fishery

After the striped bass was introduced into the Sacramento-San Joaquin Estuary in 1879, the population grew rapidly. The commercial catch in the Estuary, primarily with drift gill nets, was 7400 kg by 1889, and 560,000 kg by 1899, just 20 years after the species was introduced. The highest recorded catch, in 1915, was about 810,000 kg. Subsequent catches declined to about 328,000 kg by 1929. The decline apparently was caused by restrictions in mesh size of nets, in reduction of the areas open to fishing, in duration of the fishing season, and in size limits (Craig 1928). In 1935, commercial fishing for striped bass in California was prohibited. The closure was largely a result of conflicts between sport and commercial fishing interests and not a result of stock depletion (Stevens 1980).

Sport Fishery

Striped bass provide an extensive sport fishery in the Sacramento-San Joaquin Estuary. The present fishing regulations include a minimum length of 45.7 cm (TL) and a daily bag limit of two fish. Before 1956, the length and bag limit were usually 30.5 cm and 5 fish; from 1956-1981, the limits were adjusted to 40.6 cm and 3 fish (Sterns et al. 1985). Striped bass anglers fish in the Pacific Ocean near the Golden Gate Bridge and throughout the Estuary to the Sacramento-San Joaquin Rivers at least 200 km above the Delta. Angling occurs all year but varies by area and season in accordance with the migratory pattern of the fish (Stevens 1980).

Fishing for striped bass occurs from shore, private boats, and commercial passenger fishing boats (charter or party boats). In 1969-79, 65% of the catch was taken from private boats, 21% from shore or piers, and 14% from charter boats (White 1986). Angler success was poorer for the fishery as a whole than for the charter-boat fishery. Annual mean catch rates for anglers on charter fishing boats were 1.4 to 2.4 times higher than those for anglers on private boats. Angler success was highest from May through November, when 80% of the catch occurred--

mostly in San Francisco Bay. The catch was lowest in the San Joaquin River (White 1986).

Charter boat operators have been required to report catches to the California Department of Fish and Game since 1938. These records are the best long-term striped bass catch records available, even though only 14% of the catch is taken by party boats and fishing locations and methods have changed. The annual catch of striped bass per angler day ranged from 0.78 to 2.63 (mean 1.58) in 1938-77 and from 0.78 to 1.68 in 1972-77 (Stevens 1980).

Striped bass fishing success in the Estuary was formerly higher than it is currently. In recent years, about 200,000 anglers per year have fished for striped bass in the Estuary and have caught about 300,000 fish. In the early 1960's the annual catch was about 750,000 (Stevens 1980). The decline in fishing success appears to be due to a decrease in bass abundance that is related to low recruitment in most years since 1969 (Stevens 1977b).

Striped bass harvest rates have been estimated by tagging since 1958 (Chadwick 1968; Miller 1974; Stevens et al. 1985; White 1986). The harvest has varied from 11% of the estimated legal population (bass $\geq$ 40.6 cm TL) in 1978 to 37% in 1958. The harvest rate equaled or exceeded 19% each year from 1958 to 1964, but reached 20% in only four years from 1965 to 1979. The decrease in harvest apparently is partly a result of a decline in fishing effort that accompanied decreased success after the early 1960's (Stevens 1980).

The striped bass catch in the Estuary has varied by age and sex. From 1969 to 1979, in the San Francisco-Suisun Bay area, fish of ages III, IV, and V composed 67% of the catch; fish of age IV were generally the most numerous. In the San Francisco Bay area, females were more abundant than males in the catch in 10 of the 11 years (White 1986).

The economic value of the striped bass fishery in the Estuary area has decreased over the years. The decline in abundance of striped bass from 1970 to 1983 brought about an estimated loss of $587 million in sales revenue and $314 million in net disposable income to California (Meyer Resources 1985). Return of the value of the bass fishery to the 1968-75 average value would require a 2.5X increase in the size of the bass stock. The economic value of the striped bass sport fishery in the Estuary area (computed on the basis of average catch data for 1979-83) is shown in Table 2.

Table 2. Value (thousands of dollars) of the striped bass sport fishery in the Sacramento-San Joaquin Estuary area, based on 1979-83 average catch. (Dollar value per fish is shown in parentheses) (from Meyer Resources 1985).

Unit	Market values		Non-market values	Total net value	State income	
	Business revenue	Business profit			Total	Net
Thousands	$8,802 (71.56)	$2,641 (21.47)	$31,109 (252.92)	$33,750 (274.39)	$31,687 (257.62)	$16,944 (137.75)

Population Dynamics

The population of striped bass in the Sacramento-San Joaquin Estuary has never been dominated by strong year classes and until recently has been relatively stable. Now, however, the adult bass population is only about 25% of what it was 20 years ago, and the production of young bass over the past 8 years has been 33% to 50% of the expected numbers (Stevens et al. 1985).

The population of adult striped bass ($\geq$40.6 cm TL) in the Estuary, which has been measured on the basis of catch per effort (Hallock et al. 1957) and Petersen estimates (Bailey 1951; Stevens 1977a) since 1969, has shown a variation between about 0.8 and 1.9 million fish from 1969 to 1982, and was estimated at about 0.9 million in 1982 (Stevens et al. 1985).

The total mortality rate of adult striped bass of age V and older in the Estuary, which has been estimated annually since 1969, increased from 30% in 1971 to 49% in 1977. The greatest change occurred between 1970 and 1976 when the harvest of adult bass of age V and older increased from 15% to 27% (Stevens et al. 1985). The harvest of fish of age III and older has increased from 13% to 23% during the same period (White 1986).

The adult striped bass population in the Sacramento-San Joaquin Estuary area is at its lowest level since stock assessments were first available. The Striped Bass Working Group of scientists, appointed by the California Water Resources Control Board to analyze the problem, concluded that the decline was probably the result of a combination of (1) the reduced adult population producing fewer eggs; (2) reduced food production in the nursery area; (3) entrainment losses of YOY in water diversions; and (4) toxicity (Stevens et al. 1985).

The decline in abundance of adult striped bass in the Estuary has resulted in an 80% decline in egg production since 1975. The egg production may now be inadequate to maintain the bass population at former levels under current environmental conditions. The survival of striped bass from the egg to a length of 38 mm (FL) has been correlated with river flows and diversions (Turner and Chadwick 1972; Chadwick et al. 1977; Stevens 1977a, 1977b; Stevens et al. 1985). High outflows in recent years have not, however, resulted in high striped bass populations as they previously did. Thus, reduced egg production by the smaller adult populations has not resulted in a density-dependent increase in survival rates from egg to the 38-mm stage. Recent surveys have shown that less than half as many YOY are being produced as were produced a decade ago. Hence, any losses of adults or early life stages could contribute to the further reduction of adult striped bass in the Estuary (Stevens et al. 1985).

