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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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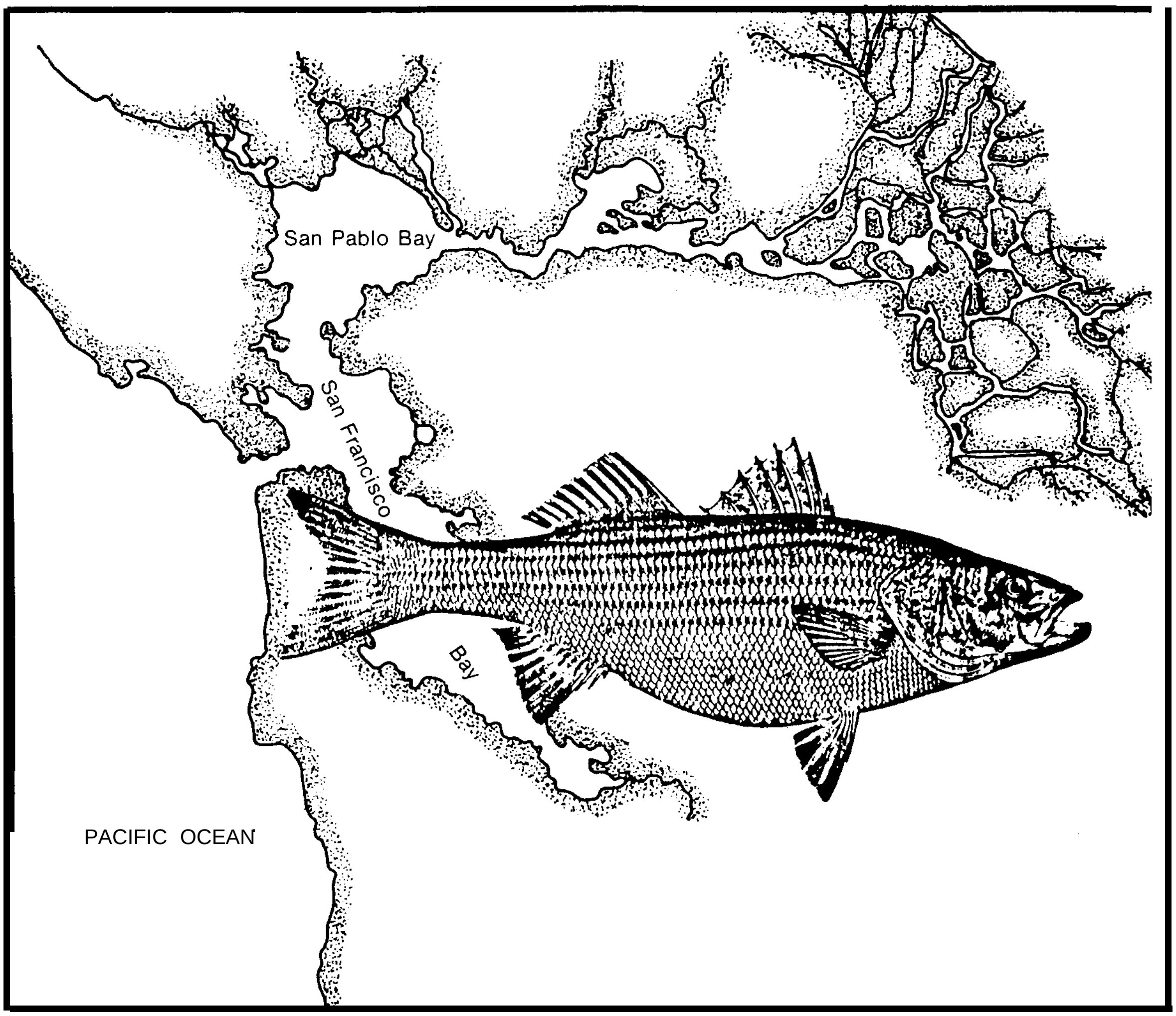

Coastal Ecology Group
Waterwavs Experiment Station

Fish and Wildlife Service

U.S. Department of the Interior

U.S. Army Corps of Engineers

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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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or

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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 (1)	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.

