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# Atlantic Sciaenid Habitats:

## A Review of Utilization, Threats, and Recommendations for Conservation, Management, and Research

*Vision: Sustainably Managing Atlantic Coastal Fisheries*

Atlantic States Marine Fisheries Commission

**Atlantic Sciaenid Habitats:**  
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**Conservation, Management, and Research**

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## CHAPTER 1: INTRODUCTION

The Atlantic States Marine Fisheries Commission (hereafter referred to as ASMFC or the Commission) is the principal agency responsible for the management of many sciaenid fish species in state waters. The mission of the Commission's Habitat Program is to work through the Commission, in cooperation with appropriate agencies and organizations, to enhance and cooperatively manage vital fish habitat for conservation, restoration, and protection, and to support the cooperative management of Commission managed species. One of the primary tasks of the Habitat Program is to develop habitat source documents on topics of immediate and broad interest to ASMFC Commissioners. Source documents provide detailed habitat information to inform conservation and management actions by ASMFC and diverse partners.

ASMFC coordinates interstate fishery management plans (FMPs) for Atlantic croaker, black drum, red drum, spot, spotted seatrout, and weakfish. This document is intended to provide up to date information on each of these species' biology, habitat needs, and habitat stresses.

### ***General Sciaenid Information***

Sciaenid fishes are found worldwide, containing approximately 70 genera and 270 species (Nelson 1994), of which 21 genera and 57 species have been described in the western Atlantic (Chao 1978). Globally, most sciaenids occur in marine and estuarine waters, while 28 species occur in freshwater. Marine species of sciaenids are found on shallow continental shelves in the Atlantic, Pacific, and Indian Oceans, but are absent from islands in the mid-Indian and Pacific oceans (Nelson 1994). Most sciaenids (with the exception of kingfish), produce deep drumming sounds by contracting and beating muscles against the swim bladder, hence the common names croaker and drum.

In the western Atlantic Ocean, sciaenids are found from Maine to Mexico, with centers of abundance most concentrated from New York to North Carolina, depending on the species. Sciaenids live in shallow coastal waters (less than 125 meters), and in larger bays and estuaries, including their tributaries. In general, they are euryhaline organisms, meaning they can adapt to a wide range of salinities, although preferred salinity varies with species and life stage. Sciaenids utilize a variety of habitats throughout their life stages, including sand and mud substrates, oyster beds, water column, and seagrass. As a group, sciaenids exploit the broadest range of foraging habits, consisting of polychaetes, bivalves, crustaceans, and fishes (Chao and Musick 1977). Their diets vary with locality, prey availability, life stage, and species.

Estuaries are important habitats for many sciaenids at every life stage. In the Mid Atlantic Bight, as many as 14 species can be present in estuaries as larvae, juveniles, or adults over the course of a year (Chao and Musick 1977; Cowan and Birdsong 1985; Able and Fahay 1997; Able et al. 2001). Weakfish, for example, use estuaries as primary spawning habitat (Nye et al. 2008), while Atlantic croaker and spot use them as nurseries and seasonal adult foraging grounds (Chao and Musick 1977; Sheridan et al. 1984). As dominant seasonal members of the estuarine fish assemblage, young sciaenids play important roles as both predators and prey (Dovel 1968; Chao and Musick 1977; Greco and Targett 1996; Able et al. 2001).

Adults form spawning aggregations and release sperm and eggs into the water column. The spawning period occurs over several months, and often entails multiple spawning events, but timing varies by



species. In fact, sciaenids partition out their spawning and nursery residences, which ultimately reduces competition. It's difficult to make generalizations about these species as a group because they have evolved to utilize distinct ecological niches in terms of feeding, timing of spawning, and spawning and nursery areas. For example, spot and Atlantic croaker spawn offshore in the winter, while other species such as weakfish, black drum, and northern kingfish spawn in the spring and summer in coastal areas. Spotted seatrout are essentially year-round estuarine residents who infrequently leave their natal estuary (Holt and Holt 2003; Lowerre-Barbieri et al. 2013).

Fertilized eggs float in the water column and hatch after 1–2 days depending on the species and water temperature. Soon after hatching, larvae are transported from coastal waters farther up into estuaries through active and passive processes. Nursery habitat use is also somewhat partitioned in space and time among species. For example, young-of-year black drum tend to be found in lower salinity habitats than other species of sciaenids. Young-of-year Atlantic croaker show up in late fall/early winter and overwinter in the estuary. Young-of-year spot are found in late winter/early spring, followed by black drum, weakfish, spotted seatrout, and finally red drum. Structurally complex nursery areas, such as seagrasses and marsh creeks, provide larvae and young fish productive feeding grounds and protection from predators (McIvor and Odum 1988; Hoss and Thayer 1993; Kneib 1997; Rountree and Able 2007). Because estuarine habitat provides such favorable conditions for juvenile growth and reduced mortality, this habitat is critical to ongoing productive coastal fisheries (Boesch and Turner 1984; Fogarty et al. 1991; Deegan et al. 2000).

### ***Anthropogenic Impacts***

Increasingly dense human populations along our coastlines threaten the health of estuaries and coastal waters. Widespread development, coastal armoring, pollution, and other human impacts have significantly altered the physical and chemical environments of estuarine and marine waters. Changes in hydrologic processes and runoff characteristics can increase turbidity and sedimentation and decrease light transmittance, which may lead to the loss of submerged aquatic vegetation (SAV). Anthropogenic alterations to the estuarine environment have been linked to changes in hydrography and salinity regimes, as well as food web modification, which can eventually reduce the quality of habitat for estuary-dependent fishes.

Temperature, salinity, and dissolved oxygen (DO), vary considerably in estuarine environments (Tyler et al. 2009) and these factors are known to affect sciaenid growth rates, spawning, and spatial and temporal distribution. As a group, sciaenids are habitat generalists rather than specialists and may therefore be relatively resilient to changes in abiotic factors. However, Atlantic coast estuaries have been profoundly altered. Despite their ability to take advantage of a range of habitats, sciaenids are not immune to habitat degradation or suboptimal conditions. For example, spotted seatrout are sensitive to cold and often are conspicuous features of “cold kills” in the northern estuaries of their range. In estuarine systems, perturbations to water quality are occurring at rates faster than natural selection can act on organisms to enable them to adapt to the new prevailing conditions (Horodysky et al. 2008).

### ***Key Habitats***

Because of the way different species of sciaenids partition their use of habitat, several different habitat types are key, including estuaries, salt marshes, freshwater marshes, oyster reefs, sea grasses, and mud banks/shores. The mouth of the estuary is also very important for staging. In coastal marine areas, the surf zone and sand bar complex is valuable nursery habitat for southern and gulf kingfish, and serves as

adult habitat for spotted seatrout, weakfish, red drum, and others. In addition, the coastal shelf (in waters less than 125 m) is used for spawning by some species (i.e., Atlantic croaker).

### **Literature Cited**

- Able, K. W. and M. P. Fahay. 1998. *The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight*. Rutgers University Press, New Brunswick, NJ.
- Able, K. W., D. M. Nemerson, R. Bush and P. Light. 2001. Spatial variation in Delaware Bay (USA) marsh creek fish assemblages. *Estuaries* 24(3): 441–452.
- Boesch, D. F. and R. E. Turner. 1984. Dependence of fishery species on salt marshes: the role of food and refuge. *Estuaries* 7(4A): 460-468.
- Chao, L. N. and J. A. Musick. 1977. Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in the York River Estuary, Virginia. *Fishery Bulletin* 75: 657–702.
- Chao, L. N. 1978. A basis for classifying western Atlantic Sciaenidae (Teleostei: Perciformes). NOAA Technical Report NMFS Circular 415.
- Cowan, J. H. and R. S. Birdsong. 1985. Seasonal occurrence of larval and juvenile fishes in a Virginia Atlantic coast estuary with emphasis on drums (Family Sciaenidae). *Estuaries* 8(1): 48–59.
- Deegan, L. A., J. E. Hughes and R. A. Rountree. 2000. Salt marsh ecosystems support of marine transient species. pp. 333–365. *In* M. P. Weinstein and D. A. Kreeger (eds.), *Concepts and controversies in tidal marsh ecology*. Kluwer Academic, Boston, MA.
- Dovel, W. L. 1968. Predation by striped bass as a possible influence on population size of the Atlantic croaker. *Transactions of the American Fisheries Society* 97(4): 313–319.
- Fogarty, M. J., M. P. Sissenwine and E. B. Cohen. 1991. Recruitment variability and the dynamics of exploited marine populations. *Trends in Ecology & Evolution* 6(8): 241–246.
- Greca, P. A. and T. E. Targett. 1996. Spatial patterns in condition and feeding of juvenile weakfish in Delaware Bay. *Transactions of the American Fisheries Society* 125(5): 803–808.
- Holt, G. J. and S. A. Holt. 2003. Effects of variable salinity on reproduction and early life stages of spotted seatrout. *In*: Bortone SA, editor. *Biology of the Spotted Seatrout*. Boca Raton (FL): CRC Press. pp. 135–145.
- Horodysky, A. Z., R. W. Brill, E. J. Warrant, J. A. Musick and R. J. Latour. 2008. Comparative visual function in five sciaenid fishes inhabiting Chesapeake Bay. *Journal of Experimental Biology* 211: 3601–3612.
- Hoss, D. E. and G. W. Thayer. 1993. The importance of habitat to the early life history of estuarine dependent fishes. pp. 147–158. *In* L. A. Fuiman (ed.), *Water quality and the early life stages of fishes*. American Fisheries Society, Bethesda, MD.
- Kneib, R. T. 1997. The role of tidal marshes in the ecology of estuarine nekton. *Oceanography and Marine Biology: an Annual Review* 35: 163–220.

- Lowerre-Barbieri, S. K., S. Walters, J. Bickford, W. Cooper and R. Muller. 2013. Site fidelity and reproductive timing at a spotted seatrout spawning aggregation site: individual versus population scale behavior. *Marine Ecology Progress Series* 481: 181–197.
- Mclvor, C. C. and W. E. Odum. 1988. Food, predation risk, and microhabitat selection in a marsh fish assemblage. *Ecology* 69(5): 1341–1351.
- Nelson, J. S. 1994. *Fishes of the world*, 3rd edition. Wiley, New York.
- Nye, J. A., T. E. Targett and T. E. Helser. 2008. Reproductive characteristics of weakfish in Delaware Bay: implications for management. *North American Journal of Fisheries Management* 27: 1–11.
- Rountree, R. A. and K. W. Able. 2007. Spatial and temporal habitat use patterns for salt marsh nekton: implications for ecological functions. *Aquatic Ecology* 41(1): 25–45.
- Sheridan, P. F., D. L. Trimm and B. M. Baker. 1984. Reproduction and food habits of seven species of northern Gulf of Mexico fishes. *Contributions in Marine Science* 27: 175–204.
- Tyler, R. M., D. C. Brady and T. E. Targett. 2009. Temporal and spatial dynamics of diel-cycling hypoxia in estuarine tributaries. *Estuaries and Coasts* 32: 123–145.

## CHAPTER 2: ATLANTIC CROAKER

Populated with Habitat Section from Amendment I to the ISFMP (ASMFC 2005)

### **Section I. General Description of Habitat**

Atlantic croaker was described by Petrik et al. (1999) as a habitat generalist. Field surveys of post-settlement croaker in estuarine nursery areas found no significant differences in abundances among SAV, marsh edge, and sandy bottom (Petrik et al. 1999). In a wetland system, Atlantic croaker along the Gulf Coast preferred non-vegetated bottom adjacent to wetlands rather than the marsh itself (Rozas and Zimmerman 2000). In North Carolina, Atlantic croaker have been documented to utilize SAV, wetlands, non-vegetated soft bottom, and to a lesser extent, shell bottom (Street et al. 2005). Juvenile croaker use these habitats for refuge and foraging and as a corridor through the estuary. In North Carolina, Atlantic croaker is one of the dominant juvenile fish species in the estuaries (North Carolina Division of Marine Fisheries, unpublished data). Because croaker utilizes multiple habitats, the effect of habitat change and condition on fish population is difficult to assess.

### **Part A. Spawning Habitat**

#### ***Geographic and Temporal Patterns of Migration***

Atlantic croaker spawn predominantly on the continental shelf, at depths ranging from 7 to 81 m (26 to 266 ft), but also in tidal inlets and estuaries (Diaz and Onuf 1985; Able and Fahay 2010). Atlantic croaker have a long spawning season that generally starts in late summer and continues to early spring, with peak reproductive activity occurring in late fall and winter (Diaz and Onuf 1985). In the Chesapeake Bay and North Carolina, spawning begins as early as August and usually peaks in October, whereas peak spawning occurs in November in the Gulf of Mexico (USFWS 1996).

#### ***Salinity***

Atlantic croaker are a euryhaline species, capable of tolerating a wide range of salinity. It is suggested that this wide tolerance continues during spawning, as they are found to spawn in estuaries and adjacent coastal oceanic waters as far out as the continental shelf (Barbieri et al. 1994). Diaz and Onuf (1985) report that they typically spawn in polyhaline brackish waters.

#### ***Substrate***

Although Atlantic croaker forage along the benthos, they are pelagic spawners in estuaries and offshore along the continental shelf (Chao and Musick 1977; Barbieri et al. 1994). These habitats tend to be dominated by soft sediment (mud and sand) (Townsend et al. 2004; Friedrichs 2009).

#### ***Temperature***

Exact spawning locations may be related to warm bottom waters (Miller et al. 2002). Spawning is reported to occur at water temperatures between 16 and 25°C in North Carolina (Street et al. 2005). In general, spawning is correlated with bottom temperatures higher than 16°C along the Mid Atlantic Bight (Norcross and Austin 1988).

### ***Dissolved Oxygen***

Prolonged exposure to hypoxia has detrimental effects on reproduction in Atlantic croaker. Hypoxia has been linked to decreased gonadal growth, gametogenesis, and endocrine function as well as lower hatching success and larval survival (Thomas et al. 2007; Thomas and Rahman 2009). A study sampling from the dead zone in coastal regions of the northern Gulf of Mexico found that Atlantic croaker experiencing persistent hypoxia displayed an approximate 74% decrease in sperm production and a 50% decrease in testicular growth compared to fish collected nearby which were not under hypoxic conditions (Thomas and Rahman 2010).

### ***Feeding Behavior***

Atlantic croaker are carnivorous. Their diet consists mainly of polychaetes and some fish and arthropods in the spawning months (Hansen 1969).

### ***Competition and Predation***

Atlantic croaker were found to be a primary food source of dolphins residing in estuaries, who locate them by listening for their characteristic thrumming sounds (Gannon and Waples 2006).

## **Part B. Egg and Larval Habitat**

### ***Geographic and Temporal Patterns of Migration***

After hatching, larvae drift into estuaries by passive and active transport mechanisms via floodtides, upstream bottom currents, and other large-scale and localized oceanographic processes (Joyeux 1998). Arrival time into estuaries varies regionally. Larvae are present as early as June on the Louisiana coast and as late as September in the Chesapeake Bay and on the North Carolina and Virginia coasts (USFWS 1996). Larval size at recruitment into Onslow Bay and Newport River estuary in North Carolina ranged from 4.3–9.9 mm standard length (SL) (Lewis and Judy 1983). Immigrating larvae into the Chesapeake Bay are typically 20–26 days old and are 5–7 mm SL (Nixon and Jones 1997). Upon initial arrival in the estuary, larval croaker are pelagic. During ebbing tides, however, larvae move to the brackish, bottom waters where they complete their development into juveniles (Miller 2002). Restriction to surface water is likely dependent on amount of vertical mixing: they will be closer to the surface in turbulent areas if they are not dense enough to sink to the bottom (Hare et al. 2006).

### ***Salinity***

Pelagic eggs are found in polyhaline and euryhaline waters. After hatching, young enter estuaries and move to areas of low salinity (Hansen 1969). These fish migrate into the estuary in the saltwater wedge along the bottom (Haven 1957).

### ***Substrate***

Larvae will remain in the water column until mobility function is developed and body density increases enough to allow for settlement (Hare et al. 2006).

### ***Temperature***

Larvae can tolerate colder water temperatures than adults, but extremely cold temperatures may be a major source of larval mortality.

### ***Dissolved Oxygen***

Eggs and larvae of Atlantic croaker are pelagic and remain offshore for approximately two to three months before ingressing into estuarine nursery habitats (Poling and Fuiman 1998). Therefore, it is unlikely these stages will encounter hypoxic conditions until settlement into the nurseries.

### ***Feeding Behavior***

Atlantic croaker larvae are planktonic feeders. Because they primarily locate their food source visually, larvae feed during the day. They may search 12–120 L of seawater for food organisms in a 12 hour day (Hunter 1981).

Diet selection depends upon availability, size of the prey item in comparison to size of the growing larvae, swimming behavior and color of the food organism, as well as prey perception, recognition, and capture (Govoni et al. 1986). Atlantic croaker larvae eat tintinnids, pteropods, pelecypods, ostracods, and the egg, naupliar, copepodid, and adult stages of copepods (Govoni et al. 1983).

### ***Competition and Predation***

Larvae enter nursery habitats within estuaries from late summer to late winter with peak ingress occurring in the fall in the western north Atlantic (Able and Fahay 2010; Ribeiro et al. 2015). For larvae of Atlantic croaker that enter estuarine nurseries (i.e., seagrass beds) in the summer, this corresponds with the ingress of other estuarine dependent sciaenid species (e.g., red drum, silver perch, weakfish) (Ribeiro et al. 2015), giving rise to the potential for inter-specific competition among these sciaenid species in nurseries. In the Chesapeake Bay, ectoparasites were prevalent on Atlantic croaker larvae in late summer and early fall (Ribeiro et al. 2016), which is another potential source of mortality in estuarine systems.

Similar to many other fishes, eggs and larval stages are commonly predated upon by gelatinous zooplankton, which reach peak densities in the Chesapeake Bay during the summer months (Purcell 1985; Olney and Boehlert 1988; Cowan et al. 1992).

## **Part C. Juvenile Habitat**

### ***Geographic and Temporal Patterns***

Juveniles use estuaries and tidal riverine habitats along the United States Atlantic coast from Massachusetts to northern Florida, and in the Gulf of Mexico, but are most common in coastal waters from New Jersey southward (Able and Fahay 1997; Robbins and Ray 1986; Diaz and Onuf 1985). Recruitment of juveniles into estuaries may be influenced by tidal fluxes in estuaries. For example, in the Pamlico Sound, North Carolina, a shallow estuary where tidal fluxes are largely controlled by wind, recruitment of juveniles is slower than the Cape Fear estuary, where 1.5 m (average) tidal fluxes are dictated by lunar cycles (Ross 2003). The Cape Fear estuary is representative of most drowned river valley Atlantic coast estuaries. Juveniles remain in these habitats until early to mid-summer (USFWS 1996). Juveniles migrate downstream as they develop and by late fall, most juveniles emigrate out of the estuaries to open ocean habitats (Migliarese et al. 1982). Juvenile Atlantic croaker tagged in Delaware Bay, New Jersey remained in a localized area of the tidal creeks before fall egress into offshore waters (Miller and Able 2002). Juvenile and adult croaker are tolerant to a wide range of salinity, temperature, and DO, but prey field seems to be correlated with the presence of croaker. Nye (2008) found that the presence of anchovy was a consistent predictor of croaker occurrence.

### ***Salinity***

Juveniles are associated with areas of stable salinity and tidal regimes and often avoid areas with large fluctuations in salinity. The upper, less saline parts of the estuaries provide the best environment for high growth and survival rates (Ross 2003; Peterson et al. 2004). Juveniles concentrate in oligohaline and mesohaline waters (0.5–18 ppt), although they may tolerate more extreme salinities (Diaz and Onuf 1985; Ross 2003). Ross (2003) showed that juveniles experience reduced mortality in less saline areas. Lower mortality in the less saline areas may be because of lower physiological stress in those environments (Ross 2003). Growth rates in juveniles may be affected by fluctuating salinities and temperatures (Peterson et al. 2004; Chao and Musick 1977). Large changes in salinity can alter the activity of croakers in a way that reduces local abundance; however, smaller changes do not appear to affect juveniles. Sharp fluctuations in salinity can cause intermediate growth rates and increase the bioenergetic costs for juveniles (Peterson et al. 2004).

Able and Fahay (1997) suggested that cold December waters in Delaware Bay are not conducive to survival of young croaker. Juvenile croaker prefer deeper tidal creeks because the salinity changes are usually less than in shallow flats and marsh creeks (Diaz and Onuf 1985). Salinity may affect the size distribution of juveniles within an estuary, which may be a result of changing physiological requirements as the juveniles develop (Migliarese et al. 1982).

### ***Substrate***

Substrate plays a large role in determining juvenile croaker distribution. Juveniles are positively correlated with mud bottoms with large amounts of detritus that houses sufficient prey (Cowan and Birdsong 1985). Sand and hard substrates are not suitable. Juvenile are often found in more turbid areas of estuaries with higher organic loads that provide a food source for individuals, but low turbidity is not a limiting factor in juvenile distribution (Diaz and Onuf 1985). The latter stages of young croaker are found more commonly in deeper channel habitats (Chao and Musick 1977; Poling and Fuiman 1998).

### ***Depth***

Juvenile Atlantic croaker live at a variety of depths, depending on the estuary. Many North Carolina estuaries and the coast of the Gulf of Mexico have small tidal fluctuations. In these areas, juvenile croakers amass in shallow, peripheral areas. In estuaries with greater tidal fluctuations such as the Delaware Bay, Chesapeake Bay, or the Cape Fear River Estuary, juvenile croaker assemble in deep channels (Chao and Musick 1977; Diaz and Onuf 1985).

### ***Temperature***

Field and laboratory data indicate that juveniles are more tolerant of lower temperatures than adults. Juveniles have been found in waters from 0.4–35.5°C (USFWS 1996) but extreme temperature changes can incapacitate juvenile croakers (Diaz and Onuf 1985). Young-of-year (30–60 mm SL) will experience 100% mortality when exposed to 1°C for a period of eight days. Prolonged exposure (12–24 d) to water temperatures of 3°C can also lead to high mortality rates (Lankford and Targett 2001). Juveniles migrate from Delaware Bay, New Jersey to offshore waters from August to October when water temperature is 15–19°C (Miller and Able 2002). Year-class strength also appears to be linked to overwinter survival of juveniles (Hare and Able 2007).

### ***Dissolved Oxygen***

Juveniles may favor conditions that can result in low DO, although juveniles will move out of an area if DO levels decrease beyond preferred tolerances (Diaz and Onuf 1985). Severe hypoxia of bottom water and sediments, often associated with eutrophication, can negatively affect juvenile croaker, causing deaths, a reduced growth rate, and reduced prey availability (Street et al. 2005).

### ***Feeding Behavior***

In Delaware Bay, Nemerson and Able (2004) found that the largest concentrations of newly recruited Atlantic croaker were collected over soft bottom habitat containing a high abundance of benthic invertebrates, and that their diet was dominated by polychaetes and crustaceans (80%) with fish comprising <4%. Annelids were an important prey component of their diet. Juveniles consume fish, but not in large quantities as do adults (Avault and Birdsong 1969). Sheridan (1979) found that small croaker rely heavily on polychaetes, but also consumed detritus, nematodes, insect larvae, and amphipods. There is evidence that croaker are somewhat crepuscular in their feeding habits (Nye 2008).

### ***Competition and Predation***

There is a potential for interspecific competition among sciaenids in estuaries from late spring to fall because juvenile Atlantic croaker, silver perch, weakfish, and spot are most abundant (Chao and Musick 1977), although sciaenids exhibit variation in morphological characters that may reduce interspecific competition in estuarine nursery habitats (Chao and Musick 1977; Deary and Hilton 2016).

## **Part D. Adult Habitat**

### ***Geographic and Temporal Patterns of Migration***

Atlantic croaker is one of the most common bottom dwelling estuarine species on the Atlantic Coast. Atlantic croaker range from the coastal waters of Cape Cod, Massachusetts to Florida, but croaker are uncommon north of New Jersey. Croaker are also found along the Gulf of Mexico coast with high abundances in Louisiana and Mississippi (Lassuy 1983). Juvenile and adult croaker are tolerant to a wide range of salinity, temperature, and DO, but prey field seems to be correlated with the presence of croaker. Nye (2008) found that the presence of anchovy was a consistent predictor of croaker occurrence.

### ***Salinity***

Adults are found in a salinity range from 0.2–70 ppt, but are most common in waters with salinities ranging from 6–20 ppt (Lassuy 1983; Eby and Crowder 2002). Adult croaker catch rates are negatively correlated with increasing salinities (TSNL 1982), but catch rates also vary with season. In spring, most adults are caught in salinity ranges from 3–9 ppt, but in summer, catch peaks in two ranges: the low salinities ranging from 6–12 ppt, and high salinities ranging from 24–27 ppt (Migliarese et al. 1982). Generally, adults avoid the mid-salinity ranges (Migliarese et al. 1982; Peterson et al. 2004). Mean total length (TL) positively correlates with bottom salinities (Migliarese et al. 1982). Turbidity, nitrate-nitrogen concentrations, and total phosphate-phosphorous concentrations also correlate positively with croaker abundance and catch (TSNL 1982).

### ***Substrate***

Adult Atlantic croaker prefer muddy and sandy substrates in waters shallow enough to support submerged aquatic plant growth. Adults have also been collected over oyster, coral, and sponge reefs, as well as man-made structures such as bridges and piers. Adult Atlantic croaker also use *Thalassia* sp.



beds for refuge although abundance in the seagrass beds is temperature-dependent and changes seasonally (TSNL 1982).

### ***Temperature***

Temperature and depth are strong predictors of adult croaker distribution, and the interaction between the two variables may also influence distribution (Eby and Crowder 2002). Adult croaker generally spend the spring and summer in estuaries, moving offshore and to southern latitudes along the Atlantic coast in the fall. Their migration is in response to cooling water temperatures because croakers cannot survive in cold winter temperatures. Adults are found in waters from 5–35.5°C, but most catch occurs in temperatures over 24°C (Migliarese et al. 1982). Generally, fish older than 1 year old are absent in waters below 10°C (Lassuy 1983). Optimal temperatures for growth and survival are not known (Eby and Crowder 2002).

### ***Dissolved Oxygen***

The distribution and extent of hypoxic zones in estuaries may also influence habitat use and distribution (Eby and Crowder 2002). Croaker generally shift from deep, hypoxic water to shallow, oxygenated waters during hypoxic events. Their distribution is further limited when hypoxic conditions occur in shallower waters. The lower threshold of DO for Atlantic croaker is about 2.0 mg L<sup>-1</sup>. Below this limit, Atlantic croaker may not survive or may experience sublethal effects. Studies have shown that Atlantic croaker are virtually absent from waters with DO levels below 2.0 mg L<sup>-1</sup>, suggesting they are very sensitive to the amount of DO present (Eby and Crowder 2002).

The size of a hypoxic zone influences habitat use as well. When hypoxic conditions spread in an estuary, Atlantic croaker are forced to use less suitable habitat. Atlantic croaker could incur increased physiological and ecological costs in these areas. For example, Atlantic croaker may face increased intra- and interspecific competition for available space or food in what are essentially compressed habitat zones. To avoid the increased ecological cost, croaker may return to waters with lower DO (Eby and Crowder 2002).

### ***Feeding Behavior***

Adult Atlantic croaker are opportunistic bottom feeders. The majority of their diet is benthic organisms and ≤20% consists of fish species (Avault and Birdsong 1969; Chao and Musick 1977; Nye et al. 2011). Sheridan (1979) found that large croaker rely heavily on polychaetes, followed by mysids and fish. Croaker have been found to be somewhat crepuscular in their feeding habits (Nye 2008).

### ***Competition and Predation***

Hypoxic zones may compress suitable habitat, increasing intra- and interspecific competition for available space or food. (Eby and Crowder 2002). Croaker compete with striped bass, weakfish, and possibly bluefish for anchovy in the Chesapeake Bay (Nye 2008).

## **Section II. Essential Fish Habitats and Habitat Areas of Particular Concern**

### ***Essential Fish Habitat***

Based on the life history requirements of Atlantic croaker, many shallow, estuarine ecosystems are essential. At all life stages, EFHs are characterized by soft substrates (mud and sand). For settlement, larvae prefer lower salinity ecosystems with SAV, but juveniles quickly move from these habitats to deeper channels (Chao and Musick 1977; Poling and Fuiman 1998).

### ***Identification of Habitat Areas of Particular Concern***

Estuaries, which are especially vulnerable to anthropogenic changes, are designated as Habitat Areas of Particular Concern (HAPCs) for Atlantic croaker, as well as for other species. Larvae are particularly vulnerable to changes in estuarine conditions. Environmental conditions in spawning areas may affect growth and mortality of egg and larval croakers (Eby and Crowder 2002).

### ***Present Condition of Habitat Areas of Particular Concern***

Estuarine areas may be functionally reduced in size or degraded by numerous activities, including but not limited to, development, dredging and filling, toxic chemical and nutrient enrichment discharges from point and non-point sources, habitat alteration (e.g., wetlands converted to agricultural use), failing septic systems, and alterations in seasonal runoff patterns (S.J. Vanderkooy, Gulf States Marine Fisheries Commission, personal communication). These events may reduce the quantity and quality of Atlantic croaker habitat. Scientists believe that Atlantic croaker are affected by these changes, but few specific studies have quantified the effects of habitat degradation on the fishery resource (S.J. Vanderkooy, Gulf States Marine Fisheries Commission, personal communication).

Many coastal and estuarine areas have inadequate water quality because of various land use activities. The Chesapeake Bay is one example of an area that experiences eutrophication from agricultural runoff. Excess nutrients entering coastal waters may cause algal blooms that reduce DO, resulting in hypoxic or anoxic conditions, especially during the summer months (R. Lukacovic, Maryland Department of Natural Resources, personal communication). Large hypoxic areas have also been documented in Louisiana's coastal waters during the summer due to nutrient loading into the Mississippi River from the Midwestern farm belt. These events can directly impact fisheries in the area (S.J. Vanderkooy, Gulf States Marine Fisheries Commission, personal communication).

## **Section III. Threats and Uncertainties**

### ***Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Atlantic Croaker***

Juvenile croaker may be affected by hydrological modifications, water quality degradation, or habitat alterations. Hydrological modifications such as ditching and channelization increase the slope of the shoreline and water velocities in the altered stream. Higher water velocity and reduced natural wetland filtration can result in increased shoreline erosion, increasing sediment and non-point pollutant loading in channelized water bodies (White 1996; EPA 2001). Several studies have found that the size, number, and species diversity of fish in channelized streams are reduced and the fisheries associated with them are less productive than those associated with unchannelized reaches of streams (Tarpsee et al. 1971; Hawkins 1980; Schoof 1980). Pate and Jones (1981) compared nursery areas in North Carolina that were altered and unaltered by channelization and found that Atlantic croaker and other estuarine-dependent species were more abundant in nursery habitats with no man-made drainage. They attributed this to the unstable salinity conditions that occurred in areas adjacent to channelized systems following moderate to heavy rainfall ( $>1$  inch  $24$  h $^{-1}$ ).

Pollutants negatively affect growth and physical condition of juvenile Atlantic croaker, with significantly reduced growth rates and condition occurring with increasing pollutant conditions (Burke et al. 1993). Low concentrations of heavy metals can accumulate in fine-grained sediments, particularly organic-rich muddy substrates, to toxic levels, and can be resuspended into the water column (Riggs et al. 1991).

Primary nursery areas in North Carolina often consist of such fine-grained sediments and are therefore susceptible to toxic contamination of bottom sediments (Street et al. 2005).

Severe hypoxia of bottom water and sediments, often associated with eutrophication, can adversely affect croaker populations through suffocation, reduced growth rates, loss of preferred benthic prey, changes in distribution, or disease (Street et al. 2005). Mass mortality of benthic infauna associated with anoxia has been documented in the deeper portions of the Neuse River estuary in North Carolina, in association with stratification of the water column in the summer (Lenihan and Peterson 1998; Luettich et al. 1999). During these events, oxygen depletion caused mass mortality of up to 90% of the dominant infauna within the affected area (Buzzelli et al. 2002). Utilizing a statistical model and field data, it was estimated that the extensive benthic invertebrate mortality, resulting from intensified hypoxia events, reduced total biomass of demersal predatory fish and crabs during summer months by 17–51% in 1997–1998 (Baird et al. 2004). The decrease in available energy from reduced benthos greatly reduced the ecosystem's ability to transfer energy to higher trophic levels at the time of year most needed by juvenile fish (Baird et al. 2004).

Alteration of natural shorelines has been shown to have a negative impact on juvenile Atlantic croaker populations. In a study along the Gulf Coast comparing fish abundance between unaltered and altered shorelines (bulkheads or rubble), croaker was most abundant at the unaltered unvegetated shoreline (Peterson et al. 2004). Other anthropogenic activities that can potentially degrade shallow shoreline habitat conditions include dredging and proliferation of docks and marinas (Street et al. 2005).

In spring and fall, moderate water temperatures and hypoxia may not be limiting Atlantic croaker distribution. However, in summer when water temperatures are higher, Atlantic croaker may avoid moderately hypoxic zones in order to avoid the additional physiological costs of staying in waters with less DO (Eby and Crowder 2002). As hypoxia increases in severity and scope within estuarine waters, croaker typically move to shallower parts of an estuary. Large hypoxic zones may limit adult croaker depth and temperature distribution, suggesting a shift in habitat use driven by the severity of a hypoxic event (Eby and Crowder 2002). Atlantic croaker may actually be limited to areas with higher-than-optimal temperatures during hypoxic events (Eby and Crowder 2002).

### ***Unknowns and Uncertainties***

Climate change is associated with a suite of perturbations to the prevailing conditions (i.e., temperature, DO, pH, salinity, turbidity, etc.) that will have direct and indirect impacts on the survival and growth of Atlantic croaker, although the magnitude of many of these impacts is not fully resolved. For example, gelatinous zooplankton abundance is expected to increase (Kemp et al. 2005), which may increase predation pressure on eggs and larvae of Atlantic croaker. In addition, hypoxic events are becoming more frequent (Kemp et al. 2005), shifting the distribution of croaker from favored juvenile channel habitats to shallow SAV habitats (Eby and Crowder 2002), which may increase interspecific competition through crowding in nursery habitats. Fish kills related to harmful algal blooms are also becoming a persistent issue in estuarine and coastal regions (Kemp et al. 2005) but the magnitude of these events is not known for Atlantic croaker. To understand how perturbations impact Atlantic croaker, baseline biological information is required (i.e., trophic interactions, sensory development, habitat use) in a developmental context.

## **Section IV. Recommendations for Habitat Management and Research**

### ***Habitat Management Recommendations***

Each state should implement a protection plan for Atlantic croaker habitat within its jurisdiction to ensure the sustainability of the spawning stock that is produced or resides within its state boundaries. Each program should inventory the historical and present range of croaker, specify the habitats that are targeted for restoration, and impose or encourage measures to preserve the quantity and quality of Atlantic croaker habitats.

1. States should notify in writing the appropriate Federal and state regulatory agencies of the locations of habitats used by Atlantic croaker for each life stage. Regulatory agencies should be advised of the types of threats to Atlantic croaker populations and recommend measures that should be employed to avoid, minimize, or eliminate any threat to current habitat quality.
2. State fishery regulatory agencies, in collaboration with state water quality agencies, should monitor hypoxic conditions in state waters (including estuaries and tidal basins) and report changes in Atlantic croaker abundance or habitat use.
3. Where sufficient knowledge is available, states should designate Atlantic croaker HAPCs for special protection. These locations should be designated High Quality Waters or Outstanding Resource Waters and should be accompanied by requirements that limit degradation of habitat, including minimization of non-point source runoff, prevention of significant increases in contaminant loadings, and prevention of the introduction of any new categories of contaminants into the area (via restrictions on National Pollutant Discharge Elimination System (NPDES) discharge permits for facilities in those areas.
4. State fishery regulatory agencies should develop protocols and schedules for providing input on water quality regulations and on Federal permits and licenses required by the Clean Water Act, Federal Power Act, and other appropriate vehicles, to ensure that Atlantic croaker habitats are protected to ensure that specific water quality needs for Atlantic croaker are met.
5. Water quality criteria for Atlantic croaker spawning and nursery areas should be established, or existing criteria should be upgraded, as to ensure successful reproduction. Any action taken should be consistent with Federal Clean Water Act guidelines and specifications.
6. All state and Federal agencies responsible for reviewing impact statements and permit applications for projects or facilities proposed for croaker spawning and nursery areas should ensure that those projects will have no or only minimal impact on local stocks. Any project that would result in the elimination of essential habitat should be avoided.
7. Federal and state fishery management agencies should take steps to limit the introduction of toxic compounds known to accumulate in Atlantic croaker and that pose threats to wildlife and human health.
8. Each state should establish windows of compatibility for activities known or suspected to adversely affect Atlantic croaker life stages and their habitats. Activities may include, but are not

limited to, navigational dredging, bridge construction, and dredged material disposal, and notify the appropriate construction or regulatory agencies in writing.

9. Projects involving water withdrawal from nursery habitats (e.g. power plants, irrigation, water supply projects) should be evaluated to ensure that larval or juvenile impingement or entrainment is minimized, and that any modifications to water flow or salinity regimes remain within croaker tolerance limits.
10. Each state should develop water use and flow regime guidelines to ensure the appropriate water levels and salinity levels are maintained for the long-term protection and sustainability of the stock. States should work to ensure that proposed water diversions or withdrawals from rivers upstream will not reduce or eliminate conditions favorable to Atlantic croaker.
11. The use of any fishing gear that is determined by management agencies to have a negative impact on Atlantic croaker habitat should be prohibited within HAPCs (e.g. trawling in spawning or primary nursery areas should be prohibited).
12. States should work to reduce the input of contaminants to Atlantic croaker habitats.
13. States should work with the U.S. Fish and Wildlife Service (USFWS), Divisions of Fish and Wildlife Management Assistance and Ecological Services and National Marine Fisheries Service (NMFS) Offices of Fisheries Conservation and Management and Habitat Conservation to identify hydropower dams that pose significant threats to maintenance of appropriated freshwater flows (volume and timing) to Atlantic croaker nursery and spawning areas and target these dams for appropriate recommendations during Federal Energy Regulatory Commission (FERC) re-licensing.

### ***Habitat Research Recommendations***

Although Atlantic croaker habitats have undergone loss and degradation; studies are needed to quantify the impact on Atlantic croaker populations. For example, there has been some speculation in recent years that extensive areas of low DO in the Chesapeake Bay killed most of the benthic organisms in the deeper water where croaker feed. Unfortunately, no research has been conducted to confirm the impact of hypoxia on food resources in this region (R. Lukacovic, Maryland Department of Natural Resources, personal communication).

The early life history of the Atlantic croaker is not well documented, yet events during this phase could have a significant impact on recruitment. A better understanding of this life stage of the species is needed to identify its habitat requirements, allowing scientists to evaluate the relative impacts of natural and anthropogenic disturbances.

Periodic review of various programs to monitor habitat and water quality could play an important role in understanding Atlantic croaker population dynamics. The following topics should be examined: nutrient loading; long-term water quality monitoring; hypoxia events; incidence of red tides, harmful dinoflagellates and *Pfisteria*; habitat modification permits; and wetlands protection.

## Literature Cited

- Able, K. W. and M.P. Fahay. 1997. *The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight*. Rutgers University Press, New Brunswick.
- Able, K. W. and Fahay, M. P. 2010. *Ecology of Estuarine Fishes: Temperate waters of the Western North Atlantic*. Johns Hopkins University Press, Baltimore.
- ASMFC (Atlantic States Marine Fisheries Commission). 2005. Amendment 1 to the Fishery Management Plan for Atlantic croaker. Fisheries Management Report No. 44, November 2005. Access: <http://www.asmfc.org/uploads/file/croakerAmendment1.pdf>.
- Avault, J. W. and C. L. Birdsong. 1969. Growth, survival, food habits, and sexual development of croaker, *Micropogon undulatus*, in brackish water ponds. *Proceedings of the Southeastern Association of Game and Fish Commissioners* 23: 251–255.
- Baird, D., R. R. Christian, C. H. Peterson, and G. A. Johnson. 2004. Application of massbalance food web modeling to assess impacts of hypoxia on trophic transfers to vertebrate consumers and ecosystem functions in a eutrophied estuary. *Ecological Applications* 14: 805–822.
- Barbieri, L. R., M. E. Chittenden Jr., and S. K. Lowerre-Barbieri. 1994. Maturity, spawning, and ovarian cycle of Atlantic croaker *Micropogonias undulatus*, in the Chesapeake Bay and adjacent coastal waters. *Fishery Bulletin* 92(4): 671–685.
- Burke, J. S., D. S. Peters and P. J. Hanson. 1993. Morphological indices and otolith microstructure of Atlantic croaker, *Micropogonias undulatus*, as indicators of habitat quality along an estuarine pollution gradient. *Environmental Biology of Fishes* 36(1): 25–33.
- Buzzelli, C. P., R. A. Luetlich Jr., S. P. Powers, C. H. Peterson, J. E. McNinch, J. L. Pinckney, and H. W. Paerl. 2002. Estimating the spatial extent of bottom water hypoxia and habitat degradation in a shallow estuary. *Marine Ecology Progress Series* 230: 103–112.
- Chao, L. N and J. A. Musick. 1977. Life history, feeding habits, and functional morphology of the juvenile sciaenid fishes in the York River Estuary. *Fishery Bulletin* 75: 657–702.
- Cowan, Jr., J. H., R. S. Birdsong, E. D. Houde, J. S. Priest, W. C., Sharp and G. B. Mateja. 1992. Enclosure experiments on survival and growth of black drum eggs and larvae in lower Chesapeake Bay. *Estuaries* 15(3): 392–402.
- Cowan, J. H. and R. S. Birdsong. 1985. Seasonal occurrence of larval and juvenile fishes in a Virginia Atlantic coast estuary with emphasis on drums (Family Sciaenidae). *Estuaries* 8(1): 48–59.
- Deary, A. L. and E. J. Hilton. 2016. Comparative ontogeny of the feeding apparatus of sympatric drums (Perciformes: Sciaenidae) in the Chesapeake Bay. *Journal of Morphology* 277: 183–195.
- Diaz, R. J., and C. P. Onuf. 1985. *Habitat Suitability Index Models: Juvenile Atlantic croaker (revised)*. Report for the National Coastal Ecosystems Team Division of Biological Services Research and Development, US Fish and Wildlife Service. Washington, DC. pp. 23.

- Eby, L. A. and L. B. Crowder. 2002. Hypoxia-based habitat compression in the Neuse River Estuary: context-dependent shifts in behavioral avoidance thresholds. *Canadian Journal of Fisheries and Aquatic Sciences* 59: 952–965.
- EPA (U.S. Environmental Protection Agency). 2001. Hydromodification chapter factsheet. <http://www.epa.gov/OWOW/NPS/MMGI/hydro.html>, 12/2001.
- Friedrichs, C. T. 2009. York River physical oceanography and sediment transport. In K. A. Moore and W. G. Reay (eds.), *A Site Profile of the Chesapeake Bay National Estuarine Research Reserve, Virginia*. *Journal of Coastal Research* SI 57: 17–22.
- Gannon, D. P. and D. M. Waples. 2006. Diets of coastal bottlenose dolphins from the U.S. Mid-Atlantic coast differ by habitat. *Marine Mammal Science* 20(3): 527–545.
- Govoni, J. J., D. E. Hoss, and A. J. Chester. 1983. Comparative feeding of three species of larval fishes in the northern Gulf of Mexico: *Brevoortia patronus*, *Leiostomus xanthurus*, and *Micropogonias undulatus*. *Marine Ecology Progress Series* 13: 189–199.
- Govoni, J. J., P. B. Ortner, F. Al-Yamani and L. C. Hill. 1986. Selective feeding of spot, *Leiostomus xanthurus*, and Atlantic croaker, *Micropogonias undulatus*, larvae in the northern Gulf of Mexico. *Marine Ecology Progress Series* 28: 175–183.
- Hansen, D. J. 1969. Food, growth, migration, reproduction, and abundance of pinfish, *Lagodon rhomboides*, and Atlantic croaker, *Micropogon undulatus*, near Pensacola, Florida, 1963–65. US Fish and Wildlife Service. *Fishery Bulletin* 68(1): 135–146.
- Hare, J. A., H. J. Walsh, and M. J. Wuenschel. 2006. Sinking rates of late-stage fish larvae: Implications for larval ingress into estuarine nursery habitats. *Journal of Experimental Marine Biology and Ecology* 330: 493–504.
- Hare, J. A. and K. W. Able. 2007. Mechanistic links between climate and fisheries along the east coast of the United States: explaining population outbursts of Atlantic croaker (*Micropogonias undulatus*). *Fisheries Oceanography* 16(1): 31–45.
- Haven, D. S. 1957. Distribution, growth, and availability of juvenile croaker, *Micropogon undulatus*, in Virginia. *Ecology* 38: 88–97.
- Hawkins, J. H. 1980. Investigations of anadromous fishes of the Neuse River, North Carolina. Division of Marine Fisheries, Morehead City, NC, Special Science Report No. 34, pp. 111.
- Hunter, J. R. 1981. Feeding ecology and predation of marine fish larvae. In: Lasker, R. (ed.) *Marine fish larvae: morphology, ecology, and relation to fisheries*. Washington Sea Grant Program, Seattle, pp. 34–77.
- Joyeux, J. C. 1998. Spatial and temporal entry patterns of fish larvae into North Carolina Estuaries: Comparisons among one pelagic and two demersal species. *Estuarine, Coastal and Shelf Science* 47: 731–752.