The striped bass situation in the Sacramento-San Joaquin Estuary is the result of several factors. The reduced number of eggs and larvae that now drift downstream to enter the nursery habitat, and the reduced production of plankton, probably combine to reduce the bass population. One management practice adopted to address this problem is the stocking of hatchery fish large enough to avoid the limiting food condition. In 1981, California passed legislation requiring striped bass anglers to purchase a striped bass stamp for $3.50. The proceeds, about $2 million a year, are to be spent on research and management (e.g., stocking) that have potential to improve the fishery. Stocking of hatchery fish is also planned to replace fish lost from the Estuary by diversions (Stevens et al. 1985).

The current use of Delta channels to convey water for export has contributed to the long-term decline of striped bass in the Estuary area. Planned increases in water export and reduced Delta outflows will heighten the problems of reduced food production and entrainment unless a properly designed and operated Delta water transfer system is built. In addition, management agencies should adopt policies to reduce losses to all sources of entrainment, to reduce the deposition of toxic substances, and to continue to evaluate the restrictions placed on the fishery in 1982 and the experimental stocking program (Stevens et al. 1985).

ECOLOGICAL ROLE

Feeding Habits

The time of first feeding of larval striped bass varies with water temperature, food concentration and rearing area. Under laboratory conditions, larvae (6.1 mm SL) began feeding 5 days after hatching (7 days after egg fertilization) at 18 °C. When larvae were >7.0 mm SL, over 80% fed actively when concentrations of brine shrimp nauplii *Artemia salina* were 0.50-5.0/ml. Larvae collected from the Sacramento-San Joaquin Estuary were 4-4.9 mm SL at the time of first feeding, and over 75% were feeding at 7.0-7.9 mm. Larvae 4-11.9 mm SL preferred cladocerans, the copepod *Cyclops* sp., and the copepod *Eurytemara* sp., which (combined) accounted for 89% of all food eaten (Eldridge et al. 1982).

Young-of-the-year striped bass (3-114 mm FL) collected in the Estuary area fed primarily on the mysid *Neomysis mercedis*, copepods, cladocerans, the amphipod *Corophium spinicorne*, and tendipedid larvae during their first year of life (Heubach et al. 1963). In summer, *Neomysis* and *Corophium* were the most important food items of bass >25 mm FL. In fall, copepods and *Corophium* were the most important. In the rivers above the Delta (freshwater), tendipedid larvae and pupae were the dominant food. Fish were unimportant in the diet of YOY. The occurrence of organisms in the stomachs generally agreed with the distribution of planktonic and benthic organisms in the Estuary. Salinity and water flow were the most important factors controlling plankton distribution -- and thus feeding habits.

The diet of young (50-230 mm FL), juvenile (130-350 mm), subadult (260-470 mm), and adult (>380 mm) striped bass from the Estuary was described by Stevens (1966). The importance of fish and invertebrates in the diet of bass varied by age and size of striped bass and season (Figure 5). The most important food items of striped bass of any age and in any season were the mysid *Neomysis awatschensis*, *Corophium*, small striped bass, threadfin shad (*Dorosoma petenense*), and discarded sardine and anchovy bait. Few stomachs contained small chinook salmon (*Oncorhynchus tshawytscha*). Thomas (1966) reported

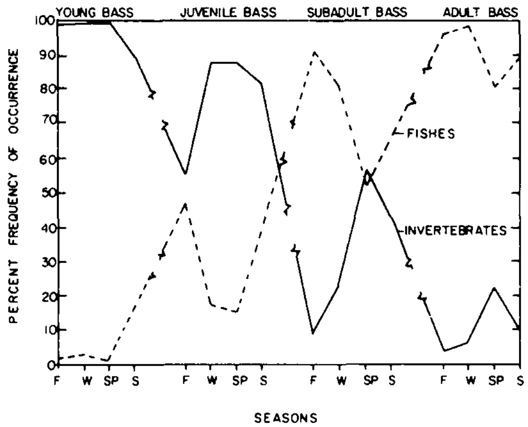

Figure 5. Occurrence of fishes and invertebrates in stomachs of striped bass of different ages in fall (F), winter (W), spring (Sp), and summer (S) (from Stevens 1966).

that juvenile bass (<416 mm TL) ate sizable quantities of small chinook salmon in the Sacramento River. Other major food items reported by Thomas in the diet of juvenile and adult striped bass in the Estuary and river included northern anchovy (Engraulis mordax), shiner perch (Cymatogaster aggregata), striped bass, common carp (Cyprinus carpio), crayfish (Pacifiastacus leniusculus), bay shrimps (Crago spp. and Palaemon macrodactylus), isopods (Synidotea sp.), scuds (Corophium spp.), and insect larvae. Threadfin shad were not an important food, perhaps because they did not become abundant in the Delta until 1962, after the data had been collected (Thomas 1966).

In the Estuary, some organisms that are of a size suitable for food are seldom eaten. American shad (Alosa sapidissima) were seldom eaten by striped bass, even when small shad were abundant (Stevens 1966; Thomas 1966). Delta smelt (Hypomesus transpacificus), white catfish (Ictalurus catus), and various native minnows were more abundant in the Delta and the Sacramento River than their occurrence in the diet of bass indicated (Thomas 1966). Striped bass consumed zoobenthos of only 8 of 35 taxa collected from the Delta, and Corophium was the only taxon eaten in significant amounts.

Young bass seemed to prefer the mysid N. awatschensis over Corophium (Stevens 1966). Indices of N. awatschensis and Corophium in the environment when compared with the frequency of occurrence of these organisms in the stomachs of bass, showed that young bass fed primarily on Corophium only if Corophium was abundant and N. awatschensis was scarce. If N. awatschensis and Corophium were abundant, if N. awatschensis was abundant and Corophium was not, and if N. awatschensis and Corophium were scarce, young bass fed primarily on N. awatschensis.

Disease and Parasites

Parasites of striped bass from the Sacramento-San Joaquin Estuary were reported by Moser et al. (1985). The two most commonly seen parasites in the Estuary were the metacestode Lacistorhynchus tenuis and the larval nematode Anisakis sp. Although striped bass from the Estuary are an incompatible host for both species of parasites, Moser et al. (1984) showed that L. tenuis is pathological to striped bass in the Estuary. There were also relatively high infections of adult striped bass with roundworm, (Anesakidae) larvae (Whipple 1983).

In the Sacramento-San Joaquin Estuary, factors other than angling cause about 15% to 30% mortality of the adult striped bass each year (Chadwick 1968; Miller 1974; Stevens 1977b). For at least 25 years, an unknown fraction of adult bass mortality has occurred during large die-offs in the Suisun-San Pablo Bay area. In recent years, the timing and location of die-offs have been monitored by the California Department of Fish and Game (Stevens 1979). Attempts to determine the cause of the mortality in the Suisun-San Pablo Bay area have been unsuccessful. Factors examined but not eliminated as causes include poisoning by heavy metals or hydrogen sulfide, bacteriological pathogens, red tides and various climatological factors. Increased temperature and reduced dissolved oxygen have also been suggested as factors (Coutant 1985). The die-offs occur only in late spring and summer, when bass migrate from fresh- to saltwater.

