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Synopsis of Biological Data on Striped Bass, *Morone saxatilis* (Walbaum)

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National Oceanic and Atmospheric Administration
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U.S. DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary

National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator

National Marine Fisheries Service
Terry L. Leitzell, Assistant Administrator for Fisheries

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*As no information was available, these sections were omitted.

Synopsis of Biological Data on Striped Bass, *Morone saxatilis* (Walbaum)[1]

EILEEN M. SETZLER,[2] WALTER R. BOYNTON. KATHRYN V. WOOD,[2] HENRY H. ZION,[2] LAWRENCE LUBBERS,[2] NANCY K. MOUNTFORD,[2] PHYLLIS FRERE,[4] LUTHER TUCKER,[2] and JOSEPH A. MIHURSKY[2]

ABSTRACT

This synopsis reviews literature on the taxonomy, morphology, distribution, life history, population, ecology, recreational and commercial harvest, and culture of the striped bass, *Morone saxatilis* (Walbaum).

The striped bass is an anadromous species distributed along the Atlantic coast from northern Florida to the St. Lawrence Estuary, Canada; along the Gulf of Mexico from western Florida to eastern Louisiana; and along the Pacific coast from Ensenada, Mexico, to British Columbia, Canada. Populations have been established in numerous inland reservoirs and lakes. Striped bass spawn from mid-February in Florida until June or July in Canadian waters, and from mid-March to late July in California waters. Spawning occurs at or near the surface in fresh or nearly fresh waters at temperatures from 10° to 23°C; peak spawning usually occurs between 15° and 20°C. Yolk-sac larvae (prolarvae) range from 2.0 to 3.7 mm TL (total length) at hatching. Larval feeding is usually initiated from 4 to 10 days after hatching. At about 13 mm TL, larval striped bass form small schools and move inshore; during their first summer, juvenile fish move downstream into higher salinity waters in many areas. Most estuarine stocks of striped bass along the Atlantic coast are involved in two types of migration: the upstream spring spawning migration and the offshore coastal migrations which apparently are not associated with spawning activity. Male striped bass reach sexual maturity at an earlier age than females; most males are mature in 2 yr and females in their fourth or fifth year.

INTRODUCTION

The necessity of assessing the effects of man's increasing perturbation of estuaries upon populations of anadromous fish, which utilize the upper portion of estuaries as spawning and nursery grounds, has initiated much study and research by a myriad of governmental, university, and private consulting agencies in the United States. Much of this collective effort has aimed at a better understanding of both the basic biology and the population dynamics of the striped bass, *Morone saxatilis* (Walbaum), one of the most important commercial and recreational species along the mid-Atlantic coast.

The widespread interest in this species has resulted in the publication of three excellent bibliographies within the last several years: Pfuderer et al. (1975); Rogers and Westin (1975); and Horseman and Kernehan (1976). There are no recent reviews of striped bass literature although a number of older, but excellent, reviews are available. One of the most intensive summaries of striped bass biology and life history was made by Raney (1952). Earlier life histories were written by Scofield (1931), Pearson (1938), and Merriman (1941). Even a cursory examination of the listings of published papers and reports in the bibliographies previously mentioned reveals a great need to review the current literature and put it into perspective.

This literature review was initiated by the staff of the Hallowing Point Field Station, Chesapeake Biological Laboratory, in conjunction with a population dynamics study of striped bass eggs, larvae, and juveniles on the Potomac River, Md. The original intent of the review was to familiarize ourselves with the available literature so that we could better interpret and analyze the findings of our own study. But, as our review increased in both depth and scope, we realized that a formal presentation of our efforts would be appropriate. Thus, this striped bass literature review has evolved, a collective contribution from the Hallowing Point staff.

This review follows the FAO species synopsis format prescribed by Rosa (1965). The primary purpose of these synopses is to make existing information readily available according to a standard pattern and to indicate gaps in knowledge of the biology of the species considered.

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1 IDENTITY

1.1 Nomenclature

1.11 Valid name

Morone saxatilis (Walbaum 1792)

1.12 Objective synonymy

Perca Rock-fish vel Striped Bass Schöpf 1788:160, New York.

Perca saxatilis Walbaum 1792:330, New York, after Schöpf.

Morone saxatilis (Walbaum) Berg 1949:1013.

1.2 Taxonomy

1.21 Affinities

Suprageneric

Phylum Chordata
 Subphylum Vertebrata
  Class Osteichthyes
   Subclass Actinopterygii
    Order Perciformes
     Family Percichthyidae (Gosline 1966, prior to 1966 placed in Family Serranidae)
      Genus *Morone*
       Species *Morone saxatilis*

Generic

Morone Mitchill 1814.

The generic concept used is that of Woolcott 1957. The following generic description is from Jordan and Evermann 1896:1127:

"Anal spines 3, well developed. Dorsal fins 2; vertebrae 25 to 36, 11 to 15 in precaudal position. Maxillary without supplemental bone; teeth all pointed, pectoral unsymmetrical, its upper rays longest; dorsal X-14; skull without cavernous structure; preopercle strongly serrate; caudal fin forked; tongue with teeth, ventral fins inserted behind axil of pectorals; teeth all alike, usually villiform, without canines, preorbital narrow; lateral line normal, straight or bent upward at base; preopercle serrate; gill rakers moderately long and slender; species generally of large size and silvery-olive coloration, mostly inhabiting fresh or brackish waters. Preopercle without antrorse spines on its lower limb."

The type-species designations given below are from Whitehead and Wheeler (1966):

Morone Mitchill 1814; a composite genus containing two serranids and a species each of *Perca* and *Lepomis*. No type-designation was made.

Morone: (Mitchill) Gill 1860; name used in a restricted sense for serranid fishes. Type-species *Labrax mucronatus* Rafinesque 1818, by designation a synonym of *Morone americana* (Gmelin 1788).

Mitchill (1814) proposed the name *Morone* on the mistaken impression that the pelvic (ventral) fins were abdominal in position, in contrast to their thoracic position in the genus *Perca*.

In Mitchill's full account of the fishes of New York, published a year later (Mitchill 1815), he placed the species which he had earlier assigned to *Morone* in the genus *Bodianus* but without comment. However, it can be inferred, from his treatment of the genus *Roccus* two pages earlier, that he realized his error concerning pelvic fin position in his original diagnosis of *Morone*, and that the nearest thoracic genus known to him at that time was *Bodianus*. Gill (1860) discussed this error and reasoned that, because Mitchill's species of *Morone* "[have the normal position of the ventrals of *Perca*] therefore [*Morone* of Mitchill was a mere synonymy of *Perca* Linnaeus]" (Whitehead and Wheeler 1966:25).

Mitchill (1814) listed four species under *Morone* (from Whitehead and Wheeler 1966):

1) *M. pallida*. "Gill (1860) identified *M. pallida* Mitchill as most likely a junior synonym of *M. americana* (Gmelin). Jordan and Eigenmann (1890) and Jordan and Evermann (1896) follow Gill without comment; Günther (1859) and Boulenger (1895) arrived at the same conclusion." (Whitehead and Wheeler 1966: 26.)

2) *M. rufa*. "DeKay (1842) lists this species as *Labrax rufus* and Günther (1859), Gill (1860), Boulenger (1895) and Jordan and Evermann (1896) place it as a synonym of *Morone americana* (Gmelin)." (Whitehead and Wheeler 1966:27.)

3) *M. flavescens* = *Perca flavescens*, yellow perch.

4) *M. maculata* = *Lepomis gibbosus*, pumpkinseed. "DeKay (1842) was the first author to review all the species included by Mitchill in the genus *Morone*, but he did not use Mitchill's genus, placing the two serranid species in the genus *Labrax* Cuvier." Gill (1860) discussed the systematic status of *Morone* at length in a *Monograph of the genus Labrax Cuvier* in which he considered the six species placed in *Labrax* by Cuvier. "Gill recognized the composite nature of Mitchill's *Morone*," and employed the name *Morone* in a restricted sense "for the serranid fishes *M. rufa* Mitchill and *M. pallida* Mitchill, both of which, together with the type of the genus which he had just proposed, *M. macronatus* (Raf.) he referred to the synonymy of *M. americana* (Gmelin 1788)." (Whitehead and Wheeler 1966:28.)

The genus *Morone* comprises four American species (Berg 1949; Woolcott 1957; Bailey et al. 1970):

Morone americana (Gmelin) white perch; Atlantic, fresh water.
M. chrysops (Rafinesque) white bass, fresh water.
M. mississippiensis (Jordan and Eigenmann) yellow bass, fresh water.
M. saxatilis (Walbaum) striped bass, Atlantic, fresh water, Pacific.

and two European species (Bailey et al. 1954; Woolcott 1957):

M. labrax (Linnaeus) found along coast of Europe from Norway to the Black Sea.
M. punctatus (Bloch) inhabits Mediterranean Sea and the Atlantic Ocean from Senegambia to the Bay of Biscay.

Roccus Mitchill 1814
(no type-species designated)

Mitchill (1814) proposed the genus *Roccus* for the same reasons he had proposed *Morone* viz. on the basis of a mistaken appreciation of the pelvic fin position. He included two species in the genus *Roccus:*

1) *Roccus striatus,* striped bass.
2) *R. comas*—Mitchill (1815) later renamed this sciaenid fish as *Labrus squeteague.* Gill (1860) and Jordan and Evermann (1898) placed this species in the synonymy of *Cynoscion regalis* (Bloch) Schneider, weakfish.

Morone versus *Roccus*

"The earliest revisers of these species were DeKay (1842) and Günther (1859) who combined them in a single genus *Labrax.* Unfortunately neither author gave a generic synonymy, so that there is no indication of their views on the priority of one Mitchill name over the other." (Whitehead and Wheeler 1966:32.) Bleeker (1876:263) was the first reviewer to combine the two Mitchill names. He gave *Morone* Mitchill priority over *Roccus* Mitchill and cited *Morone americana* Gill = *Morone rufa* Mitchill as type species. Boulenger (1895:125) combined both European and American species in the genus *Morone* Mitchill and gave a full synonymy with *Roccus* Mitchill as a junior synonym. Berg (1949) and Bailey (1951) both gave priority to *Morone* versus *Roccus.*

Specific

Type-specimens: None designated.
Type-locality: New York State (Walbaum 1792).
Table 1 summarizes meristic counts and proportional measurements of striped bass.
The following species diagnosis for adult specimens is quoted from Hardy (1978:87). See also Figure 1.

"Body elongate, moderately compressed; back slightly arched; nape not noticeably depressed; gape to middle of eye; gill rakers long and slender; teeth small, present in bands on jaws, vomer, palatines, and in two parallel patches on tongue; 2 sharp spines on margins of opercle; margins of preopercle clearly serrate.

"Scales extended on to all fins except spinous dorsal. Dorsal fins clearly separated, approximately equal; caudal forked.

"Light green, dark olive green, silvery green, silvery with brassy or coppery reflections, to steel blue or almost black above; lighter below. Sides silvery with 7 or 8 usually uninterrupted horizontal dark stripes one of which always follows the lateral line and all but the lowest of which lie above the level of the pectoral fins. Three to four stripes above lateral line, 3 below. Belly whitish or silvery with brassy reflections. Vertical fins dusky green to black, ventrals white to dusky, pectorals greenish."

Subjective synonymy

Sciaena lineata Bloch 1792:53, pl. 305.
Perca septentrionalis Bloch and Schneider 1801:90, pl. 20, New York.
Centropomis lineatus Lacépède 1802:257.
Roccus striatus Mitchill 1814:25, New York; Bean 1885:242-244, Alabama.
Perca mitchilli Mitchill 1815:413, pl. 3, fig. 4, New York.
Perca mitchilli interupta Mitchill 1815:I, 415, New York.
Perca mitchilli alternata Mitchill 1815:I, 415, New York.
Lepibema mitchilli Rafinesque 1820:23.
Labrax lineatus Cuvier and Valenciennes 1828:79-83.
Roccus lineatus Gill 1860:112.
Lepibema lineatum Steindachner 1962:504.
Roccus lineatus (Bloch) Gill. Goode and Bean 1880:145; Jordan and Gilbert 1882:529.
Roccus septentrionalis Jordan 1886:72-73.

Table 1.—Meristic counts and proportional measurements of striped bass, summarized by Hardy 1978.

D1 VIII-IX
D2 I, 9-14 (Chesapeake Bay D1 IX, 02 10-14 soft rays).
Mode D2 rays; 11 in Hudson River, 12 elsewhere.
A III, 7-13 (Chesapeake Bay 9-12).
Mode number anal rays; 11.
C 17, 15 branched.
P 13-19 (including Chesapeake Bay).
V I, 5.
Lateral line scales 50-72 (Chesapeake Bay 53-65, western Florida and Alabama 63-72, all other populations combined 50-67).
Scales above lateral line: at midbody 9-13, below 13-16; at caudal peduncle 11-13, below 12-15.
Total gill rakers first arch 19-29, upper arm 6-12, lower arm 12-15 (mean number gill rakers, Chesapeake Bay, upper arm 9.49-9.77, lower arm 12.61-13.07).
Branchiostegal rays 7.
Total vertebrae 24-25 (usually 25; 12 + 13).
Proportions as times in standard length:
Greatest depth 3.45-4.20.
Average depth at caudal peduncle 9.6, anus 3.9.
Head length 2.9-3.25.
Proportions as times in head length:
Eye 3.0-4.9.

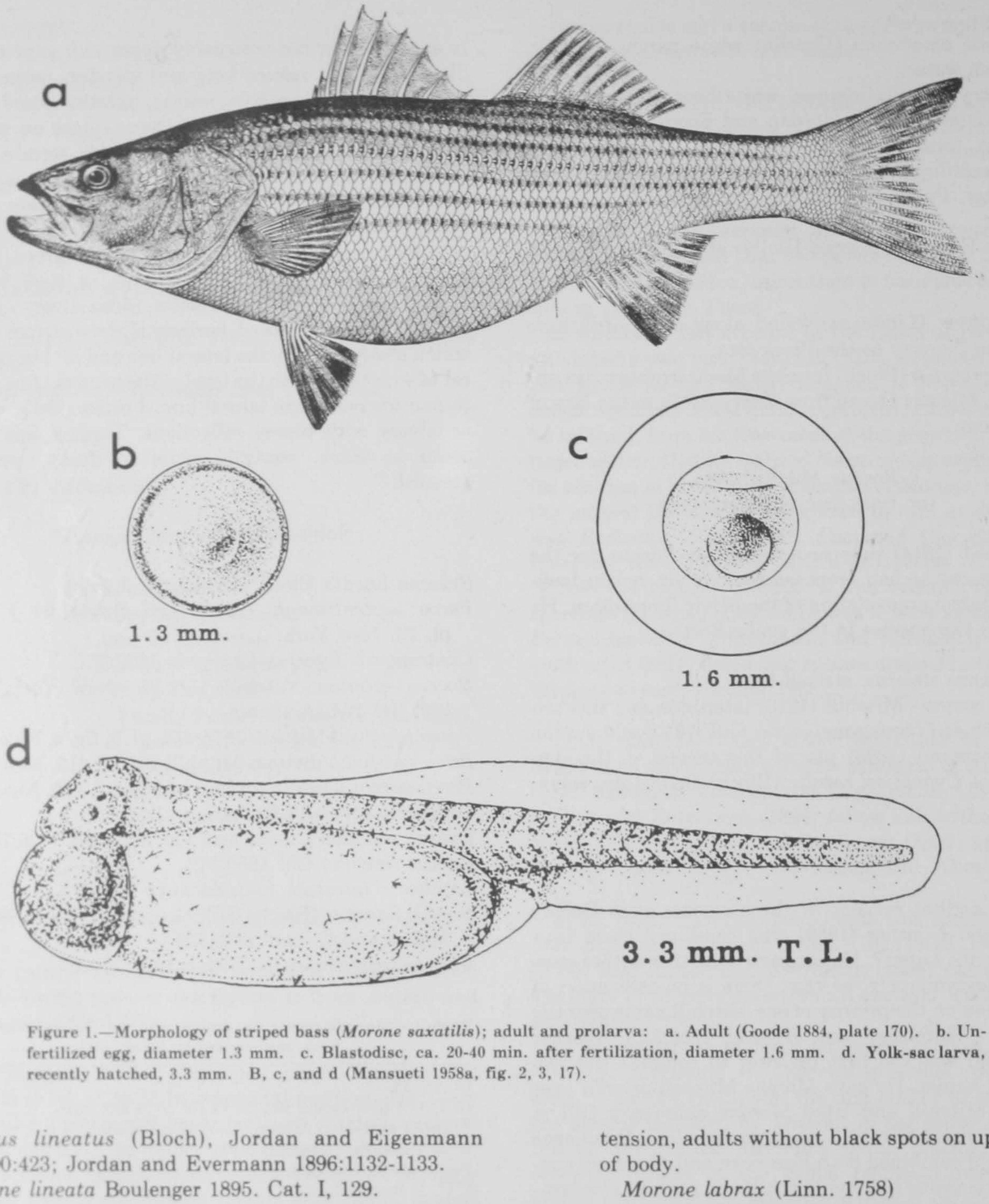

Figure 1.—Morphology of striped bass (*Morone saxatilis*); adult and prolarva: a. Adult (Goode 1884, plate 170). b. Unfertilized egg, diameter 1.3 mm. c. Blastodisc, ca. 20-40 min. after fertilization, diameter 1.6 mm. d. Yolk-sac larva, recently hatched, 3.3 mm. B, c, and d (Mansueti 1958a, fig. 2, 3, 17).

Roccus lineatus (Bloch), Jordan and Eigenmann 1890:423; Jordan and Evermann 1896:1132-1133.
Morone lineata Boulenger 1895. Cat. I, 129.

The following key is from Whitehead and Wheeler (1966:36-38): (Whitehead and Wheeler place the two European species in the genus *Dicentrarchus* Gill, the striped bass and white bass in the genus *Roccus*, and the white perch and yellow bass in the genus *Morone*.)

"I. Lower border of preoperculum with several antrorse spines; dorsal fins separated by a space; Mediterranean and eastern Atlantic, marine and estuarine.

"a. Lateral line scales 62-74 (Mode 70); vomerine teeth in subcrescentric band without posterior extension, adults without black spots on upper part of body.
Morone labrax (Linn. 1758)

"b. Lateral line scales 57-65 (Mode 60); vomerine tooth patch anchor-shaped; adults with small black spot on upper part of body.
M. punctatus (Bloch 1792)

"II. Lower border of preoperculum with small denticulations directed downwards; Western Atlantic, eastern and southern North America.

"a. Dorsal fins separate; anal spines increasingly even in length; two sharp spines on hind border of operculum; teeth on base of tongue (*Roccus* Mitchill).

"i. Body elongate, its depth more than three times in its length; lateral line scales 57-67; teeth at base of tongue in two parallel patches; marine and estuarine.
M. saxatilis (Walb. 1792)

"ii. Body deeper, its depth less than three times in its length; lateral line scales 52-58; teeth at base of tongue in a single series; fresh water.
M. chrysops (Raf. 1820)

"b. Dorsal fins connected; second anal spine almost equal in length to the third spine; a single sharp spine on the hind border of the operculum; teeth present along edges of tongue but not at base (*Morone* Mitchill).

"i. Longest dorsal spine about half head length; faint streaks on flanks; marine and fresh water.
M. americana (Gmelin 1788)

"ii. Longest dorsal spine greater than half head length; seven distinct longitudinal lines on flanks, interrupted posteriorly; freshwater, or lower Mississippi valley.
M. mississippiensis Jordan & Eigenmann 1887."

There appear to be major problems associated with the use of hatchery-raised striped bass as specimens in taxonomic keys. The available taxonomic keys give conflicting descriptions of striped bass larvae. Some of these descriptions (Ryder 1887; Mansueti 1958a; Doroshev 1970; Lippson and Moran 1974[5]; Hardy 1978) are based on hatchery-raised fish. Using the available keys, Mihursky et al. (1976)[6] were not able to conclusively distinguish some *Morone* spp. (striped bass and white perch) between 8 and 14 mm TL (total length).

1.22 Taxonomic status

This is a morphospecies, and it is polytypic.

1.23 Subspecies

None. See section 1.31 for a discussion of populations.

1.24 Standard common names, vernacular names

Striped bass, rock, rockfish, striper, linesides, and sewer trout (New England).

[5]Lippson, A. J., and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes in the Potomac River estuary. Md. Dep. Nat. Resour., Power Plant Siting Program, PPSP-MP-13, 282 p.

[6]Mihursky, J. A., W. R. Boynton, E. M. Setzler, K. V. Wood, H. H. Zion, E. W. Gordon, L. Tucker, P. Pulles, and J. Leo. 1976. Final report on Potomac estuary fisheries study; ichthyoplankton and juvenile investigations. Univ. Md. CEES Ref. No. 76-12-CBL, 241 p. Chesapeake Biological Laboratory, Solomons, MD 20688.

1.3 Morphology

1.31 External morphology

See Table 1.

A number of the morphological studies have been conducted on the genus *Morone* (Roccus). Based on skeletal examinations, Woolcott (1957) concluded that striped bass, *Morone saxatilis;* white bass, *M. chrysops;* white perch, *M. americanus;* yellow bass, *M. interruptus* (*mississippiensis*); and European bass, *M. labrax* (*dicentrarchus*) should all be in the same genus. Faulkner (1952) found that striped bass, yellow bass, white perch, and white bass were all interspecifically related based on retinal examination.

Beitch (1963) concluded that striped bass and white perch belong to the same genus based on the histomorphological similarity of the urinary systems.

Populations

A number of distinct striped bass populations are found on the Atlantic coast based on fin ray counts (Table 2), morphometric characters, and electrophoretic differences. During spawning season many of the major rivers contain discrete populations of striped bass. However, during the remainder of the year a number of neighboring river populations may school together forming "cohorts" to use Morgan's terminology.[7]

Striped bass populations described in the literature include the following:

a. Alabama River, Ala. (Brown 1965).

b. Appalachicola River, Fla. Differs from Alabama River population in number of soft dorsal and anal rays and from St. Johns River population in number of lateral line scales, soft dorsal, anal rays, and character index (Barkuloo 1970; Table 2).

c. St. Johns River, Fla. (Barkuloo 1970).

d. Santee-Cooper River system, S.C. Results of fin ray counts (Raney and Woolcott 1955) and tagging studies indicate there is little exchange between the downstream Cooper River striped bass which enter the brackish waters of the estuary and the reservoirs above Pinopolis Dam where the fish complete their entire life cycle in freshwater. The lower river population does not appear to make coastal migrations and probably does not mix with other stocks (Scruggs and Fuller 1955). Striped bass collected below Pinopolis Dam differed in body depths and caudal peduncle depths than fish collected upstream (Lund 1957). Striped bass from the Santee-Cooper River system have the lowest gill raker counts along the Atlantic coast (Lewis 1957; Table 2).

e. Cape Fear, S.C. Based on lateral line counts, Murawski (1958) concluded that the Cooper, Cape Fear, and Satilla-St. Johns populations of the Southern Atlantic Bight were mutually distinct.

[7]R. P. Morgan II, UMCEES — AEL, Frostburg State College, Gunter Hall, Frostburg, MD 21532, pers. commun. Winter 1975.

Table 2.—Meristic characters (mean count ±2 standard errors) of striped bass from various populations. ND = no data.

Station	Gill rakers Total no.[1]	Lateral line scales[2]	Dorsal fins: 1st dorsal spines	Dorsal fins: 2d dorsal soft rays	Anal rays	Character index (sum of soft rays of dorsal, anal, and both pectoral fins)
St. Laurence River, Quebec	ND	61.10±0.48		[3]11.7 ±0.10	[3]10.8 ±0.04	ND
Miramichi River, New Brunswick	23.71±0.22	60.42±0.50		11.8 ±0.10	10.4 ±0.12	56.0 ±0.20
Philips and Shubenacadie Rivers, Nova Scotia	23.50±0.22	59.92±0.56		12.0 ±0.06	11.0 +	56.7 ±0.24
Hudson River, N.Y.	25.77±0.08	59.95±0.34	[4]9.11±0.02	11.27±0.04	[4]10.57±0.02	54.0 ±0.20
Delaware River and Bay	24.99±0.18	61.78±0.40		[3]11.6 ±0.08	[3]10.8 ±0.06	55.6 ±0.40
Upper Chesapeake Bay Maryland waters	24.48±0.06	62.55±0.16	[4]0.09±0.08	11.74±0.04	[4]10.90±0.01	56.4 ±0.12
York River, Va.	24.02±0.20	60.72±0.28	9.02±0.02	11.93±0.02	10.96±0.02	[5]56.7 ±0.18
Rappahannock River, Va.	24.02±0.20	60.72±0.28	9.02±0.02	11.93±0.02	10.96±0.02	55.3 ±0.24
James River, Va.	25.22±0.20	61.66±0.26	9.31±0.04	11.53±0.04	10.74±0.04	[5]56.0 ±0.34
Albermarle Sound, N.C.	24.51±0.30	60.48±0.70		[3]11.8 ±0.10	10.9 ±0.06	[4]55.7 ±0.36
Cape Fear, S.C.	ND	56.94±0.76		ND	ND	ND
Santee-Cooper, S.C.	23.33±0.24	58.59±0.54		11.6 ±0.16	10.9 ±0.08	55.2 ±0.36
St. John's River, Fla.	ND	54.33±0.44		11.9 ±0.12	11.0 ±0.14	56.9 ±0.36
Appalachicola River, Fla. (Gulf of Mexico)	ND	66.7		11.55±0.12	9.8 ±0.50	54.3 ±0.96
Alabama and Tallapoosa Rivers, Ala.	ND	[6]66.30±0.58	8.9	[7]11.84±0.18	[7]10.84±0.18	[7]56.47±0.44
Sacramento and San Joaquin Rivers, Calif.	25.98±0.14	59.53±0.46		[8]11.76±0.08	[8]10.82±0.06	56.08±0.16

[1]Lewis 1957.
[2]Murawski 1958.
[3]Raney and Woolcott 1955.
[4]Raney 1957.
[5]Raney et al. 1954.
[6]Brown 1965.
[7]Barkuloo 1970.
[8]Raney and de Sylva 1953.

f. Roanoke River-Albermarle Sound, N.C. This population apparently separates into two groups in the winter with the smaller fish overwintering in Albemarle Sound and the larger fish (2.7-34.0 kg) overwintering in the ocean side of the outer banks (Chapoton and Sykes 1961). Albemarle Sound striped bass are distinct from James River, Va., striped bass though closely related to the York River and the Rappahannock River striped bass on the basis of lateral line scales and morphometric characters (Murawski 1958; Lund 1957). They are also distinct from South Carolina and eastern Florida populations in fin ray counts and lateral line scales (Raney and Woolcott 1955; Table 2).

g. Chesapeake Bay. Three distinct subpopulations—James River, York and Rappahannock Rivers, and upper Bay—are present within the Chesapeake drainage based on meristic studies (Raney 1957), gill raker counts (Lewis 1957), and lateral line scales (Murawski 1958). Lund (1957) concluded that four rivers within Chesapeake Bay—the James, York, Rappahannock, and Potomac—have separate subpopulations based on morphometric characters. The population of striped bass in the James River is apparently now nearly extinct (Merriner and Hoagman 1973[8]). Through electrophoresis, Morgan et al. (1973) further delineated the upper Chesapeake Bay striped bass into a series of discrete subpopulations. The most distinct subpopulation was in the Elk River. The Choptank and the Nanticoke Rivers, on the eastern shore of Chesapeake Bay, also had distinct populations although these fish appear to be closely related to the striped bass of the Patuxent and Potomac Rivers on the Bay's western shore. The Potomac River and the Patuxent River striped bass, although distinct from the other three river populations, could not be distinguished from one another. The authors attributed the formation of the various striped bass populations in the Chesapeake Bay to the homing mechanism of these fish and the geological history of the Bay.

h. Delaware River. The Delaware River population is most closely allied with the James River population based on numbers of lateral line scales (Murawski 1958) and gill raker counts (Lewis 1957).

i. Hudson River. Hudson River striped bass form a distinct population based on meristic counts (Raney and de Sylva 1953), gill rakers (Lewis 1957), lateral line scales (Murawski 1958), and morphometric measurements (Lund 1957). Within the Hudson River, striped bass caught upstream from Haverstraw differ in fin ray counts from fish from the lower Hudson River (Raney et al. 1954). The hereditary relationship between present day California and Hudson River striped bass populations is evidenced from similarity in lateral line scales (Murawski 1958), fin ray counts (Raney and de Sylva 1953), and gill raker counts (Lewis 1957; Table 2).

j. Nova Scotia; Annapolis and Shubenacadie Rivers (Merriman 1941). Raney et al. (1954) found Nova Scotia bass close in some fin ray counts to southern pop-

[8]Merriner, J. V., and W. J. Hoagman. 1973. Feasibility of increasing striped bass populations by stocking of underutilized nursery grounds. Completion Rep. Proj. FA-VA-AFS 6, July 1, 1970-Sept. 30, 1973, 197 p. Virginia Institute of Marine Sciences, Gloucester Point, VA 23062.

ulations from Albemarle Sound, N.C., and Edisto and Santee Rivers, S.C.

k. St. Lawrence River (Magnin and Beaulieu 1967). Striped bass from the St. Lawrence have a significantly higher lateral line scale count than bass from the Philips River, Nova Scotia (Murawski 1958).

Morone spp. differentiation

A recently developed cartilage staining technique [which permits identification of *Morone* spp. larvae through the use of species-specific diagnostic characters including osteology and internal pigmentation (Fritzsche and Johnson[9])] may be the solution to the inability to morphological distinguish between striped bass and white perch larvae from approximately 6 to 20 mm (Mansueti 1964).

1.32 Cytomorphology

Striped bass have 48 chromosomes (Kerby 1972). The dominant karyotype from the Hudson River, N.Y., consisted of 38 acrocentric, 8 subtelocentric, and 2 submetacentric chromosomes; a second karyotype, occasionally found had 40 acrocentric, 6 subtelocentric, and 2 submetacentric chromosomes (Rachlin et al. 1978). Striped bass from an impounded freshwater environment, Kerr Reservoir, had larger glomeruli, 55.7μ, than fish from an estuarine environment, 47.7μ (Beitch 1963).

1.33 Protein specificity

Sidell et al. (1978) successfully distinguished between striped bass and white perch larvae from 7.0 to 51.0 mm using starch gel electrophoresis and enzyme specific histochemical stains. Species specific banding patterns were found for esterase (α-naphthyl-acetate or α-naphthyl-butyrate) and phosphoglucomutase, though the level of phosphoglucomutase activity is low making this system unsuitable for larvae 10 mm TL or less. The use of enzyme specific stains requires that larvae be frozen in liquid nitrogen, thus this technique is not applicable to routine field sampling. Electrophoretic differences between soluble muscle proteins of striped bass and white perch have been demonstrated by Morgan (1971, 1975). Striped bass muscle consists of two major proteins whereas white perch muscle is composed of three major proteins. After electrophoresis of soluble muscle proteins there remain seven minor proteins in striped bass and eight in white perch.

1.34 Aging

Methods used to determine the age of striped bass include: length-frequency distributions, scale analyses, study of otolith growth bands, and study of opercle growth bands. Scofield (1931), who was the first to analyze the possible methods of striped bass age determination, concluded that age may be determined accurately in the first 8-10 yr using any of the four methods. The scale method is the most widely used.

Descriptions of striped bass scales are given in Scofield (1931), Merriman (1941), and Tiller (1943). Striped bass scales are ctenoid with radii in the anterior field. From 25 to 150 circuli form during a year's growth; circuli formation ceases in early winter (Scofield 1931). The best scales for age determination are from midbody just above the lateral line. Merriman (1941) found a linear relationship between scale growth and length in striped bass from 10.5 to 67 cm TL.

1.35 Osteology

Gregory (1918, 1933) described and illustrated the head skeleton of striped bass. Merriman's (1940) paper included detailed drawings of the trunk skeleton. Woolcott (1957) gave a detailed comparison of diagnostic osteological characters of the four American *Morone* species—*saxatilis, chrysops, americana, interrupta (mississippiensis)*—and the European species—*M. labrax*. With the exception of *americana* and *interrupta*, the species are readily separated using osteological characters.

1.36 Blood

Engel and Davis (1964), Courtois (1974), and Westin (1978) have examined striped bass hematology. Their results are summarized below:

	X±s	n	*Range*	*Author*
Hemoglobin g/100 ml	9.11± 1.63	31	4.0 -12.3	Westin 1978
	8.04± 0.97	7		Sherk et al. 1972[1]
	9.50	5	8.6 -10.4	Engel and Davis 1964
		5	7.6 -12.1	Courtois 1974
Hematocrit % packed	47.90±10.25	31	16-70	Westin 1978
	38.20± 6.46	7		Sherk et al. 1972[1]
	38.70	5	36.0 -41.3	Engel and Davis 1964
Plasma protein g/100 ml	9.38± 1.67	20	6.1 -13.0	Westin 1978
		4	6.4 - 7.4 (refractometer)	
		6	4.2 - 5.8 (chemical method)	Courtois 1974
RBC 10^6/cc	3.79± 0.55	15	2.86- 4.49	Westin 1978
	3.95	5	3.42- 4.53	Engel and Davis 1964
	2.35± 0.32	7		Sherk et al. 1972[1]
Serum total protein g%	5.18- 1.03	22	3.67- 8.32	Westin 1978
Serum calcium mg% (both sexes)	12.80± 4.01	13	4.5 -18.8	Westin 1978
(Males only)	11.74± 3.36	11	4.5 -15.1	Westin 1978

[9]R. A. Fritzsche, Department of Biology, College of Liberal Arts, University of Mississippi, University, MI 38677, and G. D. Johnson, Marine Resources Research Institute, South Carolina Wildlife and Marine Resources Department, P.O. Box 12559, Charleston, SC 29412, pers. commun. March 1976.

Serum chloride				
mEq/liter	141.46±29.76	16	80-186	Westin 1978
Osmolality				
m0,m/kg	349.4±22.50	7		Sherk et al. 1972[1]

[1]Sherk, J. A., J. M. O'Connor, and D. A. Neumann. 1972. Effects of suspended and deposited sediments on estuarine organisms. Phase II. Annu. Rep. U.S. Army Corps Eng., Proj. Year II, Nat. Resour. Inst. Ref. No. 72-9E, 106 p. Chesapeake Biological Laboratory, Solomons, Md 20688.

Blood sera from striped bass contain antibody that reacts with beef heart muscle antigen; white perch blood sera do not possess such antibody (Janssen and Meyers 1967).

2 DISTRIBUTION

2.1 Total area

Figure 2 shows the coastal distribution of striped bass. [Land areas are in three digit code; water areas in three letter code; the Geographic Classification and Codes are from FAO Current Bibliography for Aquatic Sciences and Fisheries.]

Striped bass are found along the Atlantic coast (ANW) from the St. Lawrence River, Canada (215) (Magnin and Beaulieu 1967), as far west as Montreal (215) (Vladykov and McAllister 1961), to the St. Johns River in northern Florida (238) (McLane 1955; Raney 1952), and along the Gulf of Mexico tributaries in western Florida (Barkuloo 1961), Alabama, Mississippi, and Louisiana (235) (McIlwain 1968; Brown 1965). At various times of the year they are encountered in near offshore waters from Massachusetts (236) to Cape Hatteras (238). Striped bass were introduced into the lower Sacramento River, Calif. (232), in 1879, and today are found on the Pacific coast from British Columbia (INE) south to Ensenada, Mexico (ISE) (Forrester et al. 1972). Striped bass have also been introduced into the U.S.S.R. (710) (Doroskev 1970), France (524), and Portugal (541).

The introduction of striped bass into the San Francisco Bay (INE) area is a remarkable example of utilization of an underutilized ecological niche by an immigrant species. In 1879, 135 yearling striped bass from the

Figure 2.—Coastal distribution of striped bass.

Navesink River, N.J. (237), were taken across the continent by train and introduced into the lower Sacramento River. An additional 300 yearling striped bass from the Shrewsbury River, N.J., were planted into San Francisco Bay in 1881 (Scofield 1931). Ten years after the first plant, striped bass were caught in gill nets and offered for sale on the California market, and in 1899 the commercial net catch alone was 600,000 kg (Merriman 1941). Today striped bass on the west coast are found from British Columbia (INE) south to Ensenada, Mexico (ISE) (Forrester et al. 1972).

Numerous attempts have been made to establish striped bass populations in reservoirs and rivers throughout the United States. Successful reservoir and lake introductions include: Martin, Lay, Choctawhatachee River and Bay, Jones Bluff, and Jordan in Alabama; Norfork, Beaver, Greeson, Dardanella, and Maumelle in Arkansas (235); Hunter and Julianna in Florida (238); Sinclair in Georgia; Hartwell and Clark Hill in Georgia-South Carolina (238); Herrington in Kentucky (234); Toledo Bend and D'Arbonne in Louisiana (235); Ross R. Barnett in Mississippi (235); Bardin and Norman in North Carolina (238); Greenwood and Murray in South Carolina (238); Norris, Cherokee, and J. Percy Priest in Tennessee (235); and E. V. Spence and Navarro Mills in Texas (235) (Bailey 1975). Other successful reservoir introductions include the Santee-Cooper in South Carolina (238) (Scruggs and Fuller 1955; Scruggs 1957; Stevens 1958), Kerr in Virginia (237) and North Carolina (238), Keystone in Oklahoma (235) (Mensinger 1971), and Lake of the Ozarks in Missouri (Hanson and Dillard 1976). Striped bass were unsuccessfully introduced, or survival of the introduced populations is questionable, in the Sterling Reservoir in Colorado (233) (Imler 1976); Hawaii (660) (Anonymous 1920); Kentucky (234) (Clay 1962); Ohio River (Schoumacher 1969); western Maryland and New Jersey (237) (Surber 1958); and Lake Ontario (L.21) (fry obtained from Havre de Grace, Md. (United States Commission of Fish and Fisheries 1889; Jordan and Eigenmann 1890)).

Today, localized or landlocked populations exist in the Santee-Cooper Reservoir, S.C.; Keystone Reservoir, Okla.; St. Johns River, Fla.; Roanoke River, N.C.; the Kerr Reservoir, Va.; the Colorado River (St. Amant 1959), and according to Morgan (see footnote 7) should be distributed throughout the continental United States within the next 20 yr.

2.2 Differential distribution

2.21 Larvae and juveniles

Habitat

Newly hatched striped bass live in open waters, and at approximately 13 mm form small schools and move inshore to stay through the first summer (Raney 1952). Abbott (1878) reported that at about 30 mm striped bass juveniles are found in very dense schools. Young-of-the-year are generally more abundant in areas with pronounced current (Rathjen and Miller 1957; Woolcott 1962). Juvenile striped bass appear to prefer clean sandy bottoms (Merriman 1937; Raney 1954; Rathjen and Miller 1957; Woolcott 1962; Smith 1971). Raney (1952) found juveniles (50 mm) over gravelly beaches; juveniles 71-85 mm were found over a mixture of mud, sand, gravel, and rock (Merriman 1941) and rarely over soft mud (Rathjen and Miller 1957). The largest catches of juveniles in the Hudson River generally occurred over sand or gravel bottoms (Texas Instruments, Inc., 1974[10]). In the Potomac River the majority of juveniles were seined over a sandy bottom which was covered by a 1- or 2-inch layer of silt. A mixture of sand and gravel occurred toward the beach as the slope increased in elevation (Mihursky et al. see footnote 6).

Vertical Distribution

The problem of entraining larval and early juvenile striped bass in cooling waters of power generating facilities has provided additional impetus for examining the vertical distributions of early life history stages. Several investigators have studied day versus night vertical distributions of striped bass larvae. In the Hudson River, yolk-sac larvae (prolarvae of some authors) are most abundant near the bottom during both day and night sampling (Lauer et al. 1974), although in the Chesapeake and Delaware Canal there were no significant differences in surface, middepth, and bottom densities of yolk-sac larvae over a 24-h period (Kernehan et al.[11]). Morgan et al.[12] stated that there is sufficient vertical mixing in the Chesapeake and Delaware Canal to keep striped bass eggs suspended in the water column. Mixing could also keep yolk-sac larvae suspended within the water column. In contrast, significant differences in yolk-sac larval densities related to both sampling time and depth were observed on the Potomac River (Boynton et al.[13]). Mean yolk-sac densities at all three depths—surface, middepth (4 m), and bottom (7 m)—were greater at night than during the day. Greater densities of yolk-sac larvae were found at 4 m and on the bottom during the day, and at 4 m in the evening and early morning hours.

[10]Texas Instruments, Inc. 1974. Fisheries survey of the Hudson River. March-July 1973, Vol. III; March-December 1973, Vol. IV. Prepared for Consolidated Edison Co. of New York, Inc.

[11]Kernehan, R. J., R. E. Smith, S. L. Tyler, and M. L. Brewster. 1976. Ichthyoplankton. Volume II. *In* Ecological studies in the vicinity of the proposed Summit Power Station, January through December 1975, 669 p. Ichthyological Associates, Inc., Box 286, RD # 1, Middletown, DE 19709.

[12]Morgan, R. P., II, R. E. Ulanowicz, V. J. Rasin, Jr., L. A. Noe, and G. B. Gray. 1973. Effects of water movement on eggs and larvae of striped bass and white perch. *In* Hydrographic and ecological effects of enlargement of the Chesapeake and Delaware Canal. U.S. Army Corps Eng., Phila. Dist. Contract No. DACW-61-71-C-0062. Final Rep., Append. XII, 28 p.

[13]Boynton, W. R., E. M. Setzler, K. V. Wood, H. H. Zion, and M. Homer. 1977. Draft report on Potomac River fisheries study; ichthyoplankton and juvenile investigations. Univ. Md. CEES Ref. No. 77-169 CBL. Chesapeake Biological Laboratory, Solomons, MD 20688.

The highest density of postyolk-sac larvae was near the bottom of the Hudson River during the day though at night they were much more evenly distributed throughout the water column (Lauer et al. 1974). Further studies on the Hudson River indicated no significant difference in day-night depth distributions for 6-10 mm larvae in late June. However, by mid-July, a diurnal migration pattern was evident with 7-14 mm striped bass larvae and 15-30 mm juveniles occurring in significantly greater concentrations at night on the surface and middepths than on the bottom. Larger fish were caught at night than during the day (no variances presented); likewise, larger fish were caught at the surface and at midwater than on the bottom. The older larvae and early juveniles also moved shoreward and onto shoal areas (Texas Instruments, Inc. footnote 10, 1974[14]).

Evidence of a possible diurnal migration of finfold larvae on the Potomac River has been described (Boynton et al. footnote 13). Greater densities of finfold larvae were captured at night at all three depths sampled. At 4 m and on the bottom (7 m), greater densities of finfold larvae were found throughout the evening and at night, whereas on the surface significantly greater densities were present only during the 0300 sampling. During evening hours significant differences in the vertical distribution of finfold larvae were evident with greater densities occurring at middepth and on the bottom.

In the western portion of the Sacramento-San Joaquin Delta in California young-of-the-year striped bass were generally concentrated near the bottom, while in the eastern portion the fish were more evenly distributed, although the greatest concentrations were frequently near the bottom. Young bass showed a general tendency to rise off the bottom during flood tide. The fish were concentrated along the shore rather than in the channel regions in the Delta; as they grew they became more evenly distributed (Chadwick 1964).

Several studies have shown a downstream movement of the early developmental stages of striped bass [Mihursky et al. (footnote 6) and Polgar et al. (1975[15], 1976) in the Potomac River; Texas Instruments, Inc. (footnotes 10 and 14) in the Hudson River; Chadwick et al. (1977) in the Sacramento-San Joaquin Estuary]. Work on the Hudson River indicated this downstream movement was a slight displacement and neither striped bass eggs nor yolk-sac larvae were transported at any velocity approaching that of the water. Although the Hudson River studies indicated a downstream displacement of postyolk-sac larvae from areas in which the yolk-sac larvae were concentrated, the highest densities of finfold and postfinfold larvae in the Potomac River were concentrated upstream from the areas of highest densities of yolk-sac larvae (Mihursky et al. footnote 6). Mihursky et al. concluded that the finfold larvae, especially during the early part of the 1975 spawning season, were recruited from upriver. Postfinfold larvae, however, seemed to be able to maintain their position in the river, remaining within the same areas as the finfold larvae.

