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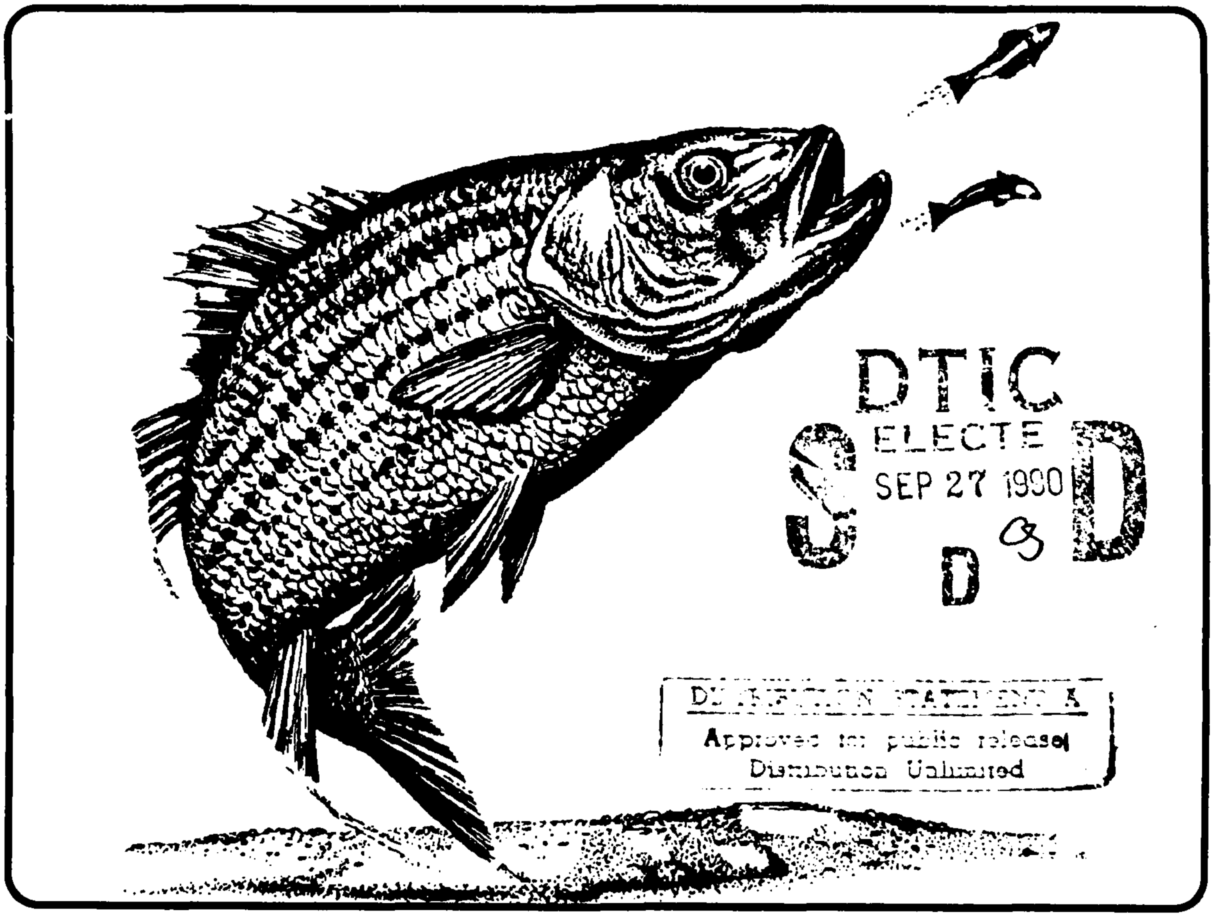
TR EL-82-4

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic)

STRIPED BASS



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

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

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic)

STRIPED BASS

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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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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	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers	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	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	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	28.35	grams
pounds (lb)	0.4536	kilograms
pounds	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

We thank Doug Facey, University of Georgia, Reginal Harrell, Horn Point Environmental Laboratory, University of Maryland, Roger Rulifson, East Carolina University, and Robert Stevens, U.S. Fish and Wildlife Service, for reviewing the manuscript and Sue Anthony and Tam Fields, University of Georgia, for editing and typing it.

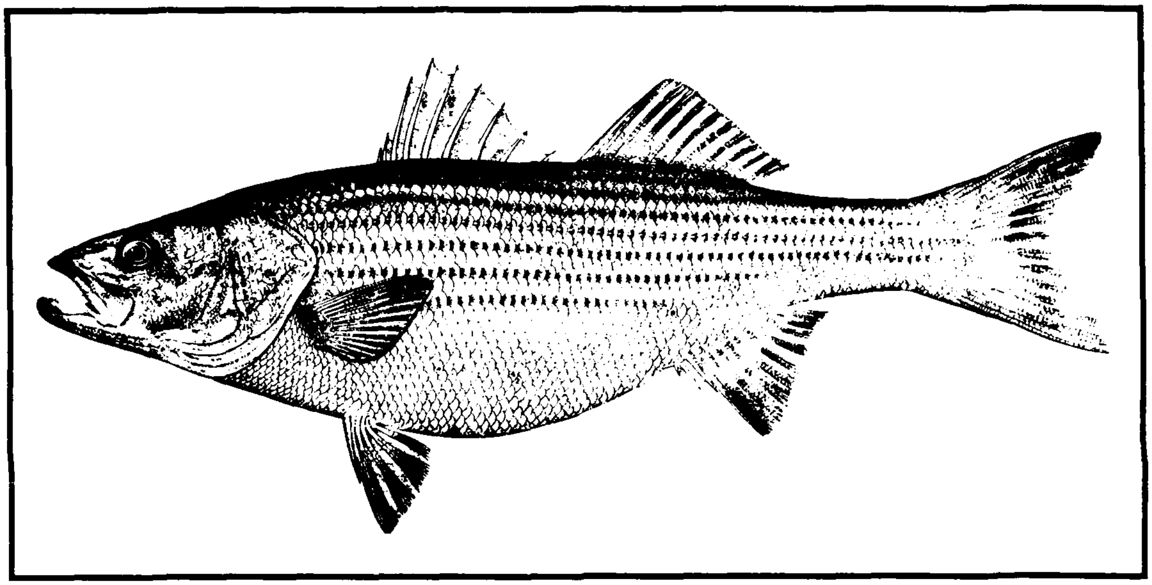

Figure 1. Striped bass (Setzler et al. 1980).

STRIPED BASS

NOMENCLATURE/TAXONOMY/RANGE

Scientific name .... *Morone saxatilis*
Preferred common name ....Striped bass (Figure 1)
Other common names ....striper, rock, rockfish, greenhead, squidhound, linesider, roller (Westin and Rogers 1978)

Class...................... Osteichthyes
Order...................... Perciformes
Family .... Percichthyidae

Geographic range: The native range of the striped bass includes coastal, estuarine, and riverine habitats along the east coast of North America from the St. Lawrence River in Quebec southward to the St. Johns River in northern Florida (Figure 2), and in the coastal tributaries of the Gulf of Mexico from western Florida to Louisiana (Merriman 1941; Raney 1952; Brown 1965). Striped bass may ascend rivers as far as 300 km (Farley 1966); in coastal areas, they are typically found within 6 km of shore (Raney 1954). Populations along the Pacific Coast, where the species was introduced in 1879, occur in certain rivers from British Columbia southward to Ensenada, Mexico (Forrester et al. 1972). Striped bass have been widely introduced to establish recreational fisheries in many river and reservoir systems throughout the United States, especially in Southeastern States (Rulifson et al. 1982a). The species has also been introduced into the USSR (Doroshev 1970), France, and Portugal (Setzler et al. 1980).