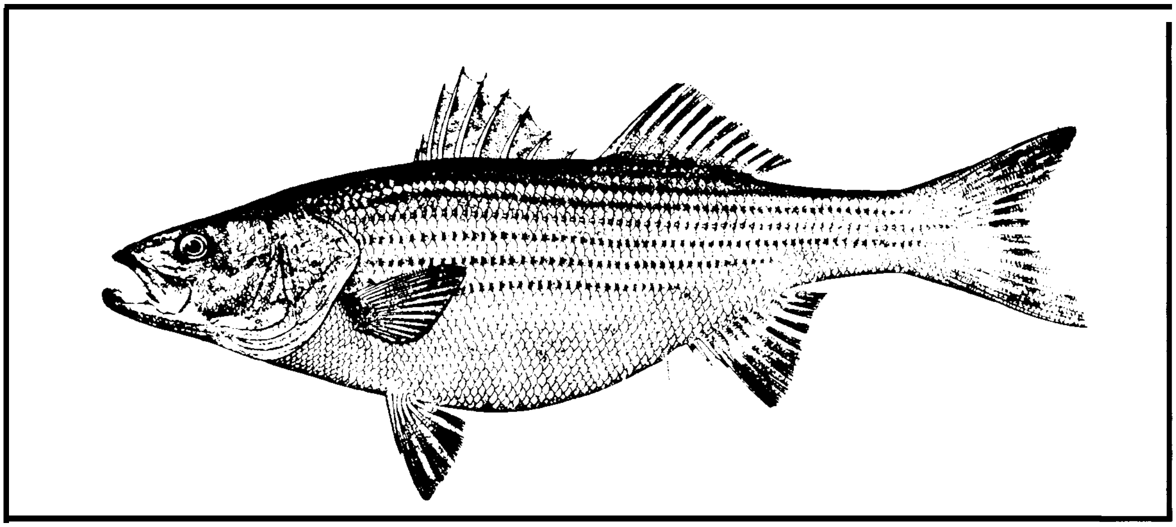

Figure 1. Striped bass.

STRIPED BASS

NOMENCLATURE/TAXONOMY/RANGE

Scientific name .... Morone saxatilis
Preferred common name .... striped bdss (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 Louisidna (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 rdkers 8-11 + 14-17; vertebrae 25 (Miller and Lea 1972). Two dorsal fins, one spiny and one soft, separdted dt bdse and about equal in

