Chapter 9

STRIPED BASS

(*Morone saxatilis*)

In Memoriam

James Benton: April 19, 1958 – November 15, 1995
David G. Deuel: July 31, 1939 – February 17, 1995
Dr. Eileen Setzler-Hamilton: April 28, 1943 – March 12, 2003
Dr. William W. Hassler: June 16, 1917 – February 16, 2008

This chapter is dedicated to the memory of Jim Benton, David G. Deuel, Dr. Eileen Setzler-Hamilton, and Dr. William W. Hassler, four friends and valued colleagues with whom those of us in the striped bass management community were privileged to work for not nearly enough years. Jim, Dave, Bill, and Eileen all worked tirelessly during their careers for the conservation of the striped bass and its supporting ecosystems in the Chesapeake Bay, the Roanoke and Neuse river basins, and off the Outer Banks of North Carolina and Virginia, and their efforts bore much fruit. They are very much missed, and remembered.

Section I. Striped Bass Description of Habitat

Striped Bass General Habitat Description and Introduction

The striped bass (*Morone saxatilis*) was one of the first fish species in North America to be actively used and managed by society (Mann 2005, 2007; Smith and Olsenius 2007). Historically, striped bass was a highly important subsistence, commercial, and recreational species to Native Americans for millennia, and to European travelers and invaders beginning with the Vikings for centuries. Their importance as a harvested species continues into the present. Aside from their importance to humans, it is likely that striped bass provide several highly important ecosystem functions, including structuring fish and invertebrate communities through predation, and providing trophic linkages between productive rivers and estuaries and the coastal Atlantic Ocean (Able 2004). From this perspective, the striped bass may be seen as an indicator of estuarine and coastal health and habitat quality. The importance of this fish species remains undiminished today, and if anything, the relatively recent collapse (early 1980's) and restoration (1995) of the migratory striped bass population and fishery has only heightened public interest in management efforts (W. Laney, personal observation).

The Chesapeake Bay is the epicenter of migratory striped bass abundance and production on the East Coast. However, other estuaries from the Cape Fear River, North Carolina, to the St. Lawrence River, Canada, as well as the nearshore Atlantic Ocean, contribute to production and are essential for the long-term survival and sustainability of the species (W. Laney, personal observation). The purpose of this chapter is to describe the habitats used by all life stages of migratory striped bass, and establish a basis for formal habitat designation.

The striped bass is an anadromous, schooling species with a historic native range extending discontinuously from the Canadian Maritime Provinces to the Gulf of Mexico (Lee et al. 1980; Fay et al. 1983; Hill et al. 1989; Rago 1992; Rulifson and Dadswell 1995; Richards and

Rago 1999). On the Atlantic coast, the range of striped bass is continuous from the St. Lawrence River and southern Gulf of St. Lawrence, Quebec, to the St. Johns River, Florida (McLane 1955; Leim and Scott 1966). The species is absent from southeast and southwest Florida rivers below roughly 29°N latitude; it appears again in the Gulf of Mexico from the Suwannee River, Florida, to Lake Pontchartrain, Louisiana (Jordan 1884; Lee et al. 1980).

Many striped bass in Atlantic Coast rivers from Albemarle Sound, North Carolina, to the St. Lawrence River are migratory as adults. They travel annually from oceanic waters to riverine spawning grounds and back to the ocean, where they undertake a northern summer migration and southward winter migration (Boreman and Lewis 1987). However, recent studies of otolith microchemistry (Morris et al. 2003; Zlokovitz et al. 2003) indicate that striped bass residing in some longer river systems (Roanoke River, North Carolina, and Hudson River, New York, respectively) may exhibit multiple life history strategies, with some individuals remaining year-round in the upper freshwater portion of the system. Additionally, one group of individuals resides in the lower river and upper estuary, another group migrates to the coastal ocean, and a final group exhibits a mid-life habitat shift between freshwater and saltwater environments (Morris et al. 2003; Zlokovitz et al. 2003).

Striped bass populations south of Albemarle Sound, North Carolina, and in the Gulf of Mexico are thought to be endemic to each river system, and are considered essentially non-migratory by most researchers (Vladykov 1947; Scruggs and Fuller 1955; Scruggs 1957; Raney 1957; Murawski 1958; Barkuloo 1970; Dudley et al. 1977; McIlwain 1980; Richkus 1990). However, it might be that past and present management measures used for these stocks have largely precluded most fish from reaching a minimum size for migration (i.e., small size limits and liberal bag limits that, in combination, effectively maintain an artificially young age structure for a species well-documented to live to at least age 30) (W. Laney, personal observation).

Historic and recent recaptures of tagged striped bass suggest that migratory behavior in southeastern stocks is displayed by at least some small percentage of larger individuals. Hess et al. (1999) reported that movement between the adjacent Savannah and Ogeechee rivers in Georgia has occasionally occurred via coastal waters. For example, a striped bass tagged in Alligator Creek (a tributary to the Cape Fear River, North Carolina) on February 18, 2004, was captured by an angler on May 13, 2005, at the mouth of the Cape Cod Canal in Buzzard’s Bay, Massachusetts (Mark Westendorf, Coastal Zone Resources, Wilmington, North Carolina, personal communication).

Additionally, two striped bass populations on the Atlantic coast, one in the John H. Kerr Reservoir on the North Carolina/Virginia border and another in the Santee-Cooper Reservoirs in South Carolina, developed upstream spawning migrations to reservoir tributaries after downstream migration was precluded by dam construction (Scruggs and Fuller 1955; Scruggs 1957; Stevens 1958; Jenkins and Burkhead 1993). Additional reproducing freshwater populations have been established in U.S. reservoirs outside the historic range of the species (in California, Oklahoma, Oklahoma/Texas and Utah; see list in Crance 1984).

On the Pacific coast, striped bass were introduced in the San Francisco Bay estuary in 1879 and 1882, and have since spread north to Vancouver Island, British Columbia, and south to Baja California, Mexico (Lee et al. 1980). The species has also been widely stocked in inland reservoirs and coastal rivers in the United States (Fuller et al. 1999) and abroad (France, Portugal and Russia; see Hill et al. 1989).

The detailed descriptions of striped bass habitats and environmental requirements in this chapter focus on those areas used by the Atlantic coastal migratory stocks under the jurisdiction of the Atlantic States Marine Fisheries Commission (ASMFC) and its member states. The stock is defined as, "...all coastal migratory striped bass stocks on the East Coast of the United States, excluding the Exclusive Economic Zone [EEZ] (3-200 nautical miles offshore), which is managed separately by NOAA Fisheries." Migratory striped bass stocks occur in the riverine, estuarine, and coastal areas of all states and jurisdictions from Maine through North Carolina, as congressionally mandated in the Atlantic Striped Bass Conservation Act (PL 98-613) (Atlantic Striped Bass Plan Development Team 2003). All habitats used by the stock are addressed, including habitats outside ASMFC jurisdiction in the EEZ. Significant environmental, temporal, and spatial factors affecting distribution of striped bass are summarized in Table 9-5. Since tagging studies have documented exchange between migratory striped bass in U.S. and Canadian rivers, cursory descriptions of Canadian striped bass habitats are also included.

Striped bass habitat use information in this document is largely based on material in Bigelow and Schroeder (1953), Hardy (1978), Bain and Bain (1982), Rulifson et al. (1982), Fay et al. (1983), Crance (1984), Richkus (1990), Funderburk et al. (1991), Rago (1992), and Rulifson and Dadswell (1995), but has been supplemented by many other sources, including references from the following anadromous fish and striped bass bibliographies: Street and Hall (1973); Pfuderer et al. (1975); Rogers and Westin (1975); Horseman and Kernehan (1976); Smith and Wells (1977); Westin and Rogers (1978); Setzler et al. (1980); and Bettross (1991).

Striped bass life stages for the purposes of this document are defined as follows (after Hardy 1978). **Eggs** are extruded, fertilized, or unfertilized ova. **Yolk-sac larvae** are newly-hatched individuals that range in length from 2.0 to 3.7 mm (Mansueti 1958a; Fay et al. 1983), with a mean of 3.1 mm (Mansueti 1964) and maximum length of 6.0 to 7.0 mm, prior to yolk absorption. **Larvae** are individuals that have absorbed the yolk sac, but have not yet acquired the minimum adult fin ray complement and assumption of adult body form. Larvae range in size from 5.0 to 36 mm (Pearson 1938; Mansueti 1958a, 1964), and include the finfold and post-finfold larval stages as described by some authors (see Setzler et al. 1980). **Juveniles** range from 36 to approximately 174 mm minimum size for males (Raney 1952) and 432 mm for females (Clark 1968), and have acquired the minimum adult fin ray complement, but have yet to reach sexual maturity. **Adults** are any fish these lengths or larger that have reached sexual maturity.

Habitat Suitability Index Models

The U.S. Fish and Wildlife Service has developed several Habitat Suitability Index (HSI) models for various applications to striped bass stocks (Bain and Bain 1982; Crance 1984). In one instance, Bain and Bain (1982) developed a model for estuarine-associated coastal stocks of striped bass that contains individual components corresponding to the spawning, egg, larval, juvenile, and adult life history stages. The model is intended for use year-round on estuarine-associated striped bass stocks located on the Atlantic, Gulf, and Pacific coasts of the United States. This model can yield one HSI value for the entire life cycle of the striped bass, if all components are used, or individual HSI values can be generated for each life stage. The model was not designed for evaluation of marine habitat. It is also not applicable to areas where partial or extensive reduction in habitat availability has occurred due to contamination by toxic substances. Habitat parameters required for running the model include: 1) For riverine habitats- percent of natural river discharge, maximum total dissolved solids, average water temperature, minimum dissolved oxygen, and average current velocity; and 2) For estuarine habitats- percent of original salt marsh, percent of original freshwater input to estuary, average water temperature, average salinity, and minimum and average dissolved oxygen. This model assumes that striped bass habitat suitability is primarily associated with water quality (physicochemical conditions) during most life stages (Bain and Bain 1982). However, food availability and water quantity are considered particularly important life requisites in some life stages (W. Laney, personal observation).

The U.S. Fish and Wildlife Service's Charleston Ecological Services Field Office modified the Bain and Bain (1982) striped bass model for use on the Savannah River, Georgia/South Carolina (EuDaly 2002). The HSI was developed specifically to assess the modeled impacts of Savannah Harbor deepening on striped bass spawning, egg, and larval habitats through changes in flow velocity, dissolved oxygen, and salinity concentrations caused by channel modifications (EuDaly 2002; Van Den Avyle et al. 1990; Winger and Lasier 1990; Reinert and Jennings 1998; Will et al. 2000). This modified model may have application potential in tributaries where migratory striped bass spawn closer to the estuary (W. Laney, personal observation). Another model, developed by Crance (1984), applies to riverine or lacustrine habitat of striped bass throughout the 48 conterminous states. The lacustrine component of the model is generally inapplicable for migratory striped bass. The riverine model applies during the spawning season, and can be used to assess spawning habitat for those populations that spawn in the inland portions of East Coast rivers. The minimum length of river required for riverine reproductive habitat in this model is about 52.6 km. This estimate may not represent the actual minimum river length required if: 1) eggs are not moving at water velocity; 2) water temperature varies from optimal; or 3) the distance required is increased by suspension of the newly-hatched embryo (suspension may be required for about 15 hours post-hatch).

Variables required to run the riverine spawning habitat model include: water temperature; dissolved oxygen concentration; and current velocity (Crance 1984). At the time of its publication, the model had not been field-tested.

Both of the striped bass models developed for the U.S. Fish and Wildlife Service (Bain and Bain (1982) and Crance (1984)) are available on the internet at the U.S. Geological Survey National Wetlands Research Center website: http://www.nwrc.usgs.gov/wdb/pub/hsi/hsiintro.htm.

An additional document prepared by the Gulf States Marine Fisheries Commission (Lukens 1988) provides a useful example of how striped bass habitat criteria may be used in assessing and prioritizing habitats for striped bass restoration efforts. HSI models should not be considered proven statements, but instead are hypothetical species-habitat relationships (Stier and Crance 1985). Values provided may not be precisely applicable to all areas along the Atlantic Coast. Information pertaining to a particular habitat should be evaluated with regard to model criteria. Despite their limitations, HSI models are useful for evaluating species-habitat relationships (Bilkovic 2000).

Part A. Striped Bass Spawning Habitat

Geographical and temporal patterns of migration

Merriman (1937b) indicated that spawning probably occurred historically in every river of any size in the northeastern United States where proper conditions were present. The present range of migratory striped bass documented as returning regularly from the Atlantic Ocean to coastal rivers to spawn is from the Roanoke and Chowan River tributaries of Albemarle Sound in North Carolina to the St. Lawrence River in Canada (Raney 1952; Bigelow and Schroeder 1953; Leim and Scott 1966; Scott and Crossman 1973; Rulifson et al. 1982; Fay et al. 1983; Hill et al. 1989; Richkus 1990; Rulifson and Dadswell 1995). In general, juveniles migrate downstream in summer and fall, while adults migrate upriver to spawn in spring, later returning downstream to the lower river, estuary, or ocean (Shepherd 2006). Additionally, inland spawning migration extent has been altered by construction of dams that prevent access to some historic spawning habitats (W. Laney, personal observation).

Spawning location (geographical)

Documented U.S. and Canadian spawning ground locations used by Atlantic migratory striped bass can be found on the DVD supplement. The principal spawning areas for migratory striped bass along the Atlantic coast are located in the Chesapeake Bay and its tributary rivers and the Hudson River (Merriman 1941; Raney 1957; Berggren and Lieberman 1978; Kernehan et al. 1981; Setzler-Hamilton and Hall 1991; Wirgin et al. 1993; Richards and Rago 1999). Additional migratory stock spawning habitats located in the Delaware River, Roanoke River, and Canadian Atlantic rivers (Rulifson and Dadswell 1995), are believed to make smaller contributions to coastal fisheries (Richards and Rago 1999). Riverine stocks in North Carolina south of Albemarle Sound (Tar-Pamlico, Neuse, Cape Fear, and Northeast Cape Fear) are believed to make minor, if any, contributions to the coastal migratory stock. However, fish tagged in the Atlantic Ocean have been recaptured in Pamlico Sound during the spring, which suggests that some exchange historically occurred (Holland and Yelverton 1973). As noted by Richards and Rago (1999), however, composition of the coastal stock varies, and is a function of variable reproductive success in given spawning areas, spawning adult year-class strength, and season.

In the southern portion of the range, the Roanoke River’s contribution to the coastal migratory stock has historically been a small percentage, with some authors stating the stock was less migratory than others (Hassler et al. 1981; Boreman and Lewis 1987; Haeseker et al. 1996). However, the Roanoke stock was historically fished at a high rate, and fish were harvested at an early age such that from 1956 through 1990, the recruited fish consisted predominantly of individuals aged two and three (NC SBSMB 1991). Few fish from the stock were surviving to an age when migratory behavior would typically be initiated. Current management measures for the stock entail a delayed harvest and lower fishing rate that provide for a broadened age structure. Under this management scheme, the percentage of migratory fish is likely to increase. The Roanoke River-Ablemarle Sound stock was declared recovered by the ASMFC in 1997 (ASFMC 1998).

Farther north, the Chesapeake Bay tributaries are thought to be the most productive spawning grounds (Merriman 1941), and have contributed as much as 90% of Atlantic coastal landings (Berggren and Lieberman 1978; Van Winkle et al. 1988). In fact, Chesapeake Bay fish make a major contribution to the fishery in the lower Hudson River and New York Bight (Berggren and Lieberman 1978). Spawning habitats in Virginia tributaries to Chesapeake Bay were documented by Tresselt (1950, 1952), Mansueti (1961b), Rinaldo (1971), McGovern and Olney (1988, 1996), Grant and Olney (1991), Olney et al. (1991), and Bilkovic et al. (2002). The only direct observations of striped bass eggs and larvae in major Virginia rivers through 1991 were made by Tresselt (1952), Rinaldo (1971), McGovern and Olney (1988), and Grant and Olney (1991).

Tresselt (1952) surveyed the Pamunkey, Mattaponi, Chickahominy, James, and Rappahannock rivers in Virginia, to determine the location of striped bass spawning grounds. Eggs were collected in appreciable numbers only on the Mattaponi River. In the Pamunkey, Mattaponi, and Chickahominy rivers, the regions of greatest egg abundance coincided with the regions of largest commercial catch. These areas were located in the first 25 miles of freshwater, and usually had high turbidity during the spawning season. The largest numbers of eggs were located 27 km above the mouth of the Pamunkey and 14 km above the mouth of the Mattaponi. Only a few eggs were collected over a wide section of the James and Rappahannock rivers (Tresselt 1952).