[14]Texas Instruments, Inc. 1974. Evaluation of the potential impact on the fisheries of the Hudson River by the Cornwall pumped-storage project. Prepared for Consolidated Edison Co. of New York, Inc.

[15]Polgar, T. T., R. E. Ulanowicz, D. A. Payne, and G. M. Krainak. 1975. Investigations of the role of physical-transport processes in determining ichthyoplankton distributions in the Potomac River. Interim report for 1974 spawning season data. Maryland Power Plant Siting Program, PPRM-11 and PPMP-14 (combined reports), 133 p.

2.22 Adults

Striped bass are found in a variety of inshore, estuarine, and freshwater habitats depending upon latitude and season. In estuarine or marine environments they can be found along sandy beaches and in shallow bays (Bigelow and Schroeder 1953), along rocky shores (Pearson 1931), sometimes associated with submerged or partly submerged rocks or boulders (hence the common names rock or rockfish), in troughs and gullies hollowed out by wave action, and over sand bars during high tide. In New England, striped bass are found along the rocky shoreline and surf swept beaches (Bigelow and Schroeder 1953). These fish also frequent mussel beds and may hide under rafts of floating rockweed. Striped bass remain in near offshore waters and are usually found no more than 6-8 km offshore (Bigelow and Schroeder 1953). Few fish have been caught beyond 16 km offshore (Raney 1954).

In fresh waters, striped bass are found in large rivers as well as small inflowing creeks (Abbott 1878).

2.3 Determinants of distribution changes

Pollution or alterations of the environment have destroyed or seriously harmed suitable striped bass habitat in a number of areas, including the Connecticut River (Merriman 1937), the Delaware River (Chittenden 1971a), the Escambia River, Fla. (Bailey et al. 1954), and Lake Ponchartrain, La. (Davis and Fontenot[16]) where no striped bass were captured in 1969. These authors suggested that this serious decline or extinction of the striped bass population was due to extensive channelization of coastal streams in the 1940's and 1950's which increased the silt load, destroyed riffle areas, and filled estuarine tributaries.

One of the most extensive areas of striped bass habitat destruction has occurred in the Susquehanna River of Maryland and Pennsylvania which empties into the upper Chesapeake Bay. The Susquehanna River was formerly the site of the greatest striped bass egg production known (Dovel 1971) with spawning being recorded as far upriver as the fork at Northumberland or beyond (Baird 1855). However, the natural features of the river were altered with the construction of canal feeder dams commencing about 1826 and the construction of hydroelectric dams in 1904. From 1904 to 1928,

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2.4 Hybridization

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The original cross, *Morone saxatilis* female × *Morone chrysops* male, was reported by Stevens (1965). A number of authors have reported successful hatching of striped bass(SB)-white bass(WB) hybrids (Smith et al. 1967; Bayless 1968, 1972; Bishop 1968; Logan 1968; Kerby 1972). The resultant eggs and fry are similar to striped bass though the incubation time is generally 3-4 h longer. Bayless (1972) has published a series of photomicrographs of various stages of the embryological development of both the hybrid cross SB × WB and the reciprocal cross WB × SB; Bayless (1972) and Kerby (1972) give morphometric descriptions of the hybrids (Table 3). Hybrid larvae (SB × WB) do not feed until 5-7 days of age.

Logan (1968) found striped bass hybrid larvae (SB × WB) had faster growth and higher survival than striped bass larvae after 71 days in 1-acre rearing ponds, Heath Spring Hatchery, S.C. Likewise survival of hybrid larvae was significantly greater than striped bass larvae when released into natural waters (Bonn et al. 1976). In the Rappahannock River, Va., hybrids grew faster than striped bass, at least for the first 2.5-3 yr (Kerby 1972).

The reciprocal hybrid (WB × SB) are approximately one-third smaller than striped bass larvae. The larval development is described by Bayless (1972). Mouth parts of reciprocal hybrids are functional and the gut is complete on the fourth day. Rearing success of reciprocal hybrids has also been substantially greater than that of striped bass. Ware (1975) reported 46% mean survival of reciprocal hybrids from the larval to the juvenile stage in six Florida ponds. Advantages of the reciprocal hybrids include the greater availability and relative ease of spawning white bass compared to striped bass. Since white bass and most male striped bass mature in 2 yr, under artificial propagation reciprocal hybrids can be produced in 2 yr, whereas 4-5 yr are required to produce the original hybrids (Bonn et al. 1976).

Production of various backcrosses and second generations has been described in detail by Bayless (1972). Although the SB × WB hybrid is not sterile, Bonn et al. (1976) stated that no successful reproduction of *Morone* hybrids has been reported in natural habitats.

Hybrid striped bass are more adaptable to inland reservoir stocking than striped bass and are reported to be of better food quality than white bass (Bishop 1968).

Striped bass, white bass, and the resultant hybrids (SB × WB) can be distinguished from one another by the following characteristics (Williams 1976):

Table 3.—Description of meristic characters for *Morone* spp. and hybrids. From Bayless 1972.

Species	Fork length/ body depth	Lateral line scales	Scales above lateral line	Scales below lateral line	Soft anal rays	2d dorsal count	2d anal spine length/ 3d anal spine length	Head length/ 2d anal spine length	Dorsal fins	Arch of back	Stripes
Striped bass	3.7-4.2 usually 3.9	58-67	7-9 usually 8	11-12 usually 11	I-12		0.73-0.83 mean 0.74	4.4-5.2 mean 4.5	Separated	Slight	Distinct (occasionally broken)
White bass	2.4-2.8 usually 2.6	[1]53-61	7-9 usually 9	[1]15	11-12	I-13-14	0.68-0.75 mean 0.72	2.4-3.1 mean 2.9	Separated	Moderate	Indistinct faint
Original white bass hybrid	2.6-3.4 usually 2.7	54-58 usually 56	10-12 usually 10	15-17 usually 16	12-13	I-12-14	0.89-0.96 mean 0.92	3.4-4.03 mean 4.01	Separated	Moderate	Distinct (frequently broken)
F_2	3.8-4.3 usually 4.1	55-62	9-11	12-14	11	I-12	0.58-0.90	3.8-5.7	Separated	Slight to moderate	Distinct (occasionally broken)
Original backcross	3.8-4.2	52-58	9-11	12-14	11-12	I-12-13	0.77-0.89	3.5-5.4	Separated	Slight	Distinct
Reciprocal backcross	3.7-4.1	52-58	8-10	12-14	8-11	I-12-13	0.26-0.83	4.0-14.3	Separated	Slight to acute	Distinct (occasionally broken)
White perch hybrid	3.8-4.2 usually 3.9	53-56	8-9	11-13 usually 12	10	I-12-13	0.81-1.0	3.4-3.8	Connected	Slight	Distinct

[1]Jordan and Evermann (1896).

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Production of various backcrosses and second generations has been described in detail by Bayless (1972). Although the SB × WB hybrid is not sterile, Bonn et al. (1976) stated that no successful reproduction of *Morone* hybrids has been reported in natural habitats.

Hybrid striped bass are more adaptable to inland reservoir stocking than striped bass and are reported to be of better food quality than white bass (Bishop 1968).

Striped bass, white bass, and the resultant hybrids (SB × WB) can be distinguished from one another by the following characteristics (Williams 1976):

Table 3.—Description of meristic characters for *Morone* spp. and hybrids. From Bayless 1972.

Species	Fork length/ body depth	Lateral line scales	Scales above lateral line	Scales below lateral line	Soft anal rays	2d dorsal count	2d anal spine length/ 3d anal spine length	Head length/ 2d anal spine length	Dorsal fins	Arch of back	Stripes
Striped bass	3.7-4.2 usually 3.9	58-67	7-9 usually 8	11-12 usually 11	I-12		0.73-0.83 mean 0.74	4.4-5.2 mean 4.5	Separated	Slight	Distinct (occasionally broken)
White bass	2.4-2.8 usually 2.6	[1]53-61	7-9 usually 9	[1]15	11-12	I-13-14	0.68-0.75 mean 0.72	2.4-3.1 mean 2.9	Separated	Moderate	Indistinct faint
Original white bass hybrid	2.6-3.4 usually 2.7	54-58 usually 56	10-12 usually 10	15-17 usually 16	12-13	I-12-14	0.89-0.96 mean 0.92	3.4-4.03 mean 4.01	Separated	Moderate	Distinct (frequently broken)
F_2	3.8-4.3 usually 4.1	55-62	9-11	12-14	11	I-12	0.58-0.90	3.8-5.7	Separated	Slight to moderate	Distinct (occasionally broken)
Original backcross	3.8-4.2	52-58	9-11	12-14	11-12	I-12-13	0.77-0.89	3.5-5.4	Separated	Slight	Distinct
Reciprocal backcross	3.7-4.1	52-58	8-10	12-14	8-11	I-12-13	0.26-0.83	4.0-14.3	Separated	Slight to acute	Distinct (occasionally broken)
White perch hybrid	3.8-4.2 usually 3.9	53-56	8-9	11-13 usually 12	10	I-12-13	0.81-1.0	3.4-3.8	Connected	Slight	Distinct

[1]Jordan and Evermann (1896).

Species	Fork length/ body depth Mean and range	Body depth/ head length Mean and range	Teeth on tongue
Striped bass	4.440 (4.018-5.316)	0.893 (0.731-0.983)	Two patches
White bass	3.477 (3.000-3.955)	1.198 (1.015-1.473)	One patch
Hybrid	3.468 (3.082-3.987)	1.158 (1.048-1.323)	Two patches

Smith et al. (1967) successfully crossed *Morone saxatilis* females and *M. americana* males. Kerby (1972) reported that the SB × WB hybrid growth apparently was somewhat less than that of natural striped bass populations, but was much greater than the growth of natural white perch populations. Hybrid survival was much better than striped bass survival under the same experimental conditions. Hybrids were able to survive and grow in estuarine salinities and could probably survive in fresh water though Kerby's data is scant. SB × WP hybrids matured in 2 yr.

Striped bass, yellow bass, *Morone interruptus*, hybrids have also been produced (Ware 1975).

2.42 Influence of natural hybridization in ecology and morphology

No natural hybridization has been reported.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

Striped bass are heterosexual. Female striped bass grow larger than males; most bass of 13.6 kg and heavier are females (Bigelow and Schroeder 1953).

Several accounts of hermaphroditism are in the literature. Schultz (1931) described a 5.4 kg, 60.3 cm SL (standard length) striped bass with a functional ovary on the left side of the body cavity and a testes containin well-developed spermatozoa on the right side of the body cavity. Schultz concluded that the fish would have spawned both sexual products. Morgan and Gerlach (1950) reported almost 3% of the striped bass sampled in Coos River, Oreg., were hermaphrodites. Occasionally both ovary and testes were ripe and in spawning condition at the same time.

3.12 Maturity

Sexual maturation of striped bass is dependent upon temperature; the warmer the water, the faster the sexual maturation. As in many fish, male striped bass reach sexual maturity at an earlier age than females. Minimum lengths at maturity are approximately 432 mm TL for females (Clark 1968) and 174 mm TL for males (Raney 1952).

Males mature primarily at 2 yr (Raney 1954; Mansueti 1956; Tagatz 1961; Mansueti and Hollis 1963). Ware (1971) found that 11-mo-old males in Florida may show "slight milt discharge"; all males were ripe at 23 mo. Females in Florida, however, showed no signs of gonadal development during the first 2 yr of life.

Lewis (1962) reported that 4% of the 3-yr-old female striped bass on the Roanoke River, N.C., were mature and capable of spawning subsequent to the 1957 and 1958 fishing seasons; 78% and 94% of the 4-yr-old fish were mature in these same years. All 5- and 6-yr-old female striped bass were sexually mature although some fish, 7 yr and older, did not spawn annually.

Female striped bass first spawn in the Chesapeake Bay during their fourth or fifth year, at a length ranging from 45 to 55 cm TL and a weight of 1.8-2.7 kg (Jackson and Tiller 1952). Although fish spawned up to the 14th year, a curtailment of spawning occurred after the 10th year.

Jones et al.[17] reported the following percent maturity for striped bass collected on Potomac River, Md., spawning grounds from 1974 to 1976:

	Males		Females	
Age	Number	% mature	Number	% mature
2	14	92.9	None collected	
3	286	99.0	9	44.4
4	448	99.8	28	78.6
5	571	98.6	138	98.6
6	All mature		All mature	

Percent maturity of striped bass collected from Potomac River overwintering and migrating areas downriver from spawning grounds from 1974 to 1976 was:

	Males		Females	
Age	Number	% mature	Number	% mature
2	1	100	3	0.0
3	73	91.8	36	16.7
4	184	96.2	58	43.1
5	All mature		7	85.7
6	All mature		All mature	

In the Delaware estuary, some 2-, most 3-, and all 4-yr-old males were sexually mature; all females ≤4 yr were sexually immature (Bason 1971). Merriman (1941) reported that 25% of 4-yr-old, 75% of 5-yr-old, and 95% of 6-yr-old females from Connecticut waters were sexually mature.

Male striped bass in the San Francisco Bay area matured by their third year (Sasaki 1966); approximately 35% of the females matured and spawned in their fourth year, 85% in their fifth year, and 98% or more in their sixth year (Scofield 1931).

Some males matured at the end of their first year in Coos Bay, Oreg., 18% of the females matured in their

[17]Jones, P. W., J. S. Wilson, R. P. Morgan II, H. R. Lunsford, Jr., and J. Lawson. 1977. Potomac River fisheries study; striped bass spawning stock assessment. Interpretive report 1974-1976. Univ. Md. CEES Ref. No. 77-56-CBL. Chesapeake Biological Laboratory, Solomons, MD 20688.

third year, 68% by their fourth year, and all by their fifth year (Morgan and Gerlach 1950).

3.13 Mating

Polygamous.

3.14 Fertilization

External.

3.15 Gonads

Lewis (1962) described three developmental stages for striped bass eggs:

1. 0.07-0.23 mm—translucent eggs, immature;
2. 0.16-0.30 mm—translucent eggs in which yolk had had begun to form as opaque speckling;
3. 0.33-1.00 mm—opaque ova, mature.

Striped bass with type 1 ova are immature, whereas those with types 2 and 3 ova are mature. Egg growth begins slowly in the summer and fall, but increases rapidly as the spawning season approaches. Ripe eggs range from 1.0 to 1.5 mm in diameter (Woodull 1947; Raney 1952; Lewis 1962); average egg size has been reported as 1.32 mm (Mansueti 1958a) and 1.35 mm (Raney 1952). Descriptons of unfertilized eggs have been summarized by Hardy (1978).

Striped bass fecundity estimates vary widely and have ranged from 15,000 eggs in a 46 cm fish (Mansueti and Hollis 1963) to 40,507,500 in an age 13, 14.5 kg fish (no size given) (Jackson and Tiller 1952). Ten percent of these eggs (4,010,325) were large (mature) and potentially capable of being spawned the following season. De Armon (1948) suggested that eggs for three consecutive seasons are contained in the ovary simultaneously. Jackson and Tiller (1952) found approximately 15% large (mature) ova in 49 striped bass from the Chesapeake Bay. Mature ova are uniformly distributed throughout both ovaries. Production of mature ova can be estimated from the equation:

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

where $\hat{Y}$ = number of mature ova
X = weight in pounds.

The 95% confidence interval for the mean large egg production of fish at a given weight is:

$$CI(\hat{Y}) = \hat{Y} \pm 24.19 \sqrt{0.0063 + \frac{(X-7.3)^2}{1{,}770}}$$

(Lewis and Bonner 1966).

Holland and Yelverton (1973) estimated fecundity for 35 female striped bass 77.0-110.0 cm FL (fork length) and 7-13 yr of age. Mean fecundity and range for each age group was:

Age	*No. of fish*	*Mean fecundity*	*Range*
		---- in thousands	----
7	1	614	614
8	4	1,703	1,044-2,222
9	13	2,100	1,067-3,716
10	4	2,922	1,996-4,058
11	10	2,928	2,167-3,911
12	2	3,408	3,304-3,511
13	1	3,391	3,391
	35	2,462	

They found the following linear relationship between fecundity and length, weight, and age:

$$F = 9.33 \times 10^4\ FL - 6.24 \times 10^6 \quad r = 0.85$$
$$F = 2.18 \times 10^5\ W - 1.17 \times 10^4 \quad r = 0.86$$
$$F = 4.33 \times 10^5\ A - 1.78 \times 10^6 \quad r = 0.66$$

where F = fecundity $\times 10^6$
FL = fork length in cm
W = weight in kg
A = age in years.

In the Roanoke River, N.C., female striped bass ≤27.2 kg, the bulk of the female spawning population, produced between 138,000 and 497,000 ova; 105,600-215,600 ova/kg of body weight. Striped bass between the ages of 4-10 yr produced approximately 100,000 mature ova/yr of life (Lewis and Bonner 1966). For a summary of striped bass fecundity estimates based on weights of fish, the reader is referred to Hardy (1978).

3.16 Spawning

Spawning times and locations

Striped bass spawn in fresh or nearly fresh waters. Along the Atlantic coast, spawning occurs from mid-February in Florida through June or July along the southern shore of the Gulf of St. Lawrence and the lower St. Lawrence River (Raney 1952; Bigelow and Schroeder 1953; Barkuloo 1970). Spawning along the Florida Gulf coast occurs from February through May (Barkuloo 1961, 1970). Table 4 summarizes striped bass spawning times along the Atlantic and Pacific coasts.

The principal spawning and nursery areas of striped bass along the Atlantic coast are found in the Chesapeake Bay and its tributaries (Merriman 1941; Raney 1957). Spawning sites on the major rivers along the Atlantic coast are given in Table 5.

Spawning occurs at or near the surface (Woodhull 1947; Calhoun et al. 1950; Raney 1952; Surber 1958); while spawning a single female may be surrounded by as many as 50 males (Worth 1903; Merriman 1941). Eggs are broadcast loosely into the water. "Spawning by an

Table 4.—Striped bass spawning season, adapted from Hardy (1978).

Location	Time	Author
Gulf of Mexico	peaks in June	Raney 1952
Mississippi	mid-February to mid-March (on basis of well-developed roe)	McIlwain 1968
Alabama	April	Raney 1952
Eastern Florida	mid-February to end of May	Barkuloo 1970
	"probably nearer mid-winter in St. John River"	McLane 1955
South Carolina	April to mid-May	Scruggs 1957
North Carolina	late April and May	Chapoton and Sykes 1961
Chesapeake Bay region	mostly April, May, early June	Chapoton and Sykes 1961; Dovel 1971
Delaware	late May to mid-July peak June	Raney 1952
Hudson River	mid-May to mid-June	Raney 1952
	peak-last 2 wk of May	Rathjen and Miller 1957
New England	June and early July	Bigelow and Schroeder 1953
Canada	June and July	Bigelow and Schroeder 1953; Pearson 1938; Raney 1952
California	mid-March to late July	Scofield 1928
	peak-May and June	Calhoun et al. 1950

individual striped bass probably is completed within a few hours" (Lewis and Bonner 1966:328).

Spawning peaks are apparently triggered by a noticeable increase in water temperature and vary greatly from year to year. The number of spawning peaks in the Roanoke River, N.C., was one in 1963 (Neal[18]), three in 1966 (Neal[19]), and four in 1961 and 1962 (Neal footnote 18). There was one spawning peak in the Potomac River, Md., during 1974 and 1975, and two during 1976 (Boynton et al. footnote 12).

In a study designed to determine optimal sampling frequency, Cheek (1961) collected striped bass eggs hourly for 15 days below the spawning area in the Roanoke River. Sampling every 3 h yielded the smallest variance.

Diel spawning patterns

Based on observations made over many years at the Weldon Fish Hatchery, spawning in the Roanoke River, N.C., can be, and often is, explosive in development with sharp spawning peaks of relatively brief duration, generally at night (Fish and McCoy 1959). In several South Carolina rivers, however, when the spawning season is considered as a whole, the natural light regime seemed to have little influence on the hour spawning occurred. May and Fuller (1965) reported that spawning in the Congaree River was evenly divided between daylight and night hours; on the Wateree River 55.5% of the spawning occurred during the day and 44.6% at night.

[18]Neal, W. E. 1964. Striped bass study. Virginia's Dingell-Johnson Proj., Job Completion Rep., F-5-R-9, Job No. 8, 14 p.

[19]Neal, W. E. 1967. Striped bass study. Virginia's Dingell-Johnson Proj., Job Completion Rep., F-5-R-12, Warm water fisheries investigations, Job No. 8, 69 p.

Table 5.—Striped bass spawning sites, adapted from Hardy (1978).

Area	Distance (upriver from mouth, km)	Author
Georgia:		
Savannah River	30-40	Dudley et al. 1977
South Carolina:		
Congaree River	68.6-83.4	
Wateree River	peak below 59.3, but up to 107.5-111.2	May and Fuller 1965
North Carolina:		
Tar River	55.6-148.2; 75% within 37 km area	Humphries 1966
Roanoke River	161.2-253.9; peak 200-241	Fish and McCoy 1959; Dovel and Edmunds 1971
Virginia:		
Stanton River	41.0-98.2 above Kerr Reservoir	Sheridan et al. 1960[1]
York River	64.9-111.2; peak 74.1	Rinaldo 1971
Pamunkey River (tributary of York)	peak-31.5 above West Point	Tresselt 1952
Mattaponi River (tributary of York)	14.8-35.2 above West Point; peak 16.7	Tresselt 1952
James River	mouth of Chickahominy to Hopewell - 120.4	
Rappahannock River	74.1-120.4	Kriete 1978[2]
Maryland:		
Potomac River	94.5-157.5 peak 97.5-139.0	Boynton et al., 1977[3]
Patuxent River	66.7-77.8	Tiller 1955
Elk River	5.6-16.7	Maryland Board of Natural Resources 1957,[4] 1958[5]
Chesapeake and Delaware Canal	throughout Canal, ≈26	Maryland Board of Natural Resources 1957,[4] 1958[5]
Nanticoke River	14-28	Maryland Board of Natural Resources 1957,[4] 1958[5]
Bohemia River	5.6	Maryland Board of Natural Resources 1957,[4] 1958[5]
Wicomico River	22.2-25.9	Maryland Board of Natural Resources 1957,[4] 1958[5]
Chester River	51.9	
Delaware:		
Delaware River	107.5-231.6	Murawski 1969
New York:		
Hudson River	first 46 of freshwater	Rathjen and Miller 1957
California:		
Sacramento River	37.1-315.0	Farley 1966

[1]Sheridan, J., B. Domrose, and B. Wollitz. 1960. Striped bass spawning investigations. *In* Virginia Dingell-Johnson Project, Annual Progress Report, 1 July 1959-30 June 1960, p. 33-43. Fed. Aid Proj. F-5-R-6, Warm water fisheries management.

[2]William H. Kriete, Jr., Virginia Institute of Marine Science, Gloucester Point, VA 23062, pers. commun. 16 Feb. 1978.

[3]Boynton, W. R., E. M. Setzler, K. V. Wood, H. H. Zion, and M. Homer. 1977. Draft report on Potomac River fisheries study; ichthyoplankton and juvenile investigations. Univ. Md. CEES Ref. No. 77-169-CBL. Chesapeake Biological Laboratory, Solomons, MD 20688.

[4]Maryland Board of Natural Resources. 1957. Fourteenth Annual Report, Annapolis, Md., p. 35-38.

[5]Maryland Board of Natural Resources. 1958. Fifteenth Annual Report, Annapolis, Md., p. 32-34.

However, Sheridan et al.[20] reported that spawning occurred in North Carolina during the late afternoon or early evening hours. Spawning times in Virginia waters appear to be highly variable. In the Staunton River

[20]Sheridan, J., B. Domrose, and B. Wollitz. 1960. Striped bass spawning investigations. *In* Virginia Dingell-Johnson Project, Annual Progress Report, 1 July 1959-30 June 1960, p. 33-43. Fed. Aid Proj. F-5-R-6, Warm water fisheries management.

spawning has reportedly occurred primarily between late afternoon and early morning hours whereas in the Dan River spawning apparently occurs from early to late afternoon. Striped bass spawning times on the West Coast are also highly variable. Woodhull (1947) reported a striped bass spawn in California waters that lasted from 1500 until noon of the following day whereas spawning in Coos Bay, Oreg., occurs throughout the day but primarily during late afternoon or early evening hours (Raney 1952; Morgan and Gerlach 1950).

Sharp spawning peaks of relatively brief duration have also been reported from the Potomac River, Md. (Mihursky et al. footnote 6), the Chesapeake and Delaware Canal, and elsewhere. In 1971 Johnson and Koo (1975) collected 76.6% of the 60,030 striped bass eggs taken in the Chesapeake and Delaware Canal during five consecutive sampling dates from 23 April to 1 May. In 1972, samples collected on 1 and 2 May yielded 54.9% of the total catch of 83,918 eggs.

Several studies have compared striped bass egg densities in day versus night sampling. McCoy (1959) found no significant differences in the numbers of eggs collected at various times over 24-h sampling periods on the Roanoke River. Likewise there was no apparent daily cyclic pattern of spawning activity, and the variation of egg catch between time periods was not the same from day to day. Kernehan et al. (footnote 11) found no significant differences in mean egg densities over a 24-h sampling period in the Chesapeake and Delaware Canal. But, on the Potomac River, egg densities were greater around midday than during the night at the three depths sampled: surface, 4 m, and bottom (7 m) (Boynton et al. footnote 13). However, these results are based on a single 24-h study, thus no spawning pattern can be ascertained.

3.17 Spawn

Striped bass eggs remain viable for about 1 h after release from the follicles into the lumen (R. E. Stevens 1966; Fig. 1b). Fertilized eggs are spherical, nonadhesive, semibuoyant, and nearly or quite transparent and are characterized by a single large oil globule, a lightly granulated yolk mass, a wide perivitelline space, and a clear tough chorion (Raney 1952; Mansueti and Mansueti 1955; Mansueti 1958a; Chadwick 1964; Fig. 1c).

Live striped bass eggs are characteristically greenish or golden green; preserved eggs are amber colored or whitish yellow and dense and granular in appearance (Mansueti 1958a). Nonwater hardened eggs range from 1.25 to 1.80 mm in diameter (Pearson 1938; Raney 1952; Mansueti and Mansueti 1955; Mansueti 1964) with average sizes reported as 1.78 mm (Woodhull 1947) and 1.58 mm (Mansueti 1964). Water hardened eggs [water hardening occurs in approximately 1-2 h at a temperature of 18°C (Mansueti 1958a)] ranged in diameter from 1.30 mm (Murawski 1969) to 4.6 mm (Albrecht 1964). Johnson and Koo (1975) reported that fertilized water hardened eggs had a mean diameter of 3.4 mm (range 2.4-3.9 mm) in the Chesapeake Canal; Mansueti and Hollis (1963) found the maximum diameter of water hardened eggs in the Chesapeake Bay region to be 3.95 mm. Hardy (1978) summarized the sizes of water hardened eggs from various localities. Murawski (1969) suggested that the small diameter of water hardened eggs in some areas may be attributed to salinity or other factors. Yolk comprised about 35% of the diameter of eggs described by Mansueti (1958a). The diameter of the perivitelline space has ranged from 65 to 85% of the egg diameter (Merriman 1941; Raney 1952; Mansueti 1958a, 1964). Mansueti (1958a) reported the mean yolk diameter of 500 striped bass eggs as 1.18 mm (range 0.90-1.50); mean oil globule diameter was 0.61 mm (range 0.40-0.85). Ryder (1887) stressed the function of the perivitelline space as a larger than usual "breathing chamber" whereas Merriman (1941) suggested that the large perivitelline space protects the embryo from jarring and thus contributes to survival in rough and rapid water.

Striped bass eggs average 280 mg total weight (Eldridge et al. 1977). Estimates of percent dry weight composition of the oil globule ranged from 38.0-56.8%, freon extraction, to 63.4%, chloroform/methanol extraction. Caloric content of striped bass eggs ranged from 7,816 to 8,323 cal/g. Eggs averaged 2.21 calories, 1.38 oil calories and 0.83 yolk calories. The caloric content of oil was higher than that of yolk, 9,291 versus 6,917 cal/g.

3.2 Preadult phase

3.21 Embryonic phase

Striped bass eggs hatch from 29 (22°C) to 80 (11°C) h after fertilization, depending upon water temperatures. Hardy (1978) has summarized incubation times at various water temperatures. The relationship between ambient temperature and incubation times is expressed in the regression:

$$I = -4.60\ T + 131.6$$

where I = development time to hatching, in hours
T = °C (Polgar et al. 1976).

Detailed descriptions of striped bass embryonic development are presented by Mansueti (1958a), 16.6°-17.2°C, and Pearson (1938), 17.9°C, and are summarized in Table 6.

Physical factors

The tolerance and optimum range of some environmental conditions for striped bass eggs based on laboratory studies, has been summarized by Doroshev (1970), Table 7.

Temperature

Temperatures measured during striped bass spawning

Table 6.—Development of striped bass embryos at 16.7°-17.2°C. From Mansueti (1958a).

Time after fertilization	
0-5 min	Perivitelline space began to form.
20-40 min	Well-defined blastomeres; 2-, 4-, and 8-cell stages.
1 h	4- and 8-cell stages predominated.
1-2 h	Blastomeres evident; perivitelline space reached greatest capacity; chorion thin, transparent, and fragile.
2 h	Some eggs 32-cell stage, though 16-cell stage predominated.
4 h	Blastoderm well-formed, berrylike in its late cleavage stages.
8 h	Blastoderm granular in appearance.
12 h	Blastoderm grown halfway down over yolk.
16 h	Blastocoel forming; germ-ring thickened around periphery of blastoderm.
20 h	Embryo developed; neural ridges and eyes visible; pigmentation present around embryo and oil-droplet.
24 h	Embryo well-differentiated, extended about half-way around circumference of yolk; embryos pigmented on dorsolateral parts of body and adjacent blastoderm.
36 h	Larvae within eggs 1.6-2.0 mm TL; eyes well-differentiated but lacked pigment; posterior part of embryo free from yolk sac.
48 h	Yolk-sac larvae hatching; 2.9-3.7 mm TL.

crease hatching percentage and increase striped bass larval deformities. One hundred percent larval mortality within 70 h was obtained at these temperatures, although striped bass eggs survived either constant or fluctuating water temperatures from 12.8° to 23.9°C.

Temperature fluctuations affect spawning. In 1963, water warmed up slowly in the Sacramento River, Calif., and fish migrated past Scramento, Calif., while in 1964 with a fast temperature rise, striped bass spawned well below the Sacramento River (Farley 1966). Sudden drops in temperature resulted in cessation of spawning (Calhoun et al. 1950; Mansueti and Hollis 1963; Boynton et al. footnote 13). Calhoun et al. (1950) observed that spawning ceased during storms.

Salinity

Albrecht (1964) has shown that low salinities, 1.69-1.74‰ (920-948 ppm Cl^-), enhance egg and larval survival and moderate salinities, 8.32-8.58‰ (4,595-4,740 ppm Cl^-), are not detrimental to survival. Turner and Farley (1971) have shown that egg survival in salinities >1.8‰ (1,000 ppm Cl^-) especially at temperatures higher than 18°C was greatly reduced if the eggs were not water

Table 7.—Tolerance (numerator) and optimum range (denominator) of some environmental factors for striped bass eggs, larvae and young. After Doroshev (1970).

Developmental stage	Flow rate m/s	Light	Temp °C	pH	Salinity (‰)	O_2 mg/l	Author
Eggs	0.3-5.0 / 1.0-2.0	+	14-23 / 17-20	?	0-10 / 1.5-3	1.5-	Mansueti (1958a)
Larvae up to 20 mm	0-5 / 0.3-1.0	++	12-23 / 16-19	6-9 / 7-8	0-15 / 5-10	2-20 / 5-28	Albrecht (1964); Tagatz (1961); Regan et al. (1968)
Young 20-50 mm	0-5 / 0-1	+	10-27 / 16-19	6-10 / 7-9	0-20 / 10-15	3-20 / 6-12	Bogdanov et al. (1967)
Young 50-100 mm	0-5 / 0-1	?	?-30 / 18-23	6-10 / 7-9	0-35 / 10-20	3-20 / 6-12	Bogdanov et al. (1967)

are summarized in Table 8. Morgan and Rasin[21] could not hatch striped bass eggs maintained at temperatures of 10.5° and 11.0°C. They found optimal survival of striped bass eggs at temperatures between 16° and 23°C with a rapid decline in percent survival at temperatures above 23°C. Rogers et al. (1977) reported that eggs incubated at 12°C seldom survived to hatching. Highest survival occurred between 15° and 18°C. Barkuloo (1970) found water temperatures below 13.4°C and above 22.2°C to be lethal for fertilized striped bass eggs obtained from a Florida population. Shannon and Smith (1968) found temperatures of 23.4°C and above to de-

[21]Morgan, R. P., II, and V. J. Rasin, Jr. 1973. Effects of salinity and temperature on the development of eggs and larvae of striped bass and white perch. *In* Hydrographic and ecological effects of enlargement of the Chesapeake and Delaware Canal. U.S. Army Corps Eng., Phila. Dist. Contract No. DACW-61-71-C-0062. Final Rep., Append. X, 38 p.

hardened in fresh water [130 ppm total dissolved solids (TDS) or less]. Striped bass eggs water harden in approximately 1½ h at 18°C. The authors found no striped bass eggs survived in 22.2°C waters at salinities >1.8‰. However, Morgan and Rasin (footnote 21) found that the percentage hatch of striped bass eggs and survival after 24 h did not vary significantly with salinities in the ranges tested (0-8‰) (25% survival at 0‰ to 34% survival at 8‰).

Radtke and Turner (1967) reported that a critical concentration of 350 ppm TDS blocked spawning up the San Joaquin River, Calif. The largest number of eggs were found in waters with TDS of <180 ppm. Farley (1966) found no significant striped bass spawning areas in the Sacramento River where the TDS exceeded 180 ppm (0.18‰). Likewise, Murawski (1969) noted that spawning in the Delaware River was in waters with a dissolved solid concentration of 180 ppm or less.

Table 8.—Temperatures (°C) associated with striped bass spawning.

Lowest	Peak	Highest	Location	Author
14.4	15.6-19.4	21.1	Atlantic coast	Talbot 1966
10.0	14.0-18.0	19.5	Hudson River, N.Y.	Institute of Environmental Medicine, N.Y. Univ. Medical Center 1973[1]
15.0		20.0	Hudson River, N.Y.	Rathjen and Miller 1957
12.4(1972)		17.0	Chesapeake and Delaware	Johnson and Koo 1975
10.5(1971)		18.8	Canal, Maryland and Delaware	
11.5	15.0-17.0	23.6	Chesapeake and Delaware Canal	Kernehan et al. 1975,[2] 1976[3]
10.9-12.4	13.9-14.6	23.4	Potomac River, Md.	Mihursky et al. 1976[4]
11.3-12.0	18.4-19.0	22.6	Potomac River, Md.	Boynton et al. 1977[5]
15.0	17.0	23.8	Smith Mt Dam, Leesville, Va.	Neal 1971
13.0	16.7-19.4	21.7	Roanoke River, N.C.	Shannon and Smith 1968; Shannon 1970
	18.0-19.0		Albemarle Sound Tributaries, N.C.	Trent 1962
15.5			Congaree River, S.C.	May and Fuller 1965
14.4	21.7		Santee Cooper Reservoir, S.C.	Scruggs 1957
16.5-17.8		22.2-23.4	Ogeechee and Savannah Rivers, Ga.	Smith 1973
19.0		24.0	Apalachicola River, Fla.	Barkuloo 1967[6]
14.4-15.0	16.1-20.6	22.2	Sacramento River Delta, Calif.	Farley 1966
15.5-15.7			Sacramento River, Calif.	Calhoun et al. 1950
	19.4		San Joaquin River, Calif.	Woodhull 1947
	19.0-20.0		Sacramento-San Joaquin Rivers, Calif.	Hatton 1942
16.0		24.0	Suisan Bay, Sacramento and San Joaquin Rivers, Calif.	Scofield 1931

[1]Institutes of Environmental Medicine. 1973. Hudson River ecosystem studies: Effects of entrainment by the Indian Point Power Plant on Hudson River estuary biota. New York Univ. Med. Cent., N.Y., 289 p.

[2]Kernehan, R. J., B. E. Beitz, and S. L. Tyler. 1975. Ichthyoplankton. Volume II. *In* Ecological studies in the vicinity of the Summit Power Station, January 1974 through December 1974, 618 p. Ichthyological Associates, Inc. Box 286, RD # 1, Middletown, DE 19709.

[3]Kernehan, R. J., R. E. Smith, S. L. Tyler, and M. L. Brewster. 1976. Ichthyoplankton. Volume II. *In* Ecological studies in the vicinity of the proposed Summit Power Station, January through December 1975, 669 p. Ichthyological Associates, Inc., Box 286, RD # 1, Middletown, DE 19709.

[4]Mihursky, J. A., W. R. Boynton, E. M. Setzler, K. V. Wood, H. H. Zion, E. W. Gordon, L. Tucker, P. Pulles, and J. Leo. 1976. Final report on Potomac estuary fisheries study; ichthyoplankton and juvenile investigations. Univ. Md., CEES Ref. No. 76-12-CBL, 241 p. Chesapeake Biological Laboratory, Solomons, MD 20688.

[5]Boynton, W. R., E. M. Setzler, K. V. Wood, H. H. Zion, and M. Homer. 1977. Draft report on Potomac River fisheries study; ichthyoplankton and juvenile investigations. Univ. Md., CEES Ref. No. 77-169-CBL. Chesapeake Biological Laboratory, Solomons, MD 20688.

[6]Barkuloo, J. M. 1967. Florida striped bass, *Roccus saxatilis* (Walbaum). Fla. Game Fresh Water Fish Comm., Fed. Aid Proj. No. F-10-R, 24 p.

Turbidity

Striped bass are adapted to silt-laden and turbid waters (Mansueti 1962; Talbot 1966); heavy sediment loads do not seem to adversely affect striped bass hatching. Schubel and Auld (1974) reported that fine-grained sediments at a concentration of 500 mg/liter had no affect on striped bass eggs. Hatching success did decrease at sediment concentrations above 1,000 mg/liter, but such high concentrations are not found even in dredge areas. Morgan et al.[22] concluded that the hatch of striped bass eggs as percent of control hatch was not significantly affected by suspended sediment levels ranging from 20 to 2,300 ppm (mg/liter). However, the developmental rate of eggs was significantly lowered at sediment levels over 1,500 ppm.

River flow

Fish and McCoy (1959) concluded that the rapids sec-

[22]Morgan, R. P., II, and V. J. Rasin, Jr., and L. A. Noe. 1973. Effects of suspended sediments on the development of eggs and larvae of striped bass and white perch. *In* Hydrographic and ecological effects of enlargement of the Chesapeake and Delaware Canal. U.S. Army Corps Eng., Phila. Dist. Contract No. DACW-61-71-C-0062. Final Rep., Append. XI, 21 p.

tion of the Roanoke River became progressively more attractive to spawning striped bass as sustain minimum flows increased above 156 cm/s (4 m stage at Weldon, N.C.). Most of the spawning stock left the rapids when river flow was 110 cm/s or less. The greater the river discharge and the more uniformly it was regulated, the greater the utilization of the rapids section by spawning striped bass.

The effects of currents on striped bass egg distribution has been demonstrated in the Potomac River (Polgar et al. footnote 15, from a study by Mihursky et al.[23]) Although the probability of encountering eggs in channel and shoal areas (when equal amounts of water strained were considered) was not significantly different, egg densities were higher and more variable in shallow waters (<2 m) than in channel areas (>2 m). Polgar et al. (footnote 15) concluded that eggs deposited in the shallow-water areas were little affected by the dispersion processes of the Potomac River. Yolk-sac larval densities, however, were nearly the same in shallow and in channel waters. Thus over the relatively long residence time of the yolk-sac stage (approximately 6 days) the dispersion process of the Potomac River distributed the larvae about equally in the shallows and in the channel areas.

Oxygen concentrations

Striped bass egg survival decreased as oxygen concentrations decreased, even under the least rigorous test conditions (18.4°C and 5.0 mg/liter O_2), (Turner and Farley 1971). At 4.0 mg/liter O_2 the mean survival of eggs at 22.2°C was ≤50% of the survival of the controls (saturated oxygen concentrations) at exposure times of 6, 12, 18, 24, 30, and 40 h (time required for hatching). At 5.0 mg/liter O_2 egg survival was ≤50% of the controls at exposure times of 6, 12, 18, 30, and 38 h (hatching time). Hatching time was slightly longer with lower DO (dissolved oxygen) concentrations. The longer striped bass eggs were exposed to lower oxygen concentrations, the lower the percentage survival of larvae after 6 days. Chittenden (1971a) reported that low DO concentrations in the freshwater tidal zone of the Delaware River have eliminated this area as a striped bass spawning ground. Likewise, Murawski (1969) contended that low DO concentrations (2.0-3.5 ppm) in the lower Delaware River may explain the absence of striped bass eggs in some areas.

Egg distribution

Several investigators have examined the vertical distribution of striped bass eggs within the water column with varying results. Egg densities in the Chesapeake and Delaware Canal increased with depth (Johnson and Koo 1975). Likewise, Kernehan et al. (1975,[24] footnote 11) found striped bass egg densities from midwater and bottom samples in the Chesapeake and Delaware Canal to be significantly greater than densities from surface samples. The percentage of viable eggs increased from surface to bottom in all 4 yr of sampling. However, on the Potomac River egg densities did not significantly differ with depth (Boynton et al. footnote 13).

Albrecht (1964) concluded that striped bass egg distribution within the water column depended upon current velocities. A minimum current velocity of 30.5 cm/s was required to maintain eggs in suspension, an important factor for egg survival. At velocities of ≤30.5 cm/s, eggs were concentrated near the bottom; egg distribution at greater velocities appeared to be random. Talbot (1966) suggested that tidal turbulence may be as important as river runoff for egg suspension.

The effects of thermal pollution, entrainment, impingement, and chemical toxicity on striped bass eggs are considered at the end of section 3.23.

3.22 Larval phase

Larval development and behavior

At hatching, striped bass range in length from 2.0 to 3.7 ($\bar{X}$ = 3.1 mm TL) (Fig. 1d). The mouth has not formed and the eyes are unpigmented. Nourishment is derived from a very large yolk sac with a large oil globule (Mansueti 1958a, 1964). The rate of absorption of the yolk is highly variable; a temperature difference of 1.5°-2.5°C has a significant effect upon the rate of absorption. Reported durations of the yolk-sac stage include:

Temperature (°C)	*Time (days)*	*Author*
12	9.0	Rogers et al. 1977
15	8.3	Rogers et al. 1977
16.7-17.8	6.0	Albrecht 1964
18	7.8	Rogers et al. 1977
18.4 (range 16.9-19.4)	5.0	Eldridge et al. 1977
21	5.1	Rogers et al. 1977
24	3.8	Rogers et al. 1977
24	3.0	Albrecht 1964

Duration of the yolk-sac stage has also been estimated at 7-14 days with traces of yolk sometimes remaining until the 22d day (Doroshev 1970). Doroshev reported that by 2 days the yolk sac had decreased 20% in volume, the oil globule had decreased 11%, and the larvae were 4.5-5.2 mm TL. At 5 days, 50% of the yolk was utilized and the larvae were 5.8 mm TL; by 8 days, the yolk was 75% absorbed and the larvae were 5.8-6.5 mm TL. Rogers et al. (1977) found the efficiency of yolk utilization greatest in larvae reared between temperatures of

[23]Mihursky, J. A., R. N. Block, K. Wood, R. Prince, and E. W. Gordon. 1974. Potomac estuary fisheries study; ichthyoplankton investigations. Univ. Md., Cent. Environ. Estuarine Stud., Nat. Resour. Inst., N.R.I. Ref. No. 74-127, 160 p. Chesapeake Biological Laboratory, Solomons, MD 20688.

[24]Kernehan, R. J., B. E. Beitz, and S. L. Tyler. 1975. Ichthyoplankton Volume II. *In* Ecological studies in the vicinity [illegible] ver Station, January 1974 through December 197 [illegible] l Associates, Inc., Box 286, RD # 1, Middlet[illegible]

18° and 21°C. Maximum length of yolk-sac larvae has been reported as 5-7 mm for laboratory-reared fish (Mansueti and Mansueti 1955; Rogers et al. 1977) and 7-8 mm for wild populations (Mihursky et al. footnote 6). Hardy (1978) reviewed and summarized available literature on the physiological and anatomical development of striped bass larvae.

