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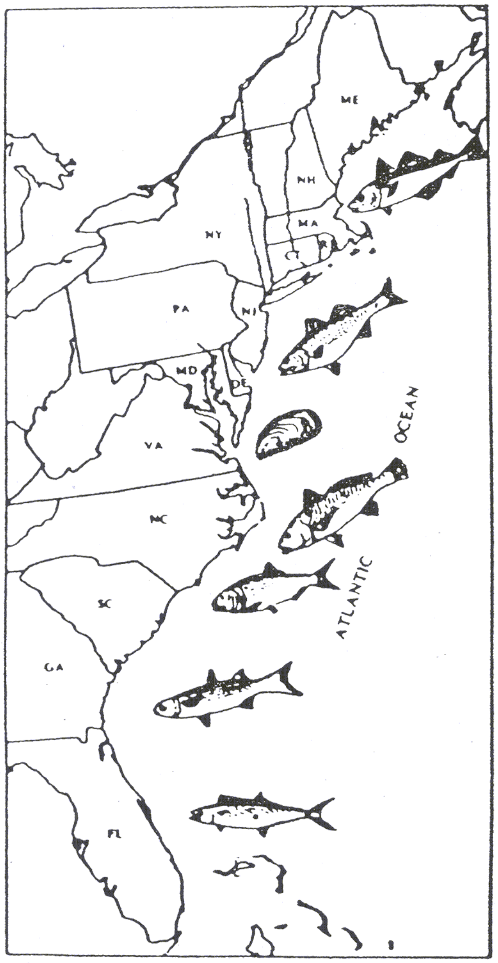

FISHERY MANAGEMENT PLAN FOR ATLANTIC CROAKER

October 1987

FISHERY MANAGEMENT PLAN

FOR

ATLANTIC CROAKER (*Micropogonias undulatus*)

Prepared by

Linda P. Mercer, Project Leader

North Carolina Department of Natural Resources
and Community Development

Division of Marine Fisheries
Morehead City, NC 28557

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1.0 EXECUTIVE SUMMARY

The Atlantic croaker is an important fishery resource along the Atlantic coast, particularly from Maryland to North Carolina. Croaker migrate seasonally, moving into estuarine areas in spring and offshore and south in fall. While inshore, croaker are harvested by a variety of commercial gear, including haul seines, pound nets, gill nets, and trawls, as well as by hook and line in the recreational fishery. During winter croaker are caught offshore in the trawl and gill net fisheries. Commercial catch statistics indicate that croaker landings have fluctuated widely. Landings exceeded 20,000 mt between 1937 and 1940 and in 1945 and declined to <1,000 mt between 1967 and 1971. The most recent peak in landings occurred in 1977 and 1978 at just over 13,000 mt annually. It is notable that recent peaks in landings are only about half the historical peaks. Fluctuations in croaker landings may be related to changes in population abundance, variations in environmental conditions, changes in fishing effort (particularly increased fishing power and recreational effort), and habitat alterations.

The major problem addressed in this management plan is the lack of stock assessment data needed for effective management of the Atlantic croaker resource. Despite the importance of croaker as both a commercial and recreational resource, little is known about its population structure and dynamics. Investigations of life history and fisheries for croaker have generally been localized and conducted at differing levels of population abundance. Catch and, in particular, effort data from both the commercial and recreational fisheries are insufficient to determine the relationship between landings and abundance. An additional possible problem is the incidental bycatch and discard mortality of small croaker in nondirected fisheries.

Atlantic croaker is a migratory species occurring along the Middle Atlantic and South Atlantic coastal states and thus, a cooperative interstate approach to management is needed. The goal of this management plan is to perpetuate the Atlantic croaker resource in fishable abundance throughout its range and generate the greatest economic and social benefits from its commercial and recreational harvest and utilization over time. The following management objectives and measures are recommended for the states of Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida.

The following objectives have been adopted for the achievement of the management goal:

1. Conduct cooperative interstate research to understand the biology of, and fisheries for, croaker.

2. Maintain a spawning stock sufficient to minimize the possibility of recruitment failure and determine the effects of the environment on year class strength.

3. Optimize yield per recruit.

4. Improve collection of catch and standardized effort statistics and description of fishing gears.

5. Promote harmonious use of the resource among various components of the fishery through the coordination of management efforts among the various political entities having jurisdiction over the croaker resource.

6. Promote the cooperative interstate collection of economic, social, and biological data required to effectively monitor and assess management efforts relative to the overall goal.

7. Promote determination and adoption of the highest possible standards of environmental quality.

The following management measures are identified as appropriate for implementation:

1. Promote the development and use of trawl efficiency devices (TEDs) through demonstration in the southern shrimp fishery, and fish separators in the finfish trawl fishery.

2. Promote increases in yield per recruit through delaying entry to croaker fisheries to age one and older.

In order to identify additional management measures, which when implemented will result in attainment of the foregoing objectives, a program of research and data collection should be undertaken as follows:

1. Identify stocks and determine coastal movements and the extent of stock mixing.

2. Collect catch and effort data, including size and age composition of the catch, determine stock mortality throughout the range, and define gear characteristics.

3. Develop and maintain a recruitment index and examine the relationships between parental stock size and environmental factors on year-class strength.

4. Define the reproductive biology of ~~spot~~ Croaker, including size at sexual maturity, fecundity, and spawning periodicity.

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3.0 INTRODUCTION

3.1 Development of the Plan

This fishery management plan for Atlantic croaker, (*Micropogonias undulatus*), was prepared under the Atlantic States Marine Fisheries Commission's (ASMFC) Interstate Fisheries Management Program and is applicable for the following states: Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida. The first phase in the development of this plan was the preparation of a profile summarizing available biological and fisheries information on Atlantic croaker (Section 11.0). The formulation of a goal statement, objectives, research needs, and management measures constituted the second phase of the program. The Sciaenid Technical Committee, consisting of scientists from the state marine fisheries agencies of Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, Florida, the National Marine Fisheries Service (NMFS) Northeast Fisheries Center, NMFS Southeast Fisheries Center and ASMFC provided technical expertise in the development of this plan. General guidance and policy were provided by the South Atlantic State-Federal Board which consists of senior administrators from the state marine fisheries agencies and NMFS.

3.2 Problems Addressed by the Plan

Historical landings of Atlantic croaker, like weakfish and other sciaenids, have fluctuated greatly. Periods of high landings have generally been followed by sudden and precipitous declines in catch. Fluctuations in croaker landings appear to be related to variations in climate and fishing pressure (Perlmutter 1959; Joseph 1972; Norcross 1983). The reasons behind fluctuations in catch require further investigation.

The incidental bycatch and discard mortality of small croaker in nondirected fisheries such as the southern shrimp fishery, and the scrap catch of croaker from the pound net, long haul seine, and trawl fisheries have been cited as potentially having significant impacts on croaker stocks. The magnitude of this problem needs to be more precisely determined. Possible solutions such as the use of trawl efficiency devices (TEDs) in the shrimp fishery should be considered.

The major problem addressed in this plan is the lack of stock assessment data needed for effective management of the Atlantic croaker resource. Basic data requirements are information on recruitment, age, size, and sex composition of the stock(s), and variations in these characteristics in time and space. In addition, accurate catch and effort data are needed from the recreational and commercial fisheries to assess the impact of fishing activities on croaker stocks.

4.0 DESCRIPTION OF STOCK

4.1 Species Distribution

The Atlantic croaker occurs in coastal waters from Cape Cod, Massachusetts to the Bay of Campeche, Mexico (Smith 1898; Welsh and Breder 1923; Hildebrand 1955; Gutherz and Thompson 1977) and possibly from southern Brazil to Argentina (Chao 1978). While uncommon north of New Jersey (Goode 1884), the croaker is one of the most abundant inshore demersal fishes from Chesapeake Bay south to Florida (Haven 1957; Bearden 1964; Anderson 1968) and in the northern Gulf of Mexico, especially off Louisiana and Mississippi (Gunter 1945; Moore et al. 1970; Franks et al. 1972; Chittenden and McEachran 1976; Lassuy 1983).

Atlantic croaker migrate seasonally along the coast, although little is known of migration patterns. A number of tagging studies have been conducted, but they usually involved small numbers of releases or had very low return rates. DeVries (1986) reported that in fall croaker in southern Pamlico Sound move out of the tributaries into deeper, more open water. In winter, croaker were recaptured in nearshore ocean waters south of Cape Hatteras, and south along the coast at least as far as Savannah, Georgia. Cape Lookout, North Carolina appears to be a primary overwintering area, at least for early one year olds from southern Pamlico Sound. Other tagging studies in Chesapeake Bay (Haven 1959), Delaware Bay (Pearson 1932), Georgia (Music and Pafford 1984) and South Carolina (Bearden 1964) indicated that croaker migrated out of estuaries in fall and generally south along the coast.

4.2 Abundance and Present Condition

Reported commercial landings of Atlantic croaker have fluctuated greatly during the past 50 years. Landings were high from the mid-1930s through the 1940s, with peak catches of 26,665 mt and 29,121 mt landed in 1938 and 1945, respectively. Croaker catches declined sharply in the late 1940s, fluctuated in the 1950s and 1960s, and reached an all-time low of 460 mt in 1970. Since 1970, croaker landings increased to over 13,000 mt in 1977 and 1978. Although trends in landings do not necessarily reflect trends in actual abundance, there are indications that croaker abundance has declined. Advances in technology have led to an increase in fishing power since the 1940s, yet recent peaks in landings are less than 50% of the all-time high which occurred in 1945. Reasons for this decline are not known; however, man's alterations of estuarine and coastal habitat are possible contributing factors.

Shifts in the geographic distribution of Atlantic croaker landings have occurred during the past 40 years. In the 1940s, catches were primarily from the Chesapeake region, probably due to the great emphasis placed on nearshore and estuarine fisheries during World War II (Wilk 1981). The most recent peak in croaker landings in the 1970s can be attributed to large increases in South Atlantic landings as well as Chesapeake landings.

Fluctuations in croaker landings appear to be related to variations in climate and fishing pressure (Perlmutter 1959). Periods of peak landings and northward range extension were associated with warming trends and mild winters. The combination of increased fishing effort, downward climate trend and series of cold winters following these peaks, led to reduced catches of croaker (Joseph 1972; Norcross 1983). Norcross (1983) quantified environmental factors controlling fluctuations in abundance of Atlantic croaker and produced a model predicting year class strength. Adult spawning and larval distribution on the continental shelf and juvenile over-wintering within Chesapeake Bay were identified as key periods of environmental vulnerability.

4.3 Ecological Relationships

Reproduction - Atlantic croaker mature between ages 2 and 3. Males attain sexual maturity at a smaller size (14-22 cm TL) than do females (18-23 cm TL) (Wallace 1940; Bearden 1964; Morse 1980). The fall-winter spawning season is prolonged; and spawning, hatching, and early larval development take place in continental shelf waters.

Age and Growth - The age composition and estimates of length at age of Atlantic croaker vary throughout the range. Age 7 was the maximum age reported for North Carolina although most fish were less than age 4 (Ross in press). Music and Pafford (1984) found age 5 croaker in Georgia; however, only age 1 and 2 were common. Most croaker in the Gulf of Mexico were ages 0 and 1 (White and Chittenden 1977; Barger 1985), although Barger (1985) found a maximum age of eight years. Estimated lengths at annulus formation were generally greater for croaker in North Carolina than in the other areas.

Food and Feeding - The Atlantic croaker is an opportunistic bottom-feeder which eats a variety of invertebrates, including polychaetes, mollusks, ostracods, copepods, amphipods, mysids, and decapods, and occasionally fish. Ontogenetic shifts in diet have been reported for croaker as well as geographic and seasonal variations in diet which are probably attributable to availability of prey species.