Similarly, Mansueti (1961b) depicted the following Virginia rivers as spawning habitat: James, Chickahominy, Pamunkey, Mattaponi, Rappahannock, and Potomac. Surveys of spawning grounds on the Chickahominy and James rivers during 1950 were conducted late, but provided the first direct documentation of striped bass spawning in those systems (Grant and Olney 1991). Additionally, Rinaldo (1971) surveyed the Pamunkey River, Virginia, during the 1966 spawning season, and determined that spawning occurred 8 to 48 km above West Point. Olney et al. (1991) documented striped bass egg mortality, production, and female biomass in Virginia rivers from 1980 to 1989. Sampling was conducted in the James, Pamunkey, Mattoponi, and Rappahannock rivers during April and May. In the Pamunkey River, eggs were collected from river kilometers (rkm) 62 to 72 and 58 to 66 in April 1987. The Pamunkey River was also sampled during 1980, 1983 to 1985, 1988, and 1989, presumably within reach 45.6 to 88.1 rkm (Olney et al. 1991).

Kernehan et al. (1981) suggested that previous, inadequate sampling underestimated the importance of the Upper Chesapeake Bay as striped bass spawning grounds. Phillips (1990) and Mansueti (1961b) identified the following Upper Chesapeake Bay spawning habitats: Potomac River, Patuxent River, Susquehanna River, Northeast River, Elk River, Chesapeake and Delaware (C&D) Canal, Bohemia River, Sassafras River, Chester River, Choptank River, Blackwater River, Honga River/Fishing Bay, Nanticoke River, Wicomico River, Monokin River, and Pocomoke River.

The Susquehanna River was historically the area of greatest egg production, and spawning was recorded as far upriver as Northumberland, Pennsylvania, or beyond (Baird 1855; Dovel 1971). However, following construction of the Conowingo Dam near the mouth (river km 16.1) of the Susquehanna River in 1928, the principal area of egg production appeared to be the main channel of Chesapeake Bay between Western Point and Chesapeake City (Dovel 1971). In the Potomac River, spawning historically occurred as far upriver as Great Falls (Baird 1855;

Hildebrand and Schroeder 1928; Shannon and Smith 1968), but in 1978 was limited to Whitestone Point and below (Nichols and Miller 1967).

In the 1960's and 1970's, major spawning activity centered in the C&D Canal (Beitch and Hoffman 1962; Johnson 1972), which led some researchers around that time to state that this canal was the most important mid-Atlantic region spawning area (Hollis 1967; Dovel 1971; Dovel and Edmunds 1971; Warsh 1977). However, based on total eggs spawned in an area, Kernehan et al. (1981) demonstrated that from 1973 to 1977, the Upper Chesapeake Bay from Turkey Point southeast to Worton Point was far more important to spawning than the relatively small C&D Canal.

For much of the 20th century, the Delaware River exhibited poor water quality and striped bass production was low (Chittenden 1971a). Murawski (1969a) reported larvae over a distance of 108 km in the Delaware, but this distance included a 45 km void in the vicinity of Philadelphia. With improvements in riverine water quality, the Delaware River began to contribute striped bass to the coastal migratory stock (Albert 1988; USDOI and USDOC 1994), and the stock was declared recovered (ASMFC 1998).

In some years, the Hudson River contributes a significant proportion of the coastal stock (Fabrizio 1987; Van Winkle et al. 1988). The Hudson River's primary contribution to the stock occurs north and east of the river (Waldman et al. 1990; Dorazio et al. 1994). Spawning occurs in the fresh-brackish reach of the river and is concentrated between rkm 54 and 88 (Boreman 1981).

In New England, spawning was historically documented in the Thames River, Connecticut (Maltezos 1960), and ripe females were taken in the Mouson River, Maine (Towne 1940). Spawning may have occurred in the past in the Connecticut River (Merriman 1937a), but at least several decades ago no spawning was evident (Whitworth et al. 1968; Thomson et al. 1978), despite the fact that adult fish annually entered the river (Talbot 1966; Whitworth et al. 1968). However, Hardy (1978) reported (based on Neville (1939) and Raney (1952)) that there was no evidence of successful spawning in coastal areas of New Jersey, or in the rivers of New England. Currently, striped bass are apparently spawning in the Kennebec River, since the Maine Division of Marine Fisheries is catching juveniles there on a regular basis (Lew Flagg, Maine Department of Natural Resources, Division of Marine Fisheries, personal communication).

Although there are no documented striped bass spawning runs in the Connecticut River, juvenile striped bass are occasionally taken in the lower river (downstream of river km 12) by electro-shock and beach seine. For the first time in 2004, eight to ten striped bass juveniles were taken in the Connecticut River by electro-fishing during July from above the salt wedge (upstream of river km 40). Although the exact origin of these striped bass juveniles could not be determined with confidence, the juvenile striped bass occasionally taken in the lower river (downstream of river km 12) are believed to have originated from the Hudson River stock. The Hudson River juvenile striped bass survey conducted annually by the New York Department of Environmental Conservation often captures juvenile striped bass as far east as Orient Point, New York (some 100 miles east of the Hudson River). However, the recent capture of juvenile striped bass from the upper Connecticut River (above river km 40) in 2004 probably resulted from limited striped bass spawning in the Connecticut River. Each spring (April to June), there are thousands of adult striped bass in the upper river (above river km 50) that use it as a primary feeding area for pre-spawned American shad and blueback herring. Large (greater than 80 cm) female striped bass are often sampled in the river during the spring, but a ripe female has not been documented in the upper river. Furthermore, during the juvenile alosine beach seine surveys from July through October (1976-2008), researchers have yet to capture a single juvenile striped bass. Given the record size of the current Atlantic coast striped bass stock, limited and occasional spawning in the Connecticut River would be expected. At this time, ecologists regard the Connecticut River as primarily an important spring feeding area for Atlantic coast striped bass, but not a primary spawning area (V. Crecco, Connecticut Bureau of Marine Fisheries, personal communication).

Farthest north, spawning in Canada was historically believed to occur in the Miramichi and Saint John rivers, New Brunswick, Annapolis and Shubenacadie rivers, Nova Scotia, and St. Lawrence River, Quebec (Leim 1924; Leim and Scott 1966; Scott and Crossman 1973). Rulifson and Dadswell (1995) reported that ten Canadian rivers were known or believed to sustain spawning striped bass populations, including:: the St. Lawrence River (where the spawning stock was stated to perhaps be extirpated); the Nepisiguit River in Chaleur Bay; the Tabusintac, Miramichi, Kouchibouguac, and Richibucto rivers in the western Gulf of St. Lawrence; the Saint John, its tributary the Kennebecasis, and the Annapolis rivers in the outer Bay of Fundy; and the Shubenacadie-Stewiacke river system in the inner Bay of Fundy.

Striped bass spawning in Canadian rivers is stated to occur in tidal streams a few weeks after ice leaves the system, and occurs near the head of tide (Rulifson and Dadswell 1995). In Bay of Fundy rivers, spawning is near, or a relatively short distance above, the head of tide. In the Saint John River, spawning occurs in tributaries of Belleisle Bay, approximately 64 km above Reversing Falls (Dadswell 1976). Historically, the main spawning area was at the head of tide around Hart Island above Fredericton, about 65 km upriver from the limit of saltwater excursion (Adams 1873), but it is thought spawning no longer occurs at this site (Jessop 1990).

The Shubenacadie-Stewiacke striped bass population is the only one documented as successfully reproducing in a tidal bore river. The Annapolis River population may also have historically spawned in a tidal bore river, but the tidal bore phenomenon was eliminated by construction of a causeway (Rulifson and Dadswell 1995). In western Gulf of St. Lawrence rivers, spawning occurs just above the head of tide (Hogans and Melvin 1984; Madden 1984). In the St. Lawrence River, spawning is believed to have occurred at, and upstream of, Trois Rivieres (Rulifson and Dadswell 1995). Other possible spawning grounds are alluded to in the literature (Vladykov 1946, 1947; Beaulieu 1962, as cited in Rulifson and Dadswell 1995), but no study of spawning habitats was ever conducted (Magnin and Beaulieu 1967, as cited in Rulifson and Dadswell 1995).

Spawning location (ecological)

There are a number of key components of striped bass spawning habitats necessary to retain functionality and remain hospitable for striped bass adult use, and egg and larval production and survival. These components include: appropriate flow regimes at various temporal scales, including suitable spring attractant flows for stocks migrating to inland spawning grounds and suitable flows during the spawning season; appropriate temperature regimes; appropriate dissolved oxygen levels; absence of adverse levels of turbidity, pH, and contaminants; and suitable prey resources for larvae (W. Laney, personal observation). Setzler et al. (1980) indicated that maintenance of adequate spawning areas with good water quality is the most critical necessity for continued survival of striped bass.

Migratory striped bass mostly spawn in groups in freshwater near the heads of Atlantic coast estuaries, or far inland up major tributaries, depending upon the estuary. Hardy (1978) summarized the general characteristics of spawning habitats used by striped bass. Spawning occurs in fresh, turbid waters in relatively shallow reaches of rivers, streams, and creeks (0.3 to 6.1 m) (Abbott 1878; Tresselt 1950; Murawski 1969b). Some populations spawn in the upper tidal freshwater portions of rivers (Raney 1952, 1956; Tresselt 1952; Humphries 1966; Talbot 1966) in areas just above tidal influence (Bigelow and Schroeder 1953), or hundreds of kilometers inland in turbulent, turbid rapids (Raney 1954; McCoy 1959). These latter areas are frequently associated with the Fall Zone (the relatively narrow belt between the Coastal Plain and Piedmont provinces, where elevation changes more rapidly), and are characterized by boulders and strong currents (Norney 1882; Raney 1952; McCoy 1959; Mansueti and Hollis 1963; Talbot 1966). Stocks in estuarine systems lacking pronounced tidal cycles tend to travel further upstream to spawn (Bain and Bain 1982). Striped bass have never been documented to spawn in lakes, within reservoirs, or in the sea (Goode et al. 1884; Bigelow and Schroeder 1953).

Striped bass spawning runs begin earlier in the southern end of the range, and occur progressively later as the season advances and water temperatures warm (Raney 1952; Bigelow and Schroeder 1953; Leim and Scott 1966; Scott and Crossman 1973; Bain and Bain 1982; Rulifson et al. 1982; Fay et al. 1983; Crance 1984; Hill et al. 1989; Richkus 1990). Pre-spawning aggregations arrive in the Chesapeake Bay during January, February, and March (Dovel 1968). However, nearly all spawning activities in the mid-Atlantic region occur in April, May, and June (Fay et al. 1983). Striped bass appear on spawning grounds in the Cape Fear River, North Carolina, from mid-April to mid-May (Sholar 1977; Fischer 1980). Other North Carolina river striped bass spawning seasons are: April to early May in the Northeast Cape Fear River (Sholar 1977); April to mid-May, or late March to late May, in the Neuse River (Baker 1968; Hawkins 1979); mid-April to mid-May in the Tar-Pamlico River, with a peak of May 3-11 (Humphries 1966); and April 15 to May or June in the Roanoke River (Chapoton and Sykes 1961; Shannon and Smith 1968; Shannon 1970; Street 1975). Spawning runs on the Roanoke River begin when water temperatures reach 7 or 8°C, typically during March, and terminate at the spawning grounds near Weldon around April 1-15 (Merriman 1941; Dickson 1958; Fish and McCoy 1959; NC WRC 1962). Peak spawning on the Roanoke River was reported by Hill et al. (1989) to be May 10-20.

Temporal periods of striped bass spawning are similar throughout Chesapeake Bay (Grant and Olney 1991). Spawning periods for Virginia rivers were reported by Grant and Olney (1991), McGovern and Olney (1996), and Bilkovic et al. (2002). Peaks in spawning were generally sharp and of limited duration. In the York River tributaries (Mattaponi and Pamunkey), peaks occurred in the fourth week of April in both years surveyed (1980 and 1983), and in the Rappahannock River in 1983. In 1982, the peak spawning in the Rappahannock occurred one week earlier. Spawning in the James River was later, peaking the first week in May in both 1981 and 1983, which is also typical in the Potomac (Setzler-Hamilton et al. 1981) and in the upper Chesapeake Bay and the C&D Canal (Johnson and Koo 1975; Kernehan et al. 1981).

The spawning season in the Potomac River was reported as mid-April to mid-June, with a peak from April 23 through May 8 (Baird 1855; Setzler-Hamilton et al. 1981). The spawning season in the Chesapeake Bay was reported as April, May, and early June (Chapoton and Sykes 1961; Dovel 1971). Similarly, in the Chesapeake and Delaware Canal, spawning occurred from mid-April to mid-June, with a peak from April 20 to May 10 (Kernehan et al. 1981). Spawning in the Delaware River was reported as occurring from late May to mid-June, with a peak in June (Raney 1952). In the Hudson River, the spawning period was reported as mid-May to mid-June, with peak activity in the last two weeks of May (Raney 1952; Rathjen and Miller 1957; Boreman and Klauda 1988).

In Canadian populations, including Bay of Fundy rivers, spawning occurs in May and June (Leim and Scott 1966; Scott and Crossman 1973; Meadows 1991; Rulifson and Dadswell 1995). In the Stewiacke, spawning begins in the fourth week of May, and depending upon the weather, continues until about June 20 (Meadows 1991). In the Annapolis River, spawning begins in late May and continues through June. Spawning in the Saint John River occurred in May, beginning May 13th and terminating May 20th (Dadswell 1976).

The exact timing of spawning activity in western Gulf of St. Lawrence rivers is not well documented (Rulifson and Dadswell 1995). Spawning may occur shortly after ice leaves the rivers. Overwintering fish migrate downstream and spawn in May and early June (Vladykov and Brousseau 1957; Hogans and Melvin 1984; Meagher et al. 1987). Spawning in the Kouchibouguac River lasts about three days (Hogans and Melvin 1984). In the Tabusintac River, local fishermen report that spawning occurs in the late summer-early fall, because large adults in reproductive condition are caught during that period. If the fishermen are correct, this would represent the only known fall-spawning population. More information is needed on the Tabusintac population to determine whether these fish are fall spawners, or are just approaching maturity for overwintering (Rulifson and Dadswell 1995).

Maturation and spawning periodicity

In U.S. rivers, males precede females to the spawning grounds in the spring, while females remain offshore or in downstream estuaries until shortly before spawning (Vladykov and Wallace 1952; Trent and Hassler 1968; Holland and Yelverton 1973). After the females arrive on the spawning grounds, characteristic mating behavior consists of a single female surrounded by up to 50 males, at or near the surface (Setzler et al. 1980). Eggs are broadcast loosely in the water, and normal spawning duration for a single female is less than four hours (Lewis and Bonner 1966). Based on the behavior of radio-tagged females in the Choptank and Nanticoke Rivers, Maryland, Hocutt et al. (1990) think that the brackish estuary downstream of spawning habitat is more important than previously recognized for females.

Striped bass appear to be repeat spawners (iteroparous) throughout their migratory range. Raney (1952) reported that striped bass spawn more than once, but not necessarily every year. Hocutt et al. (1990) reported homing of radio-tagged females to the Nanticoke River, Maryland, and believed this constituted strong evidence for annual spawning, as well as strong evidence of natal river fidelity by females.

Studies of mitochondrial DNA (mtDNA) suggest that there is higher female than male fidelity to the natal spawning grounds, at least for Chesapeake Bay populations (Chapman 1987, 1989). Chapman (1989) drew the following conclusions for Chesapeake Bay striped bass: 1) distinct matriarchal groups occurred on spawning grounds of the Choptank River, Potomac

River, and Upper Chesapeake Bay; 2) after age two, mixed aggregations of males and females formed during winter, probably derived from populations not surveyed in 1984; 3) males from the mixed aggregations appeared to have dispersed randomly to spawn in 1986, which suggested that males did not have a strong homing instinct; and 4) females appeared to return to their natal areas, as their mtDNA frequencies in 1987 matched closely the 1984 distributions. The conclusion presumes that striped bass tend to remain in their natal areas until age two (Chapman 1989).