Diseases and parasites of striped bass from other areas have been studied and reported by Bonn et al. (1976) and Paperna and Zwerner (1976). The most commonly reported diseases of striped bass are fin rot disease, pasteurellosis, columnaris, lymphocystis, and epitheliocystis (Setzler et al. 1980). Summary tables of parasites and diseases were provided by Smith and Wells (1977), Westin and Rogers (1978), and Setzler et al. (1980).

ENVIRONMENTAL REQUIREMENTS

Habitat Suitability Index Models

Habitat suitability index models have been developed for striped bass of coastal stocks (Bain and Bain 1982) and inland stocks (Crance 1984). The models were developed from a review of existing information and can be used to assess habitat impact and to develop management alternatives.

Temperature

Striped bass eggs have a broad range of temperature tolerance (Table 3). Turner (1976) collected recently fertilized eggs ($\leq$ 8 h old) at 14-21 °C in the Sacramento River. In the laboratory, eggs hatched after diurnal temperature exposures of 5.6 °C between 14 and 23 °C (Albrecht 1964). Lethal temperatures were reported to be 10 °C and below (Morgan and Rasin 1981) and 23 °C and above (Shannon and Smith 1968).

Striped bass larvae tolerated a broad range of temperatures (Table 4). The 48-h upper LT50 for larvae collected from the Sacramento-San Joaquin Estuary ranged from 30 to 33 °C for 8 to 31 mm TL larvae (Kelly and Chadwick 1971). Survival was adjusted by dividing the actual survival by the control survival and multiplying by 100.

Juvenile and adult striped bass tolerated a broad temperature range with no ill effects (Table 5). Juveniles acclimated to higher temperatures had higher lethal limits than fish acclimated to lower temperatures (Table 5). Juveniles survived abrupt transfer in freshwater from 7 to 21 °C but 20% of the fish died when transferred from 21 to 7 °C (Tagatz 1961). No juveniles died if temperature decrease was gradual (4 °C/h). Adult preferred temperatures varied with

Table 3. Effects of selected environmental factors on striped bass eggs.

Environmental factor	Tolerance	Optimum	Lethal	Source
Temperature (°C)	14-23	17-20		Mansueti (1958)
	13-24	19-21		Albrecht (1964)
		18-21	<12	Rogers et al. (1977)
	12-28	18	10	Morgan et al. (1981)
			>23	Shannon and Smith (1968)
Salinity (ppt)	0-10	1.5-3.0		Mansueti (1958)
	0-9	1.7		Albrecht (1964)
	0-8			Morgan and Rasin (1973)
Dissolved O_2 (mg/l)			<1.5	Mansueti (1958)
			<5.0	Turner and Farley (1971)
Turbidity (mg/l)	0-500		>1000	Auld and Schubel (1978)
pH	5.8-10.0			Regan et al. (1968)
Current velocity (cm/s)	30.5-500	100-200		Mansueti (1958)
			<30.5	Albrecht (1964)

Table 4. Effects of selected environmental factors on striped bass larval stages.

Environmental factor	Experimental conditions	Tolerance	Optimum	Lethal	Source
Temperature (^{o}C)		12-23	16-19		Regan et al. (1968)
		10-25	15-22	<10	Davies (1970)
			18-21		Rogers et al. (1977)
				>30	Kelly and Chadwick (1971)
Salinity (ppt)		0-15	5-10		Regan et al. (1968)
	1-6 days		3.4		Lal et al. (1977)
	7-13 days		6.7		Lal et al. (1977)
	14-20 days		13.5		Lal et al. (1977)
	21-29 days		20.2		Lal et al. (1977)
	30-35 days		33.7		Lal et al. (1977)
	Yolk sac		5-15		Rogers and Westin (1978)
	Post yolk sac		5-25		Rogers and Westin (1978)
Dissolved O_2 (mg/l)	Yolk sac			<2.3	Rogers and Westin (1978)
	Post yolk sac			<2.4	Rogers and Westin (1978)
Turbidity (mg/l)	Yolk sac			>500	Auld and Schubel (1978)
	48-h LD_{50}			3411	Morgan et al. (1973)
pH		6-10	7-8		Regan et al. (1968)
Current velocity (cm/s)		0-500	30-100		Regan et al. (1968)

ambient acclimation temperatures (Meldrim and Gift 1971). The maximum upper avoidance temperature for adults was 34 ^{o}C (ambient 27 ^{o}C) and they avoided 13 ^{o}C if acclimated at 5 ^{o}C.

In the Sacramento-San Joaquin Estuary water temperature is important to striped bass distribution and survival. Coutant (1985) summarized striped bass temperature preference (thermal niche) data from the Estuary relative to striped bass distribution and migration. He suggested that high water temperature might limit the distribution of bass in the Estuary and result in the crowding of the largest bass into areas with poor food and high toxicant levels; the result in low-flow years might be expected to be increased mortality of large fish and reduced fecundity.

Table 5. Effects of selected environmental factors on striped bass juvenile and adult stages.

Environmental factor	Experimental conditions	Tolerance	Optimum	Lethal	Source
Temperature (^{o}C)	20-50 mm TL	10-27	16-19		Bogdanov et al. (1967)
	50-100 mm TL	<39	13-23		Bogdanov et al. (1967)
	Acclim. at 15.6^{o}C			31.0	Loeber (1951)
	Acclim. at 11.0^{o}C			29.4	Loeber (1951)
Salinity (ppt)	20-50 mm TL	0-20	10-15		Bogdanov et al. (1967)
	50-100 mm TL	0-35	10-20		Bogdanov et al. (1967)
Dissolved O_2 (mg/l)		3-20	6-12		Bogdanov et al. (1967)
	Acclim. at 32.8^{o}C			<2.4	Dorfman and Westman (1970)
pH		6-10	7-9		Bogdanov et al. (1967)
				5.3	Tatum et al. (1966)
Current velocity (cm/s)		0-500	0-100		Bogdanov et al. (1967)
Temperature (^{o}C)		7.2-27			Tagatz (1961)
Salinity (ppt)		0-33.7			Rogers and Westin (1978)

Salinity

In the Sacramento-San Joaquin Estuary, striped bass eggs were observed in slightly saline water: eggs and larvae should survive all salinities encountered in the Estuary (Albrecht 1964). In the laboratory, the highest hatch of eggs and survival of larvae were achieved at low salinities (Tables 3 and 4). Lal et al. (1977) reported that 1-day-old eggs hatched at salinities of 3.4 to 16.7 ppt and that survival of eggs to hatching was higher in saline than in freshwater; however, they recommended not incubating striped bass eggs at salinities above 3.4 ppt because the survival of larvae declined progressively for eggs hatched in higher salinities.