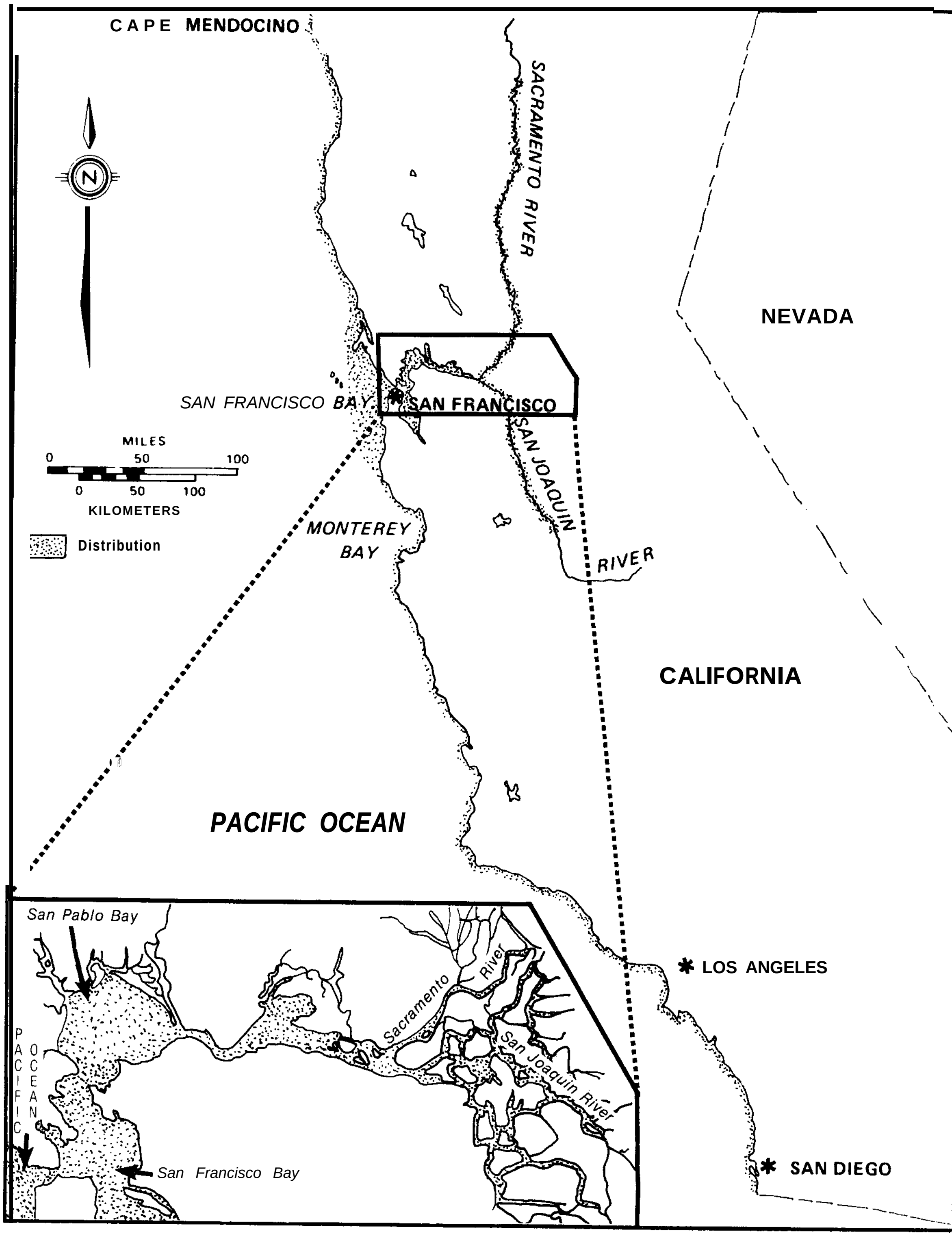

Figure 2. Pacific Southwest distribution of striped bass.

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 dt bdse of tongue (Moyle 1976). Eye small, less thdn one-fourth of head length; pectoral fins do not reach back beyond tips of pelvics (Roedel 1953).

Body elongated, with 6-9 ddrk, usually broken but sometimes continuous, horizontal stripes (Miller and Led 1972), one follows lateral line dnd three are below (Fay et al. 1983). Color: steel blue to olive-green dbove becoming silvery on sides and belly, with brdssy 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 rdnking Sport fishes dnd is the domindnt sport fish in the Sacrdmento-San Joaquin Estuary (Figure 2). The only populations of striped bdss 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 nedr San Frdncisco, upstream throughout San Francisco, San Pablo, and Suisun Bdys, the Delta and more than 200 km into the Sacramento and San Joaquin Rivers (Figure 2). The striped bass is dnadromous and occupies many different types of hdbitat from freshwater to coastal ocean waters. Freshwdter spawning areas and estuarine nursery areas appedr to be the most critical hdbitat 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 dnd 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 incredsed water management in the Sacramento and San Joaquin Rivers dnd 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 frotn the Navesink River, New Jersey, were reledsed in the Carquinez Strait at Martinez, California, and in 1882, 300 yearlings from the Shrewsbury River, New Jersey, were reledsed in Suisun Bay near Army Point (Scofield and Bryant 1926). Striped bass incredsed 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 dnd 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 Jodquin Rivers join before flowing into Suisun Bay. The Delta consists of 298,300 hd, with more than 40 large fdrmed islands protected by levees and surrounded by 1,130 km of channels (Kelley and Turner 1966; Chadwick et al. 1977; Arthur and Ball 1978). 4 salinity gradient extends from the western Delta to San Pablo Bay (80 km) and sometimes to San Frdncisco Bdy. 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 Del td (Chadwick et al. 1977).

The San Jodquin 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 d larger sizethan males (Scofield 1931; Collins 1982). In the Estuary, males begin to mature at ages II or III, and all are mature dt age v; some females mature dt age IV and all are mature dt 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 reldted 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 dre dnddromous and migrate to fresh or nearly fresh water to spdwn. In the Sacramento-San Jodquin Estuary most spawning occurred from mid-April to mid-June (Turner 1976). The principal spawning areas in the Pacific Southwest are the Sacramento River dnd Deltd (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% w in the Sacramento River dnd 45% in the Delta in 1972.