Based on egg collections, the diel timing of striped bass spawning activity appears to be variable among and between systems, and little specific information was found for many of the systems used for spawning. Spawning activity has been noted in late afternoon and early evening (Morgan and Gerlach 1950; NC WRC 1962), as well as late evening and early morning (Hardy 1978). Extensive studies of the vertical, horizontal, and temporal distribution of eggs during the spawning season were conducted in the Roanoke River, North Carolina, by McCoy (1959) and Cheek (1961). McCoy (1959) did not detect a statistically significant daily pattern of egg deposition, although there did appear to be some trends in the adjusted egg data showing higher deposition in the evening (22:00) during mid-May and in the early morning (06:00) during late May. Sampling conducted by Rulifson (1989, 1992) on the Roanoke River suggested that egg deposition occurred more frequently near dusk. Similarly, eggs were taken in the Susquehanna River early in the night (Pearson 1938).

Spawning and the saltwater interface

Salinity and total dissolved solid (TDS) concentrations are thought to be important factors during the striped bass spawning period, and may be responsible for deterring spawning or reducing spawning success (Bain and Bain 1982). In the naturalized population of the Sacramento-San Joaquin River, California, the number of eggs deposited reached a maximum when salinity was less than 0.18 ppt (Farley 1966), and spawning migrations did not occur at a critical salinity concentration of 0.35 ppt (Radtke and Turner 1967). Highly successful spawning was observed in the C&D Canal at salinities of 0.70 to 1.5 ppt (Johnson and Koo 1975). Additionally, Stevens (1979) reported that striped bass might not spawn where salinities exceed 5 ppt.

Salinities in some Canadian spawning sites are reported by Rulifson and Dadswell (1995). In the Bay of Fundy tributaries, the Shubenacadie and Stewiacke rivers, salinities during spawning in 1992 and 1994 ranged from 0.0 to 22.8 ppt. Spawning areas in the Annapolis and Saint John rivers were both located upstream of the salt wedge, and therefore presumably in freshwater (Rulifson and Dadswell 1995).

Spawning substrate associations

Rulifson and Dadswell (1995) reported the bottom composition of some spawning habitats in Canadian rivers. Tidal spawning areas in the Stewiacke River have silty bottoms, and at low tide are lined by mud and sand flats (Rulifson et al. 1987). Prior to the operation of the Annapolis Tidal Generating Station, the primary spawning area above Bridgetown (km 32 through 40, measured from the Annapolis River causeway), Nova Scotia, was characterized primarily by sand interspersed between basalt and granite rocks and boulders (Williams et al.

1984). In the Kennebecasis River, potential spawning habitats include a gravel substrate (Hooper 1967; Melvin 1991). The Kouchibouguac River spawning habitat substrate consists of cobble-sized shale rubble covered by a layer of mud, with eelgrass (*Zostera marina*) as the dominant submerged vegetation (Hogens and Melvin 1984).

Spawning depth associations

Limited information is available regarding the depth of striped bass spawning habitats. Striped bass spawning occurs at, or near, the water surface in some Atlantic coast rivers (Merriman 1941; Raney 1952). In the Shubenacadie and Stewiacke rivers in Canada, historic and present spawning habitats are tidally influenced. At high tide, the areas are deep and relatively wide. At low tide, both areas become narrow, shallow channels (Rulifson et al. 1987). Former spawning areas in the Annapolis River, Nova Scotia, were approximately 30 m wide and consistently 1.5 to 2 m deep. Western Gulf of St. Lawrence spawning habitats also are tidally influenced (Williams et al. 1984).

Spawning water temperature

Water temperature is a key variable influencing the activities of striped bass adults prior to, and during, spawning migrations (Bain and Bain 1982; Crance 1984). Spawning generally occurs in water temperatures ranging from 10.0 to 25.0°C (Nichols 1966; Hardy 1978; Merriman 1941). Spawning peaks are apparently triggered by a noticeable increase in water temperature, generally beginning at temperatures of at least 14°C (Fay et al. 1983). Mature adults usually initiate spawning runs when temperatures reach 14.4°C, exhibit peak activity from 15.8 to 19.4°C, and cease spawning at 20 to 25°C (W. Laney, personal observation). Other temperature extremes reported for spawning were a low of 10°C (IEM 1973) and a high of 26.5°C (Combs 1979).

Dickson (1958) reported that striped bass spawning on the Roanoke River, North Carolina, usually began after temperatures reached 15°C. Optimal spawning temperatures for the Roanoke River were reported as approximately 17 to 19°C, with no spawning observed below 12.8°C or above 22°C (Shannon and Smith 1968). McCoy (1959) reported a minimum spawning temperature of about 15°C and a maximum of about 22°C for the Roanoke River.

In Chesapeake Bay, the striped bass spawning water temperature range was from 10.4 to 23.9°C. However, most spawning occurred between 14.4 and 21.1°C, with peak activity from 17.8 to 20.0°C (based on egg presence) (Raney 1952; Sheridan et al. 1961; Hollis 1967; Rinaldo 1971). Peak spawning activity was observed to follow a rise of 3.5°C (Tiller 1955). Kernehan et al. (1981) collected striped bass eggs in the vicinity of the C&D Canal in temperatures ranging from 8.4 to 29.0°C, but the researchers noted that most larvae produced in the area resulted from intensive spawning in water with temperatures from 13.5 to 18.0°C. Peak egg densities in Virginia tributaries to Chesapeake Bay were limited to rapidly rising water temperatures in the range 13.7 to 19.5°C, with eggs found in a wide range of 8.0 to 21.2°C. Eggs were nearly always in freshwater (Grant and Olney 1991).

Spawning temperatures have been documented for striped bass in most of the Canadian rivers where they are present. In Canadian rivers entering the Bay of Fundy, spawning is initiated when temperatures reach 11 to 11.5°C, and ceases above 22°C (Rulifson and Dadswell 1995). In the Shubenacadie-Stewiacke system, males in spawning condition were found at 14°C, and ripe females were common at 16°C. In 1992, eggs were present at temperatures from 15.5 to 22.0°C (Rulifson and Dadswell 1995). In 1994, major spawning activity occurred when water temperatures reached 18°C (K. Tull and R. A. Rulifson, East Carolina University, unpublished data). Spawning in the Annapolis River occurred at water temperatures from 15 to 24.4°C (Williams 1978; Parker and Doe 1981; Williams et al. 1984). Spawning in the Saint John River began at about 11.5°C, and maximum activity was observed at 13.5°C (Dadswell 1976). In western Gulf of St. Lawrence rivers, spawning temperatures were: Kouchibouguac River, 12 to 14.5°C, with three-day duration (Hogans and Melvin 1984); Miramichi River, spawning condition individuals of both sexes present at 12 to 14°C; Richibucto River, both sexes ripe at 16 to 16.5°C (Rulifson et al. 1987).

Initiation and duration of spawning are both temperature-dependent (Calhoun et al. 1950; Rathjen and Miller 1957), and sudden drops in temperature as a result of the passage of cold fronts, or flood-control or hydropower operations, may interrupt spawning in U.S. rivers (Calhoun et al. 1950; Chadwick 1958; Mansueti and Hollis 1963; Farley 1966; Combs 1979; Hawkins 1979). In contrast to this pattern, in the Annapolis River, Nova Scotia, peak egg production was observed after temperature drops (Parker and Doe 1981); however, rapid temperature drops to 15 or 16°C resulted in temporary cessation of spawning (Williams 1978). Spawning generally occurs on rising temperatures (Neal 1967, 1971). Depending on the estuary, there may be one to three peaks in spawning each season. Such peaks are thought to result from major increases in temperature (Hardy 1978).

Spawning dissolved oxygen associations

Dissolved oxygen concentrations greater than 5 mg/L are recommended for all life stages of striped bass (USEPA 1976; Setzler-Hamilton and Hall 1991). Given that spawning adults are present in the spring of the year when river temperatures are usually lower, oxygen concentration is not generally a limiting factor. However, historically, striped bass spawning areas in the Delaware River were eliminated due to low oxygen concentrations. Collections of fish throughout the freshwater sections of the Delaware River from 1963 to 1966 contained no striped bass. Gross pollution of the tidal freshwater zone of the river destroyed its utility as a spawning area, and resulted in the extirpation of the striped bass from the tidal fresh and freshwater portions of the river. Restoration of striped bass was deemed possible if pollution was decreased so that the tidal freshwater portion of the river was functionally restored (Chittenden 1971a). Such restoration did in fact occur, and the striped bass once again spawns in the Delaware River (W. Laney, personal observation).

Spawning and water velocity/flow

Water flow discharge and timing in striped bass spawning rivers are significant factors determining spawning habitat suitability (Fish and McCoy 1959; Turner and Chadwick 1972; Mihursky et al. 1981). Some authors note that the suitability of a spawning area appears to increase with greater river discharge (expressed as the percent of natural flow). Consequently, Fish and McCoy (1959) found that a sustained minimum flow was necessary for suitable spawning conditions in the Roanoke River, North Carolina, and that rapid fluctuations in stream flow were detrimental to spawning.

Differences in the area and spatial extent of striped bass spawning habitat can occur in years of drought (Grant and Olney 1991). Data from the James River, Virginia, contrasted a year of severe drought (1981) with one of near-average rainfall (1983). Estimated discharge from the James River system into Chesapeake Bay during 1981 (March-May) averaged only 69,000 cfs, compared with 180,000 cfs in 1983. The peak egg production zone was displaced 15 km upriver in 1981, upstream of advancing saltwater, whereas inter-annual differences in the location of peak spawning in other river systems where drought was not a factor were not significant (less than 2 km) (Grant and Olney 1991).

Spawning suspended solid associations

Total dissolved solid (TDS) concentrations above 350 mg/L are reported to have blocked striped bass spawning runs (Radtke and Turner 1967).

Spawning feeding behavior

Spawning striped bass are reported to eat little or nothing, but the fasting process is thought to be brief (Raney 1952; Trent and Hassler 1968). Fish are reported to refrain from feeding only immediately before and during spawning (Morgan and Gerlach 1950; Hollis 1952).

Part B. Striped Bass Egg and Larval Habitat

Survival of striped bass eggs to hatching is primarily associated with relatively narrow tolerances to certain physicochemical factors, including temperature, dissolved oxygen, and current velocity. Development rates of striped bass egg and larval stages are temperature-dependent, within the range of temperatures at which the stages remain viable. Appropriate dissolved oxygen levels and current velocities are also required to maintain viability and keep egg and early larval stages in suspension (Cooper and Polgar 1981).

Survival of the striped bass larval stage is considered to be most crucial for future population abundance of mid-Atlantic striped bass stocks (Fay et al. 1983). Survival rate of larvae, in combination with environmental conditions during early life stages, probably determines the occurrence of occasional dominant year classes so evident in striped bass populations. Given the importance of the larval survival rate to the production of dominant year classes, larval habitats are especially important for sustainability of striped bass populations from individual spawning rivers (Bain and Bain 1982).

Geographical and temporal movement patterns

The habitats occupied by eggs and larvae overlap the spawning areas to a great degree, with larvae occurring further downstream than eggs. Eggs generally hatch in one to three days from fertilization, depending upon temperature (see below). Eggs are transported downstream after extrusion and fertilization, hatch as fry, and subsequently develop into post-larval and juvenile stages. In some river systems, transition from the post-larval to juvenile stage occurs in, or near, the river delta at the head of the adjacent estuary (Rulifson 1984; Rulifson et al. 1992a, 1992b).

The larval yolk-sac phase lasts three to nine days, depending upon water temperature (see below; Albrecht 1964; Eldridge et al. 1977; Rogers et al. 1977). The remaining larval development is variously reported as requiring 22 to 65 days (including an 11-day finfold stage) (Polgar et al. 1976; Rogers et al. 1977), or 35 to 50 days (Bain and Bain 1982). As summer progresses, larger larvae move downstream and by autumn some individuals have reached the mouths of estuaries (Mansueti 1954; Hassler 1958). Striped bass larvae rapidly become very motile, positively phototaxic, and continuously self-suspended (Doroshev 1970). Larvae hatched in relative proximity to estuarine nursery areas characteristically remain in the open surface waters of the estuary (Raney 1952).

In the Chesapeake Bay region, larval nursery areas are the same as the spawning areas (Rinaldo 1971). Larvae are found in both fresh and brackish waters, often in association with white perch (*Morone americana*), although the two species do not spawn in the same locations (Flemer et al. 1968). In the Delaware River, larvae have been recorded within a 103 to 107 km reach, but are found primarily in the first 13 km above Delaware Bay (Murawski 1969a).

Eggs, larvae, and the saltwater interface

Bain and Bain (1982) stated that salinity did not appear to be an important determinant of striped bass egg survival because salinities typically encountered by eggs are not detrimental to survival. However, low salinity is considered optimal for water hardening (Albrecht 1964; Morgan et al. 1981).

Eggs have been found at salinities of up to 12.0 ppt (Tresselt 1950; Hollis 1967; Bason 1971; Dovel 1971). Hollis (1967) found that larvae hatched from eggs at 4.7 to 9.7 ppt survived. Under experimental conditions, survival decreased at salinities above 4.74 ppt (Johnson 1972). Salinity tolerance of striped bass eggs has been reported as 0 to 10 ppt (Mansueti 1958a), 0 to 9 ppt (Albrecht 1964), and 0 to 8 ppt (Morgan and Rasin 1973). Optimum salinities for egg development were reported as 1.5 to 3.0 ppt (Mansueti 1958a) and 1.7 ppt (Albrecht 1964). Maximum survival occurs at 0.900 to 0.948 ppt (Albrecht 1964; Talbot 1966). In addition, development will proceed at 20 ppt, but larvae hatched die within 48 hours (Doroshev 1970).

Larvae have been documented present from 0.0 to 32.0 ppt (de Sylva et al. 1962; Albrecht 1964; Regan et al. 1968; Doroshev 1970; Dovel 1971; Rinaldo 1971; Rogers and Westin 1978). However, greatest density was found at salinity levels less than 2.0 ppt (Dovel 1971), and highest survival occurred up to 10 ppt (Doroshev 1970). Optimal salinities for yolk-sac and post-yolk-sac larvae were reported as 5 to 15 and 5 to 25 ppt, respectively (Rogers and Westin 1978). Optimal range for growth and survival as reported by Lal et al. (1977) was 3 to 7 ppt. Optimal salinities for various-aged striped bass larvae were also reported as follows: 1 to 6 day-old larvae, 3.4 ppt; 7 to 13 day-old larvae, 6.7 ppt; 14 to 20 day-old larvae, 13.5 ppt; 21 to 29 day-old larvae, 20.2 ppt; and 30 to 35 day-old larvae, 33.7 ppt (Lal et al. 1977).

In addition, salinity interactions with temperature affect egg and larval striped bass. Morgan et al. (1981) reported that a temperature-salinity interaction affected percent hatch of eggs and percent survival of newly hatched striped bass larvae, but not larval length at 24 hr of age. Equations were presented for percent hatch and percent survival as functions of temperature (“T”, in °C) and salinity (“S”, in ppt):

$$\text{Percent hatch} = -0.83T^2 + 30.64T - 0.12\,(S \times T) + (2.22 \times S) - 205.8$$

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

The optimal temperature-salinity combination for percent survival was given as 10 ppt at 18°C (Morgan et al. 1981).

Egg and larval substrate associations

Stevens (1966b) suggested that in the absence of current, partially developed eggs or larvae perhaps required sandy or rocky areas with highly oxygenated water in order to escape suffocation and survive. Additionally, Bayless (1968) observed the following percent hatch rates on various substrates: coarse sand 35.7%; plastic 36.4%; silt 13.1%; silty clay 3.2%; and muck-detritus 0.0%.

Egg and larval depth associations

Striped bass eggs are deposited near the surface during spawning activity (Raney 1952). They are buoyant (Mansueti 1958a) or semi-buoyant (Merriman 1937a; Raney 1958), and are found at varying levels within the water column from the surface to the bottom. Egg distribution in the water column appears to be random at velocities in excess of 30 cm/s (Bain and Bain 1982). Yolk-sac larvae either lie horizontally on the bottom (Rinaldo 1971), or perpendicular in the water column with their heads toward the surface (Mansueti 1958a). They may even attempt to swim to the surface, dropping back to the bottom between efforts (Pearson 1938; Dickson 1958; Mansueti 1958a). At one to two days of age, larvae stay near the surface, sometimes attached to floating objects (Mansueti 1958a). By day three, they exhibit continuous swimming ability (Tatum et al. 1966; Doroshev 1970). At about four to five days, yolk-sac larvae are able to swim horizontally, exhibit positive phototaxis, and form schools in laboratory aquaria (McGill 1967). At lengths of 5.5 to 5.8 mm, larvae remain suspended in the water column, never sinking to the bottom (Sandoz and Johnston 1966; Doroshev 1970).