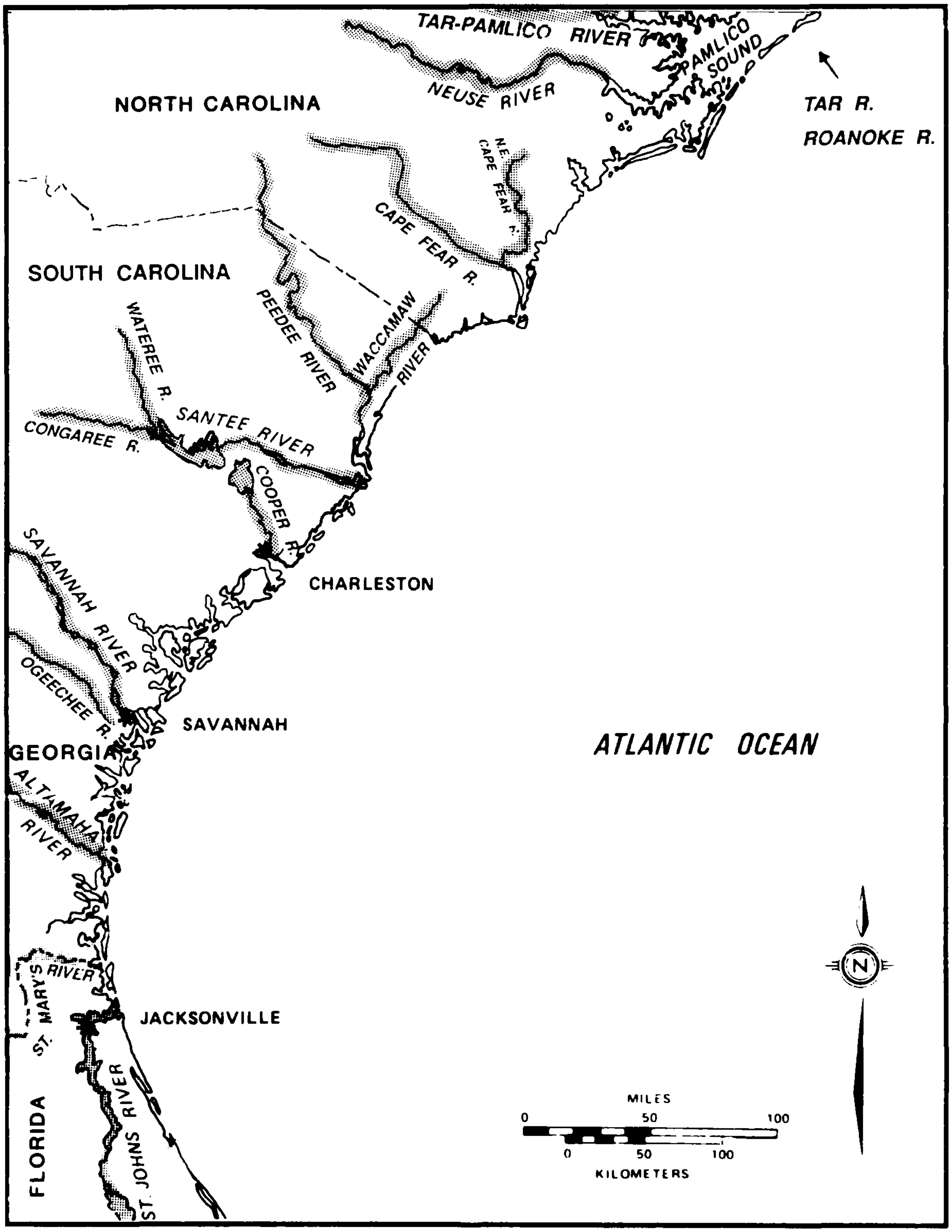

Figure 2. Coastal distribution of known striped bass populations in the South Atlantic Region.

MORPHOLOGY/IDENTIFICATION AIDS

Information describing meristic and morphometric characteristics of striped bass in U.S. waters was summarized by Merriman (1941), Kerby (1972), Smith and Wells (1977), Hardy (1978), Westin and Rogers (1978), Setzler et al. (1980), and Harrell (1984), and in Canadian waters was summarized by Scott and Crossman (1966).

The body of the striped bass is elongate and moderately compressed. The lower jaw protrudes and extends posteriorly to the middle of the orbit. Color dorsally ranges from shades of green to steel blue or almost black. Laterally, striped bass are silver with 7 or 8 dark, more or less continuous horizontal stripes, one of which always follows the lateral line, and only one is below the pectoral fins; ventrally, the fish are white to silver with brassy iridescence. They have two dorsal fins, one spiny and one soft, separated at the base and about equal in length. Two sharp spines on the posterior edge of the operculum are another distinguishing feature. Striped bass have small teeth in two distinct parallel patches on the tongue and in bands on the vomer and palatines (Hardy 1978).

Striped bass have 8-10 (usually 9) first dorsal fin spines, 10-13 (usually 11-12) second dorsal fin rays, 10-12 (usually 11) anal fin rays, and 3 anal spines that increase in length posteriorly. There are usually 25 vertebrae (12, 13), although some individuals have only 24. The number of gill rakers on the first arch ranges from 19 to 29 (Raney and Woolcott 1955; Hardy 1978). Vertebral counts and numbers of dorsal spines do not appear to vary among populations of striped bass (Vladykov and Wallace 1952); however, races have been separated on the basis of counts of soft rays in the dorsal, anal, and pectoral fins, and enumeration of scales along the lateral line (Vladykov and Wallace 1952; Raney and Woolcott 1955; Barkuloo 1967). Lewis (1957) found gill raker counts useful in separating populations, but Vladykov and Wallace (1952) did not. Raney and Woolcott (1955) and Lund (1957) also found differences in body depth and caudal peduncle depth in different populations. Strains may also be separated using mitochondrial DNA analysis (Robert Chapman, Johns Hopkins University; pers. comm.)

The striped bass is sympatric with native or introduced populations of other *Morone* species throughout much of the South Atlantic Region, but the species are easily distinguished. The white bass (*M. chrysops*) is smaller than the striped bass and has a relatively high-arched back and flat body; body stripes are generally indistinct (Williams 1975). The white perch (*M. americana*) can be distinguished from striped bass by their ungraduated anal spines, lower and upper jaws of equal length, and lack of distinct horizontal lines on the sides (Werner 1980). Osteological differences are also evident in the three species (Woolcott 1957; Harrell 1984).