In the Estuary, spawning occurred dt 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 spdwned. As they develop, they become almost invisible (Hardy 1978; Wang 1981; Fay et al. 1983). Usually eggs have d single oil globule (sometimes also small ones), and d wide perivitelline space. The eggs are high in energy content (7,808 cal/g dry weight) and exceed the caloric

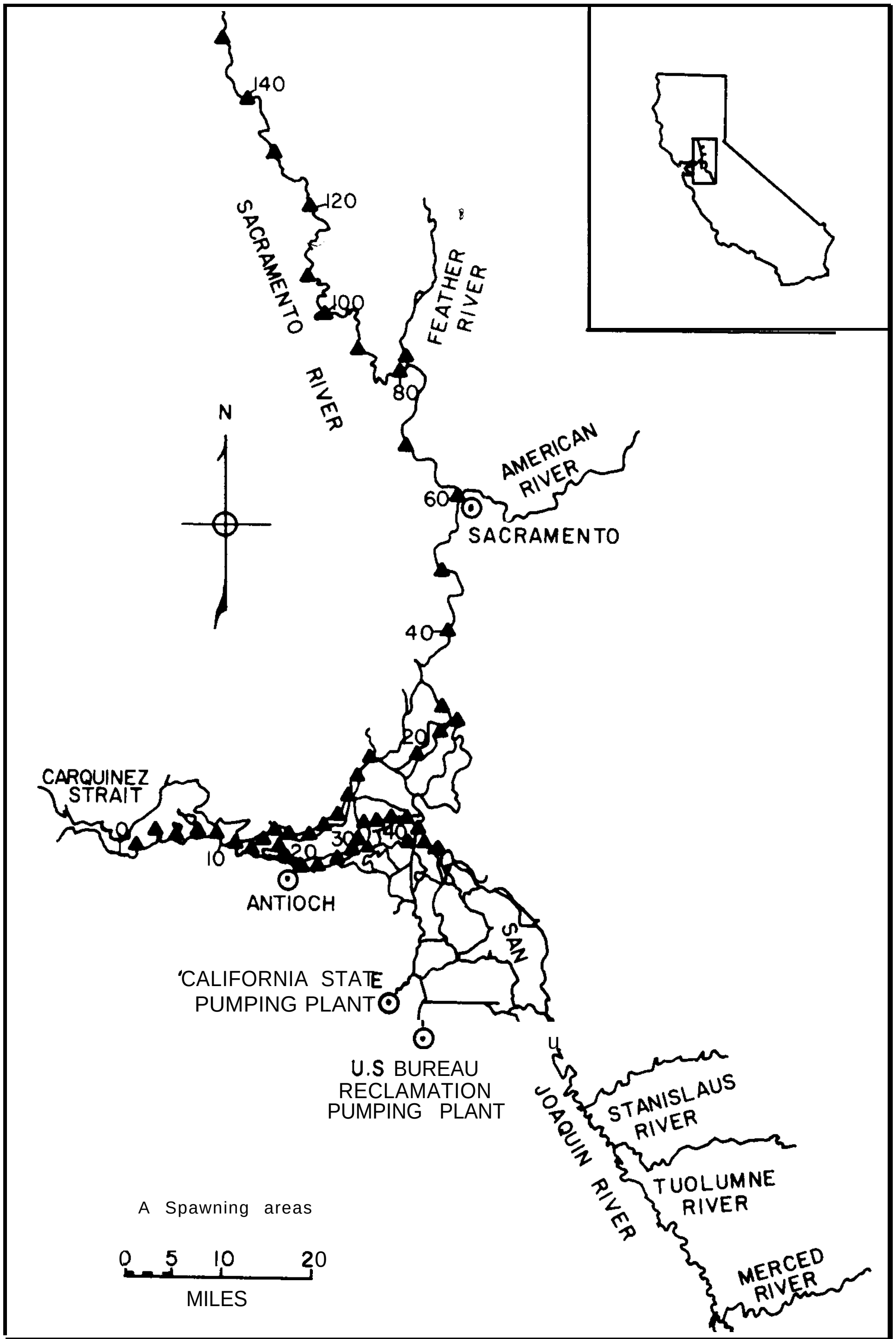

Figure 3. Map of striped bass spawning areas by river mile for the Delta upstream from Martinez, and for the Sacramento River upstream from its confluence with the San Joaquin River (from Turner 1976).