- Kemp, W. M., W. R. Boynton, J. E. Adolf, D. F. Boesch, W. C. Boicourt, G. Brush, J. C. Cornwell, T. R. Fisher, P. M. Blibert, J. D. Hagy, L. W. Harding, E. D. Houde, D. G. Kimmel, W. D. Miller, R. I. E. Newell, M. R. Roman, E. M. Smith and J. C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. *Marine Ecology Progress Series* 303: 1–29.
- Lankford, T. E. and T. E. Targett. 2001. Physiological performance of young-of-the-year Atlantic croakers from different Atlantic coast estuaries: implications for stock structure. *Transactions of the American Fisheries Society* 130: 367–375.
- Lassuy, D. R. 1983. Species profiles: life histories and environmental requirements: Atlantic croaker. Report for the National Coastal Ecosystems Team Division of Biological Services Research and Development, U.S. Fish and Wildlife Service. Washington, DC. pp. 12.
- Lenihan, H. S. and C. H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. *Ecological Applications* 8(1): 128–140.
- Lewis, R. M. and M. H. Judy. 1983. The occurrence of spot, *Leiostomus xanthurus*, and Atlantic croaker, *Micropogonias undulatus*, larvae in Onslow Bay and Newport River estuary North Carolina. *Fishery Bulletin* 81(2): 405–412.
- Luetlich, R. A., J. E. McNinch, J. L. Pinckney, M. J. Alperin, C. S. Martens, H. W. Paerl, C. H. Peterson and J. T. Wells. 1999. Neuse River estuary modeling and monitoring project, final report: Monitoring phase. Water Resources Research Institute, Raleigh, NC. pp. 190.
- Migliarese, J. V., C. W. McMillan and M. H. Shealy, Jr. 1982. Seasonal abundance of Atlantic croaker (*Micropogonias undulatus*) in Relation to bottom salinity and temperature in South Carolina estuaries. *Estuaries* 5: 216–223.
- Miller, J. M. and K. W. Able. 2002. Movements and growth of tagged young-of-the-year Atlantic croaker (*Micropogonias undulatus* L.) in restored and reference marsh creeks in Delaware Bay, USA. *Journal of Experimental Marine Biology and Ecology* 267: 15–33.
- Miller, J. M., D. M. Nemerson and K. W. Able. 2002. Seasonal distribution, abundance, and growth of young-of-the-year Atlantic croaker (*Micropogonias undulatus*) in Delaware Bay and adjacent marshes. *Fishery Bulletin* 101: 100–115.
- Nemerson, D. M. and K. W. Able. 2004. Spatial patterns in diet and distribution of juveniles of four fish species in Delaware Bay marsh creeks: factors influencing fish abundance. *Marine Ecology Progress Series* 276: 249–262.
- Nixon, S. W. and C. M. Jones. 1997. Age and growth of larval and juvenile Atlantic croaker, *Micropogonias undulatus*, from the Middle Atlantic Bight and estuarine waters of Virginia. *Fishery Bulletin* 95: 773–784.
- Norcross, B. L. and H. M. Austin. 1988. Middle Atlantic Bight meridional wind component effect on bottom water temperatures and spawning distribution of Atlantic croaker. *Continental Shelf Research* 8(1): 69–88.



- Nye, J. A. 2008. Bioenergetic and ecological consequences of diet variability in Atlantic croaker *Micropogonias undulatus* in Chesapeake Bay. Dissertation Abstracts International 69.
- Nye, J. A., D. A. Loewensteiner and T. J. Miller. 2011. Annual, Seasonal, and Regional Variability in Diet of Atlantic Croaker (*Micropogonias undulatus*) in Chesapeake Bay. *Estuaries and Coasts* 34: 691–700.
- Olney, J. E. and G. W. Boehlert. 1988. Nearshore ichthyoplankton associated with seagrass beds in the lower Chesapeake Bay. *Marine Ecology Progress Series* 45: 33–43.
- Pate, P. P. and R. Jones. 1981. Effects of upland drainage on estuary nursery areas of Pamlico Sound, North Carolina. UNC Sea Grant Program. WP-81-10. pp. 24.
- Peterson, M. S., B. H. Comyns, C. F. Rakocinski and G. L. Fulling. 2004. Defining the fundamental physiological niche of young estuarine fishes and its relationship to understanding distribution, vital metrics, and optimal nursery conditions. *Environmental Biology of Fishes* 71: 143–149.
- Petrik, R., P. S. Levin, G. W. Stunz and J. Malone. 1999. Recruitment of Atlantic croaker, *Micropogonias undulatus*: Do postsettlement processes disrupt or reinforce initial patterns of settlement? *Fishery Bulletin* 97: 954–961.
- Poling, K. R., L. A. Fuiman. 1998. Sensory development and its relation to habitat change in three species of sciaenids. *Brain, Behavior and Evolution* 52: 270–284.
- Purcell, J. E. 1985. Predation on fish eggs and larvae by pelagic cnidarians and ctenophores. *Bulletin of Marine Science* 37: 739–755.
- Ribeiro, F., E. Hale, E. J. Hilton, T. R. Clardy, A. L. Deary, T. E. Targett, and J. E. Olney. 2015. Composition and temporal patterns of larval fish communities in Chesapeake and Delaware Bays, USA. *Marine Ecology Progress Series* 527: 167–180.
- Ribeiro, F., E. J. Hilton and R. B. Carnegie. 2016. High prevalence and potential impacts of caligid ectoparasites on larval Atlantic croaker (*Micropogonias undulatus*) in the Chesapeake Bay. *Estuaries and Coasts* 39(2): 583–588.
- Riggs, S. R., J. T. Bray, E. R. Powers, J. C. Hamilton, D. V. Ames, K. L. Owens, D. D. Yeates, S. L. Lucas, J. R. Watson and H. M. Williamson. 1991. Heavy metals in organic-rich muds of the Neuse River estuarine system, Albemarle-Pamlico Estuarine Study. Report No. 90-07.
- Robins, C. R. and G. C. Ray. 1986. A field guide to Atlantic coast fishes of North America. Houghton Mifflin Company, Boston, MA. pp. 354.
- Ross, S. W. 2003. The relative value of different estuarine nursery areas in North Carolina for transient juvenile marine fishes. *Fishery Bulletin* 101: 384–404.
- Rozas, L. P. and R. J. Zimmerman. 2000. Small-scale patterns of nekton use among marsh and adjacent shallow nonvegetated areas of the Galveston bay estuary, Texas (USA). *Marine Ecology Progress Series* 193: 217–239.

- Schoof, R. 1980. Environmental impact of channel modification. *Water Resources Bulletin* 16(4): 697–701.
- Sheridan, P. F. 1979. Trophic resource utilization by three species of Sciaenid fishes in a northwest Florida Estuary. *Northeast Gulf Science* 3(1): 1–15.
- Street, M. W., A. S. Deaton, W. S. Chappell and P. D. Mooreside. 2005. North Carolina Coastal Habitat Protection Plan. Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City, pp. 607.
- Tarplee Jr., W. H., D. E. Louder, and A. J. Weber. 1971. Evaluation of the effects of channelization on fish populations in North Carolina's coastal plain streams. North Carolina Wildlife Resources Commission, Raleigh, NC.
- Texas System of Natural Laboratories (TSNL). 1982. Ecological Atlas of Texas, Fishes of Texas Waters Matrix Manuscript. A species profile: *Micropogonias undulatus*, Atlantic croaker (ed). TSNL Austin, TX.
- Thomas P., S. Rahman, I. A. Khan and J. A. Kummer. 2007. Widespread endocrine disruption and reproductive impairment in an estuarine fish population exposed to seasonal hypoxia. *Proceedings of the Royal Society Biological Sciences* 274: 2693–2701.
- Thomas, P. and S. Rahman. 2009. Chronic hypoxia impairs gamete maturation in Atlantic croaker induced by progestins through nongenomic mechanisms resulting in reduced reproductive success. *Environmental Science and Technology* 43: 4175–4180.
- Thomas, P. and S. Rahman. 2010. Region-wide impairment of Atlantic croaker testicular development and sperm production in the northern Gulf of Mexico hypoxic dead zone. *Marine Environmental Research* 69: 59–62.
- Townsend, D. W., A. C. Thomas, L. M. Mayer, M. A. Thomas and J. A. Quinlan. 2004. Oceanography of the northwest Atlantic continental shelf (1,W). In Robinson, A. R. and K. H. Brink (eds). 2004. *The Sea: The Global Coastal Ocean: Interdisciplinary. Regional Studies and Syntheses*. Harvard University Press, Boston.
- USFWS (U.S. Fish and Wildlife Service). 1996. Atlantic croaker Species Id. <http://fwie.fw.vt.edu/WWW/macsis/lists/M010250.htm>.
- White, K. 1996. Restoration of channelized streams to enhance fish habitat. <http://www.ies.wisc.edu/research/ies900/kimchannelization.htm>, Dec. 2003.

## CHAPTER 3: BLACK DRUM

EFH, HAPC, and Threats are populated with Habitat Section from the [Interstate Fishery Management Plan for Black Drum \(ASMFC 2013\)](#)

### **Section I. General Description of Habitat**

Black drum in the Atlantic form one population, and two separate populations exist in the Gulf of Mexico (Gold and Richardson 1998). Like many coastal species, oceanic spawning is followed by ingress of eggs and larvae to mid and upper estuarine habitats, although substantial variation likely exists with respect to settlement. Juvenile black drum are largely estuarine-dependent, but throughout the first year of life begin moving to the lower estuary and possibly into the coastal ocean by the fall of year one (Able and Fahay 2010). Geographic adult age structure has been suggested, with older individuals more common in the Mid-Atlantic Bight than in the South Atlantic Bight, although a general movement pattern has been described as north and inshore in the spring, and south and offshore in the fall, which may confound true patterns of habitat use.

#### **Part A. Spawning Habitat<sup>1</sup>**

##### ***Geographic and Temporal Patterns of Migration***

In the Atlantic basin, black drum spawn from April to June in the northern range (Joseph et al. 1964; Richards 1973; Silverman 1979). Black drum have been reported to spawn in nearshore waters, particularly bays and estuaries (Hoese 1965; Etzold and Christmas 1979). In the Mid-Atlantic region, spawning in the mouth of the Chesapeake Bay and larger estuaries has been well documented (Able and Fahay 2010) and the presence of a large spring/early summer fishery on spawning fish in the Delaware Bay also supports evidence of spawning occurring inshore and in the spring. Studies in Florida suggest spawning occurs in deep waters inshore, from November through April, with peaks in February and March (Murphy and Taylor 1989). It is noteworthy that the drumming sound made by black drum is associated with spawning behaviors, and several studies have measured noise in an effort to describe reproduction (Gulf of Mexico, Saucier and Baltz 1993, Locascio and Mann 2011; South America, Tellechea et al. 2010).

Fitzhugh et al. (1993) noted a difference in sex ratios in Louisiana during the spawning season between fish caught offshore by trawls (dominated by males), and fish caught inshore by gillnet and haul-seines (dominated by females). These skewed sex ratios were not found before or after the spawning period. The authors concluded the catches reflected a true segregation of the sexes during the spawning period, suggesting the use of different habitats.

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<sup>1</sup> Much of the information in this section comes from two spawning studies in the Gulf of Mexico. These studies focused on the acoustics of spawning, and included a great deal of environmental data. Therefore, the ability to generalize about spawning habitat is somewhat limited, and more research is recommended.

### **Salinity**

Salinity during drumming aggregations has been reported to range from 18.8–20.8 ppt in Louisiana (Saucier and Baltz 1993). Based on coastal ocean and lower estuary reported spawning habitats, euryhaline or full seawater salinities would be expected as optimal.

### **Substrate**

None of the spawning studies describe substrate in association with a particular spawning aggregation; however, Saucier and Baltz (1993) generally describe the study sites to be heterogeneous, and include silt, clay, mud, sand, and detritus, and Locascio and Mann (2011) describe their sites as soft muddy composite.

### **Temperature**

From studies limited to the Gulf of Mexico, spawning aggregations have been associated with temperatures ranging from 18–22°C (Locascio and Mann 2011) and with means of 18.8°C (for large drumming aggregations) and 20.8°C (for moderate drumming aggregations; Saucier and Baltz 1993).

### **Dissolved Oxygen**

Saucier and Baltz (1993) present the only DO data associated with black drum spawning. They report means of 12.3 and 11.6 mg L<sup>-1</sup> for large and moderate spawning aggregations, respectively. Inference on DO preference or tolerance ranges (or in other spatial spawning aggregations) should be approached cautiously.

### **Feeding Behavior**

No published work has reported on the feeding behaviors of spawning individuals. It might be inferred—based on nearshore and estuarine habitats—that spawning black drum feed on the same food sources as adults, which includes primarily crustaceans and mollusks.

### **Competition and Predation**

Competition among black drum and with other species is undocumented for spawning adults. Because spawning habitat is not yet described at a fine scale (microhabitat), it is unclear whether spawning habitats are limiting, and if competition exists for these habitats or inclusion in spawning aggregations. Predation of spawning adults is likely similar to adult *P. cromis*, although possibly depressed from both lower predatory metabolic demands from cooler winter and spring water temperatures, and the absence of many estuarine shark species until late spring (Ulrich et al. 2007).

## **Part B. Egg Habitat**

### **Geographic and Temporal Patterns of Migration**

Along the Atlantic coast, black drum eggs are spawned during the spring, from April to June in the northern range (Joseph et al. 1964; Richards 1973; Silverman 1979), and in February and March in the southern range (data from Florida; Murphy and Taylor 1989). Most spawning has been reported or estimated to take place nearshore in the coastal ocean, though some eggs have been sampled in the lower reaches of larger estuaries, such as the Chesapeake Bay (Daniel and Graves 1994). Spawning takes place when temperatures are between 17.5 and 19°C (Joseph et al. 1964; Richards 1973). Black drum eggs are pelagic, and at 20°C hatch in less than 24 h (Joseph et al. 1964). Some migration from tidal stream transport may take place; however, due to the short duration of the egg stage, it is unlikely that much distance is covered.

### ***Salinity***

Even though spawning occurs nearshore, black drum eggs in the coastal ocean are assumed to be exposed to full marine salinity (35 ppt) or at least polyhaline conditions for the brief duration before hatching (~24 hours).

### ***Substrate***

Since black drum eggs are pelagic and positively buoyant, substrate is not considered a critical habitat parameter.

### ***Temperature***

Spawning has been reported to take place when temperatures are between 17.5 and 19°C (Joseph et al. 1964; Richards 1973), and thus optimal (or tolerated) egg temperatures are likely very similar.

### ***Dissolved Oxygen***

Because the egg stage of black drum occurs entirely offshore, eggs are likely only ever exposed to normoxic waters (>5 mg L<sup>-1</sup>). It is not currently thought that DO is a limiting factor to survival of black drum eggs.

### ***Feeding Behavior***

Black drum eggs subsist entirely off of the yolk sac prior to hatch.

### ***Competition and Predation***

Black drum eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the oceanic or estuarine conditions). Predation of eggs undoubtedly occurs by a variety of oceanic and estuarine consumers. Specifically, Cowan et al. (1992) reported predation of black drum eggs by ctenophores and hydromedusae in the Chesapeake Bay with potentially very high levels of predation during years where both gelatinous predators have high abundances.

## **Part C. Larval Habitat**

### ***Geographic and Temporal Patterns of Migration***

Black drum larvae hatch around 2.5 mm SL (Able and Fahay 2010) and ingress from nearshore and lower estuarine egg habitats using tidal stream transport to variable locations within estuaries. Overall the general pattern documented for larvae is to move from higher salinity areas to lower salinity estuarine habitats (from otolith microchemical analyses; Rooker et al. 2004), and Gold and Richardson (1998) used molecular methods to characterize black drum as estuarine-dependent in the early years. However, black drum may be less dependent on upper, oligohaline and mesohaline estuarine habitats as larvae have been collected in higher salinities of 21 ppt (Peters and McMichael 1990). As with other sciaenids, it is likely that larval black drum settle in a range of estuarine habitats with confounding of estuarine-specific habitat availabilities.

### ***Salinity***

Peters and McMichael (1990) collected larvae off the Gulf Coast of Florida in salinities ranging from 21–31 ppt. The larval stage of black drum likely uses the lowest salinity habitats of any life stage, although there are few records of larvae collected in low salinity, upper estuarine habitats.

### ***Substrate***

Peters and McMichael (1990) collected larvae off the Gulf Coast of Florida over a variety of substrates, including sand, mud, and shells. Larval collections in the Atlantic, particularly with respect to substrate, are poorly known.

### ***Temperature***

Peters and McMichael (1990) collected larvae off the Gulf Coast of Florida in water temperatures ranging from 21.9–24.6°C.

### ***Dissolved Oxygen***

DO demands are likely met offshore, as well as inshore after ingress. Both of these habitats typically do not experience hypoxic conditions in the winter and spring, although no published studies have reported on any limitations.

### ***Feeding Behavior***

Like most larval fish, black drum feed on their yolk sac initially (up to 4 days, or to an estimated 2.8 mm SL; Joseph et al. 1964). Post-yolk sac larvae then begin to feed generally on zooplankton (Benson 1982), and more specifically copepods (Peters and McMichael 1990).

### ***Competition and Predation***

Black drum larvae may experience density dependence, although this phenomenon has not been documented and the variety of settlement habitats may release them from specific habitat or spatial constraints. Additionally, the species' relatively long spawning season may mitigate against a temporal bottleneck for habitat. Larval black drum are likely subject to predation by a range of estuarine predators; particular attention to hydromedusa and ctenophore predators has been hypothesized to impact recruitment in years of low black drum production and high densities of hydrozoans (Cowan et al. 1992).

## **Part D. Juvenile Habitat**

### ***Geographic and Temporal Patterns of Migration***

Broadly, juvenile black drum likely use a range of estuarine habitats. Small juveniles have been documented in upper and middle parts of estuaries, where salinities are low (<6 ppt; Able and Fahay 2010). However, by the summer months, juveniles begin moving down in the estuary into tidal and marsh habitats and are not found in rivers. By the fall, some juveniles are even found in ocean habitats. Beach seine sampling in Florida nearshore lagoons found high levels of juveniles, indicating juvenile black drum remain inshore (Peters and McMichael 1990).

### ***Salinity***

Salinity exposure is likely variable both across a cohort as well as the individual level. Some juveniles have been sampled in lower estuary, high salinity (>30 ppt) locations (Peters and McMichael 1990), while others have reported juvenile black drum in freshwater (Frisbie 1961; Thomas and Smith 1973). Some reports have discussed a size effect to down-estuary movement, in which migrations to lower estuarine or oceanic habitats is influenced by size. In general, smaller individuals inhabit low salinity tributaries whereas larger individuals inhabit higher salinity regions found at the mouths of bays and rivers (Frisbie 1961).

### ***Substrate***

Peters and McMichael (1990) reported juvenile black drum over unvegetated mud bottoms, and Pearson (1929) reported muddy, estuarine bottoms as the most common juvenile substrate. However, as with salinity, juveniles likely use a range of habitats and substrates.

### ***Temperature***

Juveniles likely experience a range of temperatures throughout their first year in an estuary. Juveniles in the Gulf of Mexico primarily sampled over summer and fall months were captured at 20.8–26.3°C (Peters and McMichael 1990). Winter temperature drops are common causes of estuarine fish kills, and black drum are vulnerable to this condition (Simmons and Breuer 1962). McEachron et al. (1994) noted black drum in several winter kills in Texas coastal waters, though the length data suggests many of these fish were adults and not juveniles.

### ***Dissolved Oxygen***

Currently, there is no known information on juvenile black drum sensitivity to DO levels.

### ***Feeding Behavior***

Small juveniles primarily feed on amphipods, mollusks, polychaetes, and small fishes (Peters and McMichael 1990). As juveniles grow, Peters and McMichael (1990) found their consumption of shrimp, crabs, fish, and mollusks became more dominant, with the shift correlating to the development of pharyngeal jaw toothplates and molariform teeth.

### ***Competition and Predation***

Based on the within-estuary movement during the first year of life and wide use of estuarine resources, little is reported on competition among black drum or with other estuarine species, although they likely compete with other sciaenids (Sutter et al. 1986). Pharyngeal teeth permit black drum to eat a wide variety of mollusks and other prey items, which may limit competition on a single food source (Sutter et al. 1986). Predation of juvenile black drum likely takes place by estuarine predators, such as spotted seatrout, jacks, sharks (Murphy and Muller 1995).

## **Part E. Adult Habitat**

### ***Geographic and Temporal Patterns of Migration***

While adult black drum likely move between estuarine and nearshore habitats, multiple investigators have noted two trends. The first trend is the expected movement toward deeper waters with age (i.e., out of tidal creeks and into lower estuaries). The second geographic pattern involves general adult movements north and inshore during spring, and south and offshore during fall (Richards 1973; Murphy and Taylor 1989). Jones and Wells (2001) note the possibility of age separation, with greater proportions of older fish north of Cape Hatteras, North Carolina. However, it is unclear what proportion of the Atlantic population undergoes migration or whether they are influenced by factors other than spawning. Even the literature has been inconsistent in regard to how to characterize adult habitat use. For example, Sutter (1986; citing Hoese and Moore 1977) stated that adult black drum are predominantly estuarine but other studies have cited an ocean residency period. Given the long lifespan of black drum (>50 years) and factors driving adult habitat use (e.g., spawning migration, general seasonality), it is likely that they use a variety of inshore and nearshore habitats.

### ***Salinity***

Lower estuarine and coastal oceanic environments used by black drum are likely polyhaline or full seawater. Black drum are commonly found in waters with a salinity range of 9–26 ppt (McIlwain 1978) but individuals can tolerate salinities as low as 0 ppt and as high as 80 ppt (Gunter 1956; Simmons and Breuer 1962; Leard et al 1993).

### ***Substrate***

Adults likely use a wide variety of habitats and substrates, and Sutter (1986) suggests that adults are most common over sand and soft bottoms where oysters and clams can be found. Black drum in Louisiana were observed to avoid large, open areas of soft sediment (George 2003).

### ***Temperature***

McIlwain (1978; in Sutter 1986) reported black drum adults in a range of temperatures consisting of 12–33°C. The range reported here may be interpreted as a suitable range, and more extreme temperatures may be tolerated.

### ***Dissolved Oxygen***

No studies have reported on DO requirements for black drum, though there is little reason to suspect that adults experience sustained periods of limited DO. Both their mobility and range of habitats suggest that they are not constrained to or by specific, low oxygen environments.

### ***Feeding Behavior***

Adult black drum continue their predation on benthic crustaceans and mollusks, although Ackerman (1951) reported surface feeding on menhaden. Blasina et al. (2010) reported on black drum in Argentina and also found crustaceans and mollusks to dominate the diet. With efforts underway to rehabilitate Atlantic oysters, some have looked into the ability of black drum to depress recovering oyster populations (Benson 1982; Brown et al. 2008).

### ***Competition and Predation***

Competition among black drum is likely minimal as there are no suspected habitat or forage limitations regularly imposed on adults. Adult black drum, based on their large size, are unlikely to be consumed, but have been documented to be preyed upon by sharks (Murphy and Muller 1995).

## **Section II. Essential Fish Habitats and Habitat Areas of Particular Concern**

### ***Essential Fish Habitat***

Prior to transfer of management authority for red drum from the South Atlantic Fishery Management Council (SAFMC) to ASMFC, the SAFMC reviewed the Essential Fish Habitat (EFH) and HAPC designations for red drum. The SAFMC concluded the EFH and HAPCs would still be protected, as similar areas had been designated for other federally managed species. As a result, these areas, which also serve an important role in the black drum life cycle, have retained protection and are referenced here and in the Amendment 2 to the Red Drum FMP (ASMFC 2002).

The designated EFH includes tidal freshwater, estuarine emergent vegetated wetlands (flooded salt marsh, brackish marsh, and tidal creeks), estuarine scrub/shrub (mangrove fringe), submerged rooted vascular plants (seagrass), oyster reefs and shell banks, unconsolidated bottom (soft sediment), ocean



high salinity surf zones, and artificial reefs (SAFMC 1998). The area covered ranges from Virginia through the Florida Keys, to a depth of 50 m offshore.

### ***Identification of Habitat Areas of Particular Concern***

For black drum, HAPCs includes the following habitats: tidal freshwater, estuarine emergent vegetated wetlands (flooded salt marshes, brackish marsh, and tidal creeks), estuarine scrub/shrub (mangrove fringe), submerged rooted vascular plants (seagrasses), oyster reefs and shell banks, unconsolidated bottom (soft sediments), ocean high salinity surf zones, and artificial reefs. These areas overlap with the designated HAPCs for red drum, designated in Amendment 2 to the Red Drum FMP (ASMFC 2002). These HAPCs include all coastal inlets, all state-designated nursery habitats (i.e. Primary Nursery Areas in North Carolina), sites where spawning aggregations of red drum have been documented and spawning sites yet to be identified, areas supporting SAV, as well as barrier islands off the South Atlantic states as they maintain the estuarine environment in which young black drum develop.

A species' primary nursery areas are indisputably essential to its continuing existence. Primary nursery areas for black drum can be found in estuaries, such as coastal marshes, shallow tidal creeks, bays, tidal flats of varying substrate, tidal impoundments, and seagrass beds. Since young black drum move among these environments, it is difficult to designate specific areas as deserving more protection than others. Moreover, these areas are not only primary nursery areas for black drum, but they fulfill the same role for numerous other resident and estuarine-dependent species of fish (i.e., other sciaenids) and invertebrates.

Similarly, juvenile black drum habitat extends over a broad geographic range and adheres to the criteria that define HAPCs. Juvenile black drum are found throughout tidal creeks and channels of southeastern estuaries, in backwater areas behind barrier islands and along beach fronts during certain times of the year. It is during this period that juveniles begin moving between low and higher salinity areas (Rooker et al. 2004). Therefore, the estuarine system as a whole, from the lower salinity reaches of rivers to the mouth of inlets, is vital to the continuing existence of this species.

## **Section III. Threats and Uncertainties**

### ***Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Black Drum***

Threats to black drum habitats include the following: loss of estuarine and marine wetlands, loss of oyster reefs, coastal development, nutrient enrichment of estuarine waters, poor water quality, hydrologic modifications, and alteration of freshwater flows into estuarine waters.

### ***Present Condition of Habitat Areas of Particular Concern***

#### ***Coastal Spawning Habitat: Condition and Threats Coastal Spawning***

It is reasonable to assume that areas where coastal development is taking place rapidly, habitat quality may be compromised. Coastal development is a continuous process in all states and all coastal areas in the nation are experiencing significant growth. The following section describes particular threats to the nearshore habitats in the South Atlantic that meet the characteristics of suitable spawning habitat for black drum.

One threat to the spawning habitat for black drum is navigation and related activities such as dredging and hazards associated with ports and marinas (ASMFC 2013). According to the SAFMC (1998), impacts from navigation related activities on habitat include: direct removal/burial of organisms from dredging

and disposal of dredged material, effects due to turbidity and siltation; release of contaminants and uptake of nutrients, metals and organics; release of oxygen-consuming substances, noise disturbance, and alteration of the hydrodynamic regime and physical characteristics of the habitat. All of these impacts have the potential to substantially decrease the quality and extent of black drum spawning habitat as well as prey resources.

Besides creating the need for dredging operations that directly and indirectly affect spawning habitat for black drum, ports also present the potential for spills of hazardous materials. The cargo that arrives and departs from ports includes highly toxic chemicals and petroleum products. Although spills are rare, constant concern exists since huge expanses of productive estuarine and nearshore habitat are at stake. Additional concerns related to navigation and port utilization are discharge of marine debris, garbage, and organic waste into coastal waters.

Maintenance and stabilization of coastal inlets is of concern in certain areas of the southeast. Studies have implicated jetty construction to alterations in hydrodynamic regimes thus affecting the transport of larvae of estuarine-dependent organisms through inlets (Miller et al. 1984; Miller 1988).

#### *Estuarine Nursery, Juvenile and Sub-Adult Habitat: Condition and Threats*

Coastal wetlands and their adjacent estuarine waters constitute primary nursery, juvenile, and sub-adult habitat for black drum along the coast. Between 1986 and 1997, estuarine and marine wetlands nationwide experienced an estimated net loss of 10,400 acres. However, the rate of loss was reduced over 82% since the previous decade (Dahl 2000). Most of the wetland loss resulted from urban and rural activities and the conversion of wetlands for other uses. Along the southeast Atlantic coast, the state of Florida experienced the greatest loss of coastal wetlands due to urban or rural development (Dahl 2000). However, the loss of estuarine wetlands in the southeast has been relatively low over the past decade although there is some evidence that invasion by exotic species, such as Brazilian pepper (*Schinus terebinthifolius*), in some areas could pose potential threats to fish and wildlife populations in the future (T. Dahl, personal communication).

Throughout the coast, the condition of estuarine habitat varies according to location and the level of urbanization. In general, it can be expected that estuarine habitat adjacent to highly developed areas will exhibit poorer environmental quality than more distant areas. Mollusks, which are a dominant component of the black drum diet, bioaccumulate toxins in their tissues (Shumway et al. 1990) although the impact of this bioaccumulation on black drum is not known. Hence, environmental quality concerns are best summarized on a watershed level.

Threats to estuarine habitats of the southeast were described in Amendment 2 to the Red Drum FMP (ASMFC 2002). Due to the black drum's dependence on estuarine habitats throughout its early years, these same threats are likely to impact black as well as red drum.

Nutrient enrichment of estuarine waters throughout the southeast is a major threat to the quality of estuarine habitat. Forestry practices contribute significantly to nutrient enrichment in the southeast. Areas involved are extensive and many are in proximity to estuaries. Urban and suburban developments are perhaps the most immediate threat to black drum habitat in the southeast. The almost continuous expansion of ports and marinas in the South Atlantic poses a threat to aquatic and upland habitats. Certain navigation-related activities are not as conspicuous as port terminal construction but have the potential to significantly impact the estuarine habitat that black drum require. Activities related to

watercraft operation and support pose numerous threats including discharge of pollutants from boats and runoff from impervious surfaces, contaminants generated in the course of boat maintenance, intensification of existing poor water quality conditions, and the alteration or destruction of wetlands, shellfish and other bottom communities for the construction of marinas and other related infrastructure.

Estuarine habitats of the southeast can be negatively impacted by hydrologic modifications. The latter include activities related to aquaculture, mosquito control, wildlife management, flood control, agriculture, and silviculture. Also, ditching, diking, draining and impounding activities associated with industrial, urban, and suburban development qualify as hydrologic modifications that may impact the estuarine habitat. Alteration of freshwater flows into estuarine areas may change temperature, salinity and nutrient regimes as well as alter wetland coverage. Studies have demonstrated that changes in salinity and temperature can have profound effects in estuarine fishes (Serafy et al. 1997) and that salinity partly dictates the distribution and abundance of estuarine organisms (Holland et al. 1996). Hence, black drum are probably as susceptible as any other estuarine organism to such changes in the physical regime of their environment.

Oyster reefs in Louisiana are a preferred habitat (George 2003) and oysters are a common prey (Blasina et al. 2010). However, in the Chesapeake Bay, oysters have been reduced to 1% of historical levels (Kemp et al. 2005), which represents a significant decline in both a preferred habitat and prey of black drum.

#### ***Adult Habitat: Condition and Threats***

Threats to the black drum's adult habitat are not as numerous as those faced by postlarvae, juveniles, and subadults in the estuarine and coastal waters. Current threats to the nearshore and offshore habitats that adult black drum utilize in the South Atlantic include navigation and related activities, dumping of dredged material, mining for sand and minerals, oil and gas exploration, offshore wind facilities, and commercial and industrial activities (SAFMC 1998).

An immediate threat is the sand mining for beach nourishment projects. Associated threats include burial of bottoms near the mine site or near disposal sites, release of contaminants directly or indirectly associated with mining (i.e. mining equipment and materials), increases in turbidity to harmful levels, and hydrologic alterations that could result in diminished desirable habitat.

Offshore mining for minerals may pose a threat to black drum habitat in the future. Currently, there are no mineral mining activities taking place in the South Atlantic. However, various proposals to open up additional areas off the Atlantic coast to seabed mining have been introduced by the Federal Executive and Legislative branches.

Offshore wind farms may also pose a threat to black drum habitat at different life stages in the future (ASMFC 2011). Currently, there are no offshore wind farms established in the United States. However, the Atlantic coast is a potential candidate for future wind farm sites.

#### ***Unknowns and Uncertainties***

Habitat preferences, physiological tolerances to temperature, salinity, and DO, and life history information is lacking for black drum. Without these data, it is extremely difficult to predict how black drum populations will respond to climate variability, ocean acidification, environmental toxins, and

hypoxic conditions. For example, during an hypoxic event black drum are mobile and are able to avoid hypoxic waters whereas their prey (sessile mollusks) are unable to avoid these conditions, potentially increasing mortality of black drum prey. Therefore, there are many ecological linkages in estuarine and coastal ecosystems that need to be examined to understand direct and indirect impacts of habitat degradation on the various life stages of black drum.

## **Section IV. Recommendations for Habitat Management and Research**

### ***Habitat Management Recommendations***

Particular attention should be directed toward black drum habitat utilization and habitat condition (environmental parameters). A list of existing state and Federal programs generating environmental data such as sediment characterization, contaminant analysis, and habitat coverage (marsh grass, oyster beds, SAV) should also be produced and updated as new information arises. Habitats utilized by black drum range from the tidal freshwater out to and likely beyond, the shelf break. Thus, virtually any study generating environmental data from estuarine or coastal ocean systems could be of value.

1. Where sufficient knowledge is available, states should designate black drum HAPCs for special protection. These locations should be accompanied by requirements that limit degradation of habitat, including minimization of non-point source and specifically storm water runoff, prevention of significant increases in contaminant loadings, and prevention of the introduction of any new categories of contaminants into the area.
2. Where habitat areas have already been identified and protected, states should ensure continued protection of these areas by notifying and working with other Federal, state, and local agencies. States should advise these agencies of the types of threats to black drum and recommend measures that should be employed to avoid, minimize, or eliminate any threat to current habitat quality or quantity.
3. States should minimize loss of wetlands to shoreline stabilization by using the best available information, incorporating erosion rates, and promoting incentives for use of alternatives to vertical shoreline stabilization measures (e.g., sea walls), commonly referred to as living shorelines projects.
4. All state and Federal agencies responsible for reviewing impact statements and permit applications for projects or facilities proposed for black drum spawning and nursery areas should ensure that those projects will have no or only minimal impact on local stocks. Any project that would eliminate essential habitat should be avoided, if possible, or at a minimum, adequately mitigated.
5. Each state should establish windows of compatibility for activities known or suspected to adversely affect black drum life stages and their habitats, with particular emphasis to avoid spawning season. Activities may include, but are not limited to, navigational dredging, bridge construction, and dredged material disposal, and notify the appropriate construction or regulatory agencies in writing.
6. Each state should develop water use and flow regime guidelines, where applicable, to ensure that appropriate water levels and salinity levels are maintained for the long-term

protection and sustainability of the stocks. Projects involving water withdrawal or interrupt water flow should be evaluated to ensure that any impacts are minimized, and that any modifications to water flow or salinity regimes maintain levels within black drum's tolerance limits.

7. The use of any fishing gear that is determined by management agencies to have a negative impact on black drum habitat should be prohibited within HAPCs. Further, states should protect vulnerable habitat from other types of non-fishing disturbance as well.
8. States should work with the USFWS's Divisions of Fish and Wildlife Management Assistance and Ecological Services and NMFS's Offices of Fisheries Conservation and Management and Habitat Conservation to identify hydropower and water control structures that pose significant threats to maintenance of appropriate freshwater flows (volume and timing) to black drum nursery and spawning areas and target these dams for appropriate recommendations during FERC re-licensing.
9. States should conduct research to evaluate the role of SAV and other submersed structures in the spawning success, survival, growth, and abundance of black drum. This research could include regular mapping of the bottom habitat in identified areas of concern, as well as systematic mapping of this habitat where it occurs in estuarine and marine waters of the states.
10. States should continue support for habitat restoration projects, including oyster shell recycling and oyster hatchery programs as well as seagrass restoration, to provide areas of enhanced or restored bottom habitat, which serve as nurseries or foraging grounds.
11. Water quality criteria for black drum spawning and nursery areas should be established, or existing criteria should be upgraded, to ensure successful reproduction of these species. Any action taken should be consistent with Federal Clean Water Act guidelines and specifications.
12. State fishery regulatory agencies, in collaboration with state water quality agencies, should monitor water quality in known habitat for black drum, including turbidity, nutrient levels, and DO.
13. States should work to reduce point-source pollution from wastewater through improved inspections of wastewater treatment facilities and improved maintenance of collection infrastructure.
14. States should develop protocols and schedules for providing input on water quality regulations, and on Federal permits and licenses required by the Clean Water Act, Federal Power Act, and other appropriate vehicles, to ensure that black drum habitats are protected and water quality needs are met.

### ***Habitat Research Recommendations***

The Interstate Fishery Management Plan for Black Drum (2013) states three research needs for black drum habitat.

- Expand existing fishery independent surveys in time and space to better cover black drum habitats, if possible (especially adults).
- Conduct otolith microchemistry studies to identify regional recruitment contributions.
- Conduct new and expand existing acoustic tagging programs to help identify spawning and juvenile habitat use and regional recruitment sources.

Additional research objectives also need to focus on resolving the preferred and physiological tolerances of black drum, at all life stages, for temperature, salinity, and DO. Studies also need to examine the impact of black drum consuming mollusks in polluted, industrialized regions since mollusks bioaccumulate toxins.

### **Literature Cited**

- Able, K. W. and M. P. Fahay. 2010. Ecology of Estuarine Fishes: Temperate waters of the western North Atlantic. Johns Hopkins University Press. Baltimore, MD.
- Ackerman, B. 1951. Handbook of fishes of the Atlantic seaboard. The American Publishing Co. Washington, D.C. pp. 144.
- ASMFC (Atlantic States Marine Fisheries Commission). 2002. Amendment 2 to the Red Drum Interstate Fishery Management Plan. Washington (DC): ASMFC. pp. 162.
- ASMFC (Atlantic States Marine Fisheries Commission). 2011. An Evaluation of Black Drum Data Sources and Recommendations for Coastwide Stock Assessment. Report to ISFMP Policy Board. Washington (DC): ASMFC. pp. 147.
- ASMFC (Atlantic States Marine Fisheries Commission). 2013. Harbor Deepening: Potential Habitat and Natural Resources Issues. Habitat Management Series #12. Arlington (VA): ASMFC. pp. 10.
- ASMFC (Atlantic States Marine Fisheries Commission). 2013. Interstate Fishery Management Plan for Black Drum.
- Benson, N. G. 1982. Life history requirements of selected finfish and shellfish in Mississippi Sound and adjacent areas. U.S. Fish and Wildlife Service. Biological Service Program. FWS/035-81/15.
- Blasina, G. E., S. A. Barbini and J. M. Díaz de Astarloa. 2010. Trophic ecology of the black drum, *Pogonias cromis* (Sciaenidae), in Mar Chiquita coastal lagoon (Argentina). Journal of Applied Ichthyology 26: 528–534.
- Brown, K. M., G. J. George, G. W. Peterson, B. A. Thompson and J. H. Cowan, Jr. 2008. Oyster predations by black drum varies spatially and seasonally. Estuaries and Coasts 31: 597–604.
- Cowan, Jr., J. H., R. S. Birdsong, E. D. Houde, J. S. Priest, W. C. Sharp and G. B. Mateja. 1992. Enclosure experiments on survival and growth of black drum eggs and larvae in lower Chesapeake Bay. Estuaries 15: 392–402.

- Dahl, T. E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Dept. of Interior, USFWS, Washington, DC. pp. 81.
- Daniel, III, L. B. and J. E. Graves. 1994. Morphometric and genetic identification of eggs of spring-spawning sciaenids in lower Chesapeake Bay. *Fishery Bulletin* 92: 254–261.
- Etzold, D. J. and J. Y. Christmas (eds). 1979. A Mississippi marine finfish management plan. Mississippi-Alabama Sea Grant Consortium. MASGP-78-146. pp. 36.
- Fitzhugh, G. R., B. A. Thompson and T. G. Snider III. 1993. Ovarian development, fecundity, and spawning frequency of black drum *Pogonias cromis* in Louisiana. *Fishery Bulletin* 91: 244–253.
- Frisbie, C. M. Young black drum, *Pogonias cromis*, in tidal fresh and brackish waters, especially in the Chesapeake and Delaware Bay areas. *Chesapeake Science* 2 (1/2): 94–100.
- George, G. J. 2003. Acoustic tagging of black drum on Louisiana oyster reefs: Movements, site fidelity, and habitat use. M.S. Thesis. Louisiana State University. Baton Rouge. pp. 71.
- Gold, J. and L. Richardson. 1998. Mitochondrial DNA diversification and population structure in fishes from the Gulf of Mexico and Western Atlantic. *Journal of Heredity* 89: 404–414.
- Gunter, G. 1956. A revised list of euryhalin fishes of North and Middle America. *American Midland Naturalist Journal* 56(2): 345–354.
- Hoese, H. D. 1965. Spawning of marine fishes in the Port Aransas, Texas area as determined by the distribution of young larvae. Ph.D. Dissertation. University of Texas. Austin. pp. 144.
- Hoese, H. D. and R. H. Moore. 1977. *Fishes of the Gulf of Mexico*. Texas A&M University Press, College Station. pp. 327.
- Holland, A. F., G. H. M. Riekerk, S. B. Lerberg, L. E. Zimmerman, D. M. Sanger, G. I. Scott and M. H. Fulton. 1996. Assessment of the impact of watershed development on the nursery functions of tidal creek habitats. *In*: G. S. Kleppel and M. R. DeVoe (eds). *The South Atlantic Bight Land Use Coastal Ecosystems Study (LU-CES)*, pp. 28–31. Univ. of Georgia Sea Grant and S.C. Sea Grant Program. Report of a planning workshop.
- Jones, C. M. and B. Wells. 2001. Yield-per-recruit analysis for black drum, *Pogonias cromis*, along the East Coast of the United States and management strategies for Chesapeake Bay. *Fishery Bulletin* 99: 328–337.
- Joseph, E. B., W. H. Massmann and J. J. Norcross. 1964. The pelagic eggs and early larval states of the black drum from Chesapeake Bay. *Copeia* 1964(2): 425–434.
- Kemp, W. M., W. R. Boynton, J. E. Adolf, D. F. Boesch, W. C. Boicourt, G. Brush, J. C. Cornwell, T. R. Fisher, P. M. Blibert, J. D. Hagy, L. W. Harding, E. D. Houde, D. G. Kimmel, W. D. Miller, R. I. E. Newell, M. R. Roman, E. M. Smith and J. C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. *Marine Ecology Progress Series* 303: 1–29.