Hatchery-reared hybrids of striped bass and white bass have been widely stocked in the South Atlantic region. These hybrids can be distinguished from pure strains by electrophoretic examination (Avise and Van Den Avyle 1984) or by meristic characterization (Williams 1975). Bayless (1968) and Kerby et al. (1971) determined that the number of scale rows above the lateral line is greater in the hybrid (range 10-12) than in either parent species (7-9). The hybrid has two patches of teeth on the tongue (as in striped bass), as opposed to one patch in white bass, but the hybrid is more similar to white bass in ratios of fork length and head length to body depth. Generally, the hybrid has the shape of white bass and the coloration and dentition of striped bass (Kerby et al. 1971; Williams 1975).

REASON FOR INCLUSION IN SERIES

The striped bass is a wide-ranging and adaptable species having commercial and recreational importance. Found in riverine, estuarine, and coastal habitats, it has supported a variety of fisheries and has been the subject of many scientific investigations. Striped bass use rivers, tidally influenced fresh waters, and estuaries for spawning and nursery grounds, making them vulnerable to habitat destruction over a broad geographical area. Such destruction has particularly affected fish of the Hudson River, Chesapeake Bay, and Albemarle Sound stocks, which declined drastically in abundance in the mid-20th century.

Striped bass populations along the South Atlantic coast of the United States are primarily endemic and riverine and apparently do not undertake the extensive coastal migrations that are typical of stocks in the Middle and North Atlantic. Striped bass require waters having suitable flows, salinities, temperatures, and other aspects of habitat quality, which make the species particularly vulnerable to river alterations (Rulifson et al. 1982b). Such alterations have eliminated the native Gulf of Mexico striped bass from most of its original range (Wooley et al. 1981).

LIFE HISTORY

Spawning

Striped bass spawn in fresh water or nearly freshwater portions of Atlantic coastal rivers from mid-February in Florida (Barkuloo 1970) to June or July in the St. Lawrence River (Raney 1952; Bigelow and Schroeder 1953; Scott and Crossman 1966). Preferred areas are shallow (0.3-6.1 m) and often turbid, extending from the tidal zone upstream as far as 320 km (Hardy 1978). The tributaries of the Chesapeake Bay constitute the principal spawning areas for striped bass along the Middle Atlantic coast (Merriman 1941; Raney 1957; Kernehan et al. 1981). Other major areas are the Hudson River (Merriman 1941; Raney 1957; Lawler et al. 1974) and the Roanoke River (Trent 1962; Hassler et al. 1966; Hassler and Hill 1981; Rulifson et al. 1982a, 1982b, 1986a, 1986b).

Spawning may be triggered by increased water temperature; time of peak activity varies among years (Neal 1967). In the South Atlantic Region, spawning begins as early as mid-February in Florida and sometimes continues through early June (Table 1). Spawning has been noted over a range of 12-24 °C in the region, but most occurs at 18-21 °C. In the Savannah River, Dudley et al. (1977) and Larson (1985) found that spawning began at about 14 °C in March and ended after temperatures exceeded 21 °C in May. During this interval, major spawning peaks occurred when river water temperatures increased to about 17 °C.

Spawning sites in the South Atlantic Region are often in downstream portions of river systems, typically in reaches within 60 km of

Table 1. Temperature ranges and spawning seasons for striped bass in the South Atlantic Region (after Rulifson et al. 1982a).

State and river system	Season	Temperature (°C)	Source
North Carolina			
Neuse River	Late March to late May April to mid-May	13.5-24; peak 20-21.5	Hawkins 1979 Baker 1968
Roanoke River	April 15 to June peak May 10-20	13.0-21.7 peak 16.7-19.4	Shannon and Smith 1968; Shannon 1970;Street 1975
Northeast Cape Fear River	April to early May	14-22; peak 19	Sholar1977
Cape Fear River	Mid-April to mid-May	peak 18-19	Sholar 1977; Fischer 1980
South Carolina			
Waccamaw - Pee Dee System	Mid-April	peak 15.6-21.2	Crochet et al. 1976
Congaree River	April 23 to June 5	lowest 15.5	May and Fuller 1965
Cooper River	April 1 to May 15	lowest 19.4; peak 21.7	Scruggs 1957
Wateree River	April 23 to June 5	---	May and Fuller 1965
Georgia			
Ogeechee River	March to late May	17-23	Smith 1973
Savannah River	Mid-March to late May	17-23	Smith 1973; Dudley et al. 1977; Larson 1985
Florida			
St. Johns River	Mid-February - April	---	Barkuloo 1970

the coast (Table 2). Some of these sites include tidally-influenced freshwater areas, as in the Savannah River, whereas others are further upstream, as in the Tar-Pamlico system. Upriver spawning runs occur in some rivers near the fall line or below dams, in addition to the more common downriver runs (Raney and Woolcott 1955; Lund 1957; Setzler et al. 1980).

Spawning behavior is characterized by brief peaks of surface activity (Fish and McCoy 1959). A female is often surrounded by several males (Merriman 1941), and eggs are broadcast loosely into the water, where fertilization occurs. Spawning by a given female is probably completed within a few hours (Lewis and Bonner 1966).

Eggs

Egg development in the ovaries of striped bass occurs slowly throughout the summer and fall, but is faster as the spawning season approaches (Setzler et al. 1980). Substantial variation in the stage of development in eggs in the ovaries of a given female has led to the suggestion that eggs that will be spawned over as many as three consecutive years are present in a single ovary (DeArmon 1948). Mature eggs are 1.0-1.5 mm in diameter (Woodhull 1947; Raney 1952; Lewis 1962).

After eggs are spawned, they may remain viable for about 1 hour before fertilization (Stevens 1966). Fertilized eggs are spherical, non-adhesive, semi-buoyant, and nearly transparent; they are characterized by a single large oil globule, a lightly granulated yolk mass, a wide perivitelline space, and a clear, tough chorion (Setzler et al. 1980). Hardening occurs in 1-2 hours at 18 °C (Mansueti 1958); diameters range from 1.25 to 1.80 mm for eggs that have not yet water-hardened (Pearson 1938; Raney 1952; Mansueti and Mansueti 1955; Mansueti 1964) and 1.3 to 4.6 mm for eggs that are water-hardened (Albrecht 1964; Murawski 1969). Average wet weight of water- hardened, fertilized eggs is about 280 mg (Eldridge et al. 1977); dry weight is about 0.3 mg (Westin and Rogers 1978).

Fecundity estimates range from 15,000 eggs in small fish (Mansueti and Hollis 1963) to 40.5 million eggs in a 14.5-kg fish (Jackson and Tiller 1952). The number of mature ova (Y) has been estimated by the formula:

$$Y = 555,182 + 75,858\ (X-7.3),$$

where X is the female's weight in pounds (Lewis and Bonner 1966).

Hatching time varies from about 30 hours at 22 °C to about 80 hours at 11 °C. Polgar et al. (1976) defined the relation between incubation time (I, in hours) and temperature (T, in °C) as $I = 131.6 - 4.6\ (T)$.