Lal et al. (1977) reported that optimal salinities for rearing of larvae through metamorphosis progressively increased during development (Table 4). After metamorphosis, striped bass fry were reared in sea water (33.4 ppt) for 15 months. Juvenile and adult striped bass tolerated salinities of 0-33 ppt (Table 5). Geiger and Parker (1985) compiled a water quality survey of 57 striped bass hatcheries and reported that salinity >0.5 ppt was the single most important factor influencing striped bass production.

Salinity-Temperature Interaction

The response of striped bass eggs and larvae to salinity-temperature interaction has been measured. Otwell and Merriner (1975) reported that mortality in test groups of juveniles was highest in tests combining the highest salinity with the lowest temperature. However, the combined effect of salinity and temperature did not exceed the effect of either salinity or temperature alone. Survival was higher in fish younger than 28 days than in older fish at a given salinity-temperature combination, and temperature was more limiting than salinity to growth and survival of juveniles.

Tagatz (1961) reported that striped bass survived abrupt transfers between saltwater (33 ppt) and freshwater at temperatures from 7.7 to 26.7 °C for adults and 7.7 to 21.1 °C for juveniles. Morgan and Rasin (1981) reported that salinity-temperature combinations affected the percent hatch of striped bass eggs and survival of larvae (1 day after hatching), but not mean length. The percent hatch and survival of larvae were best expressed by the following equations:

$$\text{Percent hatch} = -0.83T^2 + 30.64T - 0.12(S \times T) + 2.22S - 205.80$$

and

$$\text{Percent survival} = -1.03T^2 + 35.86T + 0.54S - 246.63$$

where T = Celsius degrees and salinity (S) = ppt. The calculated optima for survival were 18 °C and 10 ppt.

Dissolved Oxygen and pH

Striped bass select a broad range of dissolved oxygen (DO) concentrations (Table 5). Survival of eggs in the laboratory decreased to ≤50% of survival of controls (in saturated DO concentrations) with a decrease in DO to 4 and 5 ppm at 18 to 23 °C (Turner and Farley 1971). Cech et al. (1984) reported that growth of juveniles (<1g) was reduced by low DO (90 torr PO_2) at 20 and 25 °C. Meldrim et al. (1974) reported that juveniles generally avoided DO concentrations of 3.8-4 ppm. Coutant (1985) reported that adults (field and laboratory) became stressed as DO decreased to near 3 ppm, and water containing near 2 ppm DO were uninhabited by bass. Talbot (1966) suggested that 4 ppm DO may be too low for successful reproduction. Hill et al. (1981) found that juveniles selected the highest DO available (6.8-7.0 ppm).

Geiger and Parker (1985) reported the pH in 57 striped bass hatcheries ranged from 6.4 to 7.3. Hill et al. (1981) found that striped bass juveniles (55-82 mm SL) selected a preferred pH (7.1-7.2) when both DO and dissolved solids were low (3.9 and 1400-1500 ppm, respectively). However, when DO and dissolved solids were 9 and 1300 ppm, respectively, juveniles selected a pH range of 7.8-8.2. Regan et al. (1968) determined pH tolerance limits for eggs and Regan et al. (1968) for larva (Tables 3 and 4).

Turbidity

Striped bass spawn in turbid streams but turbidity was not reported (Mansueti 1962; Talbot 1966). Woodhull (1947) mentioned that in the Delta where striped bass were spawning, the water was rather turbid (visibility 15 inches). Auld and Schubel (1978) found that high turbidities were lethal to eggs and larvae (Tables 3 and 4). Morgan et al. (1973) determined the 48-h LD50 for larvae (Table 4).

Current Velocity

In the Sacramento-San Joaquin Estuary, current velocity and river discharge are important to survival of eggs and larvae. Albrecht (1964) found that a minimum current velocity of 30.5 cm/s was needed to keep striped bass eggs suspended above the bottom, and in laboratory experiments eggs allowed to rest on a gravel substrate did not hatch. Larvae will remain suspended in the water column at a bed layer velocity of 51.9 cm/sec and 21.4 cm/sec over rippled and smooth Sacramento River channel bottom, respectively (Meinz and Heubach 1978). Striped bass eggs have tolerated much higher velocities (Table 3). In the Estuary the salinity gradient zone was farther downstream than usual (Suisun Bay) when freshwater outflows were high and farther upstream (Delta) when outflows were low. Both the survival of juveniles and the production of plankton were much higher when the zone was in Suisun Bay (Stevens et al. 1985).

Entrainment

Striped bass eggs, larvae and juveniles are lost to entrainment in unscreened Sacramento and San Joaquin Rivers diversions, to export diversions of Delta water by State and Federal pumping plants, which may be screened, and to agriculture and power plants, which may also be screened. Export diversions, which affect bass substantially more than river diversions, have louver screens, but the screens do not attain even 50% efficiency until fish are 19 mm FL. Screen efficiency increases gradually to about 35% for bass longer than 100 mm FL (Skinner 1974). Stevens et al. (1985) reported that estimated losses of young striped bass ranged from 2 million to 4.5 billion in State and Federal pumping plants in 1968-79, were 598 million in 1978 and 562 million in 1979 in Delta agriculture diversions, and were 154 million in 1978 and 62 million in 1979 in power plants.

The abundance of striped bass surviving to 38 mm TL was significantly reduced by the losses from the combined entrainment (Stevens et al. 1985). This long-term reduction in young striped bass from the Estuary probably has contributed to the decline in the adult bass population. In addition, export diversion of water from the Delta causes high flow velocities in the channels that convey water from the Sacramento River to the pumping plants (Stevens 1980). The reduction in standing crops of important food organisms of young bass resulting from the high water velocities (Turner 1966; Heubach 1969) may further decrease the bass population.

River Flow and Water Diversion

Studies of striped bass in the Sacramento-San Joaquin Estuary have demonstrated that the abundance of young bass has been associated with river outflow from the Delta and the percent of the river inflow diverted (Stevens 1980). The abundance of young bass in the Estuary has been measured annually since 1959, and an index of the number surviving to 38 mm FL (juveniles) has been developed and correlated with flows (Turner and Chadwick 1972). During 1959-76, the abundance of juveniles in the Delta was correlated with the May-June outflows from the Delta and the amount of water diverted in these months. In Suisun Bay, the abundance of juveniles was best explained by the June-July outflows (Stevens et al. 1985). The data suggested that survival from eggs to 38 mm could depend on flows and diversions (Turner and Chadwick 1972; Chadwick et al. 1977; Stevens 1977b). However, since 1977, the abundance of young bass has been considerably lower than predicted by the 1959-76 regressions. Both young bass abundance and the ability to predict it have been greatly reduced (Stevens et al. 1985). An index of survival between the egg and 38 mm (1969-82), when egg production estimates were available, was developed and calculated as:

survival index =

$$\frac{\text{index of abundance at 38 mm mean FL}}{\text{egg production index}}$$

The survival index was significantly related to outflow from the Delta and described by:

Survival = 2.39 $\log_{10}$ outflow (m^3/s) from the Delta minus 3.70

The regression was significant but it only accounted for 29% of the variation in survival. The results were affected by imprecision in the variables used to calculate the survival index (Stevens et al. 1985).