Early larval behavior has been described by a number of authors. In open waters yolk-sac larvae attempted to swim to the surface (Raney 1952) but sank between swimming efforts (Pearson 1938; Mansueti 1958a; Dickson 1958). Newly hatched larvae require sufficient turbulence to keep them from settling to the bottom; otherwise, they will be smothered (Barkuloo 1970). In aquaria, larvae may be suspended perpendicularly in the water column with the head near the surface. At 1 or 2 days of age larvae were near the surface and occasionally attached to floating objects (Mansueti 1958a); at 2 days larvae laid on the bottom or floated; between 2 and 3 days striped bass larvae swam continuously (Doroshev 1970; R. E. Stevens 1966). After 4 or 5 days, larvae reared in aquaria swam horizontally, were positively phototaxic, and came to the surface to feed (McGill 1967). Likewise Sandoz and Johnston (1966) and Doroshev (1970) stated that yolk-sac larvae 5.5-5.8 mm were positively phototaxic and remained constantly suspended in the water column.

After yolk-sac absorption, striped bass spend an average of 11 days in the finfold (metamorphosing) stage (Fig. 3a) (Polgar et al. footnote 15). Minimum length of finfold larvae has been reported as 5 mm [laboratory-reared fish (Mansueti 1964)] and from 6 to 7 mm for larvae captured from the Potomac River; maximum length was approximately 12 mm (Mihursky et al. footnote 6).

An estimate of the duration of the postfinfold stage (Fig. 3b; full development of second dorsal fin) can be

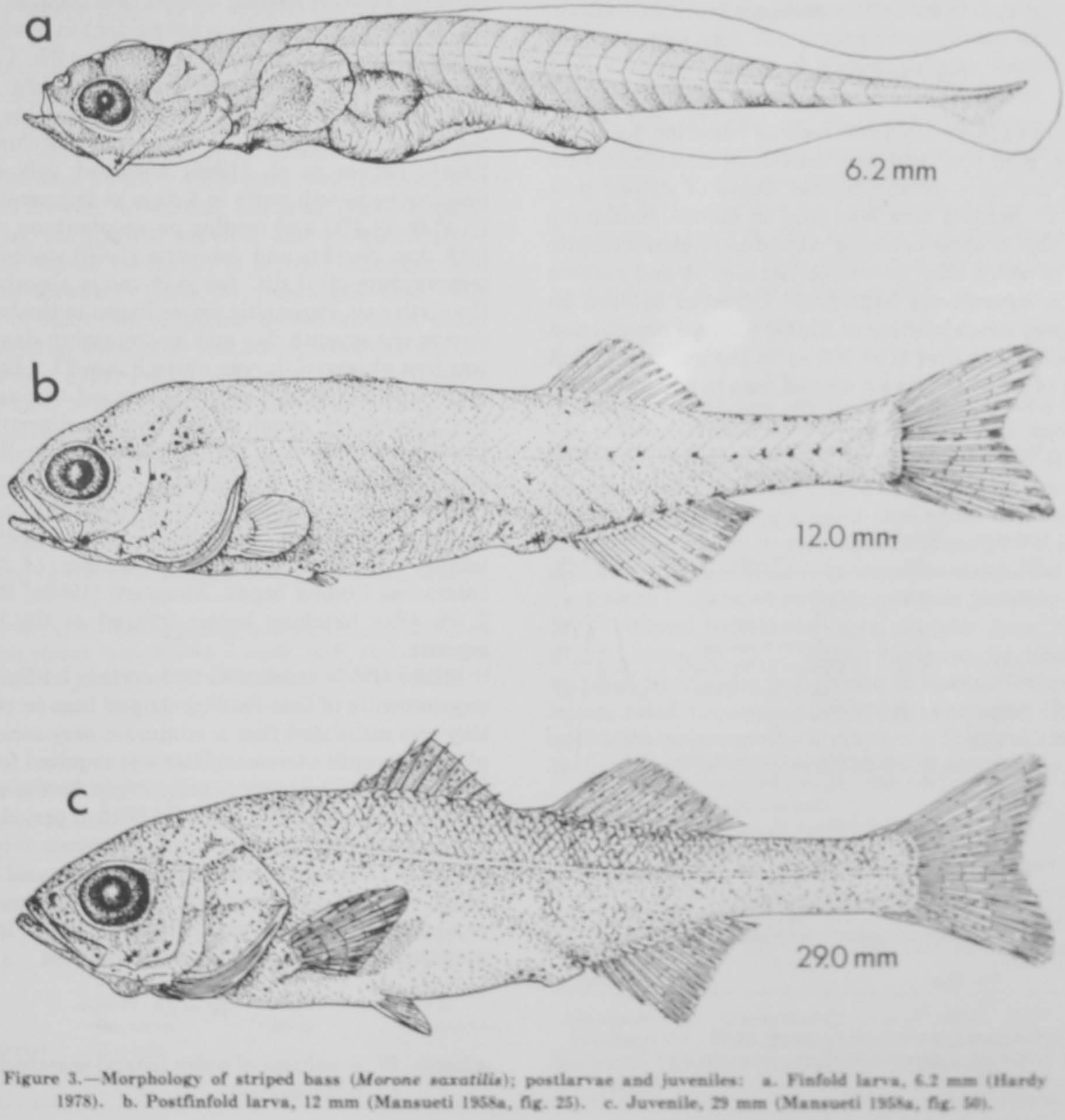

Figure 3.—Morphology of striped bass (*Morone saxatilis*); postlarvae and juveniles: a. Finfold larva, 6.2 mm (Hardy 1978). b. Postfinfold larva, 12 mm (Mansueti 1958a, fig. 25). c. Juvenile, 29 mm (Mansueti 1958a, fig. 50).

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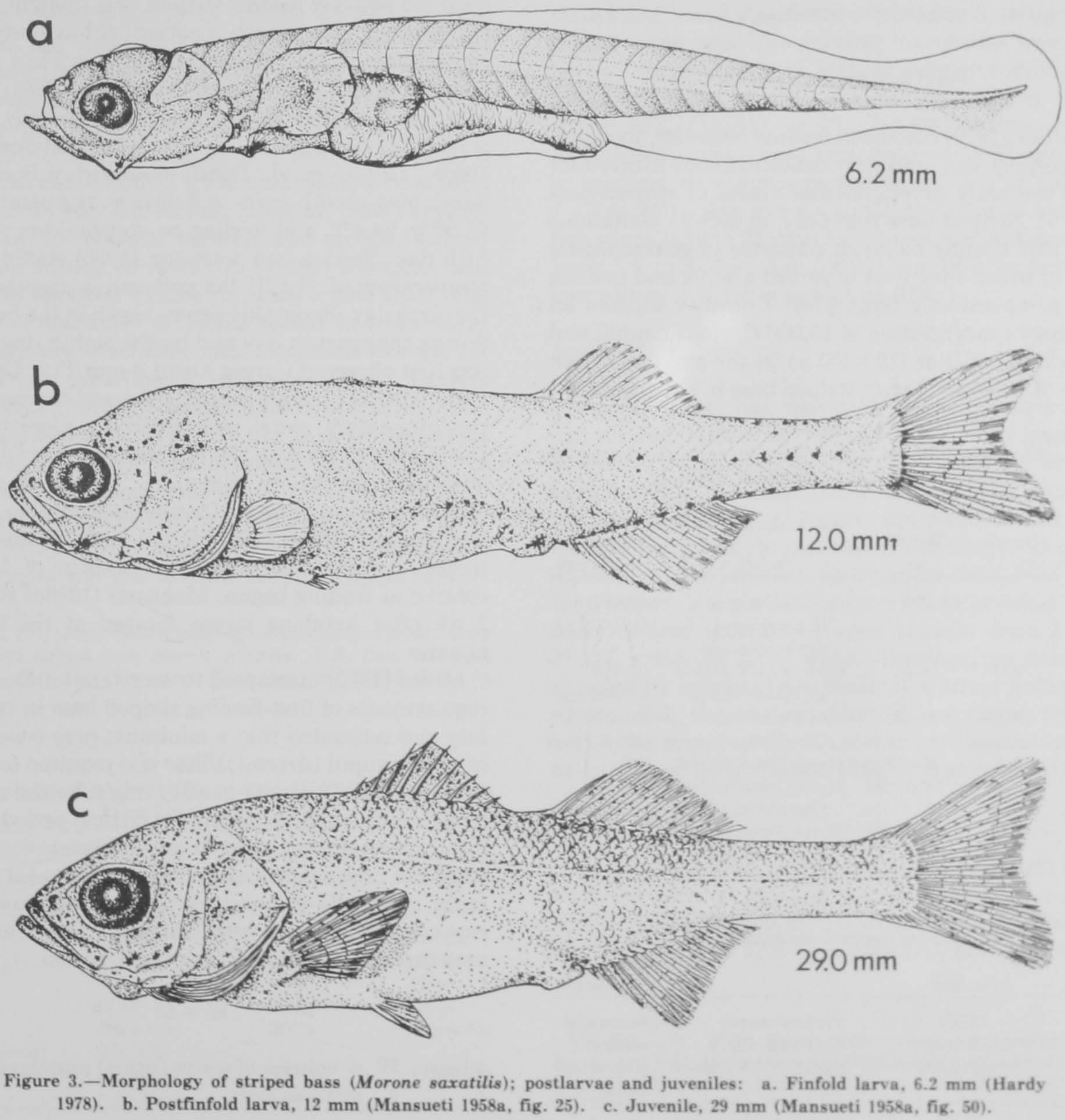

Figure 3.—Morphology of striped bass (*Morone saxatilis*); postlarvae and juveniles: a. Finfold larva, 6.2 mm (Hardy 1978). b. Postfinfold larva, 12 mm (Mansueti 1958a, fig. 25). c. Juvenile, 29 mm (Mansueti 1958a, fig. 50).

made from the lengths of postfinfold and juvenile striped bass (Fig. 3c) caught in the Potomac River during 1975 and 1976 (Mihursky et al. footnote 6; Boynton et al. footnote 13). Twenty to thirty days is a good approximation of the duration of the postfinfold stages of striped bass. Detailed descriptions of the early developmental stages are presented in Hardy (1978), Doroshev (1970), and Mansueti (1958a). Other accounts of egg and larval development include: Ryder (1887), Hildebrand and Schroeder (1928), Pearson (1938), and Bigelow and Schroeder (1953). Original illustrations of striped bass larvae are given in Ryder (1887), Pearson (1938), and Mansueti (1958a).

The duration of finfold and postfinfold stages (collectively termed larval stage by some authors; postlarval stag by others) is temperature dependent. Rogers et al. (1977) found the following durations for the larval stage:

15°C	68 days
18°C	33 days
21°C	24 days
24°C	23 days.

Food and feeding habits

Doroshev (1970) discussed feeding behavior, food preferences, prey size, and prey concentrations utilized for rearing the early developmental stages of striped bass (Table 9). Striped bass feed only on mobile planktonic food. Their feeding behavior consisted of characteristic passes in which they were observed aiming and rushing at the comparatively large prey. Doroshev utilized an initial prey concentration of 15,000 *Cyclops* nauplii and copepodites per liter (150-300 μ) in the successful first feeding of 9-day-old larval striped bass in aquaria 16.7°-17.5°C. He reduced prey concentrations to between 2,000 and 5,000/liter by day 11 to day 12 when the air bladder of most larvae was filled, energy expenditures were sharply reduced, and the effectiveness of the food search increased. Although the prey densities utilized by Doroshev are not minimal, it is obvious that the availability of sufficient concentrations of suitable prey which are required for the first several days of striped bass feeding is a critical factor in the success of any larval year class. By age 40-50 days, 22-35 mm TL, striped bass feed readily on plankton and epibenthos including mysids and chironomid larvae. Striped bass will take any food including dry floating food at age 50-60 days; by 80-90 days, striped bass 50-80 mm TL preferred foods include mysids, gammarids, and fish up to 20 mm in length (Doroshev 1970).

Table 9.—Feeding of young striped bass in early developmental stages. Adapted from Doroshev (1970).

Days after hatching	Length mm TL	Weight mg	Food items: Preferred	Food items: Diameter or length mm
9	6-7	1-5	*Cyclops;* Nauplii, I, II; *Brachionus; Artemia* nauplii	0.15-0.3 (150-300 μ)
15	9-15	8-14	*Cyclops* III-V; *Moina* sp. (Cladocerans)	0.3-0.6 (300-600 μ)
22	18-22	15-80	*Cyclops; Moina; Chaoborus*	0.8-1.5 (800-1,500 μ)
32	20-30	40-220	*Mysis;* Chironomidae	4-7
45	30-50	220-1,000	*Mysis;* Chironomidae; Gammaridae	10-15
65	50-70	1,000-3,500	*Mysis;* Gammaridae; fish fingerlings	15-20
100	80-120	5,000-20,000	Mainly fish fingerlings	up to 30

Food concentrations - Aquaria

Age in days	No./liter		Comments
9	15,000	*Cyclops* nauplii	Successful rearing of striped bass larvae
11-12	2,000-5,000	*Cyclops* II, III, IV	
16-18	1,000-1,500	*Cyclops* IV, V - *Moina*	

A number of other investigators have described the initiation of feeding in striped bass larvae which generally occurred from 4 to 10 days after hatching (see review by Hardy 1978), although Anderson (1966) recorded actively feeding striped bass thought to be 24 h old. Although the mouth is not evident in newly hatched striped bass, it is formed at an age from 2 to 4 days or at a length from 4.5 to 5.2 mm (Mansueti 1958a; Tatum et al. 1966; Doroshev 1970) though it is possibly not functional for as much as 10 days after hatching (Logan 1968). Tatum et al. (1966) observed yolk-sac larvae developing mouth parts in 4 days at temperatures from 22.8° to 24.4°C and feeding on zooplankton during the fifth day. Sandoz and Johnston (1966) stated that at a temperature of 21.8°C the yolk sac is absorbed during the sixth day. Peristaltic waves began in the body cavity during the seventh day and by the eighth day ingestion was first observed (larvae about 8 mm TL). Larvae took early copepod instars which appeared to pass through the alimentary canal untouched by digestive juices. During the ninth day, the gut contents were darker and obviously altered by digestion. Tatum et al. (1966) observed larvae to be positively phototrophic, although Rathjen and Miller (1957) found both larvae and postlarvae concentrated near the bottom of the water column as feeding began. Mansueti (1958a) stated that 2 wk after hatching larvae foraged at the bottom of aquaria.

Miller (1977) attempted to ascertain minimal feeding requirements of first-feeding striped bass in the laboratory and estimated that a minimum prey concentration of 1,864 nauplii (*Artemia*)/liter was required to establish first-feeding. This prey density might be the maximum food density required during the critical period of changing from an endogenous to an exogenous food supply, since the prey concentration required to meet the minimum metabolic demands of the striped bass could be expected to decrease with increasing larval length and prey capture efficiency. Using the equation

$$W = L^3$$

where W = volume of water (liters) searched per hour
L = TL in cm

established by Hunter (1972), Miller estimated that first-feeding striped bass larvae (5.7-6.3 mm TL) would be expected to search out a volume of 0.185-0.250 liters/h. He further estimated strike efficiency to be between 2.0 and 2.6% for first-feeding striped bass.

Environmental conditions (both larval and juvenile stages)

A number of studies have ascertained optimal conditions for survival and growth of striped bass larvae and juveniles. Table 7 summarizes tolerance and optimum range of some of these environmental conditions.

Salinity

As Table 7 indicates striped bass larvae do better in low salinity waters than in fresh water. Shell[25] reported a significantly higher mean survival rate (9%) for striped bass larvae in rearing ponds with 1‰ salinity than in freshwater rearing ponds (2%). Adding $CaCO_4$ to rearing ponds did not increase striped bass larval survival (Reeves and Germann 1972). Davies (1973) found 80% survival contours shifted toward higher temperatures as TDS (mg/liter NaCl) were increased from 100 to 900 mg/liter (0.1-0.9‰). Tatum et al. (1966) reported 24-h median tolerance limits of 4,830 ppm NaCl (4.83‰) and a pH of 5.3 for yolk-sac larvae. Lal et al. (1977) demonstrated that for optimal survival and growth, striped bass larvae should be reared in diluted seawater, and juveniles in seawater (Table 10); they stated that "The high rate of mortality of larvae reared in fresh water which continues even after metamorphosis has not occurred in our experiments with sea water." Bayless (1972) reported better growth and survival of larvae held in salinities of 3.5, 10.5, and 14.0‰ than in freshwater controls. Best growth was obtained at a salinity of 14.0‰; best survival occurred at 10.5‰. Critical salinity for striped bass larvae was between 21 and 28‰. Rathjen and Miller (1957) concluded that on the Hudson River young-of-the-year striped bass grew more rapidly in brackish water than did those upstream. Mihursky et al. (footnote 6) presented evidence which indicated that juvenile striped bass do in fact migrate to the saltier portions of the estuary after reaching a size larger than 70 mm TL.

[25]Shell, E. W. 1974. Factors limiting the survival and growth of fry and fingerling striped bass, *Morone saxatilis*. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Annu. Prog. Rep., Proj. AFC-7, Seg. 1, 54 p.

Table 10.—Optimum salinities for rearing of striped bass larvae. From Lal et al. (1977).

Optimal growth		Optimal survival	
Age: Days after hatching	Salinity ‰	Age: Days after hatching	Salinity ‰
1-9	6.75	1-6	3.37
10-19	13.49	7-13	6.75
20-29	20.24	14-20	13.49
30-35	26.98	21-29	20.24
36... (Metamorphosis)	Sea water (La Jolla sea water = 33.73)	30-35	Sea water
		36... (Metamorphosis)	Sea water

Temperature

Davies (1970) found striped bass larvae able to acclimate to temperature changes faster than juveniles although the temperature range for larval survival is much less, 10°-25°C, than for juveniles, 4.4°-35°C. Acclimation to lower temperatures was a slower process than acclimation to higher temperatures: 30-35 h versus 4 h for larvae; 8 days versus "rapidly" for juveniles.

Temperature-salinity interaction

Otwell and Merriner (1975) reared larval and juvenile striped bass in various temperature-salinity experiments and found significant effects due to temperature, salinity, and age. The greatest mortalities were at the lowest temperature and highest salinity combinations. Mean mortality at 20‰ (23.6%) was higher than at either 12‰ (15.4%) or 4‰ (11.8%). Likewise mean mortalities at the lowest temperature, 12°C were >50% in contrast to a mean mortality of 3.5% at 18°C and 7.2% at 24°C. Age was a significant factor in mortality; fish younger than 28 days had mean mortalities ranging from 3.6 to 11.0%; fish older than 28 days had mean mortalities >20% and as high as 40%.

Acclimation

Tagatz (1961) has shown that juvenile striped bass can survive transfer between salt (34‰) and fresh water at temperatures from 12.8° to 21.1°C but not at 7.2°C. Loeber (1951), however, found that although young-of-the-year and yearling striped bass could be transferred directly from fresh to salt water, the reciprocal transfer caused a shock reaction. In transfers conducted within freshwaters, Tagatz (1961) found that juvenile striped bass suffered mortalities upon transfer from 12.8° or 21.1°C water to 7.2°C water. However, no mortalities resulted by transfer from cooler to warmer waters. This agrees with the well-established conclusion that fish acclimate more rapidly to increasing temperatures than to decreasing temperatures (Meldrim et al. 1974).

Oxygen

McBay[26] observed that 47-day-old striped bass held in a rearing pond at 30°C, 3 ppm DO, and 44 ppm CO_2 were distressed; however, 31- to 33-day-old striped bass held in a pond at 27.8°C, 3 ppm DO, and 40 ppm CO_2

[26]McBay, L. G. 1971. Report on fry production and rearing of fingerling striped bass, *Morone saxatilis* (Walbaum) at Richmond Hill Fish Hatchery, Georgia. Ga. Game Fish Comm., Sport Fish. Div., Atlanta, Ga., 39 p.

did not visually appear to be distressed. Chittenden (1971b), in a study of the oxygen requirements of juvenile striped bass (81-108 mm TL), described behavior at low oxygen concentrations. At a temperature range of 16°-19°C, Chittendon found that the following oxygen concentrations (±99% confidence limits) caused these behavior patterns: 1.81 ± 0.10 mg/liter—restlessness, 1.28 ± 0.10 mg/liter—inactivity, 0.95 ± 0.06 mg/liter—equilibrium loss, and 0.72 ± 0.04 mg/liter—death. He (1971b:1829) concluded that, "dissolved oxygen concentrations of about 3.0 mg/liter may represent the minimum that enables striped bass to exist normally at water temperatures near 16-19°C. Even this amount may be insufficient to maintain optimum populations."

Klyashtorin and Yarzhombek (1975) concluded that the critical oxygen concentration for juvenile striped bass weighing 0.3-22 g was between 4.0 and 4.5 mg/liter at 22°C. Decrease in oxygen levels to this critical concentration (for standard metabolism) does not result in the death of the fish but does restrict motor activity and leads to a reduction in food consumption, increased energy expenditure for respiration, and a reduced growth rate. See also section 3.44.

Suspended sediments

Exposure to suspended sediment concentrations of 500 and 1,000 mg/liter for 48-96 h significantly reduced ($P<0.05$) the survival of striped bass yolk-sac larvae (Auld and Schubel 1978).

Sherk et al. (1975) reported LC_{50} concentrations of suspended sediments (0.78 μ median size, 72% $<2\ \mu$) for striped bass larvae; 24 h—4.85 g/liter; 48 h—2.80 g/liter.

The effects of thermal pollution, entrainment, impingement, and chemical toxicity on striped bass larvae are considered at the end of section 3.23, competition in section 3.33, and predation in section 3.34.

3.23 Juveniles phase

See also sections 3.22, 3.43, 3.44, 3.51, 3.52, 3.53, and 4.43.

Calhoun (1953) noted the following concerning juveniles collected in San Francisco Bay: a) Shallow bays tended to "trap" juveniles on strong flood tides; b) juveniles avoided deep bay areas until they were good swimmers (>50.8 mm); c) juveniles <25.4 mm did not school, larger juveniles did; d) juveniles moved to saltier areas as they grew older.

Food and feeding habits

Markle and Grant (1970) investigated the summer food habits of young-of-the-year striped bass in several Virginia rivers. Mysids dominated the diet of fish <70 mm in the York River where salinities were usually >10‰. Insects dominated the diet of fish of the same size in the James River where salinities were <5‰. Striped bass 70-150 mm TL fed on fish (primarily yolk-sac stage naked gobies, *Gobiosoma bosci*) in the York River and decapod shrimp, *Palaemonetes*, in the James River.

Bason (1971) examined the diet of young striped bass (50-100 mm FL) in the Delaware River. Salinity was the determining factor of the striped bass diet. *Neomysis americana* was the basic food of young bass in the Delaware River; *Crangon septemspinosa* was second in importance. In the tidal creeks, fish and decapods, primarily *Palaemonetes pugio*, were the most important food item volumetrically during summer, and the amphipod, *Corophium*, the most numerous. During the fall, *Corophium* was most numerous; *Palaemonetes pugio*, mysids, and fish supplemented the diet. In the Elk River, during summer, amphipods ranked first in importance and copepods second. In fall the bay anchovy, *Anchoa mitchilli*, and the Atlantic silverside, *Menidia menidia*, dominated the diet. The diet of the subadults (1-3 yr) indicated they feed primarily on or near the bottom. During 1968, crustaceans dominated the diet; amphipods were most common during summer, and mysids in the fall; fish ranked second. In 1969; bay anchovy and weakfish, *Cynoscion regalis*, were the primary food; mysids ranked second during the summer months while the grass shrimp, *Palaemonetes*, ranked second during fall.

Juvenile striped bass from the Chesapeake and Delaware Canal consumed a similar diet. Striped bass from 40 to 100 mm FL fed primarily on *Neomysis americana*, *Gammarus* spp., and *Corophium* spp. Juveniles over 100 mm consumed some fish, primarily bay anchovies, and larger invertebrates (Bason et al.[27]). During the previous year *Neomysis americana* was the principle food of young bass <100 mm, whereas fish, mainly the Atlantic menhaden, *Brevoortia tyrannus*, formed a more important part of the diet of fish up to 270 mm FL (Bason et al.,[28] footnote 27).

Young-of-the-year striped bass collected in the Hudson River fed primarily on calanoid copepods, amphipods, isopods, and chironomid larvae. Copepods were an important food item for fish between 50 and 75 mm; *Gammarus* were often consumed by larger young-of-the-year fish. Yearling striped bass fed primarily on calanoid copepods and *Gammarus*. Striped bass >150 mm TL were generally piscivorous (Texas Instruments, Inc. 1973,[29,30] footnote 10).

[27] Bason, W. H., S. E. Allison, L. O. Horseman, W. H. Keirsey, P. E. LaCivita, R. D. Sander, and C. A. Shirey. 1975. Fishes. Volume I. *In* Ecological studies in the vicinity of the proposed Summit Power Station. Jan.-Dec. 1975, 392 p. Ichthyological Associates, Inc., Box 286, RD #1, Middletown, DE 19709.

[28] Bason, W. H., S. E. Allison, L. O. Horseman, W. H. Keirsey, and C. A. Shirey. 1975. Fishes. Volume I, Part A. *In* Ecological studies in the vicinity of the proposed Summit Power Station. Jan.-Dec. 1974, 327 p. Ichthyological Associates, Inc., Box 286, RD #1, Middletown, DE 19709.

[29] Texas Instruments, Inc. 1973. Hudson River ecology study in the area of Indian Point. First Annual Report to Consolidated Edison Co. of New York, Inc., 348 p.

[30] Texas Instruments, Inc. 1973. Hudson River ecological study in the area of Indian Point. 2d Semi-Annu. Rep. Jan. 1 to June 30, 1973. Prepared for Consolidated Edison Co. of New York, Inc.

Numerous authors have examined the food habits of striped bass in the California Delta region. The mysid shrimp, *Neomysis mercedis (= N. awatschensis)*, was the most important food of young-of-the-year striped bass, with tubed amphipods, *Corophium stimpsoni* and *C. spinicorne*, ranking second, especially where *Neomysis* was scarce. If both were present, the bass selected *Neomysis* (D. E. Stevens 1966). During the second summer of life, young striped bass began feeding on small fish. Stomach contents of the striped bass depended upon position of the fish within the water column; fish caught on the bottom had been feeding on *Neomysis* and *Corophium*, whereas those caught in midwater had consumed threadfin shad (D. E. Stevens 1966).

Heubach et al. (1963) examined the food of young-of-the-year striped bass in the Sacramento-San Joaquin River System. During the summer, bass fed on: *Neomysis* (59% occurrence); copepods (59%); cladocerans (23%); *Corophium*, tubed amphipod, (12%). Percent frequency occurrence of copepods was greater in fish <2.5 cm than in fish 2.8-7.6 cm; percent frequency of *Neomysis* and *Corophium* was greater in the large fish. Occurrence of planktonic species in striped bass stomachs generally agreed with the plankton distributions in the environment. Salinity was suggested as the principle determining factor of striped bass diet as it determined copepod distributions. Copepods most commonly utilized as prey were *Eurytemora affinis, Acartia clausii,* and *Pseudodiaptomus euryhalinus* in the saline area of the Sacramento River, and further upstream, the freshwater genera *Diaptomus* and *Cyclops*. Diet in the fall depended upon location. Chief constituents of the winter and spring diet were *Neomysis* (73% occurrence), copepods (58%), and *Corophium* (23%). Striped bass did not feed on available benthic fauna with the exception of *Corophium, Nereis,* and tendipedid larvae.

A catastrophic decline in prey populations and a subsequent crash of the juvenile striped bass population occurred in the California Delta region in 1972 (Chadwick 1974). Mid-June populations of striped bass larvae in the California Delta region were approximately the same for the years 1970-72. Near the end of June 1972 salt water entered the system resulting in a 13-yr low density of *Neomysis mercedis*. By midsummer, numbers of juvenile striped bass were the lowest in 13 yr of recording. Chadwick (1974) concluded that the depressed *Neomysis* population contributed to the unusually poor survival of the 1972 striped bass year class.

The rates at which *Neomysis*, copepods, and *Corophium* are digested are not identical. This can lead to an overemphasis on the importance of the amphipod, *Corophium*, and an underestimation of the importance of copepods in the striped bass diet. Heubach et al. (1963) found most copepods still identifiable to genus after 1 h of digestion, *Neomysis* identifiable after 6 h, and *Corophium* identifiable after 8 h.

Visual cueing plays an important role in feeding. Feeding sequences observed by Bowles (1976) suggested that foraging was repeated in the same location until no food was available. Juveniles reduced interfish distances during feeding.

See section 3.41 for food conversion ratios and maintenance requirements.

See section 7.6 for a discussion of prey species utilized in striped bass culture and section 3.22 for consideration of environmental factors.

Thermal pollution

The discharge of heated waters from power plants into fish spawning or nursery areas of many marine, estuarine, anadromous, and freshwater fish species has prompted numerous investigations into the effects of thermal pollution. The effects of increased water temperature on striped bass are summarized in Table 11 and briefly discussed below.

Several investigators have attempted to ascertain the effects of exposing striped bass eggs and larvae to elevated temperatures (ΔT) for periods of time consistent with the ΔT expected during entrainment and subsequent passage through a power plant. Schubel et al. (1976) in a series of experiments summarized in Table 11 found striped bass eggs and larvae to be more resistant to increased water temperatures than eggs and larvae of either American shad or blueback herring.

The striped bass egg and larval stages most sensitive to increased temperatures are shown in Figures 4 and 5. Ambient water temperatures for these experiments (18.9°-20°C) were similar to those encountered at the end of the spawning season on the Hudson River. A ΔT of 8.3°C would exceed the maximum safe temperature of the late blastula, the most sensitive striped bass egg stage, by approximately 2.8°C for a 30-min exposure and by about 1.7°C for a 15-min exposure. The 60-min tolerance of young striped bass larvae (up to about 12 days of age) would likewise be exceeded by a rated capacity ΔT of 8.3°C (Fig. 5).

Coutant and Kedl (1975) reported that approximately 2-wk-old, 4-6 mm striped bass larvae could tolerate a temperature of 29°C for 30 min without mortalities; however, temperatures of 31° and 33°C resulted in 50% mortalities within a 5- or 6-min period.

Extensive thermal investigations have been undertaken by Kerr (1953) at the Contra Costa Steam Plant in the California Delta region. Exposure times to ΔT during these experiments were for 10 min or less. The mortalities cited in Table 11 were after a 5-day observation period. Striped bass utilized in the condenser experiments were subjected to an operating condenser at the Contra Costa Steam Plant while the unit was on full load.

Striped bass seem unable to discern lethal temperatures. Dorfman (1974), in a series of temperature gradient experiments, found that juvenile striped bass did not avoid heated waters that proved to be fatal to some fish.

The importance of dividing fish acclimation and avoidance data into responses during periods of rising field temperatures and responses during times of falling

Table 11.—Effects of increased temperatures on striped bass, *Morone saxatilis*. DO = dissolved oxygen; ΔT = elevated temperatures; ND = no data.

pH	Salinity (‰)	DO (mg/l)	Size range (mm)	Accl. temp (°C)	Exp. time	ΔT (°C)	Test temp (°C)	Mortality (%)	Comments	Author
7.5	0.9		Egg and larvae	13.3-13.9				ND	Optimum temperature for rearing	Davies 1973
			Eggs	16.6-19.6	4-60 min	7-20	23.6-29.6	0-2	Period of cooling to ambient temperature 60-300 min	Schubel et al. 1976
						15	31.6-34.6	0-2	Hatch not significantly affected	
							36.6	32		
						20	39.3	100	Total mortality within 2 min	
			Yolk-sac larvae 19-111 h old	19.3-21.1	4-30 min	7-20	26.3-41.1	Given below	Percent mortality 24 h after exposure to ΔT	
						up to 10	29.3-31.1	0-67 Not significant	Return to within 1°C of ambient within 180 min	
						15	35.0-36.1	48-77 Significant	Return to within 1°C of ambient within 95 min	
						15	34.3-36.1	0-56 Not significant	Return to within 1°C of ambient within 120 min	
						15	34.3-36.1	3-100 Significant	Return to within 4°C of ambient within 140 min	
				19.3-21.1	5-10 min	20	39.3-41.1	Virtually total	Return to within 1°C of ambient within 100-130 min.	
	Fresh	Sat.	Eggs and larvae	18.9-19.5	30-60-120 min	up to 8.3	27.2	Varied	See Figs. 4,5	Institute of Environmental Medicine 1973[1]
			4.0-6.0	21 (±2)	6 and 30 min	8	29	0	Simulated condensor tube	Coutant and Kedl 1975
					6 min	10-12	31 and 33	50		
	Fresh		47-83	22.2	10 min	11	33.3	15	Test flume	Kerr 1953
	Fresh		47-83	22.2	10 min	10	32.2	10	Test flume	
	Fresh		21-46	22.2	3½-5 min	8.9	31.1	6	Actual condensor passage	
	3		21-46	22.2	3½-5 min			<6		
			Juvenile	21.1		up to 18.1	36.7 and others	Some	Temperature preference	Dorfman 1974
7 -7.8	1-7	Sat.	34-129	5-27.2		6.6-16	12.8-34.4		Avoidance temperature	Meldrim and Gift 1971
7.3-7.4	8	Sat.	72-78	26.1	15 min	5.5	31.7	No apparent stress		
7.3-7.4	4	Sat.	70-168	15-26.1	15 min	5.5+8.3	max. of 34.4	4 dead at 8.3°C ΔT-all stressed at both ΔT		
7.0-8.0	0-4	Sat.	34-173	21-27	Summer	up to 12.2	32-34	0	Avoidance temperature; differing temperature water bath.	Meldrim et al. 1974
7.0-8.0	0-7	Sat.	87-146	10-16	Fall	up to 16	23-29	0	Avoidance temperature	
7.0-8.0	4-4.5	Sat.	76-129	5-6	Winter	up to 12.7	13-19	0	Avoidance temperature	
7.0-8.0	2.5	Sat.	82-201	5	Early spring	13.3	18		Avoidance temperature	
			5-38		48 h		30-33	50		Kelly and Chadwick 1972
			5-38		2-4-6 min	up to 10	30-32		Equilibrium loss 30°C	

Table 11.—Continued.

pH	Salinity (‰)	DO (mg/l)	Size range (mm)	Accl. temp (°C)	Exp. time	ΔT (°C)	Test temp (°C)	Mortality (%)	Comments	Author
			8	16.7	4-6 min	10	26.7	Probably significant mortality	Percent mortality 48 h after exposure to ΔT's	Chadwick 1974
			8	20.6	6 min	7	27.6	58		
					4 min	10	30.6	11		
					6 min	10	30.6	28		
					4 min	11.6	32.2	63		
			27	21.1	2 min	10	31.1	35		
					4 min	10	31.1	16		
					6 min	10	31.1	46		
			Fingerling				35	ND	Upper maximum tolerated	Loeber 1951
			Eggs and fry	16-24			27	Significant		Shannon 1969
			Around 40.6 cm			11.5			Winter sport fishery in power plant discharge canal	Marcy and Galvin 1973

[1]Institute of Environmental Medicine. 1973. Hudson River ecosystem studies: Effects of entrainment by the Indian Point Power Plant on Hudson River estuary biota. New York Univ. Med. Cent., N.Y., 289 p.

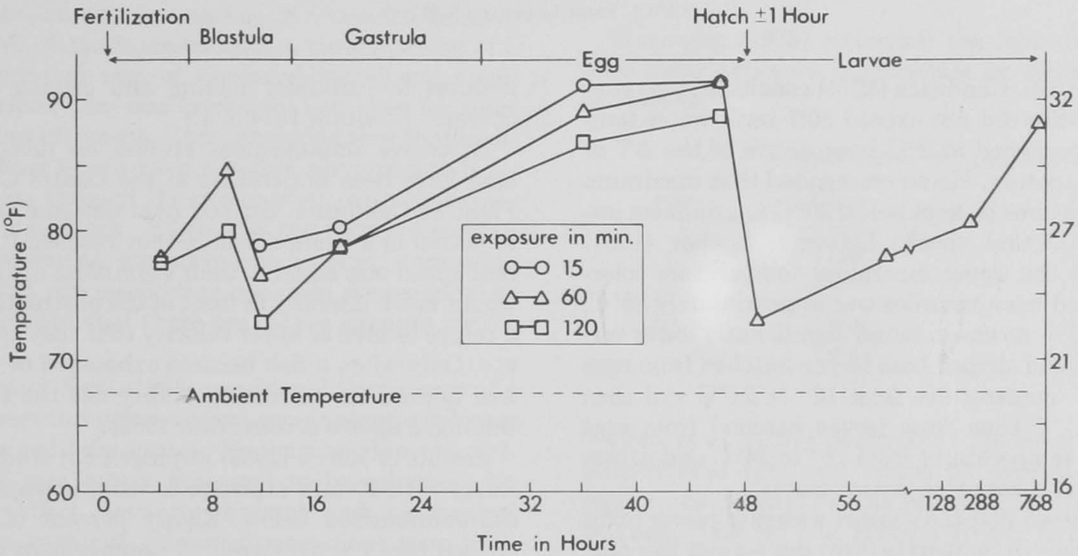

Figure 4.—Maximum safe tempertures (no apparent increase in mortality or abnormal behavior compared to controls) relative to exposure times for striped bass eggs and larevae from Monck's Corner, S.C. hatchery stock. From Lauer et al. (1974).

ambient temperatures has been demonstrated by Meldrim and Gift (1971) and Meldrim et al. (1974) who found significant seasonal differences in fish responses at a given temperature. A direct relationship between ambient acclimation temperatures (temperatures of Delaware River water at the time the experiments were conducted) and upper avoidance temperatures for juvenile striped bass was reported by Meldrim and Gift (1971). Fish acclimated to 27°C waters in late August avoided 34°C waters, whereas bass acclimated to 5°C ambient temperatures in December avoided 13°C waters. Thermal stress was noted in temperature shock experiments with a 15-min exposure to 5.5° and 8.3°C ΔT. Juvenile striped bass acclimated to 19°C suffered mortalities in two experiments with a 8.3°C ΔT. These authors concluded that striped bass were more sensitive to thermal shock than white perch. Additional temperature avoidance and acclimation studies have been undertaken by Meldrim et al. (1974) and are summarized in Table 11.

The effects of prolonged exposure to ΔT have been examined by several investigators. Kelly and Chadwick (1972) reported that larval and juvenile striped bass held for 48 h at ΔT had LC_{50} temperatures ranging from 30° to 33°C. Variations within this temperature range were not related to either acclimation temperatures or to

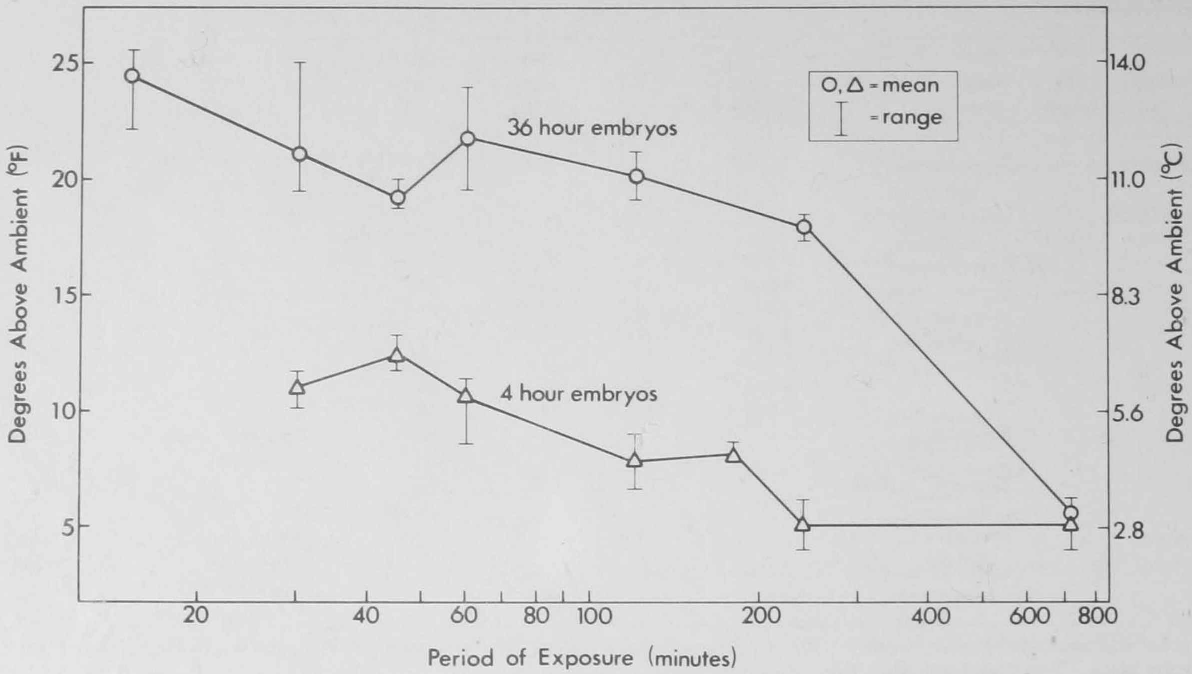

Figure 5.—Upper safe temperature limits relative to exposure time for 4- and 36-h striped bass embryos (ambient temperature = 18.9°C). From Lauer et al. (1974).

the size of the fish. Chadwick (1974) concluded that generally mortalities did not exceed 50% until water temperatures approached 32.2°C irrespective of the ΔT or duration of exposure. He recommended that maximum water temperatures be kept below 30°C to minimize losses due to thermal shock. Likewise, Loeber (1951) reported that the upper maximum temperature tolerated by striped bass juveniles was approximately 35°C. Shannon (1969), however, found significantly lower survival of 2-day-old striped bass larvae hatched from eggs incubated at temperatures from 16° to 24°C and then exposed to 27°C than from larvae hatched from eggs incubated at temperatures from 16° to 24°C and subsequently kept at these same temperatures.

It is well known that the warmer waters of power plant discharge canals in temperate latitudes attract fish during the colder months. Marcy and Gavin (1973), for example, reported a substantial winter sport fishery for striped bass in the heated discharge canal of a Connecticut power plant.

Impingement and entrainment

The terms "entrainment" and "impingement" are, on occasion, incorrectly used. Coutant (1974) defined entrainment as "the incorporation of small organisms into the cooling water flow," whereas impingement "refers to the physical blockage of larger organisms from joining this entrainment through placement of barrier screens." He further differentiated between two types of entrainment: "intake (or pumped) entrainment referring to organisms that enter the intake and are pumped through the condensers; and plume entrainment where organisms are part of the dilution water that contributes to turbulent mixing and cooling of the discharge." (Coutant 1974:3, 4.)

Extensive impingement studies on juvenile striped bass have been undertaken at the Contra Costa Steam Plant in California. Striped bass sensed a screened obstruction in a channel before they reached it. If the current speed was equal to their swimming ability, the fish would move laterally in front of the obstruction, seeking a refuge or area of lower velocity that they could negotiate. Only when a fish became exhausted or the current was beyond its swimming ability did the fish become impinged upon a screen (Kerr 1953).

Results of Kerr's (1953) impingement studies in a test flume with 10-min exposure to varying water velocities are summarized below. Eighty percent of 19-38 mm striped bass (90 fish) avoided impingement at a current velocity of 30.5 cm/s; only 5% avoided impingement at 43 cm/s. All impinged fish of this size range died. Ninety-five percent of 26-76 mm striped bass (55 fish) avoided impingement at a velocity of 61 cm/s. All 127-178 mm juvenile striped bass tested resisted a 61 cm/s velocity; one fish was impinged at a velocity of 84 cm/s (maximum attainable velocity in the test flume). Kerr (1953) concluded that striped bass 127 mm and larger could swim at will in a velocity of 84 cm/s.