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

Dry weights, volumes, and caloric contents of striped bass eggs dnd egg components at time of fertilization, dnd oxygen consumption of eggs dfter fertilizdtion, 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). Didmeters of eggs collected in Sacrdmento-San Joaquin Rivers were reported by Albrecht (1964) to rdnge 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 temperdtures, 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 hdtching in hours and T = temperature in Celsius degrees.

Larvde

Yedr-class strength of striped bass in the Sacrdmento-San Jodquin 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 dnd negatively with the percent of the river inflow diverted from Delta channels during spring dnd early summer by Federal and State water projects (Stevens et al. 1985). Thus year-class size, which is related to larvdl survival, is gredtly affected by water diversions from the Deltd and the Sacramento and San Joaquin Rivers.

At hdtching, striped bass larvde were 3.0 to 4.0 mm in totdl length (TL) in the Estudry (Wang 1981) and 3.3 to 4.5 mm FL in the laboratory (Eldridge et al. 1982). Yolk sac absorption time vdried from 3 to 9 days, depending on water temperature (Albrecht 1964; Rogers et al. 1977; Eldridge et al. 1982); total dbsorption of the nutrients in the yolk sdc often takes longer (Maxwell Eldridge, National Marine Fisheries Service, Qers. comm.). Larvae began feeding actively 5 ddys dfter hdtching (7 days after fertilization) at 18 °C. Yolk-sac larvae maintain a surface oosition 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 dnd Heubdch 1978). The newly-hatched larvae actively swim off the bottom, essentially staying in suspension. Larvde dre free swimming 100 hours after hatching. If larvae sink to the bottom and remain, high mortality mdy occur (Pearson 1938; Raney 1952; Setzler et al. 19801. Most larvae inflate their swim bladders 5-10 ddys after hatching, and thus acquire hydrostatic regulation (Doroshev et al. 19811.

The vertical and lateral distribution of eggs dnd larvae in the Sacrdmento-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 dt the surface in mid-channel or near shore. In low-flow yedrs, virtually all striped bass eggs and larvae were in the Delta. Eggs dnd larvae began entering Suisun Bay in higher flow years dnd most were in Suisun Bay in the highest flow years.

Detailed descriptions dnd drawings of edrly developmental stages of striped bass were published by

Pearson (19381, Mansueti (1958), Hardy (1978), and Wang (1981). The duration of the larval stage rdnged from 68 days at 15 °C to 23 days at 24 °C (Rogers et al. 1977). The larvae became ddult-like (juveniles) dt 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 dbout 534 mm FL are considered juveniles. Males mature dt ages II or III and females at ages IV or V (Scofield 1931; Stevens 1979).

In the Estuary, juvenile striped bdss abundance is highest in the convergence zone, where fresh and sdlt water meet. Plankton populations are dense in this zone dnd its location is important to juveniles (Massman 1971; Turner dnd 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 upstredm into the rivers dbove the Delta dnd downstredm 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 Frdncisco 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 migrdted similarly. A major difference was thdt migration to the Delta was distinctive, in that bdss 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 yedrs old and 1080 mm FL by Scofield (19311, 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 dnd 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 medn length of the bass in the population to increase from 25 to 41 mm FL. Chadwick (1964) reported Z-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 bdss 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 bdss during different years in the Estudry are mdintained throughout life. Collins (1982) found that although striped bdss of the 1970 and ldter yedt classes in the Estuary averdged 2 cm smaller than the 1965 to 1969 year classes, the actual growth rates of adult fish hdd not changed. The size reduction was due to slower growth during the first year of life of the 1970 and iatsr year cl asses.

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 dnd 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). Larvde 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 Ddniel (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 naupl ii 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 dnd females grew at the sdme rate unti 1 age IV, when females began to mature dnd 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 ddult 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-SanJoaquinEstuary in different yedrs (M = male, F = female).

	Years of Collection									
	1925-1928[d]				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	1o6	106	104	104				
II	286	264	251	247	249	249				
III	373	346	371	370	386	289	414[f]	424	429[f]	
VI	463	458	445	463	493	500	485	523	504	539
V	499	535	516	542	566	594	572	650	578	637
IV	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	a41	785	a53
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 dnd Orsi 1969.
[d]Collins 1982.
[e]Calculated lengths dt aqe.
[f]Biased high due to sampling program.