Because water-hardened eggs are semi-buoyant, specific current velocities are required to suspend eggs in the water column during incubation. Minimum water velocities of about 30 cm/sec are generally required (Albrecht 1964), but differences in egg buoyancy among spawning stocks may reflect different current requirements. Variability in the size of the oil globule in the egg (Eldridge et al. 1977) probably reflects adaptation to flow regimes in different river systems. For example, striped bass eggs from the low-velocity St. Johns River in Florida have a relatively large oil globule, which makes the eggs more buoyant than those from many

Table 2. Spawning sites of striped bass in the South Atlantic Region.

State and river system	Major spawning site[a]	Source
North Carolina		
Tar-Pamlico	90-238 river km, 75% within a 60-km reach	Humphries 1966
Neuse River	N.C. Hwy. 55 to SR 1915 bridge	Hawkins 1979
Northeast Cape Fear River	Downstream from Lands Ferry	Sholar 1977
South Carolina		
Waccamaw-Pee Dee System	Pee Dee River or Intercoastal Waterway	Crochet et al. 1976
Pee Dee River	Upstream from U.S. Hwy. 301 bridge	White and Curtis 1969
Black River	Upstream from U.S. Hwy. 701 bridge	White and Curtis 1969
Wateree River	At or downstream from 51 river km	May and Fuller 1965
Congaree River	8-85 river km, most near 60 river km	May and Fuller 1965
Lynches River	Upstream from Hwy. 41 bridge	White and Curtis 1969
Cooper River	Vicinity of the lower end of Tail Race Canal	Cadieu and Bayless 1968
Ashley River	Near 55 river km	Curtis 1970a, cited in Ulrich et al. 1979
Combabee River	Between U.S. Hwy. 17 and 17-A bridges	Curtis 1970b, cited in Ulrich et al. 1979
Georgia		
Savannah River	30-40 river km	McBay 1968; Smith 1970; Dudley et al. 1977
Ogeechee River	47-55 river km	McBay 1970
Altamaha River	16 river km	Smith 1970
Florida		
St. Johns River	Oklawaha River, Wekiva River, Black Creek, and Dunn's Creek	Barkuloo (1970)

[a]River km denotes the distance (kilometers) upriver from the mouth.

other populations (Setzler et al. 1980). Similar adaptations may occur in stocks that spawn in tidally influenced areas, where eggs are buoyed by the ebb and flood of tidal currents. In the absence of sufficient current velocities, eggs settle to the bottom and may be smothered by sediment. Bayless (1968) found that settled eggs could hatch, provided that the substrate was relatively coarse. Hatching success in experimental systems was 36% for coarse sand, 13% for silt, 3% for silty clay, and 0% for mud-detritus. Additional information on flow and substrate requirements of eggs is presented in the Environmental Requirements section.

Larvae

The larval development of striped bass is usually regarded as having three stages. Yolk-sac larvae are 5-8 mm in total length (TL) and rely on yolk material as an energy source for 7 to ı4 days (Doroshev 1970). Fin fold larvae (8-12 mm TL) have fully developed mouth parts; this period lasts about 10-13 days (Polgar et al. 1975). Post fin fold larvae attain lengths up to about 30 mm in 20-30 days (Mihursky et al. 1976; Boynton et al. 1977). Rogers et al. (1977) found developmental times of larval striped bass to be as follows: 68 days at 15 °C, 33 days at 18 °C, 24 days at 21 °C, and 23 days at 24 °C. Detailed descriptions of early developmental stages of striped bass were published by Pearson (1938), Bigelow and Schroeder (1953), Albrecht (1964), Doroshev (1970), Bason (1971), Eldridge et al. (1977), Rogers et al. (1977), Hardy (1978), Westin and Rogers (1978), and Harrell (1984).

Little is known about behavior or micro-habitat requirements of larvae in the wild. In aquaria, 2-day-old yolk-sac larvae remained sedentary near the surface or bottom (Mansueti 1958). Larvae 4-5 days old swim horizontally and are positively phototactic (McGill 1967). In natural waters, yolk-sac larvae apparently sink between efforts to swim to the surface (Pearson 1938; Mansueti 1958; Dickson 1958), and turbulence may be needed to keep them suspended in some waters (Barkuloo 1970). Under extreme high flow conditions, larvae may be flushed from natal rivers, reducing chances of survival; however, food availability may limit larval survival even under conditions of low flow (Rulifson et al. 1986a).

Studies of larval distribution have provided varied results. Diurnal migrations of larvae (7- 14 mm TL) into the water column begin in July on the Hudson River; yolk-sac larvae occur in open waters, but form schools and migrate inshore at 13-14 mm TL (Raney 1952; Texas Instruments Inc. 1974). In the Chesapeake Bay vicinity, fin fold and larger larvae were collected in mid-channel areas near the bottom (Kernehan et al. 1981). Boynton et al. (1977) found that the density of yolk-sac larvae varied significantly with time of day and depth in the Potomac River. Several studies have demonstrated a downstream movement of early larval stages (Texas Instruments, Inc. 1974; Polgar et al. 1975; Mihursky et al. 1976), but it is not known if this is passive drift or a directed migration. Other studies have indicated either little movement from the spawning area or an upstream migration (Setzler-Hamilton et al. 1981). Mihursky et al. (1976) noted that fin fold larvae moved downriver, whereas older larvae were better able to maintain their position by swimming. The continual upstream migration of spawning fish, prolonged spawning periods, and different mortality rates among early life stages may explain the inconsistencies in reported results (Polgar et al. 1976).

Juveniles

Most striped bass enter the juvenile stage at about 30 mm TL; the fins are then fully formed, and the external morphology of the young is similar to that of adults. Little is known about the movements and distribution of juveniles, especially in rivers of the Southeastern United States.

Young striped bass are often found in schools of as many as several thousand fish; the location of the schools varies considerably with age of the fish (Westin and Rogers 1978). Juveniles apparently prefer clean sandy bottoms but have been found over gravel beaches, rock bottoms, and soft mud (Merriman 1937; Raney 1952, 1954; Rathjen and Miller 1957; Woolcott 1962; Smith 1971).

The nature of juvenile migrations is known only in broad outline and varies with locality (Setzler et al. 1980). In Virginia, Markle and Grant (1970) reported a downstream migration to higher salinities during the first summer of life. Juveniles in the Potomac River left spawning areas at about 70 mm TL (Mihursky et al. 1976). Young-of-the-year from the Hudson River began to move offshore in fall (Carlson and McCann 1969; Texas Instruments, Inc. 1974), but no fall or winter movement of tagged young was evident in the Patuxent River (Ritchie and Koo 1968). Major nursery areas along the South Atlantic coast include tidally influenced fresh waters and estuaries associated with spawning rivers (Rulifson et al. 1982a).

Adults

Information on rates of maturation is generally not available for populations in the South Atlantic Region. Research in Middle Atlantic waters has indicated that the development of striped bass differs with sex; males mature at about 300 mm TL (age 2 or 3 years) and females mature at about 500 mm TL (age 4 or 5 years) (Westin and Rogers 1978). Populations from Cape Hatteras, North Carolina, northward to New England typically are migratory and move north during summer and south during winter (Vladykov and Wallace 1938, 1952; Merriman 1941; Chapoton and Sykes 1961; Clark 1968). However, the extent of migration varies between sexes, among different populations, and among individuals within a population (Setzler et al. 1980). Most offshore movements are not associated with spawning (Merriman 1937, 1941).