Impingement velocities for striped bass eggs, larvae, and smaller juveniles have also been ascertained (Skinner 1974). Water velocity appears to be a more important determinant of swimming performance than time, although survival of impinged fish is related to impingement time as well as water velocity. Skinner found 90% of larval striped bass 12-15 mm able to avoid impingement at water velocities of 6 cm/s for 6 min or less. In general, survival was <90% for striped bass <40 mm at velocities over 15 cm/s. Ninety percent of juvenile striped bass 40-50 mm were able to swim for up to 6 min at velocities not exceeding 24 cm/s. However, almost all fish of this size range tested were impinged at velocities over 49 cm/s. Survival of impinged striped bass eggs is generally related to impingement times. Although striped bass eggs may survive impingement for up to 6 min at water velocities not exceeding 24 cm/s, large variances were found in the survival rates and hatching percentages of impinged eggs (Skinner 1974).

Increased water velocity (range 0-27 cm/s) reduced the swimming range of 10, 25, and 50 mm TL striped bass (Bowles 1976). Magnitude of area covered was directly proportional to fish size. Distance between fish decreased as water velocity increased, though most fish maintained a minimum spacing equal to at least 0.5 body lengths. Rheotaxis, the orientation of a fish with respect to flow direction, was variable at low velocities. Positive rheotaxis, swimming against the current, frequently occurred at velocities of 15 and 27 cm/s; lateral and negative rheotaxis, swimming perpendicular to, and with the current, seldom occurred (Bowles 1976).

Kerr (1953) has examined the impingement of fish in a test flume equipped with interchangeable screens. Although striped bass as small as 28 mm could be stopped by a No. 4 mesh screen with a clear opening of 5 mm, the survival rate of impinged larval and small yearling striped bass was extremely low, even for short periods of impingement. Kerr concluded that the smaller striped bass would have a higher survival rate if allowed to pass through the power plant with its subsequent thermal shock. When the previously discussed velocity experiments are taken into account, a traveling screen of 0.95 cm mesh clear openings appeared to be optimal provided that there are escape avenues for the fish.

Coutant and Kedl (1975) considered the impact of a single passage through a typical power plant condenser tube on striped bass larvae. Mechanical damage of 2-wk-old, 4-6 mm larvae appeared to be minimal. No synergistic effect between thermal and mechanical stresses was apparent. Observed mortalities were similar on both control and experimental fish and were attributable to thermal exposure.

Larval and juvenile striped bass may be more susceptible to entrainment/impingement during feeding (Bowles 1976).

Screens have been developed to minimize entrainment of fish larvae and juveniles in water diversions for power plant utilization and agricultural irrigation. Skinner (1974) evaluated the Delta Fish Protective Facility, a large louver facility completed in 1968, and reported a 69% efficiency in diverting striped bass from entering the California State Pumping Station in 1970. There were no apparent differences between daytime and nighttime efficiencies of the louvers at approach velocities <76 cm/s; however, at velocities >76 cm/s, efficiencies were better during the daytime. Skinner found the relationship between approach velocity and fish lengths critical and concluded that the following factors are paramount to louver design:

1. The sizes of fish encountered and their swimming capacities must be known.
2. The facility must be designed with sufficient capacity and adequate control structures to provide rigid velocity control.

Fisher et al. (1977) described behavior of juvenile striped bass; chinook salmon, *Oncorhynchus tshawytscha;* and American shad, *Alosa sapidissima,* which would influence fish screen design for the proposed Peripheral Canal around the Sacramento-San Joaquin Estuary. Perforated plates with 3.96 mm holes or woven wire mesh with 3.55 mm square openings would prevent juvenile striped bass 17.6-37.6 mm FL, from entering the proposed Peripheral Canal. The same screen aperture sizes would protect 32-50 mm FL chinook salmon and 22-44 mm FL American shad. Interested readers are referred to Jensen (1977) for a series of papers on state-of-the-art entrainment and impingement studies.

Pressure

Ulanowicz (1975) estimated the following LC_{50}'s for time shear exposure experiments on striped bass eggs and larvae:

	Exposure time	*LC_{50}'s (dynes/cm^2)*
eggs	1 min	450
	2 min	290
	4 min	170
	2 days	70
larvae	1 min	540
	2 min	435
	4 min	310

Beck et al. (1975) determined the effects of exposing striped bass eggs and larvae to hydrostatic pressure regimes calculated for the proposed Cornwall-Pumped Storage Plant on the Hudson River. Exposure of 4-h striped bass eggs to subatmospheric pressure (5.7 psia) for 15 s resulted in a 9.6% reduction in hatching success; exposure of 106-h larvae to 5.6 psia for 5 s decreased survival by 20% immediately and by 32% after 24 h. Exposure of 7½-day-old larvae to 6.1 psia for 3 s resulted in a 20-22% decrease in survival over control fish after 24-72 h. In order to simulate potential pressure changes that could be experienced by organisms during the pumping mode of the Cornwall plant, striped bass eggs and larvae were exposed to a sudden reduction in pressure to 2 psia for approximately 2 s, followed by a 10-s return to atmospheric pressure (14.7 psia), and a sudden increase in pressure to 481 psia. Return to atmospheric pressure was approximately 12 min later. The following results were obtained:

45-h eggs — 20% reduction in survival from controls after 48 and 72 h

81-h larvae — 54% reduction in survival after 24 h
15-18 day larvae — 70-80% reduction in immediate survival; 56-64% reduction after 24 h.

Striped bass larvae, 13-17 days old, exposed to 45 psia pressure for 3 days suffered 36-64% reduction in immediate survival and a 38-58% reduction after 24 h.

Chemical toxicity

Studies have been undertaken to ascertain the effects of various chemicals on striped bass. Bonn et al. (1976) summarized the toxicity (24- and 96-h LC_{50}) of 61 pesticides, heavy metals, and pharmaceutical drugs on striped bass eggs, larvae, and juveniles.

Sublethal concentrations of benzene increased the respiratory rate of juvenile striped bass after exposure of 24 h. Fish exposed to 10 ppm benzene for longer periods exhibited a narcosis that was reversible when fish were placed in fresh water and kept longer than 6 days (Brocksen and Bailey 1973). Tricon oil spill eradicator was toxic to striped bass at 10 ppm after 48 h; however, no stress was observed at 5 ppm (Chadwick 1960). Hazel et al. (1971) determined the toxicity of undissociated ammonia to juvenile striped bass (20-93 mm TL) in a static system. Ninety-six-hour median tolerance limits (TLm) of NH_4OH were:

at 15°C	freshwater	2.8 mg/liter
	11 ppt salinity	2.8 mg/liter
	33 ppt salinity	2.0 mg/liter
at 23°C	freshwater	1.9 mg/liter
	11 ppt salinity	2.1 mg/liter
	33 ppt salinity	1.5 mg/liter.

Benville and Korn (1977) reported the following acute toxicities of monocyclic aromatics to 6 g juvenile striped bass:

Static broassays at 16°C, 25%	*24 h* LC_{50} *ppm*	*24 h 95% C.L.*	*96 h* LC_{50} *ppm*	*96 h 95% C.L.*
Benzene	6.9	([1])	5.8	([1])
Toluene	7.3	([1])	7.3	([1])
Ethylbenzene	4.3	3.9- 4.7	4.3	3.9- 4.7
m-xylene	9.2	8.3-10.0	9.2	8.8-10.0
o-xylene	11.0	9.4-12.0	11.0	9.4-12.0
p-xylene	2.0	([1])	2.0	([1])

[1]No confidence limits were calculated from tests without partial mortalities.

Korn et al. (1976) exposed 18 cm SL juvenile striped bass to two benzene concentrations, 3.5 ± 1.4, and 6.0 ± 1.6 μl/liter, for 4 wk. Initial reactions to benzene exposure were pronounced hyperactivity at the low concentration. Fish exposed to 6.0 μl/liter benzene attempted to feed, but were unable to locate and consume their ration; fish exposed to 3.0 μl/liter benzene consumed approximately 50% of their ration; control fish consumed all their ration within 5 min. Feeding success of experimental fish gradually improved; after 4 wk, control and low level fish fed normally, high level fish consumed 50% of their ration. There was a significant decrease in wet weight, dry weight, and percent fat of experimental fish.

There is limited work on the effects of heavy metals on striped bass eggs and larvae. O'Rear (1972, 1973) found yolk-sac larvae more sensitive to both zinc and copper than striped bass eggs. However, copper did retard hatching at each concentration tested (0.01-5.0 mg/liter). Rehwoldt et al. (1971) ascertained the 24, 48, and 96 h TLm's for Cu^{++}, Zn^{++}, Ni^{++}, Cd^{++}, Hg^{++}, and Cr^{++}. Tatum et al. (1966) concluded that Zn concentrations of 0.07 ppm may have caused mortalities in hatchery experiments.

The production of H_2S has been blamed for Casquiney Straight, Calif., striped bass kills (Silvey and Irwin[31]). Low tides and high temperatures resulted in anaerobic conditions in the shallow bays.

Chlorine toxicity to striped bass eggs and larvae has been investigated by Morgan and Prince 1977). All experiments were conducted at salinities of 2.8 ± 0.9‰. One hundred percent mortality was reported for striped bass eggs <13 h old subjected to 0.43 ppm total residual chlorine (TRC); for eggs between 24 and 40 h old, exposure to 0.50 ppm TRC, resulted in 100% mortality. LC_{50} concentrations for eggs <13 h old were approximately 0.22 ppm; for eggs between 24 and 40 h, approximately 0.27 ppm. Higher chlorine concentrations produced a blistering of the chorion in addition to some swelling of the eggs. At intermediate chlorine concentrations, larval development proceeded at least to the formation of a well-defined embryo in 70-85% of the eggs. Chlorine concentrations near the LC_{75}-LC_{90} range generally prevented striped bass development before embryo formation. One hundred percent mortality of yolk-sac larvae <1 day old resulted after exposure to a TRC concentration of 0.55 ppm; total mortality of larvae >70 h old was obtained at a TRC of 0.40 ppm. LC_{50} concentrations (24-h exposure) for both larvae <24 h old and larvae >70 hours were approximately 0.20 ppm.

The toxicity of total residual chlorine (all experiments were conducted at salinities from 1 to 3‰) to striped bass eggs and larvae was also determined by Middaugh et al. (1977). Beginning 8-9 h after fertilization, developing embryos were exposed continuously to TRC in flowing water with the following results:

TRC (ppm)	*Effect*
0.21	No larvae hatched.
0.07	3.5% hatched. Many larvae had curvatures of vertebral column, 3-7 somites posterior to oil globule.
0.01	23% hatched. Many larvae had difficulty detaching themselves from chorion as they hatched.
<0.01	Survival of developing embryos and emergence of larvae similar to controls.

[31]Silvey, W. D., and G. Irwin. 1969. Relation of water quality to striped bass mortalities in the Carquinez Strait in California. Open-file rep., U.S. Dep. Inter., Geol. Surv., Water Resour. Div., 12 p.

Estimated incipient LC_{50} concentrations were 0.04 ppm for both 2-day-old yolk-sac larvae and 30-day-old juveniles, and 0.07 ppm for 12-day-old larvae. Histological examination of 30-day-old juveniles which survived exposure in the incipient LC_{50} bioassay revealed gill and pseudobranch damage in fish exposed to TRC concentrations between 0.21 (71-min exposure) and 2.36 ppm (7-min exposure).

3.3 Adult phase

3.31 Longevity

Bigelow and Schroeder (1953:390) stated that "The bass grows to a great size, the heaviest of which we have found definite record being several of about 125 pounds [56.7 kg] that were taken at Edenton, N. C., in April 1891." Striped bass of 27-32 kg are not exceptional "although the average is probably not over 4 or 5 pounds; fish weighing 1½ pounds are numerous in the southern markets" (Raney 1958:5). A 29- to 31-yr-old striped bass weighing 29.5 kg was caught in Rhode Island (Merriman 1941). Female striped bass live longer than males; most fish 11 yr of age and older are females (Koo[32]).

3.32 Hardiness

Oxygen

Meldrim et al. (1974) concluded from a series of avoidance tests that striped bass avoided waters of 44% or less oxygen saturation. These authors also concluded that striped bass could tolerate higher temperatures under conditions of oxygen saturation than under conditions of reduced oxygen levels.

[32] T. S. Y. Koo, Chesapeake Biological Laboratory, Solomons, MD 20688, pers. commun. February 1978.

3.33 Competitors

Although direct information is lacking, large piscivorous species such as the bluefish, *Pomatomus saltatrix*, and weakfish probably compete with striped bass in the Atlantic since all feed on forage species including Atlantic menhaden and other clupeid species, bay anchovies, and silverside, *Menidia* spp.

Larval and juvenile striped bass and white perch utilize a common nursery area and may feed on similar prey species. White perch are usually present in greater numbers and would probably compete with striped bass for available food. For example, estimated instantaneous abundances from the portion of the Potomac River, Md., used as a common nursery during 1975 were: 1,484 $\times 10^6$ white perch, 651 $\times 10^6$ striped bass (Mihursky et al. footnote 6).

3.34 Predators

Again, direct information is lacking but large bluefish and weakfish probably prey on small striped bass in the Atlantic; likewise, large striped bass probably prey on smaller bluefish and weakfish. Adult and juvenile white perch probably consume large numbers of striped bass larvae.

3.35 Parasites, diseases, injuries and abnormalities

See also section 7.7.

Striped bass parasites are summarized in Table 12.

Table 12.—Parasites of striped bass. (From Paperna and Zerner 1976 unless otherwise indicated.)

Parasite	Host age	Percent infected	Locality range[1]	Organ affected	Heaviest infection found	Author
Protozoa						
Trichodina davisi	0+	45	O,M,E	Gills	10 per field[2]	
	1+	33				
	2+	20				
	3+	33				
Trichodinella sp.[3]	0+	<1	O,M	Skin and gills	2 per field[2]	Paperna and Zwerner 1976; Bonn et al. 1976
	1+	<1				
Epistylis sp.	1+	12	O,M	Gills	All gills densely covered	
	2+	10				
Glossatella sp.	0+	40	O,M,E	Gills	All gills densely covered	
	1+	2				
	2+	2				
Scyphilida sp.	0+	7	O	Gills		
	1+(rare)	<1				
Colponema sp.	0+	63	O,M,E		10 per field[4]	
	1+	3				
Trichophrya sp.	0+	11	O,M	Gills	2 per field[2]	
	0+(rare)	<1				

Table 12.—Parasites of striped bass. (From Paperna and Zerner 1976 unless otherwise indicated.)

Parasite	Host age	Percent infected	Locality range[1]	Organ affected	Heaviest infection found	Author
Myxosoma morone n. sp. (Johnson and Paperna in prep.)	0+	55	O	Cartilage, bone	88 cysts per fish	
Kudoa cerebralis	1+	15	M,E	Meninges of the brain and spinal cord	80 cysts per fish	Paperna and Zwerner 1974
Nosema sp.	1+	<1	M	Gills	1 cyst per fish (rare)	
Oodinium sp.	1+	<1	M	Gills	1 per fish	
	2+	<1				
Myxobolus morone	0+	73% in July to 31% in Oct. Gradually disappeared at 6-7 mo of age	O	Cartillage of gills, cranium, dorsal and anal fin rays		
Paratrichodina[3]	0+	ND[5]		Gills	ND	Bonn et al. 1976
Ambiphrya[3]	0+	ND		Gills and skin	ND	Bonn et al. 1976
Bodomonas[3]	0+	ND		Gills	ND	Bonn et al. 1976
Ichthyophthirius[3]	0+	ND		Gills and skin	ND	Bonn et al. 1976
Costia[3]	0+	ND		Gills and skin	ND	Bonn et al. 1976
Chilodon[3]	0+	ND		Gills and skin	ND	Bonn et al. 1976
Trichodina[3]	0+	ND		Gills and skin	ND	Bonn et al. 1976
Epistylis[3]	0+	ND		Skin	ND	Bonn et al. 1976
Platyhelminthes						
Cestoda						
Rhynchobothrium speciosium	ND	ND		Elongated cysts in viscera		Linton 1901
Proteocephalid larvae Type A	0+	76	O	Mesenteries	40 per fish	
Proteocephdlid larvae Type B	0+	46	O	Mesenteries and liver	9 per fish	
Scolex pleuronectis	0+	79	O,M,E	Intestine	5 per fish	
	1+	<1				
	2+	1				
Trypanorhynchid pleurocercoid	1+	<1	M	Mesenteries	3 per fish	
	2+	<1				
Trematoda						
Monogenea						
Gyrodoctylus sp.	0+	<1	O	Gills	1 seen	
Ancyrocephalinae unidentified	0+	<1	O	Gills	1 seen	
Microcotyle macura	1+	2	M,E	Gills	6 per fish	
	2+	3				
Diplectonum[3]	0+	ND		ND	ND	Bonn et al. 1976
Digenea						
Lepocreadium setiferiodes	2+	10	M,E	Intestine		
Cuculanus sp.	0+	8	O,M	Intestine	5 per fish	
	1+	<1				
Spinithectus sp. larvae	1+	<1	M,E	Intestine wall	4 per fish	
Goezia[3] sp. (larva)	1+	<1	M	Intestine wall	1 per fish	Paperna and Zwerner 1976
	1+		Isolated from 4 Florida lakes—Marine herring fed as dietary supplement probable source of infection	Cyst enlarged to pea size in severe cases, became ulcerated, severe tissue damage, may penetrate stomach wall into body cavity.	Within 30 days (one-half of infected fish died)	Ware 1971
				Encepted on external wall of stomach few in mesentary		Gaines and Rogers 1972; Bonn et al. 1976
Acanthocephala						
Pomphorhynchus[3] *rocci*	0+	14	O,M	Intestine; intensive infections caused fibrosis of liver and spleen	42 per fish	Paperna and Zwerner 1976; Bonn et al. 1976; Cordonnier and Ward 1967; Johnson and Harkema 1970; Linton 1901
	1+	25			130 per fish	
	2+	29				
	3+	67				
Pomphorhynchus rocci (larvae)	0+	34	O (M rare)	Visceral		

Table 12.—Continued.

Parasite	Host age	Percent infected	Locality range[1]	Organ affected	Heaviest infection found	Author
Ecinorhynchus proteus				Intestine	45 per fish	
E. acus				Intestine		Linton 1901
Annelida						
Hirudinea						
Myzobdella lugubris	2+	<1	M	Skin	1 per fish (rare)	
Lepocreadium areolatum	2+	14	M,E	Intestine	10 per fish	
Stephanostomum tenue	2+	14	M,E	Intestine		
Immature opecoelids	2+	9	E	Intestine	3 per fish	
Digenea sp. 1	0+	<1	O	Intestine	1 per fish (rare)	
Digenea sp. 2	1+	<1	M,E	Intestine	1 per fish (rare)	
	2+	3				
Distomum	ND	ND	E	Intestine	ND	Linton 1898, 1901
Neochasmus sogandaresi				Intestine and pyloric coeca		Overstreet 1971
Postodiplostomum[3] *minimum*	0+	ND		ND	ND	Bonn et al. 1976
Clinostomum[3]	0+	ND		Muscle	ND	Bonn et al. 1976
Uvulifer sp.[3]	0+	ND		ND	ND	Bonn et al. 1976
Diplostomulum[3] *flexicaudum*	0+	ND		ND	ND	Bonn et al. 1976
Neascus sp.	0+	3	O	Skin	105 per fish	
Diplostomulum sp.	0+	<1	O	Spleen	Rare	
Ascocotylid type sp.	0+	<1	O	Viscera	Rare	
Aschelminthes						
Nematoda						
Philometra rubra	0+	39	O,M,E	Visceral cavity and mesentenes[6]	14 per fish	
	1+	64	O,M,E		11 per fish	
	2+	77				
	3+	100				
Mollusca						
Pelecypoda						
Glochidia	0+	1	O	Gills	12 per fish	
Arthropoda						
Crustacea						
Lironica ovalis (isopod)	1+	4	M	4th gill arch		Paperna and Zwerner 1976;
	2+	3				
	1+		Freshwater tidal portion Long Is-Island and Staten Island streams	Inside operculum		Alperin 1966
	2+					
Aegathoa ocula (isopod)	2+	<1	M	Skin	1 per fish	
Ergasilus labracis[3] (copepod)	0+	19	O,M,E	Gills	2,757 per fish(1+)	Paperna and Zwerner 1976;
	1+	80				Bonn et al. 1976
	2+	83				
	3+	100			19 per fish	Paperna and Zwerner 1976; Barkuloo 1972[7]
Argulus bicolor (copepod)	1+	5	M	Skin and gills		
	2+	5				
Lernaea[3] (copepod)	ND	ND	Black Creek, Fla.			Barkuloo 1972[7]; Bonn et al. 1976
Caligus sp. (copepod)	1+	<1	M	Gills	1 per fish	
Pisces						
Rissola marginata, striped cusk eel		Rare	New Jersey	Coelom		Hammer 1966

[1]Locality range key: E = euryhaline 30-40‰ = mesohaline 5-18‰; O = oligohaline 0.5-5‰.
[2]Counts made at 100.
[3]Encountered in striped bass culture.
[4]Counts made at 970.
[5]ND = no data.
[6]Infections accompanied by visceral oedema, granuloma, and extensive visceral adhesions resulted in advanced fibrosis of liver and spleen.
[7]Barkuloo, J. M. 1967. Florida striped bass, *Roccus saxatilis* (Walbaum). Fla. Game Fresh Water Fish Comm., Fed. Aid Project No. F-10-R, 24 p.

Diseases

Fin rot disease

This disease results in necrosis of one or more of the fins. As the disease advances, fin edges become frayed, the rays separate, gaps in the fins appear, and frequently complete fin destruction occurs. Hemorrhaging, especially in the skin, often accompanies severe fin erosion (Mahoney et al. 1973). These authors noted that diseased fish were missing scales over extended portions of their bodies and, in advanced cases of skin erosion, the underlying muscle layers were exposed. During a 2-wk interval the disease progressed from only slight fin necrosis to increased fin necrosis, skin hemorrhages, and blindness. Seventy-five cultures of bacteria were isolated from fish affected with fin rot disease. Sixty of these cultures belonged to the genera *Aeromonas, Pseudomonas,* and *Vibrio.* Although isolates of all three genera produced necrosis of the caudal fins of experimental mummichogs, *Fundulus heteroclitus,* the *Vibrio* isolates caused most of the mortalities. Mahoney et al. concluded that dense bacterial populations combined with environmental stress contributed to form "epizootics" (epidemics) of fin rot disease. The disease paralleled seasonal temperatures with the rate of infection being lowest in the winter, increasing in spring, at its peak from July through September, and decreasing in the fall.

Pasteurellosis

The bacteria, *Pasteurella* sp., has reportedly caused extensive and selective mortalities of white perch and, to a lesser extent, of striped bass in the Chesapeake Bay in 1963 (Snieszko et al. 1964). Paperna and Zwerner (1976) reported mass mortalities of 1 + and 2 + striped bass due to pasteurellosis. An early indication of this pathological condition was the appearance of numerous necrotic foci visible as white spots in the spleen. In moribund fish, progressive liquefaction necrosis extended into the liver, kidneys, and finally into the intestine. Bacteria isolates were similar to the *Pasteurella* sp. implicated by Snieszko et al. (1964) in a 1963 summer fish kill in upper Chesapeake Bay.

Columnaris

This disease is caused by *Flexibacter* (*Chondrococcus* or *Bacillus*) *columnaris* and was first noted by Davis (1922) who recognized it as a "mold-like" growth on fish skin and fins. The disease was named for short columns or dome-shaped masses which form around scale debris.

Kelley (1969) found hematocrit values depressed 12-15% in striped bass infected with columnaris disease.

Lymphocystis

This virus disease of marine and freshwater fish produces nodules on the skin (Krantz 1970). Each nodule is a single infected cell which has enlarged several hundred times its normal cell size. Although nodules may reach a size of 2 mm in striped bass, the disease is rarely fatal. Paperna and Zwerner (1976) reported five cases of lymphocystis in 2-yr-old striped bass collected during January and March. Lymphocystis warts usually covered the entire fish, and often the fins were frayed and damaged. Electron microscopy confirmed the presence of virus particles on hypertrophied cells.

Kudo cerebralis
(Myxosporidea, Chloromyxidae)

Cysts are formed in the connective tissue associated with the nervous system in infected striped bass. Paperna and Zwerner (1974) found embedded cysts, up to 2.2 mm in diameter, on the ventral and lateral surfaces of the brain, usually around the posterior end of the cerebellum and medulla. The growing cysts caused distortion and displacement at the infection site and also in adjacent nerves and ganglia. Additionally, smaller cysts were found inside distal cranial nerve branches. No tissue necrosis was observed.

Epitheliocystis

Paperna and Zwerner (1976) found epitheliocystis lesions on both gill filaments and arches of striped bass and white perch. Small nodules, 0.05-0.1 mm in diameter, were found on juvenile fish from the upper York River, Va.; large nodules, 0.4-0.8 mm in diameter, were found on fish over 1 yr old from the lower York River. Wolke et al. (1970) first reported epitheliocystis from striped bass and white perch in Connecticut waters.

Striped bass, like other teleosts, are subject to neoplasia. Tumors from striped bass recorded in the Registry of Tumors in Lower Animals, U.S. National Museum (Harshbarger[33]) include a nephroblastoma, a probable leiomyoma from viscera and infestous granulomas from liver and spleen.

Abnormalities

Pugheadedness

This foreshortening of head and face area may be caused by either a germinal defect in the embryo or an oxygen deficiency in the microenvironment of early embryonic stages of development (Mansueti 1958b). However, both pugheaded and normal striped bass have been hatched from phenotypically normal parents which may imply that both environmental and genetic factors are involved. Pugheadedness does not hinder survival, although it may somewhat stunt growth (Mansueti 1960; Hickey et al. 1977). Pugheadedness had

[33] Harshbarger, J. C. (Director). 1975. Activities report. Registry of tumors in lower animals: 1975 Supplement. U.S. Natl. Mus. Nat. Hist., Contract No. N01-CB-33874, p. 11, 20, 21.

been reported in bass from postlarvae (Mansueti 1958a) up to a 7.4 kg adult caught in Massachusetts in 1948 (Lyman 1961). Hickey et al. (1977) summarize occurrences of pugheaded striped bass.

Blindness and partial blindness

Denoncourt and Bason (1970) caught four blind stripers (fish with completely opaque lenses) near Artificial Island in the Delaware River estuary. These blind 2-yr-old fish were stunted in growth, weighing less than normal 2-yr-old fish, but more than normal 1-yr-old fish. Merriman (1941) found that 10% of the stripers in the Thames and Niantic Rivers in Connecticut had cataracts; blindness was more common among the older fish and rare in 2-yr-old striped bass. Merriman suggested that a dietary deficiency may account for this high percentage of blindness.

Other striped bass abnormalities

Harelipped fish, scoliosis (lateral spinal curvature), one fish with a hole in the body near the ventral (pelvic) fin (Talbot 1966), cross-bite, lordosis (vertical spinal flexure), and a fish with five spiny rays in the first dorsal fin (Hickey et al. 1977) have been reported in the literature.

3.4 Nutrition and growth

3.41 Feeding

The striped bass is not a steady feeder; members of the school normally feed at about the same time (Raney 1952). Striped bass apparently follow and feed on schools of fish (Scofield 1928); schooling species are dominate prey (section 3.42). The extensive northward migration of striped bass (section 3.51) may be due in part to the movement of prey species. Hollis (1952) concluded that the southward fall migration within Chesapeake Bay results from pursuit of migrating fishes which leave the Bay at that time.

The amount of feeding varies with both time of day and season. Striped bass are known to feed avidly in the evening just after dark; they may also feed just before dawn (Raney 1952). Hollis (1952) found seasonal differences in the extent of striped bass feeding in Chesapeake Bay. About 50% of the stomachs examined were full during the summer-fall period whereas approximately 70% were full during the winter and early spring. However, Scofield (1931) noted that California striped bass feed most heavily during the spring and summer months. Feedings ceases during spawning (Hollis 1952; D. E. Stevens 1966; Trent and Hassler 1966; Manooch 1973; Woodull 1974).

Powell (1973) reared juvenile striped bass in cage culture for 2 mo in Alabama. Mean food conversion ratios (food fed/weight gained) were 2.0-2.1 for fish fed commercial trout chow and 5.8 for fish fed a ground fish diet (ground industrial fish—70% by weight; soybean meal—30% by weight). Valenti et al. (1976) reported food conversion ratios of 1.40-1.81 for juvenile striped bass reared in floating cages in a seawater lagoon off Shelter Island, N.Y., from June to October and fed commercial trout chow. These conversion ratios included production from consumption of natural foods, i.e., *Menidia menidia* and *Palaemonetes* sp., found in and around the cages.

Kelley (1969) reported conversion ratios of 1.07-2.81 for juvenile striped bass reared in freshwater troughs and fed commercial trout foods; conversion ratios depended upon feeding rate and brand of food utilized. He recommended a feeding rate of 3.5% body weight of commercial trough chow per day. Catchings (1973), however, recommended daily feeding rates of 4-5% body weight of trout chow for most efficient food utilization.

Redpath (1972) reported growth of 5-10 cm juvenile striped bass at five temperatures (8°, 12°, 16°, 20°, and 24°C) and five feeding levels (1, 3, 5, and 8% of body weight and repletion) of sludge worms (Tubificidae). Maintenance requirements were 3.37, 21.0, 7.5, and 11.5 mg/g fish per day at 8°, 12°, 16°, and 20°C respectively. Highest growth rates and best food conversion efficiency occurred at 16°C.

3.42 Food

See also sections 3.22 and 3.23.

Numerous studies have been made of the food habits of striped bass. As with many fish, striped bass are "generalists" in feeding, though several investigators (Stevens 1958; Ware 1971; Manooch 1973) have suggested that striped bass select soft-rayed fishes. The dominant prey consumed in a particular habitat depends upon availability, which, in turn, is regulated by environmental factors (e.g., salinity and temperature).

The dependence of diet on size of the striped bass was aptly demonstrated by Shapovalov (1936), who examined the stomach contents of 47 striped bass that had schooled together in one deep hole for over a month in Waddell Creek, Calif. His findings are summarized below:

25 fish, 20-40 cm	*Food occurrence (%)*
Small crustaceans: *Gammarus, Corophium,* and *Exophaeroma*	62.8
Young trout and salmon	2.9
Gobies	25.7
Sticklebacks	5.7
Unidentified fish remains	2.9
22 fish, 41-49 cm	
Sculpins	34.6
Young trout and salmon	30.8
Unidentified fish remains	19.2
Caddisfly cases	3.9
Small crustaceans	11.5

Ware (1971) examined the food habits of striped bass 51-483 mm TL from Florida waters. Fish comprised the major portion of the diet as is seen below:

Species	Occurrence (%)
Dorosoma petenense, threadfin shad	46.6
Gambusia affinis, mosquitofish, and *Molliensia*	9.3
Lepomis	5.9
Fundulus seminolis, Seminole killifish	4.7
Notropis	3.8
Labidesthes sicculus, brook silverside	1.3
Unidentified fish remains	5.1
Tendipedid larvae	3.4

Bass <152 mm fed mainly on mosquitofish, mollies, and shrimp, whereas threadfin shad was the dominant food item of larger stripers.

Hollis (1952) found striped bass in the Chesapeake Bay were primarily piscivorous with fish comprising 95.5% by weight of the total diet. The changes in striped bass diet throughout the year reflected the seasonal changes in the bay fish populations. During summer and fall, bay anchovy and menhaden were the dominant prey; by winter larval and juvenile spot, *Leiostomus xanthurus*, and Atlantic croaker, *Micropogonias undulatus*, which utilize the bay as a winter nursery grounds dominated the striped bass diet. White perch were the most prevalent prey consumed in the early spring and alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*, were the most abundant prey in the late spring and early summer.

Manooch (1973) investigated the seasonal food habits of striped bass in Albemerle Sound, N.C. Fish occurred in 96.2% of the striped bass examined during the summer, with clupeid species dominating. Although clupeids still dominated during the fall, with 64% occurrence, engraulids reached their maximum occurrence in the diet with bay anchovies in 37.7% of the stomachs. During the winter months the frequency of forage fish decreased and invertebrates, primarily amphipods, occurred more frequently in the diet. Blue crabs, *Callinectes sapidus*, constituted the major prey during the spring in the eastern portion of the sound. The size of forage fish consumed was dependent upon striped bass size as indicated in the equation: $Y = 0.22\,X - 0.25$ where X equals striped bass total length and Y equals forage species total length. Manooch suggested that the optimum size, gregarious behavior, and availability of young clupeids and anchovies accounted for the low predation rate on spiny rayed fish.

Stevens (1958) has shown that clupeid fish (gizzard shad, threadfin shad, alewife and blueback herring) supported the striped bass population in the Santee-Cooper Reservoir in South Carolina except during April, May, and June when mayfly nymphs, *Hexogenia bilineata*, were the dominant food items.

Trent and Hassler (1966) found striped bass feeding extensively on blueback herring and alewives in the Roanoke River. Other fish consumed included golden shiners, *Notemigonus crysoleucas;* minnows; and gizzard shad, *Dorosoma cepedianum*.

The largest deviation from the primarily piscivorous diet was noted by Schaefer (1970) in the surf waters of Long Island Sound. Eighty-five percent of the food volume of striped bass <399 mm FL consisted of invertebrates, with amphipods, *Gammarus* spp. and *Haustorius canadensis*, (45%) and mysid shrimp, *Neomysis americana* (33%), the dominant species consumed. Medium-sized striped bass, 400-599 mm FL, fed almost equally on fish (46%) (primarily bay anchovy, *Anchoa mitchilli;* Atlantic silverside, *Menidia menidia;* and scup, *Stenotomus chrysops*) and invertebrates (53%) (mainly amphipods). The largest striped bass examined (600-940 mm) consumed more fish than the smaller stripers (65% of stomach contents by volume) but still fed upon substantial numbers of invertebrates, chiefly amphipods, mysids, and the lady crab, *Ovalipes ocellatus*. Other fish consumed by these large striped bass were the squirrel hake, *Urophycis chuss;* tautog, *Tautoga onitis;* northern puffer, *Sphoeroides maculatus;* and striped mullet, *Mugil cephalus*. Schaefer suggested that the importance of invertebrates in the diet, especially in the summer months, may be attributed to the frequent turbidity of the surf environment which would make it more difficult to pursue and kill fast swimming vertebrates.

3.43 Growth rate

Growth rate for striped bass up to 70 cm can be calculated from scales with the formula:

$$l = \frac{(L-1)l^1}{L^1} + 1$$

where L = total length of fish, L^1 = scale radius, l = unknown total length, and l^1 = ratio of radius to annulus in question (Scofield 1931; Merriman 1941). Mansueti (1961) and Robinson (1960) gave body length-scale radius relationships.

Rogers et al. (1977) concluded that temperatures between 18° and 21°C were optional for larval growth between hatching and yolk absorption. Larvae reared at 18° and 21°C had greater dry weights, excluding oil globule at yolk absorption (0.15 and 0.16 mg) than larvae reared at 15° and 24°C (0.10 and 0.12 mg, respectively).

Juveniles

A number of studies have been made to determine the growth of juvenile striped bass. In lab studies using juveniles from the Chesapeake Bay, Koo and Ritchie (1973) found that monthly growth was 8.8% (Oct.), 3.8% (Nov.), 0% (Dec.-Apr.), 4.6% (May), and 9.1% (June). Growth in the fall, winter, and spring months was only 29% of the total yearly gain. There was no growth or feeding below 10°C; maximum growth occurred around 20°C. Patuxent River, Md, striped bass grew most rapidly in July, followed by August, June, September, May, and October. No growth occurred from November to April. Total lengths increased 74% between the first and second summers. Similar seasonal growth rate trends (low winter rates) for Chesapeake Bay striped bass are evident in data presented by Vladykov and Wallace (1952) and in data for California striped bass from Scofield (1931) (Fig. 6).

Trent (1962) found growth to be roughly linear between June and October for young-of-the-year in Albemarle Sound, N.C. Daily growth during this period averaged 0.35 mm/day. Total length at the end of the first season of growth was about 100 mm. Trent also reported that his data indicated no density dependence on growth rates, i.e., in years when juvenile recruitment was high, the growth rate was not lower than in years when fewer fish were present. Similar total lengths at the end of the first season have been reported for the Hudson River. However, daily growth in the Hudson River was larger (0.46 mm/day) but extended over a shorter period of time (Rathjen and Miller 1957). Juveniles from the Potomac River had similar growth rates (0.45 mm/day in 1975 and 0.46 mm/day in 1976) and reached lengths of approximately 100 mm TL by the end of the first summer (Boynton et al. footnote 13).

The relationship of both temperature and salinity to the growth of juvenile striped bass has been examined by Otwell and Merriner (1975). Mean relative growth (final fork length expressed as a percent of initial fork length) during a 7-day experimental period exceeded 20% at 24°C, equalled 14.6% at 18°C, and was <1% at 12°C. Growth at the intermediate salinity tested, 12‰, was significantly higher (10.7%, $P = 0.05$) than at either 4‰ (9.8%) or 20‰ (9.4%).

Mansueti (1958a) reported growth rates for young bass observed under a variety of conditions (Table 13). It is apparent from Table 13 that hatchery-raised fish were stunted in growth. Crowding and lack of food were suggested as reasons for the low growth rates.

Chadwick[34] found some variations between mean length of young-of-the-year fish collected in various subareas of the Sacramento-San Joaquin Delta. He suggested that the observed variations in size could be either a function of food intake, which would indicate that food was a limiting factor, or be a function of age. Mean annual growth rates of young-of-the-year fish were approximately the same for many years even though runoff and many other factors varied greatly.

Striped bass population densities have been, at times, sufficient to depress growth rates. Shearer et al. (1962) found no increase in the size of 2-yr-old Patuxent River, Md., striped bass from July to November 1960. Mean lengths and weights of 2-yr-old striped bass caught by anglers during that time period were:

Month	N	$\bar{X}$ *FL mm*	$\bar{X}$ *wt kg*
July	37	313	0.42
Aug.	61	311	0.35
Sep.	39	330	0.45
Oct.	46	330	0.44
Nov.	63	314	0.47

[34]Chadwick, H. K. 1966. Variation in the growth of young striped bass (*Roccus saxatilis*) in the Sacramento-San Joaquin System. Calif. Dep. Fish Game, Resour. Agency, Inland Fish. Admin. Rep. No. 66-11, 6 p. (Mimeogr.)

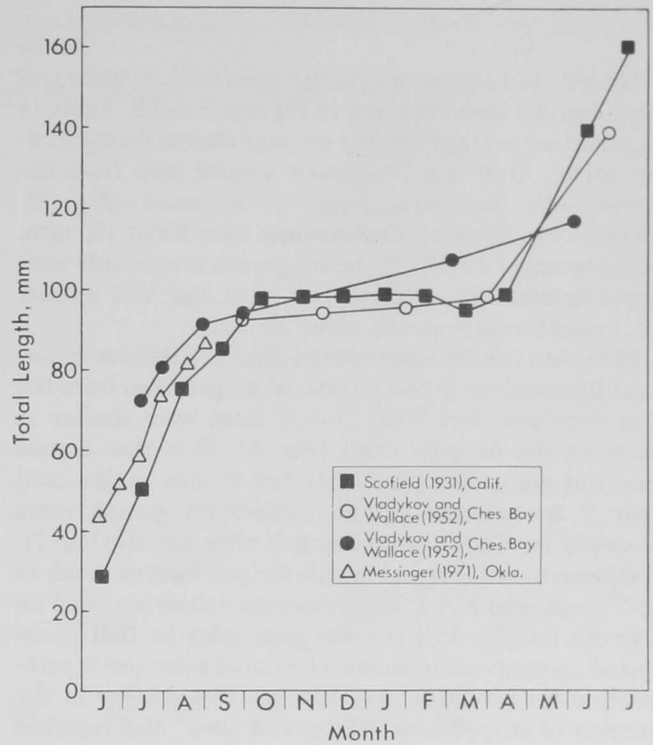

Figure 6.—Growth patterns for young-of-the-year striped bass (points indicate sample means).

Table 13.—Growth data, based on average sizes for various ages, of larval and young-of-the-year striped bass, *Morone saxatilis*. (From Mansueti 1958a.) (ND = no data.)

Hatchery-reared fish		Patuxent River fish (seine collections)		Pond-reared fish Pearson (1938)	
Observed age	Av. total length (mm)	Est. age in weeks	Av. total length (mm)	Observed age	Av. total length (mm)
Hatching	2.9	ND	ND	Hatching	3.2
1 day	3.6	ND	ND	ND	ND
1½ days	ND	ND	ND	1½ days	4.4
2 days	5.1	ND	ND	2 days	ND
3 days	5.6	ND	ND	3 days	5.2
4 days	ND	ND	ND	4 days	5.8
6 days	ND	ND	ND	6 days	6.0
8 days	ND	ND	ND	8 days	9.0
2 wk	8.1	ND	ND	16 days	13.0
3-4 wk	ND	ND	ND	3-4 wk	36.0
4 wk	11.5	4	42.0	ND	ND
6 wk	13.3	ND	ND	ND	ND
8 wk	20.1	8	68.0	ND	ND
10 wk	23.3	ND	ND	ND	ND
12 wk	25.0	ND	ND	ND	ND
14 wk	29.0	14	75.0	ND	ND

Trent (1962) determined the following linear relationships between standard, fork, and total lengths of 20-100 mm TL striped bass:

$$FL = 0.93835\ TL - 0.077817$$
$$SL = 0.80388\ TL + 0.55750$$
$$SL = 0.85675\ FL + 1.22099.$$

Adults

Growth and annual length increments of juvenile and adult striped bass are given in Figures 7 and 8. Table 14 summarizes average lengths for year classes from different areas. After age IV, female striped bass from the Chesapeake Bay were larger than males (Fig. 7). Through age III annual increments were about 120 mm; between ages IV and VII annual growth increments were approximately 60-70 mm; and after age VIII annual increments were generally about 50 mm.

Robinson (1960) reported that although there were annual fluctuations in the growth of striped bass from the San Francisco Bay area, growth rates were similar to those on the Atlantic coast (Fig. 8). Note that female bass did not grow appreciably faster than males until year V in contrast to the differential growth rates observed for Chesapeake Bay fish after age III (Fig. 7). Robinson found 6-yr-old female striped bass as much as 28% longer and 25% heavier than the values recorded for 6-yr-old females in the same area prior to 1931. Suggested causative mechanisms included a decline in competition for available prey because of a decline in the number of striped bass. Miller and Orsi[35] also reported similar results for California fish.

In the Delaware River, Bason (1971) reported that bass grew at a relatively constant rate through age VI. Yearly increments were about 100 mm which is in contrast to other bass populations where a sharp reduction in yearly increments has been noted after the second or third year. Bason concluded that Delaware River bass grew somewhat more slowly than Chesapeake and California bass during the first 3 yr, somewhat faster for the next 3 yr, and about the same for older bass (Table 14).

Several papers have considered the compensatory growth phenomenon, which tends to reduce the size variation within age classes with increasing age. Tiller (1943) found that smaller yearling individuals had more rapid growth rates in their second year. Nicholson (1946), in a study of striped bass in Albemarle Sound, N.C., found that compensatory growth occurred most frequently in year class II and to some extent in year class III.

In considering possible difference in the amount of compensatory growth in year 2 between four different year classes, Nicholson (1964) found a progressive decrease in slope of the regression (y, growth increment in year 2; x, growth increment in year 1) between the 1953 and 1954 year classes. While no explanation was given by the author he noted the similarity of the above with Lee's phenomenon.

Mensinger (1971) reported successful introductions of striped bass in Oklahoma. Growth rates greatly exceeded those of Chesapeake stocks, especially through the first few years (Table 14).

[35]Miller, L. W., and J. J. Orsi. 1969. Catch of striped bass (*Morone saxatilis*) in the Sacramento-San Joaquin estuary from 1961-1965. Calif. Dep. Fish Game, Resour. Agency, Anadromous Fish. Admin. Rep. No. 69-6, 7 p. (Mimeogr.)