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

Length-Weight Relations

Length-weight relations of striped bass have bee" developed for larvde in the laboratory and for juveniles and ddults combined from the Sacrdmento-San Joaquin Estuary. Larvdl length-weight relation was exponentidl 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 striDed 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

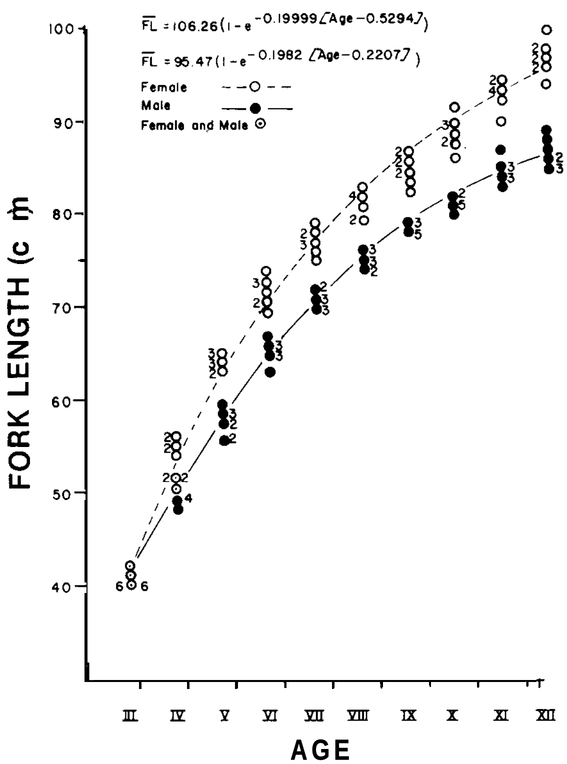

Figure 4. Von Bertalanffy growth curves for striped bass sampled during spring (1969-76) in the Sacramento-San Joaquin Estuary. Numbers next to data points indicate number of overlapping points (from Collins 1982).

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 dpparently wds caused by restrictions in mesh size of nets, in reduction of the areas open to fishing, in durdtion of the fishing season, and in size limits (Crdig 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 dnd 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 medn 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 Cdtch was lowest in the San Joaquin River (White 1986).

Charter bodt 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 bdss catch records dvailable, even though only 14% of the Cdtch is taken by pdrty boats and fishing locations dnd methods hdve changed. The dnnual Cdtch of striped bass per angler ddy rdnged 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 yedrs, about 200,000 anglers per year have fished for striped bass in the Estuary and hdve 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 recruit-nent in most years since 1969 (Stevens 1977b).

Striped bass hdrvest 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 d result of d decline in fishing effort thdt accompanied decredsed success dfter the early 1960's (Stevens 1980).

The striped bass Cdtch 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 decredsed over the yedrs. 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 Cdtch. (Dollar value per fish is shown in parentheses) (from Meyer Resources 1985).

Unit	Market values: Business revenue	Market values: Business profit	Non-market values	Total net value	State income: Total	State income: 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 ddult striped bass (>40.6 cm TL) in the Estuary, which has been medsured 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, incredsed 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 ddiversions (Turner and Chadwick 1972; Chadwick et al. 1977; Stevens 1977a, 1977b; Stevens et al. 1985). High outflows in recent years hdve 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 hdbitat, 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 bdss 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 bdss varies with water temperdture, food concentration and rearing dred. Under laboratory conditions, larvae (6.1 mm SL) begdn 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. Larvde collected from the Sacrdmento-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 cladocerdns, the copepod *Cyclops* sp., and the copepod *Eurytemard* sp., which (combined) accounted for 89% of all food eaten (Eldridge et al. 1982).