Competitors and Predators - Differences in spatial and temporal distribution, as well as differences in feeding behavior, reduce competition between juvenile sciaenids, such as croaker and spot, and allow them to coexist in the same area (Chao and Musick 1977; Woodward 1981; Currin 1984). Predators of Atlantic croaker are larger piscivorous species such as striped bass, southern flounder, bluefish, weakfish, and spotted seatrout.

Seasonal Activity - Atlantic croaker move into estuaries as post-larvae in the fall and winter, develop into juveniles in low-salinity waters, and move to areas of higher salinity in the summer and fall. Tagging studies indicate that adult Atlantic croaker generally move out of estuaries in the fall and south along the Atlantic coast.

Parasites, Diseases, Injuries, and Abnormalities - Parasites of Atlantic croaker were listed by Linton (1904), Bearden (1964), Joy (1974), Benner (1980), and Govoni (1983). Ulcerative mycosis, a skin disease primarily affecting Atlantic menhaden, has not yet been reported for Atlantic croaker.

4.4 Estimate of Maximum Sustainable Yield

Chittenden (1977) estimated parameters of the Beverton-Holt yield equation and used this model to assess the effects of harvesting croaker in the northwestern Gulf of Mexico. The annual total instantaneous mortality rate (Z) was estimated to be 3.0, based on a typical maximum life span of 1 to 2 years for croaker. The magnitude of the maximum sustainable yields (MSY) that can be obtained from Atlantic croaker depend critically on the magnitude of M (instantaneous natural mortality) which was estimated to be about 1.5-2.5. Maximum values of Y/R ranged from 3 to 40 g and were inversely related to the magnitude of M.

Chittenden[1] estimated model parameters for Atlantic croaker that inhabit waters north of Cape Hatteras. He used age IV as an estimate of t_l (the end of the fishable life span), a suggested value of 68% for the total annual mortality rate (Z=1.15), values of 0.5-1.0 for M, and calculated magnitudes of Y/R at MSY of about 32-91 g for t_c = 1.50 and 25-125 g for t_c = 3.0 (t_c = age at first capture). Ross (in press) calculated a total annual mortality rate of 73% (Z=1.3) for croaker in the North Carolina long haul seine fishery.

4.5 Probable Future Condition

The future condition of croaker stocks is difficult to predict. Norcoss (1983) showed that the croaker is characterized by density-independent recruitment. The age structure is unstable and dominated by particular year classes. Most juvenile recruitment in croaker is erratic and dependent upon specific environmental parameters. The effect of fishing is to further decrease the number of age classes present so that recruitment has a greater effect on a fished population than on an unfished one. A density-independent stock such as croaker can only be managed by individual year classes and not as a whole stock (Norcross 1983).

5.0 DESCRIPTION OF HABITAT

5.1 Condition of the Habitat

Climatic, physiographic, and hydrographic differences separate the ocean region south of Massachusetts to Florida into two distinct areas: the Middle Atlantic area and South Atlantic area, with the natural division occurring at Cape Hatteras. A major zoogeographic faunal change occurs at Cape Hatteras as a result of those differences (Briggs 1974).

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[1]Chittenden, M.E., Jr. 1977. Management implications of zoogeographic variation in population dynamics of the Atlantic croaker, *Micropogon undulatus*. Presented at Annual Meeting of AFS, Vancouver, B.C., Canada.

The Middle Atlantic area is relatively uniform physically and is influenced by large estuarine areas including Chesapeake Bay (the largest estuary in the United States), Narragansett Bay, Long Island Sound, the Hudson River, Delaware Bay, and the nearly continuous band of estuaries behind the barrier beaches from New York to Virginia. The southern edge of the region includes the estuarine complex of Currituck, Albemarle, and Pamlico sounds, a 2,500-square mile system of large interconnecting sounds behind the Outer Banks of North Carolina (Freeman and Walford 1974; 1976a, b).

The South Atlantic region is characterized by three long crescent-shaped embayments, demarcated by four prominent points of land: Cape Hatteras, Cape Lookout, and Cape Fear in North Carolina, and Cape Romain in South Carolina. Low barrier islands skirt most of the coast south of Cape Hatteras, although the sounds behind them are at most only a mile or two wide. Along the coast of Georgia and South Carolina, the barriers become a series of rather large, irregularly shaped sea islands, separated from the mainland by one of the largest coastal salt-water marsh areas in the world, through which cuts a system of anastomosing waterways. The east coast of Florida is bordered by a series of islands, separated in the north by broad estuaries which are usually deep and continuous with large coastal rivers, and in the south by narrow, shallow lagoons (Freeman and Walford 1976b, c, d).

At Cape Hatteras the continental shelf (characterized by water <198 m [108 fm] in depth) extends seaward approximately 32 km (20 mi) and widens gradually to 113 km (70 mi) off New Jersey. The substrata of the shelf in this region is predominantly sand interspersed with large pockets of sand-gravel and sand-shell. South of Cape Hatteras the shelf widens to 132 km (80 mi) near the Georgia-Florida border and narrows to 56 km (35 mi) off Cape Canaveral, Florida and 16 km (10 mi) or less off the southeast coast of Florida and the Florida Keys (Freeman and Walford 1974, 1976b, c).

The movements of the oceanic waters along the South Atlantic coast are not well defined. Portions of the Gulf Stream, which flows northward following the edge of the continental shelf, break off and become incorporated into the coastal water masses. Features of these gyres change seasonally; the inshore flow is northward along the coast to Cape Hatteras in winter and spring and southward in summer and fall. North of Hatteras, surface circulation on the shelf is generally southwesterly during all seasons. There may be a shoreward component to this drift during the warm half of the year and an offshore component during the cold half. This drift, fundamentally the result of temperature-salinity distribution, may be made final by the wind. A persistent bottom drift at speeds of tenths of nautical miles per day extends from beyond mid-shelf toward the coast and eventually into the estuaries. Offshore, the Gulf Stream flows northeasterly (Saila 1973).

5.2 Habitat Areas of Particular Concern

Habitat alterations within estuarine areas are probably damaging to croaker stocks since these areas are utilized for nursery grounds. Most estuarine areas of the United States have been altered to some degree by such activities as agricultural drainage, flood control and development. The National Estuary Study, completed in 1970, indicated that 73% of the nation's estuaries had been moderately or severely degraded. Damage and/or destruction of estuaries have largely been by filling, the dredging of navigation channels, and pollution (Gusey 1978, 1981). In the Atlantic coast states (Maine-Florida), which contain 3,152,800 acres of estuarine habitat, an estimated 129,700 acres (4.1%) were lost to dredging and filling from 1954 to 1968. Unfortunately, the effects of habitat alterations, such as channel dredging; filling of wetlands; increased turbidity associated with dredging, boating, loss of wetlands, and storm runoff; industrial pollutants; and sewage, have rarely been quantified.

5.3 Habitat Protection Programs

In recent years the coastal states have enacted coastal zone management laws to regulate dredge and fill activities and shoreline development. The federal government also regulates dredging and spoil disposal, water pollution, and creation of marine sanctuaries through the U.S. Army Corps of Engineers, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, and the Environmental Protection Agency.

State Programs

State habitat protection regulations are summarized in Table 11-14.

Federal Programs

The Coastal Zone Management Act of 1972, 16 USC 1451

The Act established a national policy and initiated a national program to encourage state planning for the management, beneficial use, protection and development of the Nation's coastal zones (generally, the submerged lands and waters of the territorial sea and the adjacent shorelands having a direct and significant impact on such waters).

Fish and Wildlife Coordination Act of 1946, USC 742(a)-754

This Act established a comprehensive national policy on fish and wildlife resources; authorized programs and investigations that may be required for the development, advancement, management, conservation and protection of the fisheries resources of the United States.

National Environmental Policy Act of 1969, 42 USC 4321-4347

This Act requires detailed environmental impact statements of proposals for legislation and other major Federal actions which may significantly affect the quality of the human environment. Prior to making the detailed statement, the responsible Federal official is required to consult with and obtain the comments of any Federal agency which has jurisdiction by law or special expertise with respect to any environmental impact involved. Also requires that documents must be available to the public and their comment must be considered.

The Ports and Waterways Safety Act of 1972, 33 USC 1221-1227

This Act deals with transportation and pollution problems resulting from operation and casualties of vessels carrying oil and other hazardous substances. It is designed to protect coastal waters, living resources, recreational resources and scenic values.

Federal Water Pollution Control Act, and Amendments of 1972, 33 USC 1251-1376

This Act initiated major changes in the enforcement mechanism of the Federal water pollution control program from water quality standards to effluent limits. Among other things, it requires that permits be issued by the environmental Protection Agency or the States for discharge of effluents into waters of the United States.

The Marine Protection, Research and Sanctuaries Act of 1972 (The Ocean Dumping Act), 33 USC 1401-1444

This Act regulates the transportation from the United States of material for dumping into the oceans, coastal and other waters, and the dumping of material from any source into waters over which the United States has jurisdiction. The Environmental Protection Agency is empowered to issue permits for transportation or dumping where it will not be unreasonably degrade or endanger human health, welfare or amenities, or the marine environment, ecological systems or economic potentialities. Section 106 of the Act provides for the provision of the Fish and Wildlife Coordination Act to apply.

Endangered Species Act of 1973, PL 93-205, 16 USC 1531 et seq.

This Act gives the Departments of Commerce and Interior regulatory and statutory authority over endangered and threatened fauna and flora not included in previous Acts. The purpose of the Act is to conserve endangered and threatened species and the ecosystems upon which they depend.

Marine Mammals Protection Act of 1971, 16 INC 1361-1407

This Act, with certain exceptions, places a moratorium on the taking and importation of all marine mammals and marine mammal products. It makes the Secretary of Commerce responsible for protecting whales, porpoises, seals, and sea lions; and the Secretary of the Interior responsible for all other marine mammals, specifically sea otters, walruses, polar bears and manatees. Also protects the habitat of marine mammals, including food sources.

Deepwater Port Act of 1974, 33 USC 1501-1524

This Act established procedures for the location, construction and operation of deepwater ports off the coasts of the United States.

Magnuson Fishery Conservation and Management Act of 1976, 16 USC 180

This Act establishes a fishery conservation and management regime to be implemented by the Secretary of Commerce. It establishes a fishery conservation zone extending from the limits of the territorial sea to 200 nautical miles from the baseline from which the territorial sea is measured. The Act defines fishery resource to include " ... any habitat of fish," and enjoins the Secretary to carry out a research program which must include "... the impact of pollution on fish, the impact of wetland and estuarine degradation, and other matters ..."

National Ocean Pollution Research and Development and Monitoring Planning Act of 1978, PL 95-273

This Act designates NOAA as the lead agency in the development of a comprehensive five-year plan for a Federal program relating to ocean pollution research, development and monitoring. This plan is to provide for the coordination of existing Federal programs relating to the oceans and for the dissemination of information emerging from these programs to interested parties. In addition, the plan shall provide for the development of a base of information necessary to the utilization, development and conservation of ocean and coastal resources in a rational, efficient and equitable manner.

NMFS Habitat Conservation Policy of 1983

This Policy will ensure that habitat is fully considered in all NMFS programs and activities, focus NMFS habitat conservation activities on species for which the agency has management or protection responsibilities under the Magnuson Fishery Conservation and Management Act, the Marine Mammal Protection Act, and the Endangered Species Act, lay the foundation for management and research cooperation on habitat issues, and strengthen NMFS partnerships with the states and the Regional Fisheries Management Councils on habitat issues.