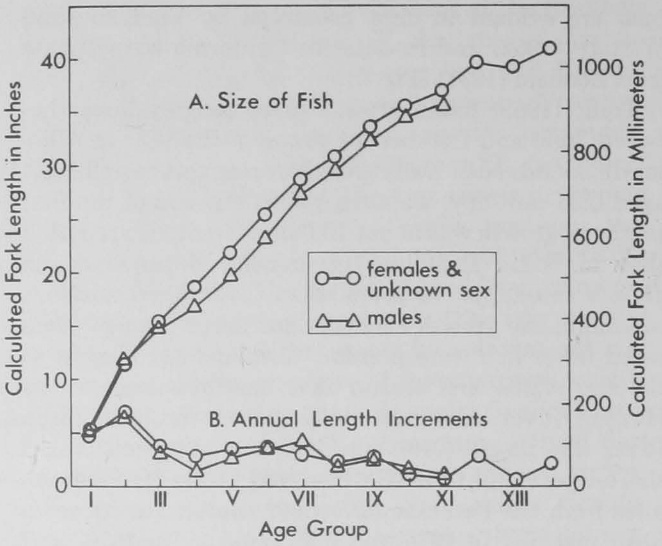

Figure 7.—Growth of striped bass, *Morone saxatilis* as calculated from scale samples of fish caught in 1957 from Chesapeake Bay, Maryland. From Mansueti (1961a).

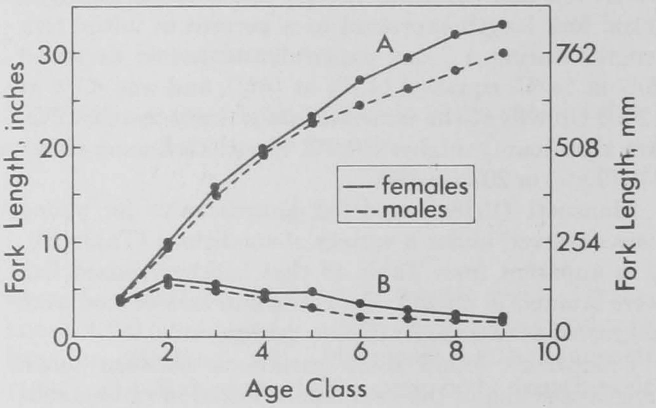

Figure 8.—Growth of Sacramento-San Joaquin Estuary, Calif., striped bass as calculated from scales: (A) Mean size per age class; (B) annual increments. From Robinson (1960).

Ware (1971) reported average yearly growth rates for striped bass taken in Florida lakes, which were among the highest recorded (Table 14). In Florida growth was more rapid during the cooler months. Accelerated growth was apparent in the young-of-the-year fish after sufficient size (150 mm) was attained to use shad as food. The increasing size of striped bass along a north-south gradient is obvious from Table 14; warmer climates apparently increase the duration of optimal growth periods.

Table 14 summarizes mean lengths of 2- to 20-yr-old males and 2- to 14 yr-old females from the Potomac River, Md. Jones et al. (footnote 17) found that female striped bass, 4 yr and older were significantly larger than males. Most fish were caught on the spawning grounds. Sexually mature males, which mature by age II, dominated the catch of 2- to 5-yr-old fish; females, which mature by age V, dominated the catch of older fish.

Table 14.—Annual growth rates (in millimeters) reported for striped bass from various locations. (Based on calculated fork length unless otherwise states.)

Age	Area	Both sexes	Increment	Males	Increment	Females	Increment	Author
I	Maine	150	147					Davis 1966
	Connecticut	124	121					Merriman 1941
	Delaware River, Del.	102	99					Bason 1971
	Chesapeake Bay			135	132	124	121	Mansueti 1961
	Albermarle Sound, N.C.	100	97					Trent 1962
	Santee-Cooper, S.C.	216 TL	213					Stevens 1958
	Florida Lake	289[1]	286					Ware 1971
	Oklahoma Reservoir	258 TL	255					Mensinger 1971
	Sacramento-San Joaquin Rivers, Calif.			104	101	104	101	Robinson 1960
	Tennessee (SB × WB[2] hybrids)	294 TL[1]	291					Bishop 1968
II	Maine	297	147					Davis 1966
	Connecticut	236	112					Merriman 1941
	Delaware River, Del.	218	116					Bason 1971
	Chesapeake Bay			297	162	292	168	Mansueti 1961
	Potomac River, Md.			324		311		Jones et al. 1977[3]
	Pamlico River and Sound, N.C.	367						Marshall 1976[4]
	Santee-Cooper, S.C.	399 TL	186					Trent 1962
	Florida Lake	459[1]	170					Ware 1971
	Oklahoma Reservoir	455 TL	197					Mensinger 1971
	Sacramento-San Joaquin Rivers, Calif.			249	145	249	145	Robinson 1960
	Tennessee (SB × WB hybrids)	458 TL[1]	167					Bishop 1968
III	Maine	409	112					Davis 1966
	Connecticut	366	130					Merriman 1941
	Delaware River, Del.	319	101					Bason 1971
	Chesapeake Bay			381	84	389	97	Mansueti 1961
	Potomac River, Md.			399	75	403	92	Jones et al. 1977[3]
	Pamlico River and Sound, N.C.	421	54					Marshall 1976[4]
	Santee-Cooper, S.C.	503 TL	104					Stevens 1958
	Oklahoma Reservoir	541 TL	86					Mensinger 1971
	Sacramento-San Joaquin Rivers, Calif.			386	137	389	140	Robinson 1960
	Coos Bay, Oreg.	368[1]						Morgan and Gerlach 1950
IV	Maine	488	79					Davis 1966
	Connecticut	450	84					Merriman 1941
	Delaware River, Del.	430	111					Bason 1971
	Chesapeake Bay			422	41	467	78	Mansueti 1961
	Potomac River, Md.			435	36	470	67	Jones et al. 1977[3]
	Pamlico River and Sound, N.C.	503	82					Marshall 1976[4]
	Santee Cooper, S.C.	582	79					Stevens 1958
	Oklahoma Reservoir	606	65					Mensinger 1971
	Sacramento-San Joaquin Rivers, Calif.			493	107	500	111	Robinson 1960
	Coos Bay, Oreg.	483	115					Morgan and Gerlach 1950
V	Maine	556	68					Davis 1966
	Connecticut	531	81					Merriman 1941
	Delaware River, Del.	530	100					Bason 1971
	Chesapeake Bay			500	78	556	89	Mansueti 1961
	Potomac River, Md.			533	98	591	121	Jones et al. 1977[3]
	Pamlico River and Sound, N.C.	534	31					Marshall 1976[4]
	Santee-Cooper, S.C.	655 TL	73					Stevens 1958
	Sacramento-San Joaquin Rivers, Calif.	577[1]	94					Morgan and Gerlach 1950
VI	Maine	617	61					Davis 1966
	Connecticut	610	79					Merriman 1941
	Delaware River, Del.	630	100					Bason 1971
	Chesapeake Bay			594	94	645	89	Mansueti 1961
	Potomac River, Md.			634	101	659	68	Jones et al. 1977[3]
	Pamlico River and Sound, N.C.	556	22					Marshall 1976[4]
	Santee-Cooper, S.C.	724 TL	69					Stevens 1958

Table 14.—Continued.

Age	Area	Both sexes	Increment	Males	Increment	Females	Increment	Author
	Sacramento-San Joaquin Rivers, Calif.			622	56	683	99	Robinson 1960
	Coos Bay, Oreg.	635[1]	58					Morgan and Gerlach 1950
VII	Maine	658	41					Davis 1966
	Connecticut	686	76					Merriman 1941
	Delaware River, Del.	708	78					Bason 1971
	Chesapeake Bay			704	110	724	79	Mansueti 1961
	Potomac River, Md.			742	108	779	120	Jones et al. 1977[3]
	Pamlico River and Sound, N.C.	614	58					Marshall 1976[4]
	Santee-Cooper, S.C.	767 TL	43					Stevens 1958
	Sacramento-San Joaquin Rivers, Calif.			671	49	747	64	Robinson 1960
	Coos Bay, Oreg.	693[1]	58					Morgan and Gerlach 1950
VIII	Connecticut	749	63					Merriman 1941
	Delaware River, Del.	795	87					Bason 1971
	Chesapeake Bay			754	50	782	58	Mansueti 1961
	Potomac River, Md.		(1 fish)	784	42	826	47	Jones et al. 1977[3]
	Pamlico Sound and River, N.C.	668	54					Marshall 1976[4]
	North Carolina coast					837		Holland and Yelverton 1973
	Sacramento-San Joaquin Rivers, Calif.			716	45	800	53	Robinson 1960
	Coos Bay, Oreg.	732[1]	39					Morgan and Gerlach 1950
IX	Connecticut	820	71					Merriman 1941
	Delaware River, Del.	869	74					Bason 1971
	Chesapeake Bay			831	77	856	74	Mansueti 1961
	Potomac River, Md.			864	80	888	62	Jones et al. 1977[3]
	Pamlico Sound and River, N.C.	840						Marshall 1976[4]
	North Carolina coast					896	59	Holland and Yelverton 1973
	Sacramento-San Joaquin Rivers, Calif.			762	46	836	36	Robinson 1960
	Coos Bay, Oreg.	762	30					Morgan and Gerlach 1950
X	Delaware River, Del.	919	50					Bason 1971
	Chesapeake Bay			876	45	899	43	Mansueti 1961
	Potomac River, Md.			839		924	36	Jones et al. 1977[3]
	Pamlico River and Sound, N.C.	872	32					Marshall 1976[4]
	North Carolina coast					978	82	Holland and Yelverton 1973
XI	Delaware River, Del.	992 (1 fish)	73					Bason 1971
	Chesapeake Bay			907	31	935	36	Mansueti 1961
	Potomac River, Md.					936	12	Jones et al. 1977[3]
	Pamlico River and Sound, N.C.	973 (1 fish)						Marshall 1976[4]
	North Carolina coast					1,002	24	Holland and Yelverton 1973
XII	Delaware River, Del.	1,045 (1 fish)	53					Bason 1971
	Chesapeake Bay					1,006	71	Mansueti, 1961
	Potomac River, Md.					973	37	Jones et al. 1977[3]
	North Carolina coast					1,245 (2 fish)		Holland and Yelverton 1973
XIII	Chesapeake Bay					983 (3 fish)		Mansueti 1961
	Potomac River, Md.					1,098 (2 fish)		Jones et al. 1977[4]
	North Carolina Coast					1,450 (1 fish)		Holland and Yelverton 1973
XIV	Chesapeake Bay					1,044 (1 fish)		Mansueti 1961
	Potomac River, Md.					1,038 (2 fish)		Jones et al. 1977[3]

[1] Measured length.

[2] SB = striped bass; WB = white bass.

[3] Jones, P. W., J. S. Wilson, R. P. Morgan II, H. R. Lunsford, Jr., and J. Lawson. 1977. Potomac River fisheries study; striped bass spawning stock assessment. Interpretive report 1974-1976. Univ. Maryland CEES Ref. No. 77-56-CBL. Chesapeake Biological Laboratory, Solomons, MD 20688.

[4] Marshall, M. D. 1976. Anadromous fisheries research program; Tar River, Pamlico River and northern Pamlico Sound. Completion Rep. Proj. AFCS-10, 15 May 1974-30 June 1976, 90 p. North Carolina Division of Marine Fisheries, Moorehead City, NC 28557.

Table 15 summarizes length-weight relationships of male and female striped bass from various areas. After maturity male striped bass of a given length weigh less than females of the same length (Merriman 1941; Mansueti 1961).

Mansueti (1961) used the factor 0.93 to convert total length to fork length, the factor 1.07 to convert fork length to total length, and the factors 1.08 and 0.92 to convert standard length to total length and total length to standard length.

Dorfman and Westman[36] found the growth rate of striped bass significantly impaired by daily exposure to diurnal oxygen fluctuations when the average concentration was <4.0 ppm.

3.44 Metabolism

The dependence of metabolic rate on temperature was investigated by Klyashtorin and Yarzhombek (1975) using striped bass weighing between 1 and 3 g and acclimatized to 22°C. Q_{10} values varied from 2.1 to 1.8 between 15° and 30°C. Oxygen consumption ranged from 250 to 1,000 mg kg^{-1} h^{-1}. Oxygen consumption per unit weight also decreased in proportion to the increase in weight of the fish and could by described by $\frac{Q}{w} = aW^k$, where Q is oxygen consumption, W the weight of the fish, and a and k coefficients having values of 0.36 and −0.25, respectively. Oxygen consumption of larger fish (8-20 g) varied sharply with temperature and averaged 0.15 g O_2/kg per h and 0.45 g O_2/kg per h at 10° and 26°C.

There appeared to be a sharp threshold in oxygen consumption dependent on ambient oxygen concentrations. For small fish (1-2 g) oxygen utilization decreased sharply when ambient concentrations reached 3-4 ppm. Oxygen uptake of 22 g fish went to zero at approximately 1 ppm. Oxygen consumption required for active metabolism is undoubtedly greater, threshold oxygen levels are probably in the range of 4-4.5 ppm for young striped bass. Only temporary oxygen consumption rate changes were observed when salinities were increased from 0 to 10‰. (Klyashtorin and Yarzhombek 1975.)

Chittenden (1971b) also observed negligible rate changes in oxygen consumption of young-of-the-year striped bass, 3.1-11.7 g, from 0.10‰ salinity (see also oxygen subsection in 3.22).

Kruger and Brocksen (1978) reported standard metabolic rates for 22.5-68.4 g, 13.0-17.5 cm striped bass at the following temperatures:

°C	*mg O_2/kg fish per h*
8	44
12	71
16	151
20	169
24	218

[36]Dorfman, D., and J. R. Westman. 1970. Responses of some anadromous fishes to varied oxygen concentrations and increased temperatures. Rutgers, State Univ., Coll. Agric. Environ. Sci., New Brunswick, N.J., PB-192312, 75 p.

Table 15.—Length-weight regressions (predictive) of striped bass from various areas.

Area	Year	Regression	N	r	Sex	Source
Maine		$Y = -3.420 + 3.049$				Davis 1966
		$Y = \log_{10}$ wt in lb				
		$X = \log_{10}$ FL in inches				
Delaware	1968	$Y = 5.028 + 3.031X$	89	0.992		Bason 1971
		$Y = 4.834 + 2.948X$	70	0.984		
	1969	$Y = -4.950 + 3.000X$	100	0.993		
		$Y = -4.736 + 2.911X$	100	0.989		
		$Y = \log_{10}$ wt in g				
		$X = \log_{10}$ FL in mm				
Chesapeake Bay, Md.		$Y = 2.406 + 3.234X$	207			Mansueti 1961
		$Y = 2.238 + 3.153X$	315			
		$Y = \log_{10}$ wt in oz				
		$X = \log_{10}$ FL in inches				
Potomac River, Md.	1974	$Y = -11.0369 + 2.9910X$	923	0.9771	Males	Jones et al. 1977—see Table 14, footnote 3
		$Y = -11.0943 + 2.9984X$	228	0.9950	Females	
	1975	$Y = -10.2610 + 2.8670X$	801	0.9763	Males	
		$Y = -10.6706 + 2.9388X$	233	0.9941	Females	
	1976	$Y = -11.3208 + 3.0419X$	144	0.9906	Males	
		$Y = -9.5418 + 2.7727X$	194	0.9791	Females	
		$Y = \ln$ wt in kg				
		$X = \ln$ FL in mm				
Sacramento-San Joaquin Rivers, Calif.		$Y = 2.1393 + 3.0038X$				Robinson 1960
		$Y = \log_{10}$ wt in lb				
		$X = \log_{10}$ FL in inches				
Albemarle Sound, N.C., young-of-year striped bass		$Y = 1.84615 + 2.91977X$				Trent 1962
		$Y = \log_{10}$ wt in mg				
		$X = \log_{10}$ TL in cm				

Mean rates of oxygen consumption of juvenile striped bass at three swimming speeds at each of five temperatures are summarized below:

Temp °C	*No. of fish*	*Rate of O_2 consumption in mg O_2/kg fish per h*[1] *1 cm/s*	*5 cm/s*	*10 cm/s*
		$\bar{X} \pm s_{\bar{x}}$	$\bar{X} \pm s_{\bar{x}}$	$\bar{X} \pm s_{\bar{x}}$
8	5	49.4± 5.5	69.2±12.8	100.8±10.9
12	6	76.2± 4.9	91.0± 4.0	118.7± 6.3
16	3	156.3± 7.7	176.0±17.9	180.7± 2.6
20	5	181.0± 2.6	206.8±15.2	276.0±23.3
24	4	228.0±19.0	—	350.8±17.5

[1]Adopted from Kruger and Brocksen 1978:59.

These authors derived the following regressions between swimming speed and rate of oxygen consumption:

8°	Log $Y = 0.6452 + 0.03454X$
12°	Log $Y = 0.8537 + 0.02152X$
16°	Log $Y = 1.1778 + 0.01117X$
20°	Log $Y = 1.2279 + 0.02002X$
24°	Log $Y = 1.3322 + 0.02112X$.

Scope for activity (difference between standard metabolic rate and active metabolic rate at a swimming velocity of 10 cm/s) at 8°, 12°, 16°, 20°, and 24°C was 55, 44, 45, 99, and 143 mg O_2/kg per h. Metabolic cost of swimming at a sustained speed of 10 cm/s was 130% of the standard metabolic rate at 8°C, 66% at 12°C, 29% at 16°C, 59% at 20°C, and 63% at 24°C. Kruger and Brocksen (1978) concluded that the optimal temperature for swimming, metabolism, and scope for activity for juvenile striped bass may be at ≈16°C.

Sherk et al.[37] reported oxygen consumption rates for 100 g striped bass swimming at the following speeds at 16°C:

cm/s	*O_2 consumption mg/h*
8.5	26.1
31	34.0
48	50.4.

Oxygen consumption increased to 47.3 mg/h with a swimming speed of 31 cm/s at 25°C.

Striped bass are not strong swimmers; juvenile striped bass are unable to swim at velocities commonly sustained by a variety of species for comparable time periods (Kruger and Brocksen 1978). Painter and Wixom[38] recorded a maximum swimming speed of 60 cm/s for 24 cm juvenile striped bass.

3.5 Behavior

3.51 Migrations and local movements

Juvenile migrations

The initiation and extent of juvenile striped bass migrations seems to vary somewhat with location. Markle and Grant (1970) stated that during the first summer young striped bass in several Virginia rivers migrated downstream into waters of high salinity; likewise, Mihursky et al. (footnote 6) presented evidence that juvenile striped bass left the mid-Potomac spawning area before reaching lengths >70 mm TL. In the Hudson River a downstream and shoreward movement of young-of-the-year began in July; the shoreward movement of young was indicated by the increasing catches of juveniles in beach seine collections and the generally declining densities of striped bass juveniles in the shoal and channel areas in many regions of the river after mid-July. This downstream migration continued through late summer; by fall the juveniles had started to move offshore into Long Island Sound (Texas Instruments, Inc. footnote 10; Carlson and McCann[39]). Raney (1952) stated that small schools of larval striped bass 12-13 mm TL moved inshore where they remain at least during their first summer. During their second summer, 15 cm juvenile striped bass schooled in rivers or moved down into the lower estuary. The concentration of juvenile striped bass in shallow waters has also been noted in the Potomac River (Mihursky et al. footnote 6) and Delaware Bay (Shuster 1959).

Tagged young-of-the-year striped bass released at the mouth of the Patuxent River (Maryland) remained in the shoal area during the summer months; 5-16 mo later some fish were recaptured 80 km or more up the Chesapeake Bay. Young-of-the-year released 27-53 km up the Patuxent River during the fall and winter months remained more or less stationary; however, there were some indications of net upriver movement into virtually fresh water. During their second summer, juvenile striped bass moved downriver into Chesapeake Bay (Ritchie and Koo[40]). Ritchie (1970) found that fish hatched in the Patuxent River moved up the Chesapeake Bay in their second to fourth years.

Sasaki (1966) reported that juvenile striped bass in the lower San Joaquin River were more concentrated over shoal areas than in deeper waters. In the fall these juveniles migrated downstream from the delta into San Pablo Bay; the 2-yr-old sexually maturing males migrated back into the delta the following spring, followed by the immature females during the summer.

There is little evidence that striped bass <2 yr undertake migrations along the Atlantic coast (Merriman 1941). Mansueti (1961) stated that striped bass spawned in the Potomac River remained within the river during the first 3 or 4 yr of life. There is little exchange between river and Chesapeake Bay populations of Maryland striped bass with the probable exception of the Patuxent River juveniles. From a tagging study conducted on the Chesapeake Bay, Vladykov and Wallace (1938) concluded that striped bass under 2 yr of age were not migratory. Massmann and Pacheco (1961) concluded that in Virginia rivers, almost all striped bass <30.5 cm TL remained within the river system in which they were spawned.

[37]Sherk, J. A., J. M. O'Connor, and D. A. Neumann. 1972. Effects of suspended and deposited sediments on estuarine organisms. Phase II. Annu. Rep. U.S. Army Corps Eng., Proj. Year II, Nat. Resour. Inst. Ref. No. 72-9E, 106 p. Chesapeake Biological Laboratory, Solomons, MD 20688.

[38]Painter, R. E., and L. H. Wixom. 1967. Striped bass fishery and swimming endurance tests. *In* Delta fish and wildlife protection study, p. 31-47. Resource Agency of the State of California.

[39]Carlson, F. T., and J. A. McCann. 1969. Report on the biological findings of the Hudson River fisheries investigations, 1965-1968. *In* Hudson River Fisheries Investigations, 1965-1968: Evaluations of a proposed pump storage project at Cornwall, New York, in relation to fish in the Hudson River, 50 p. Hudson River Pollut. Comm., N.Y. Conserv. Dep.

[40]Ritchie, D. E., and T. S. Y. Koo. 1968. Movement of juvenile striped bass in the estuary as determined by tagging and recapture. Chesapeake Biol. Lab., Rep. No. 68-31, 1 p.

Adult migration

Striped bass from the Gulf of Mexico and from both extremes of its range along the Atlantic coast rarely undertake coastal migrations. Along the Atlantic coast there is an apparent lack of coastal migrations from southern North Carolina to northern Florida (Raney 1957). Populations in the St. Johns River, Fla. (Barkuloo 1970); Savannah River, Ga. (Dudley et al. 1977); and Cooper River, S.C. (Scruggs and Fuller 1955; Scruggs 1957) are essentially riverine, as is the striped bass population in the St. Lawrence River, Canada (Vladykov 1947; Murawski 1958). Striped bass from the Quebec River, the Canadian provinces of Nova Scotia and New Brunswick, and some contingents from the Hudson River are probably isolated and do not move great distances after spawning (Bigelow and Schroeder 1953; Whitworth et al. 1968; Clark 1968). But from Cape Hatteras, N.C., north to New England substantial numbers of striped bass leave their birthplaces when they are two or more years old and migrate in groups along the open coast, moving generally north in summer and south in winter (Vladykov and Wallace 1938, 1952; Merriman 1941; Chapoton and Sykes 1961; Clark 1968).

Coastal migrations, which apparently are not associated with spawning activity (Merriman 1937, 1941; Vladykov and Wallace 1938), begin in early spring and are augmented by spent striped bass after the spawning season. Bigelow and Schroeder (1953) found that approximately 90% of all striped bass captured in northern waters were females. They suggested that the dominance of female striped bass in northern waters may be attributed to the faster growth rate and larger size of female striped bass. Large striped bass migrate farther. Striped bass catches from coastal waters of Rhode Island (Oviatt 1977) and North Carolina (Holland and Yelverton 1973) also consisted of approximately 90% females.

Likewise Schaefer (1968b) reported that 85.7% of striped bass inhabiting the surf zone along with the south shore of Long Island, N.Y., from April-November 1964 were females. These migrating striped bass, most of which originated in the tributaries of the Chesapeake Bay or other southern areas (Merriman 1941; Raney 1952; Clark 1968), are intensively fished off southeastern Long Island, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine. Some coastal migrants may enter and overwinter in northern coastal rivers such as lower Hudson, Mullica, and Delaware. However, these overwintering fish are a small percentage of the total migrating population. A successful spawning and survival of young in the Chesapeake Bay area may have a pronounced effect in following years on the number of older striped bass present at distant northern localities along the coast (Tiller 1950; Raney 1952; Mansueti 1961). More than one-half of the striped bass catch of the Atlantic coast is derived from the Chesapeake region. Koo (1970) concluded that Chesapeake Bay striped bass between age II and age III contributed significantly to the Atlantic coast stock. Sykes et al.[41] reported that most (75%) of the Atlantic coast striped bass catch was composed of 2- to 4-yr-old fish. Kohlenstein (1978) presented evidence that approximately 50% of 3-yr-old female striped bass migrated from the Chesapeake Bay in early spring and that a much smaller proportion of 2-yr-old and 4-yr-old females migrate. In contrast very few males of this age range participate in the migration.

Examination of sport and commercial landings from the York River, Va., likewise shows an exodus of age III striped bass from the river (Merriner and Hoagman footnote 8). Fish probably migrate to the lower Chesapeake Bay and become part of the migrating coastal population (Merriman 1941; Nichols and Miller 1967; Grant et al. 1970). The inshore zone (0-10 fathoms) between Cape Henry, Va., and Cape Lookout, N.C., serves as wintering grounds for the migratory segment of the Atlantic coast striped bass population. Three groups of fish congregate off the North Carolina coast from November to March: striped bass which enter Albemarle and Pamlico Sounds, N.C. (mostly small fish; range 40.0-88.5 cm FL, $\bar{X}$ = 57.5 cm); fish from the Chesapeake Bay (mixed sizes; range 32.0−94.5 cm Fl, $\bar{X}$ = 48.0 cm); and predominately large (range 33.0−112.0 cm FL, $\bar{X}$ = 80.2 cm) striped bass which spend the summer from New Jersey northward (Holland and Yelverton 1973). Adult striped bass (4 yr and older) tagged on the North Carolina coast in the late fall or winter were recovered in the commercial fisheries of North Carolina and the Chesapeake Bay prior to or during spawning season and were caught by sport fishermen along the Atlantic coast north to New England and Canada during the summer and fall months (Miller 1969; Chapoton and Sykes 1961).

It is generally thought that Hudson River striped bass contribute little to the Atlantic coast migratory stock though Clark (1968) considered the Hudson River the major source of recruitment of striped bass populations of Long Island Sound and the New York Bight (coastal area from Montauk Point, Long Island, to Barnegat Bay, N.J.). Clark (1968) concluded that five contingents (separate components of the Atlantic population) occupy Long Island Sound area at different times of the year. Three contingents—Hudson-West Sound, Hudson Estuary, and Hudson-Atlantic—occur in the Hudson River during the spring and presumably spawn there. The Hudson-West Sound contingent occurs in Long Island Sound from summer to fall, moves into the Hudson River to overwinter and spawn in the spring, and returns to the sound in the summer via inland waters. The Hudson Estuary contingent confines its seasonal movements within the Hudson Estuary system, overwintering and spawning in the Hudson River, and moving downriver into bays to feed during the summer. This contingent was first identified as part of the Hudson River race by Raney et al. (1954). There is

[41]Sykes, J. E., R. J. Mansueti, and A. H. Swartz. 1961. Striped bass research on the Atlantic Coast. 20th Annu. Conf., Atl. State Mar. Fish. Comm. (Mimeogr.)

some evidence of a Hudson-Atlantic contingent (Merriman 1941; Raney 1952) which moves into the river to spawn, spends the summer offshore in the New York Bight area and in southern New England, and overwinters in New Jersey or Delaware rivers, Chesapeake Bay, or offshore.

Additionally, the Long Island Sound contingent, which resides in the western portion of the sound, and the southern contingent, which passes through during annual migrations, may be found in these waters.

Schaefer (1968a) concluded that the abundance of striped bass inhabiting the south shore surf areas of Long Island was directly dependent upon contributions from Chesapeake Bay stocks. Only in years when this contribution was low did the influence of the Hudson River stock on the south shore become evident.

Austin and Custer (1977) evaluated an extensive tagging program conducted in Long Island Sound by the American Littoral Society. Their data indicated there was: a spring influx from both ends of Long Island Sound, but primarily from the east (Hudson River striped bass would enter the sound from the west, Chesapeake area fish from the east); a stable summer population; and a fall migration out through the eastern passages. An intra-Long Island Sound fall migration was apparent as striped bass along the Connecticut coast migrated to the central part of the sound, crossed to the Long Island shore, and then migrated out of the sound via the eastern passages. The majority of the winter tag returns were from southern waters, 72% from the Chesapeake Bay area and 11% from North Carolina.

Berggren and Lieberman (1978) estimated the relative contribution of Hudson, Chesapeake, and Roanoke stocks to the 1975 Atlantic coast striped bass fishery based on discriminant analysis of five morphological characters. The Chesapeake stock was the major contributor (90.8% iterative estimate, 90.2% adjusted estimate) to the coastal fishery from southern Maine to Cape Hatteras, N.C. Contribution of Hudson stock to the coastal fishery was greater in areas adjacent to the Hudson River than in remaining areas. Mean estimates of relative contribution of the Hudson River stock to western Long Island Sound, New York Bight, and northern New Jersey (inner zone—U.S. Nuclear Regulatory Commission) were 16% iterated and 15% adjusted; mean contribution estimates to remaining waters from Cape May, N.J., to Maine (outer zone-USNRC) were 2.8% iterated and 0.0% estimated. Sublegal-sized striped bass from western Long Island Sound and New York Bight, and striped bass overwintering in the Hudson River were predominantly of Hudson origin.

Striped bass in the Sacramento-San Joaquin Delta, Calif., undergo annual migrations (Calhoun 1952; Chadwick 1967; Orsi 1971). Striped bass tagged during the early spring in the western delta (1958-61) migrated to salt water by late spring. During the summer, adults were generally centered in San Francisco Bay though substantial numbers were caught in the Pacific Ocean from Tomales Bay, 64 km north of the Golden Gate Bridge, to Monterey, 161 km south of the bridge. Fish began returning to the delta in the fall although many overwintered in the San Francisco Bay area. By spring fish had moved into the delta or its tributaries to spawn (Chadwick 1967).

The following variations in the above migration pattern were reported by Orsi (1971) from a 1965-67 tagging study:

1. Adult striped bass shifted from San Francisco Bay to San Pablo Bay during the winter.
2. Small-sized (38-51 cm FL) and medium-sized (53-61 cm FL) fish moved downstream into San Francisco Bay during the fall.
3. Striped bass spend less time and had a reduced range in the ocean.

Orsi correlated the upstream winter displacement of striped bass from San Francisco to San Pablo Bays with a decline in herring abundance in San Francisco Bay. Bass feed on spawning herring during the winter.

3.52 Schooling

During the first 2 yr, juvenile striped bass are primarily found in small groups. In subsequent years striped bass, especially up to a weight of about 4.5 kg are likely to congregate in large schools. Although larger fish often school, individuals of 13.6-18.1 kg are more often found singly or in small groups (Raney 1952; Bigelow and Schroeder 1953).

The first attempts to determine the movements of striped bass in the Chesapeake Bay through tagging studies were made by Pearson (1933, 1938). From the results of these studies, Pearson suggested that adult striped bass showed a preference for fresh or slightly brackish water. An extensive tagging study was undertaken in the Chesapeake Bay by Vladykov and Wallace (1938). They found adult fish schooling near the surface in the open portions of the bay from June to mid-September. Likewise Pearson (1938) concluded that adult striped bass moved into open waters during the summer months. Schools of striped bass move inshore from mid-October to late November, and southward, generally along the western shore of the bay. The stripers overwintered in the deeper portions of the bay [young adults ages II-IV overwintered at 24-37 m according to Mansueti (1956)] and moved northward again during the spring spawning migration (Mansueti and Hollis 1963). Dovel (1968) described prespawning schools of striped bass in the Chesapeake Bay during January, February, and March. Vladykov and Wallace (1938) concluded that the striped bass movements were based on migration of prey fish populations rather than on variations in salinity or temperature. Pearson (1938) suggested that striped bass overwinter in deep river channels. Murawski (1969) observed striped bass overwintering in the upper portion of a number of New Jersey tidal streams. The fish chose deep areas out of the main current, remained tightly schooled, and moved only slightly when water temperatures were 1°C or less.

Raney (1952) stated that in New Jersey and Delaware striped bass overwintered in deep pools and remained relatively inactive whereas in the Chesapeake Bay feeding and movement continued throughout the winter. Talbot (1966) concluded that striped bass generally overwintered in deep holes within channels, bays, estuaries, delta regions, or rivers.

A large striped bass population is present throughout the year in the Potomac River, though the adult population is not rigidly self-contained within the river. Miller (1969), in noting the number of striped bass tagged in winter in the Potomac River and recaptured in other tributaries the following spawning season, suggested that striped bass from other areas overwinter in the lower Potomac River. Striped bass exhibit a "homing tendency," returning to the same area within the river each year to spawn. Murphy (1959) described a size-salinity gradient in overwintering striped bass on the Potomac.

3.53 Responses to stimuli

Also see sections 3.32 and 4.42.

A number of investigators have examined striped bass movement and behavior. Striped bass appeared to move en masse during tidal flows from one locality to another, apparently riding the flow (Kerr 1953). Results from sonic tracking in the Chesapeake and Delaware Canal indicated that the movements were made typically in a "rest and go" manner, often with lengthy rest periods. When the current flowed in the direction in which the fish wanted to move, the fish swam or drifted along with the current. However, when the current flowed in the opposite direction, striped bass seemed to prefer to remain stationary rather than swimming actively against it. There was not much difference between day and night activity of prespawning fish. Spent striped bass, however, did not move as actively as prespawning adults (Koo and Wilson 1972).

The behavior of juvenile striped bass in currents with velocities from zero to several feet per second has been observed in holding tanks and confirmed in flume experiments at the Contra Costa Steam Plant in California. In quiet waters fish moved in all directions, but with the first water movement they oriented into the flow. As the velocity increased this orientation became more positive with little tendency to deviate from it. Fish rarely swam with the current unless frightened or exhausted and looking for a refuge. They avoided areas of high turbulence and would not cross through vertical stream lines having a wide differential in velocity (Kerr 1953).

A variety of methods have been utilized to divert fish from intake areas of power plants. Lights were used to attract fish into areas where they could be rescued at the Contra Costa Steam Plant. The lights had an attraction for the larger fish, but it was only of a secondary nature (Kerr 1953). Meldrim and Gift (1971), however, found no definitive effects of light level in avoidance experiments. Noisemakers and vibrating contraptions were also unsuccessfully employed to frighten fish from the intake areas at the Contra Costa Steam Plant (Kerr 1953).

To ward off fish from the intake area, fish collectors utilizing 20 cm bladeless impeller pumps were designed and placed in front of the traveling screens in the screen approach channel at the Contra Costa Steam Plant. From the results of the experimental collectors, Kerr (1953) concluded that 98% of the fish entering the screen structure, from the smallest size stopped by the screen to fish approximately 36 cm in length, would be safely returned to the river.

Other behavioral observations: There have been a number of observations made on larval and juvenile striped bass kept in aquaria. Larvae are positively phototropic according to observations made by Sandoz and Johnston (1966). Tatum et al. (1966) concluded that artificial light appeared to have a tranquilizing effect upon striped bass in aquaria at the Weldon Hatchery, N.C. However, Kerr (1953) found that larval and small young-of-the-year striped bass were easily frightened into a state of shock, often resulting in death, by the movement of personnel in the aquaria area. Shock was less serious with older young-of-the-year and juvenile bass.

4 POPULATION

4.1 Structure

4.11 Sex ratio

The patterns of movement, and consequently distribution, of striped bass depend strongly on age and sex. Young males do not leave the Chesapeake Bay in significant numbers. A substantial proportion of immature females leave the Chesapeake Bay for coastal waters where they remain until they mature (Kohlenstein 1978). Consequently the stocks in coastal waters, composed largely of fish from the Chesapeake Bay, are dominated by females. Typically 90% of a sample taken in coastal waters are females (Bigelow and Schroeder 1953; Holland and Yelverton 1973; Oviatt 1977).

Within the Chesapeake Bay the sexual composition of a group of striped bass depends on location, season, and age. Males mature at age 2 or 3 and join in the spring movement on to the spawning grounds. Most females do not mature until age 5 or 6 and immature females do not move onto the spawning grounds. Consequently, the sexual composition of stock on the spawning grounds varies dramatically with age. The age specific sexual composition found in the Potomac River spawning grounds by Jones et al. (footnote 17) went from total dominance by males at age 3 to strong dominance by females at age 7:

Age	*3*	*4*	*5*	*6*	*7*
Male proportion of the stock	0.97	0.94	0.81	0.31	0.19

Often there are in aggregate more males than females on the spawning grounds (Pearson 1938; Merriman 1941; Trent and Hassler 1968; and others). Males spend more time on the spawning grounds than females (Chadwick 1967). Morgan and Gerlach (1950) reported that males dominated the commercial catch of Coos Bay, Oreg., during early April, the latter part of May, and throughout June, whereas females predominated in late April and early May. However, this sex ratio is dependent on the relative strength of the age classes in the stock. For example, the sex ratio of all striped bass sampled on the Potomac River, Md., spawning grounds was 4 to 1 female in 1974, 3.44:1 in 1975, and 1:1.3 in 1976. This transition was primarily due to the production of a dominant year class in 1970 and low spawning success from 1971 through 1973. Recruitment from the 1971-73 year classes did not compensate for the exploitation of the 1970 year class; thus the male to female ratio shifted from male dominance in 1974 to female dominance in 1976 (Jones et al. footnote 17).

The sexual composition of the stock remaining in the Chesapeake Bay in a given year is best reflected in samples obtained during the summer and fall. The 1936 and 1937 striped bass population in the Maryland portion of the Chesapeake Bay was dominated by the 1934 year class and consisted of 55% males; similar ratios were found in Virginia and North Carolina (Vladykov and Wallace 1952). Kohlenstein (1978) reports the age specific sexual composition from samples in the Chesapeake Bay in the fall of 1976.

Age	*1*	*2*	*3*	*4*
Male proportion of the stock	0.5	0.44	0.53	0.43

He notes that the changes in sexual composition with age are due to the combined influence of female migration and spring fishing pressure which is far heavier on males than on females. See also section 3.51 for sex of coastal migrants.

4.12 Age composition

Maine waters were dominated by the 1961 year class during 1964 and 1965 (4- and 5-yr-olds); numerous striped bass of the 1958 year class were also collected (Davis 1966). Schaefer (1968a) sampled the south shore of Long Island, N.Y., with a commercial seine in 1962 and 1963. The 1958 year class (4-yr-olds) dominated in 1962 and comprised ≈60% of the catch (age range 2-15 yr). This year class was abundant as 5-yr-olds in 1963; however, by October and November the 1958 year class was being replaced as the dominant group by the 1961 year class. Two-year-old fish comprised over 40% of the catch in 1963. The commercial catch of Long Island and New England was dominated by 2-yr-olds in 1936 (85% of the catch) and 2- and 3-yr-olds in 1937 (Merriman 1941).

Tiller (1950) examined the age composition of striped bass from commercial pound net catches in Chesapeake Bay from 1941 to 1945. The 1940 year class, which entered the fishery in the fall of 1941, dominated catches during 1942-43, and comprised a significant portion of the 1944-45 harvest. The 1942 year class, though not as large as the 1940 year class, significantly contributed to the catch during fall of 1943 and 1944, but was almost completely utilized by 1945. Sport fishermen caught predominantly 2- (47.7-85.3%) and 3-yr-olds in the Potomac River, Md., during 1959-61 (Frisbie and Ritchie 1963), and 2-yr-olds in the Patuxent River during 1960 (Shearer et al. 1962).

Age composition of the commercial catch of striped bass from Potomac River, 1974-76, is summarized below (Jones et al. footnote 17).

Year	*Age range*	*Dominant ages*
1974	II-XIV	IV-59.75%; III-V-85.19%
1975	II-XIII	V-75.09%; III-V-96.56%
1976	II-XIV	VI-54.91%; III-VI-95.40%

The dominance of the 1970 year class (also section 4.11) is apparent.

Grant and Joseph (1969) determined age composition of sport and commercial catches from the Rappahannock, York, and James Rivers, Va., during June 1967-March 1968. The 1965 year class dominated the James River catch during this period whereas the 1966 year class dominated the Rappahannock and the York River catch. Striped bass of age groups I-III dominated the pound and fyke net catch (nonselective gear) from these three rivers during July 1967-June 1971 comprising 84.3-99.4% of the total catch (Grant 1974). The 1966 year class dominated the 1969 and the 1970 winter gill net fishery in the Rappahannock River. An approximate tripling of landings in 1970 resulted from selection for the dominant 1966 year class (Grant et al. 1971).

Table 16 summarizes striped bass age composition of

Table 16.—Total number and percent of sample by age group of striped bass from the Albermarle Sound (North Carolina) commercial fishery, 1975-76. From Johnson et al. 1977[1].

	Number		Percent of sample	
Age	1975	1976	1975	1976
II	60	28	17	4
III	73	295	21	43
IV	88	109	26	16
V	87	162	25	24
VI	18	64	5	9
VII	10	13	3	2
VIII	6	10	2	1.5
IX	2	1	1	<1
X		1		<1
XI	1		<1	
Total	345	683		

[1] Johnson, H. B., B. F. Holland, Jr., and S. G. Keefe. 1977. Anadromous fisheries research program, northern coastal area. N.C. Div. Mar. Fish., Completion Rep., Proj. AFCS-11, 97 + 41 p. Available from U.S. Department of Commerce, NOAA, NMFS, Federal Office Building, 144 First Street, South, St. Petersburg, FL 33701.

the Albemarle Sound, N.C., commercial fishery during 1975-76. Two- to five-year-old striped bass comprised 89% of the catch during 1975, and 3- to 6-yr-old fish, 92% of the catch during 1976. Table 17 summarizes mean age and length of striped bass caught in the Albemarle Sound recreational fishery during 1974-75. The dominance of the 1972 year class is seen by the dominance of 2-yr-olds in 1974 (37%) and 3-yr-olds in 1975 (46%). Three- to four-year-old males and 4- to 5-yr-old females dominated the Roanoke River, N.C., gill net catches during springs of 1963-65 (Trent and Hassler 1968).

Table 17.—Total number, percent of sample, and mean fork length by age of striped bass from Albemarle Sound (North Carolina) recreational fishery sampled during the Elizabeth City Striped Bass Tournament, 1974-75. From Johnson et al. 1977[1].

	Number		Percent of sample		Mean fork length (mm)	
Age	1974	1975	1974	1975	1974	1975
II	54	12	37	7	315	290
III	43	85	30	46	301	329
IV	38	39	26	21	484	396
V	8	25	6	13	544	509
VI	1	24	1	13	695	578
VII	1	1	1	<1	720	655
	145	186				

[1]Johnson, H. B., B. F. Holland, Jr., and S. G. Keefe. 1977. Anadromous fisheries research program, northern coastal area. N.C. Div. Mar. Fish., Completion Rep., Proj. AFCS-11, 97 + 41 p. Available from U.S. Department of Commerce, NOAA, NMFS, Federal Office Building, 144 First Street, South, St. Petersburg, FL 33701.

Three-year-old striped bass dominated the sport fishery in the Sacramento-San Joaquin Delta, Calif., during 1957-58 (Robinson 1960).

4.13 Size composition

Length-frequency distributions are given by Scofield (1931), Merriman (1941), Tiller (1950), Morgan and Gerlach (1950), Vladykov and Wallace (1952), Trent and Hassler (1968), Schaefer (1968a), and others.

See section 3.43 for length composition of the population; Tables 14, 16, and 17 for the length composition of the catch from various locations; Tables 16 and 17 and section 5.42 for size at first capture; section 3.12 for size at maturity; section 3.31 for maximum size; and Table 15 for length-weight relationships.

4.2 Abundance and density (of population)

4.21 Average abundance

Since the main river systems along the Atlantic coast from the St. Lawrence River, Quebec, to the St. Johns River, Fla., along the Gulf coast from Apalachicola Bay, Fla., to Lake Pontchartrain, La., and along the Pacific coast from California to Washington support their own striped bass populations, it is impossible to obtain an overall estimate of population size. The term "average abundance" is a relative term which depends upon the locality and time of the year under consideration, migratory patterns which are not necessarily identical from year to year, year class success, and numerous other factors.

Acoustic surveys of the Potomac River spawning grounds were conducted during 1974 (Zankel et al.[42]). Analysis of only the large acoustic targets resulted in the distribution of adult fish >40 cm TL. That these fish were only striped bass was corroborated by concurrent, twice-weekly gill net collections of Jones et al. (footnote 17). During the spawning peak an abundance of 1 million adults, which centered around Douglas Point, river kilometer 116, was obtained. Acoustic surveys 2 wk later indicated an abundance of 0.5 million adult striped bass, centered upriver between Indian Head, river kilometer 139, and Hallowing Point, river kilometer 144.