- Leard, R. et al. 1993. The black drum fishery of the Gulf of Mexico, United States: a regional management plan. Gulf States Marine Fisheries Commission, Number 28, Ocean Springs, MS.
- Locascio, J. V. and D. A. Mann. 2011. Diel and seasonal timing of sound production by black drum (*Pogonias cromis*). Fishery Bulletin 109: 327–338.
- McEachron, L. W., G. C. Matlock, C. E. Bryan, P. Unger, T. J. Cody and J. H. Martin. 1994. Winter mass mortality of animals in Texas bays. Northeast Gulf Science 13: 121–138.
- McIlwain, T. D. 1978. An analysis of recreational angling in Biloxi Bay – 1972–1974. Ph.D. Dissertation. University of Southern Mississippi. Hattiesburg. pp. 156.
- Miller, J. M. 1988. Physical processes and the mechanisms of coastal migrations of immature marine fishes. In: M.P. Weinstein (ed). Larval Fish and Shellfish Transport Through Inlets. American Fisheries Society, Bethesda, MD. pp. 68–76.
- Miller, J. M., J. P. Read and L. J. Pietrafesa. 1984. Pattern, mechanisms and approaches to the study of migrations of estuarine-dependent fish larvae and juveniles. In: McCleave, J. D., G. P. Arnold, J. J. Dodson and W. H. Neill (eds). Mechanisms of Migrations in Fishes. Plenum Press, NY.
- Murphy, M. D. and R. G. Muller. 1995. Stock assessment of black drum *Pogonias cromis* in Florida. Florida Marine Research Institute, In-house Report Series IHR 1995-005.
- Murphy, M. D. and R. G. Taylor. 1989. Reproduction and growth of black drum, *Pogonias cromis*, in northeast Florida. Northeast Gulf Science 10: 127–137.
- Pearson, J. C. 1929. Natural history and conservation of the redfish and other commercial sciaenids on the Texas Coast. Bulletin of the U.S. Fish Commission 4: 129–214.
- Peters, K. M. and R. H. McMichael Jr. 1990. Early life history of the black drum *Pogonias cromis* (Pisces: Sciaenidae) in Tampa Bay, Florida. Northeast Gulf Science 11(1): 39–58.
- Richards, C. E. 1973. Age, growth and distribution of black drum (*Pogonias cromis*) in Virginia. Transactions of the American Fisheries Society 3: 584–590.
- Rooker, J., R. Kraus and D. Secor. 2004. Dispersive behaviors of black drum and red drum: is otolith Sr:Ca a reliable indicator of salinity history? Estuaries 27: 334–341.
- SAFMC (South Atlantic Fishery Management Council). 1998. Habitat plan for the South Atlantic region: essential fish habitat requirements for fishery management plans of the South Atlantic Fishery Management Council. SAFMC, Charleston, SC. pp. 457 + appendices.
- Saucier, M. H. and D. M. Baltz. 1993. Spawning site selection by spotted seatrout, *Cynoscion nebulosus*, and black drum, *Pogonias cromis*, in Louisiana. Environmental Biology of Fishes 36: 257–272.
- Serafy, J. E., K. C. Lindeman, T. E. Hopkins and J. S. Ault. 1997. Effects of freshwater canal discharges on subtropical marine fish assemblages: field and laboratory observations. Marine Ecology Progress Series 160: 161–172.



- Shumay, S. E., J. Barter and S. Sherman-Caswell. 1990. Auditing the impact of toxic algal blooms on oysters. *Environmental Auditor* 2(1): 41–56.
- Silverman, M. J. 1979. Biological and fisheries data on black drum, *Pogonias cromis* (Linnaeus). Sandy Hook Laboratory, NMFS Technical Series Report 22. pp. 22.
- Simmons, E. G. and J. P. Breuer. 1962. A study of redfish, *Sciaenops ocellata* Linnaeus, and black drum, *Pogonias cromis* Linnaeus. *Publications of the Institute of Marine Science* 8: 184–211.
- Sutter, F. C., R. S. Waller and T. D. McIlwain. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico): Black Drum. U.S. Fish and Wildlife Biological Report 82 (11.51). U. S. Army Corps of Engineers, TR EL-82-4. pp. 10.
- Tellechea, J. S., W. Norbis, D. Olsson and M. L. Fine. 2010. Calls of the black drum (*Pogonias cromis*: Sciaenidae): geographical differences in sound production between Northern Hemisphere and Southern Hemisphere populations. *Journal of Experimental Zoology* 313A: 1–8.
- Thomas, D. L. and B. A. Smith. 1973. Studies of young of the black drum, *Pogonia cromis*, in low salinity waters of the Delaware Estuary. *Chesapeake Science* 14: 124–130.
- Ulrich, G. F., C. M. Jones, W. B. Driggers III, J. M. Drymon, D. Oakley and C. Riley. 2007. Habitat utilization, relative abundance, and seasonality of sharks in the estuarine and nearshore waters of South Carolina. *American Fisheries Society Symposium* 50: 125–139.

## CHAPTER 4: RED DRUM

Populated with text from the [Red Drum Habitat Addendum \(2013\)](#)

### **Section I. General Description of Habitat**

#### **Part A. Spawning Habitat**

Red drum (*Sciaenops ocellatus*) spawn from late summer to late fall in a range of habitats, including estuaries, near inlets, passes, and near bay mouths (Peters and McMichael 1987). Earlier studies have illustrated that spawning often occurred in nearshore areas relative to inlets and passes (Pearson 1929; Miles 1950; Simmons and Breuer 1962; Yokel 1966; Jannke 1971; Setzler 1977; Music and Pafford 1984; Holt et al. 1985). More recent evidence, however, suggests that in addition to nearshore vicinity habitats, red drum also utilize high-salinity estuarine areas along the coast (Murphy and Taylor 1990; Johnson and Funicelli 1991; Nicholson and Jordan 1994; Woodward 1994; Luczkovich et al. 1999; Beckwith et al. 2006). Direct evidence of red drum spawning has been documented deep within estuarine waters of the Indian River Lagoon, Florida (IRL) (Murphy and Taylor 1990; Johnson and Funicelli 1991). More recently, an intensive two-year ichthyoplankton survey consistently collected preflexion (2–3 mm) red drum larvae up to 90 km away from the nearest ocean inlet from June to October with average nightly larval densities as high as 15 per 100 m<sup>3</sup> of water in the IRL (Reyier and Shenker 2007). Acoustic telemetry results for large adult red drum in the IRL further support estuarine spawning of this species within the IRL system (Reyier et al. 2011)

#### ***Geographic and Temporal Patterns of Migration***

Red drum have a range extending from the Long Island south to the western Gulf of Mexico but it rarely occurs north of the Chesapeake Bay. Although spawning can occur in a variety of nearshore habitats, it often occurs near the mouths of large embayments from July to October (Able and Fahay 2010). Peak spawning takes place between August and September. In addition, red drum are thought to return to natal estuaries for spawning (Bacheler et al. 2009a; Patterson et al. 2004).

#### ***Salinity***

High salinity, coastal estuarine areas provide optimal conditions for egg and larval development, as well as circulation patterns beneficial to transporting larvae to suitable nursery areas (Ross and Stevens 1992).

#### ***Substrate***

Substrate sediments in spawning habitats are fine to coarse, unconsolidated sands. Current regimes conducive to larval transport ensure that fine sediments are sorted out of the substrate mix. Little is known regarding specific substrate types where spawning occurs within true estuarine habitats, but limited estuarine ichthyoplankton studies on red drum suggests recently hatched larvae are found over a mix of sand, sand-shell hash and sand-mud substrates. However, the release of gametes during spawning occurs in the surface waters, away from the benthos (Barrios 2004).

#### ***Temperature***

Spawning in laboratory studies have also appeared to be temperature-dependent, occurring in a range from 22–30°C but with optimal conditions between temperatures of 22–25°C (Holt et al. 1981). Renkas

(2010) was able to duplicate environmental conditions of naturally spawning red drum from Charleston Harbor, South Carolina in a mariculture setting, and corroborated that active egg release occurred as water temperature dropped from a peak of approximately 30°C during August. Cessation of successful egg release was found at 25°C, with no spawning effort found at lower temperatures (Renkas 2010). Pelagic eggs, embryos, and larvae are transported by currents into nursery habitats for the duration of egg and larval stages (Peters and McMichael 1987; Beck et al. 2001).

### ***Dissolved Oxygen***

Little information exists regarding specific DO concentrations in relation to red drum spawning. Preliminary passive acoustic surveys in North Carolina waters suggest that DO levels of bottom waters may play a significant role for red drum aggregation formation. Spawning fish were significantly lower at sites with DO levels of bottom waters below 2.5 mg L<sup>-1</sup> (Barrios 2004)

### ***Feeding Behavior***

No published work has reported on the feeding behaviors of actively spawning individuals. It might be inferred—based on nearshore and estuarine habitats—that spawning red drum feed on the same food sources as adults, which includes primarily larger fishes, crustaceans, and mollusks. Limited sampling of adult red drum in North Carolina revealed blue crab (*Callinectes sapidus*) made up 51% of the diet by number and occurred in 48% of the stomachs (Peacock 2014). The same study found the diet of adult red drum in South Carolina was more diverse than in North Carolina, where red drum consumed mostly Atlantic menhaden (*Brevoortia tyrannus*) and a diverse group of marine decapods and brachyurans.

### ***Competition and Predation***

Predation on spawning adults is likely similar to other adult red drum, depending on habitat. Various shark species (e.g. bull shark, *Carcharhinus leucas*; blacktip shark, *C. limbatus*) are potential predators of spawning adults.

## **Part B. Egg and Larval Habitat**

Nelson et al. (1991) reported that red drum eggs are commonly encountered in several southeastern estuaries, in salinities above 25 ppt. Laboratory experiments in Texas (Neill 1987; Holt et al. 1981) established that optimum temperature and salinity for hatching and survival of red drum larvae are 25°C and 30 ppt, respectively. The spatial distribution and relative abundance of eggs in estuaries mirrors that of spawning adults in the fall (Nelson et al. 1991). Eggs and early larvae utilize high salinity waters inside inlets and passes and within the estuary. In Florida, Johnson and Funicelli (1991) collected viable red drum eggs in Mosquito Lagoon, Florida, in average daily water temperatures of 20–25°C and average salinities of 30–32 ppt. The largest number of eggs collected during the study was in depths ranging from 1.5–2.1 m and highest concentrations of eggs were found at the edge of the channel.

### ***Geographic and Temporal Patterns of Migration***

Upon hatching, red drum larvae are pelagic (Johnson 1978) and growth rates are temperature-dependent (Holt et al. 1981). They make the transition between pelagic and demersal habitats within a few weeks after reaching nursery habitats (Pearson 1929; Peters and McMichael 1987; Comyns et al. 1991; Rooker and Holt 1997; Havel et al. 2015). They ingress into lower salinity nursery habitats in estuaries using tidal (Setzler 1977; Holt et al. 1989) or density-driven currents (Mansueti 1960; Bass and Avault 1975; Setzler 1977; Weinstein 1979; Holt et al. 1983; Holt et al. 1989; Peters and McMichael

1987; McGovern 1986; Daniel 1988). Once in the nurseries, red drum larvae grow rapidly (Baltz et al 1998).

Red drum larvae along the Atlantic coast are common in most major southeastern estuaries, with the exception of Albemarle Sound, and they are abundant in the St. Johns and Indian River estuaries, Florida (Nelson et al. 1991). Data on the spatial distribution of red drum larvae in the Gulf of Mexico has been summarized by Mercer (1984). More recently, Lyczkowski-Shultz and Steen (1991) observed diel vertical stratification among red drum larvae found in depths <25 m at both offshore and nearshore locations.

### ***Salinity***

Red drum eggs have been commonly encountered in several southeastern estuaries in high salinity waters (above 25 ppt) (Nelson et al. 1991). The highest numbers of eggs were gathered in average salinities from 30–32 ppt at the edge of the channel (Johnson and Funicelli 1991). Salinities above 25 ppt allow red drum eggs to float while lower salinities cause eggs to sink (Holt et al. 1981). However, early stage red drum larvae were commonly found within estuarine waters of the IRL, Florida in salinity as low as 20 ppt (Reyier and Shenker 2007).

Spatial distribution and relative abundance of eggs in estuaries, as expected, mirrors that of spawning adults (Nelson et al. 1991); eggs and early larvae utilize high salinity waters inside inlets, passes, and in the estuary proper.

### ***Substrate***

Upon hatching, red drum larvae are pelagic (Johnson 1978; Holt et al. 1981). Newly hatched red drum spend around twenty days in the water column before associating with benthos (Rooker et al. 1999; FWCC 2008). The size at settlement is determined by the substrate of the settlement site (Havel et al. 2015). Daniel (1988), however, found larvae younger than 20 days old already settled in the Charleston Harbor estuary.

### ***Temperature***

Larval red drum (1.7–5.0 mm mean SL length) were found in temperatures between 26–28°C (Lyczkowski-Shultz and Steen 1991). Research conducted in Mosquito Lagoon, Florida, found viable red drum eggs at average daily water temperatures ranging from 20–25°C (Johnson and Funicelli 1991). In Texas, laboratory experiments conducted by Neill (1987) and Holt et al. (1981) concluded that an optimum temperature for the hatching and survival of red drum eggs and larvae was 25°C.

### ***Dissolved Oxygen***

Mean DO concentration where larval red drum were captured in the IRL, Florida was 6.3 mg L<sup>-1</sup> (Reyier 2005).

### ***Feeding Behavior***

Larval red drum are opportunistic feeders (Bass and Avault 1975). In Louisiana waters, larvae <15 mm fed heavily on zooplankton (e.g. copepods and copepod nauplii) whereas in Florida larvae (8–15 mm) in Tampa Bay feed primarily on copepods, mysids, and polychaetes (Peters and McMichael 1987).

### ***Competition and Predation***

Little information is available on competition or predation on larval red drum. Predators of larval fishes include a variety of organisms (planktonic crustaceans, chaetognaths, larger planktivorous fishes, and

gelatinous organisms) (Duffy et al. 1997). Red drum spawn in the Gulf of Mexico from late summer to early fall, which coincides with elevated numbers of several species of jellyfish that represent dominant predators of eggs and larvae (Kraeuter and Setzler 1975). For example, during peak red drum spawning season in the IRL, no red drum eggs were collected when high ctenophore numbers were present (Johnson and Funicelli 1991).

### **Part C. Juvenile Habitat**

Juvenile red drum utilize a variety of inshore habitats including tidal freshwater habitats, low-salinity reaches of estuaries, estuarine emergent vegetated wetlands, estuarine scrub/shrub, SAV, oyster reefs, shell banks, and unconsolidated bottom (SAFMC 1998).

#### ***Geographic and Temporal Patterns of Migration***

The distribution of juvenile red drum within estuaries varies seasonally as individuals grow and begin to disperse. Along the South Atlantic coast, they utilize a variety of inshore habitats. Late juveniles leave shallow nursery habitats at approximately 200 mm TL (10 months of age). They are considered subadults until they reach sexual maturity at 3–5 years (C. Wenner, personal communication). It is at this life stage that red drum use a variety of habitats within the estuary and when they are most vulnerable to exploitation (Pafford et al. 1990; Wenner 1992). Tagging studies conducted throughout the species' range indicate that most subadult red drum tend to remain in the vicinity of a given area (Beaumarrige 1969; Osburn et al. 1982; Music and Pafford 1984; Wenner, et al. 1990; Pafford et al. 1990; Ross and Stevens 1992; Woodward 1994; Marks and DiDomenico 1996; Adams and Tremain 2000). Movement within the estuary is most likely related to changes in temperature and food availability (Pafford et al. 1990; Woodward 1994).

Tagging studies indicate that late age-0 and 1 year-old red drum are common throughout the shallow portions of the estuaries and are particularly abundant along the shorelines of rivers and bays, in creeks, and over grass flats and shoals of the sounds. During the fall, those subadult fish inhabiting the rivers move to higher salinity areas such as the grass flats and shoals of the barrier islands and the front beaches. With the onset of winter temperatures, juveniles leave the shallow creeks for deeper water in the main channels of rivers (9–15 m) and returned again to the shallows in the spring. Fish that reside near inlets and along the barrier islands during the summer are more likely to enter the surfzone in the fall.

By their second and third year of growth, red drum are less common in rivers but are common along barrier islands, inhabiting the shallow water areas around the outer bars and shoals of the surf and in coastal inlets over inshore grass flats, creeks or bays. In the northern portion of the South Carolina coast, subadults use habitats use broad, gently sloping flats (up to 200 m or more in width). Along the southern part of the South Carolina coast, subadult red drum inhabit narrow (50 m or less), fairly level flats traversed by numerous small channels, typically 5–10 m wide by less than 2 m deep at low tide (ASMFC 2002).

#### ***Salinity***

Wenner et al. (1990) collected post-larval and juvenile red drum in South Carolina from June 1986 through July 1988 in shallow tidal creeks with salinities of 0.8–33.7 ppt, although the preferred salinity range in the IRL is between 19–29 ppt (Tremain and Adams 1995).

### ***Substrate***

In general, habitats supporting juvenile red drum can be characterized as detritus or mud-bottom tidal creeks as well as sand and shell hash bottoms (Daniel 1988; Ross and Stevens 1992). Within seagrass beds, investigations have shown that juveniles to prefer areas with patchy grass coverage or sites with homogeneous vegetation (Mercer 1984; Ross and Stevens 1992; Rooker and Holt 1997). In a Texas estuary, young red drum (6–27 mm SL) were never present over non-vegetated muddy-sandy bottom; areas most abundant in red drum occurred in the ecotone between seagrass and non-vegetated sand bottom (Rooker and Holt 1997). In South Carolina, Wenner (1992) indicated that very small red drum occupy small tidal creeks with mud/shell hash and live oyster as common substrates (since sub-aquatic vegetation is absent in South Carolina estuaries).

### ***Temperature***

Juvenile red drum are tolerant to a wide range of temperatures (8.5–33.5°C) (Bacheler et al. 2009b; Able and Fahay 2010). In the winter of their first year, 3–5 month old juveniles migrate to deeper, more temperature-stable parts of the estuary during colder weather (Pearson 1929). In the following spring, juveniles become more common in the shallow water habitats.

### ***Dissolved Oxygen***

In estuarine creek habitats in the IRL, FL, subadults and small adult red drum were collected in waters with mean DO levels ranging from 5 to 10 ppm (year round) (Adams and Tremain 2000). Within main lagoon habitats in the IRL, large subadults were found in DO concentrations ranging from 4–12 ppm (Adams and Tremain 2000).

### ***Feeding Behavior***

Larger juveniles are opportunistic feeders foraging on mysids, amphipods, palaemonid and penaeid shrimp, crabs, small fishes, and other sciaenids (Bass and Avault 1975). A higher diversity in prey items was found in stomachs of red drum collected over sand bottoms vs mud bottoms (Odum 1971). In Tampa Bay, FL, juvenile red drum up to 75 mm fed primarily on mysids, polychaetes, amphipods, and insects in juveniles up to 75 mm, with crabs and fish dominant in larger juveniles larger than 105 mm (Peters and McMichael 1987).

### ***Competition and Predation***

Small juvenile red drum are prey for numerous estuarine fish species and likely compete with other sciaenids. Larvae and juveniles are also consumed by pinfish (Minello and Stunz 2001).

## **Part D. Adult Habitat**

Along the Atlantic Coast adult red drum migrate north and inshore in the spring and migrate offshore and south in the fall. Overall, adults tend to spend more time in coastal waters after reaching sexual maturity. However, they do continue to frequent inshore waters on a seasonal basis. Less is known about the biology of red drum once they reach the adult stage and accordingly, there is a lack of information on habitat utilization by adult fish. The SAFMC's Habitat Plan (SAFMC 1998) cited high salinity surf zones and artificial reefs as EFH for red drum in oceanic waters, which comprise the area from the beachfront seaward. In addition, nearshore and offshore hard/live bottom areas have been known to attract concentrations of red drum. The following description of these habitats was adapted from that provided in the SAFMC's Habitat Plan (1998b).

### ***Geographic and Temporal Patterns of Migration***

Adult red drum make seasonal migrations along the Atlantic coast. In the spring, adults move north and inshore but offshore and south in the fall. Overall, adults tend to spend more time in coastal waters after reaching sexual maturity. However, they do continue to frequent inshore waters on a seasonal basis. In the IRL, FL, limited seasonal migrations (Reyier et al. 2011) including some movement to coastal inlets in fall during the spawning season have been detected (Reyier et al. 2011). In Mosquito Lagoon (northern IRL), a portion of the adult population remain within the estuary where documented spawning occurs (Johnson and Funicelli 1991, Reyier et al. 2011).

### ***Salinity***

Adult red drum inhabit high salinity surf zones along the coast and adjacent offshore waters, at full marine salinity. Adults in some areas of their range (e.g. IRL, FL) can reside in estuarine waters year-round, where salinities are variable.

### ***Substrate***

In addition to natural hard/live bottom habitats, adult red drum also use artificial reefs and other natural benthic structures. Red drum were found from late November until the following May at both natural and artificial reefs along tide rips or associated with the plume of major rivers in Georgia (Nicholson and Jordan 1994). Data from this study suggests that adult red drum exhibit high seasonal site fidelity to these features. Fish tagged in fall along shoals and beaches were relocated 9–22 km offshore during winter and then found back at the original capture site in the spring. In summer, fish moved up the Altamaha River nearly 20 km to what the authors refer to as “pre-spawn staging areas” and then returned to the same shoal or beach again in the fall.

### ***Temperature***

Bottom water temperatures in deeper hard/live bottom areas range from approximately 11–27°C whereas inshore areas typically exhibit cooler temperatures (SEAMAP's South Atlantic Bottom Mapping Work Group effort 1992).

### ***Dissolved Oxygen***

Large subadults and small adults were collected in waters of the IRL, FL where mean DO levels ranged from 5–10 ppm (year round) (Tremain and Adams 1995).

### ***Feeding Behavior***

Red drum are opportunistic foragers and their prey varies with size and season (Scharf and Schlicht 2000). Adults feed on a variety of crustaceans, mollusks, and fishes (Chao 2002). Common prey species of adult red drum of the coast of Texas are white shrimp, gulf menhaden, and swimming crabs (blue crabs and related species) (Scharf and Schlicht 2000).

### ***Competition and Predation***

Predators of large adult red drum within nearshore and offshore habitats likely include an array of shark species. Blacktip sharks and sandbar sharks have been observed within and surrounding large red drum schools off the Atlantic coast of Florida.

## **Section II. Essential Fish Habitats and Habitat Areas of Particular Concern**

### ***Essential Fish Habitat***

The SAFMC recognizes several habitats as EFH for red drum. These natural communities include tidal freshwater, estuarine emergent vegetated wetlands (flooded salt marsh, brackish marsh, and tidal creeks), estuarine scrub/shrub (mangrove fringe), submerged rooted vascular plants (seagrass), oyster reefs and shell banks, unconsolidated bottom (soft sediment), high salinity surf zones, and artificial reefs (SAFMC 1998). The area covered ranges from Virginia through the Florida Keys, to a depth of 50 m offshore.

### ***Identification of Habitat Areas of Particular Concern***

For red drum, this includes the following habitats: tidal freshwater, estuarine emergent vegetated wetlands (flooded saltmarshes, brackish marsh, and tidal creeks), estuarine scrub/shrub (mangrove fringe), submerged rooted vascular plants (sea grasses), oyster reefs and shell banks, unconsolidated bottom (soft sediments), ocean high salinity surf zones, and artificial reefs. The SAFMC, which has a similar designation for their HAPCs, has recognized HAPCs for red drum along the U.S. coast including all coastal inlets, all state-designated nursery habitats (i.e. Primary Nursery Areas in North Carolina), sites where spawning aggregations of red drum have been documented and spawning sites yet to be identified, and areas supporting SAV. The SAFMC (1998b) also cited barrier islands off the South Atlantic states as being of particular importance since they maintain the estuarine environment in which young red drum develop. Inlets between barrier islands are of concern because the productivity of the estuary depends on the slow mixing of fresh and seawater that occurs in these areas. Finally, inlets, channels, sounds and outer bars are of particular importance to red drum since spawning activity is known to occur in these areas throughout the South Atlantic. Moreover, subadult and adult red drum utilize these areas for feeding and daily movements.

A species' primary nursery areas are indisputably essential to its continuing existence. Primary nursery areas for red drum can be found throughout estuaries, usually in shallow waters of varying salinities that offer certain degree of protection. Such areas include coastal marshes, shallow tidal creeks, bays, tidal flats of varying substrate, tidal impoundments, and seagrass beds. Since red drum larvae and juveniles are ubiquitous in such environments, it is impossible to designate specific areas as deserving more protection than others. Moreover, these areas are not only primary nursery areas for red drum, but they fulfill the same role for numerous other resident and estuarine-dependent species of fish and invertebrates, especially other sciaenids.

Similarly, subadult red drum habitat extends over a broad geographic range and adheres to the criteria that define HAPCs. Subadult red drum are found throughout tidal creeks and channels of southeastern estuaries, in backwater areas behind barrier islands and in the front beaches during certain times of the year. Therefore, the estuarine system as a whole, from the lower salinity reaches of rivers to the mouth of inlets, is vital to the continuing existence of this species.

### ***SAFMC HAPC Designations for Red Drum***

Of the designated EFH, HPACs have been recognized for red drum by the SAFMC. Areas which meet the criteria for HAPC include all coastal inlets, all state-designated nursery habitats of particular importance to red drum, documented sites of spawning aggregations from North Carolina to Florida, other spawning areas identified in the future, and areas supporting SAV (SAFMC 1998). These HAPCs include the most



important habitats required during the life cycle of the species, including spawning areas and nursery grounds. Other areas of concern are barrier islands.

### ***Present Condition of Habitat Areas of Particular Concern***

Red drum populations along the Atlantic coast are managed through the Atlantic Coastal Fisheries Cooperative Management Act (Atlantic Coastal Act). Unlike the Magnuson-Stevens Fishery Conservation and Management Act which addresses fishery management by Federal agencies, the Atlantic Coastal Act does not require the ASMFC to identify habitats that warrant special protection because of their value to fishery species. Nonetheless, the Commission believes this is a good practice so that appropriate regulatory, planning, and management agencies can consider this information during their deliberations.

A subset of red drum habitats, which the Commission refers to as Habitats of Concern (HOC), is especially important as spawning and nursery areas for red drum. HOC for red drum include all coastal inlets, SAV beds, the surf zone (including outer bars), and state-designated nursery habitats (e.g., Primary Nursery Areas in North Carolina; Outstanding Resource Waters in South Carolina's coastal counties; Aquatic Preserves along the Atlantic coast of Florida).

### ***Coastal Spawning Habitat: Condition and Threat***

The productivity and diversity of coastal spawning habitat can be compromised by the effects of industrial, residential, and recreational coastal development (Vernberg et al. 1999). Coastal development continues in all states and coastlines of the nation despite the increased protection afforded by Federal and state environmental regulations. Threats to nearshore habitats in the south Atlantic that are documented spawning habitats for red drum or are suitable spawning habitats are described below.

Navigation and boating access development and maintenance activities, such as dredging and hazards from ports and marinas, are a threat to spawning habitats of red drum. According to the SAFMC (1998) and ASMFC (2002), navigation related activities can result in: removal or burial of organisms from dredging or disposal of dredged material, effects due to turbidity and siltation, release of contaminants and uptake in nutrients, metals and organics, release of oxygen-consuming substances, noise disturbance, and alteration of hydrodynamic regime and habitat characteristics. All listed effects have the potential to decrease the quality and quantity of red drum spawning habitat.

Ports also pose the threat of potential spills of hazardous materials. Cargo that arrives and departs from ports can contain highly toxic chemicals and petroleum products. The discharge of oil may have also altered migration patterns and food availability. Port discharge of marine debris, garbage, and organic waste into coastal waters is also a concern. While spills are rare, constant concern exists for extensive spans of estuarine and nearshore habitats proximal to ports are at risk of contamination. Even a small spill could result in a huge exposure of productive habitats. Oil releases such as the MC 282 or Deepwater Horizon oil release (2010) into the Gulf of Mexico has severely affected aquatic life, water quality, and habitat posing many threats such as mortality, disease, genetic damage, and immunity issues (Collier et al. 2010). Chemicals in crude oil can cause heart failure in developing fish embryos (Incardona et al. 2004, 2005, 2009). Chronic exposures for years after the Exxon Valdez oil spill were evident in fishes and other marine life, resulting in a higher pattern of mortality (Ballachey et al. 2003). Oiling of nearshore high-energy habitats along beaches of the Gulf of Mexico from Louisiana to Florida occurred for prolonged periods of time during the spring of 2010, and weathered oil products were found in offshore sediments where spawning red drum can occur.

Beach nourishment projects and development of wind and tidal energy could also alter red drum spawning and offshore adult habitat dynamics. Beach nourishment can result in removal of offshore sediments resulting in depressions and altering sediment characteristics along the shoreline (Wanless 2009). Sediments eroded from beaches after nourishment projects can also be transported offshore and bury hard bottoms, which can diminish spawning aggregation habitat for red drum. Beach nourishment projects can also alter forage species abundance, distribution, and species composition in the high-energy surf zone for a time, but this varies by species and timing of nourishment activities (Irlandi and Arnold 2008). Wind and tidal energy projects can create artificial structure in migration corridors and submarine cables may produce electrical fields that can affect red drum movement patterns and habitat use in affected areas (DONG 2006; OEER 2008; ASMFC-Habitat Committee 2012).

Use of certain types of fishing gear, such as trawls and bivalve dredges, can also adversely affect spawning habitat (Essential Fish Habitat Steering Committee 2002). Trawls and dredges remove structure-forming epifauna, alter sediment contours, redistribute reef aggregate materials (e.g. fractured rock outcroppings and boulders), and change infaunal and demersal organism abundance and community assemblages in fished areas. Fishing also reduces forage species abundance, which are common red drum prey, indirectly affecting spawning success through reduced foraging success. The most significant effect of this type of fishing gear is long-term changes in bottom structure and long-term changes in benthic trophic and ecosystem functions. These effects can be on the order of months to years in low energy environments, so alterations can have a long-term effect on red drum spawning habitat.

Spawning is optimal within a specific range of temperatures. Climate change and resulting temperature regime changes in spawning habitats could alter the timing of spawning and egg development, which may be detrimental in a specific habitat area of concern. Such alterations in phenology are recognized as such a threat to the survival of many species (USFWS 2011). Significant climate change could alter current patterns and significantly change water temperatures, affecting migration, spawning patterns, and larval survival (Hare and Able 2007; USFWS 2011).

#### *Estuarine Spawning, Nursery, Juvenile and Subadult Habitat: Condition and Threats*

Between 1986 and 1997, estuarine and marine wetlands nationwide experienced an estimated net loss of 10,400 acres (Dahl 2000). The majority of this loss was from urban and rural activities, which converted wetlands to other uses. Along the south Atlantic coast, Florida experienced the greatest loss due to urban or rural development (Dahl 2000). In Tampa Bay, 3,250 acres of seagrass have been recovered between 2008 and 2010 (EPA 2011b).

Reduced water quality can lead to increased susceptibility to pathogens, which can result in lesions, developmental issues, disease of major organs, and mortality in red drum and other fishes (Conway et al. 1991). Red drum may exhibit a higher tolerance to bacteria with age, and antibody response also increases as water temperature does (Evans et al. 1997). Atrazine, a widely used pesticide in the United States, reduced growth rates in red drum larvae by 7.9% - 9.8% (Alvarez and Fuiman 2005). Potentially toxic contaminants have been detected in red drum, including mercury (Adams and Onorato 2005) and persistent organic pollutants (Johnson-Restrepo et al. 2005).

Nutrient enrichment of estuarine waters is a major threat to water quality and habitat available to red drum. In the southeast, forestry practices significantly contribute to nutrient enrichment, as does pesticide use, fertilizers, and pollution runoff (ASMFC 2002; NSCEP 1993). Urban and suburban development are the most immediate threat to red drum habitat in the southeast. Port and marina expansion also impact the estuarine habitat important to red drum by pollution contributed from

stormwater originating from altered uplands and through alterations to hydrodynamic flows and tidal currents. Watercraft operation can result in pollutant discharge, contributing to poor water quality conditions. Facilities supporting watercraft operations also result in the alteration and destruction of wetlands, shellfish and other bottom communities through construction activities. Motorized vehicles in Class A (<16 ft) and Class 1 (16–25 ft) have seen major recreational growth in estuarine waterways (NMMA 2004). Operation of watercraft equipped with outboard and inboard engines and propellers over shallow seagrass communities can cause increased seagrass scarring (Sargent et al. 1995). Mining activities in nearby areas can also pose a threat with nutrient and contaminant runoff, dredging material deposition, and through alterations of the hydrology of the estuary.

Hydrologic modifications can negatively affect estuarine habitats. Aquaculture, mosquito control, wildlife management, flood control, agriculture, and silviculture activities can result in altered hydrology. Ditching, diking, draining, and impounding activities also qualify as hydrologic modifications that can impact estuarine environments (ASMFC 2011). Alteration of freshwater flows into estuarine areas may change temperature, salinity, and nutrient regimes as well as wetland coverage. Studies have shown that alteration in salinity and temperature can have profound effects in estuarine fishes (Serafy et al. 1997) and that salinity can dictate the abundance and distribution of organisms residing in estuaries (Holland et al. 1996). Construction of groins and jetties has altered hydrodynamic regimes and the transport of larvae of estuarine dependent organisms through inlets (Miller et al. 1984; Miller 1988).

Shoreline erosion patterns can also affect the hydrodynamics and transport of larvae to estuarine environments. Erosion has the potential to alter the freshwater flow into habitats essential for egg, larval, and juvenile survival. Whether erosion is human-induced or naturally occurring, nearshore habitats are consequently affected and eroded sediment is transported and deposited elsewhere (ASFMC 2010). Beach nourishment activities can result in sedimentation in estuaries, covering seagrass beds and other nearshore habitats, and causing water quality to deteriorate (Green 2002; DEP 2011). Along the Atlantic coast, living shorelines are becoming popular to control and minimize erosion (ASFMC 2010).

Trawl fisheries are a threat to estuarine habitat for red drum. In combination with the physical and biological effects identified in the Essential Fish Habitat Steering Committee workshop proceedings (2002), trawling activities and bivalve harvesting activities (oyster tonging, clam raking, clam kicking, etc.) can severely damage seagrass systems (Stephan et al. 2000). Such activities can reduce the productivity of estuarine red drum habitat, reduce forage species abundance, and alter movement patterns for red drum schools. Effects of these fishing gears can be mitigated through effective management strategies, such as exclusion of trawl fisheries from seagrass communities.

Climate change could result in faster erosion of certain nearshore areas and loss of shallow nursery habitats to inundation. Projections of global sea level rise are from 18–59 cm by the year 2100, with an additional contribution from ice sheets of up to 20 cm (IPCC 2007). In addition to sea level rise, climate change could alter the amount of freshwater delivery and salinity levels in estuarine areas (USFWS 2011). As temperature increases, the surface water in estuaries and marshes also increases, which reduces oxygen solubility (EPA 2011a) and can stress the environment. Estuarine waters are vulnerable to acidification, but seagrasses are particularly susceptible to changes in water column acidity (EPA 2011a), which is an important nursery habitat for larval and juvenile red drum.

#### *Adult Habitat: Condition and Threats*

While threats to adult red drum habitat exist, they are not as numerous as those faced by post-larvae, juveniles, and subadults in estuarine and coastal waters. According to the SAFMC (1998) and ASMFC

(2002), threats to both nearshore and offshore habitats that adult red drum utilize in the south Atlantic include navigation management and related activities; dredging and dumping of dredged material; mining for sand or minerals; oil and gas drilling and transport; and commercial and industrial activities, and are similar to those for red drum coastal spawning habitat.

Currently, mineral mining activities in the south Atlantic are highly limited. Offshore mining has the potential to pose a threat to adult red drum habitat in the future. Mining activities could alter the hydrology, sediment landscape, and water quality of surrounding areas, affecting both fish and their habitat, by causing sediment plumes or releasing metallic substances into the water column (Halfar 2002).

A more immediate threat to red drum adult habitat is the mining of sand for beach nourishment projects. Associated risks include burial of hard bottoms near mining or disposal sites, contamination, and an increase in turbidity and hydrological alterations that could result in a diminished habitat (Green 2002; Peterson and Bishop 2005). Although adult red drum are euryhaline and eurythermal, drastic or sudden changes in salinity and/or temperature can result in mortality (Gunter 1941; Buckley 1984).

### **Section III. Threats and Uncertainties**

#### ***Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Red Drum***

Red Drum utilize all available estuarine and nearshore habitats throughout their life history. Although regional habitat types, such as mesohaline SAV communities, might be limited locally, red drum can use multiple habitat types at each stage of their development. There is no supporting evidence that habitat is currently limiting to populations of red drum throughout their range.

Oyster reefs are an important habitat to red drum at the juvenile and subadult life stages. In South Carolina, the abundance of red drum is not limited by the availability or health of oyster reef habitat, despite significant reductions of oyster reef habitat throughout the range of the red drum population. Creeks, tributaries, and estuaries are important habitats for red drum. Larval, juvenile, and subadult red drum are particularly sensitive to pollution contributed to watersheds by human activities. There is currently no evidence that chemical pollution is a limiting factor for juvenile and subadult red drum. However, changes in hydrology due to watershed activities that alter stormwater flow and sedimentation might restrict red drum larval recruitment both locally and regionally. Additionally, sediment accumulation may alter SAV abundance and circulation patterns resulting in lower recruitment into small creeks.

#### ***Unknowns and Uncertainties***

Not much is known regarding the preferred ranges and physiological tolerances of red drum and how it changes during development. In the context of climate change, more information is needed to predict how different life stages of red drum will be impacted by increased temperatures, altered freshwater flow regimes, increased acidity, and decreased DO. In addition to direct physiological impacts of climate change on red drum, indirect effects on red drum also need to be examined (e.g., habitat degradation, reduced prey abundance, and increased disease susceptibility).

Larval and juvenile red drum are also known to use many different habitats as nurseries, although the relative contribution of a particular nursery to the adult population has not currently been assessed.

## **Section IV. Recommendations for Habitat Management and Research**

### ***Habitat Management Recommendations***

Amendment 2 to ASMFC's Interstate Fishery Management Plan for Red Drum (2002) states 15 habitat management recommendations for red drum.

1. Each state should implement identification and protection of red drum habitat within its jurisdiction, in order to ensure the sustainability of that portion of the spawning stock that either is produced or resides within its boundaries. Such efforts should inventory historical habitats through mark-recapture studies or other means as available, identify those habitats presently used for spawning or nursery areas (Section 3.8), specify those that are targeted for recovery, and impose or encourage measures to retain or increase the quantity and quality of red drum essential habitats.
2. Each state should notify in writing the appropriate Federal and state regulatory agencies of the locations of habitats used by red drum. Regulatory agencies should be advised of the types of threats to red drum populations and recommended measures which should be employed to avoid, minimize or 95 eliminated any threat to current habitat extent or quality.
3. Each state should establish HAPCs or similar designations appropriate for each state which hosts significant amounts of red drum spawning and nursery habitat. Each protected area should include sufficient amounts of necessary habitats for red drum, i.e., oyster reef, intertidal marsh or submerged rooted vascular vegetation, tidal creeks, intertidal flats, and adjacent deepwater estuarine to provide for individuals from age 0 to age 5 to reside therein. States may determine that such areas may warrant Marine Protected Area status and be closed to harvest either seasonally or permanently. It may be advantageous to locate such areas within existing special management areas such as National Wildlife Refuges, National Parks, including National Seashores, or state-designated areas such as Primary Nursery Areas (North Carolina).
4. Each state should establish freshwater inflow targets for estuaries documented as important red drum spawning, nursery or wintering habitat. Such targets should be derived where possible from flow data which predate significant hydrological alterations, and should mimic as closely as possible a natural hydrograph (defined as the pattern which predates significant anthropogenic alterations).
5. Where sufficient knowledge is available, states should seek to designate red drum essential habitats for special protection. These locations should be designated High Quality Waters or Outstanding Resource Waters and should be accompanied by requirements for non-degradation of habitat quality, including minimization of non-point source runoff, prevention of significant increases in contaminant loadings, and prevention of the introduction of any new categories of contaminants into the are (via restrictions on NPDES discharge permits for facilities in those areas).
6. State fishery regulatory agencies should develop protocols and schedules for providing input on water quality regulations to the responsible agency, to ensure to the extent possible that water

quality needs for red drum are restored, met and maintained. Water quality criteria for red drum spawning and nursery areas should be established or existing criteria should be upgraded to levels which are sufficient to ensure successful reproduction. Any action taken should be consistent with federal Clean Water Act guidelines and specifications.

7. State marine fisheries agencies should work with permitting or planning agencies in each state to develop permit conditions and planning considerations to avoid or mitigate adverse impacts on HAPCs or other habitats necessary to sustain red drum. Standard permit conditions and model policies that contain mitigation protocols should be developed. The development of Memoranda of Understanding (MOU) with other state agencies is recommended for joint review of projects and planning activities to ensure that habitat protections are adequately implemented.
8. Federal and state fishery management agencies should take steps to limit the introduction of compounds which are known or suspected to accumulate in red drum tissue and which pose a threat to human health or red drum health.
9. Each state should establish windows of compatibility for activities known or suspected to adversely affect red drum life states and their habitats, such as navigational dredging, bridge construction and dredged material disposal, and notify the appropriate construction or regulatory agencies in writing.
10. Projects involving water withdrawal from spawning or nursery habitats (e.g. power plants, irrigation, 96 water supply projects) should be scrutinized to ensure that adverse impacts resulting from larval/juvenile impingement, entrainment, and/or modification of flow, temperature and salinity regimes due to water removal will not adversely impact red drum spawning stocks, including early life stages.
11. States should endeavor to ensure the proposed water diversions/withdrawals from rivers tributary to spawning and nursery habitats will not reduce or eliminate conditions favorable to red drum use of these habitats.
12. The use of any fishing gear or practice which is documented by management agencies to have an unacceptable impact on red drum (e.g. habitat damage, or bycatch mortality) should be prohibited within the affected essential habitats (e.g. trawling in spawning areas or primary nursery areas should be prohibited).
13. Each state should review existing literature and data sources to determine the historical extent of red drum occurrence and use within its jurisdiction. Further, an assessment should be conducted of areas historically but not presently used by red drum, for which restoration is feasible.
14. Every effort should be made to eliminate existing contaminants from red drum habitats where a documented adverse impact occurs.

15. States should work in concert with the USFWS Division of Fisheries Resources and Ecological Services and the NMFS Office of Habitat Conservation to identify hydropower dams and water supply reservoirs which pose significant threat to maintenance of appropriate freshwater flows to, or migration routes for, red drum spawning areas and target them for appropriate recommendations during FERC relicensing evaluation.

### ***Habitat Research Recommendations***

Amendment 2 to ASMFC's Interstate Fishery Management Plan for Red Drum (2002) states seven research needs for red drum habitat, characterized as high (H), medium (M), and low (L) priority.

1. Identify spawning areas of red drum in each state from North Carolina to Florida so these areas may be protected from degradation and/or destruction. (H)
2. Identify changes in freshwater inflow on red drum nursery habitats. Quantify the relationship between freshwater inflows and red drum nursery/sub-adult habitats. (H)
3. Determine the impacts of dredging and beach renourishment on red drum spawning and early life history stages. (M)
4. Investigate the concept of estuarine reserves to increase the escapement rate of red drum along the Atlantic coast. (M)
5. Identify the effects of water quality degradation (changes in salinity, DO, turbidity, etc.) on the survival of red drum eggs, larvae, post-larvae, and juveniles. (M)
6. Quantify relationships between red drum production and habitat. (L)
7. Determine methods for restoring red drum habitat and/or improving existing environmental conditions that adversely affect red drum production. (L)

SAFMC's Habitat Plan for the South Atlantic Region (1998) and the NMFS Habitat Research Plan (Thayer et al. 1996) outlines the following needs and recommendations for research.

1. Investigate the relationship between habitat and yield of red drum throughout its range, including seasonality and annual variability as well as the influence of chemical and physical fluxes on these relationships.
2. Identify and quantify limiting conditions to red drum production, particularly in HAPCs.
3. Conduct cause-and-effect research to evaluate the response of red drum populations and HAPCs to anthropogenic stresses including responses to alterations in upland areas and the role of buffer zones.
4. Encourage research in the development of bio- or photo-degradable plastic products to minimize impact of refuse on inshore, coastal and offshore habitats that red drum utilize at various stages of development.

5. Quantify the impacts of acid deposition on red drum estuarine habitats.
6. Conduct research on habitat restoration and clean-up techniques including the development of new approaches and rigorous evaluation protocols. Research should focus on such topics as contaminant sequestration, bio-remediation techniques, the role and size of buffer zones, and the role of habitat heterogeneity in the restoration process.
7. Conduct research to assess the impacts of oil, gas and mineral exploration, development or transportation on red drum and red drum HAPCs.
8. Determine impacts of dredging nearshore and offshore sandbars for beach renourishment on all life history stages of red drum, particularly spawning adults.

### **Literature Cited**

- Able, K. W. and M. P. Fahay. 2010. Ecology of Estuarine Fishes: Temperate Waters of the Western North Atlantic. Johns Hopkins University Press. Baltimore, MD.
- Adams, D. H. and G. V. Onorato. 2005. Mercury concentrations in red drum, *Sciaenops ocellatus*, from estuarine and offshore waters of Florida. Marine Pollution Bulletin 50: 291–300.
- Adams, D. H. and D. M. Tremain. 2000. Association of large juvenile red drum, *Sciaenops ocellatus*, with an estuarine creek on the Atlantic coast of Florida. Environmental Biology of Fishes 58: 183–194.
- Alvarez, M. C. and L. A. Fuiman. 2005. Environmental levels of atrazine and its degradation products impair survival skills and growth of red drum larvae. *Aquatic Toxicology* 74: 229–241.
- ASMFC. 2002. Amendment 2 to the Interstate Fishery Management Plan for Red Drum; Fishery Management Report No. 38 of the Atlantic States Marine Fisheries Commission. ASMFC. pp. 69–75.
- ASMFC. 2010. Living Shorelines: Impacts of Erosion Control Strategies on Coastal Habitats. Atlantic States Marine Fisheries Commission, Washington, D.C.
- ASMFC. 2011. Spotlight on Habitat Restoration Projects: Oyster Reefs and Mosquito Ditches. Atlantic States Marine Fisheries Commission, Washington, D.C.
- ASMFC-Habitat Committee. 2012. Offshore wind in my back yard? Draft ASMFC technical information document. pp. 6.
- Bacheler, N. M., L. M. Paramore, J. A. Buckel and J. E. Hightower. 2009a. Abiotic and biotic factors influence the habitat use of an estuarine fish. *Marine Ecology Progress Series* 377: 263–277.
- Bacheler, N. M., Paramore, L. M., Burdick, S. M., Buckel, J. A. and J. E. Hightower. 2009b. Variation in movement patterns of red drum *Sciaenops ocellatus* inferred from conventional tagging and ultrasonic tracking. *Fishery Bulletin* 107: 405–419.
- Ballachey, B. E., J. L. Bodkin, D. Esler, D. B. Irons, C. H. Peterson, S. D. Rice and J. W. Short. 2003. Review: Long-Term Ecosystem Response to the Exxon Valdez Oil Spill. *Science* 302: 2082–2086.