6.0 FISHERY MANAGEMENT JURISDICTION, LAWS, AND POLICIES

6.1 Management Institutions

The Atlantic States Marine Fisheries Commission's (ASMFC) Interstate Fisheries Management Program (ISFMP), comprised of the 15 Atlantic Coast states from Maine to Florida, has the goal of achieving cooperative interstate management of shared territorial sea fisheries of the Atlantic Coast. To achieve this goal, the ISFMP has determined priorities among the territorial sea fisheries for inclusion in the program; developed, monitored, and reviewed management plans for high-priority fisheries; and recommended to the states, and where appropriate, to the Regional Fishery Management Councils and the federal government, management measures to benefit territorial sea fisheries.

The U.S. Department of Commerce, acting through the Fishery Management Councils, pursuant to P.L. 94-265 (Magnuson Fishery Conservation and Management Act), has authority to manage stocks throughout the range that are harvested predominantly in the Exclusive Economic Zone (EEZ), which extends from the territorial sea to 200 nautical miles from shore.

6.2 Treaties and International Agreements

Foreign fishing is regulated by P.L. 94-265 pursuant to which Governing International Fishing Agreements are negotiated with foreign nations for fishing within the EEZ.

6.3 Federal Laws, Regulations, and Policies

The only known Federal law that can possibly regulate the management of the Atlantic croaker fisheries is P.L. 94-265. There is no Federal fishery management plan for croaker.

6.4 State Laws, Regulations, and Policies

All states have the power to regulate or enact laws pertaining to the taking of Atlantic croaker. Those that have regulatory powers are Rhode Island, Connecticut, New Jersey, North Carolina, and Florida. Those that must adopt legislation are New York, Delaware, Maryland, South Carolina, and Georgia. Once a plan has been approved by the ASFMC, Delaware can issue regulations. Virginia has the power to regulate size limits but must enact laws pertaining to area closures. State laws and regulations are summarized in Table 11-12.

6.5 Local and Other Applicable Laws, Regulations, and Policies

No local or other laws, regulations, or policies are known to exist relative to the Atlantic croaker fishery.

7.0 DESCRIPTION OF FISHING ACTIVITIES

7.1 History of Exploitation

Commercial foodfish landings of Atlantic croaker have fluctuated greatly since the late 1800s. Annual landings by states are incomplete prior to 1929; however, the available data indicate that croaker landings increased dramatically during this time. The decreased catch at the beginning of the 1930s was probably due to poor recruitment caused by cold winters in the mid-1920s, together with the economic depression which caused a sharp decline in prices (McHugh 1977a; Norcross 1983). Croaker landings increased by 300% from 1931 to 1938 to a total of 26,665 mt and then decreased during World War II, probably due to lowered recruitment and decreased fishing effort. The largest total landings of croaker in history, 29,121 mt, occurred in 1945. Landings declined drastically to a low of 2,768 mt in 1952, most likely due to a combination of increased fishing pressure on the adults and cold winters reducing recruitment. Landings continued to fluctuate, rebuilding to 8,894 mt in 1958, declining to a record low of 460 mt in 1970, and increasing to 13,532 mt in 1977.

The geographic distribution of catches of Atlantic croaker has shifted from one area to another. Catches were primarily from Virginia in the 1930s and 1940s. The most recent peak in landings can be attributed to increased North Carolina landings.

Recreational landings, which have been collected on an annual basis since 1979 (Anonymous 1984, 1985a, b, 1986, 1987), have also fluctuated and more or less followed the commercial trend for the same years. Estimated landings declined from 3,037 mt in 1979 to 800 mt in 1982, increased to 3,350 mt in 1986.

7.2 Domestic Commercial and Recreational Fishing Activities

Commercial Fishery

The commercial fishery for Atlantic croaker consists of the inshore summer fishery, employing haul seines, pound nets, gill nets, and trawls, and the offshore winter fishery, which consists of trawls and gill nets. In addition, Atlantic croaker are commercially caught by purse seines, floating traps, trammel nets, fyke nets, hoop nets, and hand lines. These fisheries can be classified mixed species and opportunistic fisheries which may concentrate directly on croaker for brief periods of time. The methods employed to capture Atlantic croaker for foodfish have remained the same, except that a shift from pound nets to otter trawls and haul seines has occurred during the past 30 years. Industrial catches are made almost exclusively with modified otter trawls employed in the nearshore waters of the Gulf of Mexico.

Recreational Fishery

Anglers take Atlantic croaker from ocean beaches and the banks of bays and river, as well as from man-made structures such as piers, bridges, jetties, and causeways (Freeman and Walford 1974d, 1976a, b, c, d). They also catch them while fishing in estuarine and nearshore waters from anchored or drifting party/charter, private, and rental boats. Croaker are usually taken from a few feet below the high tide line to depths of 30 feet or more, over all types of bottoms, by bottom-fishing, chumming, or live-lining. Bait includes shrimp, clams, worms, cut fish, and soft or shedder crabs. A few also are taken on small jigs and weighted bucktails which are either cast or jigged from shore or boats.

8.0 DESCRIPTION OF ECONOMIC CHARACTERISTICS OF THE FISHERY

8.1 Domestic Harvesting Sector

Historical records of croaker landings indicate that successful commercial fishery for croaker has been operating at least since the late 1880s. Croaker rank second behind weakfish in their contribution to the total value of U.S. sciaenid landings. Food landings of croaker were valued at 3.7 million dollars in 1985. No values for the recreational croaker fishery have been established.

Food croaker price was highest in the Chesapeake region until 1975 when the Gulf of Mexico prices became higher for the first time. South Atlantic prices have been below Gulf of Mexico prices since 1966. Chesapeake croaker prices peaked at 25 cents per pound in 1963, but by 1975 ranged only from 9 to 14 cents in the three regions (Cato 1981).

8.2 Domestic Processing Sector

Foodfish landings of croaker are primarily sold freshly iced, whole. The industrial catch of croaker is processed into cat food, frozen crab bait, and recently, surimi.

8.3 International Trade

There are no records of exports of croaker from the U.S. Reported imports of croaker from South America may be of a congeneric species.

9.0 DESCRIPTION OF THE BUSINESSES, MARKETS AND ORGANIZATIONS ASSOCIATED WITH THE FISHERY

9.1 Relationship Among Harvesting and Processing Sectors

Most food sciaenids are sold through local fish houses (Cato 1981). Croaker were formerly sold through large wholesale markets such as Fulton Fish Market in New York City, but today are principally sold by local small fish markets. Croaker markets are widely distributed along the Gulf coast and from the Carolinas to New York. Attempts have been made in recent years to market croaker throughout the Midwest in retail seafood stores and supermarket chains.

9.2 Fishery Cooperatives or Associations

There are seven fishery cooperatives in the South Atlantic and Gulf regions: one in South Carolina, two each in Georgia and Florida, one in Mississippi, and one in Texas. These provide marketing and purchasing, marketing exclusively, and/or other services such as insurance, transportation, purchasing supplies, legislative lobbying, production, processing, and collective bargaining.

9.3 Labor Organizations

Labor organizations identified with the harvesting and processing sectors of the croaker fishery have not been specifically described; however, some of the participants in the croaker fishery are undoubtedly represented by labor organizations. Labor organizations identified with the harvesting and processing sectors of the fisheries in the Mid-Atlantic area are limited to four organizations: the Seafarers International Union of North America, the International Longshoreman's Association, the United Food and Commercial Workers International Union of the AFL-CIO, and the International Brotherhood of Teamsters. Information is not available to identify activities that relate directly to croaker. The following discussion is related to Mid-Atlantic fisheries generally and was summarized from Development Sciences, Inc. (1980) by Scarlett (1982).

In the Mid-Atlantic area, union involvement is limited almost entirely to onshore seafood handling, processing, and distribution activities. Vessel crews are not organized by any of the identified unions, although some attempts have been made in the past to include fishermen in organized unions. Onshore seafood handling is generally non-unionized, but to the extent that it is, the International Longshoremen's Association is the primary national union involved with seafood handling workers. Most union activity occurs in the region's major urban centers (New York, Philadelphia, Baltimore, and Norfolk) and includes handling workers at boat docks and in the warehousing facilities of processing plants. Fish processing workers, (oyster and clam shuckers, fish cleaners and cutters, freezermen, warehousemen, some distribution workers, and wholesale and retail clerks) when unionized, are represented by the United Food and Commercial Workers International Union. Transportation of seafood products, especially from processing facilities to wholesale and retail fish distributors, is organized under the International Brotherhood of Teamsters.

The seafood harvesting, handling, and processing industry is not highly organized in the mid-Atlantic region. Although union activity occurs in all major urban centers, the overall percentage of union members employed in the seafood industry is relatively low. For example, in the Hampton Roads area, only 5% of all workers employed in the seafood harvesting and processing industry are organized by the unions. The reasons for limited union involvement include the low-wage seasonal nature of employment in the processing industry, and the diverse, highly competitive and independent nature of the fishermen, brokers, and processors. In many instances, wages are extremely low, approaching minimum wage in some localities. Fish processing employees are often the lowest paid employees covered by the unions. These employees change employment continuously due to difficult working conditions and unstable employment prospects. Seasonality of employment and constant changeover from shellfish to finfish processing affects steady employment and limits the union's ability to organize onshore workers. Unionization of vessel crews and fishermen is limited by the small size of individual crews and the investor-owner fishing boats. National Labor Relations Board ruling against organization of fishing fleets have added to the organization and administrative problems of including fishermen in national union structures.

9.4 Foreign Investment in the Domestic Fishery

Data on foreign investment in the fishery are not known to exist. It is probable that if investment exists, it is insignificant.

10.0 GOAL STATEMENT

The goal of this management plan is to perpetuate the Atlantic croaker resources in fishable abundance throughout its range and generate the greatest economic and social benefits from its commercial and recreational harvest and utilization over time.

10.1 Specific Management Objectives

1. Conduct cooperative interstate research to understand the biology of, and fisheries for, croaker.

   Objective 1 recognizes that there is a lack of data neces-necessary for effective management of croaker stocks. Data on age and growth, reproduction, migration patterns, and stock structure are incomplete. There is a need to improve this database for future refinements of the plan.

2. Maintain a spawning stock sufficient to minimize the possibility of recruitment failure and determine the effects of the environment on year class strength.

   Juvenile recruitment in croaker is erratic and dependent upon specific environmental parameters. The effect of spawning stock size on recruitment is unknown. Until the dynamics of the croaker population are better understood, a management scheme that preserves at least some minimum spawning stock should be employed.

3. Optimize yield per recruit.

   Estimates of yield per recruit for Atlantic croaker inhabiting waters north and south of Cape Hatteras indicate that appropriate management strategies may differ considerably for croaker found in these two areas. These estimates need to be refined based on more accurate and current data. Thus, this objective cannot be fully met until objective 1 is carried out.

4. Improve collection of catch and standardized effort statistics and description of fishing gears.

   Objective 4 is a recognition of the need for accurate catch and effort data from the various commercial fisheries which harvest croaker and from the recreational fishery. These are basic requirements for stock assessment and population abundance estimates.

5. Promote harmonious use of the resource among various components of the fishery through the coordination of management efforts among the various political entities having jurisdiction over the croaker resource.

   Objective 5 recognizes that the Atlantic croaker is a migratory species. Effective management can only be accomplished through cooperative efforts among the states involved in harvesting the resource.

6. Promote the cooperative interstate collection of economic, social, and biological data required to effectively monitor and assess management efforts relative to the overall goal.

   There is a need for continual collection of data throughout the range of spot to achieve and maintain effective management.