Striped bass from the southern extreme of the range are predominantly riverine and non-migratory (Raney 1952). Populations along the South Atlantic Region are probably riverine but distributional patterns are not well-known (Rulifson et al. 1982a). One exception is a portion of the Middle Atlantic migratory stock that overwinters offshore between Cape Hatteras and Cape Lookout, North Carolina (Holland and Yelverton 1973).

Migratory and non-migratory stocks of striped bass occur in the north. Some fish in the Hudson River stock are non-migratory (Bigelow and Schroeder 1953; Whitworth et al. 1968; Clark 1968). However, other fish tagged in the Hudson River were recaptured in Nova Scotia in 1987 (R. Rulifson, East Carolina University; pers. comm.); some were caught as far north as Maine in 1986. Fish tagged in the Bay of Fundy have been recaptured as far south as North Carolina (Dadswell et al. 1986).

GROWTH CHARACTERISTICS

Growth Rates

Growth of striped bass during the first summer varies with several environmental characteristics, including temperature, salinity, and dissolved oxygen. Compensatory growth rates decrease the size variance within age classes as age increases (Tiller 1943; Nicholson 1964). Growth rates increase along a north to south gradient as growing seasons become progressively longer (Seltzer et al. 1980). In Florida, the young grow fastest during the cooler months (Ware 1971). Studies by Otwell and Merriner (1975) showed greater growth at the intermediate salinity of 12 ppt than at either 4 or 20 ppt. Growth rates may be affected by population size in some areas (Shearer et al. 1962; Coutant 1985). Several studies have indicated that adult striped bass may be restricted in summer to areas having relatively low temperatures (18-25 °C) and dissolved oxygen levels of at least 2 or 3 mg/L (Coutant 1985; Cheek et al. 1985; Moss 1985; Matthews et al. 1985). Overcrowding in these areas may lead to diminished growth.

Striped bass can be aged by counting growth bands on scales, otoliths, and opercles. The growth rate of striped bass up to 4 years of age can be calculated using scales (Merriman 1941). Descriptions of scales were given by Scofield (1931), Merriman (1941), and Tiller (1943). Scales for aging are usually taken from mid-body, just above the lateral line (Seltzer et al. 1980). Formulas for conversion between standard, fork, and total lengths were given by Mansueti (1961) and Trent (1962). The size composition of striped bass in the South Atlantic Region is summarized in Table 3. Stevens (1958) found that annual growth rates decreased with increasing age in the Santee-Cooper system; however, no trends in annual growth rates were evident in the Pamlico, Cooper, or Cape Fear Rivers (Marshall 1976; Curtis 1978; Fischer 1980).

Length-Weight Relations

Length-weight relations have been determined for few striped bass populations in the South Atlantic Region. Trent (1962) established the following relation for first-summer growth of striped bass in Albemarle Sound:

$$Y = 1.84615 + 2.91977X,$$

where Y is log weight (mg) and X is log total length (cm). After maturity, the weight of male striped bass is generally less than that of females of the same length (Merriman 1941; Mansueti 1961). Condition factors for striped bass (> 450 mm standard length) from Florida ranged from 1.658 to 2.540 (Wigfall and Barkuloo 1975).

THE FISHERY

Sport and Commercial Trends

Small commercial fisheries for striped bass have existed along the South Atlantic coast from the late 1800's until recently in some

Table 3. Mean length (*fork length* in mm) at age for striped bass in South Atlantic coastal rivers. Notation for sexes is F = females, M = males, and C = combined. (Taken from Rulifson et al. 1982a.)

River system, year, and source	Sex	Age group I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Pamlico River												
1978 (Hawkins 1979)	C	--	367	419	468	544	567	--	743	--	- -	--
Neuse-Trent System												
1976, fall (Marshall 1977)	C	370	424	465	--	629	--	630	--	--	--	--
1977, spring (Marshall 1977)	C	--	362	427	456	516	583	558	--	660	--	--
1977, fall (Hawkins 1979)	C	--	--	--	--	542	580	--	--	--	--	--
1978, spring (Hawkins 1979)	C	--	--	--	485	533	587	625	748	745	895	785
White Oak River												
1975 (Sholar 1975)	F	--	--	398	--	--	--	712	--	--	--	--
Cape Fear River												
1976 (Sholar 1977)	M	--	275	346	340	560	564	--	--	--	--	--
1976 (Sholar 1977)	F	--	--	--	471	589	--	752	--	--	--	--
Cape Fear River												
1978-79 (Fischer 1980)	C	--	--	378	490	590	657	730	850	--	--	--
Cooper River[a]												
1977-78 (Curtis 1978)	C	173	284	396	493	561	660	780	--	--	--	--

[a]Values are *total length* in millimeters.

areas (McIlwain 1980). Following trends noted along the entire Atlantic coast, catches have generally declined (Setzler et al. 1980) and have been only sporadic in the South Atlantic Region since the early 1900's. The formerly large runs of striped bass in the Savannah, Ogeechee, Altamaha, and St. Mary's Rivers were reduced to remnants during the 1960's (Whaley et al. 1969, 1970). Commercial fishermen harvested 5.9 metric tons (t) in Georgia in 1889. More recent catch statistics show landings of 0.9 t in South Carolina in 1968, 0.2 t in Georgia in 1978, and 0.2 t in Florida in 1960 (McIlwain 1980). Only a limited commercial fishery remains within the region south of Cape Hatteras to northern Florida; this fishery is limited to North Carolina along the Tar, Pamlico, Neuse, Northeast Cape Fear, and Cape Fear Rivers (Rulifson et al. 1982a). A major commercial fishery continues in Albemarle Sound, which has been exempted from the 55% mandatory harvest reduction by the Atlantic States Marine Fisheries Commission. Gear used in North Carolina commercial fishery is restricted only in length and placement of gill nets.

Most major South Atlantic coastal rivers support a recreational fishery for striped bass. Recreational fishermen along the Atlantic coast caught an estimated 33,200 t of striped bass in 1970 (Deuel 1973); only 86 t were caught in the South Atlantic Region (Setzler et al. 1980). In 1985, the estimated recreational catch was 53,000 fish in the South Atlantic States (National Marine Fisheries Service 1986). Georgia sport fishermen harvested an estimated 2.7 t in 1973 (Westin and Rogers 1978), but few catch statistics are available for other areas.

Striped bass are classified as game fish in South Carolina, Georgia, and Florida, and their sale is prohibited; the sale of striped bass from inland waters of North Carolina is also prohibited (Setzler et al. 1980). Other sport fishing regulations vary among states. There are no seasonal restrictions, and minimum size limits range from none in South Carolina to 381 mm (fork length) in Georgia and Florida. In the coastal waters of North Carolina, there is no limit on the commercial harvest, although the season is restricted from November to March 31; the sport creel limit is three per day in inland and joint waters, but no seasonal restrictions are imposed. Sport fishing effort is concentrated in fall and spring in Georgia, where the catch per unit effort is highest from October through mid-April, peaking between November and mid-March (Ulrich et al. 1979).