- Baltz, D. M., J. W. Fleeger, C. F. Rakocinski and J. N. McCall. 1998. Food, density, and microhabitat: factors affecting growth and recruitment potential of juvenile saltmarsh fishes. *Environmental Biology of Fishes* 53: 89–103.
- Barrios, A. T. 2004. Use of passive acoustic monitoring to resolve spatial and temporal patterns of spawning activity for red drum, *Sciaenops ocellatus*, in the Neuse River Estuary, North Carolina. M.S. Thesis. North Carolina State University, Raleigh, NC. pp. 113.
- Bass, R. J. and J. W. Avault, Jr. 1975. Food habit, length-weight relationship, condition factor, and growth of juvenile red drum, *Sciaenops ocellatus*, in Louisiana. *Transactions of the American Fisheries Society* 104(1): 35–45.
- Beaumarrriage, D. S. 1969. Returns from the 1965 Schlitz tagging program, including a cumulative analysis of previous results. Florida Department of Natural Resources Technical Series 59: 1–38.
- Beck, M. W., K. L. Heck, K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B. Halpern, C. G. Hays, K. Hoshino, T. J. Minello, R. J. Orth, P. F. Sheridan, and M. P. Weinstein. 2001. The identification, conservation, and management of Estuarine and Marine Nurseries for Fish and Invertebrates. *BioScience* 51(8): 633–641.
- Beckwith, A. B., G. H. Beckwith, Jr., and P. S. Rand. 2006. Identification of critical spawning habitat and male courtship vocalization characteristics of red drum, *Sciaenops ocellatus*, in the lower Neuse River estuary of North Carolina. North Carolina Sea Grant Fishery Research Grant Program, Final Report 05-EP-05. pp. 39.
- Buckley, J. 1984. Habitat Suitability Index Models: Larval and Juvenile Red Drum. U.S. Fish and Wildlife Service. pp. 1–25.
- Chao, L. N. 2003. The living marine resources of the Western Central Atlantic: Sciaenidae. Vol 3. Food and Agriculture Organization Species Identification Guide for Fishery Purposes: 1583–1603.
- Collier, T. K., J. P. Incardona, and N. L. Scholz. 2010. Oil spills and fish health: exposing the heart of the matter. Environmental Conservation Division, Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration (NOAA), Seattle, Washington, USA. *Journal of Exposure Science and Environmental Epidemiology* 21(1): 3–4.
- Comyns, B. H., J. Lyczkowski-Shultz, D. L. Nieland and C. A. Wilson. 1991. Reproduction of red drum, *Sciaenops ocellatus*, in the Northcentral Gulf of Mexico: seasonality and spawner biomass. U.S. Department of Commerce NOAA Technical Report NMFS 95: 17–26.
- Conway, P. L., S. Kjelleberg, J. C. Olsoon and A. Westerdahl. 1991. Isolation and Characterization of turbot (*Scophthalmus maximus*)- associated bacteria with inhibitory effects against *Vibrio anguillarum*. *Applied and Environmental Microbiology* 57(8): 2223–2228.
- Dahl, T. E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Department of the Interior, USFWS, Washington, DC. pp. 81.

- Daniel, III, L. B. 1988. Aspects of the biology of juvenile red drum, *Sciaenops ocellatus*, and spotted seatrout, *Cynoscion nebulosus*, (Pisces: Sciaenidae) in South Carolina. M.S. Thesis. College of Charleston, Charleston, SC. pp. 58.
- DEP (Department of Environmental Protection). 2011. Seagrass Conservation Issues. Florida Department of Environmental Protection. Retrieved February 29, 2012 from <http://www.dep.state.fl.us/coastal/habitats/seagrass/issues.htm>.
- DONG (Dansk Olie og Naturgas). 2006. Danish offshore wind key environmental issues. DONG Energy, Vattenfall, The Danish Energy Authority and the Danish Forest and Nature Agency. pp. 142.
- Duffy, J. E., B. J. Cardinale, K. E. France, P. B. McIntyre, E. Thébault and M. Loreau. 2007. The functional role of biodiversity in ecosystems: incorporating trophic complexity. *Ecology Letters* 10(6): 522–538.
- EPA (U.S. Environmental Protection Agency). 2011a. How will Climate change affect Victorian Estuaries? Environment Protection Authority of Victoria, Australia. Publication No. 1389.
- EPA (U.S. Environmental Protection Agency). 2011b. Estuaries and Coastal Watersheds. United States Environmental Protection Agency. Retrieved February 22, 2012, from <http://water.epa.gov/type/oceb/nep/challenges.cfm#hydro>.
- Evans, A. S., K. L. Webb, and P. A. Penhale. 1986. Photosynthetic temperature acclimation in two coexisting seagrasses *Zostera marina* and *Ruppia maritima*. *Aquatic Botany* 24: 185–198.
- FWCC (Florida Fish and Wildlife Conservation Commission). 2008. Red Drum, *Sciaenops ocellatus* Stock Assessment. Florida Fish and Wildlife Conservation Commission: Red Drum 61.
- Green, K. 2002. Beach nourishment: a review of the biological and physical impacts. ASMFC Habitat Management series #7. pp. 174.
- Gunter, G. 1941. Death of fishes to cold on the Texas coast, January, 1940. *Ecology* 22(2): 203–208.
- Halfar, J. 2002. Precautionary Management of Deep Sea Mining. *Marine Policy* 26(2): 103–106.
- Hare, J. A. and K. W. Able. 2007. Mechanistic links between climate and fisheries along the east coast of the United States: explaining population outbursts of Atlantic croaker (*Micropogonias undulatus*). *Fisheries Oceanography* 16: 31–45.
- Havel, L. N., L. A. Fuiman and A. F. Ojanguren. 2015. Benthic habitat properties can delay settlement in an estuarine fish (*Sciaenops ocellatus*). *Aquatic Biology* 24: 81–90.
- Holland, A. F., G. H. M. Riekerk, S. B. Lerberg, L. E. Zimmerman, D. M. Sanger, G. I. Scott and M. H. Fulton. 1996. Assessment of the impact of watershed development on the nursery functions of tidal creek habitats. *In*: G.S. Kleppel and M.R. DeVoe (eds) *The South Atlantic Bight land use – coastal ecosystems study (LU-CES)*, pp. 28–31. Univ. of Georgia Sea Grant and S.C. Sea Grant Program. Report of a planning workshop.

- Holt, J., R. Godbout and C. Arnold. 1981. Effects of temperature and salinity on egg hatching and larval survival of red drum *Sciaenops ocellatus*. *Fishery Bulletin* 79(3): 569–573.
- Holt S. A., C. L. Kitting and C. R. Arnold. 1983. Distribution of young red drums among different sea-grass meadows. *Transactions of the American Fisheries Society* 112: 267–271.
- Holt, G. J., S. A. Holt and C. R. Arnold. 1985. Diel periodicity of spawning in sciaenids. *Marine Ecology Progress Series* 27: 1–7.
- Holt, S. A., G. J. Holt and C. R. Arnold. 1989. Tidal stream transport of larval fishes into non-stratified estuaries. *Rapports du Conseil International pour l'Exploration de la Mer* 191: 100–104.
- IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Eds. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller. Cambridge University Press, United Kingdom and New York. pp. 996.
- Incardona J. P., T. K. Collier and N. L. Scholz. 2004. Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. *Toxicology and Applied Pharmacology* 196: 191–205.
- Incardona J. P., M. G. Carls, H. Teraoka, C. A. Sloan, T. K. Collier and N. L. Scholz. 2005. Aryl hydrocarbon receptor-independent toxicity of weathered crude oil during fish development. *Environmental Health Perspectives* 113: 1755–1762.
- Incardona J. P., M. G. Carls, H. L. Day, C. A. Sloan, J. L. Bolton and T. K. Collier. 2009. Cardiac arrhythmia is the primary response of embryonic Pacific herring (*Clupea pallasii*) exposed to crude oil during weathering. *Environmental Science and Technology* 43: 201–207.
- Irlandi, E. and B. Arnold. 2008. Assessment of nourishment impacts to beach habitat indicator species. Final report to the Florida Fish and Wildlife Conservation Commission for grant agreement No. 05042. pp. 39 + tables and figures.
- Jannke, T. 1971. Abundance of young sciaenid fishes in Everglades National Park, Florida, in relation to season and other variables. *University of Miami Sea Grant Technical Bulletin* 11. pp. 127.
- Johnson, D. R. and N. A. Funicelli. 1991. Estuarine spawning of the red drum in Mosquito Lagoon on the east coast of Florida. *Estuaries* 14: 74–79.
- Johnson, G. D. 1978. Development of fishes of the mid-Atlantic Bight. An atlas of egg, larval and juvenile stages. Vol IV. U.S. Fish and Wildlife Service, Biological Services Program. FSW/OBS-78/12: 190-197.
- Johnson-Restrepo, B., K. Kannan, R. Addink and D. H. Adams. 2005. Polybrominated diphenyl ethers and polychlorinated biphenyls in a marine foodweb of coastal Florida. *Environmental Science and Technology* 39: 8243–8250.

- Kraeuter, J. N. and E. M. Setzler. 1975. The seasonal cycle of Scyphozoa and Cubozoa in Georgia estuaries. *Bulletin of Marine Science* 25: 66–74.
- Luczkovich, J. J., H. J. Daniel, III and M. W. Sprague. 1999. Characterization of critical spawning habitats of weakfish, spotted seatrout and red drum in Pamlico Sound using hydroplane surveys. Completion Report, F-62, NC Division of Marine Fisheries, Morehead City, NC. pp. 128.
- Lyczkowski-Shultz, J. and J. P. Steen, Jr. 1991. Diel vertical distribution of red drum *Sciaenops ocellatus* larvae in the northcentral Gulf of Mexico. *Fishery Bulletin* 89: 631–641.
- Mansueti, R. J. 1960. Restriction of very young red drum, (*Sciaenops ocellata*) to shallow estuarine waters of the Chesapeake Bay during late autumn. *Chesapeake Science* 1: 207–210.
- Marks Jr., R. E. and G. P. DiDomenico. 1996. Tagging studies, maturity, and spawning seasonality of red drum (*Sciaenops ocellatus*) in North Carolina. Completion Report Grant F-43, 1–39.
- McGovern, J. C. 1986. Seasonal recruitment of larval and juvenile fishes into impounded and non-impounded marshes. MS Thesis. College of Charleston, Charleston, SC.
- Mercer, L. P. 1984. A biological and fisheries profile of red drum, *Sciaenops ocellatus*. North Carolina Department of Natural Resources and Community Development, Special Scientific Report No. 41, pp. 89.
- Miles, D. W. 1950. The life histories of spotted seatrout, *Cynoscion nebulosus*, and the redfish, *Sciaenops ocellatus*. Texas Game, Fish and Oyster Commission, Marine Laboratory Annual Report (1949-1950): 66–103.
- Miller, J. M. 1988. Physical processes and the mechanisms of coastal migrations of immature marine fishes. In M.P. Weinstein (ed) Larval fish and shellfish transport through inlets, pp. 68–76. American Fisheries Society, Bethesda, MD.
- Miller, J. M., J. P. Read and L. J. Pietrafesa. 1984. Pattern, mechanisms and approaches to the study of migrations of estuarine-dependent fish larvae and juveniles. In McCleave, J. D., G. P. Arnold, J. J. Dodson and W. H. Neill (eds) Mechanisms of migrations in fishes. Plenum Press, NY.
- Minello, T. J. and G. W. Stunz. 2001. Habitat-related predation on juvenile wild-caught and hatchery-reared red drum *Sciaenops ocellatus* (Linnaeus). *Journal of Experimental Marine Biology and Ecology* 260: 13–25.
- Murphy, M. D. and R. G. Taylor. 1990. Reproduction, growth and mortality of red drum, *Sciaenops ocellatus* in Florida waters. *Fishery Bulletin* 88(4): 531–542.
- Music Jr., J. L. and J. M. Pafford. 1984. Population dynamics and life history aspects of major marine sportfishes in Georgia's coastal waters. Georgia Department of Natural Resources, Coastal Resources Division. Technical Report 38. pp. 382.
- NSCEP (National Service Center for Environmental Publications). 1993. Nutrient Enrichment action Agenda (3.2) For the Gulf of Mexico.

- NMMA (National Marine Manufacturers Association). 2004. 2002 U.S. Recreational Boat Registration Statistics. National Marine Manufacturers Association, Market Statistics Department, Chicago, Illinois.
- Neill, W. H. 1987. Environmental requirements of red drum. *In*: Chamberlain, G. W. (ed) Manual on Red Drum Aquaculture. Preliminary draft of invited papers presented at the Production Shortcourse of the 1987 Red Drum Aquaculture Conference on 22–24 June, 1987 in Corpus Christi, Texas. Texas A & M University, College Station, TX. pp. 396.
- Nelson, D. M., E. A. Irlandi, L. R. Settle, M. E. Monaco and L. Coston-Clements. 1991. Distribution and abundance of fishes and invertebrates in southeast estuaries. ELMR Report No. 9, NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. pp. 167.
- Nicholson, N. and S. R. Jordan. 1994. Biotelemetry study of red drum in Georgia. Georgia Department of Natural Resources, Brunswick, GA. pp. 64.
- Essential Fish Habitat Steering Committee (Northeast Region). 2002. Workshop on the effects of fishing gear on marine habitats off the northeastern United States, October 23–25, 2001, Boston, Massachusetts. Northeast Fisheries Science Center Reference. Document 02-01. pp. 86.
- Odum, H. T. 1971. Environment, Power, and Society. Wiley, New York. pp. 331.
- OEER (Offshore Energy Environmental Research Association). 2008. Funder tidal energy strategic environmental assessment final report. Nova Scotia Department of Energy. Halifax, Nova Scotia. pp. 83.
- Osburn H. R., G. C. Matlock and A. W. Green. 1982. Red drum (*Sciaenops ocellatus*) movement in Texas bays. Contributions in Marine Science 25: 85–97.
- Pafford J. M., A. G. Woodward and N. Nicholson. 1990. Mortality, movement and growth of red drum in Georgia. Final report. Georgia Department of Natural Resources, Brunswick. pp. 85.
- Patterson, H., R. McBride and N. Julien. 2004. Population structure of red drum (*Sciaenops ocellatus*) as determined by otolith chemistry. Marine Biology 144: 855–862.
- Peacock, T. 2014. A synthesis of red drum feeding ecology and diets from North Carolina and South Carolina. M.S. Thesis. East Carolina University, Greenville, NC. pp. 96.
- Pearson, J. C. 1929. Natural history and conservation of the redfish and other commercial sciaenids on the Texas coast. Bulletin of the U.S. Bureau of Fish Commission 44: 129–214.
- Peters, K. M. and R. H. McMichael. 1987. Early life history of the red drum, *Sciaenops ocellatus* (Pisces: Sciaenidae), in Tampa Bay, Florida. Estuaries 10(2): 92–107.
- Peterson, C. H. and M. J. Bishop. 2005. Assessing the environmental impacts of beach nourishment. Bioscience. 55:10 p. 887.

- Reyier, E. A. 2005. An ichthyoplankton survey of the northern Indian River Lagoon system, Florida, with emphasis as to the function of an estuarine no-take fisheries reserve. Ph.D. Dissertation. Florida Institute of Technology, Melbourne, FL. pp. 217.
- Reyier, E. A. and J. M. Shenker. 2007. Ichthyoplankton community structure in a shallow subtropical estuary of the Florida Atlantic Coast. *Bulletin of Marine Science* 80: 267-293.
- Reyier, E. A., R. H. Lowers, D. M. Scheidt and D. H. Adams. 2011. Movement patterns of adult red drum, *Sciaenops ocellatus*, in shallow Florida lagoons as inferred through acoustic telemetry. *Environmental Biology of Fishes* 90: 343–360.
- Renkas, B. J. 2010. Description of periodicity and location of red drum (*Sciaenops ocellatus*) spawning in Charleston Harbor, South Carolina. M.S. Thesis. College of Charleston, Charleston, SC. pp. 41.
- Rooker, J. R. and S. A. Holt. 1997. Utilization of subtropical seagrass meadows by newly settled red drum *Sciaenops ocellatus*: patterns of distribution and growth. *Marine Ecology Progress Series* 158: 139–149.
- Rooker, J. R., S. A. Holt, G. J. Holt and L. A. Fuiman. 1999. Spatial and temporal variability in growth, mortality, and recruitment potential of postsettlement red drum, *Sciaenops ocellatus*, in a subtropical estuary. *Fishery Bulletin* 97: 581–590.
- Ross, J. L. and T. M. Stevens. 1992. Life history and population dynamics of red drum (*Sciaenops ocellatus*) in North Carolina waters. *Marine Fisheries Research. Completion Report, Project F-29*. North Carolina Department of Marine Fisheries, Morehead City, NC.
- SAFMC (South Atlantic Fishery Management Council). 1998. Habitat plan for the South Atlantic region: essential fish habitat requirements for fishery management plans of the South Atlantic Fishery Management Council. SAFMC, Charleston, SC. pp. 457 + appendices.
- Sargent, F. J., T. J. Leary, D. W. Crewz and C. R. Kruer. 1995. Scarring of Florida's seagrasses: assessment and management options. FMRI Tech Rep. TR-1. Florida Marine Research Institute, St. Petersburg, Florida. pp. 37 + appendices.
- Scharf, F. S. and K. K. Schlicht. 2000. Feeding habits of red drum (*Sciaenops ocellatus*) in Galveston Bay, Texas: Seasonal diet variation and predator-prey size relationships. *Estuaries* 23(1): 128–139.
- Serafy, J. E., K. C. Lindeman, T. E. Hopkins and J. S. Ault. 1997. Effects of freshwater canal discharges on subtropical marine fish assemblages: field and laboratory observations. *Marine Ecology Progress Series* 160: 161-172.
- Setzler, E. M. 1977. A quantitative study of the movement of larval and juvenile Sciaenidae and Engraulidae into the estuarine nursery grounds of Doboy Sound, Sapelo Island, Georgia. M.S. Thesis. University of Georgia.
- Simmons, E. G. and J. P. Breuer. 1962. A study of redfish, *Sciaenops ocellata* (Linnaeus), and black drum, *Pegonias cromis* (Linnaeus). *Publications of the Institute of Marine Science* 8: 184–211.

- Stephan, D. C., R. L. Peuser and M. S. Fonseca. 2000. Evaluating fishing gear impacts to submerged aquatic vegetation and determining mitigation strategies. Atlantic States Marine Fisheries Commission Habitat Management Series #5. Washington, D.C.
- Tremain, D. M. and D. H. Adams. 1995. Seasonal variations in species diversity, abundance, and composition of fish communities in the northern Indian River Lagoon, Florida. *Bulletin of Marine Science* 57: 171–192.
- Thayer, G. W., J. P. Thomas and K. V. Koski. 1996. The Habitat Research Plan of the National Marine Fisheries Service. *Fisheries* 21(5): 5–6.
- USFWS (U.S. Fish and Wildlife Service). 2011. National fish, wildlife and plants climate adaptation strategy. Washington, D.C. pp. 153.
- Vernberg, F. J., W. B. Vernberg, D. E. Porter, G. T. Chandler, H. N. McKellar, D. Tufford, T. Siewicki, M. Fulton, G. Scott, D. Bushek and M. Wahl. 1999. Impact of coastal development on land-coastal waters. Pages 613–622 *In* E. Ozhan (ed) Land-ocean interactions: Managing coastal ecosystems. MEDCOAST, Middle East Technical University, Ankara, Turkey.
- Wanless, H. R. 2009. A history of poor economic and environmental renourishment decisions in Broward County, Florida, *In* Kelley, J. T., Pilkey, O. H., and Cooper, J. A. G. (eds) America's Most Vulnerable Coastal Communities: Geological Society of America Special Paper 460, pp. 111–119.
- Weinstein, M. P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear, North Carolina. *Fishery Bulletin* 77(2): 339–357.
- Wenner, C. A., W. A. Roumillat, J. Moran, M. B. Maddox, L. B. Daniel III and J. W. Smith. 1990. Investigations on the life history and population dynamics of marine recreational fishes in South Carolina: Part 1. South Carolina Department of Natural Resources, Marine Resources Research Institute, Final Report Project F-37. pp. 179.
- Wenner, C. 1992. Red Drum: Natural History and Fishing Techniques in South Carolina. Marine Resources Research Institute. Report No. 17.
- Woodward, A. G. 1994. Tagging studies and population dynamics of red drum in coastal Georgia. Final Report. Georgia Department of Natural Resources, Brunswick, GA. pp. 71.
- Yokel, B. 1966. A contribution to the biology and distribution of the red drum, *Sciaenops ocellata*. M.S. Thesis. University of Miami, Miami, FL. pp. 166.

## CHAPTER 5: SPOT

Populated with text from the Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout (ASFMC 2012)

### **Section I. General Description of Habitat**

Spot are found in estuaries and coastal areas from the Gulf of Maine to the Bay of Campeche, Mexico, and are concentrated between the Chesapeake Bay and South Carolina (Phillips et al. 1989). Juvenile spot prefer shallow water areas, less than 8 m, over fine sediment and in tidal marshes (Phillips et al. 1989; Strickney and Cuenco 1982; Chesapeake Bay Program 1991). Juvenile spot are found in salinities ranging from 0–30 ppt and water temperatures from 5–30°C (Stickney and Cuenco 1982; Phillips et al. 1989, ASMFC 1987), and therefore are found from polyhaline to freshwater nursery areas. Adult spot are more abundant in coastal waters and lower estuaries whereas juveniles are abundant in lower salinity areas.

### **Part A. Spawning Habitat**

Data indicate that spot spawn further offshore and in deeper waters than other sciaenids. Spot typically migrate offshore and spawn in the relatively deep water of the outer continental shelf, though some evidently spawn in both nearshore waters and estuaries (Dawson 1958; Lewis and Judy 1983). Ripe adults aggregate off beaches in the fall and start migrating offshore to more southern waters (Pearson 1932). Spot may spawn repeatedly over several weeks (Hildebrand and Cable 1930), with some individuals remaining offshore after spawning (Pearson 1932; Wenner et al. 1979, 1980). Fall migrations of maturing spot to offshore waters were reported from Chesapeake Bay (Hildebrand and Schroeder 1928), North Carolina (Roelofs 1951), and South Carolina estuaries (Dawson 1958). Ripe spot were collected in depths up to 82 m off South Carolina (Dawson 1958) and 12.8–16.1 km off the Georgia coast (Hoese 1973). Smith (1907) stated that in North Carolina spot spawn in the sounds and inlets and Hildebrand and Cable (1930) suggested that spawning occurred in close proximity to passes off North Carolina; however, no evidence was offered to support these statements. Larval distributions of spot also indicate that spawning occurs more heavily offshore (26–128 m) than inshore (14.6–20.1 m; Lewis and Judy 1983; Warlen and Chester 1985).

### ***Geographic and Temporal Patterns of Migration***

By the fall, spot either remain in estuaries another year (after year 1) or migrate offshore. For those that remain nearshore, some adults may spawn on the inner continental shelf during the late fall, if water temperatures remain warm enough. For those that migrate to the outer continental shelf, spawning will occur if temperatures are suitable for spawning and egg development (17.5–25°C) (Hettler and Powell 1981). Compared to other sciaenids, spawning spot are further offshore and in deeper waters. Ripe spot have been collected in depths up to 82 m off South Carolina (Dawson 1958) and shallower waters 8–10 mi off the Georgia coast (Hoese 1973). It is unknown what proportion of spent adults return inshore, or any other habits or behaviors they exhibit (other than the assumption that some proportion return to nearshore or estuarine waters).

### ***Salinity***

There is no evidence that spawning individuals experience anything less than full seawater based on their offshore location.



### ***Substrate***

While the behaviors of juvenile and adult spot likely center on feeding, and thus substrate, it is unknown to what degree substrate influences spawning individuals. Based on the time of year and the offshore habitats required for spawning, it is unlikely that substrate plays a prominent role in spot behavior. Additionally, spot eggs are pelagic and positively buoyant, so substrates likely does not influence their distribution.

### ***Temperature***

Temperature may be the strongest driver of spawning spot behavior. Maturing individuals move offshore in the fall, and if capable (probably based on size) spawn in the late fall if water temperatures are still  $>17.5^{\circ}\text{C}$  (Hettler and Powell 1981). If these two conditions are not met, which is likely true for most of the population, mature spot continue their migration offshore to the outer continental shelf habitats where higher winter temperatures can be found.

### ***Dissolved Oxygen***

Spawning adults likely experience normoxic conditions ( $>4.0\text{ mg L}^{-1}\text{ DO}$ ) offshore, and thus DO is not a limiting factor or strong influence on behavior.

### ***Feeding Behavior***

Spawning adult feeding behaviors are likely a continuation of adult feeding, which takes place in the substrate feeding on epifauna and benthic infauna (Chao and Musick 1977); however, it is unknown how much time or effort spawning individuals spend on feeding.

### ***Competition and Predation***

Because food and space are unlikely limited, environmental constraints (e.g., temperature) are probably greater factors than competition and predation. Offshore predation of spot is not well documented, but thought to be a continuation of the predation seen in lower estuary and nearshore habitats (e.g., sharks, sciaenids, flounders).

## **Part B. Egg Habitat**

### ***Geographic and Temporal Patterns of Migration***

Offshore of the U.S. southeast Atlantic coast, spot eggs are spawned during the winter months, but spawning often extends from late fall to early spring (Flores-Coto and Warlen 1993). Exact locations of spawning are not documented, though based on spawning temperature requirements of  $17.5\text{--}25^{\circ}\text{C}$  (Hettler and Powell 1981), eggs may be spawned in the inner continental shelf early in the spawning season before temperatures decrease. It is likely, however, that the majority of spot eggs are spawned after the fall on the outer continental shelf as this is the only offshore location supporting temperatures high enough for spawning (Warlen and Chester 1985). Detailed descriptions of the egg (and larval) inshore advection processes remain an active field of study, although the positively buoyant eggs are likely moved toward the coast by a combination of wind and warm water eddies, such as those from the Gulf Stream. For example, Govoni et al. (2013) found that spot larvae in warm water cyclonic eddies that both advance development (with warm water temperatures) and enhanced feeding opportunities for late larvae (supported by increased primary productivity).

### ***Salinity***

Because the egg stage of spot occurs entirely offshore, full seawater (approximately 35 ppt) is likely necessary for proper development and transport of eggs, though no studies have explicitly reported any tolerances or thresholds.

### ***Substrate***

Because the egg stage of spot occurs entirely offshore and the eggs are positively buoyant, substrate is not considered a critical aspect of spot egg habitat.

### ***Temperature***

Spawning adults and larvae ( $\leq 15$  d old) have relatively high temperature requirements (17.5–25°C) (Hettler and Powell 1981; Warlen and Chester 1985), which suggests that spot egg temperature requirements are also between 17.5–25°C. Spot eggs hatched within 48 h under laboratory conditions at 20°C, which is likely a realistic temperature based on empirical data (Powell and Gordy 1980).

### ***Dissolved Oxygen***

Because the egg stage of spot occurs entirely offshore, eggs are likely only ever exposed to normoxic waters (5–8 mg L<sup>-1</sup>). It is not currently thought that DO is a limiting factor to survival of spot eggs.

### ***Feeding Behavior***

Spot eggs subsist entirely off the yolk sac prior to hatch.

### ***Competition and Predation***

Spot eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (temperature, salinity, and oxygen requirements largely met by the offshore conditions). Predation of eggs undoubtedly occurs but has not been well studied or reported. Although potentially large numbers of eggs are killed from predation, there is no reason to think that pelagic oceanic predators are targeting spot eggs over other, similar pelagic eggs.

## **Part C. Larval Habitat**

### ***Geographic and Migration Patterns***

Powell and Gordy (1980) report that the yolk sac and oil globule were absorbed within 5 d of hatch, in a laboratory setting at 20°C. Newly hatched larvae are likely still close to offshore spawning locations, which have been suggested to be up to or beyond 90 km offshore (Flores-Coto and Warlen 1993). Larvae cover (through a combination of passive and active migration or transport) perhaps the largest geographic distance of any life stage of spot, with the possible exception of adults migrating for spawning. As with the egg stage, larvae depend on wind and currents (e.g., warm water eddies) for transportation and complete their development over the continental shelf waters during the winter (Able and Fahay 2010). In the winter and through early spring, larval spot ingress into estuarine habitats and settle into upper regions of an estuary (Ribeiro et al. 2015).

### ***Salinity***

Corresponding with the range of habitats seen by larvae, a range of salinities is also experienced. Beginning offshore, full seawater (approximately 35 ppt) dominates until larvae enter coastal estuaries,

where salinities likely vary considerably. It is unknown what proportion of larvae settles in upper estuarine or oligohaline habitats.

### ***Substrate***

For the majority of the larval phase, spot are pelagic and not in contact with or preferring a particular type of substrate. During settlement, they will interact much more with the substrate, though it remains unclear what (if any) substrate preferences exist for post-settlement larvae.

### ***Temperature***

Govoni et al. (2013) reported the densest larval spot concentrations were found along the continental shelf, which ranged in temperature from 11–19°C. Temperatures preferences for larvae may not be as high as for spawning adults and egg development since larvae must be transported through waters that are cooler than the offshore waters in which they were spawned. Additionally, spring estuarine water temperatures, particularly in the southeast U.S., may vary substantially based on atmospheric and terrestrial factors, and thus spot toward the end of their larval phase likely experience a wide range of temperatures. Perhaps the greatest temperature threat to larval spot comes from cold temperatures in estuaries. Hoss et al. (1988) reported a stress response to cold temperatures that resulted in an energy deficit at temperatures  $\leq 10^\circ\text{C}$ .

### ***Dissolved Oxygen***

DO demands are likely met offshore, as well as inshore after ingress. Both of these habitats typically do not experience hypoxic conditions in the winter and early spring, although no published studies have reported on any limitations.

### ***Feeding Behavior***

Larval spot are planktonic feeders. Copepods and ostracods are the primary food up to 25 mm SL (Hildebrand and Cable 1930). Spot larvae are also known to eat tintinnids, pteropods, pelecypods, ostracods, and the egg, naupliar, copepodid, and adult stages of copepods (Govoni et al. 1983). By settlement into nursery habitats (~20 mm SL), sediment is found in the stomachs suggesting that spot are foraging along the bottom (Deary 2015).

### ***Competition and Predation***

Spot larvae likely do not enter into any limiting ecological competition, as their habitat demands are basic—it is unknown whether larvae are limited spatially after settlement, and they are largely planktonic feeders. Predation of larvae undoubtedly occurs both offshore and inshore, yet these processes are difficult to quantify in a way meaningful to the overall population or abundance (i.e., at broad scales and not characterized by spatial or temporal effects of a single study). Similar to the early stages of many other pelagic fish larva, the early stages of spot are significantly predated upon by gelatinous zooplankton (Purcell 1985; Olney and Boehlert 1988; Cowan et al. 1992).

## **Part D. Juvenile Habitat**

Tidal salt marshes and larger estuaries are recognized primary nurseries for spot (Weinstein 1979; Currin et al. 1984), although juvenile spot have been frequently collected offshore on the inner continental shelf (Woodland et al. 2012). Due to the generally high productivity of estuaries, this habitat provides ample prey for spot, which feed mostly on small bottom dwelling worms and crustaceans (Chao and Musick 1977). Atlantic coast estuaries are often shallow and structurally complex, providing a physical

refuge from predators. In addition, spot are well adapted to live in the physiologically stressful, low DO environment of small tidal creeks (Cochran 1994). Research in Rose Bay, North Carolina suggests that during their first summer, spot grow and disperse from shallow edges of the bay to all depths (Currin 1984). Although exceptions exist, this pattern is the generally observed for many coastal species.

### ***Geographic and Temporal Patterns of Migration***

Juveniles occupy a variety of estuarine habitats, although in the early spring they are abundant in seagrass habitats (Olney and Boehlert 1988). Young-of-year juvenile spot are abundant in shallow bay habitats and intertidal and subtidal creeks in the spring (Able et al. 2007; Able and Fahay 2010). By late summer, larger juveniles are common in intertidal and subtidal marsh habitats.

### ***Salinity***

Juvenile spot are found in salinities ranging from 0–30 ppt (polyhaline to freshwater) (Phillips et al. 1989; ASMFC 1987) in nursery areas. Ross (2003) noted spot occupy water with a wide salinity range. Even though spot are tolerant to salinity, juveniles are more abundant in less saline estuarine nursery habitats, suggesting these are preferred nurseries (Thomas 1971; Ross 2003; Able and Fahay 2010).

### ***Substrate***

Juvenile spot likely have a preference for a substrate type, such as mud (Bozeman and Dean 1980; Strickney and Cuenco 1982). However, a number of studies highlight the opportunistic aspect of spot with regard to habitat. Juvenile spot have been collected over shell, sponge, and peat substrates (Able and Fahay 1998; Able and Fahay 2010). Strickney and Cuenco (1982) report mud being the most suitable, but fine sand and coarse sand. Hettler (1989) concluded that up to 1/3 of juveniles might spend their time in *Spartina* (*Spartina alterniflora*) vegetation and Weinstein and Brooks (1983) reported spot use seagrass meadows. In many systems across the Atlantic distribution of spot, abundance may vary among substrate type, although spot are ubiquitous and a distribution-wide substrate preference has not been reported.

### ***Temperature***

The preferred temperature range of juvenile spot is 6–20°C, with a tolerable temperature range extending from 1.2–35.5°C (Parker 1971). Juvenile spot are susceptible to winter kills when estuarine temperatures drop suddenly; however, there is likely individual variation in the susceptibility to this source of mortality, and those later-spawned spot (which are smaller in size) likely have lower survival to low temperatures.

### ***Dissolved Oxygen***

Much work has been done in regard to spot DO tolerances. This work has been done largely in response to the growing number and size of hypoxic events in coastal rivers and estuaries (Breitburg et al. 2009) that spot inhabit. Originally, Ogren and Brusher (1977) reported DO preferences  $>5.0 \text{ mg L}^{-1}$ , although they can tolerate DO as low as  $0.8 \text{ mg L}^{-1}$  with 95% survival (Burton et al. 1980). Mortality increases to 95% when DO drops below  $0.8 \text{ mg L}^{-1}$  (Burton et al. 1980). Though recent work has begun to show that spot actively avoid hypoxic areas and even inhabit the margins of these areas (Campbell and Rice 2014).

### ***Feeding Behavior***

Juvenile spot feed mostly on small bottom dwelling worms and crustaceans (Chao and Musick 1977; Deary 2015). Hales and Van Den Avyle (1989) noted the flexibility in juvenile diets, including insect larvae, polychaetes, harpacticoid copepods and other crustaceans. Several studies have reported that

spot behavior is often driven more by feeding opportunities than by predation risk (Weinstein and Walters 1981; Miltner et al. 1995; Nemerson and Able 2004), which collectively suggests that prey availability and abundance many drive habitat associations to a greater degree than predators.

### ***Competition and Predation***

Density-dependence is often cited as the greatest competitive effect on juvenile spot (Craig et al. 2007), particularly as hypoxia limits available habitat and increases fish densities in suitable areas (Campbell and Rice 2014). Predators of spot include common estuarine predatory fish, such as sharks, seatrout (*Cynoscion spp.*), and flounders (*Paralichthys spp.*), among others (Rozas and Hackney 1984).

## **Part E. Adult Habitat**

Adult spot are common in coastal waters during the spawning season and in estuaries and nearshore waters during the other parts of the year. They are typically found over sandy or muddy bottoms in waters up to approximately 60 m deep.

### ***Geographic and Temporal Patterns of Migration***

Designation of 'adult' is typically defined by the presence of mature reproductive tissue or after the production of viable gametes (Helfman et al. 2006). Under this designation, it is unknown exactly when spot become adults other than vaguely suggesting around ages-1 or 2 (Hales and Van Den Avyle 1989). Given this transition and the relatively short lifespan of most spot, here we refer to adult spot as those that have lived one year and moved to offshore habitats, which typically takes place around October or November, though in the Chesapeake Bay and estuaries to the south some young-of-year may overwinter in estuaries (Able and Fahay 2010). Adults distribute in the inner continental shelf in the fall, while individuals that are mature begin to move farther offshore to warmer waters.

### ***Salinity***

Adult spot are tolerant of salinities up to 60 ppt (ASMFC 1987; Phillips et al. 1989) and are more abundant in coastal waters and lower estuaries and less abundant in lower salinity areas, compared to juveniles.

### ***Substrate***

Adult spot are bottom-oriented, and require substrates to forage on epifauna and benthic infauna (Chao and Musick 1977). Adults likely prefer muddy substrates to sand or vegetated substrate, which has been reported for juveniles (see juvenile substrate section), although offshore adults will likely utilize sand substrates, which are more common outside of estuaries.

### ***Temperature***

As with other habitat variables, adult spot are likely tolerant to a wide range of temperatures, though specifics have not been reported. Despite any tolerances, however, lower temperatures drive migrations offshore in the fall (Pacheco 1962).

### ***Dissolved Oxygen***

As with juveniles, adults are likely tolerant of a wide range of DO, but prefer normoxic conditions ( $>4.0$  mg L<sup>-1</sup>; Chao and Musick 1977). Hypoxic conditions ( $<2.0$  mg L<sup>-1</sup>) are less common offshore, and thus DO is probably less of a concern for adults than for juveniles.

### ***Feeding Behavior***

Adult feeding behaviors are a continuation of juvenile feeding, which takes place in the substrate foraging on epifauna and benthic infauna (Chao and Musick 1977). It is unknown whether adult feeding behaviors change offshore.

### ***Competition and Predation***

Density dependence may be less of a factor for adults than was for juvenile spot as there are fewer adults than juveniles because offshore habitats are likely less spatially limiting than smaller and highly-variable upper estuary environments. Holland et al. (1977) did report sharp mid-summer declines of benthic macroinvertebrates in the Chesapeake Bay, although this occurred largely in upper bay habitats where adults are less likely to inhabit. Predation of spot is dominated by sharks and other estuarine and nearshore predatory fishes, such as other sciaenids and flounders (Bowman et al. 2000).

## **Section II. Essential Fish Habitats and Habitat Areas of Particular Concern**

### ***Essential Fish Habitat***

The SAFMC's Essential Fish Habitat Plan identifies EFH for coastal migratory pelagic species as including sandy shoals of capes and offshore bars, high profile rocky bottom, and barrier island ocean-side waters, from the surf to the shelf break zone, but from the Gulf Stream shoreward, including Sargassum (SAFMC 1998). It further recognizes all coastal inlets and all state-designated nursery habitats as being of particular importance.

### ***Identification of Habitat Areas of Particular Concern***

Spot are strongly associated with the bottom as juveniles and adults and are seasonally dependent on estuaries. From Delaware to Florida, primary nursery habitat includes low salinity bays and tidal marsh creeks with mud and detrital bottoms. Juvenile spot are also found in eelgrass beds in the Chesapeake Bay and North Carolina. By late spring, juveniles are often more abundant in tidal creeks than in seagrass habitats. Estuaries, which are especially susceptible to alterations from human activities, are designated as HAPCs for spot.

Juvenile spot are associated with the estuarine or creek substrates (bottoms, which are often susceptible to degradation from human activities). Additionally, the loss of habitat due to hypoxia is a serious concern across the eastern U.S. (as well as globally), and numerous studies have reported the negative impacts on spot resulting from hypoxic events (Craig et al. 2007; Campbell and Rice 2014).

### ***Present Condition of Habitat Areas of Particular Concern***

A number of activities may affect the condition of the habitats utilized by spot. Estuaries are extremely sensitive to dredging, point and nonpoint source pollution, and destructive or unregulated practices in silviculture, agriculture, or coastal development that contribute to increased turbidity. These activities may reduce the quantity and quality of spot habitat

### **Section III. Threats and Uncertainties**

#### ***Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Spot***

For reasons outlined previously in this section, hypoxia is likely the greatest threat to juvenile spot. Spot tend to do well in warm waters, so increased temperatures from climate change are not of immediate concern; however, other impacts of climate change (e.g., changes in precipitation and subsequently salinity) (Schaffler et al. 2013) are not well understood or forecasted.

#### ***Unknowns and Uncertainties***

The early stages of spot have a ubiquitous distribution throughout estuarine ecosystems using a variety of habitats. However, it is not known if certain nursery habitats contribute more individuals to adult populations. Studies determining preferred nurseries habitats would help managers identify and conserve critical nursery habitats. In addition, spot forage within and along the sediment of the benthos, which concentrates hydrophobic toxicants, potentially increasing their exposure to these contaminants. Previous research has examined the physiological impacts on adult spot (Middaugh et al. 1980; Roberts et al. 1989), however, no known research has examined the impacts of toxicant exposure on early stage spot, which may have developmental or reproductive implications.

Another consideration for spot is the in the early stages, density-dependence is a major competitive force. With the loss of nursery habitats through anthropogenic factors and climate change, competition is expected to increase and the influence of this competitive force on recruitment dynamics is not currently understood.

### **Section IV. Recommendations for Habitat Management and Research**

#### ***Habitat Management Recommendations***

Spot eggs exist in offshore habitats for a short time in winter and likely have no interactions with other fishery activities. It is not currently thought that any management actions are needed to modify habitat or survival of spot eggs. The following management recommendations were highlighted by the Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout (ASFMC 2012):

1. To effectively maintain habitat health, HAPCs should be accompanied by minimization of non-point source and storm water runoff, prevention of significant increases in contaminant loadings, and prevention of the introduction of any new categories of contaminants into the area. Water quality should be monitored to ensure that quality standards are being met.
2. States should minimize loss of wetlands to shoreline stabilization, and monitor navigational dredging, bridge construction, dredged material disposal, and other coastal projects to minimize impact on HAPCs.
3. The use of any fishing gear that is determined by management agencies to have a negative impact on spot habitat should be prohibited within HAPCs.
4. States should identify dams that threaten freshwater flows to nursery and spawning areas, and target them for appropriate recommendations during FERC re-licensing.

5. States should continue support for habitat restoration projects, including oyster shell recycling and oyster hatchery programs as well as seagrass restoration, to provide areas of enhanced or restored bottom habitat.

### ***Habitat Research Recommendations***

From the Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout (ASMFC 2012). Particular attention should be directed toward what these data may indicate regarding habitat utilization and habitat condition (environmental parameters). A list of existing state and Federal programs generating environmental data such as sediment characterization, contaminant analysis, and habitat coverage (marsh grass, oyster beds, SAV) should also be produced and those programs polled on a similar basis. Habitats utilized by this suite of species range from the fresh water dividing line out to, and likely beyond, the shelf break. Thus, virtually any study generating environmental data from estuarine or coastal ocean systems could be of value.

1. Identify critical habitats at all life stages and assess threats by: habitat alteration, dredging and dredge spoil placement, destructive or unregulated agricultural or coastal development, recreational boating, point and nonpoint source pollution.
2. Egg stage: investigations into cyclonic eddies and other offshore distributional processes is an active area of fisheries research (Govoni and Spach 1999; Govoni et al. 2013). Although threats to spot eggs (and the eggs of other coastal species with offshore, winter-spawned stages) are likely minimal or non-existent, continued efforts into understanding these large-scale processes will likely be informative toward understanding the distribution of subsequent life stages.

### **Literature Cited**

- Able, K. W. and M. P. Fahay. 1998. *The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight*. Rutgers University Press, New Brunswick, NJ. pp. 342.
- Able, K. W., J. H. Balletto, S. M. Hagan, P. R. Jivoff and K. Strait. 2007. Linkages between salt marshes and other nekton habitats in Delaware Bay, USA. *Reviews in Fisheries Science* 15: 1–61.
- Able, K. W. and M. P. Fahay. 2010. *Ecology of Estuarine Fishes: Temperate Waters of the Western North Atlantic*. Johns Hopkins University Press. Baltimore, MD.
- ASMFC (Atlantic States Marine Fisheries Commission). 1987. *Fishery Management Plan for Spot*. Fisheries Management Report #11. pp. 90.
- ASMFC (Atlantic States Marine Fisheries Commission). 2012. *Omnibus Amendment to the Interstate Fishery Management Plans for Spanish Mackerel, Spot, and Spotted Seatrout*.
- Bowman, R. E., C. E. Stillwell, W. L. Michaels and M. D. Grosslein. 2000. Food of Northwest Atlantic Fishes and Two Common Species of Squid. NOAA Technical Memorandum NMFS-NE-155. pp. 149.
- Bozeman Jr., E. L. and J. M. Dean. 1980. The abundance of estuarine larval and juvenile fish in a South Carolina intertidal creek. *Estuaries* 3: 89–97.