7. Promote determination and adoption of the highest possible standards of environmental quality.

Objective 7 is a recognition that maintaining environmental quality is of critical importance to maintaining maximum natural production of croaker. There is a need to delineate critical habitat areas, and establish guidelines for protection to minimize effects of development.

10.2 Specific Management Measures

The following management measures are identified as appropriate for implementation:

1. Promote the development and use of trawl efficiency devices (TEDs) through demonstration in the southern shrimp fishery, and fish separators in the finfish trawl fishery.

2. Promote increases in yield per recruit through delaying entry to croaker fisheries to age one and older.

10.3 Research and Data Collection Programs

1. Identify stocks and determine coastal movements and the extent of stock mixing.

   The necessity of defining the unit stock for fisheries stock assessment and management is well established (Cushing 1975; Gulland 1983). Few species form single homogeneous populations, and most can be separated into several more or less distinct stocks, which react to fishing more or less independently (Gulland 1983). Little work has been done on croaker stock identification. Aspects of their life history differ throughout their range and suggest the need for different management strategies.

   A variety of methods have been used in stock discrimination studies of marine fishes, including tagging and migration, meristics, parasites, serology, and biochemical techniques to determine genetic differences (electrophoresis, isoelectric focusing, mt-DNA).

2. Collect catch and effort data (including size and age composition of the catch), determine stock mortality throughout the range, and define gear characteristics.

   Fisheries stock assessments depend on basic data from the commercial and recreational fisheries including catch, amount of fishing effort, catch-per-unit-effort, and biological characteristics of the catch (size, age, etc.). From these basic data, estimates of mortality and abundance can be made.

   Commercial and recreational fishery statistics are collected and compiled by the National Marine Fisheries Service in cooperation with various states. Commercial landings data are generally collected on a monthly basis by port samplers, and include pound and value of species landed, type of gear used, water body of capture, and distance caught from shore. Nominal effort data, such as the number of fishing trips, are collected for some fisheries, and the total units of gear fished are recorded on an annual basis. Recreational statistics are collected in two complementary surveys: a telephone survey of households and an intercept survey of fishermen at fishing sites. Data from the two independent sources are combined to produce estimates of catch, total effort, and participation.

The effort data presently being collected are generally inadequate for fisheries stock assessment. Standardized measures of effort need to be developed for the various fisheries which harvest croaker. Minimum biological data needed from both the commercial recreational fisheries include size and age composition of the catch. Pound nets, a relatively nonselective gear used throughout much of the spot range (Maryland to North Carolina), are recommended as a target gear for the development of a coastwide sampling program to collect catch, effort, and biological data for croaker stock assessment, and eventually to monitor the effectiveness of future management strategies. Each state marine fisheries agency should develop a list of pound nets and associated fish processors where biological samples can be collected. Development of a log system, such as has been used by NMFS, to collect accurate catch and effort data and a biological sampling program to collect length, weight, and age data are recommended. In addition, each state marine fisheries agency should document existing commercial and recreational fisheries data bases.

3. Develop and maintain a recruitment index and examine the relationships between parental stock size and environmental factors on year-class strength.

The relationship between adult croaker abundance and subsequent recruitment is not known. DeVries (1985) found a positive correlation between Atlantic croaker catch-per-unit-effort data from a juvenile survey and long haul seine landings of croaker three years later. Data on juvenile croaker abundance are available from various state estuarine surveys. The design and methodology of these surveys vary considerably among states. It is recommended that the states develop a uniform random sampling scheme in order to develop a coastwide index of abundance, determine local and seasonal distribution patterns, and determine spawning periodicity. Initially the new survey would be conducted concurrently with established surveys in order to make comparisons and utilize the previously collected data.

It is well documented that the pattern of recruitment to most fish stocks generally bears no obvious relation to the abundance of the parent stock, but rather that year-class strength is determined mostly by environmental factors at some early stage (or stages) in the life of that year class (Gulland 1983). The importance of considering environmental influences on marine fish populations is reflected in a scientific program proposed by the Food and Agricultural Organization in 1979 which identified five variables (temperature, turbulence, transport, food, and predation) as most likely to determine recruitment levels (Sullivan 1982). Present indices of spot year class strength should be analyzed with available environmental data. Additional environmental data needs should be determined as a part of the development of a uniform juvenile sampling program.

4. Define reproductive biology of croaker, including size at sexual maturity, fecundity, and spawning periodicity.

   Aspects of the reproductive biology of croaker have been reported for portions of the range; however, data are incomplete and in some instances, conflicting. Size at maturity may vary throughout the range. Data on fecundity, size at 100% sexual maturity, and spawning periodicity, collected concurrently throughout the range, are needed to determine future management strategies for croaker.

5. Conduct physiological studies to determine temperature tolerances of croaker.

   It is well-documented that juvenile croaker are susceptible to low winter temperatures (Joseph 1972). Norcross (1983) found that winter temperature was the predominant variable affecting year-class survival to the following summer in very cold years. Laboratory experiments are needed to determine the physiological mechanism of croaker response to temperature, and the timing of the response in relation to size, change in temperature, and length of time over which the temperature changes.

11.0 A Biological and Fisheries Profile of Atlantic Croaker, *Micropogonias undulatus*

11.1 Identity

11.1.1 Nomenclature

The valid name for Atlantic croaker is *Micropogonias undulatus* (Linnaeus) 1766 (Figure 11.1). The following synonymy is after Jordan and Evermann (1896):

Perca undulata, Linnaeus, 1766
Sciaena croker, Lacepede, 1802
Bodianus costatus, Mitchill, 1815
Micropogon lineatus, Cuvier and Valenciennes, 1830
Micropogon undulatus, Cuvier and Valenciennes, 1830
Micropogon costatus, DeKay, 1842

11.1.2 Taxonomy

Classification follows Greenwood et al. (1966). Taxa higher than superorder are not included.

Superorder: Acanthopterygii
Order: Perciformes
Suborder: Percoidei
Family: Sciaenidae
Genus: *Micropogonias*
Species: *Micropogonias undulatus*

The Atlantic croaker is one of 23 members of the family, Sciaenidae, found along the Atlantic and/or Gulf coasts of the United States (Robins et al. 1980; Miller and Woods 1988). This family is commonly known as the drums since many of its members, including Atlantic croaker, produce drumming sounds by vibrating their swim bladders with special muscles (Jordan and Evermann 1896; Fish and Mowbray 1970; Hill 1985). Chao (1978) assessed the phylogenetic relationships of all western Atlantic genera of Sciaenidae on the basis of swim bladder, otoliths (sagitta and lapillus), and external morphology, and presented a tested key to species and genera, including meristics and species ranges.

Atlantic croaker is the common name given *Micropogonias undulatus* by the American Fisheries Society (Robins et al. 1980). Other common names include croaker, crocus, hardhead, King Billy, corvina, roncadina, and corbina (Smith 1907; Hildebrand and Schroeder 1928; Shiino 1976).

11.1.3 Morphology

The following description is that of Johnson (1978), summarized from Jordan and Evermann (1896), Hildebrand and Schroeder (1928), Miller and Jorgenson (1973), and Chao (1976).

D. X-I, 26-30 (usually 28); A. II, 7-9 (usually 8); C 9+8, procurrent rays 8-9+8; P. 17-20 (usually 18); V. I, 5;

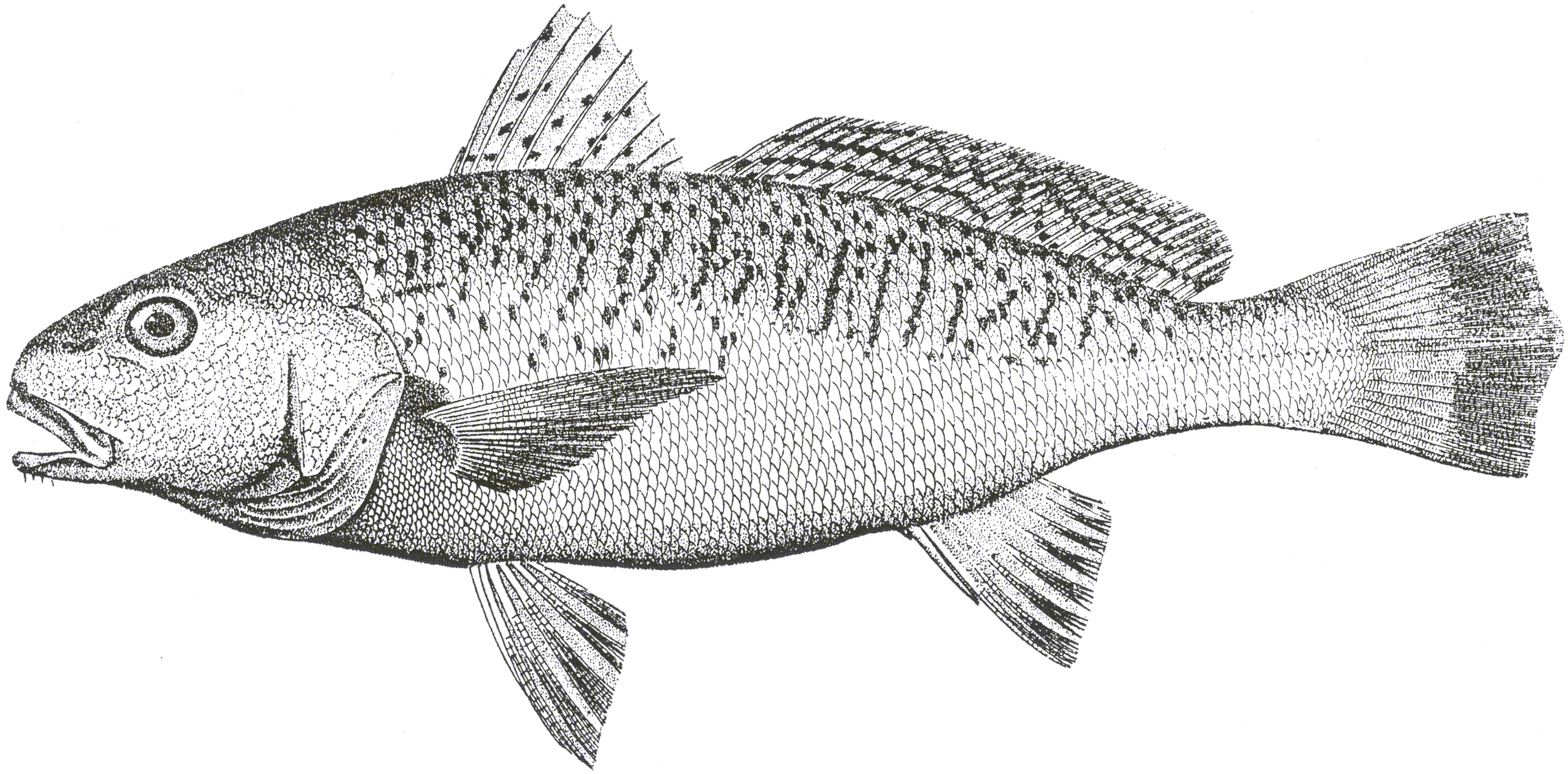

Figure 11-1. Atlantic croaker, Micropogonias undulatus (Linnaeus), 1766 (illustration by H.L. Todd from: Goode, 1884).

lateral line scales 47-50 (usually 50), scales above lateral line 7-9 (usually 8), scales below lateral line 8-9 (usually 8); vertebrae 10+15; gill rakers 8-10+14-18; branchiostegals 7; teeth small, conical, set in bands, in broad villiform bands, outer row teeth in upper jaw and inner row teeth in lower jaw enlarged, no teeth on vomer, palatines, or tongue.