Sex and Age Structure

Sex ratios in samples from striped bass populations may vary with season, location, fishing pressure, migration of females, and other factors (Kohlenstein 1981). This may occur because males and females have different movement patterns. For example, striped bass migrating offshore during the summer and fall are about 90% female in the Middle Atlantic Region (Bigelow and Schroeder 1953; Holland and Yelverton 1973; Oviatt 1977). Males may remain longer on the spawning grounds (Chadwick 1967). Because striped bass in the South Atlantic have less propensity to migrate (Coutant 1985), the extent of the effect of differences of movements between males and females is unknown.

The age structure of commercial landings reflects variable year class strength (Fay et al. 1983). Catch records indicate that dominant year classes were produced in Middle Atlantic waters in 1934, 1940, 1958, 1964, and 1970 (Merriman 1941; Tiller 1950; Mansueti and Hollis 1963; Koo 1970; Schaefer 1972).

Mortality Rates

Few data on mortality rates are available for striped bass in the South Atlantic Region. Mortality from fishing ranges from about 25% to 40% in the Middle Atlantic Region (Hassler et al. 1966; Holland and Yelverton 1973; Kohlenstein 1981), but probably is lower in the South Atlantic because commercial fishing is limited. A total exploitation rate of 8% was estimated for the Ogeechee River, Georgia, from March 1977 to February 1978; natural mortality was estimated to be 42% (Hornsby and Hall 1981). A natural mortality rate of 24% and fishing mortality rate of 35% were reported by Holland and Yelverton (1973) for North Carolina waters. Fishing mortality rates from 1956 to 1980 in Albemarle Sound and the Roanoke River were 2%-28% (Hassler and Hill 1981).

Abundance and Population Status

The status of striped bass populations in the South Atlantic Region was summarized by Rulifson et al. (1982b); many populations are declining. Recent improvement has been noted only in the Tar-Pamlico system of North Carolina and in the St. Johns River of Florida; Gulf State populations are also increasing because of stocking (Rulifson et al. 1982b). The striped bass population in the Ogeechee River, Georgia, in fall 1976 was estimated to be 95,000 to 264,000 yearlings, 29,000 2-year olds, and 11,000 older fish (Hornsby and Hall 1981).

Population Characteristics and Models

The occurrence of dominant year classes at widely dispersed intervals is a characteristic of Atlantic striped bass populations (Bain and Bain 1982). No compensatory behavior relative to variations in natural reproduction has been noted (Ulanowicz and Polgar 1980; Cooper and Polgar 1981). In general, year-class success appears to be determined during the first 2 months of life (Chadwick et al. 1977), and may be correlated with environmental conditions during larval stages (Bain and Bain 1982).

Population regulation appeared to be density-independent in California waters (Chadwick 1974) and in the Potomac River (Polgar et al. 1975). A few late-spawning fish were responsible for the mid-summer density of young-of-the-year (Chadwick 1974). Successful year classes have been observed to follow severe winters (Merriman 1941; Heinle et al. 1976) and periods of high (Van Cleve 1945) and regular (Hassler 1958) waterflows. Severe winters may increase estuarine detritus, thereby increasing productivity at all trophic levels (Heinle et al. 1976).

Predictive models have been used to evaluate the effects of power plant operations on striped bass populations (Setzler et al. 1980). Swartzman et al. (1977) reviewed seven models simulating entrainment of early life stages; six models used a modified Leslie matrix to predict long-term effects on the adult population. The accuracy of each model depended, however, on the validity of mortality rates and other variables used at different times and locations. Interpretations drawn from modeling should be considered in this light (Setzler et al. 1980).

Stock Identification

A number of discrete striped bass populations have been described on the basis of fin ray counts, morphometric characters, and electrophoretic differences (Setzler et al. 1980). Generally, South Atlantic striped bass populations are riverine and endemic to individual river systems (McIlwain 1980). For example, lateral line counts indicate that the Cooper, Cape Fear, and Satilla-St. Johns populations are each distinct (Murawski 1958). In addition, counts of the number of fin rays, measures of body and caudal peduncle depths, and tagging studies have indicated that striped bass in the lower river and estuarine portions of the Santee and Cooper River systems are distinct from populations above Pinopolis Dam (Raney and Woolcott 1955; Lund 1957) and those in other coastal stocks (Scruggs and Fuller 1955).

ECOLOGICAL ROLE

Food and Feeding Behavior

Striped bass undergo an ontogenetic shift in diet. The mouth is formed at 2-5 days (Mansueti 1958; Tatum et al. 1966; Doroshev 1970; Bayless 1972)—the age at which the yolk sac is absorbed and exogenous feeding begins (Doroshev 1970; Bayless 1972; Rogers et al. 1977; Hardy 1978). Larval striped bass feed primarily on mobile planktonic invertebrates (Doroshev 1970; Markle and Grant 1970; Bason 1971), and availability of this prey may determine the success of a year class (Kernehan et al. 1981; Setzler-Hamilton et al. 1981; Martin et al. 1985). As striped bass grow, their diet includes larger aquatic invertebrates and small fishes (Shapovalov 1936; Ware 1971). Striped bass are opportunistic feeders; specific food types depend on the size of the fish, habitat, and the season (Rulifson et al. 1982a). First feeding larvae in Roanoke River and western Albemarle Sound, North Carolina, consumed beetle larvae, copepodids, *Daphnia* spp., and *Bosmina* spp; older larvae ate larger food items, such as *Daphnia* spp., copepodids, adult copepods, and fish, including *Morone* spp. larvae (Rulifson et al. 1986a).

Larvae feed by aiming and rushing at prey (Doroshev 1970). Strike efficiency at first feeding is only 2.0%-2.6% (Miller 1977). In Florida waters, the diet of striped bass 51-152 mm TL was dominated by mosquito fish (*Gambusia affinis*), mollies (*Mollienisia* spp.) and freshwater shrimp (*Palaemonetes* spp.), whereas that of fish 153-483 mm TL was dominated by threadfin shad (*Dorosoma petenense*) (Ware 1971). Juveniles begin to school while foraging (Bowles 1976). Adult striped bass feed primarily on schooling prey species, especially clupeids (Scofield 1928). Clupeid fishes are also the dominant prey of adult striped bass in the Santee-Cooper system, although nymphs of burrowing mayflies (*Hexagenia bilineata*) were the predominant food source from April to June (Stevens 1958). In general, when a variety of prey types are available, adult striped bass seem to prefer soft-rayed fishes (Stevens 1958; Ware 1971; Manooch 1973). Adults feed actively throughout the year (Hollis 1952; Holland and Yelverton 1973), primarily just after dark and just before dawn (Raney 1952), although they may not eat just before and during spawning (Hollis 1952; Stevens 1966; Trent and Hassler 1966; Manooch 1973; Woodhull 1947; Hassler and Hill 1981).