- Breitburg, D. L., D. W. Hondorp, L. W. Davias, and R. J. Diaz. 2009. Hypoxia, nitrogen and fisheries: Integrating effects across local and global landscapes. *Annual Reviews in Marine Science* 1: 329–350.
- Burton, D. T., L. B. Richardson and C. J. Moore. 1980. Effect of oxygen reduction rate and constant low dissolved oxygen concentrations on two estuarine fish. *Transactions of the American Fisheries Society* 109: 552–557.
- Campbell, L. A. and J. A. Rice. 2014. Effects of hypoxia-induced habitat compression on growth of juvenile fish in the Neuse River Estuary, North Carolina, USA. *Marine Ecology Progress Series* 497: 199–213.
- Chao, L. N. and J. A. Musick. 1977. Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in the York River Estuary, Virginia. *Fishery Bulletin* 75: 657–702.
- Chesapeake Bay Program. 1991. Chesapeake Bay Atlantic Croaker and Spot Fishery Management Plan. U.S. Environmental Protection Agency. Contract No. 68-WO-0043. pp. 33.
- Cochran, R. E. 1994. Respiratory responses of the saltmarsh animals *Fundulus heteroclitis*, *Leiostomus xanthurus*, and *Palaemonetes pugio* to environmental hypoxia and hypercapnia and to the organophosphate pesticide, azinphosmethyl. M.S. Thesis University of Charleston, Charleston, South Carolina. pp. 57.
- Cowan Jr., J. H., R. S. Birdsong, E. D. Houde, J. S. Priest, W. C., Sharp and G. B. Mateja. 1992. Enclosure experiments on survival and growth of black drum eggs and larvae in lower Chesapeake Bay. *Estuaries* 15(3): 392–402.
- Craig, J. K., J. A. Rice, L. B. Crowder and D. A. Nadeau. 2007. Density-dependent growth and mortality in an estuary-dependent fish: an experimental approach with juvenile spot *Leiostomus xanthurus*. *Marine Ecology Progress Series* 343: 251–262.
- Currin, B. M., J. P. Reed and J. M. Miller. 1984. Growth, production, food consumption, and mortality of juvenile spot and croaker: a comparison of tidal and nontidal nursery areas. *Estuaries* 7: 451–459.
- Dawson, C. E. 1958. A study of the biology and life history of the spot, *Leiostomus xanthurus lacepede*, with specific reference to South Carolina. Bears Bluff Lab Contract 28. pp. 48.
- Deary, A. L. 2015. Ontogeny of the feeding apparatus and sensory modalities: Relationship to habitat differentiation among early life history stage drums (Sciaenidae) in the Chesapeake Bay. Ph.D. Dissertation, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA. pp. 170.
- Flores-Coto, C. and S. M. Warlen. 1993. Spawning time, growth, and recruitment of larval spot *Leiostomus xanthurus* into a North Carolina estuary. *Fishery Bulletin* 91: 8–22.
- Govoni, J. J. 1983. Helminth parasitism of three larval fishes in the northern Gulf of Mexico. *Fishery Bulletin* 81: 895–898.

- Govoni, J. J. and H. L. Spach. 1999. Exchange and flux of larval fishes across the western Gulf Stream front south of Cape Hatteras, USA, in winter. *Fisheries Oceanography* 8(Supplement 2): 77–92.
- Govoni, J. J., J. A. Hare and E. D. Davenport. 2013. The distribution of larval fishes of the Charleston Gyre region off the southeastern United States in winter shaped by mesoscale, cyclonic eddies. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 5: 246–259.
- Hales, L. S. and M. J. Van Den Avyle. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic)—spot. U.S. Fish Wildlife Service Biological Report 82(11.91). U.S. Army Corps of Engineers TR EL-82-4. pp. 24 pp.
- Helfman, G., B. B. Collette, D. E. Facey and B. W. Bowen. 2006. *The diversity of fishes: biology, evolution and ecology*, 2nd edition. Wiley-Blackwell.
- Hettler Jr., W. F. 1989. Nekton use of regularly-flooded saltmarsh cordgrass habitat in North Carolina, USA. *Marine Ecology Progress Series* 56: 111–118.
- Hettler, W. F. and A. B. Powell. 1981. Egg and larval fish production at the NMFS Beaufort Laboratory, Beaufort, N.C., USA. *Rapports et Proces-verbaux des Réunions. Conseil International pour l'Exploration de la Mer* 178: 501–503.
- Hildebrand, S. F. and L. E. Cable. 1930. Development and life history of fourteen teleostean fishes at Beaufort, North Carolina. *Bulletin of the U.S. Fish Commission* 46: 383–488.
- Hildebrand, S. F. and W. C. Schroeder. 1928. Fishes of the Chesapeake Bay. *Bulletin of the United States Bureau of Fisheries* 44. pp. 376.
- Hoese, H. D. 1973. A trawl study of nearshore fishes and invertebrates of the Georgia coast. *Contributions to Marine Science* 17: 63–98.
- Holland, A. F., N. K. Mountford and A. Mihursky. 1977. Temporal variation in Upper Bay mesohaline benthic communities: I. The 9-m mud habitat. *Chesapeake Science* 18: 370–378.
- Hoss, D. E., L. Coston-Clements, D. S. Peters and P. A. Tester. 1988. Metabolic responses of spot, *Leiostomus xanthurus*, and Atlantic croaker, *Micropogonias undulatus*, larvae to cold temperatures encountered following recruitment to estuaries. *Fishery Bulletin* 86: 483–488.
- Lewis, R. M. and M. H. Judy. 1983. The occurrence of spot, *Leiostomus xanthurus*, and Atlantic croaker, *Micropogonias undulatus*, larvae in Onslow Bay and Newport River estuary North Carolina. *Fishery Bulletin* 81(2): 405–412.
- Middaugh, D. P., L. E. Burnett and J. A. Couch. 1980. Toxicological and physiological responses of the fish, *Leiostomus xanthurus*, exposed to chlorine produced oxidants. *Estuaries* 3(2): 132–141.
- Miltner, R. J., S. W. Ross and M. H. Posey. 1995. Influence of food and predation on the depth distribution of juvenile spot (*Leiostomus xanthurus*) in tidal nurseries. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 971–982.

- Nemerson, D. M. and K. W. Able. 2004. Spatial patterns in diet and distribution of juveniles of four fish species in Delaware Bay marsh creeks: factors influencing fish abundance. *Marine Ecology Progress Series* 276: 249–262.
- Ogren, L. H. and H. A. Brusher. 1977. The distribution and abundance of fishes caught with a trawl in the St. Andrew Bay system, Florida. *Northeast Gulf Science* 1: 83–105.
- Olney, J. E. and G. W. Boehlert. 1988. Nearshore ichthyoplankton associated with seagrass beds in the lower Chesapeake Bay. *Marine Ecology Progress Series* 45: 33–43.
- Pacheco, A. L. 1962. Age and growth of spot in lower Chesapeake Bay, with notes on the distribution and abundance of juveniles in the York River system. *Chesapeake Science* 3: 18–28.
- Parker, J. C. 1971. The biology of the spot, *Leiostomus xanthurus* Lacepede, and Atlantic croaker, *Micropogon undulatus* (Linnaeus) in two Gulf of Mexico nursery areas. Ph.D. Dissertation. Texas A & M University, College Station, TX.
- Pearson, J. C. 1932. Winter trawl fishery of the Virginia and North Carolina coasts. U.S. Bureau Fisheries Investigative Report 10. pp. 31.
- Phillips, J. M., M. T. Huish, J. H. Kerby and D. P. Morgan. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) Spot. U.S. Fish Wildlife Service Biological Report 82111.98. U.S. Army Corps of Engineers, TR EL-82-4. pp. 13.
- Powell, A. B. and H. R. Gordy. 1980. Egg and larval development of the spot *Leiostomus xanthurus* (Sciaenidae). *Fishery Bulletin* 78: 701–714.
- Purcell, J. E. 1985. Predation on fish eggs and larvae by pelagic cnidarians and ctenophores. *Bulletin of Marine Science* 37: 739–755.
- Ribeiro, F., E. Hale, E. J. Hilton, T. R. Clardy, A. L. Deary, T. E. Targett and J. E. Olney. 2015. Composition and temporal patterns of larval fish communities in Chesapeake and Delaware Bays, USA. *Marine Ecology Progress Series* 527: 167–180.
- Roberts Jr., M. H., W. J. Hargis Jr., C. J. Strobel and P. F. De Lisle. 1989. Acute toxicity of PAH contaminated sediments to the estuarine fish, *Leiostomus xanthurus*. *Bulletin of Environmental Contamination and Toxicology* 42(1): 142–149.
- Roelofs, E. W. 1951. The edible finfishes of North Carolina. In Taylor, H.F. Survey of marine fisheries of North Carolina. University of North Carolina Press, Chapel Hill, NC. 127–128.
- Ross, S. W. 2003. The relative value of different estuarine nursery areas in North Carolina for transient juvenile marine fishes. *Fishery Bulletin* 101: 384–404.
- Rozas, L. P. and C. T. Hackney. 1984. Use of oligohaline marshes by fishes and macrofaunal crustaceans in North Carolina. *Estuaries* 7: 213–224.

- SAFMC (South Atlantic Fishery Management Council). 1998. Habitat plan for the South Atlantic region: essential fish habitat requirements for fishery management plans of the South Atlantic Fishery Management Council. SAFMC, Charleston, SC. pp. 457 + appendices.
- Schaffler, J. J., J. van Montfrans, C. M. Jones and R. J. Orth. 2013. Fish species distribution in seagrass habitats of Chesapeake Bay are structured by abiotic and biotic factors. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 5: 114–124.
- Smith, H. M. 1907. The fishes of North Carolina. North Carolina Geological Survey II. pp. 423.
- Strickney, R. R. and M. L. Cuenco. 1982. Habitat suitability index models: juvenile spot. U.S. Fish Wildlife Service FWS/OBS-82/10.20. pp. 12.
- Thomas, D. L. 1971. The early life history and ecology of six species of drum (Sciaenidae) in the lower Delaware River, a brackish estuary. In *An ecological study of the Delaware River in the vicinity of Artificial Island, Part III*. Ichthyological Association Bulletin 3: 1–247.
- Warlen, S. M. and A. J. Chester. 1985. Age, growth, and distribution of larval spot, *Leiostomus xanthurus*, off North Carolina. *Fishery Bulletin* 83: 587–599.
- Wenner, C. A., C. A. Barans, B. W. Stender and F. H. Berry. 1979. Results of MARMAP otter trawl investigations in the South Atlantic Bight. I. Fall, 1973. South Carolina Department of Wildlife and Marine Resource Commission Technical Report 33. pp. 79.
- Wenner, C. A., C. A. Barans, B. W. Stender and F. H. Berry. 1980. Results of MARMAP otter trawl investigations in the South Atlantic Bight. V. Summer, 1975. South Carolina Department of Wildlife and Marine Resource Commission Technical Report 45. pp. 57.
- Weinstein, M. P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. *Fishery Bulletin* 77: 339–357.
- Weinstein, M. P. and M.P. Walters. 1981. Growth, survival, and production in young-of-year populations of *Leiostomus xanthurus* Lacepede residing in tidal creeks. *Estuaries* 4: 185–197.
- Weinstein, M. P. and H. A. Brooks. 1983. Comparative ecology of nekton residing in a tidal creek and adjacent seagrass meadow: community composition and structure. *Marine Ecology Progress Series* 12: 15–27.
- Woodland, R. J., D. H. Secor, M. C. Fabrizio and M. J. Wilberg. 2012. Comparing the nursery role of inner continental shelf and estuarine habitats for temperate marine fishes. *Estuarine, Coastal, and Shelf Science* 99: 61–73.

## CHAPTER 6: SPOTTED SEATROUT

Populated with text from the Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout (ASFMC 2012)

### **Section I. General Description of Habitat**

Overall, one issue with spotted seatrout is that the species is comprised of unique spatial populations, generally associated with an estuary. Little mixing goes on outside of adjacent estuaries. This means that it is not always safe to project the findings of one subpopulation onto the whole species, and this concern is amplified by the number of studies in the Gulf of Mexico or areas not comparable to the U.S. southeast Atlantic. For example, Powell (2003) presents good information on inferred spawning habitat and egg and larval distribution of spotted seatrout in Florida Bay (Powell et al. 2004). Florida Bay is a shallow, subtropical, oligohaline estuary without lunar tides, and considering that the spotted seatrout inhabiting this area are a unique subpopulation, it makes sense to limit the inference from a population like this onto both a distinct genetic and morphological stock in the Carolinas that inhabits a very different type of estuary (reiterated by Smith et al. 2008, which found growth differences among subpopulations). Research suggests salinity tolerances are genetic and that caution should be used when applying research to other populations.

#### **Part A. Spawning Habitat**

##### ***Geographic and Temporal Patterns of Migration***

Many age-1 spotted seatrout are mature ( $L_{50}=292$  for females; Ihde 2000) and all are mature by age-2. Consistent with the other life stages, spotted seatrout are generally restricted to their natal estuary (Kucera et al. 2002) and for spawning adults this means that spawning takes place often in the lower reaches of the estuary or nearshore just outside inlets.

Spawning seasons vary throughout the species range, and tend to lengthen as a function of warmer water. For example, spawning in Florida Bay has been reported to run from March to October (Powell 2003), while spawning in South Carolina is restricted from late April to early September (Roumillat and Brouwer 2004), and may not begin until May in North Carolina (Luczkovich et al. 2008) and the Chesapeake Bay (Smith et al. 2008). Adult spotted seatrout begin to spawn in March or April in southwest and west-central Florida estuaries (e.g., Tampa Bay and Charlotte Harbor; McMichael and Peters 1989) and in April or May in the more northerly Florida estuaries (e.g., northern IRL) (Tabb 1961; Crabtree and Adams 1998). Specific estuarine spawning locations are not well documented, especially in Atlantic estuaries, although Luczkovich et al. (2008) recorded more spawning-associated calls near Bay River (western Pamlico Sound) than near Ocracoke Inlet (eastern Pamlico Sound). It is also worth mentioning that many of the environmental variables reported by Luczkovich et al. (2008) are in contrast with spawning habitat descriptions reported by Holt and others working in the Gulf of Mexico.

### ***Salinity***

Based on work in the Gulf of Mexico, Kucera et al. (2002) found differing egg characteristics from different Texas bays. Decreasing salinity resulted in increasing size and wet weight of eggs with the opposite true for increasing salinity. Eggs from spawners native to high salinity estuaries spawned at 20 ppt were not positively buoyant and died. Although it is difficult to generalize anything broadly applicable from this study, it does suggest that spawning salinity may be a locally-adapted trait.

Less work has reported on spawning salinities in the Atlantic, though Luczkovich et al. (2008) report spotted seatrout spawning-related drumming to take place in bottom salinities averaging 11.8 ppt (range 7.1–26.9 ppt), which is considerably less saline than reports from the Gulf of Mexico, but may also reflect the habitats investigated and not a uniform distribution of available salinities.

### ***Substrate***

It is unclear if spawning habitats are shared with adult habitats, and if so, what substrate preferences are. However, as eggs are pelagic, it is likely that substrate is less important than other environmental variables (such as temperature, salinity, tide, etc.).

### ***Temperature***

Spawning temperatures appear to be consistently high among all reports. For example, Louisiana spawning aggregations were highly associated with temperature  $29.7 \pm 0.31^\circ\text{C}$  (2 standard errors; Saucier and Baltz 1993), with Brown-Peterson et al. (1988) proposing a critical minimum spawning temperature of  $23^\circ\text{C}$ . Others have suggested minima of  $25.6^\circ\text{C}$  (Tabb 1966) and  $26.3^\circ\text{C}$  (Rutherford et al. 1989). Similarly in the Atlantic, spotted seatrout did not drum below  $23^\circ\text{C}$  (but one outlier), with most drumming occurring between  $25\text{--}30^\circ\text{C}$  (Luczkovich et al. 2008). Hatch dates in the Chesapeake Bay have been dated to early May, yet it remains unclear if this northern distributional population has a lower spawning temperature tolerance.

### ***Dissolved Oxygen***

As with other life stages, DO has not been widely investigated or reported for spawning adults. Despite this paucity of data, the hydroacoustic results suggests that hypoxia did not limit spotted seatrout sound production; drumming has been recorded at DO levels as low as  $0.05\text{ mg L}^{-1}$  (mean  $6.1\text{ mg L}^{-1}$ , range  $0.05\text{--}9.73\text{ mg L}^{-1}$ ; Luczkovich et al. 2008).

### ***Feeding Behavior***

The protracted spawning season of spotted seatrout suggests that they do feed during the spawning season, and feeding patterns likely reflect the same as adult spotted seatrout.

### ***Competition and Predation***

No studies of competition or predation of spotted seatrout were found. Spotted seatrout are top predators in estuarine systems and are consumed by larger predatory fishes, ospreys, and other predatory birds.

## **Part B. Egg Habitat**

Spotted Seatrout larvae use tidal flows to migrate into and within estuaries (Perret et al. 1980) where they settle in seagrass beds, shallow bays, and backwater creeks (McMichael and Peters 1989).

### ***Geographic and Temporal Patterns of Migration***

Along the Atlantic coast, spotted seatrout likely spawn in a variety of estuarine habitats. Spawning habitats are often located by identifying regions where spotted seatrout are drumming, a behavior characteristic of spawning. In a review of spotted seatrout, Johnson and Seaman (1986) report spawning habitat (and thus egg habitats) to range from non-tidal portions of estuarine tributaries, to outside of estuaries. Because eggs hatch 16–22 h after fertilization between (25–27°C; Holt et al. 1985), the egg phase is relatively short in duration.

### ***Salinity***

Preferred salinities of spotted seatrout eggs are unknown but likely varies by spawning habitat. For example, Taniguchi (1981) reported from lab work an optimum salinity for hatching at 28.1 ppt. Gray et al. (1991) reported hatching success in treatments of 30–50 ppt but the highest hatching success was observed at 30 ppt and no hatching observed after 50 ppt.

### ***Substrate***

Due to the relatively short duration of the spotted seatrout egg phase and the neutral buoyancy needed to move eggs and provide oxygen, substrate is likely not an important habitat characteristic for this species at this stage.

### ***Temperature***

Preferred temperatures of spotted seatrout eggs vary. Using eggs from Texas fish, Fable et al. (1976) reared eggs at 25°C that hatched 16–20 h after fertilization. Taniguchi (1981) reported optimum temperature for hatching to be 28°C. While general trends may be applied to Atlantic stocks of spotted seatrout, these results should be used cautiously as they are based not only on artificial conditions (controlled laboratories), but using genetically different stocks that have adapted to different temperature and salinity regimes that exists in the Gulf of Mexico.

### ***Dissolved Oxygen***

No work has been conducted or reported having to do with DO and spotted seatrout eggs. Because eggs spawned in low salinities become demersal and die, it is thought that minimally normoxic conditions are required for adequate egg development.

### ***Feeding Behavior***

Spotted Seatrout eggs subsist entirely off the yolk sac prior to hatch.

### ***Competition and Predation***

Spotted Seatrout eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the oceanic or estuarine conditions). Predation of eggs undoubtedly occurs by a variety of oceanic and estuarine consumers, particularly gelatinous zooplankton (Purcell 1985; Olney and Boehlert 1988; Cowan et al. 1992).

## **Part C. Larval Habitat**

### ***Geographic and Temporal Patterns of Migration***

In the Gulf of Mexico, Holt and Holt (2000) found the most fish along the bottom during the day and similar numbers on bottom and surface at night, suggesting vertical migration. However, Lyczkowski-Schultz and Steen (1991) observed a reverse vertical behavior. Likely both studies are an accurate

reflection of what the authors sampled, but that patterns of vertical distribution may be influenced by spatial or temporal effects not included in the studies. In the Chesapeake Bay, post-settlement, late larvae are obligate seagrass residents in meso- and polyhaline areas (Dorval et al. 2007; Jones 2013).

### ***Salinity***

Spotted Seatrout are among the more euryhaline of larval sciaenid, as Rutherford et al. (1989) could only collect spotted seatrout from 8–40 ppt (mean  $33.2 \pm 1.7$  ppt), which, along with other work (Banks et al. 1991) establishes high tolerances of salinity and high mortality at lower salinities. Tabb (1966) particularly notes that while the overall tolerance range may be wide but abrupt changes in salinity, such as from freshwater inflow resulting from precipitation, renders fish vulnerable. In the Gulf of Mexico, larvae have been collected in salinities ranging from 15–50 ppt, but most are collected at salinities >24 ppt. Low salinities reduce survival of larval spotted seatrout (Holt and Holt 2003).

### ***Substrate***

Spotted Seatrout larvae settle on a variety of substrates, though they prefer seagrass habitats when available (Dorval et al. 2005; Dorval et al. 2007; Jones 2013). In estuaries and areas lacking SAV such as much of South Carolina, Georgia, and parts of North Carolina, larval spotted seatrout have been collected in shallow marsh habitats (Wenner et al. 1990).

### ***Temperature***

Larval spotted seatrout likely tolerate a wide range of temperatures but optimum temperatures from South Florida are 23–33°C (Taniguchi 1981). In Florida Bay, most larvae were found in temperatures between temperatures 26–33°C (Powell 2003).

### ***Dissolved Oxygen***

To date, no studies of DO requirements for larval spotted seatrout have been reported.

### ***Feeding Behavior***

The overall pattern of feeding is likely an effect of prey availability in specific estuaries, but larval diet is dominated by plankton, specifically copepods. From wild spotted seatrout larvae in Texas waters, calanoid copepods and bivalve larvae were the most important food items (Holt and Holt 2000).

### ***Competition and Predation***

Explicit studies of competitors and predators is lacking; however, larvae of other sciaenids and estuarine species likely compete for similar planktonic prey items. And consistent with other predators of larval sciaenids, gelatinous predators and larger fish are likely the dominant predators of larval spotted seatrout (Purcell 1985; Olney and Boehlert 1988; Cowan et al. 1992).

## **Part D. Juvenile Habitat**

### ***Geographic and Temporal Patterns of Migration***

Throughout their range, juvenile spotted seatrout are most often associated with seagrass habitats or SAV. This is certainly true in the Gulf of Mexico (Rooker et al. 1998) and in Florida Bay, where spotted seatrout abundance and distribution has been linked to seagrass communities (Chester and Thayer 1990). In the Florida Bay study, temperature and salinity were relatively constant among sampled areas and spotted seatrout are captured in basins more than channels. In Mississippi waters, spotted seatrout have high site fidelity (Comyns et al. 2008).



In the Atlantic, seagrass beds are likely important (Jones 2013), but surprisingly few studies report on this habitat type, and many are of short duration, limited temporally, or of only a single species. In the Chesapeake Bay, juvenile spotted seatrout are obligate seagrass residents in meso- and polyhaline areas (Dorval et al. 2005; Dorval et al. 2007; Jones 2013). Seagrass beds of Chesapeake Bay provide different growth conditions depending on precipitation and freshwater flow into the bay with higher salinities support faster growth (Smith et al. 2008).

### ***Salinity***

The majority of studies involving juvenile spotted seatrout provide varying ranges of tolerated salinities, typically with mean values between 15–25 ppt. Spotted seatrout were the only one of five common coastal fish that grew slower during high river discharge years in Florida (Purtlebaugh and Allen 2010). In the Chesapeake Bay, drought years have been linked to increases in growth (Smith et al. 2008).

### ***Substrate***

Juvenile spotted seatrout prefer seagrass (SAV) but use shallow tidal salt marsh habitats when SAV is unavailable. In Florida Bay, juvenile spotted seatrout were most often captured where seagrass density and species diversity was highest (Chester and Thayer 1990).

### ***Temperature***

Temperature requirements, particularly minimum temperatures in the northern distributional limits of the species, are similar throughout their range. Based on work in South Carolina, temperatures <5°C are cause for concern as mortality begins to become a serious threat (Anweiler et al. 2014). In North Carolina, spotted seatrout experience approximately 86% mortality after being exposed to 5°C after 10 days (Ellis 2014). In North Carolina, 3.0°C was determined to be a lethal threshold whereas 5°C represents a lethal limit if the exposure persists (Ellis 2014).

### ***Dissolved Oxygen***

To date, no studies of DO requirements for larval spotted seatrout have been reported.

### ***Feeding Behavior***

Juvenile spotted seatrout eat mysids and caridean shrimp whereas larger juveniles eat penaeid shrimp and fishes (Johnson and Seaman 1986; Able and Fahay 2010).

### ***Competition and Predation***

Studies of competitors and predators are lacking; however, juvenile spotted seatrout and other juvenile sciaenids compete for space in upper-estuary habitats, and food in years of limited prey production. However, these are generalities and not based on specific studies of spotted seatrout. Juvenile spotted seatrout are preyed upon by larger fishes, such as striped bass (*Morone saxatilis*), Atlantic croaker (*Micropogonias undulatus*), Atlantic tarpon (*Megalops atlanticus*), and barracuda (*Sphyraena barracuda*) (Mercer 1984; Able and Fahay 2010).

## **Part E. Adult Habitat**

Adult and juvenile spotted seatrout occupy similar habitats (i.e., seagrass beds) but they do partition their foraging habitats through ontogenetic diet shifts (Deary 2015). As adult spotted seatrout increase in size, pelagic fishes and penaeid shrimp become increasingly important in their diet (Lorio and Schafer

1966; ASMFC 1984; Mercer 1984; Daniel 1988). Diet analysis of spotted seatrout in the lower Cape Fear River, North Carolina, revealed that spotted seatrout are mainly piscivorous after reaching age 1 (Tayloe and Scharf 2006).

### ***Geographic and Temporal Patterns of Migration***

Most individuals of adult spotted seatrout have high site fidelity and display limited movement. In Florida's Gulf of Mexico waters 9–72 cm TL fish were tagged and 95% of recaptures were found within 48.3 km of the original tagging site (Iversen and Tabb 1962). More recently, Hendon et al. (2002) reported similar findings in that 92% of recaptured spotted seatrout moved <10 km, 82% moved <3 km.

In the Atlantic, Music (1981) observed the vast majority of recaptures within the estuary of capture with a mean distance traveled of 8.9 km. In addition, genetic studies corroborate the findings of tagging studies with significant genetic differentiation among estuaries along the Atlantic coast (O'Donnell et al. 2014). There was some evidence of movement in and out of open sounds from creeks and rivers in fall and winter, and to beach habitat in spring and summer (Music 1981). While movement in and out of an estuary is reported range-wide in association with feeding, spawning, and avoidance of specific temperature or salinity conditions (Lorio and Perrett 1980; Johnson and Seaman 1986), seasonal movements out of Chesapeake Bay may be the only example of a true migration by any subpopulations of spotted seatrout (Mercer 1984; Wiley and Chapman 2003).

### ***Salinity***

Adult spotted seatrout are likely tolerant of seawater but less tolerant of freshwater.

### ***Substrate***

Adult spotted seatrout likely use a range of habitats including lower-estuary and nearshore beaches. However, adult substrate preferences have not been reported and throughout their range estuarine habitats likely vary (e.g., presence or absence of SAV) making a universal substrate designation unlikely. As with juveniles, SAV is likely preferred, but limiting in many estuaries.

### ***Temperature***

Experimental work on minimum temperatures in juvenile spotted seatrout are similar for adults (Anweiler et al. 2014), and as with other environmental parameters, estuarine or region specific preferences and tolerances should not be assumed to apply throughout the range.

### ***Dissolved Oxygen***

To date, no studies of DO requirements for adult spotted seatrout have been reported.

### ***Feeding Behavior***

Tabb (1961) reported Indian River, Florida spotted seatrout switching prey throughout the year based on prey availability, and consumed fishes include many common estuarine species (anchovies, pinfish, silverside, mullet, croaker, and others) (Johnson and Seaman 1986).

### ***Competition and Predation***

No studies of competition or predation of spotted seatrout were found.

## **Section II. Essential Fish Habitats and Habitat Areas of Particular Concern**

### ***Essential Fish Habitat***

Spotted seatrout are an estuarine fish, which relies heavily on SAV throughout all life stages. They also utilize shallow, soft bottom estuarine habitats as nurseries and as foraging and refuge habitats. Spotted seatrout are also known to use marine soft bottom habitat during summer and winter estuarine temperature extremes (ASMFC 2012).

### ***Identification of Habitat Areas of Particular Concern***

The ASMFC lists SAV as a HAPC for spotted seatrout (ASMFC 1984). Spotted seatrout are commonly found in SAV, but it is yet to be determined whether it is an EFH.

Environmental conditions in spawning areas may affect growth and mortality of egg and larvae, as sudden salinity reductions cause spotted seatrout eggs to sink, thus reducing dispersal and survival (Holt and Holt 2003).

Winter water temperature dynamics are of particular importance to habitat quality for spotted seatrout. Generally, spotted seatrout overwinter in estuaries, only moving to deeper channels or to nearshore ocean habitats in response to water temperatures below 10°C (Tabb 1966; ASMFC 1984). Sudden cold snaps have been found to stun and kill large numbers of spotted seatrout in estuarine habitats during winter (Tabb 1966; Perret et al. 1980; ASMFC 1984; Mercer 1984). These large mortality events are often associated with rapid declines (less than 12 h) in temperature, which numb fish before they can escape to warmer waters (Tabb 1958, 1966). It should be noted that cold stun events appear to have a large influence on spotted seatrout population dynamics and that cumulative degree day, which characterizes temperatures across time, are potentially more appropriate predictor of cold stress over large spatial scales (Ellis 2014). Periodic increases in mortality associated with cold stuns should be considered when implementing management measures as they are likely to continue to occur on a periodic basis and are largely unpredictable (NCDMF 2010).

### ***Present Condition of Habitat Areas of Particular Concern***

By nature, the extent of SAV coverage tends to fluctuate on a scale of days to decades, depending on species, physical conditions, and location (Fonseca et al. 1998). Globally, SAV habitat is declining. Rapid, large-scale SAV losses have been observed in the European Mediterranean, Japan, Chesapeake Bay, Florida Bay, and Australia (Orth et al. 2006). While threats to the stability of SAV health and distribution are many, water quality degradation, including nutrient enrichment and sediment loading, is the greatest threat (Orth et al. 2006). The impacts of nutrient enrichment and sediment loading, such as increased turbidity, increased epiphytic loads, and sedimentation, and increased concentrations of toxic hydrogen sulfide directly reduce SAV growth, survival, and production (Dennison et al. 1993; Fonseca et al. 1998; SAFMC 1998). The effects of eutrophication are most severe in sheltered, low flow areas with concentrated nutrient loads and large temperature fluctuations (Burkholder et al. 1994).

Once SAV habitat is lost, the associated sediments are destabilized, which can result in accelerated shoreline erosion and turbidity. These are conditions that are not favorable to vegetation recolonization and expansion in the affected area. SAV in adjacent areas may also be impacted by the resulting increase of turbidity in surrounding habitats, increasing the total area affected (Durako 1994; Fonseca 1996). Losses of SAV on much larger scales are particularly problematic because the rate of recovery through propagation, recolonization, etc. is often much slower than the rate of loss (Fonseca et al. 1998).

Nevertheless, recovery of SAV habitat may be possible with improvements to water quality as evidenced by the net gain of SAV acreage in Tampa Bay, Florida and Hervey Bay, Australia following strict water quality standards (Orth et al. 2006).

Dredging for navigational purposes, marinas, or infrastructure can directly impact SAV through large-scale removal or destruction of existing grass beds. Docks constructed over SAV and the associated shading can lead to the gradual loss of seagrass both beneath and adjacent to the structure (Loflin 1995; Shafer 1999; Florida Department of Environmental Protection, unpublished data). In addition to the impacts of shoreline development and dredging on SAV, the associated increase in boating activity can lead to increased prop scarring through vegetated areas. The propeller cuts leaves, shoots, and roots structures and makes a trench through the sediment. Recovery of SAV from prop scarring can take upwards of 10 years, depending on species and local conditions (Zieman 1976). Wakes associated with increased boating can lead to the destabilization of sediments, which, in turn, can increase turbidity and impact growth potential.

Use of bottom disturbing fishing gears also have the potential to damage or destroy vegetation. Although the damage from each gear varies in severity, shearing of leaves and stems, and uprooting whole plants are the most common impacts of bottom disturbing gears (ASMFC 2000). Shearing of leaves and stems does not necessarily result in mortality of seagrass, but in general, productivity is reduced (ASMFC 2000). Gears that result in below-ground disturbance may cause total loss of SAV and require months to years for the affected area to recover.

A newly emerging threat to SAV is the potential impacts of global climate change on this sensitive habitat. While climate change has occurred throughout history, the rate at which sea surface temperature, sea-level, and CO<sub>2</sub> concentrations are increasing is much faster than experienced in the last 100 million years (Orth et al. 2006). These changes may be occurring at a rate too fast to allow seagrass species to adapt. This leads to the potential for further large-scale losses of habitat globally. If SAV is indeed able to adapt to the pace of climate change, shoreline stabilization projects in many coastal areas impede the shoreward migration necessitated by rising sea-level (Orth et al. 2006). Additionally, the increased frequency and intensity of coastal storms and hurricanes, and the associated delivery of freshwater, nutrients, and sediments threaten to further degrade water quality in estuaries and coastal rivers, reducing the health and potential extent of SAV (Scavia et al. 2002; Orth et al. 2006).

### **Section III. Threats and Uncertainties**

#### ***Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Spotted Seatrout***

Though largely estuarine, spotted seatrout may move into marine environments during summer and winter estuarine temperature extremes (ASMFC 2012). Another concern for the conservation of this species is the loss of seagrasses, which are a primary habitat for spotted seatrout and can affect their distribution within estuaries.

#### ***Unknowns and Uncertainties***

The physiological tolerances of spotted seatrout to environmental variables (e.g., DO, temperature, salinity) have not been investigated throughout their range or at different life history stages. Without these data, it is difficult to predict the impact of environmental perturbations on spotted seatrout, which are necessary to sustainably manage this species. Unlike other sciaenids that are mobile, spotted

seatrout have high site fidelity. In addition, not much data is available regarding inter- and intra-specific competition, which will become an increasingly common problem as the extent of seagrasses declines (Orth et al. 2006). Future habitat loss is associated with anthropogenic factors (i.e., nutrient enrichment, boating, dredging, etc.) as well as climatic drivers (sea level rise, warming, acidification), which will increase environmental stressors on spotted seatrout populations. Pollution, including mercury, may have negative health effects on spotted seatrout (Adams et al. 2010), and an array of contaminants have been detected in this species (Johnson-Restrepo 2005; Adams et al. 2003; Adams and Paperno 2012).

## **Section IV. Recommendations for Habitat Management and Research**

### ***Habitat Management Recommendations***

As with spot, management recommendations for spotted seatrout have been highlighted by the Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout (ASFMC 2012):

1. To effectively maintain habitat health, HAPCs should be accompanied by minimization of non-point source and storm water runoff, prevention of significant increases in contaminant loadings, and prevention of the introduction of any new categories of contaminants into the area. Water quality should be monitored to ensure that quality standards are being met.
2. States should minimize loss of wetlands to shoreline stabilization, and monitor navigational dredging, bridge construction, dredged material disposal, and other coastal projects to minimize impact on HAPCs.
3. The use of any fishing gear that is determined by management agencies to have a negative impact on spotted seatrout habitat should be prohibited within HAPCs.
4. States should identify dams that threaten freshwater flows to nursery and spawning areas, and target them for appropriate recommendations during FERC re-licensing.
5. States should continue support for habitat restoration projects, including oyster shell recycling and oyster hatchery programs as well as seagrass restoration, to provide areas of enhanced or restored bottom habitat.

### ***Habitat Research Recommendations***

The following research needs were recommended by the Omnibus Amendment to the ISFMP for Spanish Mackerel, Spot, and Spotted Seatrout (ASFMC 2012):

1. Identify essential habitat requirements.
2. Identify unique spawning location.
3. Evaluate the role of SAV on the spawning success of spotted seatrout.
4. Develop water quality criteria for spawning and nursery areas.
5. Evaluate the role of shell hash and shell bottom in spotted seatrout recruitment, particularly where SAV is absent.

6. Expand nursery sampling to include critical habitat (SAV) sampling in high and low salinity areas during the months of July through September.
7. Investigate the relationship between temperature and mortality of adults and juveniles.
8. Define overwintering habitat requirements.

### **Literature Cited**

- Able, K. W. and M. P. Fahay. 2010. Ecology of Estuarine Fishes: Temperate Waters of the Western North Atlantic. Johns Hopkins University Press. Baltimore, MD.
- Adams, D. H., C. Sonne, N. Basu, R. Dietz, D. Nam, P. S. Leifsson and A. L. Jensen. 2010. Mercury contamination in spotted seatrout, *Cynoscion nebulosus*: An assessment of liver, kidney, blood, and nervous system health. Science of the Total Environment 408: 5808–5816.
- Adams, D. H., R. H. McMichael Jr. and G. E. Henderson. 2003. Mercury levels in marine and estuarine fishes of Florida 1989–2001. Florida Marine Research Institute Technical Reports. Florida Fish and Wildlife Conservation Commission. FMRI Technical Report TR-9.
- Adams, D. H. and R. Paperno. 2012. Stable isotopes and mercury in a model estuarine fish: Multibasin comparisons with water quality, community structure, and available prey base. Science of the Total Environment 414: 445–455.
- Anweiler, K. V., S. A. Arnott and M. R. Denson. 2014. Low-temperature tolerance of juvenile spotted seatrout in South Carolina. Transactions of the American Fisheries Society 143: 999–1010.
- ASMFC (Atlantic States Marine Fisheries Commission). 1984. Fishery Management Plan for Spotted Seatrout. Fisheries Management Report #4. pp. 101.
- ASMFC (Atlantic States Marine Fisheries Commission). 2012. Omnibus Amendment to the Interstate Fishery Management Plans for Spanish Mackerel, Spot, and Spotted Seatrout. pp. 18.
- Banks, M. A., G. J. Holt and J. M. Wakeman. 1991. Age-linked changes in salinity tolerance of larval spotted seatrout (*Cynoscion nebulosus*, Cuvier). Journal of Fish Biology 39: 505–514.
- Brown-Peterson, N. J., P. Thomas and C. Arnold. 1988. Reproductive biology of the spotted seatrout, *Cynoscion nebulosus*, in South Texas. Fishery Bulletin 86: 373–387.
- Burkholder, J. M., H. B. Glasgow Jr. and J. E. Cooke. 1994. Comparative effects of water-column nitrate enrichment on eelgrass *Zostera marina*, shoalgrass *Halodule wrightii*, and widgeongrass *Ruppia maritima*. Marine Ecology Progress Series 105: 121–138.
- Chester, A. J. and G. W. Thayer. 1990. Distribution of spotted seatrout (*Cynoscion nebulosus*) and gray snapper (*Lutjanus griseus*) juveniles in seagrass habitats of western Florida Bay. Bulletin of Marine Science 46: 345–357.

- Comyns, B. H., C. F. Rakocinski, M. S. Peterson and A. M. Shiller. 2008. Otolith chemistry of juvenile spotted seatrout *Cynoscion nebulosus* reflects local natal regions of coastal Mississippi, USA. *Marine Ecology Progress Series* 371: 243–252.
- Cowan Jr., J. H., R. S. Birdsong, E. D. Houde, J. S. Priest, W. C., Sharp and G. B. Mateja. 1992. Enclosure experiments on survival and growth of black drum eggs and larvae in lower Chesapeake Bay. *Estuaries* 15(3): 392–402.
- Crabtree, R. E. and D. H. Adams. 1998. Spawning and fecundity of spotted seatrout, *Cynoscion nebulosus*, in the Indian River Lagoon, Florida. *In: Investigations into nearshore and estuarine gamefish abundance, ecology, and life history in Florida (Project F-59)*. FWC-FMRI technical report to U.S. Fish and Wildlife Service, pp. 526–566.
- Daniel, L. B. III. 1988. Aspects of the biology of juvenile red drum, *Sciaenops ocellatus* and spotted seatrout, *Cynoscion nebulosus* (Pisces: Sciaenidae) in South Carolina. M.S. Thesis, College of Charleston, Charleston, SC. pp. 58.
- Deary, A. L. 2015. Ontogeny of the feeding apparatus and sensory modalities: Relationship to habitat differentiation among early life history stage drums (Sciaenidae) in the Chesapeake Bay. Ph.D. Dissertation, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA. 170 pp.
- Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. W. Bergstrom and R. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. *Bioscience* 43: 86–94.
- Dorval, E., C. M. Jones, R. Hannigan and J. van Montfrans. 2005. Can otolith chemistry be used for identifying essential seagrass habitats for juvenile spotted sea trout, *Cynoscion nebulosus*, in Chesapeake Bay? *Marine and Freshwater Research* 56: 645–653.
- Dorval, E., C. M. Jones, R. Hannigan and J. van Montfrans. 2007. Relating otolith chemistry to surface water chemistry in a coastal plain estuary. *Canadian Journal of Fisheries and Aquatic Sciences* 64: 411–424.
- Durako, M. J. 1994. Seagrass die-off in Florida Bay (USA): changes in shoot demographic characteristics and population dynamics in *Thalassia testudinum*. *Marine Ecology Progress Series* 110: 59–66.
- Ellis, T. A. 2014. Mortality and movement of spotted seatrout at its northern latitudinal limits. Ph.D. dissertation. North Carolina State University, Raleigh, NC. pp. 260.
- Fable, Jr., F. A., T. D. Williams and C. R. Arnold. 1978. Description of reared eggs and young larvae of the spotted seatrout, *Cynoscion nebulosus*. *Fishery Bulletin* 76: 65–71.
- Fonseca M. S., W. J. Kenworthy and G. W. Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. Silver Spring, MD: National Oceanographic and Atmospheric Administration. NOAA Coastal Ocean Program Decision Analysis Series No 12. pp. 222.
- Gray, J. D., T. L. King and R. L. Colura. 1991. Effects of temperature and hypersalinity on hatching success of spotted seatrout eggs. *The Progressive Fish-Culturist* 53: 81–84.

- Hendon, J. R., J. R. Warren, J. S. Franks and M. V. Buchanan. 2002. Movements of spotted seatrout (*Cynoscion nebulosus*) in Mississippi coastal waters based on tag-recapture. *Gulf of Mexico Science* 20: 91–97.
- Holt, G. J. and S. A. Holt. 2003. Effects of variable salinity on reproduction and early life stages of spotted seatrout. *In: Bortone S. A. (ed). Biology of the Spotted Seatrout*. CRC Press, Boca Raton, FL. pp. 135–145.
- Holt, G. J. and S. A. Holt. 2000. Vertical distribution and the role of physical processes in the feeding dynamics of two larval sciaenids *Sciaenops ocellatus* and *Cynoscion nebulosus*. *Marine Ecology Progress Series* 193: 181–190.
- Holt, G. J., S. A. Holt and C. R. Arnold. 1985. Diel periodicity of spawning in sciaenids. *Marine Ecology Progressive Series* 27: 1–7.
- Ihde, T. F. 2000. Biology of the spotted seatrout, *Cynoscion nebulosus*, in the Chesapeake Bay region. M.S. Thesis, College of William and Mary, Williamsburg, VA. pp. 121.
- Iverson, E. S. and D. C. Tabb. 1962. Subpopulations based on growth and tagging studies of spotted seatrout, *Cynoscion nebulosus*, in Florida. *Copeia* 3: 544–548.
- Johnson, D. R. and W. Seaman Jr. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (south Florida)—spotted seatrout. U.S. Fish Wildlife Service Biological Report 82(11.43). U.S. Army Corps of Engineers, TR EL-82-4. pp. 18.
- Johnson-Restrepo, B., K. Kannan, R. Addink and D. H. Adams. 2005. Polybrominated diphenyl ethers and polychlorinated biphenyls in a marine foodweb of coastal Florida. *Environmental Science and Technology* 39: 8243–8250.
- Jones, C. M. 2013. Can we predict the future: juvenile finfish and their seagrass nurseries in the Chesapeake Bay. *ICES Journal of Marine Science* doi:10.1093/icesjms/fst142.
- Kucera, C. J., C. K. Faulk and G. J. Holt. 2002. The effect of spawning salinity on eggs of spotted seatrout (*Cynoscion nebulosus*, Cuvier) from two bays with historically different salinity regimes. *Journal of Experimental Marine Biology and Ecology* 272: 147–158.
- Loflin, R. K. 1995. The effects of docks on seagrass beds in the Charlotte Harbor estuary. *Florida Scientist* 58(2): 198–205.
- Lorio, W. J. and W. S. Perret. 1980. Biology and ecology of the spotted seatrout (*Cynoscion nebulosus* Cuvier). *In: Proceedings: Colloquium on the Biology and Management of Red Drum and Seatrout*. Gulf States Marine Fisheries Commission Publication Number 5. Ocean Springs, Mississippi. pp. 7–14.
- Lorio, W. J. and H. E. Schafer. 1966. A food habit study of the spotted seatrout, *Cynoscion nebulosus*, in the Biloxi Marsh Area, Louisiana. *Proceedings of the Annual Conference of the Southeastern Game and Fisheries Commission* 19: 289–296.