Estimates of adult striped bass abundance for the Sacramento-San Joaquin Estuary, Calif., based on catch records for 1958-72 ranged from 86,020 in 1971 to 322,250 in 1961 (Stevens 1977a). Biases which affect this population index were discussed by the author. Stevens (1977b) estimated the following abundance of various age classes for 1969 and 1972 with the Peterson mark-recapture method:

Age	*No. in 1969*	*No. in 1972*
3	5,000,000	600,000
4	200,000	190,000
5	100,000	150,000
6	80,000	50,000
7	30,000	40,000

4.22 Changes in abundance

Raney (1952) reviewed available literature on changes in striped bass abundance since colonial days. He (1952:67) concluded that "the general trend in abundance of striped bass for the past 150 years has been one of gradual decline broken only by periods of abundance due to the production and survival of occasional large year-classes." Koo (1970) gave a detailed analysis of the Atlantic coast striped bass fishery from 1930 through 1966. During that period catches increased ninefold from a low of 1 million pounds in 1934. Koo (1970:89) concluded "that the gradual long-term rising trend in striped bass landings along the Atlantic (exclusive of North Carolina) since the early 1930's is due mainly to an increase of abundance of fish." However, the catch has declined in recent years. This decline is reflected in the catch per unit effort (100 m^2 of net fished for 24 h) of experimental gill nets fished on the Potomac River from 1974 to 1977. Catch per unit effort of the 114 and 152 mm mesh nets was: 8.149 in 1974; 4.270 in 1975; 1.850 in 1976; 0.543 in 1977 (Jones[43]).

[42]Zankel, K. L., L. H. Bongers, T. T. Polgar, W. A. Richkus, and R. E. Thorne. 1975. Size and distribution of the 1974 striped bass spawning stock in the Potomac River. Ref. No. PRFP 75-1. Martin Marietta Corp., Environmental Center, 1450 S. Rolling Road, Baltimore, MD 21227.

Reduction in young-of-the-year abundance as the season progresses (Rathjen and Miller 1957; Trent 1962) has been attributed to three factors: mortality (primary), dispersion out of the sampling area, and gear-selectivity. Sasaki (1966) described downstream migrations of young-of-the-year and juvenile striped bass from the Sacramento-San Joaquin Delta. Turner and Chadwick (1972) demonstrated that survival of striped bass up to 38 mm was directly related to summer river flow through the delta. See section 4.33 for a discussion of losses of young-of-the-year striped bass through water diversions in the delta.

4.23 Average density

The term "average density" is a relative term which depends upon locality and time of year under consideration, year class success, migratory patterns, and numerous other factors. Egg and larval densities for the Hudson River are given in the papers by Lawler et al. (1974), Texas Instruments (footnote 14), and Lauer et al. (1974); Chesapeake and Delaware Canal by Kernehan et al. (footnotes 24, 11); Potomac River by Mihursky et al. (footnote 6) and Boynton et al. (footnote 13); Sacramento-San Joaquin Estuary by Turner (1976). Juvenile densities from the Hudson River are available in the papers by Lawler et al. (1974) and Texas Instruments (footnote 10); Potomac River by Boynton et al. (footnote 13) and Mihursky et al. (footnote 6); James, York, and Rappahannock Rivers by Grant and Merriner[44] and and Merriner and Hoagman (footnote 8); Albemarle Sound by Trent (1962); Sacramento-San Joaquin Estuary by Calhoun (1953), Chadwick (1964), Sasaki (1966), and Turner and Chadwick (1972).

4.24 Changes in density

Vertical distribution of striped bass larvae and juveniles is discussed in section 2.21.

4.3 Natality and recruitment

4.31 Reproduction rates

The intensive quantitative ichthyoplankton studies that have been undertaken in recent years have enabled estimates of striped bass egg and larval production to be made with varying degrees of accuracy and precision. Striped bass egg, yolk sac, finfold and postfinfold larval densities and estimates of abundance and production from the Potomac River for the years 1974 through 1976 have been given in the following papers: 1974—Mihursky et al. (footnote 23), Polgar et al. (1976); 1975—Mihursky et al. (footnote 6); 1976—Boynton et al. (footnote 13), and are summarized in Table 18. These production estimates assumed uniform age distribution for the egg and larval stages. One consequence of this assumption is that production is likely to be underestimated due to the short mean life expectancy of each stage. This has led to the development of two production models assuming an exponential age distribution of each stage (Polgar 1977). Estimates of striped bass egg production on the Potomac River during 1974 ranged from 5.71×10^9 (Polgar 1977) and 8.11×10^9 (Table 17), both based on an arithmetic model with uniform age distribution, to 26.9×10^9 (exponential age distribution). A concurrent study of the adult swimming population indicated a potential egg production of 73×10^9.

Table 18.—Estimated striped bass production from the Potomac River (Maryland) calculated from an arithmetic model assuming uniform age distribution for egg and larval stages. From Boynton et al. (1977).[1]

	1974	1975	1976
Eggs	8106.71×10^6	1159.33×10^6	885.03×10^6
% mortality	99.20	[2]63.62	92.99
Yolk-sac larvae	74.71×10^6	421.69×10^6	62.07×10^6
% mortality	96.15	94.02	81.70
Finfold larvae	2.49×10^6	26.87×10^6	11.36×10^6
% mortality	81.65	80.59	93.94
Postfinfold larvae	0.46×10^6	4.69×10^6	0.73×10^6

[1]Boynton, W. R., E. M. Setzler, K. V. Wood, H. H. Zion, and M. Homer. 1977. Draft report on Potomac River fisheries study; ichthyoplankton and juvenile investigations. Univ. Md. CEES Ref. No. 77-169-CBL. Chesapeake Biological Laboratory, Solomons, MD 20688.

[2]Sampling (once per week) missed peak spawn.

Hassler[45] made quantitative estimates of striped bass spawning in the Tar River, N.C., for 1967-69. As estimated 17×10^7 eggs were spawned in 1967, 2.8×10^7 in 1968, and 0.1×10^7 in 1969. Egg vitality declined from 85% in 1967 and 1968 to 58% in 1969.

4.32 Factors affecting reproduction

Van Cleve (1945) in California and Hassler (1958) in the Roanoke River, N.C., suggested water flow (both velocity and volume) to be very important in developing successful spawns. Hassler suggested that the number of spawning striped bass in the Roanoke River was directly related to river flow. High and regular flows resulted in the most successful spawns.

In addition to water flow, colder than normal winter temperatures have been associated with successful striped bass spawns. Heinle et al. (1976) related the pulsed input of detritus in the late winter in an upper Patuxent River, Md., marsh to the production of the estuarine copepod, *Eurytemora affinis*, and suggested that the enrichment of the detritus food chain was directly

[43]P. W. Jones, Chesapeake Biological Laboratory, Solomons, MD 20688, pers. commun. February 1978.

[44]Grant, S. C., and J. V. Merriner. 1971. Feasibility of increasing striped bass populations by stocking underutilized nursery grounds. Anadromous Fish Act, Annu. Prog. Rep., AFS-6-1, 89 p. Virginia Institute of Marine Science, Gloucester Point, VA 23062.

[45]Hassler, W. W. 1970. The status, abundance, and exploitation of striped bass (*Roccus saxatilis*) in Roanoke River and Albemarle Sound, North Carolina. N.C. State Univ., Zool. Dep., Completion Rep. Proj. AFC-1, 63 p.

related to the severity of the winter. Heinle and Flemer (1975) hypothesized a relatively simple food chain in the upper Patuxent River during April and May consisting of detritus, *E. affinis, Neomysis americana,* and anadromous fish larvae. They attributed the increased mortality rate and observed population decline of *E. affinis* in the Patuxent River during April and May to predation. Heinle et al. (1976) noted that *E. affinis* production in the Patuxent River was about 4.5 times greater during a spring (1970) that led to a strong year class of striped bass than during one (1969) that did not. Merriman (1941) observed that the occurrence of strong year classes of striped bass was related to low water temperatures. Strong year classes occurred only (but not always) after severe winters; mild winters never produced a strong year class. Koo (1970) identified the dominant year classes between 1934 and 1964 in the Chesapeake region and proposed a 6-yr cycle with three unexpectedly low year classes: 1946, 1952, and possibly 1928. Using data from Merriman (1941) and Koo (1970), Heinle et al. (1976) summarized the deviations from long-term mean temperatures during the years from 1892 to 1970 when dominant year classes were observed or expected. During this time strong year classes of striped bass were always associated with subnormal winter temperatures. Boynton et al. (footnote 13) demonstrated that dominant year classes of striped bass of the Potomac River were preceded by colder than normal winters and greater than normal spring flows.

In the California Delta large year classes of striped bass result from years of high river flow. Turner and Chadwick (1972) demonstrated that in the Sacramento-San Joaquin System survival of young striped bass up to 3.8 cm TL (first 2 mo of life) is related to summer river flow through the delta, which controls the transport of young bass to suitable nursery areas. Stevens (1977a) and Chadwick et al. (1977) have shown that these flows impact recruitment to the sport fishery several years later and are largely responsible for population abundance fluctuations (for further discussion of this topic see section 4.33 of this review).

4.33 Recruitment

Attempts at forecasting recruitment have used the following indices as a basis for a forecast: a) beach seining for young-of-the-year fish, b) age and size composition analysis, and c) winter trawl sampling for the young-of-the-year.

Schaefer (1972) developed a short-range forecast for striped bass fishing in New York waters. To obtain catch projections, he plotted the New York harvest versus the average 4-yr brood production from Maryland waters of the Chesapeake Bay 3-6 yr prior to the harvest (Fig. 9). Thus, if the average brood stock index for a 3-yr period 3-6 yr prior to a harvest date was 10 fish/seine haul, Schaefer's model would predict a commercial harvest of 45,360 kg. While this method is somewhat attractive, the mechanism is not stated and could be misleading if other factors, not in the model, change. For instance,

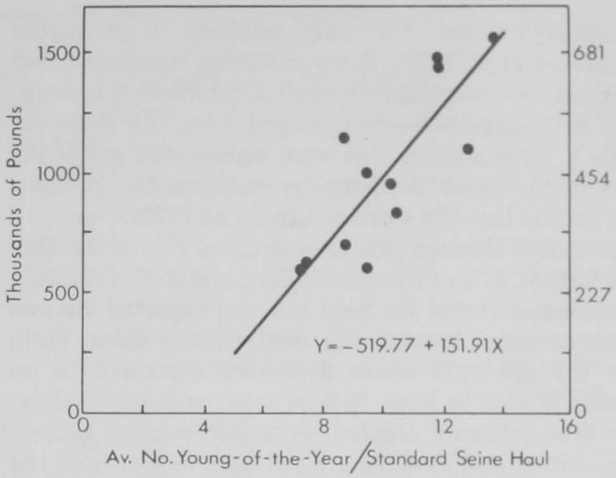

Figure 9.—Relationship of New York commercial landings of striped bass to average brood production in the Maryland waters of Chesapeake Bay 3-6 yr prior to harvest. From Schaefer (1972); r = 0.85.

Briggs (1965) reported a large increase in Long Island, N.Y., fishing effort that did not appear to be related to larger bass stocks. Social factors, such as demand for recreation, seemed more important than the size of the stock.

Modal length of sublegal II+ striped bass collected in the Long Island, N.Y., commercial fishery during 1972 (1970 year class) was smaller, 245 mm FL, than in 1974 (1972 year class), 295 mm FL (Austin and Hickey 1978). The 1970 year class was the most abundant Chesapeake Bay year class on record (Schaefer 1972). Correlation analysis between eight annual modal lengths of age II+ fish and their respective Chesapeake Bay year class strengths 2 yr earlier (number of juveniles per seine haul) indicated that 90% of the annual variation in modal lengths of age II+ striped bass in New York waters could be explained by annual fluctuations in year class strength of striped bass from Maryland waters of Chesapeake Bay 2 yr earlier. Correlation analyses between New York striped bass landings and a 4-yr and a 5-yr mean of computed modal lengths of age II+ fish 1-4 yr and 1-5 yr prior to harvest were highly significant: 1-4 yr, r^2 = 0.74; 1-5 yr, r^2 = 0.69. Austin and Hickey noted that striped bass apparently migrate by size rather than by age. During 1972, 100% of the 454 sublegal fish tagged were age II; whereas in 1974, 28% of 696 sublegal fish tagged were age II, 65% age III, and 7% age IV.

Studies in the San Joaquin Delta, Calif., have ascertained that the success of a striped bass year class is determined within the first 2 mo of life (Chadwick et al. 1977). Abundance indices based on the number of surviving juvenile striped bass when the population mean length reaches 38 mm have been developed (Chadwick 1964; Turner and Chadwick 1972; Stevens 1977b). Turner and Chadwick (1972) reported correlation coefficients of +0.889 and −0.904 between this juvenile index, mean daily June-July delta outflow, and mean percent of June-July inflow diverted for local consumption and export. Similarly, about 70% of the variation of the 1956-71 abundance indices for age II striped bass was correlated to the June-July outflows 3 yr earlier (Chadwick et al. 1977). Stevens (1977a) concluded that delta outflow controlled the spatial distribution and survival of young-of-the-year striped bass. As flows increased, more striped bass were transported out of the delta to the larger downstream embayments, particularly Suisan Bay (Turner and Chadwick 1972).

From 1959 through 1970 an average of 25% of the May delta inflow, 51% of the June inflow, and 65% of the July inflow was diverted for local use and exported via two large pumping plants in the southwestern delta. From 1971 through 1976 water diversions increased to an average of 41% in May, 59% in June, and 69% in July. The flow patterns created by water exports subject many larval and juvenile striped bass to loss from the delta region. Although fish screens have been installed at the pumping plant intakes, there are still substantial losses to the young-of-the-year population. For example, Skinner (1974) estimated that 31% of the striped bass approaching the state pumping plant in 1970 were exported from the delta. Chadwick et al. (1977) concluded that density-independent processes, particularly mortality due to losses in water diversions from the delta, play a major role in controlling the size of the striped bass population.

Density independence of a successful year class: Years of higher river flow in the California Delta resulted in large year classes. However, virtually all the eggs produced in the early and midportion of the spawning season, in these years of high river flow, are swept into the lower bays of the delta where survival is extremely low. The midsummer size distribution of the young-of-the-year fish indicates that these striped bass were produced from a small fraction of late spawning fish (Chadwick 1974). Likewise in the Potomac River, most of the 1974 striped bass larval production was attributed to spawning activities during the latter portion of the season (Polgar et al. footnote 16). Such results would seem to indicate that the production of a successful year class is a density-independent phenomenon, a conclusion first alluded to by Vladykov and Wallace (1952).

4.4 Mortality and morbidity

4.41 Mortality rates

Also see sections 4.31, 4.32, and 4.5.

Mortality rate estimates of various striped bass populations are given in Table 19. Mortality rates for the California population were calculated from disk-dangler tag returns. Mortality rates for the Virginia rivers were based on internal anchor tag returns; North Carolina rates were based on Floy dart tag returns.

Several studies have evaluated tags suitable for striped bass population dynamics investigations. Chadwick (1963) evaluated disk-dangler, spaghetti, hydrostatic, dart, and streamer tags. Although no tag was completely successful, disk-dangler and hydrostatic tags produced the most satisfactory results. Subsequent California studies (Chadwick 1968; Sommani 1972; Miller 1974) have used disk-dangler tags. Lewis (1961) compared Petersen disk, nylon streamer, and jaw ring tags. Streamer and jaw ring tags were equally suitable; streamer tags were chosen because they were easier to obtain. Streamer tags were the most satisfactory of the three tags (streamer, Petersen, and spaghetti) tested by Davis (1959). Miller (1974) discussed the biases inherent in estimating population parameters from mark-recapture data.

Street et al.[46] estimated a total annual mortality of 51% for striped bass age 3 through 6 yr in Albemarle Sound, N.C., from 1972 through 1974. However, total annual mortalities apparently decreased to 33% in 1975 and 25% in 1976 (Johnson et al.[47]). Holland and Yelverton (1973) projected a mean monthly fishing mortality rate of 3.6% to an annual harvest rate of 35% for striped bass tagged in the ocean off North Carolina and recaptured from North Carolina to Maine.

Sykes et al. (footnote 41) concluded that about 40% of the available striped bass were taken in the Potomac River, Md., spring fishery. This left approximately 60% for the recreational fishery and recruitment in brood stock. Kohlenstein (1978) estimated a 35% mortality of 3-yr-old males from the Chesapeake Bay spring commercial fishery.

Saila and Lorda (1977: 320) summarized the following survival probability from studies of the Hudson River, N.Y., striped bass population:

Age class and life stage	*Duration (days)*	*Probability of survival through life stage or age class*
0		
Eggs and yolk-sac	10	0.06
Postyolk-sac	24	0.04
Juvenile 1	30	0.20
Juvenile 2	145	0.51
Juvenile 3	156	0.16
Total	365	
I	365	0.40
II	365	0.60

4.42 Factors causing or affecting mortality

See sections 3.22, 3.23, 3.32, 3.34, 4.32, 4.5, 5.4, and 6.1.

Striped bass apparently migrate by size rather than by age (section 3.51). Austin and Hickey (1968) concluded that faster growing individuals of any given year class or larger individuals of a less abundant year class would be subject to earlier exploitation in Chesapeake Bay and along the Atlantic seaboard. Slower growing

[46]Street, M. W., P. P. Potts, Jr., B. F. Holland, Jr., and A. B. Powell. 1975. Anadromous fisheries research program, north coastal region. N.C. Div. Mar. Fish., Completion Rep., Proj. AFCS-8, 173 + 62 p.

[47]Johnson, H. B., B. F. Holland, Jr., and S. G. Keefe. 1977. Anadromous fisheries research program, northern coastal area. N.C. Div. Mar. Fish., Completion Rep., Proj. AFCS-11, 97 + 41 p.

Table 19.—Survival and mortality rate estimates of various striped bass populations.

Area	Year	Survival rate		Exploitation rate		Expectation of death from natural causes		Instantaneous mortality rate: Total		Instantaneous mortality rate: Fishing		Instantaneous mortality rate: Natural		Author
Virginia:	1963	[1]0.33	[2]—					[1]0.66	[2]—					
York River[1]	1966	0.04	0.02					0.96						Grant and Merrimer 1971[3]
Rapphannock River[2]	1967	0.02	0.01					0.98						
	1970	0.07	0.14					0.93						Merriner and
	1971	0.02	0.15					0.98						Hoagman 1973[4]
North Carolina:	1966			0.260										Hassler et al. 1965[5]
Roanoke River	1967			0.245										Hassler et al. 1966[6]
North Carolina	1972							0.278		0.036		0.243		Holland and Yelverton 1973
California	1958	[7]0.319	[8]0.316	[7]0.372	[8]0.372	[7]0.309	[8]0.312	[7]1.14	[8]1.15	[7]0.62	[8]0.63	[7]0.52	[8]0.53	Chadwick 1968[7]
	1959	0.534	0.535	0.247	0.255	0.219	0.210	0.63	0.63	0.33	0.34	0.30	0.28	Sommani 1972[8]
	1960	0.601	0.590	0.243	0.253	0.156	0.157	0.51	0.53	0.31	0.33	0.20	0.20	
	1961	0.662	0.672	0.190	0.202	0.148	0.126	0.41	0.40	0.23	0.25	0.18	0.15	
	1962	0.592	0.675	0.200	0.200	0.208	0.126	0.52	0.39	0.25	0.24	0.27	0.15	
	1963	0.511	0.632	0.281	0.246	0.208	0.122	0.67	0.46	0.39	0.31	0.28	0.15	
	1964	0.577	0.705	0.235	0.167	0.208	0.128	0.67	0.35	0.36	0.20	0.31	0.15	
	1965	[9]0.655	0.664	[9]0.142	0.136	[9]0.203	0.200	[9]0.42	0.41	[9]0.17	0.17	[9]0.25	0.24	Miller 1974[9]
	1966	0.628	0.678	0.179	0.176	0.193	0.147	0.46	0.39	0.22	0.21	0.24	0.18	
	1967	0.647	0.703	0.160	0.148	0.193	0.149	0.44	0.35	0.20	0.18	0.24	0.18	
	1968	0.687	0.750	0.120	0.096	0.193	0.154	0.37	0.29	0.14	0.11	0.23	0.18	
	1969	0.614		0.193		0.193		0.49		0.24		0.25		
	1970	0.688		0.119		0.193		0.37		0.14		0.23		
	1971	0.660		0.147		0.193		0.41		0.18		0.32		

[1]Chadwick (1968) ratio of 1962 to 1961 returns used as estimate of 1961 survival; annual expectation of deaths from natural causes from 1962-1964 equal to 1958-1961 mean.

[2]Miller (1974) assumed expectation of natural death was equal to mean for 1959, 1960, and 1965.

[3]Grant, G. C., and J. V. Merriner. 1971. Feasibility of increasing striped bass populations by stocking of underutilized nursery grounds. Anadromous Fish Proj., Annu. Prog. Rep., AFS-6-1, 89 p. Virginia Institute of Marine Science, Gloucester Point, VA 23062.

[4]Merriner, J. V., and W. J. Hoagman. 1973. Feasibility of increasing striped bass populations by stocking of underutilized nursery grounds. Va. Comm. Game Inland Fish., Annu. Prog. Rep., AFS-06-02, 66 p.

[5]Hassler, W. W., W. L. Trent, and B. J. Florence. 1966. The status and abundance of the striped bass in the Roanoke River, North Carolina for 1965. Report to the North Carolina Department of Conservation and Development, Division of Commercial and Sport Fisheries, Raleigh, N.C., 52 p. (Mimeo.)

[6]Hassler, W. W., W. T. Hogarth, and H. L. Liner III. 1967. The status and abundance of the striped bass in the Roanoke River, North Carolina for 1966. Report to the North Carolina Department of Conservation and Development, Division of Commercial and Sport Fisheries, Raleigh, N.C., 53 p. (Mimeo.)

[7]Chadwick 1968.

[8]Sommani 1972.

[9]Miller 1974.

fish or smaller fish from a dominant year class might be recruited several months later than normal in the Chesapeake and not perhaps until a full year later in northern Atlantic states. Thus, late recruitment in the Chesapeake could result in a greater availability of striped bass to other coastal states.

4.43 Factors affecting morbidity

See section 3.35.

4.5 Dynamics of population

Numerous models have been developed to evaluate the impact of power plant operations on populations of commercially and recreationally important fish species spawning upriver or in the neighborhood of a power plant. Swartzman et al. (1977) evaluated the following seven models which simulate the entrainment of striped bass eggs and larvae through the cooling systems of power plants:

Hudson River Striped Bass Models (Bowline, Indian Point, and Roseton Power Stations).

1. 1972 Lowler, Matusky and Skelly Engineers (LMS) model with no longitudinal segmentation or vertical stratification of the Hudson River.
2. 1972 LMS model with longitudinal segmentation but no vertical stratification of the Hudson River.
3. 1973 Oak Ridge National Laboratory (ORNL) model with longitudinal segmentation but no vertical stratification of the Hudson River.
4. 1975 LMS model with both longitudinal segmentation and vertical stratification of the Hudson River.

Chesapeake and Delaware (C & D) Canal Striped Bass Models (Summit Nuclear Power Station).

5. United Engineers & Constructors model.
6. ORNL model.
7. Johns Hopkins University model.

Major differences in biological assumptions in the striped bass young-of-the-year models were the choice of life stage durations and the inclusion of compensatory mortality at both high and low fish densities.

Six of the models reviewed by Swartzman et al. (1977) included a life cycle model, in the form of a modified Leslie matrix, to translate the effect of power plant mortality into a long-term impact on the adult population and fishery. Major differences in predictions of yield and population from these models resulted from using density-dependent versus density-independent fishing mortality and from using different values for the probability of natural survival of 1- to 3-yr-old fish. The interested reader is referred to Swartzman et al. (1977) for further detail.

Saila and Lorda (1977) utilized a Leslie matrix model to conduct a sensitivity analysis of the effects of changes in the survival rates of five striped bass young-of-the-year life stages due to entrainment and impingement, on the short-term dynamics of the population.

Durations of young-of-the-year life stages were: eggs and yolk-sac, 10 days; postyolk-sac, 24 days; juvenile 1, 30 days; juvenile 2, 145 days; and juvenile 3, 156 days. Sensitivity analysis results by Saila and Lorda (1977: 331) included:

"3. If only one of the five life stages in age class 0 is subjected to increased mortality, the population seems capable of tolerating losses up to 20% before being reduced to about 50% of its initial size in 20 years.

"4. If each of the five life stages in age class 0 is subjected to increased mortality, the percent loss per life stage must be less than 5% in order to not have the size of the adult population reduced by 50% or more in 20 years.

"5. Any reduction in the fishing mortality in one or several of the age classes 3 to 20 will permit a higher tolerance for additional mortality in the y-o-y [young-of-the-year] life stages."

Several models of early life history stages of Potomac River striped bass populations have been formulated. Warsh[48] modeled entrainment of striped bass eggs and larvae by a proposed power plant at Douglas Point. He predicted that the proposed plant, operating at an intake rate of 2.3 cm during the spawning season would probably destroy about 0.6% of the spawn in an average year, about 1% of the spawn in a bad year, and most probably no more than 1.2% of the spawn even if serious errors were made in the selection of values for model parameters.

Polgar (1977) developed two models with an exponential age distribution with each early life history stage (eggs, yolk-sac, finfold, and postfinfold larvae) which allowed estimation of mortality rates within each stage. One model used a uniform age distribution model to obtain an independent estimate for one of the mortality rates and "guesstimated" remaining mortality rates. The second model assumed an equal mortality rate in the finfold and postfinfold stages. Both models assumed constant mortality rates within each early life history stage.

A major difficulty in the derivation of any model which attempts to calculate mortality rates is the limitation imposed by the state-of-the-art sampling design for the population in question. Thus, it is simplistic to assume that mortality rates are constant over the duration of the striped bass spawning season on the Potomac River. Additionally, mortality rates are probably dependent upon position within the river (upstream versus downstream) and possibly upon horizontal distribution across the river (channel versus shoal areas). Superimposed upon the differential mortality question are the effects of possible diurnal-spawning activity on egg production estimates, the unrealistic assumption of constant developmental times for the yolk-sac, finfold, and postfinfold stages, and the complex physical transport processes that continually redistribute ichthyoplankton. Such problems warrant attempts at resolution before more realistic production models can be formulated.

Chadwick (1969) developed a mathematical equilibrium model for San Francisco Bay stocks. From the modeling effort Chadwick reported that recruitment was not closely related to the parent stock size. Highest recruitment was found to be at stock sizes slightly less than the equilibrium size (equilibrium size is that size of stock where recruitment equals parent stock).

4.6 The population in the community and the ecosystem

See also sections 2.1, 2.2, 2.3, 3.16, 3.22, 3.23, 3.32, 3.35, 3.42, 3.51, 4.12, 4.13, and 4.32.

Species composition and seasonal abundance of communities associated with striped bass have been reported for the surf zone (Schaefer 1967); Hudson River estuary (Texas Instruments footnotes 10, 14); Delaware River estuary (Smith 1971; de Sylva et al. 1962); Chesapeake and Delaware Canal (Bason et al. footnotes 28, 27); Potomac River (Mihursky et al. footnote 6; Boynton et al. footnote 13); North Carolina coastal waters (Holland and Yelverton 1973); and the Sacramento-San Joaquin Estuary (Turner and Kelly 1966).

5 EXPLOITATION

Historical perspectives

The striped bass is mentioned early in American literature, undoubtedly due to its great abundance and availability to the early colonists. Captain John Smith

[48]Warsh, K. L. 1977. Final summary of estimates of the entrainment rate of spawn of the striped bass (*Morone saxatilis*) into the proposed power plant at Douglas Point. SHU, PPSE-T-2. Prepared for the State of Maryland Power Plant Siting Program by the Johns Hopkins University, Applied Physics Laboratory, Johns Hopkins Road, Laurel, MD 20810.

wrote: "The Basse is an excellent fish, both fresh & salte . . . . They are so large, the head of one will give a good eater a dinner, & for daintinesse of diet they excell the Marybones of Beefe. There are such multitudes that I have seene stopped in the river close adjoining to my house with a sande at one tide as many as will loade a ship of 100 tonnes." (Jordan and Evermann 1902:374.)

William Wood in his New England's Prospect (1634:35) describes how to catch a really large bass: "The Basse is one of the best fishes in the countrey, . . . the way to catch them is with hooke and line: the fisherman taking a great cod-line, to which he fastneth a peece of lobster, and throwes it into the sea, the fish biting at it he pulls her to him, and knockes her on the head with a sticke . . . the English at the top of an high water do crosse the creekes with long seanes or Basse netts, which stop in the fish; and the water ebbing from hem they are left on the dry ground, sometimes two or three thousand at a set . . . ."

Striped bass were also caught and dried in great numbers by the Indians in New England (Fearing 1903). Striped bass and codfish were the first natural resources in Colonial America that were subject to conservation measures enacted by statute. In 1639, the General Court of the Massachusetts Bay Colony passed a law that neither fish could be sold as fertilizer. But the catch increased, and by 1776 New York and Massachusetts had passed laws prohibiting sales of these fish in winter months (Bayless 1964).

Another distinction shared by the striped bass was an act of the Plymouth Colony in 1670 that stated that all income accrued annually to the colony from the fisheries at Cape Cod for striped bass, mackerel, or herring be used for a free school in some town of the jurisdiction. As a result of this act the first public school of the New World was made possible through moneys derived in part from the sale of striped bass. A portion of this fund was also utilized in aiding the widows and orphans of men formerly engaged in the service of the colony (Pearson 1938).

Striped bass continued to be rather plentiful in Massachusetts Bay during the early 1800's, but by the middle of the 19th century the abundance there had declined markedly. The 1865-1907 catch records of the Cuttyhunk Club, a striped bass club located south of Cape Cod, Mass., showed a steady decline with some fluctuations (Merriman 1941). Jordan and Evermann (1902) noted that the striped bass, though still abundant, was less common and continuing to decrease. Raney (1952) summarized the overall declining trend in striped bass fisheries from the 1800's; a trend offset periodically with greatly increased catches from a dominant year class 2-3 yr earlier.

5.1 Fishing equipment

5.11 Gear

The commercial fishery employs a variety of gear including stationary and drift gill nets, haul seines, fyke nets, pound nets, fish traps, and hoop nets. Choice of gear depends upon geographical area and state regulations. In North Carolina, anchor gill nets, haul seines, and pound nets are popular in inland waters; haul seines are used along the outer banks. Anchored gill nets [monofilament gill nets are only legal in Virginia waters and the Potomac River (Merriner[49])] are now most effective in Chesapeake Bay and in the Chincoteague area; drift gill nets, pound nets, and haul seines are also utilized. Pound nets catch most stripers in New Jersey where it is illegal to fish exclusively for striped bass. The haul seine is the most productive gear in New York. Fish traps are the only legal gear in Rhode Island. In Massachusetts waters the largest catches are made with rod and reel (Nicholson and Lewis[50]).

Changes in striped bass fishing gear have been discussed by Scofield (1931), Raney (1952), Vladykov and Wallace (1952), and Koo (1970). Table 20 summarizes percentage of striped bass landings by gear type along the Atlantic coast.

5.12 Boats

Variety of small wooden vessels—usually <8 m (26 ft) in length. Many bay-built boats are utilized in Chesapeake Bay area.

[49] J. V. Merriner, Virginia Institute of Marine Science, Gloucester Point, VA 23062, pers. commun. March 1978.

[50] Nicholson, W. R., and R. M. Lewis. 1973. Briefing paper on the status of striped bass. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Atl. Estuarine Fish. Cent., Beaufort, N.C., 42 p.

Table 20.—Percentage of striped bass landings by state and by gear type along the Atlantic coast from 1962 to 1966. (From Koo 1970.)

	Maine	Rhode Island	New York	New Jersey	Delaware	Maryland	Virginia	North Carolina	Total
Handline	93.2	33.8	2.4	0.6	—	3.7	—	—	7.9
Floating trap	0.2	56.2	—	—	—	—	—	—	1.2
Pound net	6.0	—	3.5	2.2	—	6.1	30.3	20.3	13.1
Otter trawl	—	6.4	14.6	75.9	3.3	0.4	0.3	—	7.6
Haul seines	—	2.4	71.6	3.2	—	9.0	29.1	17.3	19.8
Fixed gill net	—	—	5.3	9.0	96.7	55.3	29.3	58.9	36.5
Drift and run-about gill net	—	—	2.6	6.0	—	25.4	3.5	0.7	11.9
Fyke net and other	0.6	1.2	—	3.1	—	0.1	7.5	2.8	2.0

5.2 Fishing areas

5.21 General geographical distribution

See section 2.1.

5.22 Geographic ranges

Also section 2.1. Areas of greatest abundance as determined by commercial landings per state are discussed in section 5.4.

Areas heavily fished for striped bass by recreational fishermen (Nicholson and Lewis footnote 50) include:

ATLANTIC COAST
- Florida
  - St. Johns River
- Georgia
  - Savannah River
  - Ogeechee River
  - Altamaha River
- North Carolina
  - Albemarle Sound and Tributaries
  - Pamlico Sound and Tributaries
  - Roanoke River
  - Outer Banks
  - Kerr Lake
- Virginia
  - Chesapeake Bay and Tributaries
- Maryland
  - Chesapeake Bay and Tributaries
- Delaware
  - Delaware Bay
  - Rehobeth Bay
  - Indian River
- South Carolina
  - Santee River
  - Cooper River
  - Lake Marion
  - Lake Moultrie
- New Jersey
  - Coastline
  - All major rivers and bays
- Connecticut, Rhode Island, Massachusetts
  - Coastline
  - All major rivers and bays
- New Hampshire, Maine
  - Most major rivers
- New Brunswick, Nova Scotia, Quebec
  - Coastal rivers north to St. Lawrence River

GULF COAST
- Alabama
  - Mobile Bay
  - Alabama Bay
- Florida
  - Rivers West of Apalachicola

PACIFIC COAST
- California
  - San Francisco Bay and Tributaries
- Oregon
  - Umpqua River
  - Coos Bay

5.23 Depth ranges

See section 2.3.

Striped bass are pelagic fish. Fishing depths depend upon geographical location and gear utilized.

5.24 Condition of the grounds

Pollution has forced the closure of commercial fisheries on the James River, Va.—Kepone, and the Hudson River, N.Y.—PCB's. Recreational fishermen are advised against consumption of their catch from these rivers. Water diversions for hydroelectric power generation have altered flow through spawning grounds on the Roanoke River, N.C. (Fish and McCoy 1959). Deterioration of spawning grounds as a result of poor water quality on the Delaware River, and dam construction on the Susquehanna River, was discussed in section 2.3. Water diversions for irrigation play a major role in determining the size of the striped bass population in the Sacramento-San Joaquin Estuary (Chadwick et al. 1977).

5.3 Fishing seasons

Seasons for the commercial striped bass fishery are summarized in Table 23 of section 6.1; seasons for the recreational striped bass fishery are summarized in Table 24 of section 6.1. Fishing off most Middle Atlantic and New England states is seasonal and directed by migrations of the fish.

5.4 Fishing operations and results

5.41 Effort and intensity

Commercial striped bass landing per unit effort by various gear types for the four Atlantic coast regions are summarized in Table 21. The state which landed the most striped bass in each of the four regions and the most important gear type or a combination of several important gears were used for this summary.

Entry of a dominant year class into the stock results in increased fishing effort. Dominant year classes represented in catches several years later were 1934 (Merriman 1941), 1940 (Tiller 1950), 1958 (Mansueti and Hollis 1963; Shearer et al. 1962), 1964 (increased landings by 1966, Koo 1970), and 1970 (Schaefer 1972).

5.42 Selectivity

Nonselective gear used to estimate age and length-frequency composition of various striped bass populations include pound nets (Tiller 1950), pound and fyke nets (Grant and Joseph 1969), and bow nets (Trent and Hassler 1968). Selective gear include gill nets, which select

Table 21.—Commercial striped bass catches per unit effort of various gear types from selected areas along the Atlantic coast. (Summarized from tabular data presented by Koo 1970)

Massachusetts — New England Region — Mean Massachusetts handline catches

Year	No. lines	No. hooks	Catch × 10^3 kg	Catch kg/1 hook
1947-49	638	793	26	32
1950-59	780	837	32	40
1960-66	1,967	2,352	178	74

1947-66 total catch by handlines = 1,644,300 kg, 90.8% of total landings by all gears.

New York — Middle Atlantic Region — Mean New York haul seine catches

Year	Length of nets	Catch 10^3 kg	Catch (kg)/100 m
1947-49	70,568	149	206
1950-59	49,025	187	638
1960-66	8,937	263	5,801

1947-66 total landings by haul seines = 4,155,611 kg, 76.8% of total landings by all gears.

Maryland — Chesapeake Region — Mean Maryland landings by pound nets, haul seines, fixed gill nets, and drift gill nets

	Pound nets		Haul seines			Drift gill nets			Fixed gill nets			
Year	No.	Catch 10^3 kg	Nets 10^2 m	Catch 10^3 kg	Equivalent pound net units[1,2]	Nets $m^2 \times 10^3$	Catch 10^3 kg	Equivalent pound net units[3]	Nets $m^2 \times 10^3$	Catch 10^3 kg	Equivalent pound net units[4]	Landings/fishing unit
1930-39	588	202	278	115	280	250	66	210	236	101	269	377
1940-49	581	315	650	218	655	481	125	405	685	243	780	412
1950-59	506	176	682	278	688	947	242	797	1,099	476	1,251	368
1960-66	266	121	438	262	442	660	440	555	1,509	887	1,718	578

1930-66 total landings by 4 gears = 36,625,478 kg, 98.0% of total landings by all gears.

North Carolina — South Atlantic Region — Mean North Carolina landings by pound nets, haul seines, and fixed gill nets.

	Pound nets		Haul seines			Fixed gill nets			
Year	No.	Catch 10^3 kg	Nets 10^2 m	Catch 10^3 kg	Equivalent pound net unit[5]	Nets $m^2 \times 10^3$	Catch 10^3 kg	Equivalent pound net units[6]	Landings/fishing unit
1950-59	1,282	134	467	57	750	625	129	1,304	96
1960-66	754	65	196	56	314	773	163	1,613	108

1950-66 total landings by 3 gear = 5,184,194 kg, 89.6% of total landings by all gears.

[1]Pound net arbitrarily chosen as basic fishing unit; other gears were converted into equivalent pound net units by comparison of mean catches between pound net and gear in question.
[2]91.44 m of haul seine = 0.922 pound net units.
[3]836.1 m^2 of drift gill nets = 0.703 pound net units.
[4]836.1 m^2 of fixed gill nets = 0.952 pound net units.
[5]91.44 m of haul seine = 1.469 pound net units.
[6]836.1 m^2 of fixed gill nets = 1.744 pound net units.

for size dependent upon mesh size utilized (Tiller 1950; Vladykov and Wallace 1952; Mansueti 1961; Trent and Hassler 1968; and others), and haul seines, which select for larger sized fish (Vladykov and Wallace 1952) and may make almost pure catches of a single year class (Tiller 1950). Sport fisheries are selective primarily due to seasonality of effort and schooling behavior of striped bass (Grant and Joseph 1969).

Trent and Hassler (1968) found the following linear relationship between gill net mesh size and mean length of male striped bass caught:

$$Y = 3.41\ X + 2.24 \text{ inches}$$

where Y = FL in inches
X = stretched mesh size in inches.

Their estimates of the most efficient mesh size for capturing various age groups of striped bass are presented below:

	Male		*Female*	
Age group	*$\bar{X}$ FL (cm)*	*Mesh size (cm)*	*$\bar{X}$ FL (cm)*	*Mesh size (cm)*
III	42	11	46	12
IV	46	12	51	13
V	50	13	54	14
VI	55	15	60	16

Mansueti (1961) demonstrated that the length-frequency distribution of aged II-IV striped bass was not identical for 7.6-10.1 cm and 10.1-12.7 cm stretched mesh (S.M.) gill net. Modal length of age II striped bass caught in the 7.6-10.1 cm S.M. gill net was 30.5 cm versus a modal length of 35.6 cm for fish caught in the 10.1-12.7 cm net. Modal length of age III striped bass were 39.4 and 40.6 cm for the 7.6-10.1 and the 10.1-12.7 cm nets, respectively. Data were too fragmentary for modal estimates of age group IV. Mansueti concluded that gill nets with 7.6-12.7 cm S.M. principally harvest age groups II and III.

Jones et al. (footnote 17) summarized mean lengths and weights of striped bass caught over a 3-yr period with various sized stretch mesh gill nets.

Mesh size (cm)	Male $\bar{X}$ *TL (mm)*	$\bar{X}$ *wt (kg)*	*Female* $\bar{X}$ *TL (mm)*	$\bar{X}$ *wt (kg)*
9.5	394	0.9	424	1.3
11.4	442	1.4	527	3.0
13.0	500	2.1	615	4.1
15.3	574	3.1	693	6.3
20.3	717	6.0	815	9.1

5.43 Catches

Table 22 summarizes commercial striped bass landings by state along the Atlantic coast. During the years 1963-73, Maryland and Virginia landings were between 48 and 68% of the total catch. See Koo (1970) for a detailed analysis of the catch from 1888 to 1966.

Commercial landings of striped bass from 1974 to 1977 are summarized below:

Year	*Maine-New York*[1]	*New York*	*New Jersey-North Carolina*[1]	*New Jersey*	*Total U.S. catch*[2]
			--------in metric tons--------		
1974	841	626	3,662	324	5,085
1975	[3]685	516	2,724	155	3,903
1976					2,648
1977					2,331

[1]McHugh 1977.
[2]U.S. Dep. Commer., NOAA, NMFS, 1974-78.
[3]Unavailable landings in New Hampshire, Connecticut, and Delaware = average of recent years.

Table 22.—Commercial striped bass landings by state (in thousands of kg).[1]

Year	New Hampshire	Maine	Rhode Island	Connecticut	New York	New Jersey	Delaware	Maryland	Virginia	North Carolina	Total
1930		12	27	1	30	17	46	557	193	207	1,090
1931		22	18	2	29	8	24	288	218	148	757
1932		14	3	2	15	5	4	197	269	230	739
1933		9	18	1	9	4	5	142	235		424
1934								151	141	164	456
1935		2	7		17	4	8	421	170		629
1936							12	845	236	348	1,442
1937		55	144	6	60	109	15	912	456	323	2,080
1938		37	95	4	63	67	11	777	524	237	1,816
1939		29	97	4	83	110	9	784	437	154	1,707
1940		34	29	4	77	78	19	535	299	245	1,320
1941								555	392		947
1942	4	44	43	8	121	43	27	1,138	353		1,780
1943	9	45	33	11	144	73	17				332
1944	5	87	55	8	229	117	18	1,216	845		2,579
1945	4	84	43	12	137	190	29	701	961	276	2,437
1946		73	98	9	219			733	945		2,077
1947	1	25	24	5	111	27	49	1,060	782		2,085
1948		35	29	5	161	19	164	1,202	1,112		2,727
1949		33	37	4	284	10	116	1,192	868		2,543
1950		21	51	3	235	49	123	1,378	1,268	362	3,490
1951		60	51	10	284	64	98	1,060	818	318	2,762
1952		57	23	5	220	243	54	985	563	293	2,445
1953		48	37	3	219	197	48	1,045	364	343	2,304
1954		31	53		199	23	66	956	431	509	2,268
1955		33	15		230	16	40	1,167	406	334	2,194
1956		32	12	<1	179	23	13	975	451	347	2,032
1957		25	10	<1	251	60	7	843	421	271	1,890
1958		23	19	1	181	27	10	1,408	597	497	2,763
1959		37	14	4	244	89	5	1,973	951	396	3,712
1960		59	35	2	332	52	11	2,000	1,033	355	3,878
1961		95	76	9	413	125	30	2,453	841	249	4,291
1962		267	28	15	298	224	49	1,805	882	339	3,906
1963		218	32	14	305	342	22	1,701	1,246	334	4,213
1964		237	34	16	451	452	14	1,497	857	324	3,881
1965	4	210	27		336	345	15	1,338	1,004	220	3,497
1966	4	265	113		476	143	29	1,518	1,271	296	4,116
1967	4	300	60		739	148	30	1,882	761	824	4,749
1968	5	396	44		685	27	22	2,056	732	867	4,835
1969	5	471	60		696	141	19	2,308	1,212	711	5,623
1970	6	610	38		607	101	24	1,804	808	1,051	5,051
1971	7	340	59		537	132	18	1,244	554	657	3,548
1972	7	533	140		379	169	112	1,465	1,206	572	4,584
1973	7	629	283		790	347	266	2,257	1,310	795	6,335
1974	2	571	152		639	324	96	1,589	1,163	461	4,997

[1]Fishery Statistics of the United States 1930-1974.