The analysis of recent data (1969-82) implies that the relationship between survival from egg to 38 mm FL and flow and diversion has not changed substantially. Survival rates still appear to be controlled by Delta outflow (Stevens et al. 1985). Even though survival to 38 mm appears to be associated with flows and diversions, the current thinking is that reduced striped bass abundance in the Estuary is related to the factors mentioned on page 12--reduced adult stocks, reduced food production, entrainment losses, and toxicity (Donald Stevens, California Department of Fish and Game, pers. comm.)

Environmental Contaminants

The steady decline in abundance of striped bass in the Sacramento-San Joaquin Estuary since the 1960s may be related to chemical residues. Whipple (1983), who summarized work on the effects of pollutants on striped bass in the Estuary, wrote that field and laboratory studies of spawning bass showed concentrations of monocyclic aromatic hydrocarbons (benzene, xylene) and zinc were correlated with reduced bass reproductive capacity, fecundity, and gametic viability. Crosby et al. (1983), who also analyzed tissues and organs of striped bass from the Estuary, found that common chlorinated hydrocarbons represented the most prevalent tissue residues (Table 6). They stated that Sacramento River striped bass contained levels of hydrocarbons that exceeded limits for fish survival recommended by the National Academy of Science as well as the actionable levels for animal feed published by the U.S. Department of Agriculture. The Sacramento fish were in poor health, compared with those from Coos River, Oregon, and showed mottled-pink livers with fibrous lesions, parasites, and external lesions. The Oregon bass were larger and older than the Estuary bass but had significantly lower tissue burdens of toxic pollutants. Whipple et al. (1981) reported alicyclic hexanes in liver and ovary tissue (0.02 to 16 µl/kg wet weight) of striped bass from the Estuary. Benville et al. (1985) determined that the 96-h LC50s for seven alicyclic hexanes ranged from 3.2 to 9.3 µl/l for striped bass from the Estuary.

The effects and lethal concentrations of pesticides, heavy metals, pharmaceutical drugs, and other commonly discharged chemical substances on striped bass from other areas were summarized by Bonn et al. (1976) and Westin and Rogers (1978). Palawski et al. (1985) determined the toxicity to young striped bass of a mixture of 18 chemicals and the individual toxicities of the inorganic and organic fractions that composed the mixture. They also determined that the sensitivity of young striped bass to seven inorganic compounds and three organic pesticides equaled or slightly exceeded that of most salmonids, and exceeded that of certain cyprinids, ictalurids, and centrarchids.

Table 6. Mean (n = 8) residue levels (ppm) for major classes of organochlorine compounds in tissues of female striped bass from the Sacramento River, 1981 (from Crosby et al. 1983).[a]

Compound	Source of residue					
	Lateral line		Ovary		Liver	
	LW	TW	LW	TW	LW	TW
Aroclor 1260	18.01	1.36	9.05	1.70	12.30	1.03
Aroclor 1254	13.16	1.18	9.69	1.84	11.64	1.67
Toxaphene	1.85	0.18	1.83	0.35	1.82	0.12
DDT	10.35	0.90	7.21	1.33	6.13	0.53
Other Organochlorines[b]	3.89	0.35	1.94	0.35	1.98	0.20
Total Organochlorines	48.81	4.14	30.72	5.77	36.24	3.38

[a]LW = lipid weight basis; TW = tissue weight basis.
[b]Chlorinated cyclodienes, hexachlorobenzene.

LITERATURE CITED

Albrecht, A.B. 1964. Some observations on factors associated with survival of striped bass eggs and larvae. Calif. Fish Game 50:100-113.

Arthur, J.F., and M.D. Ball. 1978. Entrapment of suspended materials in the San Francisco Bay-Delta Estuary. U.S. Bureau of Reclamation, Water Quality Branch, Mid-Pacific Region, Sacramento, Calif. 106 pp.

Arthur, J.F., and M.D. Ball. 1979. Factors influencing the entrapment of suspended material in the San Francisco Bay-Delta Estuary. Pages 143-174 in T.J. Conomos, ed. San Francisco Bay: the urbanized estuary. Pacific Division American Association for the Advancement of Science, San Francisco, Calif.

Auld, A.B., and J.R. Schubel. 1978. Effects of suspended sediment on fish eggs and larvae: a laboratory assessment. Estuarine Coastal Mar. Sci. 6:153-164.

Bailey, N.T.J. 1951. On estimating the size of mobile populations from recapture data. Biometrika 38:293-306.

Bain, M.B., and J.L. Bain. 1982. Habitat suitability index models: Coastal stocks of striped bass. U.S. Fish Wildl. Serv. Rep. FWS/OBS-82/10.1. 29 pp.

Benville, P.E., Jr., J.A. Whipple, and M.B. Eldridge. 1985. Acute toxicity of seven alicyclic hexanes to striped bass, Morone saxatilis, and bay shrimp, Crangon franciscorum, in seawater. Calif. Fish Game 71:132-140.

Bogdanov, A.S., S.I. Doroshev, and A.F. Karpevich. 1967. Experimental transfer of (Salmo gairdneri) and (Roccus saxatilis) from the USA for acclimatization in bodies of water of the USSR. Vopr. Ikhtiol. 42:185-187. (Translated from Russian by R.M. Howland, Narragansett Marine Game Fish Research Laboratory, R.I.)

Bonn, E.W., W.M. Bailey, J.D. Bayless, K.E. Erickson, and R.E. Stevens, eds. 1976. Guidelines for striped bass culture. Striped Bass Committee of the Southern Division, American Fisheries Society, Bethesda, Md. 103 pp.

Calhoun, A.J. 1952. Annual migrations of California striped bass. Calif. Fish Game 38:391-403.

Calhoun, A.J., C.A. Woodhull, and W.C. Johnson. 1950. Striped bass reproduction in the Sacramento River system in 1948. Calif. Fish Game 36:135-145.

Cech, J.C., Jr., S.J. Mitchell, and T.E. Wragg. 1984. Comparative growth of juvenile white sturgeon and striped bass: effects of temperature and hypoxia. Estuaries 7:12-18.

Chadwick, H.K. 1964. Annual abundance of young striped bass (Roccus saxatilis) in the Sacramento-San Joaquin Delta, California. Calif. Fish Game 50:69-99.

Chadwick, H.K. 1966. Variation in the growth of young striped bass (Roccus saxatilis) in the Sacramento-San Joaquin system. Calif. Dep. Fish Game Inland Fish. Admin. Rep. No. 66-11: 6 pp.