There are indications of a general dispersal of striped bass larvae toward the bottom as feeding begins (Rathjen and Miller 1957; Mansueti 1958a). Two weeks after hatching, larvae forage at the bottom (Rathjen and Miller 1957; Mansueti 1958a), sometimes settling over silt and mud (Hassler 1958). When individuals are about 12 mm long, schools move shoreward and remain in the shore zone throughout the first summer (Raney 1958; Nichols 1966).

Extensive information regarding the horizontal and vertical distribution of striped bass egg and larval stages (yolk-sac, finfold, and post-finfold) was provided for the Potomac River Estuary and the Chesapeake and Delaware Canal, respectively, by Setzler-Hamilton et al. (1981) and Kernehan et al. (1981). Generally, larval stages remained in, or near, the area spawned, although an apparent change in location occurred upstream in the Potomac Estuary, despite a new downstream flow of water (Setzler-Hamilton et al. 1981). The mechanisms proposed to explain this observation (Polgar et al. 1976) were: 1) the active spawning stock continually migrated upstream over time, and therefore, samples indicated an “upstream movement” of larvae; or 2) there was a differential (higher) mortality of early-spawned versus late-spawned larvae. In the C&D Canal, post yolk-sac stages tended to be mid-channel oriented and in highest concentrations near the river or estuary bottom (Kernehan et al. 1981).

Egg and larval water temperature

There is some discrepancy over temperature tolerance for striped bass eggs. Table 9-1 reviews the various findings of researchers on the topic. Morgan and Rasin (1973) and Rogers et al. (1977) indicated that egg survival rapidly declines as water temperature approaches 23°C, and gradually declines as temperature drops below 17°C.

Characterization	Temperature Range (°C)	Citation
Present	8.0 to 25.0	Dovel (1971)
Tolerance	14 to 23	Mansueti (1958a)

Characterization	Temperature Range (°C)	Citation
Optimal	17 to 20	Barkuloo (1970); Doroshev (1970); Morgan et al. (1981); Bain and Bain (1982); Fay et al. (1983)
Optimal	18 to 21	Rogers et al. (1977)
Optimal	19.9 to 20.5	Albrecht (1964)
Maximum	22.2	Barkuloo (1970)
Maximum	21.1	Stevens and Fuller (1965)
Maximum	23	Shannon and Smith (1968)
Maximum	24	Morgan and Rasin (1973)
Minimum	12.8	Albrecht (1964)
Minimum	12	Shannon and Smith (1968); Morgan and Rasin (1973)

Table 9-1. Water temperature tolerance ranges for striped bass eggs

The egg life stage is brief in comparison to other striped bass life stages (Bain and Bain 1982). In general, lower temperatures lead to longer incubation periods (Hardy 1978). Several authors documented hatching at approximately 48 hours after fertilization at a temperature of 18°C (Bain and Bain 1982). In other studies, hatching time varied from 29 hr at 22°C to 80 hr at 11°C (Pearson 1938; Raney 1952; Mansueti 1958a; Hardy 1978).

Two equations have been reported for calculating hatching time of striped bass eggs (Polgar et al. 1976; Rogers et al. 1977). Polgar et al. (1976) gave the following equation based on their observations in the Potomac River: $I = - 4.6 T + 131.6$, where I is incubation time in hours and T is incubation temperature in degrees Celsius. However, Rogers et al. (1977) began their analysis of hatching time with a regression equation: $\mathrm{Log}_{10}\mathrm{length} = bx + a$. Then they gave this equation for time to hatching as a function of temperature: $T_h = ae^b$, where T_h = time to hatching in hours, a = y-intercept of regression equation, b = slope of regression equation, e = base of natural logarithms, and x = temperature in degrees Celsius.

There is also some discrepancy over temperature tolerance for striped bass larvae. Table 9-2 shows the findings of researchers. Additionally, temperature was found to interact with first larval feeding time to determine survival (Rogers and Westin 1981). Time to death for unfed larvae was longer at lower temperatures, within the range of 15 to 24°C (Rogers and Westin 1981).

Characterization	Temperature Range (°C)	Citation
Tolerance	14 to 23	Mansueti (1958a)
Tolerance	11 to 22	Murawski (1969a)
Tolerance	10 to 25	Davies (1970)
Tolerance	12 to 23	Doroshev (1970)
Optimum	16 to 19	Murawski (1969a)
Optimum	15 to 22	Davies (1970)
Optimum	18 to 21	Rogers et al. (1977)
Maximum	23	Shannon and Smith (1968); Doroshev (1970)
Maximum	28	Kelly and Chadwick (1971)
Minimum	10	Davies (1970)
Minimum	11	Doroshev (1970)
Minimum	12	Rogers et al. (1977)

Table 9-2. Water temperature tolerance ranges for striped bass larvae

Duration of the various striped bass larval stages is temperature-dependent (Table 9-2). For example, the yolk-sac stage lasts three days at 23.9°C and six days at 16.7 to 17.8°C (Albrecht 1964). Finfold and post-finfold stages are also temperature-mediated, and last from 11 to 65 days, with higher temperatures shortening duration of the phase (Polgar et al. 1976; Rogers et al. 1977).

Very young striped bass have lower preferred and optimal survival temperatures (less than or equal to 20°C) (Doroshev 1970; Westin and Rogers 1978; Setzler et al. 1980; Coutant 1985). These preferences and physiological optima correspond with spring spawning temperatures, but do not stay that low for very long (Coutant 1985). In the Hudson River, for example, post-yolk-sac larvae were concentrated at depths below 6 m in the main channel during June and July, but migrated to shoal and shore zones as the water temperature increased (McFadden 1977).

Egg and larval dissolved oxygen associations

Sufficient dissolved oxygen is an important factor in ensuring the survival of striped bass eggs and larvae. Low dissolved oxygen concentrations (2.0 to 3.5 mg/L) were determined to be responsible for the absence of eggs and larvae in the Delaware River (Murawski 1969a; Chittenden 1971a). Turner and Farley (1971) reported that even moderate reductions in dissolved oxygen concentrations (from 5 to 4 mg/L) decreased the survival of eggs. Lethal limits for eggs were reported as oxygen concentrations of less than 1.5 mg/L (Mansueti 1958a) and less than 5.0 mg/L (Turner and Farley 1971). The latter value was given as “predisposing to other mortality sources,” rather than being directly lethal.

Dissolved oxygen requirements for larvae are essentially identical to those required for eggs (Bain and Bain 1982). Striped bass larvae need a minimum of 3 mg/L dissolved oxygen to survive (Chittenden 1971a). Moderate reductions in dissolved oxygen concentration (from 5 to 4 mg/L) also reduced the survival of larvae (Turner and Farley 1971). Rogers and Westin (1978) reported that lethal limits were below 2.3 mg/L for yolk-sac, and below 2.4 mg/L for post-yolk-sac larvae.

Egg and larval pH associations

Striped bass egg tolerance limits for pH were reported as 6.6 to 9.0 by Bowker et al. (1969). Regan et al. (1968) reported a pH tolerance of 6 to –9, with an optimum of 7 to 8 for striped bass larvae. In addition, Davies (1970) derived a calculated optimal pH range of 7.46 to 7.85 for striped bass fry.

The effects of pH on larval striped bass, and pH trends in Chesapeake Bay spawning rivers were reviewed by Rago (1992). Laboratory tests indicated that exposure of larval striped bass (less than 50 days old) to pH less than or equal to 6.0 caused rapid mortality, which was amplified as the toxicity of total aluminum increased with decreasing pH (Rago 1992). However, increased water hardness (290 ppm) and increased salinity (5 ppt) reduce the toxic effects of low pH and inorganic contaminants (Palawski et al. 1985). Furthermore, the toxicity of low pH declines after 50 to 80 days post-hatch (Buckler et al. 1987).

Studies of contaminants conducted in association with the Emergency Striped Bass Study (see Rago 1992) demonstrated that low pH rainfall, episodic pH depressions, and extended periods of low pH conditions can occur in some poorly buffered rivers of Chesapeake Bay. Rago (1992) noted that determining the importance of such conditions to the long-term trend (in the case of the late 1970's and early 1980's, a decline) of striped bass populations is much more difficult. For acid deposition to have been a primary cause of the striped bass decline that occurred subsequent to 1970, there must have been a decreasing pH trend in spawning rivers, an increase in the frequency of low pH events during spawning periods, or a combination of both. A thorough survey of data sets on striped bass spawning habitats in Chesapeake Bay indicated no statistically significant ($p<0.10$) changes in the frequency or magnitude of extreme pH events (defined as levels of pH less than 6.5) since 1970 (Janicki et al. 1986). In the Choptank River, extreme pH events were relatively common both before and after 1970, with frequencies of 32% and 39%, respectively. In the Rappahannock River, pH events below 6.5 did not increase after 1970, but pH events in the 6.8 to 7.0 range were more frequent ($p<0.05$). In the York, James and Potomac rivers, extreme pH events were infrequent or absent in the data record (Janicki et al. 1986).

Monte Carlo simulations indicated that daily sampling would have been necessary to detect statistically significant changes ($p<0.10$) in the frequency of low pH events that were observed in the Choptank and Rappahannock rivers (Rago 1992). Low pH and high aluminum concentrations are detrimental to striped bass larvae, but there was no evidence of systematic changes in frequency or magnitude of extreme pH events in any of the Chesapeake Bay spawning rivers in the 1970’s. In most locations, the historical monitoring programs were inadequate to detect all but exceptionally large changes in the frequency and magnitude of extreme pH events (Janicki et al. 1986).

Egg and larval water velocity/flow

A critical factor for egg survival and hatching success is sufficient current velocity to maintain eggs in suspension as they drift downstream (Mansueti 1958a; Albrecht 1964; Talbot 1966; Regan et al. 1968; Bain and Bain 1982). Either tidal turbulence or river discharge can provide sufficient water movement to suspend the eggs (Bain and Bain 1982).

Eggs are slightly heavier than fresh water (Raney 1952; Mansueti 1958a), with an average specific gravity of 1.0005 (Albrecht 1964; Talbot 1966), but are easily floated by agitation (Merriman 1937a; Mansueti 1958a). Specific gravity levels change during early development, and consequently alter the amount of current necessary for suspension. Eggs are less buoyant immediately after fertilization (vertical water movement of 125 cm/sec required for suspension), compared with buoyancy two to three hours later (60 cm/sec required for suspension). Additionally, after 12 hours, unfertilized eggs become opaque and more buoyant than fertilized eggs (Tatem et al. 1966).

Striped bass eggs drift with currents downstream from the spawning areas, sometimes at speeds up to 2.06 km/hr and for distances up to 150 km (Neal 1964). Eggs have been recorded in water flow rates of 54.4 to 269.6 m^3/sec (Sheridan et al. 1960), tolerate current velocities of 30.5 to 500 cm/sec, and survive best at optima of 100 to 200 cm/sec (Mansueti 1958a). In current velocities of less than 30 cm/sec, eggs are generally concentrated near the bottom, and often experience mortality (Albrecht 1964). Talbot (1966) also thought that unsuspended eggs had a poor chance of survival. Similarly, yolk-sac larvae require enough turbulence to keep them from settling to the bottom where they are often smothered (Pearson 1938; Raney 1952; Mansueti 1958a). Larvae tolerate 0 to 500 cm/sec current velocity, but survive optimally at 30 to 100 cm/sec (Regan et al. 1968). In contrast, Bayless (1968) demonstrated that eggs would hatch without any period of suspension, although the percent hatch increased with length of suspension during the first 15 hours post-fertilization.

Egg and larval suspended solid associations

Striped bass eggs appear to be adapted to high turbidity and heavy suspended sediment loads (Bain and Bain 1982). Although neither turbidity nor suspended sediments have been observed to significantly decrease hatching success (Talbot 1966; Schubel and Auld 1974), Auld and Schulbel (1978) reported tolerance limits of 0 to 500 mg/L for larvae, and a lethal limit of 1,000 mg/L for eggs. Auld and Schubel (1978) reported lethality of yolk-sac larvae at levels over 500 mg/L. The lethal dose at which 50% of larvae died after two days (i.e., 48 hr LD_{50}) was reported as 3411 mg/L by Morgan et al. (1973).

Egg and larval feeding behavior

Feeding is generally thought to begin within four to ten days post-hatch (Mansueti 1958b; Tatum 1966). Doroshev (1970) indicated that feeding began at approximately eight days and 6 to 7 mm total length (TL). In laboratory studies, Doroshev (1970) found that first-feeding larvae (less than 10 mm) preferred *Cyclops* nauplii and copepodites. In the Potomac River, Beaven and Mihursky (1980) reported positive electivity of larger copepods and cladocerans, and negative electivity of copepod nauplii and rotifers in a sample of 605 striped bass larvae. At lengths greater than 10 mm, larvae feed primarily on larger zooplankton and macroinvertebrates (Humphries and Cumming 1973).

The availability of sufficient concentrations of suitable prey (i.e., abundant zooplankton) during the first several days of feeding is a critical factor influencing larval survival (Setzler et al. 1980; Cooper and Polgar 1981; Eldridge et al. 1981; Bain and Bain 1982) and subsequent year class strength (Heinle et al. 1975; Eldridge et al. 1981). Miller (1977) estimated that a minimum concentration of 1,864 nauplii per liter was required for successful initiation of feeding. Although zooplankton abundance fluctuates widely over time in any estuary, the potential for an abundance of zooplankton appears to be related to estuarine productivity (Bain and Bain 1982). The level of productivity in an estuary is a function of both freshwater nutrient (detritus) input to the estuary (Biggs and Flemer 1972; Hobbie et al. 1973; Saila 1975; Day et al. 1975; Polgar et al. 1976), and detritus production in adjacent salt marshes (Teal 1962; Odum and Heald 1973; Reimold et al. 1973; Stevenson et al. 1975). Detrital input to the estuary from freshwater inflow is typically greatest during the late winter and early spring (Bain and Bain 1982). Heinle et al. (1975) and others have proposed that certain climatic events, which affect nutrient release from the salt marsh and nutrient contribution by freshwater input, can influence plankton abundance during the critical larval stage and consequently affect year-class size in striped bass.

The complex relationship of estuarine productivity, zooplankton abundance, and larval striped bass survival appears to have important ramifications for the success of striped bass in estuarine systems and for the evaluation of habitat suitability (Bain and Bain 1982). Apparently, even optimal habitat will only occasionally produce ideal conditions for striped bass survival, and hence produce a strong year class. However, the loss of habitat suitability, which would diminish the potential to produce strong year classes, might ultimately have serious consequences for maintenance of a viable striped bass population.

Egg and larval competition and predation

Predation may have a significant effect on egg and larval survival; however, quantitative estimates of the magnitude of predation are lacking for fish eggs and larval fish in general (May 1974; Dahlberg 1979), and for striped bass in particular (Setzler et al. 1980, McGovern and Olney 1988). Setzler et al. (1980) and Fay et al. (1983) speculated that adult and juvenile white perch probably consume large numbers of striped bass larvae. In addition, Dendy (1978) reported predation on striped bass larvae by sessile freshwater hydra polyps, *Crespedacusta sowerbyi*. Smith and Kernehan (1981) found significant predation on striped bass larvae by the free-living copepod *Cyclops bicuspidatus.*

McGovern and Olney (1988) assessed predation by fish and invertebrates on the early life history stages of striped bass in the Pamunkey River, Virginia. Field surveys during the spawning season indicated that numerous fish and invertebrate predators varied in spatiotemporal coincidence with eggs and larvae of striped bass. Neither eggs nor larvae of striped bass were positively identified in gut samples (235 stomachs of 14 species) from field-collected fishes, although various fish species did consume many white perch eggs. In the laboratory, striped bass larvae were either attacked and killed, or eaten, by the cyclopoid copepod *Acanthocyclops vernalis,* and juvenile or adult satinfin shiner *Notropis analostanus,* spottail shiner *N. hudsonius*, tessellated darter *Etheostoma olmstedi*, white perch *Morone* *americana,* striped bass, bluegill *Lepomis macrochirus,* pumpkinseed *L. gibbosus,* channel catfish *Ictalurus punctatus,* and white catfish *I. catus*. Consumption of larvae by spottail and satinfin shiners increased with larger prey densities to maximal ingestion of 150 and 81 larvae per predator per hour, respectively. At prey concentrations simulating ambient densities in the Pamunkey River (20 to 100 larvae/m^3), consumption by both fish species ranged from zero to five larvae per hour. Those estimates were considered to be lower limits because prey densities were not maintained during the experiments (McGovern and Olney 1988).

