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croaker is one of the dominant juvenile fish species in the estuaries (North Carolina Division of Marine Fisheries, unpublished data).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 mortaility 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 (Miglarese 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 (Miglarese 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 (Miglarese et al. 1982). Generally, adults avoid the mid-salinity ranges (Miglarese et al. 1982; Peterson et al. 2004). Mean total length (TL) positively correlates with bottom salinities (Miglarese 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 (Miglarese 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^{-1}. 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^{-1}, 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).

Excerpted from Atlantic Sciaenid Habitats: A Review of Utilization, Threats, and Recommendations for Conservation, Management, and Research

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 (Tarplee 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.

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