Chadwick, H.K. 1967. Recent migrations of the Sacramento-San Joaquin River striped bass population. Trans. Am. Fish. Soc. 96:327-342.

Chadwick, H.K. 1968. Mortality rates in the California striped bass population. Calif. Fish Game 54:228-246.

Chadwick, H.K., D.E. Stevens, and L.W. Miller. 1977. Some factors regulating the striped bass population in the Sacramento-San Joaquin Estuary, California. Pages 18-35 in W. Van Winkle, ed. Proceedings of the conference on assessing the effects of powerplant-induced mortality on fish populations. Pergamon Press, New York.

Clark, G.H. 1938. Weight and age determination of striped bass. Calif. Fish Game 24:176-177.

Collins, B.W. 1982. Growth of adult striped bass in the Sacramento-San Joaquin Estuary. Calif. Fish Game 68:146-159.

Coutant, C.C. 1985. Striped bass, temperature and dissolved oxygen: a speculative hypothesis for environmental risk. Trans. Am. Fish. Soc. 114:31-61.

Craig, J.A. 1928. The striped bass supply of California. Calif. Fish Game 14:265-272.

Crance, J.H. 1984. Habitat suitability index models and instream flow suitability curves: inland stocks of striped bass. U.S. Fish Wildl. Serv. FWS/OBS-82/10.85. 63 pp.

Crosby, D.G., K. Hogan, and G.W. Bowes. 1983. Pages 191-200 in Third progress report, cooperative striped bass study. Calif. State Water Resour. Control Board, Toxic Substances Control Program, Spec. Proj. Rep. 83-3SP.

Daniel, D.A. 1976. A laboratory study to define the relationship between survival of young striped bass (Marone saxatilis) and their food supply. Calif. Dep. Fish Game Anad. Fish Branch, Admin. Rep. No. 76-1. 13 pp.

Davies, W.D. 1970. The effects of temperature, pH, and total dissolved solids on the survival of immature striped bass. Ph.D. Thesis. North Carolina State University, Raleigh. 100 pp.

Dorfman, D., and J. Westman. 1970. Responses of some anadromous fishes to varied oxygen concentration and increases in temperature. Water Resour. Res. Inst. Publ. No. PB 192312 (Rutgers Univ.). 75 pp.

Doroshev, S.I. 1970. Biological features of the eggs, larvae and young of the striped bass Roccus saxatilis (Walbaum) in connection with the problem of its acclimatization in the USSR. J. Ichthyol. 10:235-278.

Doroshev, S.I., J.W. Cornacchia, and K. Hogan. 1981. Initial swim bladder inflation in the larvae of physoclistous fishes and its importance for larval culture. Rapp. P.-v. Rein Cons. int. Explor. Mer, 178:495-500.

Eldridge, M.B., J.A. Whipple, M.J. Bowers, and B.M. Jarvis. 1981. Effects of food and feeding factors on laboratory-reared striped bass larvae. Trans. Am. Fish. Soc. 110:111-120.

Eldridge, M.B., J.A. Whipple, and M.J. Bowers. 1982. Bioenergetics and growth of striped bass, Morone saxatilis, embryos and larvae. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 80:461-474.

Farley, T.C. 1966. Striped bass (Roccus saxatilis) spawning in the Sacramento-San Joaquin River system during 1963 and 1964. Calif. Dep. Fish Game Fish Bull. 136:28-43.

Fay, C.W., R.J. Neves, and G.B. Pardue. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) -- striped bass. U.S. Fish Wildl. Serv. FWS/OBS-82/11.8; U.S. Army Corps of Engineers, TR EL-82-4. 36 pp.

Forrester, C.R., A.E. Peden, and R.M. Wilson. 1972. First records of the striped bass, Morone saxatilis, in British Columbia waters. J. Fish. Res. Board Can. 29:337-339.

Geiger, J.G., and N.C. Parker. 1985. Survey of striped bass hatchery management in the southeastern United States. Prog. Fish-Cult. 47:1-13.

Hallock, R.J., D.H. Fry, Jr., and D.A. LaFaunce. 1957. The use of wire fyke traps to estimate runs of adult salmon and steelhead in the Sacramento River. Calif. Fish Game 43:271-298.

Hardy, J.D., Jr. 1973. Development of fishes of the mid-Atlantic Bight: an atlas of the egg, larval and juvenile stages, Vol. 3. U.S. Fish Wildl. Serv. Biol. Serv. Program FWS/OBS-78/12. 394 pp.

Heubach, W. 1969. Neomysis awatschensis in the Sacramento-San Joaquin River Estuary. Limnol. Oceanogr. 14:533-546.

Heubach, W., R.J. Toth, and A.M. McCready. 1963. Food of young-of-the-year striped bass (Roccus saxatilis) in the Sacramento-San Joaquin River system. Calif. Fish Game 49:224-239.

Hill, L.G., G.H. Schnell, and W.J. Matthews. 1981. Locomotor responses of the striped bass, (Morone saxatilis), to environmental variables. Am. Midland Nat. 105:139-148.

Kelley, D.W., and J.L. Turner. 1966. Fisheries protection and enhancement with water development of the Sacramento-San Joaquin Estuary. Pages 78-82 in R.F. Smith, A.H. Swartz and W.H. Mossman, eds. A symposium on estuarine fisheries. Am. Fish. Soc. Spec. Publ. No. 3.

Kelly, R., and H.K. Chadwick. 1971. Some observations on striped bass temperature tolerances. Calif. Dep. Fish Game Anad. Fish Branch Admin. Rep. No. 71-9. 11 pp.

Lal, K., R. Lasker, and A. Kuljis. 1977. Acclimation and rearing striped bass larvae. Calif. Fish Game 63:210-218.

Loeber, T.S. 1951. A report of an investigation of the temperature and salinity relationships of striped bass and salmon in connection with the Reber plan. Calif. Dep. Fish Game Inland Fish Admin. Rep. No. 51-27. 40 pp.

Magnin, E., and G. Beaulieu. 1967. Striped bass of the St. Lawrence River. Nat. Can. (Que.) 94:539-555.

Mansueti, R.J. 1958. Eggs, larvae, and young of the striped bass. Chesapeake Lab. Biol. Contrib. No. 112. 35 pp.

Mansueti, R.J. 1962. Effects of civilization on striped bass and other estuarine biota in Chesapeake Bay and tributaries. Proc. Gulf Caribb. Fish. Inst., 14th Annu. Sess. p. 110-136.

Massman, W.H. 1971. The significance of an estuary on the biology of aquatic organisms of the middle Atlantic region. Pages 96-109 in P.A. Douglas and R.H. Stroud, eds. A symposium on the biological significance of estuaries. Sport Fishing Institute, Washington, D.C.

McIlwain, T.D. 1968. Distribution of striped bass, Roccus saxatilis (Walbaum), in Mississippi waters. Proc. Annu. Conf. Southeast. Game Fish Comm. 21:254-257.