Based on their work and that of previous authors (Dendy 1978; Kohler and Ney 1980; Smith and Kernehan 1981), McGovern and Olney (1988) concluded that six fish families (i.e., clupeids, cyprinids, ictalurids, percids, centrarchids, and moronids) and at least two invertebrate species (copepod *A. vernalis*, and hydra *C. sowerbyi*) were potential predators on striped bass early life stages. Furthermore, based on population abundance at the spawning grounds and knowledge of feeding behavior, the researchers indicated that bay anchovy *Anchoa mitchelli*, Atlantic menhaden *Brevoortia tyrannus*, other clupeids, yellow perch *Perca flavescens*, inland silverside *Menidia beryllina*, other percids, other cyploid copepod species, and insect larvae, should all be considered potential predators (McGovern and Olney 1988). McGovern and Olney (1988) noted that some of the additional fish species, as well as six cyclopoid copepod species, are abundant on striped bass spawning grounds in the Chesapeake Bay region and may be predators of striped bass larvae. Juvenile bay anchovy were viewed as a potential key striped bass larval predator in tidal freshwater systems, given their abundance in mid-channel areas of the Pamunkey River, and documented laboratory predation rates on other species (Dowd 1986).

Cannibalism and predation by moronid larvae or juveniles have been suggested as additional sources of striped bass larval mortality. Larval fish replaced insect larvae as the dominant food item of juvenile striped bass (25 to 100 mm SL) in some areas of the Potomac River, suggesting that slow-growing or late-spawned striped bass larvae could be cannibalized (Boynton et al. 1981). McGovern and Olney (1988) reported predation on striped bass larvae in the laboratory by 29-day-old striped bass (15 to 18 mm SL), and concluded that cannibalism could occur within the duration of a normal spawning period.

Effects of contaminants on eggs and larvae

Several authors have summarized the effects of various pesticides, heavy metals, pharmaceutical drugs, and other commonly discharged chemical substances on striped bass eggs, larvae, and juveniles (Bonn et al. 1976; Middaugh et al. 1977; Morgan and Prince 1977; Westin and Rogers 1978). Three classes of substances have been the primary focus of study: 1) monocyclic aromatic hydrocarbons (e.g., benzene); 2) chlorinated hydrocarbons (e.g., polychlorinated biphenyls, or PCBs); and 3) residual chlorines.

Relatively low levels of residual chlorine produced pronounced impacts to striped bass eggs and larvae (Middaugh et al. 1977; Morgan and Prince 1977). Eggs experienced 100% mortality at 0.21 mg/L residual chlorine; 3.5% hatch and scoliosis (spinal curvature) at 0.07 mg/L residual chlorine; and 23% hatch, with difficult chorion detachment, at 0.01 mg/L residual chlorine (Middaugh et al. 1977). There were no significant effects at levels below 0.01 mg/L residual chlorine (Middaugh et al. 1977).

The incipient lethal concentration (level at which mortality is first observed) of residual chlorine for yolk-sac larvae was 0.04 mg/L (Middaugh et al. 1977). Eggs less than 13 hours old suffered 100% mortality at 0.43 mg/L residual chlorine (Morgan and Prince 1977). Eggs that were 24 to 40 hours old experienced 100% mortality at 0.50 mg/L residual chlorine. The LC_{50} values of residual chlorine for less than 13 hour and 24 to 40 hour-old eggs, respectively, were 0.22 and 0.27 mg/L. The corresponding value for yolk-sac larvae was 0.2 mg/L residual chlorine (Morgan and Prince 1977).

Other factors involving eggs and larvae

Striped bass populations in the past have been characterized by dramatic fluctuations in year-class size (Bain and Bain 1982). Merriman (1941) first noted the occasional occurrence of unusually large year classes of striped bass, and suggested a relationship between certain climatic conditions and strong year classes. Larval survival is traditionally considered a crucial factor in the determination of adult population size in species exhibiting large fluctuations in abundance (May 1974; Dahlberg 1979). Research indicates that this concept is particularly applicable to striped bass (Polgar et al. 1976; Cooper and Polgar 1981; Eldridge et al. 1981).

In addition, Chesapeake Bay spawning and nursery habitats for striped bass may be of primary importance in sustaining the coastal migratory stock of striped bass, given that a majority (variously stated as from 50 to 90%) of the Atlantic coastal catch of migratory striped bass originates from spawning grounds in Chesapeake Bay (Setzler et al. 1980). Spawning success and young-of-the-year survival in the Chesapeake Bay area may largely determine subsequent striped bass catches from Long Island to Maine (Tiller 1950; Raney 1952; Mansueti 1961b).

Part C. Striped Bass Juvenile and Adult Riverine and Estuarine Habitat

Geographical and temporal movement patterns

Juvenile striped bass from coastal populations generally reside in riverine and estuarine habitats on a year-round basis, and rarely complete coastal migrations. Juveniles of various (or unspecified) sizes are documented from streams (Abbott 1878), rivers (Rathjen 1955), bays (Raney 1958), sounds (King 1947), sheltered coves (Rathjen and Miller 1957), flats (Howarth 1961), and freshwater ponds (Alperin 1966b). Apparently juvenile striped bass will use various nearshore microhabitats and do not appear to require specific microhabitat conditions (Bain and Bain 1982). Older juveniles may begin to move offshore in the fall (Carlson and McCann 1969; Texas Instruments 1974), or remain in the lower river (Ritchie and Koo 1968).

Young-of-year striped bass generally move downstream to higher salinity estuarine areas during their first summer (Markle and Grant 1970; Mihursky et al. 1976; Setzler et al. 1980; Raney 1952; Carlson and McCann 1969; Texas Instruments 1974; Kernehan et al. 1981). In general, there is a downstream movement of juveniles with age (Rinaldo 1971), but this movement may be more pronounced in the second summer for fish of 150 mm or more in length. Such fish may be present in the lower reaches of rivers, or may have already entered bays and sounds (Rathjen and Miller 1957; Raney 1958; Trent 1962; Alperin 1966b; Nichols 1966).

Initiation and extent of juvenile striped bass migrations vary with location (Westin and Rogers 1978), and most juveniles remain in the river and estuarine areas where they were spawned. Fay et al. (1983) reported that little evidence exists for coastal migrations of fish less than two years old, based on Vladykov and Wallace (1938), Merriman (1941), Mansueti (1961a) and Massman and Pacheco (1961). However, many do leave their natal rivers when they are two or more years of age (Atlantic Striped Bass Plan Development Team 2003).

Both juvenile and adult striped bass form schools. Small schools of juveniles are maintained into the second year of life (Abbott 1878; Raney 1952, 1954; Bigelow and Schroeder 1953; Mansueti and Hollis 1963). Westin and Rogers (1978) reported that juvenile striped bass are found in groups of a few fish to thousands in riverine and estuarine areas. Schooling is typical for striped bass as large as 4.5 kg. Larger fish school at various times, but individuals over 13.6 kg are more often found singly or in small groups (Raney 1952; Bigelow and Schroeder 1953). Additionally, striped bass appear to school by size rather than age (Westin and Rogers 1978). Vladykov and Wallace (1938) concluded that striped bass schooling patterns were based on schooled prey fish movements, rather than isotherms or salinity variations.

In the upper Chesapeake Bay, juvenile striped bass primarily remain in nursery areas, although some move through the C&D Canal into Delaware Bay (Ritchie 1970). Juveniles in deep water in lower Chesapeake Bay estuaries in November and December move into holes over 30.5 m deep in February and March (Mansueti 1954). Additionally, young-of-year striped bass released at the mouth of the Patuxent River, Maryland, remained in shoal areas during the summer (Ritchie and Koo 1968). Five to sixteen months later, some of the fish were captured 80 km or more up the Chesapeake Bay. Young-of-the-year released 27 to 53 km up the Patuxent River in fall and winter remained more or less stationary, although there were indications of a net upriver movement extending virtually into freshwater. In the following summer (second year of life), there was a definite movement downriver and into the Chesapeake Bay (Ritchie and Koo

1968). Ritchie (1970) found that fish hatched in the Patuxent River moved up the Chesapeake Bay in their second to forth year. Similarly, Setzler-Hamilton et al. (1981) found some upstream movement of 1976 juvenile striped bass during their first summer in the Potomac River estuary.

Coutant and Benson (1990) evaluated summer water temperatures, dissolved oxygen concentrations, distribution of striped bass sub-adults and adults, and juvenile abundance indices in Chesapeake Bay to discern any influences of summer habitat suitability on historical changes in populations. Criteria used to define summer habitat suitability were the same as identified for freshwater reservoirs (temperatures below 25°C and dissolved oxygen above 2 to 3 mg/L), and were confirmed for the York-Pamunkey estuary in the lower Chesapeake Bay. Habitat suitability in the upper central basin of Chesapeake Bay declined significantly from 1962 to 1987, as did striped bass juvenile abundance indices (i.e., mean catch per standard seine haul). Thickness of the suitable temperature-oxygen habitat correlated significantly with Maryland juvenile indices the following year. Relative reproduction performance of upper bay (Maryland) and lower bay (Virginia) striped bass changed between 1967 to 1973 and 1980 to 1988, in parallel with reductions in upper bay summer habitat (Coutant and Benson 1990).

Two key habitat areas for striped bass sub-adults and adults were identified in Chesapeake Bay, based on the annual temperature-oxygen cycle (Coutant and Benson 1990). The areas were: 1) a zone of cool water in north-central Chesapeake Bay near Annapolis, Maryland, where sub-adult and adult fish congregate in summer; and 2) a shallow sill across the lower bay near the mouth of the Rappahannock River, Virginia, where warm surface waters (greater than 25°C) in summer impinge on the bottom and may block egress from the bay. Reduced juvenile production at the head of the bay and subsequent population decline would be consistent with limitation of historically important habitat in summer. The resultant physiological stresses of high temperature and low dissolved oxygen would affect reproductive competence the following year (Coutant and Benson 1990).

Local movements of adult striped bass within estuaries have also been investigated. Results from sonic tracking by Koo and Wilson (1972) in the C&D Canal indicated that movements were made in a “rest and go” manner, often with lengthy rest periods. If currents moved in a desirable direction, the fish swam or drifted with the current. In an opposing current, fish remained stationary. There was little difference between day and night movements (Koo and Wilson 1972).

Great South Bay, Long Island, New York, was determined to constitute an important post-spawning habitat for young striped bass aged two to four from multiple localities, based on tagging conducted by Alperin (1966a). Of 1,917 fish seined and tagged in May and June, 281 were recovered, with 63% from New York, 11% from New England, and the remaining 26% from areas south of New York. In New York, more recoveries came from eastern than western Long Island waters, and only 2.4% were from the Hudson River. The author speculated that the irregular presence of large numbers of striped bass in Great South Bay was related to the appearance of fish from dominant year classes originating outside the state, probably from the Delaware and Chesapeake bays. If emigration from the south diminishes, Alperin (1966a) suggested that the principal source of striped bass using the bay might be of Hudson River origin.

Juveniles/adults and the saltwater interface

Characterization	Salinity (ppt)	Life Stage	Size (mm)	Citation
Tolerance	0.2 to 16.0	Juvenile		Merriman (1937a); Dovel (1971)
Tolerance	0 to 35	Juvenile	50 to 100	Bogdanov et al. (1967)
Tolerance	0 to 20	Juvenile	20 to 50	Bogdanov et al. (1967)
Tolerance	0 to 33.7	Adult		Rogers and Westin (1978)
Optimal	10 to 20	Juvenile	50 to 100	Bogdanov et al. (1967)
Optimal	10 to 15	Juvenile	20 to 50	Bogdanov et al. (1967)
Summer	> 2.0	Sub-adult		Bason (1971)
Overwinter	< 10	Resident riverine		Bason (1971)

Table 9-3. Juvenile and adult riverine and estuarine salinity ranges

Various salinity ranges are given in Table 9-3 for juvenile and adult striped bass. In the Potomac River, large fish were found upstream in salinities of 7 to 11 ppt, beyond which body size decreased with decreasing salinity (Mansueti 1959). Mason (1882) found that young fish appeared less able to adapt to abrupt salinity changes than adults.

A significant interaction between salinity and temperature tolerance has been reported for striped bass by several authors (Tagatz 1961; Otwell and Merriner 1975; Morgan et al. 1981). Tagatz (1961) reported that a transfer of juveniles from saltwater directly to freshwater was only lethal below an acclimation temperature of 12.8°C. Otwell and Merriner (1975) reported that the highest mortality of test groups occurred for the highest salinity/lowest temperature test combination. Fish younger than 28 days had significantly lower mortality rates than fish over 28 days old, for any given temperature-salinity combination. Additionally, Doroshev (1970) found that fish 100 to 170 mm in length died when transferred from freshwater at 21.1°C to 35 ppt at 7°C, but survived the reciprocal transfer.

Juvenile/adult substrate associations

Juvenile striped bass are generally found over clean, sandy bottom (Merriman 1937a; Raney 1952, 1954; Rathjen and Miller 1957; Wolcott 1962; Smith 1971). However, juveniles with an average length of 50 mm have also been found over gravel beaches (Raney 1952), and those 71 to 85 mm have been found over a mixture of mud, sand, gravel, and rock (Merriman 1941). Rathjen and Miller (1957) found them rarely over soft bottom. Additionally, juveniles in the Hudson River used shoals as nursery habitat (Carlson and McCann 1968).

Juvenile/adult depth associations

Information on juvenile striped bass depth associations is limited. Juveniles were generally found in shallow water, although “fingerlings” were recorded from deep water (over

30.5 m) in Chesapeake Bay (Mansueti 1954). Merriman (1941) recorded specimens 71 to 85 mm long in water 2.4 m deep. Overwintering occurred in depths of up to 37 m (Mansueti 1956).

Juvenile/adult water temperature

Water temperature is a key variable in determining the distribution of juvenile and adult striped bass, as a consequence of the species' thermal niche (defined by Coutant (1985) as near 24 to 26°C) (Coutant 1985, 1986). Many field studies documented that first-year migratory juveniles occupied shallow, inshore waters of estuaries during summer (Merriman 1937a; Raney 1952, 1954; Rathjen and Miller 1957; Mansueti 1961a; Smith 1971; McFadden 1977). Water temperatures in these habitats often are above 24°C. In fact, juvenile growth in temperate estuaries is always fastest in midsummer, when temperatures are highest (Vladykov and Wallace 1952; Rathjen and Miller 1957; Koo and Ritchie 1973; Texas Instruments 1975, 1976). Indices of juvenile striped bass abundance in estuaries typically are obtained by seining or trawling in shallow nursery areas. Examples include Albemarle Sound (Hassler et al. 1981), Chesapeake Bay (Scott and Boone 1973), and the Hudson River (McFadden 1977).

The high thermal affinities of juvenile striped bass have also been observed experimentally. Davies (1973) acclimated first-year striped bass to 26.7°C, from which they tolerated transfers to 32.2°C, but died at temperatures above 35°C. Bowker et al. (1969) reported that juveniles tolerated temperatures as high as 29°C in ponds. Growth and feeding rates of one-month-old juveniles increased with temperature between 12 and 24°C (Otwell and Merriner 1975). In gradient studies in the laboratory, temperature preference of juveniles was near 25°C (Meldrim and Gift 1971). Short-term preferred temperatures were determined by Texas Instruments (1976) to be 29 to 31°C, 26 to 27°C, 23 to 24°C, and 14 to 17°C for acclimation temperatures of 24, 21 to 22, 17, and 6°C, respectively.

High summer-fall abundances of age-0 striped bass in the Patuxent River estuary, Maryland, were positively associated with low winter temperatures (Wingate and Secor 2008). Winter temperature at the site (near the mouth of the river) ranged from 3.3 to 6.6°C. Wingate and Secor (2008) did not directly address the mechanisms by which winter conditions affect the summer-fall nursery fish assemblage. However, the researchers noted that winter conditions can affect subsequent spring and summer estuarine production, spawning and recruitment phenology, and distributions of juvenile striped bass. Winter temperatures and flow may affect nursery stability and production differentially among species (i.e., anadromous versus coastal-spawning species) (Wingate and Secor 2008). It is well-documented that nursery zones expand for anadromous species during years with cold, wet winter conditions (Secor 2000; Jung and Houde 2003; North and Houde 2003).