Head 2.9-3.4, depth 2.9-3.6 in SL; snout 2.8-3.7, eye 3.3-4.8, interorbital 3.3-3.8, maxillary 2-3-2.8, pectoral fin 1.1-1.5 in head.

Body elongate, moderately compressed; back slightly elevated; head rather long; snout conical, projecting beyond mouth; mouth moderate, horizontal, inferior; maxillary reaching a little past front margin of eye to below middle of eye; chin with five pores and 3 pairs of short, slender barbels. Scales moderate, strongly ctenoid, reduced anteriorly above lateral line, extending onto caudal, but not on other fins. Dorsal fin continuous with a deep notch between the spinous and soft portions; third and fourth dorsal spines longest, higher than any of soft rays; caudal fin slightly double concave, the middle rays longest; pectoral fin reaching well beyond tip of pelvic fin. Preopercular margin with strong spines.

Pigmentation: Greenish or grayish silvery above, silvery white below, highly iridescent in life; back and sides with numerous brassy or brownish dark spots arranged in oblique, wavy bars or sides, becoming less distinct in large individuals; dorsal fin with numerous dark spots; faint longitudinal streaks usually present on soft portion of dorsal fin; caudal and pectoral fins greenish dusky; base of pectoral fin dusky; anal and pelvic fins yellowish to orange. Spawning coloration distinctly bronze or yellow; iris golden on dorsal margin; pelvic fin yellow; pectoral fin blackish at base; inside of mouth pinkish red; anal fin bronze yellow; caudal fin faint yellow; preopercle bronze. (This coloration characterizes all large specimens and may not be associated with spawning).

Readily recognized by inferior mouth, series of short barbels on each side of chin, and strongly serrated preopercular margin.

Hill (1985) examined the ontogeny of the swimbladder and sonic muscles in croaker and found that both sexes possessed the sonic muscles, but they grew larger and heavier in males than in females. Muscle development began at 45 mm SL in both sexes when the fish were approximately 4-5 months old and the gonads were starting to develop. Bridges (1971) described the pattern of scale development in juvenile Atlantic croaker.

Standard length-total length relationships for croaker in Georgia (Jorgenson and Miller 1968) and Galveston Bay, Texas (Matlock et al. 1975) and a girth-total length relationship for croaker in Texas bays and the Gulf of Mexico (White and Chittenden 1977) are presented in Table 11.1. Rivas and Roithmayr (1970) provided morphometrics and

Table 11.1. Reported standard length-total length and total length-girth relationships for Atlantic croaker (SL = standard length, TL = total length, G = girth (grams).

Source	Location	Size range	N	Relationship	r
Jorgenson and Miller (1968)	Georgia	7- 38 mm SL	16	SL = 1.270 + 1. 369 SL	
		8- 52 mm TL	16	SL = 0.995 + 0. 728 TL	
Matlock et al. (1975)	Galveston Bay, Texas	28- 95 mm SL	179	TL = 1.21591 + 1.26753 SL	0.998
		102-159 mm SL	73	TL = 9.70548 + 1.17538 SL	0.990
		168-255 mm SL	37	TL = 19.88505 + 1.10952 SL	0.993
White and Chittenden (1977)	Texas	90-360 mm TL	2,081	G = -11.84 + 0.71 TL	0.94

meristics for a single large croaker (668 mm TL) from the northern Gulf of Mexico.

11.2 Distribution

A summary of published information on the distribution of Atlantic croaker was presented by Darovec (1983).

11.2.1 General Distribution

The Atlantic croaker occurs in coastal waters of the western Atlantic Ocean from Cape Cod, Massachusetts to Campeche Bank, Mexico (Smith 1898; Welsh and Breder 1923; Hildebrand 1955; Gutherz and Thompson 1977) and possibly from southern Brazil to Argentina (Chao 1978). While uncommon north of New Jersey (Goode 1884), the croaker is one of the most abundant inshore demersal fishes along the southeast coast of the United States (Haven 1957; Bearden 1964; Anderson 1968) and in the northern Gulf of Mexico (Gunter 1945; Moore et al. 1970; Franks et al. 1972; Chittenden and McEachran 1976).

11.2.2 Differential Distribution

11.2.2.1 Spawn, Larvae, and Juveniles

Although eggs of Atlantic croaker have not been identified in field collections, evidence suggests that spawning occurs in fall in continental shelf waters some distance from shore. Adults in spawning condition were collected on the shelf from Cape May, New Jersey to Cape Hatteras at depths of 7-131 m (Morse 1980), 5 to 50 km offshore of South Carolina at depths of 40 to 91 m (Bearden 1964), and 19 km off the Georgia coast (Hoese 1973).

Atlantic croaker larvae have been collected from near the edge of the continental shelf (183 m) to within estuaries. The mean length of larvae caught in the ocean was significantly smaller than those caught in the estuary and preflexion larvae (2.0-4.0 mm), which denote recent spawning, have only been collected in the ocean (Hildebrand and Cable 1930; Williams and Deubler 1968; Fruge 1977; Setzler 1977; Berrien et al. 1978; Powles and Stender 1978; Houde et al. 1979; Warlen 1980; Lewis and Judy 1983). Larvae (2.1-11.6 mm SL) have been collected in shelf waters from August through March, although most were collected in November and December (Berrien et al. 1978; Powles and Stender 1978; Warlen 1980; Lewis and Judy 1983). Preflexion larvae (2.0-4.0 mm SL) are buoyant and occur in surface waters, probably becoming demersal during flexion (4.1-5.0 mm SL) and postflexion (>5.0 mm SL) stages (Lewis and Judy 1983).

Recruitment of young-of-the-year croaker to estuarine areas occurs over an extended period of time but generally peaks in the fall north of Cape Hatteras, North Carolina and in the winter and early spring to the south. Young-of-the-year were collected in October in the Delaware River (Thomas 1971), October to February in a Virginia Atlantic coast estuary (Richards and Castagna 1970; Cowan and Birdsong 1985), and July to November in Chesapeake Bay (Pearson 1941; Haven 1957; Chao and

Musick 1977; Norcross 1983). Recruitment to estuaries south of Chesapeake Bay occurred as early as August in North Carolina (Tagatz and Dudley 1961) but usually from late October to April, peaking in December through February for North Carolina (Hildebrand and Cable 1930; Williams and Deubler 1968; Warlen 1980; Lewis and Judy 1983), South Carolina (Bearden 1964; Shenker and Dean 1979; Bozeman and Dean 1980; Miglarese et al. 1982), Georgia (Dahlberg 1972; Hoese 1973; Rogers et al. 1984) and Florida (Tagatz 1967). Recruitment to Gulf coast estuaries is also reported to occur from October to April with peaks from November-January near Pensacola, Florida (Hansen 1969), January-February in Mobile Bay, Alabama (Nelson 1969), December-March in Louisiana (Parker 1971; Sabins and Truesdale 1974; Rogers 1979) and February-March in Texas (Pearson 1929; Parker 1971).

Young-of-the-year croaker have been collected in the deeper waters and channels of the Delaware River (Thomas 1971), Chesapeake Bay and its tributaries (Wallace 1940; Haven 1957; Markle 1976; Merriner et al. 1976; Chao and Musick 1977), Cape Fear River, North Carolina (Weinstein 1979; Weinstein et al. 1980 a, b), Doboy Sound, Georgia (Setzler 1977), and Lake Pontchartrain, Louisiana (Suttkus 1955), as well as shallow areas of Pamlico Sound, North Carolina (Epperly 1984; Ross and Epperly 1985 and Galveston Bay, Texas (Parker 1971; Sheridan 1983).

Transport of post-larval and juvenile croakers within estuaries varies according to the type of estuarine circulation pattern. Norcross (1985) found that the majority of croaker larvae were in the inward-flowing lower layers at the mouth of the Chesapeake Bay. This supports earlier hypotheses that croaker most likely move upriver using salt wedge transport (Wallace 1940; Pritchard 1951; Haven 1957; Weinstein 1979). When deep channels are not available and there is no two-layer flow, croaker will go into marsh shallows (Weinstein et al. 1980 a). The circulation patterns of the shallow water column of Pamlico Sound is wind driven rather than tidally driven and juvenile croakers move into the salt marshes instead of concentrating in the channels (Miller et al. 1984).

Numerous studies along the Atlantic and Gulf coasts indicate that croaker generally use low salinity habitats as nursery areas (Raney and Massmann 1953; Massmann 1954; Haven 1957; Tagatz and Dudley 1961; Bearden 1964; Hansen 1969; Dahlberg 1972; Chao and Musick 1977; Miglarese et al. 1982; Rozas and Hackney 1983, 1984; Rulifson 1985). Chittenden[2] collected juvenile croaker (40-80 mm TL) in the Gulf of Mexico off Texas in December which suggests that they may also use the open ocean as a nursery under at least some circumstances. The smallest individuals are found at the upper reaches (oligohaline areas) of estuaries and larger croaker at the lower reaches (Gunter 1957; Haven 1957; Miglarese et al. 1982). Weaver and Holloway (1974) reported that juvenile croaker were caught in open-water areas rather than submerged vegetation areas.

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[2]Pers. commun. Mark Chittenden, Virginia Institute of Marine Science, Gloucester Point, VA.

The reported time at which young-of-the year begin to emigrate from estuarine nursery areas varies from spring along parts of Gulf coast to late summer or fall on the Atlantic coast. Wallace (1940) reported that immature croaker remain in Chesapeake Bay until driven out by adverse temperatures, whereas Haven (1957) reported a gradual emigration through late summer and fall. In South Carolina most of the croaker population left inshore waters by late summer, followed by a mass exodus of the remaining fish when water temperatures began to decline (Bearden 1964). Studies in Florida (Springer and Woodburn 1960; Hansen 1969), Mississippi (Franks et al. 1972), Louisiana (Suttkus 1955) and Texas (Pearson 1929) indicated that young croaker did not move offshore until fall. Parker (1971) hypothesized a mass exodus of croakers into the Gulf of Mexico in June from Lake Borgne, Louisiana, and even earlier from Galveston Bay, Texas. Chittenden[3] observed that young begin to enter the Gulf off Texas about March-May and under some circumstances they are abundant in the Gulf in December-January. Mark-recapture studies of juvenile croaker in semi-impounded marshes in Louisiana indicated that individuals remained in nursery areas for only 1-4 months and that larger individuals were continually emigrating back to the Gulf (Arnoldi et al. 1974; Yakupzack et al. 1977; Knudsen and Herke 1978). Clairain (1974) reported two dominant emigration periods, May and June, from a southwest Louisiana marsh. Emigration descriptions in the literature vary from (1) gradual seaward movements, to (2) mass outward movements, to (3) a "bleeding off" of the larger individuals (Yakupzack et al. 1977).

Movements of young-of-the-year Atlantic croaker in Virginia and North Carolina are shown in Figures 11.2-11.5[4]. Croaker enter Chesapeake Bay and its tributaries in fall, remain in deeper waters during winter, move into lower salinity waters in spring, and return to higher salinity water in the summer. In North Carolina young croaker enter the sounds in fall and winter and are found in low salinity tidal creeks in the spring where they remain until late summer.

11.2.2.2 Adults

Croaker spend their second winter (age 1+) on the continental shelf and enter estuaries during the following spring and summer (Figures 11.2-11.5).[4] Mature croaker return to shelf waters in late summer and fall of their second year to spawn, while younger fish emigrate with declining water temperatures. Croaker move back into estuarine waters in spring. In the South Atlantic Bight (Cape Fear, North Carolina to Cape Canaveral, Florida), the abundance of croaker in continental shelf waters varied seasonally, with maximum abundance in the late summer and early fall and lowest abundance during late winter and spring (Anderson

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[3]Pers. commun. Mark Chittenden, Virginia Institute of Marine Science, Gloucester Point, VA.