The distance of the commercial catch off United States shores from 1973 to 1977 is given below (U.S. Dep. Commer., NOAA, NMFS, 1974-78):

Year	*0-4 km*	*4-19 km*	*19-322 km*
	in thousands of kg		
1973	5,655	464	6.4
1974	4,628	444	13.6
1975	3,682	212	9.1
1976	2,566	79	2.7
1977	2,266	66 (4-322 km)	

Canadian commercial catches of striped bass were 9×10^3 kg in 1974, 7×10^3 kg in 1975, and 10×10^3 kg in 1976; Japanese commercial catches were 9×10^3 kg in 1974 and 22×10^3 kg in 1976 (FAO 1977:56).

In addition to commercial landings, recreational fishermen along the Atlantic coast caught an estimated 17×10^6 kg in 1960 (Clark [1963]), 25.7×10^6 kg in 1965 (Deuel and Clark 1968), and 33.2×10^6 kg in 1970 (Deuel 1973). Sport catches on the Pacific coast for the same 3 yr were estimated at 8.9, 6.4, and 4.7×10^6 kg/yr, respectively. Commercial fishing for striped bass on the Pacific coast is illegal in California and Washington.

The 1970 U.S. marine recreational catch by region is given below:

Region	*Catch* $\times 10^3$ *kg*
North Atlantic; Maine-New York	20,795
Middle Atlantic; New Jersey-Cape Hatteras	12,366
South Atlantic; Cape Hatteras-southern Florida	86
North Pacific; Point Conception, Calif.-Washington	4,757

Elser[51] estimated that the sport fishery catch of striped bass in the Chesapeake Bay during 1962 was $4,200 \times 10^3$ kg in comparison to a commerical catch of $1,800 \times 10^3$ kg (based on extrapolation of recreational catch from study area to the whole Maryland tidewater).

Kohlenstein (1978) estimated the Maryland recreational striped bass catch from the two major creel surveys in the Chesapeake Bay waters: 1962 by Elser (footnote 51) and 1976 by Speir et al.[52] His analysis indicated that the 1962 recreational fishery took approximately the same harvest by weight as the *reported* commercial landings. The 1976 recreational fishery was taking primarily the 1970 year class in the vicinity of the Chesapeake Bay bridge and much smaller fish in other study areas. The 1976 recreational catch in pounds was approximately one-third of the *reported* commercial landings; in numbers, approximately 60% of *reported* commercial landings.

[51]Elser, H. J. 1965. Chesapeake Bay Creel census, 1962. Univ. Md., Nat. Resour. Inst., Chesapeake Biol. Lab., Ref. No. 65, 26 p.

[52]Speir, H. J., D. R. Weinrich, and R. S. Early. 1977. 1976 Maryland Chesapeake Bay sport fishing survey. Maryland Department of Natural Resources, Fisheries Administration, Tawes State Office Building, Anapolis, MD 21401.

6 PROTECTION AND MANAGEMENT

6.1 Regulatory measures

6.11 Limitation or reduction of total catch

Table 23 summarizes regulations on commercial harvesting of striped bass in the United States; Table 24 summarizes regulations on the striped bass sport fishery in various states.

6.12 Protection of portions of population

See Tables 23 and 24.

6.2 Control or alteration of physical features of the environment

6.21 Regulation of flow

The Santee-Cooper Reservoir, S.C., was created by waters impounded through completion of the Pinopolis Dam on the Cooper River. Striped bass trapped in the reservoir plus those using the navigation lock at the Pinopolis Dam have established a successfully reproducing, landlocked population (Scruggs and Fuller 1955).

The effects of water flow on spawning success of Roanoke River, N.C., and California striped bass populations are discussed in section 4.32.

6.22 Control of water levels

Section 4.33 discusses diversion of Sacramento-San Joaquin Delta waters and its influence on year class success.

Striped bass are anadromous fish which utilize the upper portions of estuaries as nursery grounds. In many coastal areas more than 50% of the original marshland and other shallow areas important to striped bass have been altered or destroyed through dredging, filling, or pollution. Clark (1967) reported that between 1955 and 1964, 45,000 acres of tidal marshland were destroyed between Maine and Delaware. Dredging destroyed 34% of that total acreage; housing developments, 27%; parks, beaches and marinas, 15%; bridges and roads, 10%; industrial development, 7%; dumping sites, 6%; other causes, 1%. See Clark (1967) for information on what Atlantic coastal states are doing to protect their remaining marshes.

6.23 Control of erosion and silting

Construction of hydroelectric impoundments on the Roanoke River, N.C., has decreased water turbidity downstream from the dams (Hassler 1958).

6.24 Fishways at artificial and natural obstructions

Some migrating striped bass apparently utilize the

Table 23.—Summary of regulations on commercial harvesting of striped bass. (Adapted from Reintjes 1974.[1])

State	Type gear	Season	Illegal areas	Minimum size	Maximum size	Source
Rhode Island	Fish traps only[2]	Sept. 1-Oct. 14	—	406 mm (16 in) FL	None	
New York	Seines, fyke, and hoop nets prohibited[3]	Hudson River below Barrier Dam, Troy, N.Y. Mar. 16-Nov. 30[4]	Delaware River	406 mm (16 in) FL	None	
Delaware	Haul seines—stretch mesh at least 51 mm (2 in). Drifting gill nets—stretch mesh at least 70 mm (2½ in)[5]	Nov. 1-Apr. 30	All areas except Delaware Bay and River	305 mm (12 in) FL	9.1 kg (20 lb)	
Maryland	All gear except purse seines and otter trawls. Minimum size of netting mesh—4 mm (2½ in) for gill nets and haul seines; 57 mm (2¼ in) for pound and fyke nets.	No restrictions. Gill netting in Potomac from Mar. 1-May 26 only—gill net max. length 366 m (1,200 ft).	Severn and Magothy Rivers certain parts of Susquehanna River flats	305 mm (12 in) TL	6.5 kg (15 lb) 813 mm (32 in) effective 1/1/78	Mansueti and Hollis (1963)
Virginia	No restrictions	No restrictions	None	356 mm (14 in) TL	18.1 kg (40 lb)	
North Carolina	Gill nets limited to 91.4 mm (100 yd) in length; must be at least 45.7 m (50 yd) from any other fixed net.[6]	No restrictions	New Hanover County	305 mm (12 in) FL[7]	None	
Oregon	Gill nets only; no monofilament.		Not known.	406 mm (16 in) FL	None	

[1]J. W. Reintjes. Atlantic Estuarine Fisheries Center, National Marine Fisheries Service, NOAA, Beaufort, N.C. 28576, pers. commun. 10 June 1974.
[2]Rhode Island laws relating to striped bass, fish traps, seines, nets, and weirs. Part of Rhode Island Laws, Chapters 14, 18, and 19, 22 p. Department of Natural Resources, Veteran's Memorial Building, Providence, RI. 02903.
[3]New York State Department of Environmental Conservation, Commercial Inland Fisheries Pamphlet, FW-P35. Department of Environmental Conservation, Division of Fish and Wildlife, Albany, NY 12201.
[4]1976-commercial harvesting prohibited due to polychlorinated biphenyls (PCB) contamination.
[5]1974. Striped bass fishing laws. Part of Delaware Fishing Laws, Sections 933, 1120, and 1123. Department of Natural Resources and Environmental Control, Dover, DE 19901.
[6]1974. North Carolina Inland Fisheries Regulations, 47 p. Wildlife Resources Commission, Department of Natural and Economic Resources, Raleigh, NC 27602.
[7]No more than 5% of catch may be <305 mm (12 in) FL.

navigation lock at the Pinopolis Dam, Cooper River, S.C. (Scruggs and Fuller 1955; Scruggs 1957).

6.25 Fish screens

See section 3.23 for a discussion of the louver facility used to prevent fish from entering the California State Pumping Station on the Sacramento-San Joaquin Delta. Kerr (1953) discussed the successful use of fish screens and collectors in diverting striped bass from the Contra Costa Steam Plant in California.

6.3 Control or alteration of chemical features of the environment

6.31 Water pollution control

See section 5.24 for a discussion of effects of water pollution on striped bass populations.

6.32 Salinity control

High total dissolved solids (350 ppm) apparently blocked the striped bass block spawning migrations in the San Joaquin River, Calif. (Radtke and Turner 1967).

6.33 Artificial fertilization of waters

See section 7.5 on pond management.

6.4 Control or alteration of the biological features of the environment

6.42 Introduction of fish foods (plant, invertebrate, forage fish)

Striped bass have been stocked in some lakes and reservoirs to control gizzard shad, *Dorosoma cepedianum,* and threadfin shad, *D. petenense,* populations.

Table 24.—Summary of regulations on sport fishery of striped bass (from Reintjes 1974[1]).

State	Minimum size	Daily creel limit	Sale of fish	Remarks
Maine	406 mm (16 in) FL[2]	None	No restrictions	
New Hampshire	406 mm (16 in) FL	None	No restrictions	
Massachusetts	406 mm (16 in) FL	None	No restrictions	Rod and reel license required to sell daily catch over 45.4 kg (100 lb).
Rhode Island	406 mm (16 in) FL	None	No restrictions	
Connecticut	406 mm (16 in) FL	None	Not permitted	Closed season; 1 Mar.-19 Apr.[3]
New York	406 mm (16 in) FL	None	No restrictions	Closed season in Hudson and Delaware Rivers from 1 Dec. to 15 Mar.
New Jersey	457 mm (18 in) TL	10	No restrictions	Closed season in saltwater 1 Jan.-28 Feb; no closed season in freshwater. Tidal Delaware River-minimum size 254 mm (10 in) TL; maximum weight 9.1 kg (20 lb). In Delaware River between New Jersey and Pennsylvania fish >305 mm (12 in) TL but <4.5 kg (10 lb) can be taken from 1 Mar. to 31 Dec.
Delaware	None	None	No restrictions	
Maryland	305 mm (12 in) TL	None	No restrictions	Maximum size 6.8 kg (15 lb) 1 Mar.-27 May; sport fishermen allowed 1 fish/day above 6.8 kg from 28 May to 29 Feb.[5]
Virginia	356 mm (14 in) TL	None	No restrictions	No more than 2 fish/day over 1,016 mm (40 in). Fish from inland waters at least 508 mm (20 in) TL limit of 4 fish/day except for Buggs Island and Gaston Lake where 305 mm (12 in) TL fish are legal, limit of 8 fish/day.[6]
North Carolina	305 mm (12 in) TL	None	Sale from inland waters prohibited	Creel limit in reservoirs and their tributaries 8 fish/day; 25 fish/day in all other waters. Dip, bow, and gill nets permitted in inland public waters from 1 Dec. to 5 June.[6]
South Carolina	None	10	Not permitted	Creel limit 5 or 2 fish/day in some lakes.
Georgia	381 mm (15 in) FL	5	Not permitted	
Florida	381mm (15 in) FL	6	Not permitted	
Alabama	None	5	Not permitted	
Alabama	None	6	Not permitted	No creel limit in salwater.
Mississippi	381 mm (15 in) FL	3	Not permitted	No creel limit in saltwater.
Louisiana	None	2	Not permitted	
Texas	None	2	Not permitted	Not present in coastal waters; land locked only.
California	406 mm (16 in) TL	3	Not permitted	Spear, harpoon, bow and arrow illegal in San Francisco Bay. One line with maximum of 3 hooks.
Oregon	406 mm (16 in) TL	5	Not permitted	
Washington	None	None	No restrictions	No regulations.

[1]Reintjes, J. W. 1974. State regulations. Private letter, 10 June 1974; Atlantic Estuarine Fisheries Center, National Marine Fisheries Service, NOAA, Beaufort, N.C. 28516.

[2]Flagg, L. N. 1974. Striped bass in Maine. Private letter, 12 June 1974; Department of Marine Resources, Augusta, ME 04330.

[3]1973-1974. Fishing. Part of Connecticut Hunting, Trapping and Sport Fishing, Abstract of Laws and Regulations, p. 26-32. Connecticut Department of Environmental Protection, Hartford, Conn.

[4]1974. Striped bass laws. Part of Compendius of New Jersey Fish Laws including regulations of 1974 Fish Code, p. 13, 15, 18. Department of Environmental Protection, Division of Fish, Game, and Shellfisheries, Trenton, NJ 08625.

[5]1970. Tidal waters. Annotated Code of the Public General Laws of Maryland 1957 (1970 Replacement Volume), Artic. 66c, Part 2, Sect. 263-264, p. 636-639. Maryland Department of Natural Resources, Annapolis, MD 21401.

[6]1974. Virginia Fishing Laws. Digest A-6, Game Commission Form (6-73-600M). Virginia Commission of Game and Inland Fisheries, P.O. Box 11104, Richmond, VA 23230.

[7]1974. North Carolina Inland Fishing Regulations, 47 p. Wildlife Resources Commission, Department of Natural and Economic Resources, Raleigh, NC 27602.

6.5 Artificial stocking

6.51 Maintenance stocking

Most hatchery-produced striped bass are used to provide sport fishing and/or control shad populations in inland waters.

6.52 Transportation; introduction

See section 2.1.

7 POND FISH CULTURE

The Striped Bass Committee of the Southern Division, American Fisheries Society, has recently compiled an authoritative text, *Guidelines for Striped Bass Culture* (Bonn et al. 1976). Included in this publication are discussion of hatching facilities; broodstock sources; capture and handling; spawning, incubation, and transportation of eggs and larvae; pond culture; intensive culture; hybrids; and parasites and diseases.

7.1 Use of cultured fish

See section 6.51.

Striped bass stocking is undertaken by State and Federal hatcheries and agencies. States producing striped bass include Alabama, Arkansas, Florida, Georgia, Kansas, Kentucky, Louisiana, Mississippi, Missouri, Nebraska, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. Federal hatcheries producing striped bass for stocking are located in Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, and South Carolina (Texas Instruments[53]).

Merriner and Hoagman[54] attempted to stock underutilized brackish water nursery areas of the Mobjack Bay system, Va., with 3-day-old yolk-sac larvae (1971) and 20-65 mm FL young-of-the-year (1972) striped bass. Stocking was apparently unsuccessful. Approximately 1 million yolk-sac larvae (40.5 larvae/acre) were stocked in Mobjack Bay during 1971. To obtain a juvenile density of 1 per acre by December, 32,500 larvae/acre or ≈800 million yolk-sac larvae would have to be released in early June (assuming a 5.2% daily mortality rate) (Turner and Chadwick 1971). Merriner and Hoagman estimated that approximately 31 striped bass were added to the Mobjack Bay population by December from the 1 million yolk-sac larvae stocked. Four thousand 50-day-old juvenile striped bass were stocked in Mobjack Bay during 1972 (0.16 per acre for depths <6 m). Total contribution to Mobjack Bay from the 1972 stocking effort was 1.4 fish, assuming a 5.2% daily mortality rate from day 50 to day 200, or 9 fish, assuming a 4% daily mortality rate for the same period. A target density of 1 fish/acre in December would require the stocking of 69 million 50-day-old fish (2,800 per acre) assuming 5.2% daily mortality, or 11.2 million fish (454 per acre) assuming 4.2% daily mortality. The authors concluded that stocking of striped bass to augment or utilize available tidal nursery areas had little hope of success.

7.2 Procurement of stocks

Striped bass broodstock capture methods include electrofishing, stationary and drift gill nets, bow nets, trap nets, fyke nets, hoop nets, and hook-and-line fishing when all other methods have failed. Broodfish should be transported in 100 ppm Furacin and 0.3 to 1.0 ppt NaCl or reconstituted seawater (Bonn et al. 1976). Smith et al. (1967) kept females anesthetized with 7 ppm quinaldine until injection with chorionic gonadotropin. However, Bonn et al. (1976) stated that broodfish should be injected with gonadotropin at the time of capture. Either human or veterinary chorionic gonadotropin can be used to induce ovulation; various workers have recommended dosages from 125 to 300 international units (IU)/lb (McBay footnote 26; Smith et al. 1967; R. E. Stevens 1966; Wirtanen and Ray 1971). Bishop (1975) recommended hormone injection of male broodfish at a dosage of 50-75 IU/lb of chorionic gonadotropin for obtaining maximum milt production. As a precaution against fungal infections, fish have been immersed for 30 s in a 1:15,000 part solution of malachite green (Smith et al. 1967).

7.4 Spawning

Egg procurement has been discussed by Bayless (1972), McBay (footnote 26), Smith et al. (1967), and R. E. Stevens (1966) and is summarized by Bonn et al. (1976). After hormone injection a female is held from 20 to 28 h, depending upon water temperature, and the eggs sampled by catheter (Bayless 1972). Eggs taken more than 15 h prior to ovulation cannot be accurately aged. Bayless (1972) published photographs depicting hourly changes in unfertilized eggs. As ovulation occurs ova become detached from the ovarian tissue. The resultant lack of oxygen results in anoxia in a short period of time if the eggs remain in the body. Stevens (1967) indicated the maximum period between ovulation and overripeness is approximately 60 min. Bayless (1972) found the optimum time for egg removal to be between 15 and 30 min following the first indication of ovulation. Overripeness and abortion due to stress were the major causes of egg mortality (Smith et al. 1967). Ripe females are anesthetized with MS-222 or quinaldine and manually stripped.

Bishop (1975) spawned striped bass in circular tanks. Fish were injected with chorionic gonadotropin before being placed in the tanks, but were not stripped. Tank spawning reduced handling and imposed less stress on broodfish.

After fertilization, eggs are incubated in McDonald hatching jars, aquaria, circular tanks, or swimming pools. Eggs are kept suspended within the water column. A velocity of 0.3 m/s is sufficient for suspension (Bardach et al. 1972). Bayless (1968) evaluated the effects of sedimentation on hatching success of striped bass eggs. Based on 100% hatching success for the agitated controls, mean hatching rates were: 35.7% for eggs placed on coarse sand; 36.4% for eggs on plastic; 13.1% for eggs on a silt-sand substrate; 3.2% for eggs on a silt-clay-sand substrate; and 0% for striped bass eggs over a muck-detritus substrate. The percent hatch improved as the time of egg suspension increased (up to 15 h at temperatures from 17.8° to 20.0°C) prior to sedimentation. Low salinities provided the best egg survival: 2-3‰ (Lal et al. 1977); 1.5-3.0‰ (Mansueti 1958a). Shannon (1969) found no significant differences in percent hatch at incubation temperatures between 16° and 24°C though Shannon and Smith (1968) reported that at temperatures of 23°-27°C no striped

[53]Texas Instruments, Inc. 1977. Feasibility of culturing and stocking Hudson River striped bass. An overview, 1973-1975. Prepared for Consolidated Edison Co. of New York, Inc., June.

[54]Merriner, J. V., and W. J. Hoagman. 1973. Feasibility of increasing striped bass populations by stocking of underutilized nursery grounds. Completion Rep. Proj. FA-VA-AFS 6, 1970-1973, 197 p. Virginia Institute of Marine Science, Goucester Point, VA 23062.

bass fry survived >70 h after hatching. For a summary of tolerance and optimum ranges of salinity and temperature on striped bass eggs and larvae see Table 7 in section 3.21 of this review.

Rogers et al. (1977) found hatching success of striped bass eggs in static systems enhanced by antibiotic treatment of 50,000 IU/liter of penicillin G and 50 mg/liter of streptomycin sulfate.

Yolk-sac larvae from 1-4 days old can be held at high densities provided the water currents are sufficient to keep the larvae suspended. Bonn et al. (1976) stated that as many as 1.5 million yolk-sac larvae can be successfully held in a 30-gal aquarium provided the rate of water exchange is 1 gal/min.

Rhodes and Merriner (1973) successfully reared 3-day-old yolk-sac larvae to 20-25 mm fish in a 3 m diameter, 0.6 m deep, circular wading pool. They recommended the following procedures for successful closed system culture:

1. Initial numbers should not exceed 100,000/3 m diameter pool (3,409 liter capacity).
2. Salinity should be increased from 0.2 to 4.0‰ after feeding has begun.
3. Larger, potentially canibalistic fish should be removed and isolated from the population.

7.5 Pond management

Braschler (1975) summarized the development of pond culture techniques. Bonn et al. (1976) presented a detailed summary of the state of the art of striped bass pond culture. Harper and Jarman (1972) tested various stocking rates of striped bass larvae in Oklahoma culture ponds over a 3-yr period. Stocking rates ranged from 10,000 to 160,000 larvae/acre. Bonn et al. (1976) stated that 100,000 fish/acre was the accepted optimum stocking rate.

Predation can be a problem in the densely stocked culturing ponds. Tatum et al. (1966) reported phantom midge larvae, *Chaoborus* spp., and mosquitofish, *Gambusia affinis*, preyed upon yolk-sac larvae in rearing ponds at the Weldon Hatchery, N.C.

Water quality for fry rearing recommended by Davies (1973) included temperatures from 14° to 21°C, pH of 7.5, and low dissolved solids. Bonn et al. (1976) summarized optimum conditions for the rearing of striped bass larvae. For further consideration of water quality and food requirements for larval survival see section 3.22 of this review.

7.6 Foods; feeding

Striped bass larvae are usually fed brine shrimp, *Artemia salina* nauplii, from initiation of feeding until introduction into rearing ponds. Larvae feed on zooplankton in rearing ponds.

The prime importance of copepods in the diet of larval striped bass has been aptly demonstrated. Harper et al. (1969) in a study of striped bass cultured at the State Fish Hatchery in Durant, Okla., showed that striped bass <30 mm TL consumed greater volumes of copepods than other organisms. Copepods in the rearing ponds included *Diaptomus* sp. and *Cyclops* sp. The culicid *Chaoborus* was a significant food item in the 10-19 mm striped bass, comprising 14% by volume of food consumed. Early instar stages of copepods and cladocerans were required for first-feeding fish; striped bass (10-15 mm TL) began feeding on adult copepods and cladocerans. Percent frequency occurrence of food items for the smallest striped bass in Oklahoma culture ponds was presented by Harper and Jarman (1972):

Food organisms	*5-9 mm TL*	*10-14 mm TL*	*15-19 mm TL*
Cladocera	69.23%	43.47%	25.00%
Copepoda	15.38%	73.91%	50.00%
Diptera	—	13.04%	25.00%
Amarphoris	7.69%	8.69%	—

Cladocerans were extensively utilized by striped bass between 20 and 110 mm from Oklahoma culture ponds (Harper and Jarman 1972). *Diaphanosoma, Moina,* and *Ceriodaphnia* were the most prevalent genera. Striped bass between 120 and 160 mm fed primarily on insects (Harper and Jarman 1972).

Humphries and Cumming (1972) examined the stomach contents of 213 striped bass, 11.4-80.0 mm TL, from culture ponds at the Front Royal Fish Cultural Station in Virginia. Cladocerans of the families Sididae, Daphnidae, and Bosminidae constituted the major portion of the diet. Daphnidae were mainly represented by *Daphnia, Ceriodaphnia,* and *Scapholeberis*; Bosminidae by the genus *Bosmina.* Copepods of the family Cyclopidae and insects of the family Chironomidae were also important. After the fish reached 30-40 mm, copepod consumption increased and insects remained stable in the diet. The striped bass negatively selected Brachionida (rotifers) and copepod nauplii (small in size in relation to fish). The cladoceran families Daphnidae and Bosminidae were positively selected; the genus *Diaphanosoma* was positively selected when present in small numbers and eaten in proportion to its abundance when present in large numbers. Copepods were consumed in proportion to their abundance.

Meshaw (1969) determined the feeding selectivity of juvenile striped bass in relation to natural zooplankton populations in hatchery ponds at the Edenton Natural Fish Hatchery, Edenton, N.C. Young striped bass were highly selective for *Cyclops* while they ignored *Bosmina, Ceriodaphnia, Daphnia,* copepod nauplii, and rotifers. Although chironomid larvae and ostracods were occasionally consumed in large numbers by the fish, selectivity for these taxa could not be ascertained because of the inadequacy of the sampling method for these organisms.

Supplemental feeding in pond culture is discussed by Bonn et al. (1976) and Harper and Jarman (1972).

7.7 Disease and parasite control

Diseases

Columnaris, caused by the flexibacterium, *Flexibacter columnaris,* is the most frequent and serious bacterial disease of striped bass (Bonn et al. 1976). It is characterized by macroscopic external lesions on the gill filaments and body of infected fish. Other diseases include: red vent disease, a form of bacterial hemorrhagic septicemia caused by *Aeromonas* sp. and *Pseudomonas* sp.; and vibriosis, caused by *Vibrio* sp., which can infect striped bass cultured in brackish water.

Bonn et al. (1976) summarized recommended treatments for the following pathogenic bacteria: *Flexibacter, Aeromonas, Pseudomonas,* and *Vibrio,* and the fungus, *Saprolegnia.*

Blue-sac disease symptoms include: hemorrhaging in the head and thoracic region; blistering on the sides of the body above the pectoral fins and yolk sac; a fluid-filled coelom light blue in color (hence the name of the disease); kyphosis; general circulatory system damage including deterioration of blood vessels and formation of blood clots; lockjaw; lighter anemic coloration than usual; and white spot formation in the yolk sac. Death is presumably due to immobility and suffocation. See Mansueti (1958a) for a detailed account of the advancing stages of this disease.

Mansueti (1958a) reported the following abnormalities of cultured striped bass eggs; eggs that did not fully water harden, eggs with the oil globule disengaged from the yolk, and cloudy eggs with coagulated fluid. None of these eggs were viable. Mansueti also found the following larval deformities and aberrant conditions:

a) Pugheadedness.
b) Larvae with heads bent backwards, eye perpendicular to the body and very little pigmentation on the body and eyes. In these larvae the yolk had settled into an odd-shaped mass in the posterioventral portion of the yolk sac.
c) Humpbacked larvae.
d) Gas embolism—gas bubbles are attached to larvae or are swallowed (visible in the intestine), and white spots develop on the yolk sac. This fatal condition is apparently associated with waters supersaturated with atmospheric gases.

Parasites

Parasites found under culture conditions are noted in Table 12 by footnote 3. Bonn et al. (1976) summarized recommended treatments.

7.8 Harvest

For maximum production, striped bass juveniles should be harvested from ponds when they reach 1,540-2,200 individuals/kg. Fish have been harvested by dip net in smaller ponds or by partial drainage in large ponds and use of glass V traps and/or seining. It is recommended that juveniles be held in tanks for 24 h for recovery from stress, disease treatment, and flushing of the digestive system. During this time, treatment with 100-500 ppm Furacin and 10 ppt NaCl for a 2- to 5-h period is advised (Bonn et al. 1976).

7.9 Transport

Striped bass larvae have been successfully transported in concentrations of 9,000-13,000/liter in plastic bags in an oxygen atmosphere (McGill 1967; Bayless 1972; Braschler 1975).

Harper and Jarman (1972) reported that juveniles were successfully transported in agitator tanks filled with dechlorinated tap water containing 1% NaCl (10 ppt) and 0.25 ppm quinaldine. The anesthetic MS 222 at a concentration of 21 ppm can also be used in transport to slow down fish metabolism and thus reduce the chance of shock and injury. Schoumacher (1969) successfully transferred adult striped bass after anesthetization with 1-3 ppm quinaldine. Fish were transported for 15.5 h in 125-gal tanks in water containing 2 ppm quinaldine, 0.4% NaCl, and a little antifoam-A (Dow). Pumps circulated and aerated the water; oxygen was added as a precautionary measure during the latter half of the trip.

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LITERATURE CITED

ABBOTT, C. C.

1878. Notes on some fishes of the Delaware River. Rep. U.S. Fish Comm. 4(1875-1876):825-845.

ALBRECHT, A. B.

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

ALPERIN, I. M.

1966. A new parasite of striped bass. N.Y. Fish Game J. 13:121-123.

ANDERSON, J. C.

1966. Production of striped bass fingerlings. Prog. Fish-Cult. 28:162-164.

ANONYMOUS.

1920. California furnishes striped bass to Hawaiian Islands. Calif. Fish Game 6:18-19.

AULD, A. H., and J. R. SCHUBEL.

1978. Effects of suspended sediment on fish eggs and larvae: a laboratory assessment. Estuarine Coastal Mar. Sci. 6:153-164.

AUSTIN, H. M., and O. CUSTER.

1977. Seasonal migration of striped bass in Long Island Sound. N.Y. Fish Game J. 24:53-68.

AUSTIN, H. M., and C. R. HICKEY, Jr.

1978. Predicting abundance of striped bass, *Morone saxatilis*, in New York waters from modal lengths. Fish. Bull., U.S. 76:467-473.

BAILEY, R. M.

1951. A check-list of the fishes of Iowa, with keys for identification. *In* J. R. Harlan and E. B. Speaker, Iowa fish and fishing, p. 185-238. Iowa State Conservation Commission, Des Moines.

BAILEY, R. M., J. E. FITCH, E. S. HERALD, E. A. LACHNER, C. C. LINDSEY, C. R. ROBINS, and W. B. SCOTT.

1970. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc., Spec. Publ. 6, 150 p.

BAILEY, R. M., H. E. WINN, and C. L. SMITH.

1954. Fishes from the Escambia River, Alabama and Florida, with ecologic and taxonomic notes. Proc. Acad. Nat. Sci. Phila. 106:109-164.

BAILEY, W. M.

1975. An evaluation of striped bass introductions in the southeastern United States. Proc. 28th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1974:54-68.

BAIRD, S. F.

1855. Fishes observed on the coasts of New Jersey and Long Island during the summer of 1854. Ninth Annu. Rep. Smithson. Inst., p. 317-355.

BARDACH, J. E., J. H. RYTHER, and W. O. McLARNEY.

1972. Culture of miscellaneous anadromous fishes (shad and striped bass). *In* Aquaculture. The farming and husbandry of freshwater and marine organisms, p. 528-530. Wiley-Interscience, N.Y.

BARKULOO, J. M.

1961. Distribution and abundance of striped bass (*Roccus saxatilis*, Walbaum) on the Florida Gulf Coast. Proc. 15th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1961:223-226.

1970. Taxonomic status and reproduction of striped bass (*Morone saxatilis*) in Florida. U.S. Bur. Sport Fish. Wildl., Tech. Pap. 44, 16 p.

BASON, W. H.

1971. Ecology and early life history of striped bass, *Morone saxatilis*, in the Delaware Estuary. Ichthyol. Assoc. Bull. 4, 122 p.

BAYLESS, J. D.

1964. Tall tales, Wildl. N.C. 28(5):4-6.

1968. Striped bass hatching and hybridization experiments. Proc. 21st Annu. Conf. Southeast Assoc. Game Fish Comm. 1967:233-244.

[1972.] Artificial propagation and hybridization of striped bass, *Morone saxatilis* (Walbaum). S.C. Wildl. Mar. Res. Dep., 135 p.

BEAN, T. H.

1885. On the occurrence of the striped bass in the lower Mississippi valley. Proc. U.S. Natl. Mus. 7(1884):242-244.

BECK, A. P., G. V. POJE, and W. T. WALLER.

1975. A laboratory study on the effects of the exposure of some entrainable Hudson River biota to hydrostatic pressure regimes calculated for the proposed Cornwall pumped-storage plant. *In* S. B. Saila (editor), Fisheries and energy production: A symposium, p. 167-204. Lexington Books, Lexington, Mass.

BEITCH, I.

1963. A histomorphological comparison of the urinary systems in the serranid fishes, *Roccus saxatilis* and *Roccus americanus*. Chesapeake Sci. 4:75-83.

BENVILLE, P. E., Jr., and S. KORN.

1977. The acute toxicity of six monocyclic aromatic crude oil components to striped bass (*Morone saxatilis*) and bay shrimp (*Cargo franciscorum*). Calif. Fish Game 63:204-209.

BERG, L. S.

1949. Freshwater fishes of the U.S.S.R. and adjacent countries. (Ryby presnykh vod SSSR i sopredel'nykh stran.) 4th ed., improved and augmented, transl. by Isr. Progr. Sci. Transl. 1962. 3 vols. (Available from the Office of Technical Services, U.S. Dep. Commer., Wash. D.C. as OTS 61-31218).

BERGGREN, T. J., and J. T. LIEBERMAN.

1978. Relative contribution of Hudson, Chesapeake, and Roanoke striped bass, *Morone saxatilis*, stocks to the Atlantic coast fishery. Fish. Bull., U.S. 76:335-345.

BIGELOW, H. B., and W. C. SCHROEDER.

1953. Striped bass *Roccus saxatilis* (Walbaum) 1792. *In* Fishes of the Gulf of Maine, p. 389-404. U.S. Fish Wildl. Serv., Fish Bull. 53.

BISHOP, R. D.

1968. Evaluation of the striped bass (*Roccus saxatilis*) and white bass (*R. chrysops*) hybrids after two years. Proc. 21st Annu. Conf. Southeast Assoc. Game Fish Comm. 1967:245-254.

1975. The use of circular tanks for spawning striped bass (*Morone saxatilis*). Proc. 28th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1974:35-44.

BLEEKER, P.

1876. Systema percarum revisum. Arch. Neerl. Sci. Nat. 11(1):247-288.

BLOCH, M. E.

1792. Naturgeschichte der ausländischen Fische, Berlin 6:53, pl 305.

BLOCH, M. E., and J. G. SCHNEIDER.

1801. Systema Ichthyologiae. Berlin, 584 p.

BOGDANOV, A. S., S. I. DOROSHEV, and A. F. KARPEVICH.

1967. Experimental transfer of *Salmo gairdneri* (Richardson) and *Roccus saxatilis* (Walbaum) from the U.S.A. for acclimatization in bodies of water of the U.S.S.R. Vopr. Ikhtiol. 42:185-187. (Translated from Russian by R. M. Howland, Narragansett Mar. Game Fish Res. Lab., Narragansett, R.I.)

BONN, E. W., W. M. BAILEY, J. D. BAYLESS, K. E. ERICKSON, and R. E. STEVENS (editors).

1976. Guidelines for striped bass culture. American Fisheries Society, Striped Bass Committee of the Southern Division, 103 p.

BOULENGER, G. A.

1895. Catalogue of the Perciform fishes in the British Museum. 2d. ed. Trustees Br. Mus. (Nat. Hist.), 391 p.

BOWLES, R. R.

1976. Effects of water velocity on activity patterns of juvenile striped bass. Proc. 29th. Annu. Conf. Southeast. Assoc. Game Fish Comm. 1975:142-151.

BRASCHLER, E. W.

1975. Development of pond culture techniques for striped bass *Morone saxatilis* (Walbaum). Proc. 28th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1974:44-48.

BRIGGS, P. T.

1965. The sport fishery in the surf on the south shore of Long Island from Jones Inlet to Shinnecock Inlet. N.Y. Fish Game J. 12:31-47.

BROCKSEN, R. W., and H. T. BAILEY.

1973. Respiratory response of juvenile chinook salmon and striped bass exposed to benzene, a water-soluble component of crude oil. *In* Proceedings of joint conference on prevention and control of oil spills, p. 783-791. [Am. Pet. Inst., Environ. Prot. Agency, U.S. Coast Guard, Wash., D.C.]

BROWN, B. E.
1965. Meristic counts of striped bass from Alabama. Trans. Am. Fish. Soc. 94:278-279.

CALHOUN, A. J.
1952. Annual migrations of California striped bass. Calif. Fish Game 38:391-403.
1953. Distribution of stiped bass fry in relation to major water diversions. Calif. Fish Game 39:279-299.

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

CATCHINGS, E. D.
1973. The effects of increased salinity and of feeding treatment on the survival and growth of striped bass, *Morone saxatilis* (Walbaum), fry in hatching jars, and fingerling striped bass in troughs. M.S. Thesis, Auburn Univ., Auburn, Ala., 61 p.

CHADWICK, H. K.
1960. Toxicity of tricon oil spill eradicator to striped bass (*Roccus saxatilis*). Calif. Fish Game 46:371-372.
1963. An evaluation of five tag types used in a striped bass mortality rate and migration study. Calif. Fish Game 49:64-83.
1964. Annual abundance of young striped bass, *Roccus saxatilis,* in the Sacramento-San Joaquin Delta, California. Calif. Fish Game 50:69-99.
1967. Recent migrations of the Sacramento-San Joaquin River striped bass population. Trans. Am. Fish. Soc. 96:327-342.
1968. Mortality rates in the California striped bass population. Calif. Fish Game 54:228-246.
1969. An evaluation of striped bass angling regulations based on an equilibrium yield model. Calif. Fish Game 55:12-19.
1974. Entrainment and thermal effects on a mysid shrimp and striped bass in the Sacramento-San Joaquin Delta. *In* L. D. Jensen (editor), Second workshop on entrainment and intake screening, p. 23-30. Elec. Power Res. Inst., Palo Alto, Calif., Publ. 74-049-00-5.

CHADWICK, H. K., D. E. STEVENS, and L. W. MILLER.
1977. Some factors regulating the striped bass population in the Sacramento-San Joaquin Estuary, California. *In* W. Van Winkle (editor), Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations, Gatlinburg, Tennessee, May 3-6, 1977, p. 18-35. Pergamon Press, N.Y.

CHAPOTON, R. B., and J. E. SYKES.
1961. Atlantic coast migration of large striped bass as evidenced by fisheries and tagging. Trans. Am. Fish. Soc. 90:13-20.

CHEEK, R. P.
1961. Quantitative aspects of striped bass, *Roccus saxatilis* (Walbaum), spawning in the Roanoke River, North Carolina. M.S. Thesis, N.C. State Univ., Raleigh, 99 p.

CHITTENDEN, M. E., Jr.
1971a. Status of striped bass, *Morone saxatilis,* in the Delaware River. Chesapeake Sci. 12:131-136.
1971b. Effects of handling and salinity on oxygen requirements of the striped bass, *Morone saxatilis.* J. Fish. Res. Board Can. 28:1823-1830.

CLARK, J. R.
[1963.] The 1960 salt-water angling survey. U.S. Fish Wildl. Serv., Circ. 153, 36 p.
1967. Fish & man. Conflict in the Atlantic estuaries. Am. Litt. Soc., Spec. Publ. 5, 78 p.
1968. Seasonal movements of striped bass contingents of Long Island Sound and the New York Bight. Trans. Am. Fish. Soc. 97:320-343.

CLAY, W. M.
1962. A field manual of Kentucky fishes. Ky. Dep. Fish Wildl. Resour., Frankfort, 147 p.

CORDONNIER, L. M., and H. L. WARD.
1967. *Pomphorphynchus rocci* sp. n. (Acanthocephala) from the rock bass, *Roccus saxatilis*. J. Parasitol. 53:1295-1297.

COURTOIS, L. A.
1974. Physiological responses of striped bass, *Roccus saxatilis* (Walbaum), to changes in diet, salanity, temperature, and acute copper exposure. Ph.D. Thesis, Univ. California, Davis, 118 p.

COUTANT, C. C.
1974. Evaluation of entrainment effect. Opening remarks at Entrainment and Intake Screening Workshop. *In* L. D. Jensen (editor), Second workshop on entrainment and intake screening, p. 1-11. Elect. Power Res. Inst., Palo Alto, Calif., Publ. 74-049-00-5.

COUTANT, C. C., and R. J. KEDL.
1975. Survival of larval striped bass exposed to fluid-induced and thermal stresses in a simulated condenser tube. Oak Ridge Nat. Lab., Environ. Sci. Div. Publ. 637, 37 p.

CUVIER, G., and A. VALENCIENNES.
1828. Histoire naturelle des Poissons, II. Paris, 490 p.

DAVIES, W. D.
1970. The effect of temperature, pH and total dissolved solids on the survival of immature striped bass, *Morone saxatilis* (Walbaum). Ph.D. Thesis, N.C. State Univ., Raleigh, 100 p.
1973. The effects of total dissolved solids, temperature, and pH on the survival of immature striped bass: A response surface experiment. Prog. Fish-Cult. 35:157-160.

DAVIS, H. S.
1922. A new bacterial disease of fresh-water fishes. Bull. U.S. Bur. Fish. 38:261-280.

DAVIS, R. H., Jr.
1966. Population studies of striped bass, *Roccus saxatilis* (Walbaum), in Maine based on age distributions and growth rate. M.S. Thesis, Univ. Maine, Orono, 50 p.

DAVIS, W. S.
1959. Field tests of Petersen, streamer, and spaghetti tags on striped bass, *Roccus saxatilis* (Walbaum). Trans. Am. Fish. Soc. 88:319-329.

DeARMON, I. A., Jr.
1948. Sampling techniques on the ovary of the striped bass, *Roccus saxatilis* (Walbaum). M.S. Thesis, Virginia Polytechnic Inst., Blacksburg, 40 p.

De KAY, J. E.
1842. Zoology of New York; or, The New York fauna. *In* Natural history of New York geographical survey, Vol. I, Part 4, Fishes, 415 p.

DENONCOURT, R. F., and W. H. BASON.
1970. Blind striped bass, *Roccus saxatilis* (Walbaum), from the Delaware River estuary. Chesapeake Sci. 11:132-134.

de SYLVA, D. P., F. A. KALBER, Jr., and C. N. SHUSTER, Jr.
1962. Fishes and ecological conditions in the shore zone of the Delaware River estuary, with notes on other species collected in deeper water. Univ. Del. Mar. Lab., Inf. Ser., Publ. 5, 164 p.

DEUEL, D. G.
1973. 1970 salt-water angling survey. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Curr. Fish. Stat. 6200, 54 p.

DEUEL, D. G., and J. R. CLARK.
1968. The 1965 salt-water angling survey. U.S. Bur. Sport Fish. Wildl. Resour. Publ. 67, 51 p.

DICKSON, A. W.
1958. The status of striped bass (*Roccus saxatilis*) (Walbaum) in North Carolina waters. Proc. 11th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1957:264-268.

DORFMAN, D.
1974. Responses of striped bass to temperature gradients. Underwater Nat. 8(1):42-43.

DOROSHEV, S. I.
1970. Biological features of the eggs, larvae and young of the striped bass [*Roccus saxatilis* (Walbaum)] in connection with the problem of its acclimatization in the USSR. J. Ichthyol. 10:235-248.

DOVEL, W. L.
1968. Predation by striped bass as a possible influence on population size of the Atlantic croaker. Trans. Am. Fish. Soc. 97:313-319.
1971. Fish eggs and larvae of the upper Chesapeake Bay. Univ. Md., Nat. Resour. Inst., Spec. Rep. 4, 71 p.

DOVEL, W. L., and J. R. EDMUNDS IV.
1971. Recent changes in striped bass (*Morone saxatilis*) spawning

sites and commercial fishing areas in upper Chesapeake Bay; possible influencing factors. Chesapeake Sci. 12:33-39.

DUDLEY, R. G., A. W. MULLIS, and J. W. TERRELL.
1977. Movements of adult striped bass (*Morone saxatilis*) in the Savannah River, Georgia. Trans. Am. Fish. Soc. 106:314-322.

ELDRIDGE, M. B., D. J. KING, D. ENG, and M. J. BOWERS.
1977. Role of the oil globule in survival and growth of striped bass (*Morone saxatilis*) larvae. Proc. 57th Annu. Conf. West Assoc. State Game Fish Comm., p. 303-313.

ENGEL, D. W., and E. M. DAVIS.
1964. Relationship between activity and blood composition in certain marine teleosts. Copeia 1964:586-587.

FARLEY, T. C.
1966. Striped bass, *Roccus saxatilis*, spawning in the Sacramento-San Joaquin River system, during 1963 and 1964. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin estuary. Part II. Fishes of the delta, p. 28-43. Calif. Dep. Fish Game, Fish Bull. 136.

FAULKNER, R. C.
1952. A comparative study of the retinae of four serranid fishes, *Lepibema chrysops* (Rafinesque), *Morone interrupta* (Gill), *Morone americana* (Gmelin), and *Roccus saxatilis* (Walbaum). M.S. Thesis, Univ. Oklahoma, Norman, 43 p.