The thermal niche of adult striped bass, based on a literature review by Coutant (1985), was 18 to 25°C (centered around 20°C). However, such a niche would be a realized one, rather than the fundamental niche (Coutant 1990) because temperature selection by large striped bass in the studies reviewed was constrained by a lack of alternative temperatures or by hypoxia. In contrast, Bettoli (2005) conducted a study in a reservoir where a broad range of temperatures were present and hypoxia uncommon; they suggested that the fundamental thermal niche of adult landlocked striped bass might be lower than literature estimates.

Characterization	Temperature Range (°C)	Citation
Tolerance	10 to 27	Bogdanov et al. (1967); Davies (1970); Hester and Stevens (1970)
Optimal	14 to 21	Krouse 1968; Doroshev 1970)
Maximum	35	Talbot (1966); Gift and Westman (1972)
Overwintering	3.55 to 6	Vladykov and Wallace (1952)

Table 9-4. Water temperature ranges for juvenile riverine and estuarine striped bass

Temperature is an important factor affecting growth and survival of juvenile striped bass (Bain and Bain 1982). Water temperature ranges are presented for juvenile striped bass in Table 9-4. Meldrim and Gift (1971) found that specimens 80 to 149 mm in length preferred temperatures varied from about 15°C, in December, to around 26°C, in October. In addition, Loeber (1951) found that juveniles acclimated to higher temperatures exhibited higher lethal limits than those acclimated to lower temperatures. For example, those acclimated at 15.6°C had an LD_{50} of 31.0°C; those acclimated at 11.0°C had an LD_{50} of 29.4°C (Loeber 1951). In another study, Tagatz (1961) found that transfers of juvenile striped bass from 12.8 and 21.1°C to 7.2°C were lethal, but the reciprocal transfer (cold to warm) was not (Tagatz 1961). These findings agree with the premise that fish acclimate more easily to rising temperatures than to falling temperatures. Furthermore, juveniles appeared to be less tolerant of abrupt temperature changes than adults (Tagatz 1961).

In comparison, adult striped bass were reported by Tagatz (1961) to tolerate temperatures from 0 to 30°C with no apparent ill effects. However, adult striped bass temperature preferences depend on ambient acclimation temperatures. The maximum upper avoidance temperature is 34°C for striped bass acclimated to 27°C in late August, while striped bass acclimated to 5°C in December avoid 13°C water (Meldrim and Gift 1971). Maximum preferred temperature of 25 to 27°C was reported during the growing season (Merriman 1941).

An important hypothesis regarding striped bass adult temperature and dissolved oxygen limitations was postulated by Coutant (1985). Coutant (1985) noted that striped bass had a “paradoxical record” of distribution and abundance, including population declines in coastal waters and variable success when introduced in various freshwater reservoirs. He analyzed the record for consistency with his hypothesis that striped bass could be “squeezed” into areas delimited by their thermal and dissolved oxygen preferences or requirements. He suggested that field and laboratory observations confirmed striped bass possessed an inherent thermal niche that changed to lower temperatures as the fish aged. Such a shift could cause local conditions, especially warm surface waters and deoxygenated deep water, to be incompatible with the success of large fish. Crowding due to temperature preferences alone, or coupled with avoidance of low oxygen concentrations, could lead further to pathology, or overfishing, and thereby be a contributing factor to population declines. The thermal niche-dissolved oxygen hypothesis was proposed as a unified perspective of the habitat requirements of striped bass that could aid in study and management of the species (Coutant 1985). Furthermore, subsequent analysis of changes in habitat quality within Chesapeake Bay (Coutant and Benson 1990) suggested that “habitat squeeze” may have been a factor in past population declines.

Juvenile/adult dissolved oxygen associations

Mansueti (1961a) was among the first to recognize that striped bass could tolerate waters having marginal water quality. This observation was supported by studies of respiratory metabolism (Neumann et al. 1981). One factor, the sensitivity of striped bass to different dissolved oxygen levels, was reviewed by Coutant (1985). Striped bass field observations and experimental results in both freshwater and estuarine systems support the statement that striped bass become physiologically stressed as the dissolved oxygen content decreases to around 3 mg/L, and that concentrations near 2 mg/L are considered uninhabitable (Coutant 1985). In Chesapeake Bay, Chittenden (1971a, 1971b) found the 3 mg/L dissolved oxygen isopleth approximately restricted the distribution of striped bass. In addition, Talbot (1966) suggested that 4 mg/L might be too low for successful reproduction.

Several studies reviewed by Coutant (1985) attempted to experimentally define the limit of striped bass performance in reduced dissolved oxygen conditions (Hoff et al. 1966; Krouse 1968; Dorfman and Westman 1970; Chittenden 1971b; Meldrim et al. 1974). Restlessness was observed at about 3 mg/L (at 16 to 19°C), followed by inactivity, loss of equilibrium, and finally death as dissolved oxygen was further lowered (Chittenden 1971b). Ventilation rate (measured in gulps per second) was maximized at 2 to 3 mg/L, but declined at lower dissolved oxygen concentrations.

Survival among juvenile striped bass transferred from ambient concentrations to 2 mg/L (at 20°C) and 3 mg/L (at 25.6°C) was 80%(Dorfman and Westman 1970). Krouse (1968) concluded, based on experiments in the water temperature range of 13 to 25°C, that striped bass were capable of surviving dissolved oxygen concentrations of 3 mg/L, but not 1 mg/L. Similarly, Bogdanov et al. (1967) reported that striped bass tolerated dissolved oxygen concentrations of 3 to 20 mg/L, and optimal values were stated as 6 to 12 mg/L. Fish acclimated at 32.8°C experienced lethality after long exposure to concentrations less than 2.4 mg/L (Dorfman and Westman 1970).

Meldrim et al. (1974) found that juvenile striped bass acclimated at 18°C generally avoided dissolved oxygen concentrations of 3.8 to 4 mg/L in experimental gradients. Furthermore, adult striped bass are known to avoid areas of 44% dissolved oxygen saturation or less (Meldrim et al. 1974). Additionally, low dissolved oxygen was determined to adversely affect appetite, and the effects of prolonged poor feeding were serious (Hoff et al. 1966).

Juvenile/adult pH associations

Davies (1970) calculated an optimal pH range for juveniles (cultured fingerlings) of 7.06 to 8.35.

Juvenile/adult water velocity/flow

Young-of-the-year striped bass are generally more abundant in areas with pronounced currents (Rathjen and Miller 1957; Wolcott 1962). Striped bass were reported to tolerate current velocities from 0 to 500 cm/sec, but optimum values were given as 0 to 100 cm/sec (Bogdanov et al. 1967).

Wingate and Secor (2008 found that high summer-fall abundances of young-of-the-year striped bass near the mouth of the Patuxent River, Maryland, were positively associated with high winter flows. In addition to expanding the nursery zone for anadromous species, high flow also intensifies the formation of the maximum turbidity zone and provides favorable early foraging conditions for estuary-spawning fishes (North and Houde 2003). Ross (2003) found that fish population abundances were correlated with availability of nursery habitat that promotes growth and survival. The lower Patuxent River study site used by Wingate and Secor (2008) was situated in a transitional zone along the river-estuary gradient and the upper-lower Chesapeake Bay gradient, and distributional shifts related to availability of nursery habitats might occur in this zone. Winter conditions might also influence the timing of migration and spawning of adult fish, as well as survival of eggs and larvae to juvenile stages (Wingate and Secor 2008). As an example, the timing of spring spawning is a critical determinant of recruitment success in anadromous species, such as striped bass and American shad, *Alosa sapidissima* (Limburg 1995; Secor and Houde 1995).

Juvenile/adult suspended solid associations

Striped bass were reported to avoid areas were total dissolved solid concentrations exceeded 180 mg/L (Farley 1966; Murawski 1969a).

Juvenile/adult feeding behavior

Young striped bass feed on zooplankton, macroinvertebrates, and fish. Stevens (1966a) reported that juveniles in the Sacramento and San Joaquin River estuary fed mainly on invertebrates in winter and spring, and switched to small fish prey when they became available in the summer. They began feeding on larger fish in their second summer (Stevens 1966a). In general, early studies determined that juveniles were not highly selective and consumed food items based on availability (Heuback et al. 1963; Stevens 1966a; Hester and Stevens 1970; Manooch 1973; Boynton et al. 1981).

In Albemarle Sound, the nursery area for the Roanoke River and the Meherrin and Nottoway tributaries of the Chowan River in North Carolina, Manooch (1973) sampled 1,094 yearling and adult striped bass for food habit analysis. The striped bass sampled ranged in size from 125 to 714 mm TL. Approximately 77% of the stomachs contained food organisms. Fifteen species of fish and ten invertebrate prey taxa were identified. Food habits varied substantially with size of fish, area of collection, and season of collection. Striped bass were capable of consuming clupeids approximately 60%of their length, but generally fed on smaller fish averaging 20% of their length. Striped bass preferred soft-rayed species, which generally occurred as juveniles in the Sound (Manooch 1973).

Manooch (1973) noted that fish were the main striped bass prey in Albemarle Sound, and occurred in 93% of the stomachs containing food. Predominant species identified were: Atlantic menhaden (*Brevoortia tyrannus*), blueback herring (*Alosa aestivalis*), and bay anchovy (*Anchoa mitchelli*). Atlantic menhaden constituted 54% of the diet (50% of volume), with medium-sized striped bass commonly containing 20 to 30 Atlantic menhaden. Approximately 12.5% of the striped bass contained bay anchovy, the only other soft-rayed fish that contributed significantly to the diet. American eel (*Anguilla rostrata*) were present in four stomachs (0.12%). Two of the

American eel were adults, and two were immature individuals, all found in spring-collected large striped bass (Manooch 1973).

Manooch (1973) noted that American eel elvers were available during the spring season and thousands were observed migrating up the Roanoke River in North Carolina, but no specimens were noted in striped bass stomachs from that area. Spiny-rayed fish occurred in only 6.7% of the stomachs, but comprised approximately 18% of the volume. Spiny-rayed species present included: spot (*Leiostomus xanthurus*), weakfish (*Cynoscion regalis*), silver perch (*Bairdiella chrysura*), Atlantic croaker (*Micropogonius undulatus*), and white perch (*Morone americana*). Species that occurred only rarely included: Atlantic silversides (*Menidia menidia*), striped bass, pumpkinseed (*Lepomis gibbosus*), and yellow perch (*Perca flavescens*).

Manooch (1973) thought that cannibalism was a rare event, with only two yearling striped bass of 229 examined containing juveniles of the same species. No striped bass were found in larger specimens. Manooch (1973) noted that the low incidence of cannibalism agreed with other prior studies on the East Coast (Hollis 1952; Stevens 1958; Schaefer 1970; Ware 1970).

Invertebrates were of secondary importance to striped bass in Albemarle Sound, and consisted primarily of blue crabs (*Callinectes sapidus*), penaeid shrimp, and gammarid amphipods. Invertebrates occurred in less than 10% of the striped bass stomachs, although they were relatively numerous (18.1% frequency) when present. Total crustacean volume was less than 3% of the stomach bulk, and frequency of occurrence values ranged from 0 to 41% during the study period. The blue crab (18 to 30 mm carapace width) was the most frequently encountered crustacean, yet it occurred in only 5.4% of stomachs (Manooch 1973).

Small striped bass (125 to 304 mm) in Albemarle Sound consumed predominantly juvenile fish. Fish occurred in approximately 96% of the stomachs. Clupeids were the principal forage group present, occurring in 59.58% of the stomachs with food. Bay anchovy was a main component of the yearling diet, present in 28.5% of the stomachs, with frequency of occurrence increasing during late summer and fall. Blueback herring (28%) and Atlantic menhaden (27.5%) were also important prey species. Spiny-rayed fish were infrequently encountered and invertebrates were of little importance, occurring in only 8 of 229 stomachs, and comprising less than 1% of the food volume (Manooch 1973).

Large striped bass (305 to 714 mm) also predominantly consumed fish (91.9%) in Albemarle Sound, but invertebrates were of more importance than they were for small striped bass, occurring in 10.43% of stomachs with food. The predominant prey of large striped bass was clupeid fish, which were identified in 75% of the stomachs. Atlantic menhaden was the primary prey species (62%), although adult blueback herring and alewife contributed to the diet during the spring. Blue crabs were the most frequent invertebrate recovered, but amphipods were of numerical importance. As many as 126 amphipods were removed from a single stomach, suggesting they were selectively ingested (Manooch 1973).

Manooch (1973) found that there were significant differences in the striped bass diet correlated with the area of collection. Chi-square tests indicated that fish taken in the eastern, more saline portion of Albemarle Sound, contained significantly more blue crabs, penaeid shrimps, and gammarid amphipods (25.4%) than those in the western Sound (2.8%). Bay anchovy, spot, Atlantic croaker, silver perch, and weakfish were also more abundant in striped bass stomachs taken from fish in the more saline waters (Manooch 1973).

Manooch (1973) also found significant seasonal variations in Albemarle Sound striped bass food habits. Striped bass collected in summer and fall fed almost exclusively on fish, and specimens collected in winter and spring contained higher percentages of invertebrates. Bay anchovy was more prevalent in fall and spring, Atlantic menhaden in summer and fall, spiny-rayed fishes in fall and winter, adult blueback herring and alewife in spring (during their spawning season), juveniles of those species during the summer (during their nursery residence), and gizzard shad in winter and spring (Manooch 1973).

Researchers at North Carolina State University sampled striped bass (aged 1, 2, and 3+ years) again in western Albemarle Sound, including the Chowan River, in May through October of 2002 and 2003, to characterize diet, prey type, and size selectivity. In this updated study, *Alosa* spp., Atlantic menhaden, bay anchovy, silversides (*Menidia* spp.), and yellow perch dominated the diets of age-1 striped bass, while Atlantic menhaden dominated the diets of older striped bass. Striped bass of all ages consumed predominantly fish prey, regardless of month or year. Each age category of striped bass selected for one or more species of prey from among the clupeids. Averaged by year, striped bass of all ages displayed strong selection *for* Atlantic menhaden and *against* spiny-rayed fish prey. Striped bass demonstrated either neutral size selectivity, or selected for relatively small prey (J. A. Buckel, Center for Marine Sciences and Technology, North Carolina State University, personal communication).

Working in the summer in the York and James Rivers, Virginia, Markle and Grant (1970) found that striped bass less than 70 mm consumed primarily mysid shrimp and insects, respectively. Juveniles between 70 and 150 mm fed primarily on naked gobies (*Gobiosoma bosci*) in the York River and grass shrimp (*Palaemonetes* spp.) in the James River (Markle and Grant 1970).

In the Chesapeake Bay, juvenile striped bass (40 to 100 mm) fed on mysid shrimp (*Neomysis americana*), as well as amphipods (*Gammarus* spp.) and *Corophium* spp. Fish from 100 to 270 mm fed on bay anchovy and various invertebrates (Bason et al. 1975). In addition, Markle and Grant (1970) and Bason (1971) stated that prey selection by juvenile striped bass varied with the salinity of the nursery environment and the corresponding food item availability.

Hollis (1952) examined the stomachs of 1,736 striped bass from Chesapeake Bay during the period June 1936 through April 1937. Striped bass were primarily piscivorous, with fish comprising 95.5% of the diet by weight. Similar to other studies, it was determined that the most common prey during summer and fall were Atlantic menhaden and bay anchovy. Young spot and Atlantic croaker were also prominent prey, dominating the diet during the winter. Less than 2% of Chesapeake Bay striped bass stomach content weight was comprised of crustaceans (0 to 46% frequency). White perch and river herring (*Alosa aestivalis* or *A. pseudoharengus*) were common in spring and early summer. Freshwater organisms were dominant in samples taken from the head of the Bay. Furthermore, there was a tendency toward reduction of feeding in late May and early June, corresponding to the spawning season (Hollis 1952).

Diet of striped bass (aged 0, 1, and 2+) in Chesapeake Bay, and its Choptank, lower Patuxent, and Potomac River tributaries, was also examined between January 1990 and March 1992 by Hartman and Brandt (1995). In general, the contribution of invertebrates to the diet declined with increases in age. Age-0 striped bass ate mostly invertebrates, predominantly polychaetes, gammarid amphipods, and to a lesser degree grass shrimp and mysid shrimp, and also juvenile naked gobies. Age-1 striped bass ate mostly invertebrates (gammarids, softshell clams (*Mya arenaria*), and mysid shrimp) for the first half of the year, but contributions of fish (bay anchovy and Atlantic menhaden) to the diet increased thereafter. Age-2 and older striped bass ate mostly fish (primarily Atlantic menhaden). However, during spring and early summer, age-0 spot, age-1 and older white perch, and polychaetes represented as much as 74 to 89% (combined) of the diets (Hartman and Brandt 1995).