[4]Ross, S.W., and B. Sullivan. 1985. Population (stock) determination for Atlantic croaker. Presented at the Stock Identification Workshop, November 5-7, 1985, Panama City Beach, Florida.

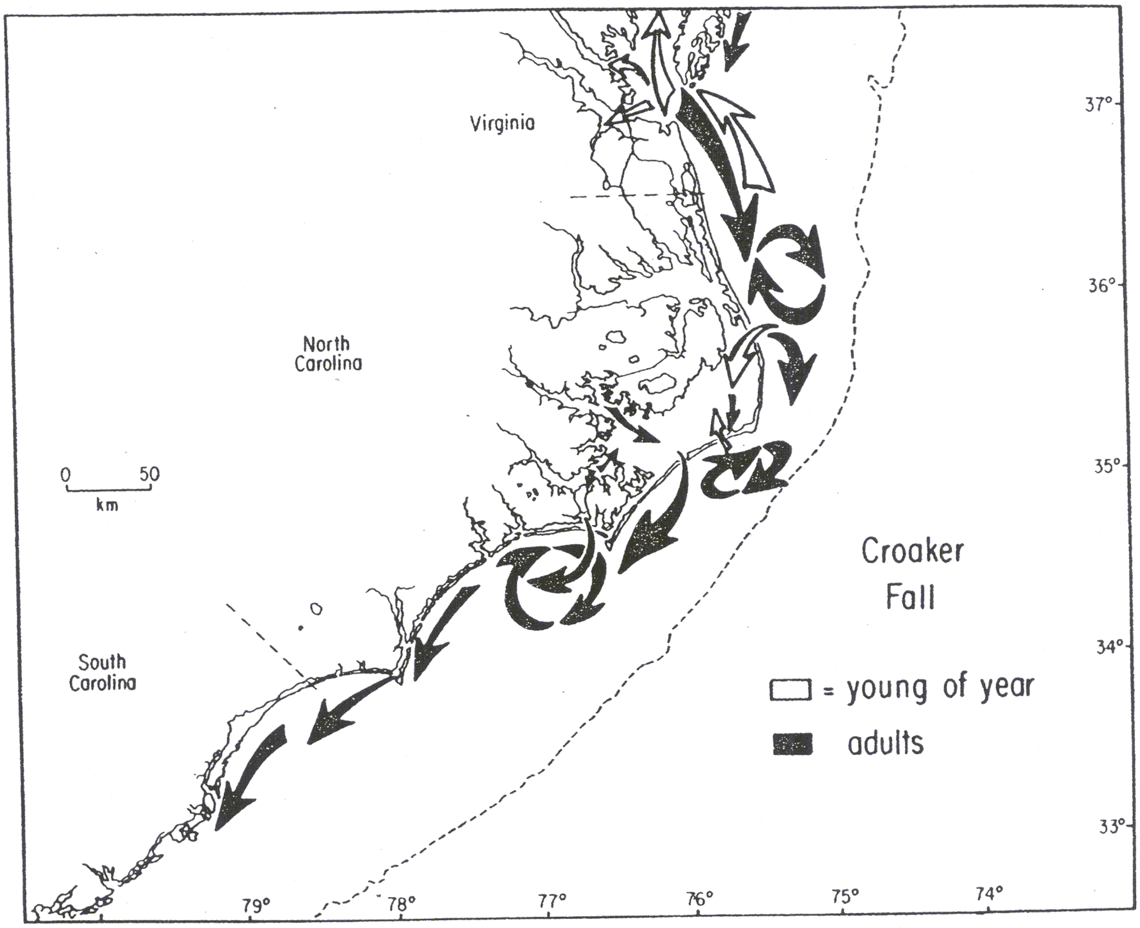

Figure 11-2. Movements of young-of-the-year and adult Atlantic croaker during Fall in North Carolina waters (from S.W. Ross).

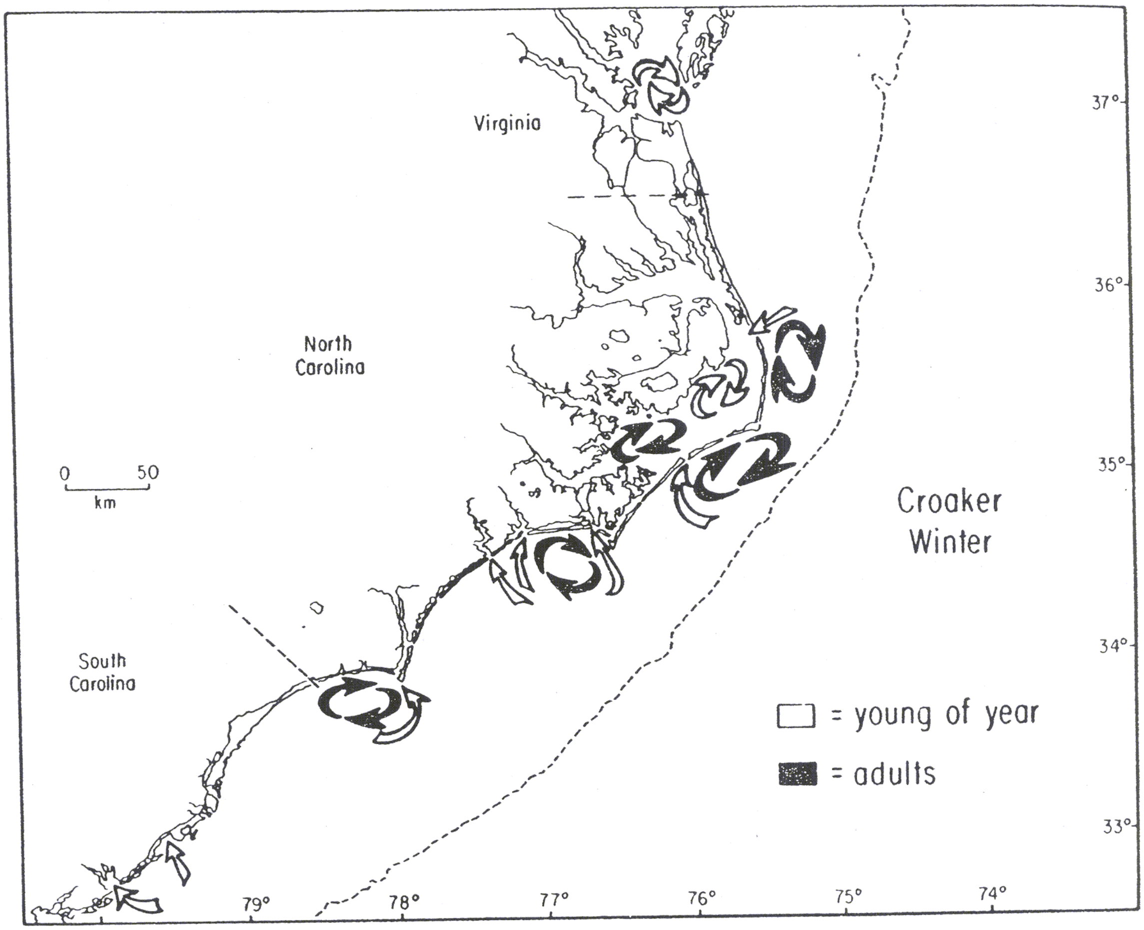

Figure 11-3. Movements of young-of-the-year and adult Atlantic croaker during Winter in North Carolina waters (from S.W. Ross).

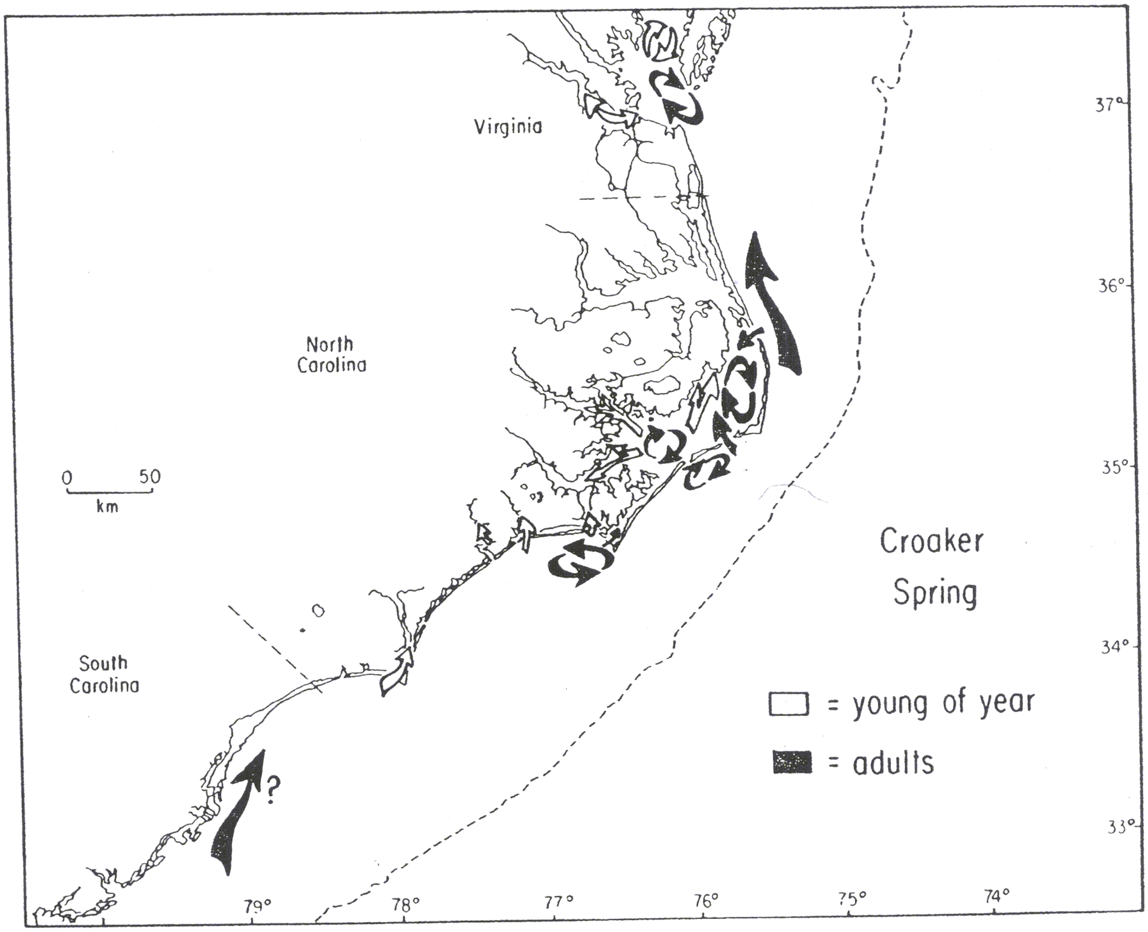

Figure 11-4. Movements of young-of-the-year and adult Atlantic croaker during Spring in North Carolina waters (from S.W. Ross).