FEARING, D. B.
1903. Some early notes on striped bass. Trans. Am. Fish. Soc. 32:90-98.

FISH, F. F., and E. G. McCOY.
1969. The river discharges required for effective spawning by striped bass in the rapids of the Roanoke River of North Carolina. N.C. Wildl. Res. Comm., Raleigh, 38 p.

FISHER, F. W., D. B. ODENWELLER, and J. E. SKINNER.
1977. Recent progress in fish facility research for California water diversion projects. *In* L. D. Jensen (editor), Third national workshop on entrainment and impingement. Section 316(b)-research and compliance, p. 381-403. Ecological Analysis, Inc., Melville, N.Y.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
1977. Yearbook of fishery statistics. Vol. 42.

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

FRISBIE, C. M., and D. E. RITCHIE, Jr.
1963. Sport fishing survey of the lower Potomac Estuary, 1959-1961. Chesapeake Sci. 4:175-191.

GAINES, J. L., Jr., and W. A. ROGERS.
1972. Fish mortalities associated with *Goezia* sp. (Nematoda: Ascaroidea) in central Florida. Proc. 25th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1971:496-497.

GILL, T. N.
1861. Monograph of the genus *Labrax* of Cuvier. Proc. Acad. Nat. Sci. Phila. 108-119.

GOODE, G. B.
1884. The food fishes of the United States. *In* G. B. Goode and a Staff of Associates, The fisheries and fishery industries of the United States. Section I. Natural history of useful aquatic animals, p. 163-682. U.S. Gov. Print. Off., Wash., D.C.

GOODE, G. B., and T. H. BEAN.
1880. Catalogue of a collection of fishes sent from Pensacola, Florida and vicinity, by Mr. Silas Stearns, with descriptions of six new species. Proc. U.S. Natl. Mus. 2(1879):121-156.

GOSLINE, W. A.
1966. The limits of the fish family Serranidae, with notes on other lower percoids. Proc. Calif. Acad. Sci. 33:91-112.

GRANT, G. C.
1974. The age composition of striped bass catches in Virginia Rivers, 1967-1971, and a description of the fishery. Fish. Bull., U.S. 72:193-199.

GRANT, G. C., V. G. BURRELL, Jr., and W. H. KRIETE, Jr.
1971. Age composition and magnitude of striped bass winter gill-net catches in the Rappahannock River, 1967-1970. Proc. 24th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1970:659-667.

GRANT, G. C., V. G. BURRELL, Jr., C. E. RICHARDS, and E. B. JOSEPH.
1970. Preliminary results from striped bass tagging in Virginia, 1968-1969. Proc. 23d Annu. Conf. Southeast. Assoc. Game Fish Comm. 1969:558-570.

GRANT, G. C., and E. B. JOSEPH.
1969. Comparative strength of the 1966 year class of striped bass, *Roccus saxatilis* (Walbaum), in three Virginia rivers. Proc. 22d Annu. Conf. Southeast. Assoc. Game Fish Comm. 1968:501-509.

GREGORY, W. K.
1918. The structure and mechanism of fishes. *In* J. T. Nichols (editor), Fishes of the vicinity of New York city, p. 5-17. Am. Mus. Nat. Hist., Handb. Ser. 7.
1933. Fish skulls: A study of the evolution of natural mechanisms. Trans. Am. Philos. Soc., N.S. 23, part, 2:75-481.

GUNTHER, A.
1859. Catalogue of the Acanthopterygian fishes in the collection of the British Museum. Trustees Br. Mus. (Nat. Hist.), Lond., Vol. 1, 524 p.

HAMER, P. E.
1966. The occurrence of striped cusk-eel, *Rissola marginata*, in the body cavity of striped bass, *Roccus saxatilis*. Chesapeake Sci. 7:214-215.

HANSON, W. D., and J. G. DILLARD.
1976. Contribution of striped bass to the fishery of Lake of the Ozarks, Missouri. Proc. 29th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1975:162-167.

HARDY, J. D., Jr.
1978. Development of fishes of the Mid-Atlantic Bight: An atlas of the egg, larval and juvenile stages. Vol. III. Aphredoderidae through Rachycentridae. U.S. Fish Wildl. Serv., Biol. Serv. Prog. FWS/OBS-78/12, 394 p.

HARPER, J. L., and R. JARMAN.
1972. Investigation of striped bass, *Roccus saxatilis* (Walbaum), culture in Oklahoma. Proc. 25th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1971:510-512.

HARPER, J. L., R. JARMAN, and J. T. YACOVINO.
1969. Food habits of young striped bass, *Roccus saxatilis* (Walbaum), in culture ponds. Proc. 22d Annu. Conf. Southeast. Assoc. Game Fish Comm. 1968:373-380.

HASSLER, W. W.
1958. The striped bass in relation to the multiple use of the Roanoke River, North Carolina. Trans. 23d North Am. Wildl. Conf. 378-391.

HATTON, S. R.
1942. Striped bass spawning areas in California. Calif. Fish Game 28:65.

HAZEL, C. R., W. THOMSEN, and S. J. MEITH.
1971. Sensitivity of striped bass and stickleback to ammonia in relation to temperature and salinity. Calif. Fish Game 57:138-153.

HEINLE, D. R., and D. A. FLEMER.
1975. Carbon requirements of a population of the estuarine copepod, *Eurytemora affinis*. Mar. Biol. (Berl.) 31:235-247.

HEINLE, D. R., D. A. FLEMER, and J. F. USTACH.
1976. Contribution of tidal marshlands to mid-Atlantic estuarine food chains. *In* M. Wiley (editor), Estuarine processes. Vol. II. Circulation, sediments, and transfer of material in the estuary, p. 309-320. Academic Press, N.Y.

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

HICKEY, C. R., Jr., B. H. YOUNG, and R. D. BISHOP.
1977. Skeletal abnormalities in striped bass. N.Y. Fish Game J. 24:69-85.

HILDEBRAND, S. F., and W. C. SCHROEDER.
1928. Fishes of Chesapeake Bay. Bull. U.S. Bur. Fish. 43:247-250.

HOLLAND, B. F., Jr., and G. F. YELVERTON.
1973. Distribution and biological studies of anadromous fishes offshore North Carolina. Div. Commer. Sport Fish., N.C. Dep. Nat. Econ. Resour. Spec. Sci. Rep. 24, 132 p.

HOLLIS, E. H.
1952. Variations in the feeding habits of the striped bass, *Roccus saxatilis* (Walbaum), in Chesapeake Bay. Bull. Bingham Oceanogr. Collect., Yale Univ. 14(1):111-131.

HORSEMAN, L. O., and R. J. KERNEHAN.
1976. An indexed bibliography of the striped bass, *Morone saxatilis*, 1670-1976. Ichthyol. Assoc. Bull. 13, 118 p.

HUMPHRIES, E. T.
1966. Spawning grounds of the striped bass, *Roccus saxatilis* (Walbaum) in the Tar River, North Carolina. M.S. Thesis, East Carolina Univ., Greenville, 50 p.

HUMPHRIES, E. T., and K. B. CUMMING.
1972. Food habits and feeding selectivity of striped bass fingerlings in culture ponds. Proc. 25th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1971:522-536.

HUNTER, J. R.
1972. Swimming and feeding behavior of larval anchovy, *Engraulis mordax*. Fish. Bull., U.S. 70:821-838.

IMLER, R. L.
1976. Striped bass introductions. Colorado Fisheries Review 1972-1975, No. 8, p. 19-20.

JACKSON, H. W., and R. E. TILLER.
1952. Preliminary observations on spawning potential in the striped bass, *Roccus saxatilis* (Walbaum). Md. Dep. Res. Educ. No. 93, 16 p.

JANSSEN, W. A., and C. D. MEYERS.
1967. Antibody against an antigen in beef heart muscle found in striped bass serum and absent in white perch serum. Chesapeake Sci. 8:66.

JENSEN, L. D. (editor).
1977. Third national workshop on entrainment and impingement, Section 316(b)-research and compliance. Ecological Analysts, Inc., Melville, N.Y., 425 p.

JOHNSON, C. A., and R. HARKEMA.
1970. A preliminary report on the life history of *Pomphorhynchus rocci*, an acanthocephalan parasite of the striped bass. J. Elisha Mitchell Sci. Soc. 86:184-185.

JOHNSON, R. K., and T. S. Y. KOO.
1975. Production and distribution of striped bass (*Morone saxatilis*) eggs in the Chesapeake and Delaware Canal. Chesapeake Sci. 16:39-55.

JORDAN, D. S.
1886. Notes on the scientific name of the yellow perch, the striped bass, and other North American fishes. Proc. U.S. Natl. Mus. 8(1885):72-73.

JORDAN, D. S., and C. H. EIGENMANN.
1890. A review of the genera and species of Serranidae found in the waters of America and Europe. Bull. U.S. Fish Comm. 8(1888):329-441.

JORDAN, D. S., and B. W. EVERMANN.
1896. The fishes of North and Middle America. U.S. Natl. Mus. Bull. 47(Part 1), 1240 p.
1898. The fishes of North and Middle America. U.S. Natl. Mus. Bull. 47(Part 2):1241-2183.
1902. American food and game fishes. Doubleday, Page & Co., N.Y., 572 p.

JORDAN, D. S., and C. H. GILBERT.
1882. Synopsis of the fishes of North America. Bull. U.S. Natl. Mus. 16, 1018 p.

KELLEY, J. R., Jr.
1969. Investigations on the propagation of striped bass, *Roccus saxatilis* (Walbaum). Ph.D. Thesis, Auburn Univ., Auburn, 113 p.

KELLEY, R., and H. K. CHADWICK.
1972. Some observations on striped bass temperature tolerances. Calif. Dep. Fish Game, Anad. Fish Br., Admin. Rep. 71-9, 11 p.

KERBY, J. H.
1972. Feasibility of artificial propagation and introduction of hybrids of the *Morone* complex into estuarine environments with a meristic and morphometric description of the hybrids. Ph.D. Thesis, Univ. Virginia, Richmond, 172 p.

KERR, J. E.
1953. Studies on fish preservation at the Contra Costa Steam Plant of the Pacific Gas and Electric Company. Calif. Dep. Fish Game, Fish Bull. 92, 66 p.

KLYASHTORIN, L. B., and A. A. YARZHOMBEK.
1975. Some aspects of the physiology of the striped bass, *Morone saxatilis*. J. Ichthyol. 15:985-989.

KOHLENSTEIN, L. C.
1978. On the proportion of the Chesapeake Bay stock of striped bass that migrates into the coastal fishery. *In* J. Cooper (editor), Proceedings of a symposium on advances in striped bass life history and population dynamics. The American Fisheries Society, 108th Annual Meeting, University of Rhode Island, Kingston, R.I., Aug. 22, 1978.

KOO, T. S. Y.
1970. The striped bass fishery in the Atlantic states. Chesapeake Sci. 11:73-93.

KOO, T. S. Y., and D. E. RITCHIE, Jr.
1973. Growth of juvenile striped bass, *Morone saxatilis*, as determined by tagging and recapture. *In* A. L. Pacheco (editor), Proceedings of a workshop on egg, larval and juvenile stages of fish in the Atlantic Coast Estuaries, p. 124-125. U.S. Dep. Commer., NOAA, NMFS, Middle Atl. Coastal Fish. Cent., Tech. Publ. No. 1, 338 p.

KOO, T. S. Y., and J. S. WILSON.
1972. Sonic tracking striped bass in the Chesapeake and Delaware Canal. Trans. Am. Fish. Soc. 101:453-462.

KORN, S., J. W. STRUHSAKER, and P. BENVILLE, Jr.
1976. Effects of benzene on growth, fat content, and caloric content of striped bass, *Morone saxatilis*. Fish. Bull., U.S. 74:694-698.

KRANTZ, G. E.
1970. Lymphocystis in striped bass, *Roccus saxatilis*, in Chesapeake Bay. Chesapeake Sci. 11:137-139.

KRUGER, R. L., and R. W. BROCKSEN.
1978. Respiratory metabolism of striped bass, *Morone saxatilis* (Walbaum), in relation to temperature. J. Exp. Mar. Biol. Ecol. 31:55-66.

LACÉPÈDE, B. G. E.
1802. Histoire naturelle des Poissons, IV. Paris, 257.

LAL, K., R. LASKER, and A. KULJIS.
1977. Acclimation and rearing of striped bass larvae in sea water. Calif. Fish Game 63:210-218.

LAUER, G. J., W. T. WALLER, D. W. BATH, W. MEEKS, R. HEFFNER, T. GINN, L. ZUBARIK, P. BIBKO, and P. C. STORM.
1974. Entrainment study on Hudson River organisms. *In* L. D. Jensen (editor), Second workshop on entrainment and intake screening, p. 37-82. Elec. Power Res. Inst., Palo Alto, Calif., Publ. 74-049-00-5.

LAWLER, J. P., R. A. NORRIS, G. GOLDWYN, K. A. ABOOD, and T. L. ENGLERT.
1974. Hudson River striped bass life cycle model. *In* L. D. Jensen (editor), Second workshop on entrainment and intake screening, p. 83-94. Elec. Power Res. Inst., Palo Alto, Calif., Publ. 74-049-00-5.

LEWIS, R. M.
1957. Comparative study of populations of the striped bass. U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish. 204, 54 p.
1961. Comparison of three tags on striped bass in the Chesapeake Bay area. Chesapeake Sci. 2:3-8.
1962. Sexual maturity as determined from ovum diameters in striped bass from North Carolina. Trans. Am. Fish. Soc. 91:279-282.

LEWIS, R. M., and R. R. BONNER, Jr.
1966. Fecundity of the striped bass, *Roccus saxatilis* (Walbaum). Trans. Am. Fish. Soc. 95:328-331.

LINTON, E.
1898. Notes on trematode parasites of fishes. Proc. U.S. Natl. Mus. 20:407-548.
1901. Parasites of fishes of the Woods Hole region. Bull. U.S. Fish Comm. 19:405-492.

LOEBER, T. S.
1951. A report of an investigation of the temperature and salinity

relationships of striped bass and salmon in connection with the Reber plan. Calif. Dep. Fish Game, Inland Fish Br., Rep. Bur. Fish Conserv., 40 p.

LOGAN, H. J.
1968. Comparison of growth and survival rates of striped bass and striped bass × white bass hybrids under controlled environments. Proc. 21st Annu. Conf. Southeast. Assoc. Fish Game Comm. 1967:260-263.

LUND, W. A., Jr.
1957. Morphometric study of the striped bass, *Roccus saxatilis.* U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish. 216, 24 p.

LYMAN, H.
1961. A sixteen pound pugheaded striped bass from Massachusetts. Chesapeake Sci. 2:101-102.

MAGNIN, E., and G. BEAULIEU.
1967. Le Bar, *Roccus saxatilis* (Walbaum), du Fleuve Saint-Laurent. Nat. Can. (Que.) 94:539-555.

MAHONEY, J. B., F. H. MIDLIGE, and D. G. DEUEL.
1973. A fin rot disease of marine and euryhaline fishes in the New York Bight. Trans. Am. Fish. Soc. 102:596-605.

MANOOCH, C. S., III.
1973. Food habits of yearling and adult striped bass, *Morone saxatilis* (Walbaum), from Albemarle Sound, North Carolina. Chesapeake Sci. 14:73-86.

MANSUETI, R. J.
1956. Recaptures of tagged striped bass, *Roccus saxatilis* (Walbaum), caught in deep waters of Chesapeake Bay, Maryland. Md. Dep. Res. Educ. Resour. Study Rep. 10, 9 p.
1958a. Eggs, larvae and young of the striped bass, *Roccus saxatilis.* Chesapeake Biol. Lab. Contrib. 112, 35 p.
1958b. The development of anal spines and soft-rays in young striped bass, *Roccus saxatilis.* Chesapeake Biol. Lab. Contrib. 113, 12 p.
1959. Exploratory trawling for striped bass in Potomac River, 1959. Md. Tidewater News 15(1):3, 4.
1960. An unusually large pugheaded striped bass, *Roccus saxatilis,* from Chesapeake Bay, Maryland. Chesapeake Sci. 1:111-113.
1961. Age, growth, and movements of the striped bass, *Roccus saxatilis,* taken in size selective fishing gear in Maryland. Chesapeake Sci. 2:9-36.
1962. Effects of civilization on striped bass and other estuarine biota in Chesapeake Bay and tributaries. Proc. Gulf Caribb. Fish. Inst., 14th Annu. Sess., p. 110-136.
1964. Eggs, larvae, and young of the white perch, *Roccus americanus,* with comments on its ecology in the estuary. Chesapeake Sci. 5:3-45.

MANSUETI, R. J., and A. J. MANSUETI.
1955. White perch eggs and larvae studied in lab. Md. Tidewater News 12(7):1-3.

MANSUETI, R. J., and E. H. HOLLIS.
1963. Striped bass in Maryland tidewater. Univ. Md., Nat. Res. Inst., Educ. Ser. 61, 28 p.

MARCY, B. C., Jr., and R. C. GALVIN.
1973. Winter-spring sport fishery in the heated discharge of a nuclear power plant. J. Fish. Biol. 5:541-547.

MARKLE, D. F., and G. C. GRANT.
1970. The summer food habits of young-of-the-year striped bass in three Virginia rivers. Chesapeake Sci. 11:50-54.

MASSMAN, W. H., and A. L. PACHECO.
1961. Movements of striped bass tagged in Virginia waters of Chesapeake Bay. Chesapeake Sci. 2:37-44.

MAY, O. D., Jr., and J. C. FULLER, Jr.
1965. A study on striped bass egg production in the Congaree and Wateree Rivers. Proc. 16th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1962:285-301.

McCOY, E. G.
1959. Quantitative sampling of striped bass, *Roccus saxatilis* (Walbaum), eggs in the Roanoke River, North Carolina. M.S. Thesis, N.C. State College, Raleigh, 136 p.

McGILL, E. M., Jr.
1967. Pond water for rearing striped bass fry, *Roccus saxatilis* (Walbaum), in aquaria. Proc. 20th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1966:331-340.

McHUGH, J. L.
1977. Fisheries and fishery resources of New York Bight. U.S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 401, 50 p.

McILWAIN, T. D.
1968. Distribution of the striped bass, *Roccus saxatilis* (Walbaum) in Mississippi waters. Proc. 21st Annu. Conf. Southeast. Assoc. Game Fish Comm. 1967:254-257.

McLANE, W. M.
1955. The fishes of the St. John's River system. Ph.D. Thesis, Univ. Florida, Gainesville, 361 p.

MELDRIM, J. W., and J. J. GIFT.
1971. Temperature preference, avoidance and shock experiments with estuarine fishes. Ichthyol. Assoc. Bull. 7, 75 p.

MELDRIM, J. W., J. J. GIFT, and B. R. PETROSKY.
1974. The effect of temperature and chemical pollutants on the behavior of several estuarine organisms. Ichthyol. Assoc. Bull. 11, 129 p.

MENSINGER, G. C.
1971. Observations of the striped bass, *Morone saxatilis,* in Keystone Reservoir, Oklahoma. Proc. 24th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1970:447-463.

MERRIMAN, D.
1937. Notes on the life history of the striped bass, *Roccus lineatus.* Copeia 1937:15-36.
1940. The osteology of the striped bass (*Roccus saxatilis*). Ann. Mag. Nat. Hist., Ser. 11, 5:55-64.
1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic Coast. U.S. Fish Wildl. Serv., Fish Bull. 50:1-77.

MESHAW, J. C., Jr.
1969. A study of feeding selectivity of striped bass fry and fingerlings in relation to zooplankton availability. M.S. Thesis, N.C. State Univ., Raleigh, 58 p.

MIDDAUGH, D. P., J. A. COUCH, and A. M. CRANE.
1977. Responses to early life history stages of the striped bass, *Morone saxatilis* to chlorination. Chesapeake Sci. 18:141-153.

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

MILLER, P. E.
1977. Experimental study and modeling of striped bass egg and larval mortality. Ph.D. Thesis, The Johns Hopkins Univ., Baltimore, 99 p.

MILLER, R. V.
1969. Continental migrations of fishes. Underwater Nat. 6(1):15-23, 44, 45.

MITCHILL, S. L.
1814. Report, in part, of Samuel L. Mitchill, M.D., Professor of Natural History, & C., on the fishes of New York. D. Carlisle, N.Y., 28 p.
1815. The fishes of New York, described and arranged. Trans. Lit. Philos. Soc. N.Y. 1:355-492.

MORGAN, A. R., and A. R. GERLACH.
1950. Striped bass studies on Coos Bay in 1949 and 1950. Oreg. Fish. Comm. Contrib. 14, 31 p.

MORGAN, R. P., II.
1971. Comparative electrophoretic studies on the striped bass, *Morone saxatilis,* and white perch, *M. americana,* and electrophoretic identification of five populations of striped bass in the upper Chesapeake Bay. Ph.D. Thesis, Univ. Maryland, College Park, 92 p.
1975. Distinguishing larval white perch and striped bass by electrophoresis. Chesapeake Sci. 16:68-70.

MORGAN, R. P., II, and R. D. PRINCE.
1977. Chlorine toxicity to eggs and larvae of five Chesapeake Bay fishes. Trans. Am. Fish. Soc. 106:380-385.

MORGAN, R. P., II, T. S. Y. KOO, and G. E. KRANTZ.
1973. Electrophoretic determination of populations of the striped bass, *Morone saxatilis,* in the Upper Chesapeake Bay. Trans. Am. Fish. Soc. 102:21-32.

MURAWSKI, W. S.

1958. Comparative study of populations of the striped bass, *Roccus saxatilis* (Walbaum), based on lateral-line scale counts. M.S. Thesis, Cornell Univ., Ithaca, 80 p.

1969. The distribution of striped bass, *Roccus saxatilis,* eggs and larvae in the lower Delaware River. N.J. Dep. Conserv. Econ. Dev., Div. Fish Game, Nacote Creek Res. Stn., Misc. Rep. 1M, 39 p.

MURPHY, G. J.

1959. Exploratory trawling for striped bass in Potomac River, 1959. Maryland Tidewater News 15(1):3-4. (Md. Dep. Res. Educ., Chesapeake Biol. Lab.)

NEAL, W. E.

1971. Landlocked striped bass of John H. Kerr Reservoir, a ten year summary of research and management activities. Va. Comm. Game Inland Fish. Proj. F-5, 41 p.

NICHOLS, P. R., and R. V. MILLER.

1967. Seasonal movements of striped bass, *Roccus saxatilis* (Walbaum), tagged and released in the Potomac River, Maryland, 1959-61. Chesapeake Sci. 8:102-124.

NICHOLSON, W. R.

1964. Growth compensation in four year classes of striped bass, *Roccus saxatilis,* from Albemarle Sound, North Carolina. Chesapeake Sci. 5:145-149.

O'REAR, C. W., Jr.

1972. Some environmental influences of the zinc and copper content of striped bass, *Morone saxatilis* (Walbaum). Ph.D. Thesis, Virginia Poly. Inst., Blacksburg, 78 p.

1973. The toxicity of zinc and copper to striped bass eggs and fry with methods for providing confidence limits. Proc. 26th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1972:484-489.

ORSI, J. J.

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

OTWELL, W. S., and J. V. MERRINER.

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

OVERSTREET, R. M.

1971. *Neochasmus sogandaresi* n. sp. (Trematoda: Cryptogonimidae) from the striped bass in Mississippi. Trans. Am. Microsc. Soc. 90:87-89.

OVIATT, C. A.

1977. Menhaden, sport fish and fishermen. Univ. R.I., Mar. Tech. Rep. 60.

PAPERNA, I., and D. E. ZWERNER.

1974. *Kudoa cerebralis* sp. n. (Myxosporidea, Chloromyxidae) from the striped bass, *Morone saxatilis* (Walbaum). J. Protozool. 21:15-19.

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

PEARSON, J. C.

1931. Sport fishing in Chesapeake Bay. U.S. Bur. Fish Fish. Circ. 1, 19 p.

1933. Movements of striped bass in Chesapeake Bay. Md. Fish. 22:15-17.

1938. The life history of the striped bass, or rockfish, *Roccus saxatilis* (Walbaum). U.S. Bur. Fish. Bull. 49:825-860.

PFUDERER, H. A., S. S. TALMAGE, B. N. COLLIER, W. VAN WINKLE, Jr., and C. P. GOODYEAR.

1975. Striped bass - a selected annotated bibliography. Oak Ridge Natl. Lab., Environ. Sci. Div., Publ. 615, 158 p.

POLGAR, T. T.

1977. Striped bass ichthyoplankton abundance, mortality, and production estimation for the Potomac River population. *In* W. Van Winkle (editor), Proceedings of a conference on assessing the effects of power-plant-induced mortality on fish populations, Gatlinburg, Tennessee, May 3-6, 1977, p. 110-126. Pergamon Press, N.Y.

POLGAR, T. T., J. A. MIHURSKY, R. E. ULANOWICZ, R. P. MORGAN II, and J. S. WILSON.

1976. An analysis of 1974 striped bass spawning success in the Potomac estuary. *In* M. Wiley (editor), Estuarine processes, Vol. I. Uses, stresses, and adaptation to the estuary, p. 151-165. Acad. Press, N.Y.

POWELL, M. R.

1973. Cage and raceway culture of striped bass in brackish water in Alabama. Proc. 26th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1972:345-356.

RACHLIN, J. W., A. P. BECK, and J. M. O'CONNOR.

1978. Karyotypic analysis of the Hudson River striped bass, *Morone saxatilis.* Copeia 1978:343-345.

RADTKE, L. D., and J. L. TURNER.

1967. High concentrations of total dissolved solids block spawning migration of striped bass, *Roccus saxatilis,* in the San Joaquin River, California. Trans. Am. Fish. Soc. 96:405-407.

RAFINESQUE, C. S.

1820. Ichthyologia Ohiensis, or natural history of the fishes inhabiting the river Ohio and its tributary streams, preceded by a physical description of the Ohio and its branches. Lexington, Kentucky, 23 p.

RANEY, E. C.

1952. The life history of the striped bass, *Roccus saxatilis* (Walbaum). Bull. Bingham Oceanogr. Collect., Yale Univ. 14(1):5-97.

1954. The striped bass in New York waters. Conservationist 8(4):14-17.

1957. Subpopulations of the striped bass *Roccus saxatilis* (Walbaum), in tributaries of Chesapeake Bay. *In* J. C. Marr (coordinator), Contributions to the study of subpopulations of fishes, p. 85-107. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 208.

1958. The striped bass. U.S. Fish Wildl. Serv., Fish. Leafl. 451, 6 p.

RANEY, E. C., and D. P. de SYLVA.

1953. Racial investigations of the striped bass, *Roccus saxatilis* (Walbaum). J. Wildl. Manage. 17:495-509.

RANEY, E. C., and W. S. WOOLCOTT.

1955. Races of the striped bass, *Roccus saxatilis* (Walbaum), in southeastern United States. J. Wildl. Manage. 19:444-450.

RANEY, E. C., W. S. WOOLCOTT, and A. G. MEHRING.

1954. Migratory pattern and racial structure of Atlantic coast striped bass. Trans. 19th North Am. Wildl. Nat. Resour. Conf., p. 376-396.

RATHJEN, W. F., and L. C. MILLER.

1957. Aspects of the early life history of the striped bass (*Roccus saxatilis*) in the Hudson River. N.Y. Fish Game J. 4:43-60.

REDPATH, G. S.

1972. Temperature and its effect on the growth and production of juvenile striped bass, *Morone saxatilis.* M.S. Thesis, Univ. California, Davis, 37 p.

REEVES, W. C., and J. F. GERMANN.

1972. Effects of increased water hardness, source of fry and age at stocking on survival of striped bass fry in earthen ponds. Proc. 25th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1971:542-548.

REGAN, D. M., T. L. WELLBORN, Jr., and R. G. BOWKER.

1968. Striped bass, *Roccus saxatilis* (Walbaum), development of essential requirements for production. U.S. Fish Wildl. Serv., Bur. Sport Fish. Wildl., Div. Fish. Hatcheries, Atlanta, Ga., 133 p.

REHWOLDT, R., G. BIDA, and B. NERRIE.

1971. Acute toxicity of copper, nickel and zinc ions to some Hudson River fish species. Bull. Environ. Contam. Toxicol. 6:445-448.

RHODES, W., and J. V. MERRINER.

1973. A preliminary report on closed system rearing of striped bass sac fry to fingerling size. Prog. Fish-Cult. 35:199-201.

RINALDO, R. G.

1971. Analysis of *Morone saxatilis* and *Morone americana* spawning and nursery area in the York and Pamunkey Rivers, Virginia. M.S. Thesis, College of William and Mary, Williamsburg, 56 p.

RITCHIE, D. E., Jr.

1970. Striped bass tagging study shows results. Chesapeake Bay Affairs 3(2):1-2.

ROBINSON, J. B.
1960. The age and growth of striped bass (*Roccus saxatilis*) in California. Calif. Fish Game 46:279-290.
ROGERS, B. A., and D. T. WESTIN.
1975. A bibliography on the biology of the striped bass, *Morone saxatilis* (Walbaum). Univ. R.I., Mar. Tech. Rep. 37, 134 p.
ROGERS, B. A., D. T. WESTIN, and S. B. SAILA.
1977. Life stage duration studies on Hudson River striped bass. Univ. R.I., Applied Mar. Res. Group, NOAA Sea Grant, Mar. Tech. Rep. 31, 111 p.
ROSA, H., Jr.
1965. Preparation of synopses on the biology of species of living aquatic organisms. FAO (Food Agric. Organ. U.N.) Fish. Biol. Synop. 1, Rev. 1, 75 p.
RYDER, J. A.
1887. *Roccus lineatus* (Bloch) Gill: (The striped bass, or rockfish). *In* On the development of osseous fishes, including marine and freshwater forms. Rep. U.S. Fish.Comm. 1885, 13:502-505.
SAILA, S. B., and E. LORDA.
1977. Sensitivity analysis applied to a matrix model of the Hudson River striped bass population. *In* W. Van Winkle (editor), Proceedings of a conference on assessing the effects of power-plant-induced mortality on fish populations, Gatlinburg, Tennessee, May 3-6, 1977, p. 311-332. Pergamon Press, N.Y.
ST. AMANT, J. A.
1959. Striped bass introduced into the Colorado River. Calif. Fish Game 45:353.
SANDOZ, O., and K. H. JOHNSTON.
1966. Culture of striped bass *Roccus saxatilis* (Walbaum). Proc. 19th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1965:390-394.
SASAKI, S.
1966. Distribution of juvenile striped bass, *Roccus saxatilis,* in the Sacramento-San Joaquin Delta. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin Delta. Part II. Fishes of the delta, p. 59-67. Calif. Dep. Fish Game, Fish Bull. 136.
SCHAEFER, R. H.
1967. Species composition, size and seasonal abundance of fish in the surf waters of Long Island. N.Y. Fish Game J. 14:1-46.
1968a. Size, age composition and migration of striped bass from the surf waters of Long Island. N.Y. Fish Game J. 15:1-51.
1968b. Sex composition of striped bass from the Long Island surf. N.Y. Fish Game J. 15:117-118.
1970. Feeding habits of striped bass from the surf waters of Long Island. N.Y. Fish Game J. 17:1-17.
1972. A short-range forecast function for predicting the relative abundance of striped bass in Long Island waters. N.Y. Fish Game J. 19:178-181.
SCHÖPF, J. D.
1788. Beschreibung einiger nord-amerikanischen Fische vorzüglich aus den neu-yorkischen Gewässern. Schrift Ges Naturf Freunde Berlin, 8:138-194.
SCHOUMACHER, R.
1969. Transportation of adult striped bass. Prog. Fish-Cult. 31:230.
SCHUBEL, J. R., and A. H. AULD.
1974. Hatching success of blueback-herring and striped bass eggs with various time vs. temperature histories. *In* J. W. Gibbons and R. R. Sharitz (editors), Thermal ecology. Proceedings of a symposium held at Augusta, Georgia, May 3-5, 1973, p. 164-190. Tech. Inf. Cent., Off. Int. Serv., U.S. AEC, Oak Ridge, Tenn.
SCHUBEL, J. R., T. S. Y. KOO, and C. F. SMITH.
1976. Thermal effects of power plant entrainment on survival of fish eggs and larvae: A laboratory assessment. John Hopkins Univ., Chesapeake Bay Inst., Ref. 76-5, Spec. Rep. 52, 37 p.
SCHULTZ, L. P.
1931. Hermaphroditism in the striped bass. Copeia 1951:64.
SCOFIELD, E. C.
1928. Striped bass studies. Calif. Fish Game 14:29-37.
1931. The life history of the striped bass. *In* The striped bass of California (*Roccus lineatus*). Div. Fish Game Calif., Fish Bull. 29, p. 26-60.
SCRUGGS, G. D., Jr.
1957. Reproduction of resident striped bass in Santee-Cooper Reservoir, South Carolina. Trans. Am. Fish. Soc. 85:144-159.
SCRUGGS, G. D., Jr., and J. C. FULLER, Jr.
1955. Indications of a freshwater population of striped bass, "*Roccus saxatilis*" (Walbaum), in Santee-Cooper Reservoir. Proc. Southeast. Assoc. Game Fish Comm. 1954:64-70.
SHANNON, E. H.
1969. Effect of temperature changes upon developing striped bass eggs and fry. N.C. Wildl. Res. Comm., Div. Inland Fish., 6 p.
1970. Effect of temperature changes upon developing striped bass eggs and fry. Proc. 23d Annu. Conf. Southeast. Assoc. Game Fish Comm. 1969:265-274.
SHANNON, E. H., and W. B. SMITH.
1968. Preliminary observations on the effect of temperature on striped bass eggs and sac fry. Proc. 21st Annu. Conf. Southeast. Assoc. Game Fish Comm. 1967:257-260.
SHAPOVALOV, L.
1936. Food of the striped bass. Calif. Fish Game 22:261-271.
SHEARER, L. W., D. E. RITCHIE, Jr., and C. M. FRISBIE.
1962. Sport fishing survey in 1960 of the lower Patuxent estuary and the 1958 year-class of striped bass. Chesapeake Sci. 3:1-17.
SHERK, J. A., J. M. O'CONNOR, and D. A. NEUMANN.
1975. Effects of suspended and deposited sediments on estuarine environments. *In* L. E. Cronin (editor), Estuarine research. Vol. II. Geology and engineering, p. 541-558. Acad. Press, N.Y.
SHUSTER, C. N., Jr.
1959. A biological evaluation of the Delaware River estuary. Univ. Del. Mar. Lab., Inf. Ser. Publ. 3, 77 p.
SIDELL, B. D., R. G. OTTO, and D. A. POWERS.
1978. A biochemical method for distinction of striped bass and white perch larvae. Copeia 1978:340-343.
SKINNER, J. E.
1974. A functional evaluation of a large louver screen installation and fish facilities research on California water diversion projects. *In* L. D. Jensen (editor), Second workshop on entrainment and intake screening, p. 225-250. Elec. Power Res. Inst., Palo Alto, Calif., EPRI Publ. No. 74-049-00-5.
SMITH, B. A.
1971. The fishes of four low-salinity tidal tributaries of the Delaware River estuary. M.S. Thesis, Cornell Univ., Ithaca, 304 p.
SMITH, L. D.
1973. Life history studies of striped bass. Dep. Nat. Res., Game and Fish Div., Fish. Sect., Sport Fish. Div., Brunswick, Ga., 143 p.
SMITH, W. B., W. R. BONNER, and B. L. TATUM.
1967. Premature egg procurement from striped bass. Proc. 20th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1966:324-330.
SNIESZKO, S. F., G. L. BULLOCK, E. HOLLIS, and J. G. BOONE.
1964. *Pastuerella* sp. from an epizootic of white perch (*Roccus americanus*) in Chesapeake Bay tidewater areas. J. Bacterial 88:1814-1815.
SOMMANI, P.
1972. A study on the population dynamics of striped bass (*Morone saxatilis* Walbaum) in the San Francisco Bay estuary. Ph.D. Thesis, Univ. Washington, Seattle, 145 p.
STEINDACHNER, F.
1862. Ichthyologische Mittheilungen (IV.) Verh. Zool.-Bot. Ges. Wien. 12:497-504.
STEVENS, D. E.
1966. Food habits of striped bass, *Roccus saxatilis,* in the Sacramento-San Joaquin delta. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin Delta. Part II. Fishes of the delta, p. 68-96. Calif. Dep. Fish Game, Fish. Bull. 136.
1977a. Striped bass (*Morone saxatilis*) year class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Trans. Am. Fish. Soc. 106:34-42.
1977b. Striped bass (*Morone saxatilis*) monitoring techniques in the Sacramento-San Joaquin Estuary. *In* W. Van Winkle (editor), Proceedings of the conference on assessing the effects of

power-plant-induced mortality on fish populations, Gatlinburg, Tennessee, May 3-6, 1977, p. 91-109. Pergamon Press, N.Y.

STEVENS, R. E.

1958. The striped bass of the Santee-Cooper Reservoir. Proc. 11th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1957:253-264.

1965. A report on the operation of the Moncks Corner striped bass hatchery. South Carolina Wildlife Marine Resources Department, 21 p.

1966. Hormone-induced spawning of striped bass for reservoir stocking. Prog. Fish-Cult. 28:19-28.

1967. A final report on the use of hormones to ovulate striped bass, *Roccus saxatilis* (Walbaum). Proc. 18th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1964:525-538.

SURBER, E. W.

1958. Results of striped bass (*Roccus saxatilis*) introduction into freshwater impoundments. Proc. 11th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1957:273-276.

SWARTZMAN, G., R. DERISO, and C. COWAN.

1977. Comparison of stimulation models used in assessing the effects of power-plant-induced mortality on fish populations. *In* W. Van Winkle (editor), Proceedings of a conference on assessing the effects of power-plant-induced mortality on fish populations, Gatlinburg, Tennessee, May 3-6, 1977, p. 333-361. Pergamon Press, N.Y.

TAGATZ, M. E.

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

TALBOT, G. B.

1966. Estuarine environmental requirements and limiting factors for striped bass. *In* A symposium on estuarine fisheries, p. 37-49. Am. Fish. Soc., Spec. Publ. 3.

TATUM, B. L., J. D. BAYLESS, E. G. McCOY, AND W. B. SMITH.

1966. Preliminary experiments in the artificial propagation of striped bass, *Roccus saxatilis*. Proc. 19th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1965:374-389.

TILLER, R. E.

1943. Indications of compensatory growth in the striped bass, *Roccus saxatilis* Walbaum, as revealed by a study of the scales. Chesapeake Biol. Lab. Publ. 57, 16 p.

1950. A five-year study of the striped bass fishery of Maryland, based on analyses of the scales. Chesapeake Biol. Lab. Publ. 85, 30 p.

1955. Spawning areas of striped bass in Patuxent River explored. Md. Tidewater News 12(6):1, 4.

TRENT, L., and W. H. HASSLER.

1966. Feeding behavior of adult striped bass, *Roccus saxatilis*, in relation to stages of sexual maturity. Chesapeake Sci. 7:189-192.

1968. Gill net selection, migration, size and age composition, sex ratio, harvest efficiency, and management of striped bass in the Roanoke River, North Carolina. Chesapeake Sci. 9:217-232.

TRENT, W. L.

1962. Growth and abundance of young-of-year striped bass, *Roccus saxatilis* (Walbaum), in Albemarle Sound, North Carolina. M.S. Thesis, North Carolina State Univ., Raleigh, 66 p.

TRESSELT, E. F.

1952. Spawning grounds of the striped bass or rock, *Roccus saxatilis* (Walbaum), in Virginia. Bull. Bingham Oceanogr. Collect., Yale Univ. 14:98-110.

TURNER, J. L.

1976. Striped bass spawning in the Sacramento and San Joaquin rivers in central California from 1963 to 1972. Calif. Fish Game 62:106-118.

TURNER, J. L., and H. K. CHADWICK.

1972. Distribution and abundance of young-of-the-year striped bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin estuary. Trans. Am. Fish. Soc. 101:442-452.

TURNER, J. L., and T. C. FARLEY.

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

TURNER, J. L., and D. W. KELLEY (compilers).

1966. Ecological studies of the Sacramento-San Joaquin Delta. Part II. Fishes of the delta. Calif. Dep. Fish Game, Fish. Bull. 136, 168 p.

ULANOWICZ, R. E.

1975. The mechanical effects of water flow on fish eggs and larvae. *In* S. B. Saila (editor), Fisheries and energy production: A symposium, p. 77-87. Lexington Books, Lexington, Mass.

UNITED STATES COMMISSION OF FISH AND FISHERIES.

1889. The rockfish or striped bass, *Roccus lineatus*. Rep. Comm. Fish Fish. 1886, 14:XXX-XXXI.

UNITED STATES DEPARTMENT OF COMMERCE.

1974-78. Fisheries of the United States, 1973-1977. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Curr. Fish. Stat. 6400, 6700, 6900, 7200, 7500.

VALENTI, R. J., J. ALDRED, and J. LIEBELL.

1976. Experimental marine cage culture of striped bass in northern waters. Proc. 7th Annu. Meet. World Mariculture Soc., p. 99-108.

VAN CLEVE, R.

1945. A preliminary report on the fishery resources of California in relation to the Central Valley project. Calif. Fish Game 31:35-52.

VLADYKOV, V. D.

1947. Rapport du biologiste du department des percheries Cont. Que. Dep. Fish. 22:1-89.

VLADYKOV, V. D., and D. E. McALLISTER.

1961. Preliminary list of marine fishes of Quebec. Nat. Can. 88:53-78.

VLADYKOV, V. D., and D. H. WALLACE.

1938. Is the striped bass (*Roccus lineatus*) of Chesapeake Bay a migratory fish? Trans. Am. Fish. Soc., 67th Annu. Meet., August 23, 24 and 25, 1937:67-86.

1952. Studies of the striped bass, *Roccus saxatilis* (Walbaum), with special reference to the Chesapeake Bay region during 1936-1938. Bull. Bingham Oceanogr. Collect., Yale Univ. 14:132-177.

WALBAUM, J. J.

1792. Petri Artedi suici genera Piscium in quibus systema totum ichthyologiae proponitur cum classibus ordinibus generum characteribus, specierum differentiis, observationibus plurimis. Ichthyologiae Pars III. Grypeswaldiae, (ed. II), 723 p.

WARE, F. J.

1971. Some early life history of Florida's inland striped bass, *Morone saxatilis*. Proc. 24th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1970:439-447.

1975. Progress with *Morone* hybrids in fresh water. Proc. 28th Annu. Southeast. Assoc. Game Fish Comm. 1974:48-54.

WESTIN, D. J.

1978. Serum and blood from adult striped bass, *Morone saxatilis*. Estuaries 1:126-128.

WHITEHEAD, P. J. P., and A. C. WHEELER.

1966. The generic names used for the sea basses of Europe and North America (Pisces: Serranidae). Ann. Mus. Civ. Stor. Nat. Genova 76:23-41.

WHITWORTH, W. R., P. L. BERRIEN, and W. J. KELLER.

1968. Freshwater fishes of Connecticut. State Geol. Nat. Hist. Surv. Conn., Bull. 101, 134 p.

WILLIAMS, H. M.

1976. Characteristics for distinguishing white bass, striped bass and their hybrid (striped bass × white bass). Proc. 29th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1975:168-172.

WIRTANEN, L. J., and R. H. RAY.

1971. Striped bass, *Morone saxatilis* (Walbaum); 1970 report on the development of essential requirements for production. U.S. Fish Wildl. Serv., Bur. Sport Fish. Wildl., Div. Fish Hatcheries, Atlanta, Ga., 37 p.

WOLKE, R. E., D. S. WYAND, and L. H. KHAIRALLAH.

1970. A light and electron microscopic study of epitheliocystis disease in the gills of Connecticut striped bass (*Morone saxatilis*) and white perch (*Morone americanus*). J. Comp. Pathol. 80:559-563.

WOOD, W.

1634. New England's prospect. Tho. Coates for John Bellamie, Lond., 98 p.

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

'OOLCOTT, W. S.
1957. Comparative osteology of serranid fishes of the genus *Roccus* (Mitchill). Copeia 1957:1-10.
1962. Infraspecific variation in the white perch, *Roccus americanus* (Gmelin). Chesapeake Sci. 3:94-113.

ORTH, S. G.
1903. Striped bass hatching in North Carolina. Trans. Am. Fish. Soc. 32:98-102.