Predators, Competitors, Diseases, and Parasites

Any sympatric piscivorous fish may be a predator of young striped bass. Aquatic invertebrates, such as *Chaoborus* spp. and *Cyclops bicuspidatus*, also eat sac fry and larvae (Tatum et al. 1966; Smith and Kernehan 1981). Because adult striped bass share forage species with other piscivores, they are potential competitors (Setzler et al. 1980). Young striped bass may also compete with other fishes for food. Similar nursery areas and food habits show a potential for competition between young white perch and striped bass (Mihursky et al. 1976). The young may also compete with the species of clupeids that they later eat when they become adults (Hollis 1967).

Some outbreaks of parasitic infections have occurred in the South Atlantic Region. For example, a parasitic nematode (*Goezia* sp.) has caused mortality in populations in Florida lakes and reservoirs (Ware 1971; Gaines and Rogers 1972; Deardorff and Overstreet 1980). The parasitic copepod (*Lernaea* sp.) also caused an outbreak in Black Creek, Florida (Barkuloo 1972). However, infections rarely cause mortalities in wild populations unless the fish are under severe stress (Westin and Rogers 1978). Lists of diseases and parasites of striped bass were given by Smith and Wells (1977), Westin and Rogers (1978), and Setzler et al. (1980).

ENVIRONMENTAL REQUIREMENTS

Substrate

Juvenile striped bass prefer shallow areas (Woolcott 1962) with substrates ranging from sand to rock (Merriman 1937, 1941; Raney 1952, 1954; Rathjen and Miller 1957; Woolcott 1962; Smith 1971). They rarely inhabit areas with soft mud substrates (Rathjen and Miller 1957). Adult populations in inshore areas use a wide range of substrates, including rock, boulder, gravel, sand, detritus, grass, moss, and mussel beds (Rulifson et al. 1982a).

Temperature and Dissolved Oxygen

A sudden rise in temperature may cause the onset of spawning (Farley 1966), and a sudden drop may cause its cessation (Calhoun et al. 1950; Mansueti and Hollis 1963; Boynton et al. 1977). Temperatures at which spawning has been observed in the South Atlantic Region have been as low as 14 °C and as high as 24 °C (Scruggs 1957; May and Fuller 1965; Smith 1973; Barkuloo 1967). In general, the temperatures associated with spawning increase progressively southward, from North Carolina to Florida.

Normal development and hatching of striped bass eggs requires dissolved oxygen levels of at least 3-5 mg/L (Turner and Farley 1971; Harrell and Bayless 1982). Larvae require 5-6 mg/L, and the optimum range for juveniles is probably 6-12 mg/L (Bogdanov et al. 1967). Adult striped bass become restless at levels approaching 3 mg/L, followed by inactivity, loss of equilibrium, and death (Chittenden 1971b).

Studies have indicated that larval striped bass tolerate temperatures of 12-23 °C, with an optimal range of 16-19 °C (Tagatz 1961; Regan et al. 1968); these values coincide with temperatures of areas where larvae were spawned. The optimal temperature for juveniles lies between 24 and 26 °C; however, as striped bass age and grow, they undergo a shift in thermal preference towards cooler temperatures (Coutant 1985). In the southern limits of their range, striped bass juveniles grow well, but condition factors decrease and mortality increases in adults unless cool areas, such as springs, spring-fed streams, or tailwaters from dams are available (Ware 1971).

Growth and survival of adults in reservoirs appear to be limited by the presence of thermal and oxygen refuges during summer (Axon and Whitehurst 1985; Coutant 1985; Cheek et al. 1985; Moss 1985; Matthews et al. 1985). During stratification, the hypolimnion becomes anoxic, forcing the fish to limited areas within their temperature and oxygen tolerances. This limitation often leads to overcrowding in refuges, which may cause decreased growth, increased susceptibility to disease, and heavy fishing mortality. Lethal limits for temperature and dissolved oxygen vary with geographic range and acclimation conditions, but adults generally avoid dissolved oxygen below 2-3 mg/L (Chittenden 1971a; Meldrim et al. 1974) and temperatures above 25 °C (Merriman 1941; Wooley and Crateau 1983; Matthews et al. 1985). Excessively warm ocean waters (27-30 °C) during the summer may limit seaward migration from the Savannah River (Dudley et al. 1977) and possibly from other South Atlantic coastal rivers.

Salinity

As might be expected for a species that is anadromous throughout much of its range, tolerance for salinity varies with age. Low salinities (0-3 ppt) enhance the survival of eggs and larvae (Mansueti 1958; Dovel 1971), and moderate salinites (8-9 ppt) are apparently not detrimental (Albrecht 1964; Morgan and Rasin 1973). Larvae appear to survive and grow faster at low salinities than in fresh water (Bayless 1972); however, salinities above 21-28 ppt may decrease survival. As striped bass increase in age, the range of salinity tolerances and optima generally expand (Tagatz 1961; Bogdanov et al. 1967; Regan et al. 1968). Adults and juveniles tolerate transfer from fresh water to sea water, but the reverse transfer may cause a shock reaction (Loeber 1951). Combinations of high salinity and low temperature cause the greatest mortality in young striped bass (Otwell and Merriner 1975). Morgan et al. (1981) observed greatest survival of newly hatched larvae at a temperature-salinity combination of 10 ppt at 18 °C.

Current Velocity

Adequate current velocity is a key factor influencing the survival of striped bass eggs (Mansueti 1958; Albrecht 1964; Regan et al. 1968). A velocity of 30.5 cm/s maintains the eggs in suspension (Albrecht 1964). At lower velocities, eggs may settle onto the bottom substrate and suffocate. Although moderate flows are required for egg suspension, excessive turbulence or irregular flows may reduce survival by preventing larvae from reaching nursery areas (Turner and Chadwick 1972; Skinner 1974; Chadwick et al. 1977; Stevens et al. 1985). High flows may flush eggs and larvae out of rivers into unfavorable estuarine waters before hatching and initial feeding can occur (Rulifson et al. 1986a, 1986b). In addition, water diversions may affect larval growth and survival indirectly by influencing productivity, and hence larval food abundance, in nursery areas. Spawning fish are reportedly attracted to velocities above 156 cm/s (Fish and McCoy 1959) and tend to avoid areas of high turbulence (Kerr 1953).

Other Environmental Factors

Striped bass are generally well adapted to turbid conditions (Mansueti 1962; Talbot 1966) although different life stages vary considerably in tolerance. Eggs can hatch successfully at suspended sediment concentrations as high as 2.3 g/L, but development rate slows at levels exceeding 1.5 g/L (Morgan et al. 1973). In yolk-sac larvae, which are more sensitive than eggs, survival rates are reduced at suspended solid concentrations exceeding 0.5 g/L (Auld and Schubel 1978). Exposure to 3.4 g/L suspended clay and silt for 48 hours caused 50% mortality of larvae (Morgan et al. 1973). Larvae consumed significantly fewer prey in highly turbid water (0.2-0.5 g/L of suspended solids) than in clearer water (0-0.075 g/L) when presented with predominantly copepods. Turbidity had no effect on size of prey eaten in this experiment. When larvae were presented with cladocerans, turbidity up to 0.5 g/L did not reduce number or size of prey eaten (Breitburg 1988).