In the Delaware River, juvenile striped bass 50 to 100 mm fed primarily on mysid shrimp (*Neomysis americana*) and sand shrimp (*Crangon septemspinosa*). In low salinity tidal creeks of the Delaware drainage, fish, decapod crustaceans, amphipods, and mysid shrimp were the most important food items (Bason 1971).

In Long Island Sound, Schaefer (1970) found that striped bass between 275 and 399 mm FL fed primarily on *Gammarus* spp., *Haustorius canadensis*, and *Neomysis americana*. Fish from 400 to 599 mm fed equally on fish (bay anchovy, Atlantic silverside (*Menidia menidia*), and scup (*Stenotomus chrysops*)) and amphipods. Striped bass between 600 and 940 mm FL fed more on fish than other length groups (65% of dietary volume), but still consumed amphipods, mysid-shrimp, and lady crabs (*Ovalipes ocellatus*) (Schaefer 1970).

In the Hudson River, striped bass up to 75 mm preferred *Gammarus* spp., calanoid copepods, and chironomid larvae. Juveniles from 76 to 125 mm preferred *Gammarus* sp. and calanoids, and those from 116 to 200 mm preferred Atlantic tomcod (*Microgadus tomcod*) (Texas Instruments 1976).

Sampling by Buckel and McKown (2002) was conducted in three New York Bight embayments (Manhassett Bay, Little Neck Bay, and Jamaica Bay) from May to November in 1997 and 1998. A total of 602 juvenile striped bass were examined for dietary analysis (224 age-0; 378 age-1). Diets of age-0 and age-1 striped bass were dominated by sand shrimp (*Crangon septemspinosa*). Other important prey included mysid shrimp, amphipods, horseshoe crab eggs and juveniles, and polychaete worms (mostly *Nereis* spp.). Similar to other areas of the coast, fish prey (Atlantic silversides, killifish, and bay anchovy) became important for age-1 striped bass starting in mid-summer and fall. These same fish prey made up 25 to 30%, by weight, of age-0 striped bass diets (Buckel and McKown 2002).

Other stomach contents reported for striped bass by Smith and Wells (1977) included the following: alewife (*Alosa pseudoharengus*); blueback herring (*Alosa aestivalis*); mummichog (*Fundulus heteroclitus*); striped mullet (*Mugil cephalus*); rainbow smelt (*Osmerus mordax*); weakfish (*Cynoscion regalis*); silver hake (*Merluccius bilinearis*); American eel (*Anguilla rostrata*); American lobster (*Homarus americanus*); squid (*Ilex* and *Loligo*); and various crab, clam, and mussel species.

Juvenile/adult competition and predation

Mihursky et al. (1976) noted that larval and juvenile striped bass shared common nursery areas with white perch (*Morone americana*), which are usually more abundant than striped bass. The researchers speculated that some competition for food resources probably occurred between the two species (Mihursky et al. 1976).

Bluefish (*Pomatomus saltatrix*) co-occur with striped bass as juveniles and adults in coastal bays and estuaries during the summer and fall, and biotic interactions between the two species have been hypothesized to explain opposite trends in historic landings data (Buckel and

McKown 2002). Fay et al. (1983) noted that direct evidence for competition with adult striped bass was lacking, but speculated that other large piscivores, such as bluefish and weakfish, probably compete with them for schooling forage species.

The diets of young striped bass, bluefish, and weakfish from Chesapeake Bay, and its Patuxent and Choptank River tributaries, were defined and compared across seasons by Hartman and Brandt (1995). Dietary overlap among species and across cohorts within a species was low (24 to 51% bimonthly average range, Schoener's index). Bluefish often had higher dietary overlap values with striped bass and weakfish than with other bluefish cohorts. However, dietary overlap between striped bass and weakfish cohorts was usually low due to disparity in the use of bay anchovy by striped bass (less than 31% in all months) and weakfish (greater than 50% for most age-0 and age-1) (Hartman and Brandt 1995).

In New York, Buckel and McKown (2002) recently examined the potential for competition to influence the population dynamics of bluefish and striped bass through interactions at the juvenile stage. Juvenile bluefish and striped bass were seldom captured together during the summer and early fall, suggesting low habitat overlap at the scale of a beach seine haul. Diet overlap was low also, with age-0 bluefish (both spring- and summer-spawned cohorts) having a more piscivorous diet than age-0 and age-1 striped bass. Laboratory experiments tested for interference competition between age-0 bluefish (spring-spawned) and age-1 striped bass in both mixed and single-species treatments. Results showed that bluefish grew significantly faster than striped bass, but there was no significant difference in growth between mixed and single-species treatments. Long-term field-monitoring data showed that annual estimates of growth rate for bluefish and striped bass were not correlated with annual estimates of their potential competitor's density. Both the field and laboratory data provided no evidence for competitive dietary interactions between juvenile striped bass and bluefish (Buckel and McKown 2002).

Buckel et al. (1999) also studied predation by age-0 bluefish upon age-0 striped bass in the Hudson River estuary. Researchers measured bluefish weight, density, prey size, and diet in order to estimate loss of young-of-the-year striped bass to young-of-the-year bluefish predation. Predation mortality was compared with the total loss of striped bass in the system. Data from sampling surveys conducted since the mid-1970's were used to examine relationships between bluefish abundance and striped bass recruitment levels. Bluefish diets were dominated by young-of-the-year striped bass, bay anchovy, Atlantic silverside, and *Alosa* spp. Bluefish avoided striped bass at low densities, but selected for them at high densities, suggesting a density-dependent feeding response. In the early summer of 1993, bluefish predation accounted for 50 to 100% of the total estimated loss of young-of-the-year striped bass. A significant negative correlation existed between the relative magnitude of striped bass recruitment and bluefish abundance. The authors concluded that young-of-the-year bluefish were important predators of estuarine fish and could have a substantial impact on their recruitment (Buckel et al. 1999).

Effects of contaminants on juveniles/adults

Acute toxicities (24-hour LC_{50}) of monocyclic aromatic hydrocarbons (often present in oil spills) to 6 gram juvenile striped bass were reported by Benville and Korn (1977). The acute levels were: benzene 6.9 mg/L; toluene 7.3 mg/L; ethylbenzene 4.3 mg/L; metaxylene 9.2 mg/L;

orthoxylene 11.0 mg/L; and paraxylene 2.0 mg/L (Benville and Korn 1977). Chronic effects of exposure to sub-lethal benzene concentrations of 3.5 and 6.0 μg/L were tested for four weeks by Korn et al. (1976). The initial reaction was pronounced hyperactivity. Chronic reaction to both levels included an inability to locate and consume food properly, lower percent body fat, and lower dry and wet weight at the end of the test period (Korn et al. 1976).

The relationship between bone strength, bone health and development, and levels of organic and inorganic contaminants was examined in young-of-the-year striped bass from the Nanticoke, Potomac, and Hudson Rivers, and from a North Carolina hatchery (Mehrle et al. 1982). PCBs were the most prevalent organic contaminant found. Hudson River fish had the highest PCB levels, and both Potomac and Hudson River fish had significantly higher levels of total organic contaminant residues than the Nanticoke and hatchery groups. Arsenic, lead, selenium, and cadmium were the most prevalent inorganic contaminants found. Levels of organochlorine residues and heavy metals were highly correlated with bone strength, stiffness, toughness, and stress tolerance. Hudson River fish had the highest residue levels and the poorest bone quality and bone health of the four groups evaluated (Mehrle et al. 1982).

Additionally, the incipient lethal concentration of total residual chlorine to juvenile striped bass was 0.04 mg/L (Middaugh et al. 1977).

Effects of parasites and diseases on juveniles/adults

Parasites and diseases of striped bass are reported in Paperna and Zwerner (1976) and Bonn et al. (1976). Summary tables of parasite and disease literature are provided in Westin and Rogers (1978), Smith and Wells (1977), and Setzler et al. (1980). Commonly reported diseases of striped bass include: fin rot diseases, pasteurellosis, columnaris, lymphocystis, and epitheliocystis (Setzler et al. 1980).

Since the late 1990's, mycobacterial infections in Chesapeake Bay fish have become a concern (Ottinger and Jacobs 2006). Blazer (2006) gives a thorough review on what is known about the disease and how it affects migratory striped bass. Mycobacteriosis in striped bass is characterized by cutaneous reddish lesions, visceral lesions, or a combination of the two. It is a chronic disease that develops slowly. Pathogenesis is dependent on the species of *Mycobacterium* involved, is temperature dependent (e.g., more prevalent at high temperatures), and may be dose dependent. Furthermore, striped bass can be infected without exhibiting pathology (Blazer 2006).

Part D. Late Stage Striped Bass Juvenile and Adult Marine Habitat

Geographical and temporal patterns at sea

Migration of Atlantic coast striped bass occurs during the juvenile and adult life history stages (Atlantic Striped Bass Plan Development Team 2003), and transits habitats in the nearshore Atlantic Ocean from Topsail Island, North Carolina, to Nova Scotia, Canada. Individuals migrating to the ocean generally are found moving north along the coast in summer and fall, and south during the winter, with the extent of migration varying with age, gender, and population (Vladykov and Wallace 1938, 1952; Truitt 1940; Merriman 1941; Bigelow and Schroeder 1953; Chapoton and Sykes 1961; Sykes et al. 1961; Mansueti and Hollis 1963; Nichols et al. 1966; Clark 1968; Miller 1969; Hamer 1971; Hill et al. 1989; Morris et al. 2003; Zlokovitz et al. 2003). However, some individuals are thought to overwinter in New England (Merriman 1938; Bigelow and Schroeder 1953; Raney 1958; Saila and Pratt 1973). These migrations involve fish age-2 and older, and may include some immature females (Raney 1954). These coastal migrations are not associated with spawning and usually begin in early spring, but this time period can be prolonged by the migration of striped bass that are spawning (Bain and Bain 1982).

Striped bass tagged in U.S. waters may overwinter both with Bay of Fundy fish (in freshwater) and with Gulf of St. Lawrence fish (in estuaries). The natal origin of these fish is unknown. The incidence of U.S. fish mixing with Canadian stocks likely fluctuates with population size of the U.S. migratory stock as well as the prevailing water temperatures in the Gulf of Maine, Bay of Fundy, and Gulf of St. Lawrence (Rulifson and Dadswell 1995).

Areas along the central and south Atlantic coast are used as wintering grounds by some portion of migratory adult striped bass. The inshore zones between Cape Henry, Virginia, and Topsail Island, North Carolina, serve as winter habitat for a migratory segment of the Atlantic coast striped bass population (Holland and Yelverton 1973; Setzler et al. 1980; Laney et al. 2007; Welsh et al. 2007; U.S. Fish and Wildlife Service, Maryland Fisheries Resources Office, (Annapolis, Maryland), and South Atlantic Fisheries Coordination Office (Morehead City, North Carolina), unpublished data). At least three groups of striped bass were historically present in this area, including fish from: 1) Albemarle and Pamlico Sounds, North Carolina; 2) Chesapeake Bay; and 3) New Jersey and further north, including some fish from the Hudson River population (Holland and Yelverton 1973; U.S. Fish and Wildlife Service, Maryland Fisheries Resources Office and South Atlantic Fisheries Coordination Office, unpublished data). Based on tagging studies conducted under the auspices of the North Carolina Division of Marine Fisheries from 1968 to 1971 (Holland and Yelverton 1973), and the Atlantic States Marine Fisheries Commission from 1988 to present, striped bass wintering off Virginia and North Carolina range widely up and down the Atlantic coast, at least as far north as Nova Scotia, and represent all major migratory stocks (U.S. Fish and Wildlife Service, Maryland Fisheries Resources Office and South Atlantic Fisheries Coordination Office, unpublished data; Striped Bass Tagging Committee 2003; Welsh et al. 2007).Larger, typically female, striped bass tend to migrate greater distances (Mansueti 1961a; Fay et al. 1983). Bigelow and Schroeder (1953) found that 90% of all striped bass caught in northern waters were female. Striped bass catches from the Rhode Island (Oviatt 1977) and North Carolina (Holland and Yelverton 1973) coasts, and from Long Island’s south shore (Schaefer 1968b) consisted of 90%, 90%, and 85.7% females, respectively.

The extent of involvement of North Carolina striped bass in the migration was at one time not well known (Saila and Pratt 1973). At least a portion of the North Carolina population was documented to remain in North Carolina throughout the summer (Dickson 1958). Few, if any, striped bass from south of Cape Hatteras, North Carolina, were thought to take part in the annual coastal migration (Bigelow and Schroeder 1953).

In the Chesapeake Bay drainage, estimates of percent migration vary from 1.5% of the Potomac River striped bass population to around 10% of the total Bay population (W. Laney, personal observation). Koo (1970) concluded that Chesapeake Bay striped bass between ages 2 and 3 contributed significantly to the entire Atlantic coast fishery. In support, Kohlenstein (1981) showed that approximately 50% of the age-3 female striped bass in Chesapeake Bay, and a smaller percentage of age-2 and age-4 females, moved to the coast to join the migration annually. However, few males of that age exhibited migratory behavior. In addition, Berggren and Lieberman (1978) used discriminant function analysis to show that 90.2% of the coastal striped bass landed from southern Maine to Cape Hatteras, North Carolina, were derived from fish spawned in Chesapeake Bay. Other studies (Schaefer 1968a; Austin and Custer 1977) also support the importance of Chesapeake Bay-derived fish to the migratory striped bass stock.

The principal migration route for striped bass might be up the Chesapeake Bay, through the C&D Canal and Delaware Bay, and northward along the coast (Vladykov and Wallace 1938; Mansueti and Hollis 1963; Schaefer 1968a; Shubart and Koo 1968; Nichols and Miller 1967; Miller 1969). Fish returning from northern waters apparently enter Chesapeake Bay through the C&D Canal (Whitworth et al. 1968). Additionally, a winter migration from the upper Chesapeake Bay to the James River, Virginia, was reported by Truitt (1938), but he noted it did not occur in all years.

Results of studies using tagging, parasites, meristic and morphometric characters, and biochemical genetics suggest that Canadian and U.S. striped bass populations mix during their annual migrations (Rulifson and Dadswell 1995). The extent of this mixing is undetermined (Melvin 1978; Dadswell et al. 1984; Hogans 1984; Boreman and Lewis 1987; Rulifson et al. 1987; Harris and Rulifson 1988; Waldman et al. 1988). Boreman and Lewis (1987) reported that striped bass tagged by American Littoral Society members along the U.S. eastern seaboard as far south as New Jersey have been recaptured in the Canadian maritimes. Potomac River (Maryland) and Hudson River (New York) releases have been recaptured in the Annapolis River (New Brunswick) and in Minas Basin (Rulifson and Dadswell 1995). Striped bass tagged in Nova Scotia and New Brunswick waters have been recaptured as far south as New Jersey, Delaware, Virginia, and North Carolina (Nichols and Miller 1967; Rulifson and Dadswell 1995).Striped bass populations in southeastern Canada, the Hudson River, and possibly, the Delaware River, were thought to be more or less isolated and not move great distances after spawning (Bigelow and Schroeder 1953; Morris et al. 2003; Zlokovitz et al. 2003). The Hudson River population was reported to move only as far as Long Island Sound and the New York Bight (Lyman and Woolner 1954; Clark 1968; Whitworth et al. 1968). This non-migratory behavior is supported by tagging studies in the Hudson River-Long Island Sound area (Raney 1954; Clark 1968; Schaefer 1968b; Texas Instruments 1974), southern New Jersey (Hamer 1971), Chesapeake Bay (Mansueti 1961a; Moore and Burton 1975), Potomac River (Nichols and Miller 1967; Miller 1969), and Virginia Rivers (Massman and Pacheco 1961). In almost every one of these studies, some tagged striped bass appeared to remain in the same area all year, while others were recaptured 1,000 km or more from the release area. The basis for migratory versus non-migratory behavior is unknown (W. Laney, personal observation).