- Luczkovich, J. J., R. C. Pullinger, S. E. Johnson and M. W. Sprague. 2008. Identifying sciaenid critical spawning habitats by the use of passive acoustics. *Transactions of the American Fisheries Society* 137: 576–605.
- Lyczkowski-Shultz J. and J. P. Steen. 1991. Diel vertical distribution of red drum (*Sciaenops ocellatus*) larvae in the northcentral Gulf of Mexico. *Fishery Bulletin* 89: 631–641.
- McMichael Jr., R. H. and K. M. Peters. 1989. Early life history of spotted seatrout *Cynoscion nebulosus* (Pisces: Sciaenidae) in Tampa Bay, Florida. *Estuaries* 12: 98–110.
- Mercer, L. P. 1984. A biological and fisheries profile of spotted seatrout, *Cynoscion nebulosus*. Morehead City, NC: North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries. Special Scientific Report No 40. pp. 87.
- Music, J. L. J. 1981. Seasonal movement and migration of Spotted Seatrout (*Cynoscion nebulosus*). *Estuaries* 4(3): 280–280.
- NCDMF (North Carolina Division of Marine Fisheries). 2010. A Social and Economic Survey of Recreational Saltwater Anglers in North Carolina. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries.
- O'Donnell, T. P., M. R. Denson and T. L. Darden. 2014. Genetic population structure of spotted seatrout *Cynoscion nebulosus* along the south-eastern U.S.A. *Journal of Fish Biology* 85: 374–393.
- Olney, J. E. and G. W. Boehlert. 1988. Nearshore ichthyoplankton associated with seagrass beds in the lower Chesapeake Bay. *Marine Ecology Progress Series* 45: 33–43.
- Orth, R. J., T. J. B. Carruthers, W. C. Dennison, C. M. Duarte, J. W. Fourqurean, K. L. Heck Jr., A. R. Hughes, G. A. Kendrick, W. J. Kenworthy, S. Olyarnik, F. T. Short, M. Waycott and S. L. Williams. 2006. A global crisis for seagrass ecosystems. *Bioscience* 56(12): 987–996.
- Perret, W. S., J. E. Weaver, R. O. Williams, P. L. Johansen, T. D. McIlwain, R. C. Raulerson and W. M. Tatum. 1980. Fishery profiles of red drum and spotted seatrout. Ocean Springs, MS: Gulf States Marine Fisheries Commission. Report No 6. pp. 60.
- Powell, A. B. 2003. Larval abundance, distribution, and spawning habits of spotted seatrout (*Cynoscion nebulosus*) in Florida Bay, Everglades National Park, FL. *Fishery Bulletin* 101: 704–711.
- Powell, A. B., R. T. Cheshire, E. H. Laban, J. Colvocoresses, P. O'Donnell and M. Davidian. 2004. Growth, mortality, and hatchdate distributions of larval and juvenile spotted seatrout (*Cynoscion nebulosus*) in Florida Bay, Everglades National Park. *Fishery Bulletin* 102: 142–155.
- Purcell, J. E. 1985. Predation on fish eggs and larvae by pelagic cnidarians and ctenophores. *Bulletin of Marine Science* 37: 739–755.
- Purtlebaugh, C. H. and M. S. Allen. 2010. Relative abundance, growth, and mortality of five age-0 estuarine fishes in relation to discharge of the Suwannee River, Florida. *Transactions of the American Fisheries Society* 139: 1233–1246.

- Rooker, J. R., S. A. Holt, M. A. Soto and G. J. Holt. 1998. Postsettlement patterns of habitat use by sciaenid fishes in subtropical seagrass meadows. *Estuaries* 21(2): 318–327.
- Roumillat, W. A. and M. C. Brouwer. 2004. Reproductive dynamics of female spotted seatrout (*Cynoscion nebulosus*) in South Carolina. *Fishery Bulletin* 102(3): 473–487.
- Rutherford, E. S., T. W. Schmidt and J. T. Tilmant. 1989. Early life history of spotted seatrout (*Cynoscion nebulosus*) and gray snapper (*Lutjanus griseus*) in Florida Bay, Everglades National Park, Florida. *Bulletin of Marine Science* 44: 49–64.
- Saucier, M. H. and D. M. Baltz. 1993. Spawning site selection by spotted seatrout, *Cynoscion nebulosus*, and black drum, *Pogonias cromis*, in Louisiana. *Environmental Biology of Fishes* 36: 257–272.
- Scavia D., J. C. Field, D. F. Boesch, R. W. Buddemeier, V. Burkett, D. R. Cayan, M. Fogarty, M. A. Harwell, R. W. Howarth, C. Mason, D. J. Reed, T. C. Royer, A. H. Sallenger and J. G. Titus. 2002. Climate change impacts on U.S. coastal and marine ecosystems. *Estuaries* 25(2): 149–164.
- Smith, N. G., C. M. Jones and J. van Montfrans. 2008. Spatial and temporal variability of juvenile spotted seatrout *Cynoscion nebulosus* growth in Chesapeake Bay. *Journal of Fish Biology* 73: 597–607.
- Street M. W., A. S. Deaton, W. S. Chappell and P. D. Mooreside. 2005. North Carolina Coastal Habitat Protection Plan. Morehead City, NC: North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries. pp. 656.
- Tabb, D. C. 1958. Differences in the estuarine ecology of Florida waters and their effect on populations of spotted weakfish, *Cynoscion nebulosus* (Cuvier and Valenciennes). *Proceedings of the North American Wildlife Conference* 23: 392–401.
- Tabb, D. 1961. A contribution to the biology of the spotted sea trout, *Cynoscion nebulosus*, in East Central Florida. *Florida State Board of Conservation Technical Series* 35: 1–23.
- Tabb, D. C. 1966. The estuary as a habitat for spotted seatrout (*Cynoscion nebulosus*). *American Fisheries Society Special Publication* No. 3: 59–67.
- Taniguchi, A. K. 1981. Survival and growth of larval spotted seatrout (*Cynoscion nebulosus*) in relation to temperature, prey abundance and stocking densities. *Rapports et Proces-Verbaux Reunions. International Council for Exploration of the Sea* 178: 507–508.
- Tayloe, W. B. and F. S. Scharf. 2006. Age, growth, and feeding habits of spotted seatrout (*Cynoscion nebulosus*) in the lower Cape Fear River [poster]. *In: Tidewater Chapter (AFS) Annual Meeting; February 2006; Atlantic Beach, NC.*
- Wenner, C. A., W. A. Roumillat, J. R. Moran, Jr., M. B. Maddox, L. B. Daniel, III and J. W. Smith. 1990. Investigations on the life history and population dynamics of marine recreational fishes in South Carolina. *Marine Resources Research Institute. SC Department of Natural Resources, F-37. Charleston, SC.*

Wiley, B. A. and R. W. Chapman. 2003. Population structure of spotted seatrout, *Cynoscion nebulosus*, along the Atlantic coast of the U.S. *In*: S. A. Bortone (ed) *Biology of Spotted Seatrout*, pp. 31–40. CRC Press, Boca Raton, FL. pp. 312.

Zieman, J. C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. *Aquatic Botany* 2: 127–139.

## CHAPTER 7: WEAKFISH

Populated from [Amendment IV to the Weakfish FMP \(2002\)](#)

### **Section I. General Description of Habitat**

Weakfish are another sciaenid species that uses a variety of coastal and estuarine habitats throughout their life. Although spawning may take place closer to estuaries or in lower estuaries (as opposed to offshore), larval weakfish recruit to upper estuarine habitats but move down the estuary as they grow. Much work has been done on juvenile weakfish, particularly with respect to hypoxia, and like other sciaenids, weakfish exhibit a complex relationship with DO concentrations. Adults often move out of estuaries and spawn in nearshore habitats. Unlike other sciaenids, weakfish exhibit natal homing behaviors.

### **Part A. Spawning Habitat**

#### ***Geographic and Temporal Patterns of Migration***

The vast majority of age-1 weakfish are mature (Lowerre-Barbieri et al. 1996a; Nye and Targett 2008) and begin spawning in late winter in the south and progressively later in the spring in northern estuaries. Spawning typically peaks in May and June, and ends in the late summer, though temporal variability in eggs and larvae have been observed that suggest either multiple spawning peaks (Goshorn and Epifanio 1991) or an annual shift in peaks (Lowerre-Barbieri et al. 1996b). Regardless of the variability, weakfish are considered to have a protracted spawning period consisting of several months in most locations, with multiple reports of spawning (inferred from drumming) taking place in the evening (Connaughton and Taylor 1995; Luczkovich et al. 2008).

Spawning activities occur near the coast or within estuaries, many of which are natal estuaries (or adjacent estuaries) (Thorrold et al. 1998; 2001). In Delaware Bay, inshore, midwater, and offshore sites (all <6 km from shore) have reported spawning-associated drumming from mid-May to late-July (Connaughton and Taylor 1995). The drumming suggests the presence of large spawning aggregations in shallow waters earlier in the spawning season, with midwater and offshore drumming activity increasing later in the spawning season. It was hypothesized that the spawning aggregates were not just moving as a function of time, but as a function of increasing inshore temperatures, and that spawning may have continued past July in deeper waters than the study examined.

The spawning period in North Carolina is longer and begins in March and continues to September (Merriner 1976). This has led to clinal variability in life histories and reproduction (Shepherd and Grimes 1984). Weakfish that spawn in southern locations live shorter lives and reproduce at smaller sizes compared to weakfish living in northern locations. Shepherd and Grimes (1984) interpret this as 'bet hedging' (Stearns 1976) against cold spring waters that prevent weakfish egg from hatching. That is, northern weakfish have longer lives and more annual reproductive events because northern bays are more temperature variable, whereas southern bays are warm enough to ensure hatching. Unique spatial life histories combined with the strong evidence for natal homing suggests that while habitat for

spawning and other life stages may be variable, spatial structuring exists, and estuary-specific habitat use and preference may be more important population-level structuring.

### ***Salinity***

Lower estuary and coastal spawning habitats experience moderate to high salinities. No studies have explicitly investigated salinity in relation to spawning habitat; however some studies have reported salinity values during inferred spawning events. Luczkovich et al. (1999) reported mean salinity to be 28.8 ppt (range 15.1–34.7 ppt). Another study found that weakfish were commonly heard in higher salinity habitats (mean 15.4 ppt, range 7.8–28.3 ppt).

### ***Substrate***

Although depth is considered an important spawning habitat variable (Luczkovich et al. 2008), no studies report on spawning habitat substrate. Additionally, weakfish eggs are pelagic and thus substrate and bottom features are considered minimally important during and after spawning.

### ***Temperature***

Photoperiod and temperature are thought to drive seasonal maturation (Epifanio et al. 1988), along with the hypothesized avoidance of cooler spring temperatures that pose a mortality threat to larval and juvenile weakfish (Shepherd and Grimes 1984). Luczkovich et al. (1999) reported weakfish drumming in a mean temperature of 20.7°C (range 19.1–22.6°C); another study reported bottom temperatures associated with weakfish drumming to average 25.3°C (range 17–31°C) (Luczkovich et al. 2008).

### ***Dissolved Oxygen***

DO is not well reported in adult and spawning weakfish, and based on spawning locations (deep estuaries and nearshore) low DO and hypoxic conditions are likely rare. Luczkovich et al. (2008) did measure bottom and surface DO and reported means of 7.9 and 7.6 mg L<sup>-1</sup>, respectively. In the same study, only one sonobuoy reported any drumming noises at <4.0 mg L<sup>-1</sup> DO, although other sciaenids (spotted seatrout and silver perch) both exhibited spawning-associated noises at low DO, even hypoxic conditions.

### ***Feeding Behavior***

No studies have reported the feeding habits of spawning weakfish, though it might be safely inferred that adult feeding habits apply to spawners, particularly because the duration of the spawning season suggests that spawning is integrated into their adult lives, rather than a small, discrete period of time that may necessitate a different foraging strategy.

### ***Competition and Predation***

No studies have examined competition or predation on spawning weakfish, though it might be inferred that adult competition and predation descriptions apply to spawning adults. Adults are commonly preyed on by bluefish and other estuarine predatory fishes.

## **Part B. Egg Habitat**

Nursery habitats are those areas in which larval weakfish reside or migrate after hatching until they reach sexual maturity (90% by age 1, 100% by age 2). These areas include the nearshore waters as well as the bays, estuaries, and sounds to which they are transported by currents and hatch.

### ***Geographic and Temporal Patterns of Migration***

Mature weakfish spawn in the nearshore ocean and lower reaches of large east coast estuaries. Egg hatching occurs about 36–40 h post-fertilization (Welsh and Breder 1923) at 20–21°C. Spawning begins in the southern region of the distribution (e.g., North Carolina) early in the spring (March; Merriner 1976) and later in northern bays and estuaries. Because spawning can continue into the summer (July in the Mid Atlantic Bight) (Berrien and Sibunka 1999) and there are reports of two peaks in spawning (Delaware Bay: Thomas 1971; Goshorn and Epifanio 1991), it is likely that weakfish eggs experience a range of conditions and that local adaptation may influence differences in latitudinal environments. Additionally, Berrien et al. (1978) report weakfish larvae occurring from nearshore waters to 70 km offshore, suggesting that eggs may be found over a wide geographic area that extends away from the coast.

### ***Salinity***

Olney (1983) noted a distinct polyhaline distribution of sciaenid eggs, with high concentrations at the mouth of the Chesapeake Bay. Although he was not able to identify the eggs to the species level, the large number of eggs collected and the timing of collection strongly suggest that weakfish eggs were present, if not a substantial percentage of the sample. Olney (1983) reported that sampling across a range of salinities (11–31 ppt) resulted in 84% of sciaenid eggs collected in salinities >26 ppt. The Chesapeake Bay Weakfish and Spotted Seatrout Fishery Management Plan (Chesapeake Bay Program 1990) reports fertilized eggs collected between 12.1 and 31.3 ppt.

### ***Substrate***

Like many marine fish eggs, weakfish eggs are buoyant and the entire egg phase takes place in the pelagic zone of nearshore or lower estuarine waters, and thus substrate is not likely encountered.

### ***Temperature***

Minimum temperature is likely the main driver of weakfish reproduction and thus a necessary condition for egg development. Harmic (1958) reported a range of 12–16°C necessary for successful hatching; however, weakfish eggs have been collected across a range of temperatures (17–26.5°C) (Chesapeake Bay Program 1990), which likely reflects their broad geographic occurrence.

### ***Dissolved Oxygen***

DO is probably not an issue for short-lived weakfish eggs that remain buoyant and pelagic, and thus out of hypoxic and anoxic bottom waters. However, Harmic (1958) reported reduced hatching success at DO <4.3 mg L<sup>-1</sup>.

### ***Feeding Behavior***

Weakfish eggs subsist entirely off the yolk sac prior to hatch.

### ***Competition and Predation***

Weakfish eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the offshore conditions). Predation of eggs undoubtedly occurs and is likely dominated by gelatinous zooplankton (Purcell 1985; Olney and Boehlert 1988; Cowan et al. 1992). Although potentially large numbers of eggs are killed from predation, there is no initial reason to think that pelagic oceanic predators are targeting weakfish eggs over other, similar pelagic eggs.

## **Part C. Larval Habitat**

Nursery habitats are those areas in which larval weakfish reside or migrate after hatching until they reach sexual maturity (90% by age 1, 100% by age 2). These areas include the nearshore waters as well as the bays, estuaries, and sounds to which they are transported by currents or in which they hatch.

### ***Geographic and Temporal Patterns of Migration***

Weakfish larvae are widely distributed and have been reported from nearshore waters to 70 km offshore (Berrien et al. 1978), as well as throughout estuaries. Wherever eggs hatch, larvae spend approximately three weeks moving toward or up estuaries. In both Delaware and Chesapeake Bays, larvae have been sampled throughout the estuary, suggesting relatively quick and even post-hatch dispersal, or substantial within-estuary reproduction. Additionally, the protracted spawning season, taking place over months in many locations, provides a constant source of larvae to estuarine habitats. Olney (1983) found weakfish larvae distributed throughout the lower Chesapeake Bay. Ribeiro et al. (2015) identified weakfish as a component of the summer larval fish assemblage in the York River estuary of the Chesapeake Bay.

Larval weakfish migration has been an active area of research. Rowe and Epifanio (1994a) report that in Delaware Bay larvae were more abundant at depth (2 and 7 m off the bottom) than at surface. They report no effect of tidal stage on yolk sac larvae, but greater abundance of post-yolk sac larvae during flood tide, suggesting that post-yolk sac may use selective tidal stream transport to migrate into upper estuarine regions. Rowe and Epifanio (1994b) report mean larval flux to be greater during flood phase for all early and late stage larvae, but not for yolk sac larvae. Together, these studies suggest that while yolk sac larvae are passively transported as part of general sub-tidal circulation, post-yolk sac larvae use selective tidal stream transport to migrate up estuaries.

### ***Salinity***

Owing to the wide distribution of weakfish larvae, a range of salinities is likely tolerated. In the lower Chesapeake Bay, Olney (1983) reported salinities during larval weakfish sampling to range from 11.2 to 31.5 ppt. Rowe and Epifanio (1994a) report salinities of migrating larvae to be 20.1–27.8 ppt.

### ***Substrate***

Larval weakfish are planktonic (Welsh and Breder 1923) and thus do not come in contact with the substrate over which they are dispersed.

### ***Temperature***

As with salinity, both Olney (1983) and Rowe and Epifanio (1994a) provide similar temperature ranges for larval weakfish, with a range of 18.1–28.1°C and 16.8–22.9°C, respectively.

### ***Dissolved Oxygen***

Due to the relatively short larval duration, the pelagic habitat, and the migratory behaviors of weakfish larvae, it is unlikely that they encounter any habitats in which DO imposes a limitation or threat currently.

### **Feeding Behavior**

A number of studies have investigated the feeding behaviors of larval weakfish, both in laboratory settings as well as in the field. Goshorn and Epifanio (1991) found that larval weakfish began exogenous feeding 2 days post hatch at 20°C and that invertebrate eggs and tintinnids were important prey (larvae <0.5 mm notochord length, NL). Polychaete larvae were important for all size classes and dominant in weakfish >3.55 mm NL. Small copepods (*Acartia tonsa*) were also important for all weakfish larvae, but dominant at sizes >7.55 mm NL.

### **Competition and Predation**

Little work has looked at competition and predation of larval weakfish. Some competition likely takes place when a high-density larval patch settles on limited habitat; however, the wide range of settled habitats and protracted spawning season suggest that widespread competition is unlikely. Furthermore, work on natal homing (Thorrold et al. 1998; 2001) suggests that adult weakfish return to natal estuaries to spawn, adding a level of population structure to mitigate against widespread competition.

No studies have explicitly reported on predation of larval weakfish, although larvae are likely subject to predation by a range of estuarine predators. Cowan et al. (1992) examined hydromedusa (*Nemopsis bachei*) and ctenophore (*Mnemiopsis leidyi*) predation on black drum, suggesting that high densities of hydrozoans could impact larval weakfish abundance.

## **Part C. Juvenile Habitat**

Juvenile weakfish inhabit deeper waters of bays, estuaries, and sounds, including their tributary rivers. They also use the nearshore Atlantic Ocean as nursery areas. In North Carolina and other states, juveniles are associated with sand or sand/seagrass bottom. They feed initially on zooplankton, switching to mysid shrimp and anchovies as they grow. In Chesapeake and Delaware Bays, they migrate to the Atlantic Ocean by December.

### **Geographic and Temporal Patterns of Migration**

The general pattern of habitat use by juvenile weakfish is estuarine-wide, but often beginning in late spring and early summer in upper estuarine habitats (or even freshwater) (Massman 1954) and moving down estuary during the fall to nearshore habitats.

Able et al. (2001) found high abundance of weakfish in June throughout Delaware Bay tidal creeks, and the large numbers of fish were attributed somewhat to high recruitment and that higher abundances were observed in upper bay sites over lower bay sites. Paperno et al. (2000) also reported that juvenile weakfish recruited to all parts of Delaware Bay, but higher abundances were observed in lower salinities. Higher temperature and lower salinity habitats are preferred by juveniles early in the season or for earlier cohorts (Lankford and Targett 1994).

In the York River, Virginia, juveniles were caught in spring and summer, to which Chao and Musick (1977) attributed water temperature and DO as the most important factor driving distribution. Weakfish were abundant in late summer and fall with age 1 fish returning in the spring but young-of-year individuals absent until late summer. Inshore and nearshore of the Chesapeake Bay, a pattern of similar habitat use in early and late summer was discovered when comparing inner continental shelf and estuarine habitats, with an expected strong shift to inner continental shelf habitat use over estuary by fall (Woodland et al. 2012). Growth rates between habitats were similar, suggesting no growth



advantage in either habitat, but in late summer larger fish were concentrated in the inner continental shelf while smaller fish were in estuary. Pincin et al. (2014) examined weakfish abundance in coastal Maryland bays and found no effect of seagrass and Olney and Boehlert (1988) observed that larval weakfish are rare in seagrass sites.

### **Salinity**

Juvenile weakfish salinity preferences likely increase with size and age and is broad since weakfish use oligohaline to polyhaline habitats throughout the first year of life. Lankford and Targett (1994) found salinity effects on specific growth rates and gross growth efficiencies were optimal 20 ppt for 40–50 mm fish. Feeding rate was significantly higher at 5 ppt than at 19 ppt salinity.

### **Substrate**

Weakfish are pelagic predators (Chao and Musick 1977; Horodysky et al. 2008) that are not expected to interact with the benthos so substrate type is not an ecologically important environmental variable for weakfish.

### **Temperature**

Juvenile weakfish likely tolerate a wide range of temperatures, though temperature is considered to be an important variable driving their distribution. Although temperature has been documented in a number of descriptive studies, Lankford and Targett (1994) examined temperature effects on specific growth rates and gross growth efficiencies, and found significant effects at 27 and 29°C treatments. Overall, mean feeding rates increased with increasing temperature (from experimental treatments of 20–28°C).

### **Dissolved Oxygen**

A relatively large body of research has been done on the effects of DO levels on juvenile weakfish. Tyler and Targett (2007) reported low weakfish densities in early morning (during diurnal hypoxic conditions) but relatively high weakfish densities later in the day and an avoidance threshold of 2.0 mg L<sup>-1</sup>. A lower threshold of avoidance (<1.4 mg L<sup>-1</sup> DO) was reported for hypoxia-acclimated fish (Brady and Targett 2013), supporting the idea that not only are these fish less inclined to swim to avoid hypoxia, but they can tolerate lower levels than fish that have never been exposed to hypoxia. Stierhoff et al. 2009 reported avoidance of low DO ( $\leq 1$  mg L<sup>-1</sup>), but no preference to DO levels > 2.0mg L<sup>-1</sup>, suggesting weakfish are tolerant of low DO conditions.

### **Feeding Behavior**

Juvenile weakfish experience ontogenetic diet shifts (Chao and Musick 1977; Nemerson and Able 2004; Deary 2015). In the Delaware Bay, mysid shrimp (*Neomysis americana*) dominated the diet (Grecay and Targett 1996a). Larger juvenile weakfish (67–183 mm) in the Chesapeake Bay consumed bay anchovy (*Anchoa mitchilli*) and mysid shrimp (*N. americana*) (Chao and Musick 1977), which highlights the transition from mysids to fish (piscivory) around 60 mm TL (Thomas 1971).

### **Competition and Predation**

Due to the wide spatial distribution and extended temporal period of recruiting juvenile weakfish, it is unlikely that any large-scale competitive factors drive the population. Annual fluctuations in recruitment and micro-scale habitat and foraging competition probably result in patches of competition. Forage items are typically not limited, though in years of low prey abundance (and high turbidity) (Grecay and Targett 1996b) competition may result in decreased growth rates for less fit individuals.

Juvenile weakfish are likely preyed upon opportunistically by a range of estuarine and nearshore predators (fishes); however, Mancini and Able (2005) report silver perch and bluefish as the main documented predators. Large predators are typically less abundant or absent in oligotrophic, upper estuarine areas, yet as temperatures increase in summer, the interactions of temperature and salinity result in a suboptimal physicochemical environment (Lankford and Targett 1994; Lankford and Targett 1997).

#### **Part D. Adult Habitat**

Adult weakfish reside in estuarine and nearshore Atlantic Ocean habitats. Warming of coastal waters in the spring cues inshore migration and northward from the wintering grounds to bays, estuaries, and sounds. Larger fish move inshore first and tend to congregate in the northern part of the range. Catch data from commercial fisheries in Chesapeake and Delaware Bays and Pamlico Sound indicate that the larger fish are followed by smaller weakfish in summer. Shortly after their initial spring appearance, weakfish return to the larger bays and nearshore ocean to spawn. In northern areas, a greater portion of the adults spend the summer in the ocean rather than estuaries.

Weakfish form aggregations and move offshore as temperatures decline in the fall. They move generally offshore and southward. The continental shelf from Chesapeake Bay to Cape Lookout, North Carolina appears to be the major wintering ground at depths of 18–55 m. Some weakfish remain in inshore waters from North Carolina southward.

#### ***Geographic and Temporal Patterns of Migration***

After juvenile weakfish overwinter in offshore environments, the vast majority (>90%) mature during their second year of life (age-1). The general pattern of adult habitat use is considered to be seasonal migrations south (toward Cape Hatteras, North Carolina) and offshore in fall and winter, and north and inshore during spring and summer (Able and Fahay 2010). Summer inshore habitats are shallow, averaging around 17 m, while offshore winter habitats average 59 m, but include depths up to 159 m (Able and Fahay 2010).

Off the New Jersey coast in the summer, weakfish occurred primarily inshore in shallow strata in coastal New Jersey (the Navesink River) during the summer. Tagged weakfish left the estuary when temperatures were above 28°C and when freshwater discharge was low ( $<2 \text{ m}^3 \text{ s}^{-1}$ ). Smaller weakfish were more like to have longer overall residence times, although even large individuals (>400 mm TL) demonstrated estuarine habitat use  $\geq 40$  d (with some >60 d residence). These tagged weakfish were also found to leave the estuary when temperatures decreased below 23°C. Thorrold et al. (1998; 2001) concluded that 60–81% of weakfish exhibit estuarine fidelity as adults, despite the fact that the same fish from across the eastern U.S. were genetically panmictic.

#### ***Salinity***

Adult weakfish occur primarily in nearshore or lower estuarine habitats where salinities are near full seawater. In a review of weakfish, Mercer (1989) report that adults were collected in salinities ranging from 6.6–32.3 ppt. Adult weakfish prefer higher salinities when inhabiting estuaries in the summer; Rountree and Able (1992) sampled adults in 22–32 ppt shallow sub- and intertidal marsh creeks in New Jersey. As with other habitat variables, salinity is probably tolerated at variable levels reflected in the variety of inshore and nearshore habitats populated by adult weakfish.

### ***Substrate***

In accordance with the variety of habitats used by adults, specific habitat use or habitat preference in adult weakfish has not been reported. Able and Fahay (2010) report the use of sandy or muddy substrates by adults in bays and estuaries, but substrates used are likely as variable as the overall habitats in which adult weakfish are found. In addition, weakfish are pelagic, open water foragers (Chao and Musick 1977; Horodysky et al. 2008), therefore substrate is not a significant environment variable.

### ***Temperature***

Temperature is likely a major driving in development of reproductive tissue and spawning behaviors in weakfish, though it is still an important habitat factor among resting (not reproductively active) adults. Weakfish have been captured in a wide range of temperatures (Mercer 1989). Contemporary studies of weakfish temperature occurrence or preference are lacking, likely due to their wide distribution, inferred tolerance for a range of temperatures, and the relatively high effort put into studying juvenile weakfish habitat. Temperatures above 28°C but below 23°C resulted in the egress of adult weakfish from coastal estuaries (Wuenschel et al. 2014).

### ***Dissolved Oxygen***

Adult weakfish likely experience normoxic conditions, as they typically avoid the upper estuary reaches inhabited by juvenile weakfish where hypoxia is most commonly reported. Without any explicit studies of adult weakfish DO tolerances or preferences, such values might be estimated from the extensive body of work conducted on juvenile weakfish. Later stage juvenile weakfish may have physiologies (and subsequent tolerances) similar to adults.

### ***Feeding Behavior***

Adult weakfish feed primarily between dawn and dusk on clupeid species, anchovies, blue crabs, and spot (Mercer 1989). More recent work has supported piscivory as the main adult weakfish feeding mode, but also note crustaceans, mollusks, shrimp, squid, and other common estuarine prey (Able and Fahay 2010). Overall diets vary in proportion to available prey but adult diets are relatively stable from June to October (Wuenschel et al. 2013).

### ***Competition and Predation***

Competition among adult weakfish is not well known. Silver perch and bluefish are commonly cited as the primary predators (Mancini and Able 2005), though predation of larger adults likely decreases with size and may include occasional larger coastal predators. Weakfish were consumed by summer flounder, bluefish, and other weakfish (Wuenschel et al. 2013). The same study noted that by October, summer flounder and bluefish predation was extensive (~25%).

## **Section II. Essential Fish Habitats and Habitat Areas of Particular Concern**

### ***Essential Fish Habitat***

Habitats used by weakfish include spawning sites in coastal bays, sounds, and the nearshore Atlantic ocean, as well as nursery areas including the upper and lower portions of the rivers and their associated bays and estuaries (ASMFC 2002).

### ***Identification of Habitat Areas of Particular Concern***

There is no HAPC designation for weakfish.

### ***Present Condition of Habitat Areas of Particular Concern***

The quality of weakfish habitats has been compromised largely by impacts resulting from human activities. It is generally assumed that weakfish habitats have undergone some degree of loss and degradation; however, few studies quantify the impacts in terms of the area of habitat lost or degraded.

Loss due to water quality degradation is evident in the northeast Atlantic coast estuaries. The New York Bight is one example of an area that has regularly received deposits of contaminated dredged material, sewage sludge, and industrial wastes. These deposits have contributed to oxygen depletion and the creation of large masses of anoxic waters during the summer months.

Some losses have likely occurred due to the intense coastal development that has taken place during the last several decades, although no quantification has been done. Losses have likely resulted from dredging and filling activities that have eliminated shallow water nursery habitat.

Further functional losses have likely occurred due to water quality degradation from point and non-point source discharges. Intensive conversion of coastal wetlands to agricultural use also contributed to the functional loss of weakfish nursery area habitat. Other functional loss of riverine and estuarine areas may have resulted from changes in water discharge patterns due to withdrawals or flow regulation. Estuarine nursery areas for weakfish, as well as adult spawning and pre-spawning staging areas, may be affected by prolonged extreme conditions from inland water management practices.

Power plant cooling facilities continue to impact weakfish populations. The Environmental Protection Agency (EPA) estimates the number of age 1 weakfish lost as a result of entrainment at all transition zone cooling water intake structures in the Delaware Bay is over 2.2 million individuals. Other threats stem from the continued alteration of freshwater flows and discharge patterns to spawning, nursery, and adult habitats in rivers and estuaries. Additional threats arise from placement of additional municipal water intakes in spawning and nursery areas, although the impacts may be mitigated to some degree with proper screening (ASMFC 2002).

### **Section III. Threats and Uncertainties**

#### ***Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Weakfish***

The following is taken from Amendment IV to the Weakfish FMP, Section 1.4.2:

Habitat loss due to water quality degradation is evident in the northeast Atlantic coast estuaries. For example, the New York Bight has regularly received deposits of contaminated dredged material, sewage sludge, and industrial wastes, which has led to oxygen depletion and large masses of anoxic waters during the summer months. Some losses have likely occurred due to the intense coastal development in the last several decades, including dredging and filling activities in shallow nursery habitats, point and non-point source discharges, and intensive conversion of coastal wetlands for agricultural use (ASMFC 2002).

Flow regulation may have also contributed to functional loss of riverine and estuarine areas due to possible changes in water discharge patterns. Estuarine pre-spawning staging areas, spawning, and nursery areas may be affected by prolonged extreme conditions resulting from inland water

management practices. Power plant cooling facilities continue to impact weakfish populations through the entrainment of larvae and juveniles.

### ***Unknowns and Uncertainties***

Weakfish are pelagic fishes in estuarine systems and more common in the main channel of bays, sounds, and tributaries (Chao and Musick 1977). Therefore, perturbations to substrate and seagrass habitats through dredging, coastal development, and boating are not going to impact weakfish as much as benthic sciaenids. However, weakfish are visual predators (Horodysky et al. 2008) and human activities (e.g., dredging, eutrophication, sediment runoff) that increase turbidity are likely to reduce foraging efficiency for weakfish at all life stages. In addition, individuals are attracted to spawning aggregations through drumming but humans are increasing underwater noise pollution in coastal estuaries, which can increase stress and reduce the effectiveness of acoustic calls needed to initiate spawning (Slabbekoorn et al. 2010). It is not known how weakfish respond to increasing noise pollution and particular attention is needed in regards to the impacts of noise pollution on spawning adults as well as estimates of egg production.

Although weakfish are tolerant of low DO conditions (Stierhoff et al. 2009), other environmental variables are changing due to climate change. For weakfish, increasing acidification may be the more significant than other climate driven environmental changes since reduced pH decrease responsiveness to sensory cues, which can reduce foraging efficiency and predator avoidance (Dixson et al. 2010). Additional work, needs to be conducted to understand how ocean acidification may impact weakfish in estuarine systems at different life history stages.

## **Section IV. Recommendations for Habitat Management and Research**

### ***Habitat Management Recommendations***

The following research recommendations are from Amendment IV to the Weakfish FMP, Section 6.1.1 and ranked high priority (H), medium priority (M), or low priority (L):

1. Collect catch and effort data including size and age composition of the catch, determine stock mortality throughout the range, and define gear characteristics. In particular, increase length-frequency sampling, particularly in fisheries from Maryland and further north. (H)
2. Derive estimates of discard mortality rates and the magnitude of discards for all commercial gear types from both directed and non-directed fisheries. In particular, quantify trawl bycatch, refine estimates of mortality for below minimum size fish, and focus on factors such as distance from shore and geographical differences. (H)
3. Update the scale – otolith comparison for weakfish. (H)
4. Define reproductive biology of weakfish, including size at sexual maturity, maturity schedules, fecundity, and spawning periodicity. Continue research on female spawning patterns: what is the seasonal and geographical extent of "batch" spawning; do females exhibit spawning site fidelity? (M)
5. Conduct hydrophonic studies to delineate weakfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc.) and enable quantification of spawning habitat. (M)

6. Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent. (M)
7. Identify stocks and determine coastal movements and the extent of stock mixing, including characterization of stocks in overwintering grounds (e.g., tagging). (L)
8. Biological studies should be conducted to better understand migratory aspects and how this relates to observed trends in weight at age. (L)
9. Document the impact of power plants and other water intakes on larval, post larval and juvenile weakfish mortality in spawning and nursery areas, and calculate the resultant impact to adult stock size. (L)
10. Define restrictions necessary for implementation of projects in spawning and overwintering areas and develop policies on limiting development projects seasonally or spatially. (L)
11. Develop a coastwide tagging database. (L)
12. Develop a spawner recruit relationship and examine the relationships between parental stock size and environmental factors on year-class strength. (L)

### ***Habitat Research Recommendations***

The following research recommendations are from Amendment IV to the Weakfish FMP, Section 6.1.4:

1. Conduct hydrophonic studies to delineate weakfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc.) and enable quantification of spawning habitat.
2. Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
3. Document the impact of power plants and other water intakes on larval, post larval and juvenile weakfish mortality in spawning and nursery areas, and calculate the resulting impacts on adult stock size.
4. Define restrictions necessary for implementation of projects in spawning and overwintering areas and develop policies on limiting development projects seasonally or spatially.

### **Literature Cited**

- Able, K. W. and M. P. Fahay. 2010. Ecology of Estuarine Fishes: Temperate Waters of the Western North Atlantic. Johns Hopkins University Press. Baltimore, MD.
- Able, K. W., D. M. Nemerson, R. Bush and P. Light. 2001. Spatial variation in Delaware Bay (U.S.A.) marsh creek fish assemblages. Estuaries 24: 441–452.

- ASMFC (Atlantic States Marine Fisheries Commission). 2002. Amendment IV to the Interstate Fishery Management Plan for Weakfish. pp. 12.
- Berrien, P. and J. Sibunka. 1999. Distribution patterns of fish eggs in the northeast continental shelf ecosystem. Seattle, WA: National Oceanic and Atmospheric Administration Technical Report National Marine Fisheries Service-145. pp. 310.
- Berrien, P. L., M. P. Fahay, A. W. Kendall Jr. and W. G. Smith. 1978. Ichthyoplankton from the RV Dolphin survey of continental shelf waters between Martha's Vineyard, Massachusetts and Cape Lookout, North Carolina, 1965–66. NOAA, NMFS, Sandy Hook Laboratory, Technical Service Report No. 15. pp. 152.
- Brady, D. C. and T. E. Targett. 2013. Movement of juvenile weakfish *Cynoscion regalis* and spot *Leiostomus xanthurus* in relation to diel-cycling hypoxia in an estuarine tidal tributary. Marine Ecology Progress Series 491: 199–219.
- Chao, L. N. and J. A. Musick. 1977. Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in the York River Estuary, Virginia. Fishery Bulletin 75: 657–702.
- Chesapeake Bay Program. 1990. Chesapeake Bay weakfish and spotted seatrout fishery management plan review. Annapolis, MD. pp. 48.
- Connaughton, M. A. and M. H. Taylor. 1995. Seasonal and daily cycles in sound production associated with spawning in the weakfish, *Cynoscion regalis*. Environmental Biology of Fishes 42: 233–240.
- Cowan Jr., J. H., R. S. Birdsong, E. D. Houde, J. S. Priest, W. C. Sharp and G. B. Mateja. 1992. Enclosure Experiments on Survival and Growth of Black Drum Eggs and Larvae in Lower Chesapeake Bay. Estuaries 15: 392–402.
- Deary, A. L. 2015. Ontogeny of the feeding apparatus and sensory modalities: Relationship to habitat differentiation among early life history stage drums (Sciaenidae) in the Chesapeake Bay. Ph.D. Dissertation, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA. pp. 170.
- Dixson, D. L., P. L. Munday and G. P. Jones. 2010. Ocean acidification disrupts the innate ability of fish to detect predator olfactory cues. Ecology Letters 16: 68–75.
- Duffy, J. T. and C. E. Epifanio. 1994. Effects of larval density on the growth and survival of weakfish *Cynoscion regalis* in large-volume enclosures. Marine Ecology Progress Series 104: 227–233.
- Epifanio, C. E., D. Goshorn and T. E. Targett. 1988. Induction of spawning in the weakfish *Cynoscion regalis*. U.S. National Marine Fisheries Service Bulletin 86: 168–171.
- Goshorn, D. M. and C. E. Epifanio. 1991. Diet of larval weakfish and prey abundance in Delaware Bay. Transactions of the American Fisheries Society 120: 684–692.
- Greccay, P. A. and T. E. Targett. 1996a. Spatial patterns in condition and feeding of juvenile weakfish in Delaware Bay. Transactions of the American Fisheries Society 125: 803–808.

- Grecoy, P. A. and T. E. Targett. 1996b. Effects of turbidity, light level and prey concentration on feeding of juvenile weakfish *Cynoscion regalis*. Marine Ecology Progress Series 131: 11–16.
- Harmic, J. L. 1958. Some aspects of the development and ecology of the pelagic phase of the gray squeteague, *Cynoscion regalis* (Bloch and Schneider), in the Delaware estuary. Ph.D. Dissertation, University of Delaware, Newark, DE. pp. 84.
- Horodysky, A. Z., R. W. Brill, E. J. Warrant, J. A. Musick and R. J. Latour. 2008. Comparative visual function in five sciaenid fishes inhabiting Chesapeake Bay. Journal of Experimental Biology 211: 3601–3612.
- Lankford Jr., T. E. and T. E. Targett. 1997. Selective predation by juvenile weakfish: post-consumptive constraints on energy maximization and growth. Ecology 78: 1049–1061.
- Lankford Jr., T. E. and T. E. Targett. 1994. Suitability of estuarine nursery zones for juvenile weakfish (*Cynoscion regalis*): effects of temperature and salinity on feeding, growth and survival. Marine Biology 119: 611–620.
- Lowerre-Barbieri, S. K., M. E. Chittenden Jr. and L. R. Barbieri. 1996a. The multiple spawning pattern of weakfish in the Chesapeake Bay and Middle Atlantic Bight. Journal of Fish Biology 48: 1139–1163.
- Lowerre-Barbieri, S. K., M. E. Chittenden Jr. and L. R. Barbieri. 1996b. Variable spawning activity and annual fecundity of weakfish in Chesapeake Bay. Transactions of the American Fisheries Society 125: 532–545.
- Luczkovich, J. J., M. W. Sprague, S. E. Johnson and R. C. Pullinger. 1999. Delimiting spawning areas of weakfish *Cynoscion regalis* (family Sciaenidae) in Pamlico Sound, North Carolina using passive hydroacoustic surveys. Bioacoustics: The International Journal of Animal Sound and its Recording 10: 143–160.
- Luczkovich, J. J., R. C. Pullinger, S. E. Johnson and M. W. Sprague. 2008. Identifying sciaenid critical spawning habitats by the use of passive acoustics. Transactions of the American Fisheries Society 137: 576–605.
- Mancini, F. and K. W. Able. 2005. Food habits of young-of-the-year estuarine fishes in Middle Atlantic Bight estuaries: a synthesis. Rutgers University Institute of Marine and Coastal Sciences Technical Report 2005-15.
- Massmann, W. H. 1954. Marine fishes in fresh and brackish waters of Virginia rivers. Ecology 35(1): 75–78.
- Mercer, L. P. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic)–weakfish. U.S. Fish and Wildlife Biological Report 82 (11.109). U. S. Army Corps of Engineers, TR EL-82-4. pp. 17.
- Merriner, J. V. 1976. Aspects of the reproductive biology of the weakfish *Cynoscion regalis* (Sciaenidae) in North Carolina. Fishery Bulletin 74: 18–26.



- Nemerson, D. M. and K. W. Able. 2004. Spatial patterns in diet and distribution of juveniles of four fish species in Delaware Bay marsh creeks: factors influencing fish abundance. *Marine Ecology Progress Series* 276: 249–262.
- Nye, J. A., T. E. Targett and T. E. Helser. 2008. Reproductive characteristics of weakfish in Delaware Bay: implications for management. *North American Journal of Fisheries Management* 27: 1–11.
- Olney, J. E. 1983. Eggs and early larvae of the bay anchovy, *Anchoa mitchilli*, and the weakfish, *Cynoscion regalis*, in lower Chesapeake Bay with notes on associated ichthyoplankton. *Estuaries* 6: 20–35.
- Olney, J. E. and G. W. Boehlert. 1988. Nearshore ichthyoplankton associated with seagrass beds in the lower Chesapeake Bay. *Marine Ecology Progress Series* 45: 33–43.
- Paperno, R., T. E. Targett and P. A. Greco. 2000. Spatial and temporal variation in recent growth, overall growth, and mortality of juvenile weakfish (*Cynoscion regalis*) in Delaware Bay. *Estuaries* 23: 10–20.
- Pincin, J., M. J. Wilberg, L. Harris and A. Willey. 2014. Trends in abundance indices of fishes in Maryland's coastal bays during 1972–2009. *Estuaries and Coasts* 37: 791–800.
- Purcell, J. E. 1985. Predation on fish eggs and larvae by pelagic cnidarians and ctenophores. *Bulletin of Marine Science* 37: 739–755.
- Ribeiro, F., E. Hale, E. J. Hilton, T. R. Clardy, A. L. Deary, T. E. Targett, and J. E. Olney. 2015. Composition and temporal patterns of larval fish communities in Chesapeake and Delaware Bays, USA. *Marine Ecology Progress Series* 527: 167–180.
- Rountree, R. A. and K. W. Able. 1992. Fauna of polyhaline subtidal marsh creeks in southern New Jersey: composition, abundance and biomass. *Estuaries* 15(2): 171–185.
- Rowe, P. M. and C. E. Epifanio. 1994a. Tidal stream transport of weakfish larvae in Delaware Bay, USA. *Marine Ecology Progress Series* 110: 105–114.
- Rowe, P. M. and C. E. Epifanio. 1994b. Flux and transport of larval weakfish in Delaware Bay, USA. *Marine Ecology Progress Series* 110: 115–120.
- Shepherd, G. R. and C. B. Grimes. 1984. Reproduction of weakfish, *Cynoscion regalis*, in the New York Bight and evidence for geographically specific life history characteristics. *Fishery Bulletin* 82: 501–511.
- Slabbekoorn, H., N. Bouton, I. van Opzeeland, A. Coers, C. ten Cate and A. N. Popper. 2010. A noisy spring: the impact of globally rising underwater sound levels on fish. *Trends in Ecology and Evolution* 25(7): 419–427.
- Stearns, S. C. 1976. Life-History Tactics: A Review of the Ideas. *The Quarterly Review of Biology* 51: 3–47.
- Stierhoff, K. L., R. M. Tyler and T. E. Targett. 2009. Hypoxia tolerance of juvenile weakfish (*Cynoscion regalis*): laboratory assessment of growth and behavioral avoidance responses. *Journal of Experimental Marine Biology and Ecology* 381: S173–S179.