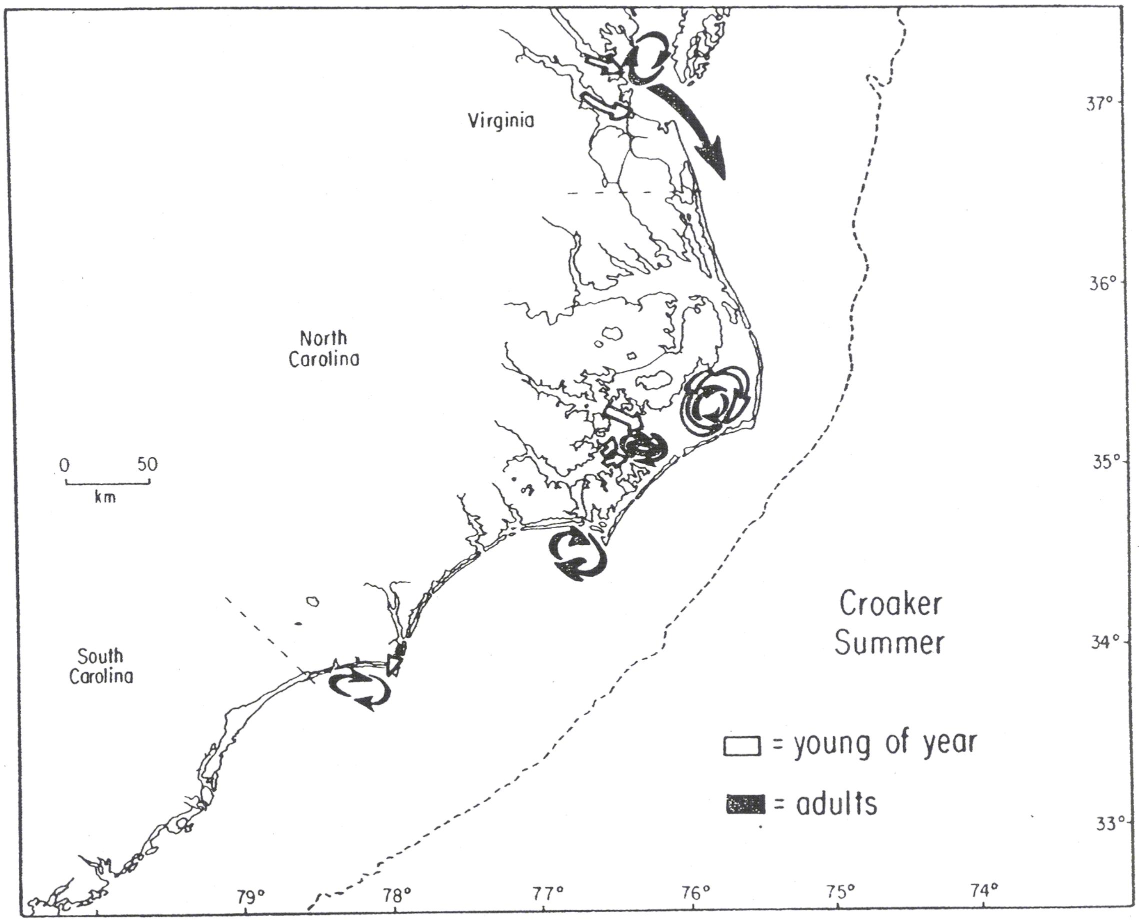

Figure 11-5. Movements of young-of-the-year and adult Atlantic croaker during Summer in North Carolina waters (from S.W. Ross).

1968; Wenner 1987a). Atlantic croaker was the second most abundant species, by number and weight, taken in a trawl survey of groundfish in coastal waters (4.6-9.1 m) of the South Atlantic Bight (Wenner 1987a). During winter and spring surveys, croaker were taken more frequently in trawl tows south of Savannah, Georgia. The mean sizes of croaker caught during the surveys were 17 cm TL (range: 2-28 cm TL) in winter, 13 cm TL (range: 4-32 cm TL) in spring, 17 cm TL (range: 6-29 cm TL) during summer, and 18 cm TL (range: 11-29 cm TL) in fall. Chittenden and McEachran (1976) reported that croaker was the most abundant species on white shrimp grounds (3.5-22 m depth) and were also abundant on the brown shrimp grounds (22-91 m) in the northwestern Gulf of Mexico. Croaker prefer a muddy bottom and are generally not found in depths exceeding 120 m (Gutherz 1976).

11.2.3 Determinants of Distribution

The Atlantic croaker is euryhaline, having been collected over a salinity range of 0 to 75 °/₀₀ (Gunter 1945; Haven 1957; Simmons 1957; Tagatz and Dudley 1961; Bearden 1964; Keup and Bayless 1964; Tagatz 1967; Dahlberg 1972; Turner and Johnson 1973; Shealy et al. 1974). Juvenile croaker utilize low salinity and oligohaline areas of estuaries as nursery areas and are apparently more tolerant than adults of low salinities (Welsh and Breder 1923; Gunter 1942; Raney and Massmann 1953; Massmann 1954). Salinity fluctuation may be an important determinant of estuarine fish distribution. Gerry (1981) and Moser and Gerry (in press) found a significant positive correlation ($P=0.05$) between juvenile spot/croaker ratios and salinity fluctuations in North Carolina marsh creeks. The sampling site with the greatest fluctuations had an approximate 2:1 ratio of spot to croaker, while the most stable site had an approximate 1:3 ratio of spot to croaker. Integrated laboratory studies indicated that croaker avoid crossing salinity gradients significantly more than spot. Mulligan and Snelson (1983) reported that croaker showed a trend for increasing abundance with increasing salinity, and the catches were significantly higher at salinities >34 °/₀₀ in the Indian River Lagoon system. Clairain (1974) suggested that emigration of juvenile croaker after April from a southwest Louisiana marsh was stimulated by sudden salinity changes.

Croaker have been collected over a temperature range of 8-34°C on the Atlantic coast (Tagatz 1967; Shealy et al. 1974) and 0.4-35.5°C in Texas and Louisiana (Parker 1971). Parker (1971) reported that juveniles were generally collected from 6-20°C, but adults (>1 year old) were generally absent at temperatures below 10°C. Clairain (1974) suggested that sudden drops in temperature seemed to be the primary stimulus initiating emigration of juveniles prior to the end of April from a southwest Louisiana marsh. Temperature increases of 14.4°C caused stress reactions in croaker acclimated to 18°C, and a increase of 16.6°C physiologically incapacitated croaker.

Temperature-induced mortalities of juvenile Atlantic croaker have been observed in the field in Chesapeake Bay at temperatures below 1.0-1.5°C (Van Engel and Joseph 1968; Joseph 1972; Wojcik 1978), and in the laboratory at 0.0-3.3°C (Schwartz 1964; Joseph 1972). Hildebrand and Cable (1930) found adult croaker (178-254 mm TL) numb and drifting ashore at Beaufort, N.C., after a 6-day cold spell when water temperatures ranged from 5-9°C, but found no mortality among smaller fish. Gunter and Hildebrand (1951) found stunned and dead croaker on the shore of Aransas Pass harbor following a 6-day period of air temperatures from -7.8 to 3.9°C. Norcross (1983) quantified the effect of "cold" winter temperatures on juvenile croaker survival the following summer and found that winter temperature is the predominant variable in very cold years (Jan-Mar temperature <5°C) but not in very warm years, and the magnitude of its effect is related to initial strength of year-class recruitment in the fall.

Hoss (1967) measured oxygen consumption in Atlantic croaker (10-80 g) at 20°C and 33°/₀₀ salinity, and presented the following relationship between respiration rate (Q) and body weight (W): $Q = 0.198\ W^{0.874}$. Oxygen consumption per gram decreased with increased weight. Respiration differed between croaker, pinfish, and black sea bass over a comparable size range.

A Habitat Suitability Index (HSI) model was developed for juvenile Atlantic croaker for use in impact assessment and habitat management (Diaz 1982). The water quality assumptions of the model were: (1) high turbidity levels are positively related to croaker abundance; (2) low levels of dissolved oxygen (<3 mg/l) are not suitable; (3) the range of optimal salinity is much narrower than the maximum range, and obigohaline and lower mesohaline salinities are optimum; (4) salinity stability is optimal; and (5) high temperature stability is optimal. In general the primary habitats for juvenile croaker are estuarine marshes and estuarine open water areas. Cover type component assumptions were: (1a) optimal cover diversity of marsh and tidal creek is found when approximately equal amounts of both are present; (1b) optimal cover is found when all bottom is deeper than 1.8 m MLW; (2) soft mud is most suitable; and (3) highly organic muds are optimal. These variables are weighted in the model according to their importance and the model is scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimal suitable habitat).

11.3 Life History

Summaries of published information on the life history of Atlantic croaker were presented by Gutherz (1976), Darovec (1983), and Lassuy (1983).

11.3.1 Reproduction

Atlantic croaker have a prolonged fall-winter spawning season throughout their range. Colton et al. (1979) reported that spawning occurred from August through December from Chesapeake Bay to Cape Hatteras. Welsh and Breder (1923) observed that males with running milt were taken in the ocean off Atlantic City, New Jersey in July, although no ripe females were recorded earlier than September. Wallace (1940) reported a seaward spawning migration from Chesapeake Bay from July through November. Maturity stages for Atlantic croaker collected between Cape May, New Jersey and Cape Hatteras, North Carolina indicated that spawning commenced at least as early as the beginning of September, peaked during

October, and ended by late December (Morse 1980). Larvae (<10 mm) were collected every month from September through May, but were most abundant from October through March in North Carolina waters (Hildebrand and Cable 1930). Based on larval collections, Warlen (1980) found that spawning in North Carolina waters occurs over a five-month period from mid-September to late February, with the majority probably spawning in October and November. Bearden (1964) reported that the principal months for spawning off South Carolina were October to January, based on frequency of appearance of larvae and post-larvae. Setzler (1977) reported September-April spawning off Sapelo Island, Georgia based on larval collections. Spawning in the Gulf of Mexico also occurs during fall and winter at least from September to late March with a distinct peak in October (White and Chittenden 1977).

Reported size and age at maturity for Atlantic croaker vary. Welsh and Breder (1923) stated that maturity is reached at the age of three or four years on the Atlantic coast while Pearson (1929) concluded that croaker in Texas waters spawn at the end of their second year. Wallace (1940) examined over 1,000 gonads of croakers of various ages in Chesapeake Bay and the ocean and found that only about 45% of the males were mature at the end of the second year, and no females reached sexual maturity until their third year. The smallest mature male was 24 cm TL and age II while the smallest mature female observed was 27.5 cm. Morse (1980) calculated L_{50}s (length at which 50% are mature) using probit analysis for male and female Atlantic croaker between Cape May, New Jersey and Cape Hatteras, North Carolina, 1973-1976. L_{50}s for males and females ranged from 18.71-22.35 cm TL and 18.52-23.27 cm TL, respectively. Bearden (1964) collected seven females (178-230 mm TL) with ripe ovaries and five males (137-185 mm TL) with running milt off South Carolina in September, and 19 fish (195-243 mm TL) with well-developed roe and running milt in December.

Fecundity of Atlantic croaker ranged from 100,800 to 1,742,000 for fish 196 to 390 mm TL (Morse 1980). Hildebrand and Schroeder (1928) reported that a 395 mm female contained approximately 180,000 eggs. Morse (1980) presented the following relationships between fecundity (F) and length (L in mm TL), fish weight (W in g), and ovary weight (V in g) for 113 Atlantic croaker:

$$\log F = -2.586 + 3.361 \log L, \; r = 0.86$$

$$F = -29{,}175 + 1{,}624\, W, \; r = 0.89$$

and

$$F = 8{,}603 + 19{,}966\, V, \; r = 0.98.$$

11.3.2 Pre-Adult Phase

Atlantic croaker eggs have not been described. Hatching size is 1.5 mm TL (Lippson and Moran 1974). Embyronic development of laboratory-spawned croaker was described by Middaugh and Yoakum (1974). Various sizes of larvae, post-larvae and juveniles were described and illustratrated by Welsh and Breder (1923), Pearson (1929), Hildebrand and Cable (1930), Lippson and Moran (1974), and Fruge and Truesdale (1978). Powles and Stender (1978) described the development of morphometric and meristic characters of Atlantic croaker, 3.1-41.0 mm. Hildebrand and Cable (1930) and Fruge and Truesdale (1978) compared larval development of spot and croaker from North Carolina and the northern Gulf of Mexico, respectively. Larvae <4.5 mm SL can be distinguished from one another only by pigmentation.