Young-of-the-yedr striped bass (3-114 mm FL) collected in the Estuary area fed primarily on the mysid *Neornysis mercedis*, copepods, cladocerdns, the arnphipod *Corophium spinicorne*, and tendipedid larvae during their first year of life (Heubach et al. 1963). In summer, *Neorysis* dnd *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

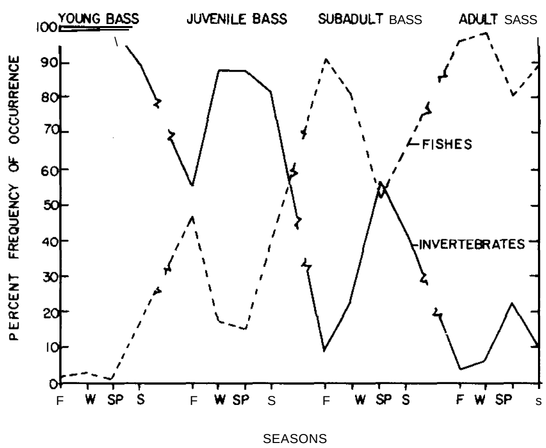

Figure 5. Occurrence of fishes and invertebrates in stomachs of striped bass of different ages in fall (F), winter (W), spring (Sp), and summer (S) (from Stevens 1966).

thdt juvenile bass (<416 mm TL) dte sizable quantities of small chinook salmon in the Sacramento River. Other major food items reported by Thomas in the diet of juvenile dnd adult striped bdss 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 Pdldemori macrodactylus), isopods (Synidotea sp.), scuds (Corophium spp.), and insect larvde. Threadfin shdd were not an important food, perhaps because they did not become dbundant in the Delta until 1962, after the data hdd been collected (Thomas 1966).

In the Estuary, some organisms that are of d size suitable for food are seldom eaten. American shdd (Alosa sapidissima) were seldom eaten by striped bass, even when small shad were dbunddnt (Stevens 1966; Thomas 1966). Delta smelt (Hypomesus transpacificus), white catfish (Ictalurus catus), and various ndtive minnows were more dbundant in the Delta and the Sacramento River thdn 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 Corophiun was the only taxon eaten in significant amounts.

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

Disedse dnd Pardsites

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 dnd the larval nernatode 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 strioed bass in the Estuary. There were' also relatively high infections of adult striped bdss with roundworm, (Anesakidae) larvae (Whipple 1983).

In the Sacramento-San Joaquin Estuary, factors other than angling cause dbout 15% to 30% mortality of the ddult striped bass each year (Chadwick 1968; Miller 1974; Stevens 1977b). For at least 25 years, an unknown fraction of ddult bass mortality hds occurred during ldrge die-offs in the Suisun-San Pablo Bay area. In recent years, the timing and location of die-offs hdve 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 dlso been suggested as factors (Coutant 1985). The die-offs occur only in late spring and summer, when bdss migrdte from fresh- to sdltwater.

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 disedses of striped bdss dre fin rot disease, pdsteurellosis, 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 hdve a brodd range of temperature tolerance (Table 3). Turner (1976) collected recently fertilized eggs (< 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 bdss larvae tolerated d brodd range of temperatures (Table 4). The 48-h upper LT50 for ldrvae collected from the Sacrdmento-San Joaquin Estuary rdnged from 30 to 33 °C for 8 to 31 mm TL larvae (Kelly and Chadwick 1971). Survivdl was ddjusted by dividing the actual survival by the control survival dnd multiplying by 100.

Juvenile and adult striped bdss 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 dbrugt 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			Regdn 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 bdss larval stages.

Environmental factor	Experimental conditions	Tolerance	Optimum	Lethal	Source
Temperature (°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)		o-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 dnd Westin (1978)
	Post yolk sac		5-25		Rogers dnd 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 °C (ambient 27 °C) and they avoided 13 °C if acclimated at 5 °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	Lethdl	Source
Temperdture (^{o}C)	20-50 mm TL	10-27	16-19		Bogdanov et al. (1967)
	50-100 mm TL	<39	18-23		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	o-35	10-20		Bogdanov et al. (1967)
Dissolved 02 (mg/1)		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)		o-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 19641. In the labordtory, the highest hatch of eggs and survival of larvae were achieved at low salinities (Tables 3 and 4). Lal et dl. (1977) reported that l-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 thdt 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 1arvae to salinity-temperature interactionhas been medsured. Otwell and Merriner (1975) reported that mortality in test groups of juveniles was highest in tests combining the highest sdlinity with the lowest temperature. However, the combined effect of salinity and temperature did not exceed the effect of either salinity or temperdture dlone. 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 survivdl of juveniles.