- Thomas, D. L. 1971. The early life history and ecology of six species of drum (*Sciaenidae*) in the lower Delaware River, a brackish tidal estuary. Delaware Progress Report 3 (Part 111), Ichthyology Association, Middletown, DE 19709. pp. 247.
- Thorrold, S. R., C. Latkoczy, P. K. Swart and C. M. Jones. 2001. Natal homing in a marine fish metapopulation. *Science* 291: 297–299.
- Thorrold, S. R., C. M. Jones, P. K. Swart and T. E. Targett. 1998. Accurate classification of juvenile weakfish *Cynoscion regalis* to estuarine nursery areas based on chemical signatures in otoliths. *Marine Ecology Progress Series* 173: 253–265.
- Tyler, R. M. and T. E. Targett. 2007. Juvenile weakfish *Cynoscion regalis* distribution in relation to diel-cycling dissolved oxygen in an estuarine tributary. *Marine Ecology Progress Series* 333: 257–269.
- Welsh, W. W. and C. M. Breder Jr. 1923. Contributions to the life histories of Sciaenidae of the eastern United States coast. *Bulletin of the U. S. Bureau of Fisheries* 39: 141–201.
- Woodland, R. J., D. H. Secor, M. C. Fabrizio and M. J. Wilberg. 2012. Comparing the nursery role of inner continental shelf and estuarine habitats for temperate marine fishes. *Estuarine, Coastal, and Shelf Science* 99: 61–73.
- Wuenschel, M. J., K. W. Able, J. M. Vasslides and D. M. Byrne. 2013. Habitat and diet overlap of 4 piscivorous fishes: variation on the inner continental shelf off New Jersey. *Fishery Bulletin* 111: 352–369.

## CHAPTER 8: NORTHERN KINGFISH

### **Section I. General Description of Habitat**

Northern kingfish are found in estuaries and coastal areas from Maine to the Yucatan, Mexico (Irwin 1971) and are more common in the Mid Atlantic Bight than in the South Atlantic Bight (Hildebrand and Schroeder 1928; Schaefer 1965; Ralph 1982). Northern kingfish prefer habitats in close proximity to inlets and in the ocean to depths up to 20 m (Welsh and Breder 1923; Bearden 1963; Irwin 1971; Ralph 1982). Juvenile northern kingfish inhabit shallower waters than the adult northern kingfish and were typically found in the surfzone and rivers (Bearden 1963; Ralph 1982).

### **Part A. Spawning Habitat**

#### ***Geographic and Temporal Patterns of Migration***

Northern kingfish are thought to migrate inshore and northward from their overwintering habitats during the spring and summer while spawning is occurring (Hildebrand and Cable 1934). Fish in spawning condition have been observed from March through September based on macroscopic inspection of gonads for fish in North Carolina (Collier in prep) and from June through August based on the size distribution of young of the year fish (Welsh and Breder 1923; Schaefer 1965; Miller et al. 2002). Spawning is thought to occur in the nearshore-ocean or within inlets in deep channels (Irwin 1971; Ralph 1982).

#### ***Salinity***

Adult northern kingfish are thought to spawn in lower estuary and coastal habitats with moderate to high salinities (Ralph 1982). Spawning occurs along the bottom (Ralph 1982).

#### ***Substrate***

The spawning habitat has not been described for northern kingfish but they are typically found over sandy bottoms (Welsh and Breder 1923; Hildebrand and Cable 1934; Bearden 1963) with some reports of northern kingfish around oysters and hard bottom (Irwin 1971). It is expected that northern kingfish spawn over sandy or muddy bottoms in the ocean and in deeper channels.

#### ***Temperature***

Northern kingfish migrate based on temperature and will remain in the lower estuary and nearshore ocean during the spawning season. Spawning adults have been observed in temperatures ranging from 7.8–35.8°C (Irwin 1971). The temperature range is likely to vary with latitude with northern kingfish from the Mid-Atlantic experiencing lower temperatures than fish inhabiting the South Atlantic and Gulf of Mexico.

#### ***Dissolved Oxygen***

Preferences for DO have not been reported for adult and spawning northern kingfish. Based on suspected spawning locations (deep estuaries and nearshore) low DO and hypoxic conditions are likely rare.

### ***Feeding Behavior***

Diets of northern kingfish were reported during the summer months, which includes the spawning season. The diet of northern kingfish is comprised of penaeid shrimp, polychaete worms, and amphipods in the South Atlantic Bight (Welsh and Breder 1923; Bearden 1963) and shrimp, crabs, and squids in northern latitudes (Irwin 1971).

### ***Competition and Predation***

Competitors of northern kingfish include other sciaenids including its congeners, southern and gulf kingfishes, spot, Atlantic croaker, red drum, and black drum, due to diet and habitat overlap (Ralph 1982). No studies have reported on competition or predation of spawning northern kingfish, though it might be safely inferred that adult competition and predation descriptions apply to spawners, particularly because the duration spawning season suggests that spawning is integrated into their adult lives, rather than a small, discrete period that may necessitate a different behavioral strategy.

## **Part B. Egg and Larval Habitat**

The eggs of northern kingfish are buoyant and the water column is the primary habitat. Eggs have been reported in the water column of the nearshore-ocean and in estuaries. Larvae are defined as kingfish <25 mm SL although the size of transition is not clearly defined (Welsh and Breder 1923). It is likely the nursery habitats for northern kingfish extend from the nearshore ocean into upper reaches of estuaries due to tidal transport. The greatest concentration of larvae northern kingfish occur in the nearshore ocean and lower estuaries (Irwin 1971; Ralph 1982).

### ***Geographic and Temporal Patterns of Migration***

Mature northern kingfish spawn in the nearshore ocean and lower reaches of deep estuaries. Egg hatching occurs about 46–50 hours post-fertilization at 20–21°C (Welsh and Breder 1923). Spawning begins in the southern region of the distribution (e.g., North Carolina) early in the spring and likely begins later in the spring in northern latitudes (Irwin 1971). Eggs are likely subjected to a variety of environmental conditions due to a protracted spawning season and broad geographic distribution from Florida to Maine in euryhaline areas similar to southern kingfish (Bearden 1963).

Northern kingfish larvae are widely distributed and have been reported in nearshore ocean waters and throughout estuaries (Bearden 1963; Irwin 1971; Ralph 1982). It is likely the larval transport of northern kingfish is similar to the larval transport of other sciaenids using tidal stream transport (e.g., weakfish, southern kingfish) given the general overlap in spawning season and location.

### ***Salinity***

Although salinity has not been reported, eggs and larvae of kingfishes (some studies do not differentiate among species) are concentrated near ocean near inlets and the lower parts of estuaries where salinities are higher (Ralph 1982; Flores-Coto et al. 1999; Reiss and McConaughy 1999).

Northern kingfish larvae likely tolerate a wide range of salinities based on their wide distribution but are most common in waters with salinities greater than 20 ppt, similar to southern kingfish (Bearden 1963). As northern kingfish grow, they are found in higher salinity waters (Ralph 1982). Although northern kingfish larvae are distributed over a range of salinities, it is not known if rapid changes in salinity impact survival.

### ***Substrate***

Like many marine fish eggs, northern kingfish eggs are spherical, buoyant, and have a relatively short phase. In addition, the entire egg phase takes place in the pelagic zone of nearshore or lower estuarine waters, and thus substrate is not likely encountered (Welsh and Breder 1923).

### ***Temperature***

Minimum temperature is likely the main driver of northern kingfish reproduction and thus a necessary condition for egg development. Welsh and Breder (1923) spawned northern kingfish at 20–21°C and based on average ocean temperatures for months listed as spawning times, northern kingfish likely spawn at temperatures between 18–27°C.

### ***Dissolved Oxygen***

DO is probably not an issue for short-lived northern kingfish eggs that remain buoyant and pelagic, and thus out of hypoxic and anoxic zones.

### ***Feeding Behavior***

Northern kingfish eggs subsist entirely off the yolk sac prior to hatch. The feeding behaviors of larval northern kingfish have not been described. However, they likely consume zooplankton prey, such as copepods, decapods, and polychaetes (Able and Fahay 2010), similar to other sciaenids.

### ***Competition and Predation***

Northern kingfish eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the offshore conditions). Predation of eggs undoubtedly occurs but has not been well studied or reported. Although potentially large numbers of eggs are killed from predation, there is no initial reason to think that pelagic oceanic predators are targeting northern kingfish eggs and larvae over other species. In the early stages (eggs and larvae), gelatinous zooplankton are likely the main predators of northern kingfish (Purcell 1985; Olney and Boehlert 1988; Cowan et al. 1992).

No study has looked at competition and predation of larval northern kingfish but the larvae likely compete with gulf and southern kingfishes and other sciaenids including spot, Atlantic croaker, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963). Some competition likely takes place when a high-density larval patch settles on limited habitat; however, the wide range of settled habitats and protracted spawning season suggest that widespread competition is unlikely.

## **Part C. Juvenile Habitat**

Juvenile northern kingfish are between 25 and 150 or 230 mm SL. The upper size varies between sexes due to the differential size at maturity. Juvenile northern kingfish inhabit the nearshore ocean and surfzone and the deeper waters of bays, estuaries, and sounds, including their tributary rivers. Northern kingfish are summer estuarine residents of estuarine beaches (Miller et al. 2002).

### ***Geographic and Temporal Patterns of Migration***

The general pattern of habitat use by juvenile northern kingfish is estuarine-wide beginning in late spring and early summer in lower estuarine and nearshore habitats. Juveniles move to deeper, more

saline waters in the fall (Ralph 1982; Miller et al. 2002). Northern kingfish tend to remain in localized areas throughout the summer (Miller et al. 2002).

### ***Salinity***

Juvenile northern kingfish migrate to deeper more saline waters as they get larger. By the fall most northern kingfishes migrate out of the shallow estuarine and nearshore oceanic habitats to the deeper ocean habitats to overwinter (Bearden 1963; Ralph 1982; Miller et al. 2002). Growth rates were compared among different habitats and no significant differences were detected indicating that salinity does not impact growth rates (Miller et al. 2002). The fish tended to leave the estuarine beaches at smaller sizes than at oceanic beaches (165 TL vs. 230 TL).

### ***Substrate***

Juvenile northern kingfish are typically observed over sandy sediment in shallow estuarine and surfzone environments and can be found over mud environments (Welsh and Breder 1923; Irwin 1971; Ralph 1982). There are reports of northern kingfish being caught over hard substrate including oyster shell (Irwin 1971; Ralph 1982).

### ***Temperature***

Juvenile northern kingfish likely tolerate a wide range of temperatures and it is considered to be an important variable driving their distribution. They are rarely seen in temperatures below 20°C and migrate out of shallow waters in September and October (Ralph 1982; Miller et al. 2002). In a tank experiment, they avoided temperatures above 30°C.

### ***Dissolved Oxygen***

Little has been reported on the impact of DO levels on juvenile northern kingfish. The lower estuary and surfzone environments may have fewer occurrences of hypoxic and anoxic events compared to upper estuarine habitats. However, northern kingfish do have a relatively fast growth rate (1.8–2.4 mm d<sup>-1</sup> as juveniles) (Miller et al. 2002), which could be attributed to the elevated metabolic rate of the species (Horodysky 2011).

### ***Feeding Behavior***

Juvenile northern kingfish are benthic foragers (Chao and Musick 1977). They use their single barbel to detect prey. The juvenile diet consists of nematodes, polychaete worms, mysid shrimp, penaeid shrimp, isopods, amphipods, copepods, fishes, and detritus (Ralph 1982).

### ***Competition and Predation***

No study has looked at competition and predation of juvenile northern kingfish but the juveniles likely compete with gulf and southern kingfishes, other benthic foraging sciaenids (spot, Atlantic croaker, red drum, and black drum) (Ralph 1982), and Florida pompano and silversides in the surfzone (Bearden 1963).

## **Part D. Adult Habitat**

Adult northern kingfish are schooling fish that reside in both estuarine and nearshore Atlantic Ocean habitats. Adult are found over clean sandy sediment with some reports of northern kingfish around hard substrate. Warming of coastal waters in the spring is a cue for a migration inshore and northward from

the wintering grounds to nearshore ocean, bays, estuaries, and sounds. Northern kingfish migrate offshore and southward as temperatures decline in the fall.

### ***Geographic and Temporal Patterns of Migration***

Most northern kingfish mature after their first winter (Schaefer 1965; Collier et al. in prep). The general pattern of adult habitat use includes a seasonal migrations south and offshore in fall and winter and north and inshore during spring and summer (Irwin 1971; Ralph 1982; Miller et al. 2002). Summer inshore habitats extend from the estuaries to continental shelf in depths less than 18 m (Ralph 1982). Although it is not clear the depth where overwintering occurs, northern kingfish have been captured in depths of 36 m in the late fall off North Carolina with the deepest record being 128 m (Irwin 1971).

### ***Salinity***

Adult northern kingfish occur primarily in nearshore-ocean or lower estuarine habitats where salinities are at or near full seawater.

### ***Substrate***

In accordance with the variety of habitats used by adults, specific habitat use or habitat preference in adult northern kingfish has not been reported. Northern kingfish are typically found over sandy or muddy-sand substrates in the ocean, bays, and estuaries, but substrates used are likely as variable as the overall habitats in which adults are found. Some reports indicate that northern kingfish are found among hard substrate (Irwin 1971; Ralph 1982) and, anecdotally, fishermen indicated catches of northern kingfish are typically higher in close proximity to hard substrates.

### ***Temperature***

Temperature appears is driving factor in the movement of northern kingfish. They have reported temperature tolerances of 7.8–35.8°C. In areas south of Cape Hatteras, northern kingfish are rarely seen in temperatures <20°C. Adults have been reported dying due to cold stun in the northern part of their range (Irwin 1971). They have an upper thermal limit of 35°C and avoid temperatures >31°C (Ralph 1982).

### ***Dissolved Oxygen***

Adult northern kingfish likely experience normoxic conditions, as they typically are found in lower estuary or nearshore ocean. Without any explicit studies of adult northern kingfish DO tolerances or preferences, values can be inferred from other sciaenids that have overlapping habitat occurrences. It should be noted that the metabolic rate for northern kingfish was significantly higher than spot and Atlantic croaker (Horodysky et al. 2011), which suggests that northern kingfish may be more sensitive to hypoxia than other sciaenids.

### ***Feeding Behavior***

Adult northern kingfish are benthic feeders and use single barbel on the chin to detect the prey. Northern kingfish have been observed to consume shrimp, amphipods, mysids, and polychaete worms (Welsh and Breder 1923; Woodland et al. 2011).

### ***Competition and Predation***

Competition among adults is not well known. As with other life stages, northern kingfish overlap in their distribution with southern and gulf kingfishes, suggesting a potential for competition among these

species. However, the diet of gulf kingfish appears to be more specialized than the other two species and the diets of southern and northern kingfishes indicated niche segregation (Woodland et al. 2011). Other potential competitors include other sciaenids and Florida pompano.

Kingfish spp. otoliths have been observed in the stomachs of cetaceans (Tyner 2004) and likely predators include larger sciaenids and coastal sharks.

## **Section II. Essential Fish Habitats and Habitat Areas of Particular Concern**

### ***Essential Fish Habitat***

Northern kingfish use a variety of habitats in lower reaches of estuaries and nearshore oceanic habitats. They are observed over sand and mud substrate in nearshore ocean, bays, estuaries, and sounds. Some studies have reported around hard substrate (Welsh and Breder 1923; Irwin 1971; Ralph 1982).

### ***Identification of Habitat Areas of Particular Concern***

There is no HAPC designation for northern kingfish.

### ***Present Condition of Habitat Areas of Particular Concern***

The quality of northern kingfish habitats has been compromised largely by impacts from human activities. It is generally assumed that these habitats have undergone some degree of loss and degradation; however, few studies quantify the impacts in terms of the area of habitat lost or degraded.

Habitat loss due to water quality degradation is evident in the northeast Atlantic coast estuaries. The New York Bight, for example, has regularly received deposits of contaminated dredged material, sewage sludge, and industrial wastes. These deposits have contributed to oxygen depletion and the creation of large masses of anoxic waters during the summer months.

Some losses have likely occurred due to the intense coastal development that has occurred during the last several decades, although no quantification has been done. Losses have likely resulted from dredging and filling activities that have eliminated shallow water nursery habitats. Further functional losses have likely occurred due to water quality degradation from point and non-point sources. Intensive conversion of coastal wetlands to agricultural use also is likely to have contributed to functional loss of northern kingfish nursery area habitat, particularly estuarine beaches.

Other functional loss of riverine and estuarine areas may have resulted from changes in water discharge patterns resulting from withdrawals or flow regulation. Estuarine nursery areas for northern kingfish, as well as adult spawning and pre-spawning areas, may be affected by prolonged exposure to extreme conditions from inland water management practices.

Beach renourishment projects are likely to have an impact on northern kingfish. Kingfishes utilize the surfzone to different degrees as they develop. Juveniles are residents of the surfzone and lower estuaries (Miller et al. 2002). Northern kingfish densities were highest during a beach renourishment project, suggesting that individuals were attracted to the bioturbated region (Wilber et al. 2003). Short-term and long-term monitoring on the effects of beach renourishment is needed to better understand the impacts on kingfish.



### **Section III. Threats and Uncertainties**

#### ***Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Northern Kingfish***

The timing of seasonal and spawning migrations appear to be linked to temperature, as well as their overall distribution within estuarine and coastal ecosystems. As temperatures cool in the fall, northern kingfish move south and offshore to deeper water that is more stable in temperature. They return to northern, inshore habitats as temperatures increase again in the spring and summer (Irwin 1971; Ralph 1982; Miller et al. 2002). In the summer, individuals use sand and mud bottomed habitats in lower estuaries and along the continental shelf in depths less than 18 m (Ralph 1982).

#### ***Unknowns and Uncertainties***

Little research has been conducted on northern kingfish at any life stage and a comprehensive coastwide study that covers their geographic range is needed. The impacts of dredge and fill projects including renourishment projects cannot be fully assessed without additional research to understand habitats that are EFH.

In addition, it is often difficult to distinguish the early stages of kingfish spp., which adds confusion when investigating and determining physiological tolerances to environmental conditions. More research is required in the biology and life history of northern kingfish following a revision of the diagnostic characters used to identify northern kingfish in larval and juvenile collections.

Another consideration for northern kingfish is that they forage within and along the sediment of the benthos, which concentrates hydrophobic toxicants, potentially increasing their exposure to these contaminants. No known research has examined the impacts of toxicant exposure on early stage northern kingfish, which may have developmental or reproductive implications.

### **Section IV. Recommendations for Habitat Management and Research**

#### ***Habitat Management Recommendations***

Currently, northern kingfish are not managed through the Interstate Fisheries Management Program (ASMFC 2014). The following recommendations are based on recommendations made in North Carolina Division of Marine Fisheries (NCDMF) 2007 and FMPs for other sciaenids:

1. Protect known nursery areas from activities likely to negatively impact northern kingfish.
2. Integrate beach and inlet management plans into a coastwide plan that minimizes impacts to the habitat of kingfishes and other estuarine fishes.
3. Require beach renourishment and dredge and fill projects adhere to state, regional, or national policies and require robust monitoring before and after dredge, renourishment, and fill activities.
4. Modify stormwater rules or policies to more effectively reduce the volume and pollutant loading of stormwater runoff entering coastal waters.

5. Minimize contamination of bottom sediments through protection and enhancement of wetlands utilizing regulatory and non-regulatory measures, such as land use planning, land acquisition, vegetated buffers, and permitting regulations.
6. Implement and enforce sediment compatibility criteria for beach nourishment projects.

### ***Habitat Research Recommendations***

Currently, northern kingfish are not managed through the Interstate Fisheries Management Program (ASMFC 2014). The following recommendations are based on recommendations made in NCDMF 2007 and FMPs for other sciaenids to improve our understanding of the biology, habitat use, and potential stressors of northern kingfish.

1. Conduct studies to delineate northern kingfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc.) and enable quantification of spawning habitat.
2. Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
3. Define restrictions necessary for implementation of projects in spawning and overwintering areas and develop policies on limiting development projects seasonally or spatially.
4. Recommend BACI studies for beach renourishment projects to describe the impact/benefit of renourishment.
5. Develop consistent methods for studying impact of beach renourishment to allow for comparison spatially and temporally.
6. Determine impact of beach stormwater outfalls on kingfish populations.
7. Determine impact of bottom disturbing gear on kingfish spawning, nursery, and feeding habitats.
8. Assess the distribution, concentration, and threat of heavy metals and other toxic contaminants in freshwater and estuarine sediments and identify the areas of greatest concern to focus water quality improvement efforts.

### **Literature Cited**

Able, K. W. and M. P. Fahay. 1998. *The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight*. Rutgers University Press, New Brunswick, NJ.

ASMFC (Atlantic State Marine Fisheries Commission). 2014. *Sheepshead Fishery Overview*. South Atlantic State/Federal Management Board.

Bearden, C. W. 1963. A contribution to the biology of the king whiting, genus *Menticirrhus* of South Carolina. *Contributions of Bears Bluff Laboratory* 38: 1–27.

Chao, L. N and J. A. Musick. 1977. Life history, feeding habits, and functional morphology of the juvenile sciaenid fishes in the York River Estuary. *Fishery Bulletin* 75: 657–702.

- Cowan Jr., J. H., R. S. Birdsong, E. D. Houde, J. S. Priest, W. C., Sharp and G. B. Mateja. 1992. Enclosure experiments on survival and growth of black drum eggs and larvae in lower Chesapeake Bay. *Estuaries* 15(3): 392–402.
- Flores-Coto, C., P. Figueroa and F. Zavala Garcia. 1999. Distribution and abundance of Sciaenidae larvae in the water column in the southern Gulf of Mexico. *Hidrobiologica* 9: 135–144.
- Hildebrand, S. F. and L. E. Cable. 1934. Reproduction and development of whiting or kingfishes, drums, spot, croaker, and weakfishes or seatrouts, family Sciaenidae, of the Atlantic coast of the United States. *Bulletin of U.S. Bureau of Fisheries*. 48: 41–117.
- Hildebrand, S. F. and W. C. Schroeder. 1928. The fishes of the Chesapeake Bay. *Bulletin of U.S. Bureau of Fisheries*. 43: 1–388.
- Horodysky, A. Z., R. W. Brill, P. G. Bushnell, J. A. Musick and R. J. Latour. 2011. Comparative metabolic rates of common western North Atlantic Ocean sciaenid fishes. *Journal of Fish Biology* 79: 235–255.
- Irwin, R. J. 1971. Geographical variation, systematics, and general biology of shore fishes of the genus *Menticirrhus*, family Sciaenidae. Ph.D. Dissertation. Tulane University, New Orleans, LA. pp. 295.
- Miller, M. J., P. M. Rowe and K. W. Able. 2002. Occurrence and growth rates of young-of-year northern kingfish, *Menticirrhus saxatilis*, on ocean and estuarine beaches in southern New Jersey. *Copeia* 2002: 815–823.
- NCDMF (North Carolina Division of Marine Fisheries). 2007. North Carolina Fishery Management Plan: Kingfish. pp. 243.
- Olney, J. E. and G. W. Boehlert. 1988. Nearshore ichthyoplankton associated with seagrass beds in the lower Chesapeake Bay. *Marine Ecology Progress Series* 45: 33–43.
- Purcell, J. E. 1985. Predation on fish eggs and larvae by pelagic cnidarians and ctenophores. *Bulletin of Marine Science* 37: 739–755.
- Ralph, D. E. 1982. Biological and fisheries data on the northern kingfish, *Menticirrhus saxatilis*. NOAA Technical Series Report. No. 27.
- Reiss, C. S. and J. R. McConaugha. 1999. Cross-frontal transport and distribution of ichthyoplankton associated with Chesapeake Bay plume dynamics. *Continental Shelf Research* 19: 151–170.
- Schaefer, R. H. 1965. Age and growth of the northern kingfish in New York waters. *New York Fish and Game Journal* 12: 191–216.
- Tyner, C. E. 2004. Development of an otolith-based taxonomic key of North Carolina coastal fishes for identifying the dietary remains of piscivorous predators. Honors Thesis, University of North Carolina, Wilmington, NC.
- Welsh, W. W. and C. M. Breder. 1923. Contributions to the life histories of Sciaenidae of the eastern United States coast. *Bulletin of U.S. Bureau of Fisheries* 39: 141–201.
- Wilber, D. H., D. G. Clarke, G. L. Ray and M. Burlas. 2003. Response of surf zone fish to beach nourishment operations on the northern coast of New Jersey, USA. *Marine Ecology Progress Series* 250: 231–246.

Woodland, R. J., D. H. Secor and M. E. Wedge. 2011. Trophic resource overlap between small elasmobranchs and sympatric teleosts in Mid-Atlantic Bight nearshore habitats. *Estuaries and Coasts* 34: 391–404.

## CHAPTER 9: SOUTHERN KINGFISH

### **Section I. General Description of Habitat**

Southern kingfish are found in estuaries and coastal areas from Long Island, New York to Buenos Aires, Argentina (Irwin 1971) and are more common in the South Atlantic Bight than Mid Atlantic Bight (Hildebrand and Schroeder 1928; Smith and Wenner 1985). Southern kingfish prefer habitats close to inlets and in the ocean at depths ranging from 5–27 m (Bearden 1963; Harding and Chittenden 1987). Juvenile southern kingfish inhabit shallower waters than the adult southern kingfish and were found in waters less than 16 m whereas adults are found in waters less than 23 m (Bearden 1963; Crowe 1984; Harding and Chittenden 1987).

### **Part A. Spawning Habitat**

#### ***Geographic and Temporal Patterns of Migration***

Southern kingfish are thought to migrate southward during the winter and northward prior to the spawning season (Hildebrand and Cable 1934; Smith and Wenner 1985; Beresoff and Schoolfield 2002).

#### ***Salinity***

Adult southern kingfish are spawn in lower estuarine and coastal habitats in waters that have moderate to high salinities (Bearden 1963; Irwin 1971; Dahlberg 1972; Smith and Wenner 1985). They are found in higher salinity waters than juveniles (>20 ppt) (Bearden 1963; Irwin 1971; Crowe 1984).

#### ***Substrate***

The spawning habitat has not been described for southern kingfish but they are typically found over sandy and muddy bottoms in the ocean or in deeper channels (Welsh and Breder 1923; Hildebrand and Cable 1934; Bearden 1963).

#### ***Temperature***

Southern kingfish migrate based on temperature and will remain in the lower estuary and nearshore ocean during the spawning season. They have been observed in temperatures from 8–37°C (Crowe 1984). The temperature range is likely to vary with latitude with southern kingfish from the Mid Atlantic experiencing lower temperatures than fish inhabiting the South Atlantic and Gulf of Mexico.

#### ***Dissolved Oxygen***

Preferences for DO have not been reported for adult and spawning southern kingfish. Based on suspected spawning locations (deep estuaries and nearshore ocean) low DO and hypoxic conditions are likely rare.

#### ***Feeding Behavior***

Diets of southern kingfish were typically reported during the summer months, which include the spawning season. The diet varied and was often comprised of fished (including silversides, anchovies, star drum, and tonguefish), *Squilla*, *Crangon*, penaeid shrimp, mysids, polychaete worms, and copepods in the South Atlantic Bight (Irwin 1971; Woodland et al. 2011).

### ***Competition and Predation***

Competitors of southern kingfish likely include other sciaenids (northern kingfish, gulf kingfish, spot, Atlantic croaker, red drum, and black drum) due to diet and habitat overlap. One study reported dietary overlap between southern kingfish, clearnose skate, and smooth dogfish (Woodland et al. 2011). Few studies have reported on competition or predation of spawning southern kingfish, though it might be safely inferred that adult competition and predation descriptions apply to spawners, particularly because the prolonged spawning season, which suggests that spawning is integrated into the ecology of adults.

### **Part B. Egg and Larval Habitat**

The eggs of southern kingfish are buoyant and the water column is the primary habitat. Eggs have been reported in the water column of the nearshore ocean and in estuaries.

Larvae of southern kingfish are defined as kingfish <25 mm SL although the size of transition is not clearly defined (Welsh and Breder 1923). It is likely the nursery habitats for southern kingfish extend from the nearshore ocean into upper reaches of estuaries due to tidal transport. The greatest concentration of larvae southern kingfish occur in the nearshore ocean and lower estuaries (Irwin 1971; Ralph 1982; Flores-Coto et al. 1999; Reiss and McConaugha 1999; Markovsky 2009).

### ***Geographic and Temporal Patterns of Migration***

Mature southern kingfish spawn in the nearshore ocean and lower reaches of deep estuaries (NCDMF 2007). Spawning begins in the southern region of the distribution (e.g., Florida) early in the spring and likely begins later in the spring at northern latitudes (Irwin 1971). Eggs are likely subjected to a variety of environmental conditions due to the protracted spawning season and broad geographic distribution from Florida to Maine in euryhaline areas (Bearden 1963).

Southern kingfish larvae are widely distributed and have been reported in nearshore ocean waters and throughout estuaries (Bearden 1963; Irwin 1971; Crowe 1984). This wide distribution is driven by the use of currents to migrate into nurseries.

### ***Salinity***

Salinity has not been reported but eggs and larvae of kingfishes (some studies do not differentiate) indicate they are concentrated in the ocean near inlets and the lower parts of estuaries where salinities are higher (Flores-Coto et al. 1999; Reiss and McConaugha 1999; Markovsky 2009).

Southern kingfish larvae likely tolerate a wide range of salinities based on their wide distribution but are most common in waters with salinities >20 ppt (Bearden 1963). As southern kingfish grow, they are increasing found in higher salinity waters (Bearden 1963; Crowe 1984).

### ***Substrate***

Like many marine fish eggs, southern kingfish eggs are buoyant, and have a relatively short phase (compared to other life stages) with the entire egg phase taking place in the pelagic zone of nearshore or lower estuarine waters, and thus substrate is not likely encountered.

Larval southern kingfish are likely planktonic and then benthic after settlement (Hildebrand and Cable 1934). The likely substrates include sandy, muddy, and shell substrate in shallow estuarine and surfzone environments (Hildebrand and Cable 1934).

### ***Temperature***

Minimum temperature is likely the main driver of southern kingfish reproduction and thus a necessary condition for egg development. Based on observations for larvae, southern kingfish were observed in temperatures from 24–30°C in the Gulf of Mexico (Crowe 1984). This range of temperatures might be narrower than the temperature tolerance in the Atlantic based on reported months of spawning from March to September (20–30°C).

### ***Dissolved Oxygen***

Due to a likely short larval duration similar to southern kingfish and the pelagic habitat, it is unlikely that they encounter any habitats in which DO imposes a limitation or threat.

### ***Feeding Behavior***

Southern kingfish eggs subsist entirely off the yolk sac prior to hatch. The feeding behaviors of larval southern kingfish has been described as more general than adults in that the early stages are consuming planktonic prey (Chao and Musick 1977).

### ***Competition and Predation***

Southern kingfish eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the offshore conditions). Predation of eggs undoubtedly occurs but has not been well studied or reported. Although potentially large numbers of eggs are killed from predation, there is no initial reason to think that pelagic oceanic predators are targeting weakfish eggs over other, similar pelagic eggs. As with other marine fishes, eggs and larvae are susceptible to predation by gelatinous zooplankton (Purcell 1985; Olney and Boehlert 1988; Cowan et al. 1992).

No study has looked at competition and predation of larval southern kingfish but they likely compete with gulf and northern kingfishes and other members of the sciaenid family including spot, Atlantic croaker, weakfish, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963). Some competition likely takes place when a high-density larval patch settles on limited habitat; however, the wide range of settled habitats and protracted spawning season suggest that widespread competition is unlikely.

## **Part C. Juvenile Habitat**

Juvenile southern kingfish are generally between the sizes of 25 and 120 or 180 mm SL, due to different size at maturing between the sexes. Juvenile southern kingfish inhabit the nearshore ocean and surfzone and the deeper waters of bays, estuaries, and sounds, including their tributary rivers.

### ***Geographic and Temporal Patterns of Migration***

The general pattern of habitat use by juveniles is estuarine-wide and begins in late spring and early summer in lower estuarine and nearshore habitats. In the fall, juveniles move to deeper, more saline waters (Crowe 1984). Southern kingfish are summer residents of the surfzone and estuaries (Dahlberg 1972; Crowe 1984).

### ***Salinity***

Juvenile southern kingfish migrate to deeper more saline waters as size increases. By the fall most southern kingfish migrate out of the shallow estuarine and nearshore ocean environment to the deeper ocean habitats to overwinter (Bearden 1963; Harding and Chittenden 1987). The fish tended to leave the estuarine beaches at smaller sizes than oceanic beaches (160 mm TL vs. 200 mm TL) (Harding and Chittenden 1987). It is not known if salinities impact growth rates.

### ***Substrate***

Juveniles are observed over sandy, muddy, and shell substrates in shallow estuarine and surfzone environments (Bearden 1963; Irwin 1971; Harding and Chittenden 1987). In the fall, the most juvenile southern kingfish will migrate into the ocean (Hildebrand and Cable 1934; Smith and Wenner 1985; Harding and Chittenden 1987). However, some individuals will remain in the estuary throughout the winter (Bearden 1963).

### ***Temperature***

Juvenile southern kingfish tolerate a wide range of temperatures. They are rarely seen in temperatures below 15°C and migrate out of shallow waters in September and October (Crowe 1984; Harding and Chittenden 1987).

### ***Dissolved Oxygen***

Little has been reported on the impact of DO levels on juvenile southern kingfish. The lower estuary and surfzone environments may have fewer occurrences of hypoxic and anoxic events compared to upper estuarine habitats. However, southern kingfish do have a relatively fast growth rate (Hildebrand and Cable 1934; Bearden 1963; Crowe 1984) and likely contributes to the elevated metabolic rate (Horodysky et al. 2011) and increased oxygen consumption.

### ***Feeding Behavior***

Juveniles are benthic foragers and use a single barbel to detect prey. The juvenile diet consists of nematodes, polychaete worms, mysid shrimp, penaeid shrimp, isopods, amphipods, copepods, fishes, and detritus (Welsh and Breder 1923; Bearden 1963).

### ***Competition and Predation***

No study has looked at competition and predation of juvenile southern kingfish but the juveniles likely compete with gulf and northern kingfishes and other sciaenids (spot, Atlantic croaker, red drum, and black drum) (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963).

## **Part D. Adult Habitat**

Adults are schooling fish that reside in both estuarine and nearshore Atlantic Ocean habitats. Adult southern kingfish are typically found over clean, sandy sediment with some reports of southern kingfish found over muddy and shell bottoms. Warming of coastal waters in the spring keys migration northward from the wintering grounds (Smith and Wenner 1985). Southern kingfish migrate generally southward as temperatures decline in the fall (Smith and Wenner 1985).



### ***Geographic and Temporal Patterns of Migration***

Most southern kingfish mature after their first winter (Smith and Wenner 1985; Collier et al. in prep). Adults undertake seasonal migrations south and offshore in fall and winter and north and inshore during spring and summer (Irwin 1971; Smith and Wenner 1985; Beresoff and Schoolfield 2002). Summer inshore habitats are from the estuary to continental shelf in depths between <5–30 m (Harding and Chittenden 1987). Although it is not clear at which depth overwintering occurs, southern kingfish have been captured in depths up to 54 m in the late fall (Bearden 1963).

### ***Salinity***

Adult southern kingfish occur primarily in nearshore ocean or lower estuarine habitats and salinities are near full seawater.

### ***Substrate***

Southern kingfish are typically found over sandy or muddy-sand substrates in the ocean, bays, and estuaries (Irwin 1971; Harding and Chittenden 1987).

### ***Temperature***

Temperature appears to be a driving factor in the movement of southern kingfish. They have reported temperature tolerances of 7–33°C (Irwin 1971; Crowe 1984). In areas south of Cape Hatteras, southern kingfish are more commonly seen in temperatures >15°C (Irwin 1971).

### ***Dissolved Oxygen***

Adults likely experience normoxic conditions, as they typically are found in lower estuary or nearshore ocean. Without any explicit studies of adult southern kingfish DO tolerances or preferences, DO requirements might be inferred from other sciaenids with overlapping habitat occurrences southern kingfish have high metabolic rates (Horodysky et al. 2011) and may be more sensitive to low DO conditions.

### ***Feeding Behavior***

Adult southern kingfish are benthic feeders that consume fishes (including silversides, anchovies, star drum, and tonguefish), *Squilla*, *Crangon*, Penaeid shrimp, mysids, polychaete worms, and copepods in the South Atlantic Bight (Irwin 1971; Woodland et al. 2011).

### ***Competition and Predation***

Competition among adults is not well known. Based on reports, southern kingfish overlap their distribution with northern and gulf kingfishes; however the diet of gulf kingfish appears to be much more specialized. The diet of southern and northern kingfishes indicate niche segregation is present. However, southern kingfish diets did overlap with smooth dogfish and clearnose skates (Woodland et al. 2011). Other potential competitors include other members of the sciaenid family and Florida pompano.

Kingfish spp. otoliths have been observed in the stomachs of cetaceans (Tyner 2004) and likely predators include larger sciaenids and coastal sharks.

## **Section II. Essential Fish Habitats and Habitat Areas of Particular Concern**

### ***Essential Fish Habitat***

Unlike northern kingfish, southern kingfish are more abundant in the South Atlantic Bight in slightly deeper waters (27 m vs. 20 m for northern kingfish) (Welsh and Breder 1923; Bearden 1963; Schaefer 1965; Harding and Chittenden 1987; Miller et al. 2002). However, both species are found near inlets and nearshore ocean habitats, although the peak range of abundance is spatially separated, there is a high degree of habitat overlap between northern and southern kingfishes.

Southern kingfish use a variety of habitats in lower reaches of estuaries and nearshore oceanic habitats. They are observed over sand, mud, and shell substrates in the surfzone, nearshore ocean, bays, estuaries, and sounds (Bearden 1963; Harding and Chittenden 1987).

### ***Identification of Habitat Areas of Particular Concern***

There is no HAPC designation for southern kingfish.

### ***Present Condition of Habitat Areas of Particular Concern***

The quality of southern kingfish habitats has been compromised largely by impacts resulting from human activities. It is generally assumed that these habitats have undergone some degree of loss and degradation; however, few studies quantify the magnitude of habitat lost or degradation.

Loss due to water quality degradation is evident in the northeast Atlantic coast estuaries. The New York Bight, for example, has regularly received deposits of contaminated dredged material, sewage sludge and industrial wastes. These deposits have contributed to oxygen depletion and the formation of large masses of anoxic waters during the summer months, which may reduce the habitat available to southern kingfish.

Some losses have likely occurred due to the intense coastal development that has occurred during the last several decades, although no quantification has been done. Losses have likely resulted from dredging and filling activities that have eliminated shallow water nursery habitat. Further functional losses have likely occurred due to water quality degradation resulting from point and non-point discharge sources. Intensive conversion of coastal wetlands to agricultural use also is likely to have contributed to functional loss of southern kingfish nursery area habitat. Other functional loss of riverine and estuarine areas may have resulted from changes in water discharge patterns resulting from withdrawals or flow regulation. Estuarine nursery areas for southern kingfish, as well as adult spawning and pre-spawning areas, may be affected by prolonged exposure to extreme conditions from inland water management practices.

Beach renourishment projects are likely to have an impact on southern kingfish. Kingfish utilize the surfzone to different degrees as they progress through their life stages. Juveniles are localized-residents of the surfzone and lower estuaries (Miller et al. 2002). Southern kingfish were observed to increase in density during a beach renourishment project, potentially attracted to the bioturbation (Wilber et al. 2003). Short-term and long-term monitoring on the effects of beach renourishment is needed to better understand the impacts on kingfish.

### **Section III. Threats and Uncertainties**

#### ***Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Southern Kingfish***

The timing of seasonal and spawning migrations appear to be linked to temperature, as well as their overall distribution within estuarine and coastal ecosystems. As temperatures cool in the fall, southern kingfish move south and offshore to deeper water that is more stable in temperature. They return to northern, inshore habitats as temperatures increase again in the spring and summer (Hildebrand and Schroeder 1928; Bearden 1963; Smith and Wenner 1985; Harding and Chittenden 1987). In the summer, individuals use deeper habitats than northern kingfish over sand, mud, and shell bottomed habitats in lower estuaries and along the continental shelf in depths less than 27 m (Bearden 1963; Harding and Chittenden 1987).

#### ***Unknowns and Uncertainties***

Little research has been conducted on southern kingfish at any life stage and a comprehensive coastwide study that covers their geographic range is needed. The impacts of dredge and fill projects including renourishment projects cannot be fully assessed without additional research to understand habitats that are EFH.

In addition, it is often difficult to distinguish the early stages of kingfish spp., which adds confusion when investigating and determining physiological tolerances to environmental conditions. Slight differences in diet and habitat have been described among kingfishes but more work is needed to fully resolve these ecological differences so that they can be implemented into a management perspective.

Another consideration for southern kingfish is that they forage within and along the sediment of the benthos, which concentrates hydrophobic toxicants, potentially increasing their exposure to these contaminants. No known research has examined the impacts of toxicant exposure on early stage southern kingfish, which may have developmental or reproductive implications.

### **Section IV. Recommendations for Habitat Management and Research**

#### ***Habitat Management Recommendations***

Currently, southern kingfish are not managed through the Interstate Fisheries Management Program (ASMFC 2014). The following recommendations are based on recommendations made in NCDMF 2007 and FMPs for other sciaenids:

1. Protect known nursery areas from activities likely to negatively impact southern kingfish.
2. Integrate beach and inlet management plans into a coastwide plan that minimizes impacts to the habitat of kingfishes and other estuarine fishes.
3. Require beach renourishment and dredge and fill projects adhere to state, regional, or national policies and require robust monitoring before and after dredge, renourishment, and fill activities.
4. Modify stormwater rules or policies to more effectively reduce the volume and pollutant loading of stormwater runoff entering coastal waters.

5. Minimize contamination of bottom sediments through protection and enhancement of wetlands utilizing regulatory and non-regulatory measures, such as land use planning, land acquisition, vegetated buffers, and permitting regulations.
6. Implement and enforce sediment compatibility criteria for beach nourishment projects.

### ***Habitat Research Recommendations***

Currently, southern kingfish are not managed through the Interstate Fisheries Management Program (ASMFC 2014). The following recommendations are based on recommendations made in NCDMF 2007 and FMPs for other sciaenids to improve our understanding of the biology, habitat use, and potential stressors of southern kingfish.

1. Conduct studies to delineate southern kingfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc.) and enable quantification of spawning habitat.
2. Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
3. Define restrictions necessary for implementation of projects in spawning and overwintering areas and develop policies on limiting development projects seasonally or spatially.
4. Recommend BACI studies for beach renourishment projects to describe the impact/benefit of renourishment.
5. Develop consistent methods for studying impact of beach renourishment to allow for comparison spatially and temporally.
6. Determine impact of beach stormwater outfalls on kingfish populations.
7. Determine impact of bottom disturbing gear on kingfish spawning, nursery, and feeding habitats.
8. Assess the distribution, concentration, and threat of heavy metals and other toxic contaminants in freshwater and estuarine sediments and identify the areas of greatest concern to focus water quality improvement efforts.

### **Literature Cited**

- ASMFC (Atlantic State Marine Fisheries Commission). 2014. Sheepshead Fishery Overview. South Atlantic State/Federal Management Board.
- Bearden, C. W. 1963. A contribution to the biology of the king whiting, genus *Menticirrhus* of South Carolina. Contributions of Bears Bluff Laboratory 38: 1–27.
- Beresoff, D. and J. H. Schoolfield. 2002. Movements of Kingfishes off North Carolina. NC Sea Grant 99-FEG-03.