McLaren et al. (1981) found that most striped bass tagged on the Hudson River remained all year within 50 km of tagging sites. Most fish that moved out of the Long Island Sound area moved northeastward. The most northerly recapture area, which encompassed over two years of study, was Provincetown, Massachusetts. No dependence on age, size, or sex was found for the migratory segment of the Hudson River population. Evidence indicated that the Hudson River population was most likely self-perpetuating and self-contained within the river and immediate surrounding coastal area. Little evidence existed for mingling of Chesapeake and Hudson stocks, either during migrations or within overwintering populations (McLaren et al. 1981).

In contrast, there was evidence to suggest that the Delaware River population moved down the coast after spawning (Whitworth et al. 1968; Bason 1971). Furthermore, some portion of the migratory striped bass population enters and overwinters in mid-coastal rivers such as the Hudson, Mullica, and Delaware River. However, these fish are thought to make up only a small percentage of the total migratory population (Westin and Rogers 1978).

From a more ecological perspective, larger, older juveniles and adults typically remain nearshore. In fact, striped bass are usually not found more than six to eight kilometers offshore (Bigelow and Schroeder 1953; Holland and Yelverton 1973), with few beyond 16 km (Raney 1954). The maximum recorded distance offshore is around 97 to 113 km, but such individuals were viewed as strays (Raney 1952). Striped bass are found into the surf zone along ocean beaches, primarily while foraging for prey (Rosko 1966; Schwind 1972; Reiger 1997; DiBenedetto 2003). In addition, striped bass exhibit schooling behavior (Raney 1952; Raney and DeSylva 1953) throughout their range.

Salinity associations at sea

Striped bass have been recorded from 0.0 to 35.0 ppt (Bigelow and Schroeder 1953; Smith 1971). In general, the species is able to withstand abrupt salinity changes (Tagatz 1961).

Substrate associations at sea

Striped bass occur over a wide variety of substrates in oceanic inshore and nearshore areas, including: rock and boulders (Raney 1952; Bigelow and Schroeder 1953); gravel (Haddaway 1930); sand (Bigelow and Schroeder 1953); eelgrass (Haddaway 1930); and mussel beds (Bigelow and Schroeder 1953). In both estuarine and marine habitats, striped bass have been documented often along sandy beaches (Bigelow and Schroeder 1953) and rocky shores (Pearson 1931). They have been recorded from shallow bays, troughs, and gullies hollowed out by wave action, sand bars (Bigelow and Schroeder 1953), in the surf (Schaefer 1967), and sometimes under rafts of floating rockweed (Bigelow and Schroeder 1953).

Depth associations at sea

Most depths recorded for striped bass range from 0.6 to 46 m (Haddaway 1930; Nichols 1966), with larger fish generally in deeper water. As noted in many angling publications and fishing accounts, large fish also frequent the surf zone of beaches from Maine through North Carolina (Rosko 1966; Schwind 1972; Reiger 1997; DiBenedetto 2003). Off the North Carolina Outer Banks during the winter, striped bass are commonly present from the surf zone out to depths of 18.3 m. As an exception, Bigelow and Schroeder (1953) reported the capture of an 18-inch striped bass taken by trawl in 128 m during February 1949, about 111 km south of Martha's Vineyard. The researchers believed this constituted evidence for possible wintering by some striped bass on the bottom, "...well out on the continental shelf in localities where the otter trawlers do not ordinarily operate..." (Bigelow and Schroeder 1953).

Water temperature associations at sea

Striped bass have been recorded in the ocean at water temperatures ranging from 0.1°C (Clark 1968) to around 27°C, although kills may occur at the higher temperatures (Raney 1952; Bigelow and Schroeder 1953; Talbot 1966). Adult striped bass normally avoid temperatures higher than about 18.5 to 21.0°C (Goode et al. 1884). However, they can remain active down to 1.0°C, and can withstand abrupt temperature changes (Mansueti 1959; Tagatz 1961).

Water velocity/flow associations at sea

Striped bass are typically found where some current is running (Raney 1952; Bigelow and Schroeder 1953). Bigelow and Schroeder (1953) give a good description of typical striped bass haunts in Gulf of Maine habitats:

> The best spots along rocky shores are in the surf generally, and in the wash of breaking waves behind offlying boulders and among them, or where a tidal current flows most swiftly past some jutting point. In the mouths of estuaries they are apt to hold to the side where the current is the strongest, and in the breakers out along the bar on that side. In shallow bays, they often pursue small fry among the submerged sedge grass when the tide is high, dropping back into the deeper channels on the ebb. And they frequent mussel beds, both in enclosed waters and on shoal grounds outside, probably because these are likely to harbor an abundance of sea worms (*Nereis*).

Feeding behavior at sea

Schaefer (1970) examined the food habits of striped bass taken from the surf on Long Island, New York. He noted that the bay anchovy was the dominant vertebrate prey item, and that amphipods and mysid shrimp were the dominant invertebrate prey. Relative occurrence of invertebrates in the diet of striped bass in the Long Island surf decreased significantly between spring and fall, but no-significant differences were attributable to fish size. The relative occurrence of vertebrate prey increased significantly between spring and fall, as well as with increases in fish size (Schaefer 1970). In contrast, Oviatt (1977) reported that striped bass feeding inshore ate Atlantic menhaden, while those captured offshore fed on sand lance (*Ammodytes* spp.).

Food habits of striped bass in Massachusetts coastal waters were determined by Nelson et al. (2003). Striped bass were collected from four different habitats (i.e., estuaries, ocean-facing beaches, rocky shorelines, and ocean waters more than 900 m offshore) in the North Shore, Cape Cod Bay, and Nantucket Sound regions. Sampling was conducted from June through September of 1997 through 2000. Stomach contents of 3,006 striped bass were examined for patterns in prey composition and body size related to coastal region, time period of capture, foraging habitat, and length of striped bass. Length of striped bass sampled ranged from 290 to 1,162 mm TL. Over 48 prey species representing 55 families from six phyla were found in the stomachs. Fish (mostly clupeids, silversides (*Menidia* sp.), and sand lance (*Ammodytes* sp.)) and crustaceans (mostly sand shrimp (*Crangon septemspinosa*), rock crab (*Cancer irroratus*), and American lobster (*Homarus americanus*)) dominated the diet of striped bass by both weight (91 to 95%) and number (87 to 97%), and had a high frequency of occurrence (42 to 66%) in the stomachs. Similarity in prey taxa among coastal regions was moderate to high (58 to 74%) (Nelson et al. 2003).

In addition, stomach contents of striped bass larger than 675 mm TL collected during August and September from estuaries and rocky shoreline habitats in the North Shore and Cape Cod Bay regions had a higher average percentage of Atlantic menhaden (*Brevoortia tyrannus*) by weight than similar-sized striped bass collected during June and July from the same habitats. Also, in the North Shore area, striped bass larger than 675 mm TL sampled in rocky shorelines contained a higher average percentage of rock crabs by weight than similar-sized bass taken in estuaries. Striped bass larger than 675 mm TL in rocky habitats consumed more American lobster than smaller striped bass residing in this same habitat. Furthermore, the size distribution of the dominant fishes and crabs (i.e., sand lance, American menhaden, rock crab, and green crab (*Carcinus maenus*)) consumed by striped bass was related to bass body size. In summary, benthic prey types were found to be a major component of the diet of striped bass in Massachusetts coastal waters (Nelson et al. 2003).

Section II. Identification and Distribution of Habitat Areas of Particular Concern for Striped Bass

Since migratory striped bass are not a species managed jointly with a federal Fishery Management Council, and since there is no formal federal Fishery Management Plan for the species, Essential Fish Habitat (EFH) has not been formally described or designated. Therefore, the definition of a Habitat Area of Particular Concern (HAPC) is modified to be areas within the species' habitat that satisfy one or more of the following criteria: 1) provides important ecological function; 2) is sensitive to human-induced environmental degradation; 3) is susceptible to coastal development activities; or 4) is considered to be rarer than other habitat types. Any HAPC designated by the ASMFC for a species solely under its management is not subject to the consultant requirements of the Magnuson-Stevens Act. Any HAPC described for Atlantic migratory striped bass will be a subset of the habitats described in Section I. There are four habitat types that might qualify as HAPCs for Atlantic migratory striped bass, and they are discussed below**.**

Spawning sites occur in the freshwater portions of estuaries, or their tributaries, along the Atlantic coast. Such sites provide the critical ecological function of reproduction; are sensitive to anthropogenic impacts such as dam emplacement, nutrient and sediment loading, and pollution; are susceptible to navigational dredging and other coastal development activities; and are relatively small in extent and extremely rare in comparison to the areal extent of other migratory striped bass habitats.

Nursery areas are much broader in extent. These areas include the freshwater and low-salinity portions of tributaries and their receiving estuaries for age 0 to 2 striped bass, and the higher salinity bays, estuaries, and the nearshore ocean for older juveniles. These sites provide the critical ecological function of growth to maturity; are sensitive to anthropogenic impacts such as navigational dredging and port development, sedimentation, toxic and hypoxic conditions, nutrient loading, and hypoxia; are highly susceptible to coastal development impacts from recreational and commercial vessel traffic, and receive all terrestrial runoff; and are limited in extent, although less rare than ***spawning habitats***.

Inlets provide the only means of ingress and egress for striped bass adults and older juveniles migrating to and from riverine spawning and estuarine nursery habitats. They provide the critical ecological function of access to habitats necessary for reproduction and growth to maturity; they are sensitive to human-induced environmental degradation as a result of channel alterations, such as deepening and stabilization; they are all coastal and highly susceptible to coastal development activities, both commercial and recreational; and they are perhaps rarer (smaller in extent) than ***spawning habitats***.

Finally, ***wintering grounds*** occur in the nearshore Atlantic Ocean from Long Island Sound south to at least Topsail Island, North Carolina. These habitats provide the critical ecological function of foraging and cover for adults most of the year; are sensitive to human-induced environmental degradation due to fishing activities, commercial navigation, offshore oil and gas exploration, and construction of offshore liquid natural gas (LNG) facilities; they are all coastal and subject to the aforementioned coastal development activities; and they are restricted to a relatively narrow band of nearshore ocean, although not as rare as ***spawning habitats*** and ***inlets***.

Section III. Present Condition of Habitats and Habitat Areas of Particular Concern for Striped Bass

Concerns regarding the condition of, and threats to, habitats used by striped bass and other Atlantic coast estuarine-dependent fish species are not new. As an example, the following quotations are provided:

> *The warning here is that fish resources of the seashores and bays of the Atlantic coast are in danger of extreme depletion from poorly planned community and industrial development* (Clark 1967, page 1).
>
> *It is the sad truth that our Atlantic estuaries are not being maintained in good condition—instead they are being systematically demolished, altered or poisoned in almost every town and county along the sea coast. Big and small projects are gradually eating away this precious environment and wreaking havoc with fish and shellfish resources harvested there* (Clark 1967, page 11).
>
> *Frequently, the real effects of estuarine projects are masked until the last moment and then the work is steamrollered in the face of the last minute opposition* (Clark 1967, page 17).

The statements, just as applicable today as when they were written almost forty years ago (despite the intervening passage of the Clean Water Act and National Environmental Policy Act), are from John Clark's *Fish and Man: Conflict in the Atlantic Estuaries* (1967). Clark (1967) summarized the threats to Atlantic estuaries (e.g., filling to establish upland, navigational dredging, gravel and sand mining, mosquito control, marsh impoundment, highway construction, and water control), and described measures the fourteen coastal states were taking to mitigate their impacts.

Two authors have addressed the long-term impacts on striped bass of human alterations to habitats in Chesapeake Bay (Mansueti 1961b; Rago 1992). Rago (1992) reviewed the consequences of habitat degradation for striped bass, and the difficulty of linking such degradation to striped bass population trends. It was noted that estuarine environments, such as Chesapeake Bay, are dynamic ecosystems, and organisms that persist in them must be highly adaptable to change (Saila 1975).

Due to the large amount of information and time constraints, portions of Section III of this chapter are based on information provided in the two National Coastal Condition reports (Summers 2001, 2004), which address habitat quality in most of the estuaries occupied by migratory striped bass juveniles and adults. Additional information was derived from the State Comprehensive Wildlife Conservation Strategies, and individual state efforts such as the North Carolina Coastal Habitat Protection Plan (CHPP) (Street et al. 2005), which contain evaluations of habitats used by striped bass.

Habitat quantity

Striped bass spawning migrations formerly extended much farther upstream in a number of rivers than they do at present, at least under conditions of high spring river discharges. In many systems, access to former spawning habitats above the Fall Line is either totally or partially blocked by dams and locks, or dams equipped with fish passage devices that allow only partial passage of spawning striped bass. On a range-wide basis there has been an overall net loss of, and/or reduction of, access to spawning habitat. For example, in the Cape Fear River, North Carolina, navigation locks and associated low-head dams constructed by the U. S. Army Corps of Engineers, as well as upstream dams constructed for cooling water supply (e.g., Progress Energy Carolinas, Inc., Buckhorn Dam) and flood control (e.g., U. S. Army Corps of Engineers, B. Everett Jordan Dam and Reservoir), reduce or prevent access to historic spawning habitats. The same situation exists for many dams and locks along the Atlantic coast.

Habitat quality

The quality of striped bass spawning habitats has been compromised by reduced access, the presence of contaminants, adverse flow regimes due to hydropower generation from upstream dams, and functional loss due to changes induced by navigational dredging and filling to create uplands for development.

Section IV. Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Striped Bass

Table 9-5. Significant environmental, temporal, and spatial factors affecting distribution of striped bass. This table summarizes the current literature on striped bass habitat associations. For most categories, optimal and tolerable ranges have not been identified, and the summarized habitat parameters are listed under the category reported. Please note that, although there may be subtle variations between systems, the following variables may include a broad range of values to encompass the different systems that occur along the East Coast. NIF = No Information Found.

Life Stage	Time of Year and Location	Depth (m)	Temperature (^{o}C)	Salinity (ppt)	Substrate	Current Velocity (m/sec)	Dissolved Oxygen (mg/L)
Adult (Spawning)	Migration into natal rivers along the Atlantic coast, from North Carolina to Quebec in late February to June (south to north progression)	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** 14-20 **Optimal:** 15.8-20 **Reported:** 10-26.5	**Tolerable:** NIF **Optimal:** 0-1.5 **Reported:** 0-23	**Tolerable:** NIF **Optimal:** NIF **Reported:** Silt, mud/sand, cobble, or rock bottom	**Tolerable:** NIF **Optimal:** NIF **Reported:** Suitability increases with increased flow	**Tolerable:** >5 **Optimal:** NIF **Reported:** >3
Egg and Larval	Spawning grounds of individual rivers in late February to June (south to north progression)	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** 14-23 (egg); 10-25 (larvae) **Optimal:** 17-21 (egg); 15-22 (larvae) **Reported:** 12-24 (egg); 10-28 (larvae)	**Tolerable:** NIF **Optimal:** 1.5-3 (egg); 3-7 (larvae) **Reported:** 0-10 (egg); 0-32 (larvae)	**Tolerable:** NIF **Optimal:** NIF **Reported:** Sandy/rocky	**Tolerable:** 7.3 (egg); 0-5 (larvae) **Optimal:** 0.3-1 (larvae) **Reported:** NIF	**Tolerable:** >5 **Optimal:** NIF **Reported:** NIF

Life Stage	Time of Year and Location	Depth (m)	Temperature (^{o}C)	Salinity (ppt)	Substrate	Current Velocity (m/sec)	Dissolved Oxygen (mg/L)
Early Juvenile – Riverine Environment	Year round residency; move downstream with age	**Tolerable:** NIF **Optimal:** NIF **Reported:** 0-37	**Tolerable:** 10-27 **Optimal:** 14-21 **Reported:** 3.55-35	**Tolerable:** 0-35 **Optimal:** 10-20 **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** Mixture of mud, sand, gravel, rock; rarely soft bottom	**Tolerable:** 0-5 **Optimal:** 0-1 **Reported:** NIF	**Tolerable:** 3-20 **Optimal:** 6-12 **Reported:** >3
Juvenile and Adult (At-sea)	Coastal migrations beginning in spring	**Tolerable:** NIF **Optimal:** NIF **Reported:** 0.6-46	**Tolerable:** 1-18.5 **Optimal:** NIF **Reported:** 0.1-27	**Tolerable:** NIF **Optimal:** NIF **Reported:** 0-35	**Tolerable:** NIF **Optimal:** NIF **Reported:** Rock, boulder, sand, gravel, mussel beds	**Tolerable:** NIF **Optimal:** NIF **Reported:** Swift flow	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF

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