McLane, W.M. 1955. The fishes of the St. John's River system. Ph.D. Thesis. University of Florida, Gainesville. 361 pp.

Meinz, M. and W. Heubach. 1978. Factors affecting sinking rates of striped bass (Morone saxatilis) eggs and larval. Calif. Dept. Fish Game Anad. Fish Branch, Admin. Rep. No. 77-7. 22 pp.

Meldrim, J.W., and J.J. Gift. 1971. Temperature preference, avoidance and shock experiments with estuarine fishes. Ichthyol. Assoc. Bull. 7. 75 pp.

Meldrim, J.W., J.J. Gift, and B.R. Petrosky. 1974. The effect of temperature and chemical pollutants on the behavior of several estuarine organisms. Ichthyol. Assoc. Bull. No. 17. 129 pp.

Meyer Resources, Inc. 1985. The economic value of striped bass (Morone saxatilis), chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Salmo gairdneri) of the Sacramento and San Joaquin River systems. Calif. Dep. Fish Game Anad. Fish Branch Admin. Rep. No. 85-03 Revised. 44 pp.

Miller, L.W. 1974. Mortality rates for California striped bass (Morone saxatilis) from 1965-1971. Calif. Fish Game 60:157-171.

Miller, L.W., and R.J. McKechnie. 1968. Observation on striped bass spawning in the Sacramento River. Calif. Fish Game 54:306-307.

Miller, L.W., and J.J. Orsi. 1969. Growth of striped bass (Morone saxatilis) in the Sacramento-San Joaquin Estuary from 1961-1965. Calif. Dept. Fish Game, Anad. Fish Branch Admin. Rep. No. 16-6. 7 pp.

Miller, D.J., and R.H. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game Fish Bull. 157. 249 pp.

Morgan, A.R., and A.R. Gerlach. 1950. Striped bass studies in Coos Bay, Oregon, in 1949 and 1950. Oregon Fish. Comm. No. 14. 31 pp.

Morgan, R.P., II, and V.J. Rasin, Jr. 1973. Effects of salinity and temperature on the development of eggs and larvae of striped bass and white perch. Chesapeake Bay Inst. Nat. Resour. Ref. No. 73-110. 21 pp.

Morgan, R.P., II, and V.J. Rasin Jr. 1981. Temperature and salinity effects on development of striped bass eggs and larvae. Trans. Am. Fish. Soc. 110:95-99.

Morgan, R.P., II, V.J. Rasin, Jr., and L.A. Noe. 1973. Effects of suspended sediments on the development of eggs and larvae of striped bass and white perch. In Hydrographic and ecological effects of enlargement of the Chesapeake and Delaware Canal. U.S. Army Corps of Engineers, Philadelphia District Contract No. DACW-61-71-C-0062. 21 pp.

Morgan, R.P., II, V.J. Rasin, Jr., and R.L. Copp. 1981. Temperature and salinity effects on development of striped bass eggs and larvae. Trans. Am. Fish. Soc. 110:95-99.

Moser, M., J. Sakanari, S. Welling and K. Lindstrom. 1984. Incompatability between San Francisco striped bass Morone saxatilis (Walbaum), and the metacestode Lacistorhynchus tenuis (Beneden 1958). J. Fish Dis. 7:397-400.

Moser, M., J.A. Sakanari, C.A. Reilly and J. Whipple. 1985. Prevalence, intensity, longevity, and persistence of Anisakis sp. larvae and Lacistorhynchus tenuis metacestodes in San Francisco striped bass. NOAA Tech. Rep. NMFS 29. 4 pp.

Moyle, P.B. 1976. Inland fishes of California. University of California Press, Berkeley. 405 pp.

Orsi, J.J. 1971. The 1965-1967 migrations of the Sacramento-San Joaquin Estuary striped bass population. Calif. Fish Game 57:257-267.

Orsi, J.J., and A.C. Knutson. 1979. The role of mysid shrimp in the Sacramento-San Joaquin Estuary and factors affecting their abundance and distribution. Pages 401-408 in T.J. Conomos, ed. San Francisco Bay: the urbanized estuary. Pacific Division, American Association for the Advancement of Science, San Francisco, Calif.

Otwell, W.S., and J.V. Merriner. 1975. Survival and growth of juvenile striped bass, Morone saxatilis, in a factorial experiment with temperature, salinity and age. Trans. Am. Fish. Soc. 104:560-566.

Palawski, D., J.B. Hunn, and F.J. Dwyer. 1985. Sensitivity of young striped bass to organic and inorganic contaminants in fresh and saline waters. Trans. Am. Fish Soc. 114:748-753.

Paperna, I., and D.E. Zwerner. 1976. Parasites and diseases of striped bass (Morone saxatilis) Walbaum, from the lower Chesapeake Bay. J. Fish Biol. 9:267-281.

Parks, N.B. 1978. The Pacific Northwest commercial fishery for striped bass, 1922-1974. Mar. Fish. Rev. 40:18-20.

Pearson, J.C. 1938. The life history of the striped bass, or rockfish, Roccus saxatilis (Walbaum). U.S. Bur. Fish. Bull. 48:825-851.

Polgar, T., J.A. Mihursky, R.E. Ulanowicz, R.P. Morgan, and J.S. Wilson. 1976. An analysis of 1974 striped bass spawning success in the Potomac Estuary. Pages 151-165 in M. Wiley, ed. Estuarine processes, Volume I. Academic Press, New York.

Radovich, J. 1961. Relationships of some marine organisms of the northeast Pacific to water temperature particularly during 1957 through 1959. Calif. Dept. Fish Game Fish Bull. 112. 62 pp.

Raney, E.C. 1952. The life history of the striped bass. Bingham Oceanogr. Collect. Yale Univ. Bull. 14:5-97.

Regan, D.M., T.L. Wellborn, Jr., and R.G. Bowker. 1968. Striped bass: development of essential requirements for production. U.S. Fish Wildl. Serv. Bur. Sport Fish. Wildl., Div. Fish Hatcheries, Atlanta, Ga. 133 pp.

Robinson, J.B. 1960. The age and growth of striped bass (Roccus saxatilis) in California. Calif. Fish Game 46:279-290.

Roedel, P.M. 1953. Common ocean fishes of the California coast. Calif. Dep. Fish Game Fish Bull. 91. 184 pp.

Rogers, B.A., and D.T. Westin. 1978. A culture methodology for striped bass. EPA Ecol. Res. Ser. Rep. No. 660/3-78-000.

Rogers, B.A., D.T. Westin, and S.B. Saila. 1977. Life stage duration in Hudson River striped bass. Univ. R.I. Mar. Tech. Rep. No. 3. 111 pp.

Sasaki, S. 1966. Distribution of young striped bass, Roccus saxatilis, in the Sacramento-San Joaquin Delta. Calif. Dep. Fish Game Fish Bull. 136, Part 2:44-58.