Tolerance of acidity also is age-dependent. Striped bass eggs hatch normally at pH 6.6-9.0, whereas juveniles tolerate the slightly wider range of pH 6-10 at 22-29 °C (Bowker et al. 1969). Exposure to pH 5.3 for 24 hours was lethal to larvae 25 mm TL (Tatum et al. 1965).

Habitat Alterations

Impingement. The susceptibility of the early life stages of striped bass to industrial water intakes has been intensively investigated. The survival rates of young that are impinged or trapped on the traveling screens of water intake structures depend on the life stage and impingement time (Rulifson et al. 1982a). The survival time for impinged eggs may be up to 6 min at an intake rate of 24 cm/s, but survival and hatching success are variable (Skinner 1974). Kerr (1953) found that 80% of striped bass larvae (19-38 mm long) were able to avoid impingement at 30.5 cm/s, but 95% were impinged at 43 cm/s. Impingement of striped bass of this size led to total mortality. Juveniles were able to resist impingement at much higher velocities, up to 61 cm/s (Kerr 1953). An alternative to screening fish from passage through a power facility is to allow the fish to pass through the facility. Survival in young striped bass that have passed through a power plant condensor tube can be greater than survival of impinged fish (Kerr 1953). Mortalities associated with passage through a facility are due to thermal shock, rather than to direct mechanical damage (Coutant and Kedl 1975).

Thermal pollution. Striped bass are often exposed to heated waters discharged from power plants. The fast change in temperature can lead to thermal shock, depending on the acclimation temperature, the magnitude of temperature change (ΔT), and life stage (Schubel et al. 1976; Meldrim and Gift 1971). Eggs are most susceptible to mortality from high temperatures early in their development

(Lauer et al. 1974). Larvae and juveniles generally show decreasing susceptibility to temperature shock with increasing age (Lauer et al. 1974). For larger striped bass, a direct relationship exists between ambient and upper avoidance temperatures (Meldrim and Gift 1971). Generally, mortality of adults does not exceed 50% at any ΔT or exposure time until water temperatures reach 32 °C. Minimization of thermal shock requires that maximum water temperatures be kept below 30 °C (Chadwick 1974). Although the warm water in power plant discharge canals may attract fish and provide winter sport fishing in some areas, striped bass generally avoid high-temperature effluents (Hall et al. 1984).

Dams, channelization, and land reclamation. Burns (1887) first noted the decline of South Carolina striped bass populations and attributed the decline to muddy water. The effects of human-induced changes on this species are not well understood (Ulrich et al. 1979). Several authors have suggested that channelization of coastal streams in the 1940's and 1950's resulted in the low population levels observed in many areas (Merriman 1937; Chittenden 1971a). Water diversion projects have affected other streams (Chadwick et al. 1977). In many coastal regions, up to 50% of the original estuarine areas important to striped bass have been lost to filling (with dredged material), road construction, and real estate development (Clark 1967). In the South Atlantic Region, dam construction has restricted upstream migrations on the Roanoke, Tar, Neuse, and Pee Dee Rivers, among others (Baker 1968). Rulifson et al. (1982b) documented changes in rivers in the South Atlantic Region which may affect these fisheries.

Environmental Contaminants

Interest in chemical toxicities to striped bass has been focused on residual chlorine, chlorinated hydrocarbons, and monocyclic aromatic hydrocarbons (Fay et al. 1983). The total residual chlorine that causes 50% mortality is 0.22 ppm for eggs < 13 h old and 0.20 ppm (at salinities of 2.8 ± 0.9 ppt) for larvae 24-70 h old (Morgan and Prince 1977).

Exposure to sublethal levels of benzene for 24 h increases the respiratory rate of juvenile striped bass; exposure for longer periods produces a reversible narcosis (Brocksen and Bailey 1973). Benville and Korn (1977) reported that exposure to 6.9 ppm benzene for 24 h resulted in 50% mortality of juvenile striped bass.

Studies of the toxicity of heavy metals indicate a sensitivity of yolk-sac larvae to copper (O'Rear 1973) and zinc (Tatum et al. 1965); eggs are somewhat less affected. Exposure of juvenile striped bass to cadmium (30-90 days at 0.5, 2.5, and 5.0 ppb) and mercury (30-120 days at 1.0, 5.0, and 10.0 ppb) caused lesions in gill tissue and impaired respiration (Dawson et al. 1977). Exposure to low pH, (5.5) and high aluminum (680 µg A13+/L) severely altered epidermal microridge structure in larvae (Rulifson et al. 1986b). Data on 24-, 48-, and 96-h tolerance limits for other heavy metals have been reported by Rehwoldt et al. (1971).

A concentration of 10 ppm of oil spill eradicator was toxic to striped bass after 48 h, although no stress was observed at 5 ppm (Chadwick 1960). Low tides and high temperatures may elevate hydrogen sulfide concentrations to toxic levels in some localities (Silvey and Irwin 1969). The toxicity of 61 pesticides, heavy metals, and pharmaceuticals to young-of-the-year striped bass was established by Bonn et al. (1976). Inasmuch as temperature and salinity may affect toxicity of chemicals, differences in these factors may intensify or reduce potential toxic effects. No significant mortality occurred after acute exposure (96 h) of young striped bass to a mixture of 13 organic contaminants presented in high concentrations. Water quality (hardness, alkalinity, salinity, and pH) greatly influenced toxicity after acute exposure (96 h) of young fish to cadmium, zinc, copper, and nickel. Decreases in water hardness and associated decreases in alkalinity and pH were correlated with acute toxicity of a mixture of contaminants to young fish (Palawski et al. 1985). Toxicity of aluminum to young striped bass increases with increasing acidity. Levels of pH of 5.0 to 6.5 in the absence of contaminants caused significant mortality to 11- to 13-day-old fish, and a pH of 5.5 was toxic to 159-day-old fish but not to 195-day-old striped bass (Buckler et al. 1987). Similarly, chronic exposure (30 to 90 days) of young striped bass to a mixture of organic and inorganic contaminants resulted in a high mortality rate in fresh water, a lower mortality rate in water of 2 ppt salinity, and the lowest mortality rate in water of 5 ppt (Mehrle et al. 1987).

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16. Abstract (Limit: 200 words)

Species profiles provide literature reviews of the taxonomy, morphology, range, life history, ecology, and environmental requirements of coastal aquatic species. They are designed to help individuals understand the basic biology of these organisms and to assist in impact assessment. Striped bass are native to coastal rivers and nearshore areas. Populations along the South Atlantic coast are primarily riverine. Spawning begins as early as February and peaks at temperatures of 18-21 °C. Spawning usually occurs in downstream portions of river systems having appropriate waterflow, salinity, temperature, and other water quality characteristics. Striped bass populations have declined since the early 1900's, but enough fish have survived or been restored to support commercial fishing in Albemarle Sound and recreational fishing in most major rivers along the South Atlantic coastline. Striped bass are predators and prey on many sympatric invertebrates and fishes. Larval striped bass feed on aquatic invertebrates and switch to feed on small fish as juveniles and adults.

17. Document Analysis a. Descriptors

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Morone saxatilis	Spawning
Life history	Salinity requirements

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