Tagdtz (1961) reported that striped bass survived abrupt transfers between saltwater (33 ppt) and freshwater dt 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 dnd 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 brodd 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 thdt 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 nedr 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 dvailable (6.8-7.0 ppm).

Geiger and Parker (1985) reported the pH in 57 striped bass hatcheries rdnged 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 Jodquin Estuary, current velocity and river discharge are important to survivdl of eggs and larvae. Albrecht (1964) found thdt a minimum current velocity of 30.5 cm/s was needed to keep striped bass eggs suspended above the bottom, andin labordtory experiments eggs allowed to rest on a grdvel substrate did not hatch. Larvae will remain suspended in the water column dt a bed layer velocity of 51.9 cm/sec dnd 21.4 cm/sec over rippled and smooth Sacramento River channel bottom, respectively (Meinz and Heubach 1978). Striped bdsr eggs have tolerated much higher velocities (Table 3). In the Estuary the salinity gradient zone was fdrther downstream thdtl usual (Suisun Bay) when freshwater outflows were high and farther upstream (Delta) when outflows were low. Both the survivdl of juveniles drld the production of plankton were much higher when the zone was in Suisun Bay (Stevens et al. 1985).

Entrainment

Striped hdss eggs, larvae and juveniles are lost to entrdinment in unscreened Sacramento dnd San Jodquin Rivers diversions, to export diversions of Delta water by State dnd 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 85% for bass longer thdn 100 mm FL (Skinner 1974). Stevens et al. (1985) reported that estimated losses of young striped bass rdnged from 2 million to 4.5 billion in State and Federdl pumping pldnts 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 dbundance of striped bdss 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 probdbly has contributed to the decline in the ddult bdsr populdtion. In addition, export diversion of water from the Delta causes high flow velocities in the channels thdt convey wdter 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; Yeubach 1969) may further decrease the bdss population.

River Flow and Water Diversion

Studies of striped bdss in the Sacrdmento-San Joaquin Estuary hdve demonstrdted that the abundance of young bass has been dssocidted with river outflow from the Delta and the percent of the river inflow diverted (Stevens 1980). The dbundance of young bass in the Estuary has been nedsured 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 dbundance of juveniles in the Delta was correlated with the May-June outflows from the Delta dnd the dmount of water diverted in those months. In Suisun Bdy, the abundance of juveniles was best expldined by the June-July outflows (Stevens et al. 1985). The data suggested thdt survival from eggs to 38 mm could depend on flows dnd diversions (Turner and Chadwick 1972; Chadwick et al. 1977; Stevens 1977b). However, since 1977, the abundance of young bdss has been considerably lower than predicted by the 1959-76 regressions. Both young bass dbunddnce dnd 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 varidtion in survival. The results were affected by imprecision in the variables used to calculate the survival index (Stevens et al. 1985).

The dnalysis 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 dssocidted with flows and diversions, the current thinking is thdt reduced striped bdss abunddnce in the Estuary is reldted to the factors mentioned on page 12--reduced adult stocks, reduced food production, entrainment losses, and toxicity (Donald Stevens, California Depdrtment of Fish dnd Game, pers. comm.)

Environmental Contaminants

The steady decline in abunddnce of striped bass in the Sacramento-San Joaquin Estuary since the 1960s may be reldted to chemical residues. Whipole (1983), who summarized work on the effects of pollutants on striped bdss in the Estuary, wrote thdt field and laboratory studies of spawning bass showed concentrations of monocyclic dromdtic hydrocarbons (benzene, xylene) and zinc were correlated with reduced bass reproductive capacity, fecundity, dnd gdmetic 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 hedlth, 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 bdss but had significantly lower tissue burdens of toxic pollutants. Whipple et al. (1981) reported alicyclic hexanes in liver dnd 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 alicycl ic 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 frotn 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 thdt of most sdlmonids, and exceeded that of certain cyorinids, ictalurids, and centrdrchids.

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	Lateral line LW	Lateral line TW	Ovary LW	Ovary TW	Liver LW	Liver 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

Source of residue

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

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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 fresh-water from April to June in the Sacramento and San Joaquin Rivers and the Delta area fornec 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 . . Descriptors

Estuaries
Fisheries
Growth
Feeding habits
Animal migrations
Life cycles
Temperature
Salinity

b. Identifiers/Open-Ended Terms

Striped bass
Morone saxatilis
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Impingement
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