Scofield, E.C. 1931. The striped bass of California (Roccus lineatus). Calif. Dep. Fish Game Fish Bull. 29. 84 pp.

Scofield, N.B., and H.C. Bryant. 1926. The striped bass in California. Calif. Fish Game 12:55-74.

Setzler, E.M., W.R. Boynton, K.V. Wood, H.H. Zion, L. Lubbers, N.K. Mountford, P. Frere, L. Tucker, and J.A. Mihursky. 1980. Synopsis of biological data on striped bass. Natl. Mar. Fish. Serv., FAO Synops. No. 121. 69 pp.

Shannon, E.H., and W.B. Smith. 1968. Preliminary observations on the effect of temperature on striped bass eggs and sac fry. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 21:257-260.

Skinner, J.E. 1974. A functional evaluation of a large louver screen installation and fish facilities research on California water diversion projects. Pages 225-249 in L.D. Jensen, ed. Proceedings of the second entrainment and intake screening workshop. John Hopkins Univ. Cooling Water Res. Proj. Rep. No. 15.

Smith, W.G., and A. Wells. 1977. Biological and fisheries data on striped bass. Sandy Hook Lab. Tech. Ser. Rep. No. 4. 42 pp.

Stevens, D.E. 1966. Food habits of striped bass (Roccus saxatilis) in the Sacramento-San Joaquin Delta. Calif. Dep. Fish Game Fish Bull. 136, Part 2:68-96.

Stevens, D.E. 1977a. Striped bass (Morone saxatilis) monitoring techniques in the Sacramento-San Joaquin Estuary. Pages 91-109 in W. Van Winkle, ed. Proceedings of a conference on assessing the effects of powerplant-induced mortality on fish populations. Pergamon Press, New York.

Stevens, D.E. 1977b. Striped bass (Morone saxatilis) year class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Trans. Am. Fish. Soc. 106:34-42.

Stevens, D.E. 1979. Environmental factors affecting striped bass (Morone saxatilis) in the Sacramento-San Joaquin Estuary. Pages 469-478 in T.J. Conomos, ed. San Francisco Bay: the urbanized estuary. American Association of the Advancement of Science, Pacific Division, San Francisco, Calif.

Stevens, D.E. 1980. Factors affecting the striped bass fisheries of the west coast. Pages 15-28 in H. Clepper, ed. Marine recreational fisheries 5. Sport Fishing Institute, Washington, D.C.

Stevens, D.E., D.W. Kohlhorst, and L.W. Miller. 1985. The decline of striped bass in the Sacramento-San Joaquin Estuary, California. Trans. Am. Fish. Soc. 114:12-30.

Tagatz, M.E. 1961. Tolerance of striped bass and American shad to changes of temperature and salinity. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 388. 8 pp.

Talbot, G.B. 1966. Estuarine requirements and limiting factors for striped bass. American

Fisheries Society Special Publication 3:37-49.

Tatum, B.L., J. Bayless, E.G. McCoy, and W.B. Smith. 1966. Preliminary experiments in artificial propagation of striped bass. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 19:374-389.

Thomas, J.L. 1966. The diet of juvenile and adult striped bass, Roccus saxatilis, in the Sacramento-San Joaquin River system. Calif. Fish Game 53:49-62.

Turner, J.L. 1966. Seasonal distribution of crustacean plankters in the Sacramento-San Joaquin Delta. Calif. Dep. Fish Game Fish Bull. 133:95-104.

Turner, J.L. 1976. Striped bass spawning in the Sacramento and San Joaquin Rivers in Central California from 1963 to 1972. Calif. Fish Game 62:106-118.

Turner, J.L., and T.C. Farley. 1971. Effects of temperature, salinity, and dissolved oxygen on the survival of striped bass eggs and larvae. Calif. Fish Game 57:268-273.

Turner, J.L., and H.K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, Morone saxatilis, in relation to river flow in the Sacramento-San Joaquin Estuary. Trans. Am. Fish. Soc. 101:442-452.

Vladykov, V.D., and D.E. McAllister. 1961. Preliminary list of marine fishes of Quebec. Nat. Can. (Que.) 88:53-78.

Wang, J.C.S. 1981. Taxonomy of the early life stages of fishes -- fishes of the Sacramento-San Joaquin Estuary and Moss Landing Harbor -- Elkhorn Slough, California. Pacific Gas and Electric Company San Francisco, California. 168 pp.

Westin, D.J. 1978. Serum and blood from adult striped bass (Morone saxatilis). Estuaries 1:126-128.

Westin, D.T., and B.A. Rogers. 1978. Synopsis of the biological data on the striped bass. Univ. R.I. Mar. Tech. Rep. No. 67. 154 pp.

Whipple, J.A. 1983. Cooperative sampling program. Pages 1-190. in Third progress report, cooperative striped bass study. Calif. State Water Resourc. Control Board, Toxic Substances Control Program, Spec. Proj. Rep. No. 83-3SP.

Whipple, J.A., M.B. Eldridge, and P. Benville, Jr. 1981. An ecological perspective of the effects of monocyclic aromatic hydrocarbons on fishes. Pages 483-551 in F.J. Vernberg, A. Calabrese, F.P. Thurberg and W.B. Vernberg, eds. Biological monitoring of marine pollutants. Academic Press, New York.

White, J.R. 1986. The striped bass sport fishery in the Sacramento-San Joaquin Estuary, 1969-1979. Calif. Fish Game 72:17-37.

Woodhull, C. 1947. Spawning habits of the striped bass (Roccus saxatilis) in California waters. Calif. Fish Game 33:97-102.

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries of the taxonomy, morphology, range, life history, and environmental requirements of coastal aquatic species. They are designed to assist in environmental impact assessment. The striped bass supports one of the most important sport fisheries in the Pacific Southwest. The only population of striped bass of consequence in the Pacific Southwest is in the Sacramento-San Joaquin Estuary and Pacific Ocean within 40 km of San Francisco Bay. Males mature at age 2 or 3 and females at ages 4 to 7. Striped bass are anadromous and spawn in fresh- or nearly freshwater from April to June in the Sacramento and San Joaquin Rivers and the Delta area formed by the rivers. The semibuoyant eggs require a minimum current of 30.5 cm/s during development to keep them from settling to the bottom and dying. Year-class size of striped bass in the estuary has been correlated with survival during early life. The abundance of young bass, mean FL 38 mm, has been associated with river outflow from the Delta and the percentage of the river inflow diverted. The abundance of striped bass in the estuary has steadily declined since the 1960's; the decline is believed to be related to a combination of toxic substances and entrainment of young bass. Temperature, salinity, and river discharge are also important environmental factors affecting the survival of striped bass.

17. Document Analysis a. Descriptors
Estuaries
Fisheries
Growth
Feeding habits
Animal migrations
Life cycles
Temperature
Salinity

b. Identifiers/Open-Ended Terms
Striped bass
Morone saxatilis
Spawning
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Impingement
Water diversions

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