- Chao, L. N and J. A. Musick. 1977. Life history, feeding habits, and functional morphology of the juvenile sciaenid fishes in the York River Estuary. *Fishery Bulletin* 75: 657–702.
- Cowan Jr., J. H., R. S. Birdsong, E. D. Houde, J. S. Priest, W. C., Sharp and G. B. Mateja. 1992. Enclosure experiments on survival and growth of black drum eggs and larvae in lower Chesapeake Bay. *Estuaries* 15(3): 392–402.
- Crowe, B. J. 1984. Distribution, length-frequency data of southern kingfish, *Menticirrhus americanus*, in Mississippi. *Fishery Bulletin* 82: 427–434.
- Dahlberg, M. D. 1972. An ecological study of coastal fishes. *Fishery Bulletin* 70: 323–354.
- Flores-Coto, C., P. Figueroa and F. Zavala Garcia. 1999. Distribution and abundance of Sciaenidae larvae in the water column in the southern Gulf of Mexico. *Hidrobiologica* 9: 135–144.
- Harding, S. M., and M. E. Chittenden Jr. 1987. Reproduction, movements, and population dynamics of the southern kingfish, *Menticirrhus americanus*, in the Northwestern Gulf of Mexico. NOAA Technical Report National Marine Fisheries Service 49: 1–21.
- Hildebrand, S. F. and L. E. Cable. 1934. Reproduction and development of whiting or kingfishes, drums, spot, croaker, and weakfishes or seatrouts, family Sciaenidae, of the Atlantic coast of the United States. *Bulletin of U.S. Bureau of Fisheries* 48: 41–117.
- Hildebrand, S. F. and W. C. Schroeder. 1928. The fishes of the Chesapeake Bay. *Bulletin of U.S. Bureau of Fisheries* 43: 1–388.
- Horodysky, A. Z., R. W. Brill, P. G. Bushnell, J. A. Musick and R. J. Latour. 2011. Comparative metabolic rates of common western North Atlantic Ocean sciaenid fishes. *Journal of Fish Biology* 79: 235–255.
- Irwin, R. J. 1971. Geographical variation, systematics, and general biology of shore fishes of the genus *Menticirrhus*, family Sciaenidae. Ph.D. Dissertation. Tulane University, New Orleans, LA. pp. 295.
- Markovsky, W. C. 2009. The role of the Cape Fear River discharge plume in fisheries production: aggregation and trophic enhancement. M.S. Thesis. University of North Carolina, Wilmington, NC. pp. 74.
- Miller, M. J., P. M. Rowe and K. W. Able. 2002. Occurrence and growth rates of young-of-year northern kingfish, *Menticirrhus saxatilis*, on ocean and estuarine beaches in southern New Jersey. *Copeia* 2002: 815–823.
- NCDMF (North Carolina Division of Marine Fisheries). 2007. North Carolina Fishery Management Plan: Kingfish. pp. 243.
- Olney, J. E. and G. W. Boehlert. 1988. Nearshore ichthyoplankton associated with seagrass beds in the lower Chesapeake Bay. *Marine Ecology Progress Series* 45: 33–43.
- Purcell, J. E. 1985. Predation on fish eggs and larvae by pelagic cnidarians and ctenophores. *Bulletin of Marine Science* 37: 739–755.
- Ralph, D. E. 1982. Biological and fisheries data on the northern kingfish, *Menticirrhus saxatilis*. NOAA Technical Series Report No. 27.
- Reiss, C. S. and J. R. McConaugha. 1999. Cross-frontal transport and distribution of ichthyoplankton associated with Chesapeake Bay plume dynamics. *Continental Shelf Research* 19: 151–170.

- Smith, J. W. and C. A. Wenner. 1985. Biology of the southern kingfish in the South Atlantic Bight. *Transactions of the American Fisheries Society* 114: 356–366.
- Tyner, C. E. 2004. Development of an otolith-based taxonomic key of North Carolina coastal fishes for identifying the dietary remains of piscivorous predators. Honors Thesis, University of North Carolina, Wilmington, NC.
- Welsh, W. W. and C. M. Breder. 1923. Contributions to the life histories of Sciaenidae of the eastern United States coast. *Bulletin of U.S. Bureau of Fisheries* 39: 141–201.
- Wilber, D. H., D. G. Clarke, G. L. Ray and M. Burlas. 2003. Response of surf zone fish to beach nourishment operations on the northern coast of New Jersey, USA. *Marine Ecology Progress Series* 250: 231–246.
- Woodland, R. J., D. H. Secor and M. E. Wedge. 2011. Trophic resource overlap between small elasmobranchs and sympatric teleosts in Mid-Atlantic Bight nearshore habitats. *Estuaries and Coasts* 34: 391–404.

## CHAPTER 10: GULF KINGFISH

### **Section I. General Description of Habitat**

Gulf kingfish are found in coastal areas from Chincoteague, Virginia to Rio Grande, Brazil and are most common south of Cape Hatteras and in the Gulf of Mexico (Irwin 1971). This species prefers surfzone habitats and oceanic habitats <10 m deep (Welsh and Breder 1923; Bearden 1963; Irwin 1971). Gulf kingfish are rarely found in habitats other than the nearshore-ocean unlike southern and northern kingfishes which utilize estuarine habitats along with the nearshore ocean.

### **Part A. Spawning Habitat**

#### ***Geographic and Temporal Patterns of Migration***

Gulf kingfish are thought to migrate inshore and northward from their overwintering habitats during the spring and summer while spawning is occurring (Hildebrand and Cable 1934). Fish in spawning condition have been observed from April through September in North Carolina (Collier in prep; Hildebrand and Cable 1934; Bearden 1963; Modde 1980). Spawning occurs in the shallow nearshore ocean (Irwin 1971; Braun and Fontoura 2004).

#### ***Salinity***

Adult gulf kingfish spawn in the nearshore-ocean where the waters are at full salinity (Braun and Fontoura 2004).

#### ***Substrate***

The spawning habitat has not been described for gulf kingfish but spawners are typically found over sandy bottoms (Hildebrand and Cable 1934; Bearden 1963).

#### ***Temperature***

Gulf kingfish migrate based on temperature and nearshore ocean during the spawning season. They have been observed in temperatures from 10–31°C (Irwin 1971). Little research has been conducted on temperature preferences for spawning gulf kingfish but based on the temperatures where juveniles are observed spawning likely occurs between 18 and 30°C.

#### ***Dissolved Oxygen***

Preferences for DO have not been reported for adult and spawning gulf kingfish. Based on suspected spawning locations, low DO and hypoxic conditions are likely rare.

#### ***Feeding Behavior***

Diets were described during the summer months, which includes the spawning season. The diet of gulf kingfish is more specialized than northern and southern kingfishes likely due to their more limited habitat range and molar-like pharyngeal teeth. Gulf kingfish diet includes mole crabs, *Donax*, polychaetes, brachyurans, stomatopod, *Squilla*, and fishes (Bearden 1963; McMichael and Ross 1987).

#### ***Competition and Predation***

Competitors likely include other members of sciaenid family, especially other benthic sciaenids (southern and northern kingfishes, spot, Atlantic croaker, red drum, and black drum) based on diet and habitat overlap. No studies have reported on competition or predation of spawning gulf kingfish, though

adult competition and predation descriptions apply to spawners, particularly because the long spawning season.

## **Part B. Egg and Larval Habitat**

The eggs of gulf kingfish are likely buoyant and water column is the primary habitat. Research has not been conducted on egg and larval development.

Larvae of gulf kingfish are defined as kingfish <25 mm SL although the size of transition is not clearly defined (Hildebrand and Cable 1934). It is likely the nursery habitats for gulf kingfish extend from the nearshore ocean to the surfzone since the greatest concentration of larvae occur in these areas (Bearden 1963; Irwin 1971; Modde 1980).

### ***Geographic and Temporal Patterns of Migration***

Mature gulf kingfish spawn in the nearshore ocean (Braun and Fontoura 2004). Eggs are likely subjected to a variety of environmental conditions due to the protracted spawning season and broad geographic distribution from Florida to Virginia (Bearden 1963).

Gulf kingfish larvae are widely distributed in nearshore-ocean waters and surfzone (Bearden 1963; Irwin 1971). It is likely the larval transport of gulf kingfish is through longshore currents.

### ***Salinity***

Salinity preferences/tolerances have not been reported for gulf kingfish eggs but larvae and juveniles of gulf kingfish are rarely reported in areas other than nearshore ocean and surfzone. It is not known if eggs can tolerate salinities less than full strength seawater, but larvae and juvenile gulf kingfish are rare in lower salinity estuarine systems. Larvae likely tolerate a narrow range of salinities based on their primarily oceanic distribution (Bearden 1963).

### ***Substrate***

Like many marine fish eggs, gulf kingfish eggs are pelagic and found in nearshore or lower estuarine waters, and thus substrate is not likely encountered. When larvae are planktonic, the larvae would not come in contact with the substrate over which they are dispersed but when larvae settle, they likely settle on sand substrate similar to the substrate used by juveniles.

### ***Temperature***

Minimum temperature is likely the main driver of gulf kingfish reproduction and thus a necessary condition for egg development. Gulf kingfish are uncommon under 20°C (Bearden 1963) in the nearshore ocean, which is the spawning location (Braun and Fontoura 2004). Based on average ocean temperatures for months listed as spawning times, gulf kingfish likely spawn at temperatures between 18–27°C, which is the likely preferred temperature range for eggs and larvae.

### ***Dissolved Oxygen***

DO is probably not an issue for short-lived gulf kingfish eggs that likely remain buoyant and pelagic, and thus out of hypoxic and anoxic zones. Due to the likely short larval duration and oceanic habitat, it is unlikely that they encounter any habitats in which DO imposes a limitation or threat.



### ***Feeding Behavior***

Gulf kingfish eggs subsist entirely off the yolk sac prior to hatching. The feeding behaviors of larvae have not been described. Additional research is needed, but the behaviors are likely similar to other sciaenids in that they feed on planktonic organisms, primarily copepods.

### ***Competition and Predation***

Gulf kingfish eggs likely do not enter into any meaningful ecological competition, as their habitat demands are basic (and largely met by the offshore conditions). Predation of eggs undoubtedly occurs but has not been well studied or reported. Although potentially large numbers of eggs are killed from predation, there is no initial reason to think that pelagic oceanic predators are targeting gulf kingfish eggs over other, similar pelagic eggs. Gelatinous zooplankton are the likely predators of gulf kingfish eggs and larvae (Purcell 1985; Olney and Boehlert 1988; Cowan et al. 1992).

No study has examined competition and predation of larval gulf kingfish but the larval probably compete with northern and southern kingfishes (McMichael and Ross 1987) and other sciaenids including spot, Atlantic croaker, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963). Some competition likely takes place when a high-density larval patch settles on limited habitat; however, the wide range of settled habitats and protracted spawning season suggest that widespread competition is unlikely.

### **Part C. Juvenile Habitat**

Juveniles are between the sizes of 25 and 150 or 230 mm SL (upper size varies between sexes). Juvenile gulf kingfish inhabit the nearshore ocean and surfzone. Gulf kingfish are summer residents of the surfzone (Ross and Lancaster 2002; Felix et al. 2007; Branson 2009).

### ***Geographic and Temporal Patterns of Migration***

Juvenile gulf kingfish use the surfzone in late spring and early summer and move to deeper waters as temperatures cool (Braun and Fontoura 2004). Gulf kingfish tend to remain in localized areas throughout the summer (Ross and Lancaster 2002; Felix et al. 2007; Branson 2009).

### ***Salinity***

Juveniles migrate to deeper waters as they get larger (Braun and Fontoura 2004). By the fall most gulf kingfish migrate out of the nearshore ocean environment to the deeper ocean habitats to overwinter (Bearden 1963) and therefore remain at full marine salinity. There are also few reports of gulf kingfish being caught in estuaries (Bearden 1963; Irwin 1971; Branson 2009).

### ***Substrate***

Juveniles are typically observed over sandy sediment in surfzone environments (Hildebrand and Cable 1934; Irwin 1971; Ross and Lancaster 2002).

### ***Temperature***

Juvenile gulf kingfish tolerate a wide range of temperatures. Juvenils are rarely found in temperatures below 20°C and migrate out of shallow waters in September and October (Bearden 1963; Modde 1980).

### ***Dissolved Oxygen***

Little has been reported on the impact of DO levels on juvenile gulf kingfish. The surfzone environment may have fewer occurrences of hypoxic and anoxic events compared to estuarine habitats.

### ***Feeding Behavior***

Juvenile gulf kingfish are typically described as benthic foragers. They use their barbel to detect prey and their molar-like pharyngeal teeth to crush shells. The juvenile diet consists of bivalve siphon tips, cumaceans, copepods, mysids, and amphipods, and polychaetes (Bearden 1963; McMichael and Ross 1987). Juveniles appear to atrophy their swimbladder at smaller size than other kingfishes and likely switch to a more benthic diet at smaller sizes.

### ***Competition and Predation***

No study has looked at competition and predation of juvenile gulf kingfish but the juveniles compete with northern and southern kingfishes (McMichael and Ross 1987) and other sciaenids such as spot, Atlantic croaker, red drum, and black drum (Ralph 1982) as well as Florida pompano and silversides in the surfzone (Bearden 1963).

## **Part D. Adult Habitat**

Adult gulf kingfish reside in nearshore Atlantic Ocean habitats. Adults are typically found over clean sandy sediment with few reports of gulf kingfish found in estuarine habitats. Most gulf kingfish mature after their first winter (Collier et al. in prep). Warming of coastal waters in the spring keys migration inshore and northward from the wintering grounds. Adults migrate generally offshore and southward as temperatures decline in the fall.

### ***Geographic and Temporal Patterns of Migration***

Adults undergo seasonal migrations south and offshore in fall and winter and north and inshore during spring and summer (Irwin 1971). Although it is not clear the depth at which overwintering occurs, gulf kingfish have been captured in depths of 27 m in the Gulf of Mexico during the winter (Irwin 1971). Adults migrate inshore from deeper habitats for spawning (Braun and Fontoura 2004).

### ***Salinity***

Adult gulf kingfish occur primarily in nearshore ocean habitats where salinities are near full seawater.

### ***Substrate***

Gulf kingfish are typically found over sandy substrates in the nearshore ocean and surfzone.

### ***Temperature***

Temperature appears to be a driving factor in the movement of gulf kingfish. Gulf kingfish have reported temperature tolerances of 10–31°C (Irwin 1971) and are rarely observed in temperatures <20°C (Bearden 1963).

### ***Dissolved Oxygen***

Adults likely experience normoxic conditions, as they are found in the nearshore ocean. Without any explicit studies of adult gulf kingfish DO tolerances or preferences, values might be inferred from other sciaenids that have overlapping habitat occurrences. Like other kingfishes, gulf kingfish have high

metabolic rates (Horodysky et al. 2011), which suggests that they are more sensitive to low DO than other sciaenids.

### ***Feeding Behavior***

The diet has been reported to include: whole *Donax*, polychaetes, *Emerita*, brachyurans, *Squilla*, and fishes (Bearden 1963; McMichael and Ross 1987).

### ***Competition and Predation***

Competition among adult gulf kingfish is not well known. Based on reports, gulf kingfish overlap their distribution with southern and northern kingfishes (McMichael and Ross 1987); however the diet of gulf kingfish appears to be much more specialized than the other kingfishes. Other potential competitors include other members of the sciaenid family and Florida pompano. Kingfish spp. otoliths have been observed in the stomachs of cetaceans (Tyner 2004) and likely predators include larger sciaenids and coastal sharks.

## **Section II. Essential Fish Habitats and Habitat Areas of Particular Concern**

### ***Essential Fish Habitat***

Unlike northern and southern kingfishes, gulf kingfish are more abundant in surfzone habitats and rarely venture into the lower reaches of estuaries in depths less than 10 m (Welsh and Breder 1923; Bearden 1963; Irwin 1971). Gulf kingfish are observed over sand substrates almost exclusively in the surfzone (Hildebrand and Cable 1934; Irwin 1971; Branson 2009).

### ***Identification of Habitat Areas of Particular Concern***

There is no HAPC designation for gulf kingfish.

### ***Present Condition of Habitat Areas of Particular Concern***

The quality of gulf kingfish habitats has been compromised largely by impacts resulting from human activities. It is generally assumed that these habitats have undergone some degree of loss and degradation; however, few studies quantify the impacts of habitat loss or degradation.

Some losses have occurred due to the intense coastal development that has occurred during the last several decades, although this has not been quantified. Losses have resulted from dredging and filling activities that have eliminated shallow water nursery habitats. Further functional losses have occurred due to water quality degradation due to discharges from point and non-point sources.

Beach renourishment projects are likely to have an impact on gulf kingfish. Kingfishes utilize the surfzone to different degrees as they progress through their life stages. Juveniles are localized-residents of the surfzone (Ross and Lancaster 2002; Felix et al. 2007) and are found in few other habitats. Short-term and long-term monitoring on the effects of beach renourishment is needed to better understand the impacts on kingfish.

### **Section III. Threats and Uncertainties**

#### ***Significant Environmental, Temporal, and Spatial Factors Affecting Distribution of Gulf Kingfish***

The timing of seasonal and spawning migrations appear to be linked to temperature. As temperatures cool in the fall, gulf kingfish move south and offshore to deeper water that is more stable in temperature. They return to northern, inshore habitats as temperatures increase again in the spring and summer (Irwin 1971). When gulf kingfish are nearshore, they remain in the coastal surfzone full marine salinity and rarely move into estuarine environments (Bearden 1963; Irwin 1971). Gulf kingfish prefer sandy substrates (Irwin 1971; Ross and Lancaster 2002).

#### ***Unknowns and Uncertainties***

Little research has been conducted on gulf kingfish at any life stage and a comprehensive coastwide study that covers their geographic range is needed. The impacts of dredge and fill projects including renourishment projects cannot be fully assessed without additional research to understand which habitats are EFH.

In addition, it is often difficult to distinguish the early stages of kingfish spp., which adds confusion when investigating and determining physiological tolerances to environmental conditions. Slight differences in diet and habitat have been described among kingfishes but more work is needed to fully resolve these ecological differences so that they can be implemented into a management perspective.

Another consideration for gulf kingfish is that they forage within and along the sediment of the benthos, which concentrates hydrophobic toxicants, potentially increasing their exposure to these contaminants. No known research has examined the impacts of toxicant exposure on early stage gulf kingfish, which may have developmental or reproductive implications.

### **Section IV. Recommendations for Habitat Management and Research**

#### ***Habitat Management Recommendations***

Currently, gulf kingfish are not managed through the Interstate Fisheries Management Program (ASMFC 2014). The following recommendations are based on recommendations made in NCDMF 2007 and FMPs for other sciaenids:

1. Protect known nursery areas from activities likely to negatively impact gulf kingfish.
2. Integrate beach and inlet management plans into a coastwide plan that minimizes impacts to the habitat of kingfishes and other estuarine fishes.
3. Require beach renourishment and dredge and fill projects adhere to state, regional, or national policies and require robust monitoring before and after dredge, renourishment, and fill activities.
4. Modify stormwater rules or policies to more effectively reduce the volume and pollutant loading of stormwater runoff entering coastal waters.

5. Minimize contamination of bottom sediments through protection and enhancement of wetlands utilizing regulatory and non-regulatory measures, such as land use planning, land acquisition, vegetated buffers, and permitting regulations.
6. Implement and enforce sediment compatibility criteria for beach nourishment projects.

### ***Habitat Research Recommendations***

Currently, gulf kingfish are not managed through the Interstate Fisheries Management Program (ASMFC 2014). The following recommendations are based on recommendations made in NCDMF 2007 and FMPs for other sciaenids to improve our understanding of the biology, habitat use, and potential stressors of gulf kingfish.

1. Conduct studies to delineate gulf kingfish spawning habitat locations and environmental preferences (temperature, depth, substrate, etc.) and enable quantification of spawning habitat.
2. Compile existing data on larval and juvenile distribution from existing databases in order to obtain preliminary indications of spawning and nursery habitat location and extent.
3. Define restrictions necessary for implementation of projects in spawning and overwintering areas and develop policies on limiting development projects seasonally or spatially.
4. Recommend BACI studies for beach renourishment projects to describe the impact/benefit of renourishment.
5. Develop consistent methods for studying impact of beach renourishment to allow for comparison spatially and temporally.
6. Determine impact of beach stormwater outfalls on kingfish populations.
7. Determine impact of bottom disturbing gear on kingfish spawning, nursery, and feeding habitats.
8. Assess the distribution, concentration, and threat of heavy metals and other toxic contaminants in freshwater and estuarine sediments and identify the areas of greatest concern to focus water quality improvement efforts.

### **Literature Cited**

- ASMFC (Atlantic State Marine Fisheries Commission). 2014. Sheepshead Fishery Overview. South Atlantic State/Federal Management Board.
- Bearden, C. W. 1963. A contribution to the biology of the king whiting, genus *Menticirrhus* of South Carolina. Contributions of Bears Bluff Laboratory 38: 1–27.
- Branson, A. 2009. A comparison of fish assemblages utilizing estuarine and ocean surf habitats in southeastern North Carolina. M.S. Thesis. University of North Carolina, Wilmington, NC. pp. 59.
- Braun, A. S. and N. F. Fontoura. 2004. Reproductive biology of *Menticirrhus littoralis* in southern Brazil (Actinopterygii: Perciformes: Sciaenidae). Neotropical Ichthyology 2: 31–36.

- Cowan Jr., J. H., R. S. Birdsong, E. D. Houde, J. S. Priest, W. C., Sharp and G. B. Mateja. 1992. Enclosure experiments on survival and growth of black drum eggs and larvae in lower Chesapeake Bay. *Estuaries* 15(3): 392–402.
- Felix, F. C., H. L. Spach, P. S. Moro, R. Schwarz Jr., C. Santos, C. W. Hackradt and M. Hostim-Silva. Utilization patterns of surf zone inhabiting fish from beaches in southern Brazil. *Pan-American Journal of Aquatic Sciences* 2: 27–39.
- Hildebrand, S. F. and L. E. Cable. 1934. Reproduction and development of whiting or kingfishes, drums, spot, croaker, and weakfishes or seatrouts, family Sciaenidae, of the Atlantic coast of the United States. *Bulletin of U.S. Bureau of Fisheries* 48: 41–117.
- Horodysky, A. Z., R. W. Brill, P. G. Bushnell, J. A. Musick and R. J. Latour. 2011. Comparative metabolic rates of common western North Atlantic Ocean sciaenid fishes. *Journal of Fish Biology* 79: 235–255.
- Irwin, R. J. 1971. Geographical variation, systematics, and general biology of shore fishes of the genus *Menticirrhus*, family Sciaenidae. Ph.D. Dissertation. Tulane University, New Orleans, LA. pp. 295.
- McMichael Jr., R. H. and S. T. Ross. 1987. The relative abundance and feeding habits of juvenile kingfish (Sciaenidae: *Menticirrhus*) in a Gulf of Mexico surf zone. *Northeast Gulf Sciences* 9: 109–123.
- Modde, T. 1980. Growth and residency of juvenile fishes within a surf zone habitat in the Gulf of Mexico. *Gulf Research Reports* 6: 377–385.
- NCDMF (North Carolina Division of Marine Fisheries). 2007. North Carolina Fishery Management Plan: Kingfish. pp. 243.
- Olney, J. E. and G. W. Boehlert. 1988. Nearshore ichthyoplankton associated with seagrass beds in the lower Chesapeake Bay. *Marine Ecology Progress Series* 45: 33–43.
- Purcell, J. E. 1985. Predation on fish eggs and larvae by pelagic cnidarians and ctenophores. *Bulletin of Marine Science* 37: 739–755.
- Ralph, D. E. 1982. Biological and fisheries data on the northern kingfish, *Menticirrhus saxatilis*. NOAA Technical Series Report No. 27.
- Ross, S. W. and J. E. Lancaster. 2002. Movements and site fidelity of two juvenile fish species using surf zone nursery habitats along the southeastern North Carolina coast. *Environmental Biology of Fishes* 63: 161–172.
- Tyner, C. E. 2004. Development of an otolith-based taxonomic key of North Carolina coastal fishes for identifying the dietary remains of piscivorous predators. Honors Thesis, University of North Carolina, Wilmington, NC.
- Welsh, W. W. and C. M. Breder. 1923. Contributions to the life histories of Sciaenidae of the eastern United States coast. *Bulletin of U.S. Bureau of Fisheries* 39: 141–201.

## Chapter 11: THREATS TO ATLANTIC SCIAENID HABITATS

### **Section I. Identification of Threats**

The habitat threats that are outlined below pertain to the Atlantic sciaenids outlined in this document, although certain species and life stages may be more impacted than others. All of the Atlantic sciaenids have life stages that are estuarine-dependent, as nurseries or seasonal foraging areas (Murdy and Musick 2013; Deary and Hilton 2016).

#### ***Threat 1: Beach renourishment***

Source of Threat: Human activities to contribute more sediment to recreational beaches and provide material for infill. The threats of beach renourishment on sciaenids is from removal of preferred substrate (particularly sediment size), burial of individuals and potential prey, changes in prey community (Irlandi and Arnold 2008), increased turbidity (Green 2002; Peterson and Bishop 2005), and release of toxicants buried in sediments. Although beach renourishment can impact all sciaenids through increased turbidity, which can decrease the visual abilities of sciaenids, but renourishment projects probably affect benthic associated sciaenids (red drum, spot, Atlantic croaker, kingfishes, black drum) since they spend most of their lives associated with the benthos.

Rank of Threat: According to the ASMFC's Interstate Fishery Management Plan for Red Drum (2002), the impacts of beach renourishments were ranked as **Medium**.

#### ***Threat 2: Degradation of water quality (Pollutants, nutrient enrichment, sediment loading, hypoxia)***

Source of Threat: Human activities in many cases are the sources of water quality degradation. Industrial waste accumulates in bottom sediments and can be disturbed during dredging and beach renourishment projects (Riggs et al. 1991). Many coastal estuarine systems due to their proximity to industrial areas and sediment characteristics are susceptible to toxicant contamination (Street et al. 2005). In Atlantic croaker, toxicants have been noted to significantly reduce growth rates and condition (Burke et al. 1993), which are likely to be observed in other sciaenids exposed to toxicants. In larval fishes, certain toxicants are known to result in heart failure in developing embryos (Ballachey et al. 2003).

Pollutants and nutrient enrichment can originate from point and non-point discharge sources. Nutrient enrichment is a major threat to estuarine ecosystems, particularly forestry practices, agriculture, pesticides, and fertilizers (ASMFC 2002; NSCEP 1993). In polluted areas, pathogens can start proliferating and cause disease in red drum and other estuarine fishes (Conway et al. 1991). Nutrient enrichment can also reduce the extent and species diversity of SAV (Dennison et al. 1993; Fonseca et al. 1998; SAFMC 1998). The effects of nutrient enrichment are also most pronounced in sheltered, low flow areas susceptible to large temperature fluctuations (Burkholder et al. 1994). Sediment loading can also reduce the coverage of SAV through reduced light penetration in shallow, estuarine systems (Dennison et al. 1993; Fonseca et al. 1998; SAFMC 1998).

Eutrophication can also lead to depleted bottom oxygen conditions (Street et al. 2005). Many sciaenids are mobile and able to move out of hypoxic conditions, which can increase densities in shallow habitats

and subsequent competition and density-dependence in these habitats (Craig et al. 2007; Campbell and Rice 2014). For example, under hypoxic conditions, Atlantic croaker will move out of these areas to shallower areas (Eby and Crowder 2002).

Rank of Threat: According to the ASMFC's Interstate Fishery Management Plan for Red Drum (2002), water quality degradation was ranked as **Medium**.

### ***Threat 3: Coastal Development (Altered shorelines, urbanization, altered hydrology, habitat loss)***

Source of Threat: Coastal development and the infrastructure needed to support human inhabitation of coastal ecosystem have greatly altered aquatic ecosystems through altered flow regimes (damming, increased runoff), channelization, port and marina construction, and boating. In many cases, these alterations to aquatic ecosystems have led to declines in coastal and estuarine habitats that serve as nurseries and foraging grounds for sciaenids, as well as other fishes.

Channelized streams have reduced species diversity, decreasing productivity in these systems (Tarplee et al. 1971; Hawkins 1980; Schoof 1980). The construction of docks and marinas perturb shallow, nearshore habitats and for example reduce the number of Atlantic croaker in these disturbed habitats (Peterson et al. 2000). Shoreline stabilization projects can alter local hydrology and change the physical processes the transport larvae into estuarine systems (Miller et al. 1984; Miller 1988). Activities associated with urbanization can alter freshwater flows and subsequently increase the exposure of fishes to sudden salinity changes (Sefray et al. 1997), which can influence the abundance and distribution of organisms within estuarine ecosystems (Holland et al. 1996).

Increased boating activity leads to increases in underwater noise pollution, seagrass scarring, and increased marina and dock construction. Together, boating can increase stress on fishes and lead to habitat loss seagrass beds that can take at least a decade for recovery to occur (Zieman 1976).

Rank of Threat: **High**

### ***Threat 4: Navigation and Dredging***

Source of Threat: Dredging activities are associated with the construction and maintenance of ports and marinas. Many of the impacts of dredging related activities are from the direct removal of sediment, which degrades many different habitats including soft and hard substrates and SAV (SAFMC 1998; ASMFC 2002). Dredging activities also resuspend sediments, which increases local turbidity and exposure to contaminants. In addition, dredging activities can initiate hypoxic events as well as bury organisms (ASMFC 2002).

Rank of Threat: According to the ASMFC's Interstate Fishery Management Plan for Red Drum (2002), the impacts of navigation and dredging were ranked as **Medium**.

### ***Threat 5: Fishing***

Source of Threat: In addition to losses of abundance as target and bycatch, some fishing gears, particularly dredges and trawls, can impact sciaenid habitats (Essential Fish Habitat Steering Committee



2002). These gears remove epifauna, alter bathymetry, reef distribute substrates, and change organism assemblages. Habitat loss by fishing gears can take months to years to recover.

Rank of Threat: **Medium**

### ***Threat 6: Climate change***

Source of Threat: Climate change involves a complex set of factors such as increasing temperature, sea level rise, increasing carbon dioxide levels, and changing precipitation regimes. Warming of oceanic temperatures can result in fishes spawning earlier than previously reported (USFWS 2011). Increasing temperatures can also expand species ranges, increasing competition in estuarine ecosystems. Rising sea level can flood shallow nursery habitat and accelerate the loss of SAV (Orth et al. 2006; IPCC 2007). Altered precipitation can also change the delivery of freshwater to aquatic ecosystems and can rapidly change salinity in estuarine areas (USFWS 2011).

Rank of Threat: **High**

## **Section II. Effects of Habitat Degradation on Sciaenid Populations**

The above mentioned threats are expected to decrease the spawning and nursery habitats required for sciaenid populations to persist. Disturbed habitats reduce growth likely through increased competition, reduced shelter, and reduced prey availability. In addition, disturbed habitats and increased stress can increase the susceptibility of sciaenids to disease. Since sciaenids are estuarine-dependent fishes (Murdy and Musick 2013), many of their habitats have been disturbed and are in close proximity to urbanized regions.

## **Section III. Recommendations to Mitigate Threats to Sciaenid Habitats**

The following recommendations to mitigate threats to sciaenid habitats have been collated from the Habitat Management Recommendations section found in each species profile within this report (ASMFC 2002, 2012) and the North Carolina Coastal Protection Plan (NCDEQ 2015). In many instances, common recommendations were identified among species.

1. HAPCs locations should be accompanied by requirements that limit degradation of habitat, including minimization of non-point source and specifically storm water runoff, prevention of significant increases in contaminant loadings, and prevention of the introduction of any new categories of contaminants into the area.
2. States should coordinate and enhance the monitoring of water quality and habitat from tributaries to the nearshore ocean. Part of this monitoring should also assess the effectiveness of already established rules that protect these coastal habitats in each state.
3. States should minimize loss of wetlands to shoreline stabilization by using the best available information, incorporating erosion rates, and promoting incentives for use of alternatives to vertical shoreline stabilization measures (e.g., sea walls), commonly referred to as living shorelines projects.

4. Each state should establish windows of compatibility for activities known or suspected to adversely affect sciaenid life stages and their habitats, with particular emphasis to avoid spawning season. Activities may include, but are not limited to, navigational dredging, bridge construction, and dredged material disposal, and notify the appropriate construction or regulatory agencies in writing.
5. The use of any fishing gear that is determined by management agencies to have a negative impact on sciaenid habitat should be prohibited within HAPCs. Further, states should protect vulnerable habitat from other types of non-fishing disturbance as well.
6. States should conduct research to evaluate the role of SAV and habitats in the spawning success, survival, growth, and abundance of sciaenids. This research could include regular mapping of the bottom habitat in identified areas of concern, as well as systematic mapping of this habitat where it occurs in estuarine and marine waters of the states.
7. Restoration efforts should be enacted to restore critical habitats of sciaenids including oyster reefs, riparian wetlands, SAV habitats, barrier island systems, and soft bottom areas.
8. Federal and state fishery management agencies should take steps to limit the introduction of compounds which are known or suspected to accumulate in sciaenid tissues and which pose a threat to human or sciaenid health.
9. Each state should establish windows of compatibility for activities known or suspected to adversely affect sciaenid life states and their habitats, such as navigational dredging, bridge construction and dredged material disposal, and notify the appropriate construction or regulatory agencies in writing.
10. States should identify dams that threaten freshwater flows to nursery and spawning areas, and target them for appropriate recommendations during FERC re-licensing.
11. States need to expand education and outreach activities that explain management measures in place for sciaenids to stress the value of sciaenids and their critical habitats for their sustainability. Emphasis should be used to describe threats from land use and other challenges that sciaenid species face in each state.

### **Literature Cited**

ASMFC (Atlantic States Marine Fisheries Commission). 2002. Amendment II to the Red Drum Interstate Fishery Management Plan. pp. 162.

ASMFC (Atlantic States Marine Fisheries Commission). 2012. Omnibus Amendment to the Interstate Fishery Management Plans for Spanish Mackerel, Spot, and Spotted Seatrout.

Ballachey, B. E., J. L. Bodkin, D. Esler, D. B. Irons, C. H. Peterson, S. D. Rice and J. W. Short. 2003. Review: long-term ecosystem response to the Exxon Valdez Oil Spill. *Science* 302: 2082–2086.

- Burke, J. S., D. S. Peters and P. J. Hanson. 1993. Morphological indices and otolith microstructure of Atlantic croaker, *Micropogonias undulatus*, as indicators of habitat quality along an estuarine pollution gradient. *Environmental Biology of Fishes* 36(1): 25–33.
- Burkholder, J. M., H. B. Glasgow Jr. and J. E. Cooke. 1994. Comparative effects of water-column nitrate enrichment on eelgrass *Zostera marina*, shoalgrass *Halodule wrightii*, and widgeongrass *Ruppia maritima*. *Marine Ecology Progress Series* 105: 121–138.
- Campbell, L. A. and J. A. Rice. 2014. Effects of hypoxia-induced habitat compression on growth of juvenile fish in the Neuse River Estuary, North Carolina, USA. *Marine Ecology Progress Series* 497: 199–213.
- Conway, P. L., S. Kjelleberg, J. C. Olsoon and A. Westerdahl. 1991. Isolation and characterization of turbot (*Scophthalmus maximus*)- associated bacteria with inhibitory effects against *Vibrio anguillarum*. *Applied and Environmental Microbiology* 57(8): 2223–2228.
- Craig, J. K., J. A. Rice, L. B. Crowder and D. A. Nadeau. 2007. Density-dependent growth and mortality in an estuary-dependent fish: an experimental approach with juvenile spot *Leiostomus xanthurus*. *Marine Ecology Progress Series* 343: 251–262.
- Deary, A. L. and E. J. Hilton. 2016. Comparative ontogeny of the feeding apparatus of sympatric drums (Perciformes: Sciaenidae) in the Chesapeake Bay. *Journal of Morphology* 277: 183–195.
- Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. W. Bergstrom and R. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. *Bioscience* 43: 86–94.
- Eby, L. A. and L. B. Crowder. 2002. Hypoxia-based habitat compression in the Neuse River Estuary: context-dependent shifts in behavioral avoidance thresholds. *Canadian Journal of Fisheries and Aquatic Sciences* 59: 952–965.
- Essential Fish Habitat Steering Committee (Northeast Region). 2002. Workshop on the effects of fishing gear on marine habitats off the northeastern United States, October 23–25, 2001, Boston, Massachusetts. Northeast Fisheries Science Center Reference. Document 02-01. pp. 86.
- Fonseca M. S., W. J. Kenworthy and G. W. Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. Silver Spring, MD: National Oceanographic and Atmospheric Administration. NOAA Coastal Ocean Program Decision Analysis Series No 12. pp. 222.
- Green, K. 2002. Beach nourishment: a review of the biological and physical impacts. ASMFC Habitat Management series #7. pp. 174.
- Hawkins, J. H. 1980. Investigations of anadromous fishes of the Neuse River, North Carolina. Division of Marine Fisheries, Morehead City, NC. Special Science Report No. 34. pp. 111.
- Holland, A. F., G. H. M. Riekerk, S. B. Lerberg, L. E. Zimmerman, D. M. Sanger, G. I. Scott and M. H. Fulton. 1996. Assessment of the impact of watershed development on the nursery functions of tidal creek habitats. *In*: G. S. Kleppel and M. R DeVoe (eds) *The South Atlantic Bight Land Use*

- Coastal Ecosystems Study (LU-CES), pp. 28–31. Univ. of Georgia Sea Grant and S.C. Sea Grant Program. Report of a planning workshop.
- IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.” Eds. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller. Cambridge University Press, United Kingdom and New York. pp. 996.
- Irlandi, E. and B. Arnold. 2008. Assessment of nourishment impacts to beach habitat indicator species. Final report to the Florida Fish and Wildlife Conservation Commission for grant agreement No. 05042. pp. 39 + tables and figures.
- Miller, J. M. 1988. Physical processes and the mechanisms of coastal migrations of immature marine fishes. *In*: M.P. Weinstein (ed) Larval fish and shellfish transport through inlets. American Fisheries Society, Bethesda, MD. pp. 68–76.
- Miller, J. M., J. P. Read and L. J. Pietrafesa. 1984. Pattern, mechanisms and approaches to the study of migrations of estuarine-dependent fish larvae and juveniles. *In*: McCleave, J. D., G. P. Arnold, J. J. Dodson and W. H. Neill (eds) Mechanisms of Migrations in Fishes. Plenum Press, NY.
- Murdy, E. O. and J. A. Musick. 2013. Fishes of Chesapeake Bay. Baltimore: Johns Hopkins University Press.
- NCDEQ (North Carolina Department of Environmental Quality). 2015. North Carolina Coastal Habitat Protection Plan. Barrett, T. J., A. S. Deaton, E. F. Hain and J. Johnson (eds). Division of Marine Fisheries. Morehead City, NC.
- NSCEP (National Service Center for Environmental Publications). 1993. Nutrient Enrichment action Agenda (3.2) For the Gulf of Mexico.
- Orth, R. J., T. J. B. Carruthers, W. C. Dennison, C. M. Duarte, J. W. Fourqurean, K. L. Heck Jr., A. R. Hughes, G. A. Kendrick, W. J. Kenworthy, S. Olyarnik, F. T. Short, M. Waycott and S. L. Williams. 2006. A global crisis for seagrass ecosystems. *Bioscience* 56(12): 987–996.
- Peterson, C. H. and M. J. Bishop. 2005. Assessing the environmental impacts of beach nourishment. *Bioscience*. 55(10): 887-896.
- Peterson, M. S., C. F. Rakocinski, B. H. Comyns and G. L. Fulling. 2000. Laboratory growth responses of juvenile *Mugil* sp. to temperature and salinity: delineating optimal field growth conditions. *Proceedings of the Gulf and Caribbean Fisheries Institute* 51: 341–352.
- Riggs, S. R., J. T. Bray, E. R. Powers, J. C. Hamilton, D. V. Ames, K. L. Owens, D. D. Yeates, S. L. Lucas, J. R. Watson and H. M. Williamson. 1991. Heavy metals in organic-rich muds of the Neuse River estuarine system, Albemarle-Pamlico Estuarine Study. Report No. 90–07.
- SAFMC (South Atlantic Fishery Management Council). 1998. Habitat plan for the South Atlantic region: essential fish habitat requirements for fishery management plans of the South Atlantic Fishery Management Council. SAFMC, Charleston, SC. pp. 457 + appendices.

- Schoof, R. 1980. Environmental impact of channel modification. *Journal of the American Water Resources Association* 16(4): 697–701.
- Sefray, J. E. M., K. C. Lindeman, T. E. Hopkins and J. S. Ault. 1997. Effects of freshwater canal discharges on subtropical marine fish assemblages: field and laboratory observations. *Marine Ecology Progress Series* 160: 161–172.
- Street, M. W., A. S. Deaton, W. S. Chappell and P. D. Mooreside. 2005. North Carolina Coastal Habitat Protection Plan. Department of Environment and Natural Resources, Division of Marine Fisheries. Morehead City, NC. pp. 607.
- Tarplee Jr., W. H., D. E. Louder, and A. J. Weber. 1971. Evaluation of the effects of channelization on fish populations in North Carolina's coastal plain streams. North Carolina Wildlife Resources Commission, Raleigh, NC.
- USFWS (U.S. Fish and Wildlife Service). 2011. National fish, wildlife and plants climate adaptation strategy. Washington, DC. pp. 153.
- Zieman, J. C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. *Aquatic Botany* 2: 127–139.

## CHAPTER 12: HABITAT RESEARCH NEEDS FOR SCIAENID SPECIES

### **Section I: General Research Needs for Atlantic Sciaenids**

Many of the research needs for Atlantic sciaenids revolve around understanding changes in habitat use through development. For example, black drum use a variety of habitats as larvae and juveniles, which may buffer them from the effects of habitat degradation, but it is unknown if certain habitats are more critical for black drum (i.e., enhanced growth, decreased mortality) and contribute more to the adult population. In addition, not much is known about the effects of habitat degradation on early life history stages (egg through juveniles), which are often the life stages that are most sensitive to perturbations. Individual research needs for each sciaenid species are outlined in the next section. Research needs for Atlantic sciaenids includes:

1. Identify the location and habitat characteristics of spawning grounds.
2. Determine the physiological tolerances and preferences to environmental variables (temperature, salinity, DO) for each life stage that maximize hatching success, growth, and survival. With these data, predict regions, species, and life stages that will be most susceptible to climate change.
3. Assess the impacts of perturbations to environmental variables on each life stage to understand how water quality degradation may affect spawning, hatching success, growth, and survival. With these data, determine acceptable and unacceptable water quality parameters for spawning and essential habitats.
4. Assess population connectivity along the coast to determine if local extirpation is an issue and if so, identify the species that are most susceptible.
5. Identify essential habitats as well as habitat requirements for each life stage to prioritize areas for conservation.
6. Examine the impacts of toxicant exposure and harmful algal blooms.
7. Assess impacts of habitat alterations from coastal development (urbanization, shoreline armoring, beach renourishment, and dredging) on Atlantic sciaenids at all life stages, particularly examining the effects of increased turbidity, burial, prey availability, and contaminant release on the health, growth, and survival of all life history stages.

### **Section II: Species-Specific Research Needs**

#### ***Atlantic croaker***

1. Assess the impact of hypoxia on the foraging and overall health.

#### ***Black drum***

1. Expand the temporal and spatial coverage of fishery independent surveys to include black drum habitats.

2. Conduct otolith microchemistry studies to identify recruitment contributions of various regions and habitats.

### ***Red drum***

1. Quantify relationships between red drum productivity and habitat at all life stages.
2. Assess the impact of alter freshwater flow regimes on red drum nursery and other essential larval and juvenile habitats.

### ***Spot***

1. Examine potential offshore, pelagic nursery habitats (eddies) and physics the influence the hatching success and distribution of larvae.

### ***Spotted seatrout***

1. Quantify the relationship between SAV and spawning success. In areas where SAV is sparse or absent, identify alternative spawning and nursery habitats.
2. Define overwintering habitat requirements of early stages and adults since this species exhibits high site fidelity.

### ***Weakfish***

1. Examine the impact of water intakes on larval and juvenile mortality in spawning and nursery areas.
2. Quantify the relationship between weakfish productivity and spawning habitat.

### ***Northern kingfish***

1. Determine life history characteristics and diagnostic characters to distinguish among the kingfishes in the early stages in order to determine environmental preferences for each essential habitat from field collections.
2. Monitor the impacts of beach renourishment on northern kingfish at all life stages.
3. Assess competition among kingfishes and other benthic sciaenids.

### ***Southern kingfish***

1. Determine life history characteristics and diagnostic characters to distinguish among the kingfishes in the early stages in order to determine environmental preferences for each essential habitat from field collections.
2. Monitor the impacts of beach renourishment on southern kingfish at all life stages.
3. Assess competition among kingfishes and other benthic sciaenids.

***Gulf kingfish***

1. Determine life history characteristics and diagnostic characters to distinguish among the kingfishes in the early stages in order to determine environmental preferences for each essential habitat from field collections.
2. Monitor the impacts of beach renourishment on gulf kingfish at all life stages.
3. Assess competition among kingfishes and other benthic sciaenids.