11.3.3 Adult Phase

The maximum age reported for croaker in North Carolina waters is seven or eight years at sizes >500 mm TL (Ross in press). The largest croaker reported in the literature is a specimen 668 mm TL (26.1 in), weighing 3.6 kg (8 lb) gutted, from the Gulf of Mexico (Rivas and Roithmayr 1970). Croaker in the Carolinean Province are typically small and have a short life span and high mortality rate (Gunter 1950; White and Chittenden 1977). Gunter (1950) suggested that size differences were produced by temperature. The largest croaker observed in warm-temperature waters were generally <300 mm (Hildebrand and Cable 1930; Reid 1955; Bearden 1964; Nelson 1969; Hansen 1969; Parker 1971; Hoese 1973; White and Chittenden 1977), although some fish were as large as 330-380 mm (Pearson 1929; Gunter 1945; Suttkus 1955; Franks et al. 1972; Christmas and Waller 1973).

Similarities in diet and habitat have suggested that spot and croaker are in direct competition with one another (Parker 1971; Sheridan 1979); however, other studies indicate that competition is avoided by subtle differences in feeding habits and distribution. A study of the life history, feeding habits, and functional morphology of juvenile sciaenid fishes (including spot and croaker) in the York River estuary, Virginia concluded that juvenile sciaenids are able to coexist in the same area because of differences in spatial and temporal distribution. Young-of-the-year croaker entered the estuary in August and stayed throughout the winter, whereas young-of-the-year spot were first caught in early April and left the estuary by December. Croaker fed on the substrate, on the epifauna, and spot fed more "into" the substrate on infauna (Chao and Musick 1977; Currin 1984). Enclosure studies of food resource partitioning between juvenile spot and croaker revealed that spot increased their consumption of meiobenthos and croaker ate more zooplankton in response to depleted macrobenthic prey (bivalve siphons). These differences in feeding behavior should allow the species to partition food resources during periods of low abundances of preferred prey and thereby relieve competitive pressures for food (Woodward 1981). Govoni et al. (1983, 1986) reported that spot and croaker larvae collected in the Gulf of Mexico had distinct, non-overlapping diets and were spatially segregated, implying that they do not compete for food.

Predators of Atlantic croaker are larger piscivorous species such as striped bass (Hollis 1952; Raney 1952; Dovel 1968), southern flounder (Darnell 1961; Matlock and Garcia 1983), bull shark, blue catfish, yellow bass, spotted seatrout, croaker, sheepshead (Darnell 1958, 1961), bluefish (Wilk 1977) and weakfish (Merriner 1975).

Parasites of Atlantic croaker were reported by Linton (1904), Bearden (1964), Joy (1974), Benner (1980), and Govoni (1983). Govoni (1983) reported helminth infections of croaker larvae collected in the Gulf of Mexico. Benner (1980) analyzed the effects of a migration from a coastal to an estuarine habitat on the parasitocoenose of the Atlantic croaker and noted a gradual change in the parasite fauna through the summer.

11.3.4 Nutrition and Growth

The Atlantic croaker is an opportunistic bottom-feeding carnivore which feeds on a variety of invertebrates, including polychaetes, mollusks, ostracods, copepods, amphipods, mysids, and decapods, and occasionally fish (Linton 1904; Welsh and Breder 1923; Hildebrand and Schroeder 1928; Pearson 1929; Gunter 1945; Roelofs 1954; Reid 1954; Darnell 1958, 1961; Avault et al. 1969; Hansen 1969; Fontenot and Rogillio 1970; Parker 1971; Thomas 1971; Diener et al. 1974; Weaver and Holloway 1974; Stickney et al. 1975; Chen 1976; Chao and Musick 1977; Overstreet and Heard 1978; Kobylinski and Sheridan 1979; Sheridan 1979; Woodward 1981; Sutherland 1982; Divita et al. 1983; Matlock and Garcia 1983; Shipman 1983; Sheridan and Trimm 1983; Currin 1984; Music and Pafford 1984) (Table 11.2). Chao and Musick (1977) compared morphological structures related to feeding habits in six species of sciaenids and concluded that Atlantic croaker feed on the bottom on epifauna by sight, olfaction, and touch. Feeding adaptations in croaker include an inferior mouth, villiform teeth, and compared to other sciaenids, an intermediate number of gill rakers and a long intestine. Roelofs (1954) reported that croaker, feeding in laboratory aquaria, dived deeply into the bottom with some force and that food items were sorted from debris with the gill rakers. Numerous investigators reported the presence of large quantities of indeterminable matter and organic debris in croaker stomachs.

Ontogenetic shifts in diet were reported for Atlantic croaker (Darnell 1958; Parker 1971; Stickney et al. 1975; Overstreet and Heard 1978; Stickney and McGeachin 1978; Kobylinski and Sheridan 1979; Sheridan 1979; Currin 1984). The diet of larval Atlantic croaker collected in the Gulf of Mexico consisted of 200 plankton such as copepodites and adult copepods (Govoni et al. 1983). Govoni et al. (1986) reported that croaker larvae feed selectively on copepodid and adult copepods in the Gulf of Mexico and that selection appears to be related not only to the width, but also to the swimming behavior and color of the food organisms. Young croaker, <40 mm SL, feed on polychaetes amphipods, ostracods, copepods, and mysids. Fish, 40-90 mm SL, feed on a greater variety of organisms, including small crustaceans, fish, and polychaetes, while larger fish, >90 mm SL, contain crustaceans, annelids, and mollusks. Sheridan (1979) reported that polychaetes formed the basis of the croaker diet, averaging 32% by weight for all size classes.

Geographic and seasonal variations in diet are probably attributable to availability of prey species (Darnell 1958; Chao and Musick 1977). Sheridan (1979) reported that croaker mainly ate small crustaceans in shallow, low salinity areas, and polychaetes in deep, high salinity areas. Intermediate-sized croakers (70-124 mm TL) collected in a Louisiana estuary contained large amounts of mollusks, insects, amphipods, and isopods, whereas the same size fish collected in a Texas estuary contained more mud, sand, and vascular plants (Parker 1971).

Food consumption for juvenile croaker in nontidal marsh area in North Carolina was estimated at 1.44g dry wt/m^2/yr (Currin et al. 1984). The production value for croaker was 0.43 g/m^2/yr and fell within the range of estimates for spot.

Table 11.2. Stomach contents of croaker, Micropogonias undulatus, from different estuarine areas along U.S. Atlantic and Gulf of Mexico coasts (from Chao and Musick 1977).

Author	Chao (1976)	Thomas (1971)	Roelofs (1954)	Welsh and Breder (1923)		Stickney et al. (1975)	Hansen (1969)	Parker (1971)			
Locality	York River, Va.	Delaware River Del.	North Carolina coast	Winyah Bay S.C.	Cape Canaveral Florida	Savannah River Ossabaw Sound, Ga.	Pensacola Fla.	Lake Pontchartrain Louisiana		Clear Lake Texas	
Period	Jun-Aug 1973	Nov-Dec 1970	All seasons 1950	Jul 1915	Dec 1919	May 1972-Jul 1973	Aug 1963 Dec 1965	Jan 1963 Dec 1965 D		Jan 1963 Dec 1965	
Source	Original	Table 71	Table 1	p. 184	p. 183	Table 1	Table 5	Table 28		Table 28	
Number of specimens	69	25	159	37	24	196	2,520	63	44	1,866	475
Empty stomachs	5	3	?	0	6	15	?	2	6	194	15
Length of specimens	56-199 mm TL	23-50 mm TL	60-140 mm TL		4.2-6.2 cm SL	39-180 mm SL	76-173 mm TL	10-74 mm TL	75-124 mm TL	10-96 mm TL	70-110 mm TL
Quantitative method	% occurrence	% occurrence	% occurrence	% of volume		% occurrence	% of volume	% occurrence			
Fish and remains	20.3		3.1	0.7		7.5	[1]15.9 14.3	11	9	4	5
Macrozooplankton											
Mysidacea	3.1	64.0	5.7			1.0		5	4.5	2	2
Neomysis americana	35.9					16.9					
Isopoda	1.6	4.0				1.0		6.5	8.0	10.5	18.0
Decapoda (shrimp)	9.4		3.1	7.0	24.0	3.0		3	18.5	19.5	14.5
Insecta	1.6					0.5		3	18.5	13.0	20.0
Others and remains	3.1			7.0							
Microzooplankton:											
Copepoda	3.1	76.0	25.2			7.0		2.0	6.5	1.0	3.0
Calanoid	10.9					1.0					
Harpacticoid						10.0					
Ostracoda						0.5		8.0	12.0	9.0	8.0
Others and remains	6.3		4.4	2.0							
Epibenthos:											
Annelids (polychaetes)	67.2		89.9	29.0	3.0	12.4	61.5	17.0	6.5	6.0	7.0

Table 11.2 (continued).

Author	Chao (1976)	Thomas (1971)	Roelofs (1954)	Welsh and Breder (1923)		Stickney et al. (1975)	Hansen (1969)	Parker (1971)			
Locality	York River, Va.	Delaware River Del.	North Carolina coast	Winyah Bay S.C.	Cape Canaveral Florida	Savannah River Ossabaw Sound, Ga.	Pensacola Fla.	Lake Pontchartrain Louisiana		Clear Lake Texas	
Period	Jun-Aug 1973	Nov-Dec 1970	All seasons 1950	Jul 1915	Dec 1919	May 1972-Jul 1973	Aug 1963 Dec 1965	Jan 1963 Dec 1965 D		Jan 1963 Dec 1965	
Source	Original	Table 71	Table 1	p. 184	p. 183	Table 1	Table 5	Table 28		Table 28	
Number of specimens	69	25	159	37	24	196	2,520	63	44	1,866	475
Empty stomachs	5	3	?	0	6	15	?	2	6	194	15
Length of specimens	56-199 mm TL	23-50 mm TL	60-140 mm TL		4.2-6.2 cm SL	39-180 mm SL	76-173 mm TL	10-74 mm TL	75-124 mm TL	10-96 mm TL	70-11[illegible] mm TL
Quantitative method	% occurrence	% occurrence	% occurrence	% of volume		% occurrence	% of volume	% occurrence			
Nearis succinea		18.8					3.0				
Glycinde solitaria		9.4									
Phyllodocid		1.6									
Spionid		6.3				1.0					
Cumacea		4.7			2.0		6.0	4.0	4.5	5.0	16.0
Amphipoda		21.9		5.7			8.0				
Gammarus sp.		7.9					9.5	17.0	10.0	16.0	10.5
Crabs		3.1			1.8		4.5	17.0	18.5	22.0	18.0
Others and remains		6.3			1.0	2.5	7.0				
Infauna:											
Pectinaria gouldii		15.6									
Ampharetid		1.6									
Gastropoda		1.6						[2]9.0	[2]3.0	[2]18.0	[2]18.-
Pelecypoda			11.3			2.5	[2]3.5				
Nematoda			0.6				0.3				
Unidentified remains and organic matters		23.5	4.4	22.0	48.0	35.6	2.5	17.0	14.0	12.0	9.0

1. Arthropods.
2. Mollusks.

Growth of croaker has been estimated from length frequency analysis and mark-recapture studies, and daily growth increments on otoliths. First year growth estimates from various studies were summarized by Knudsen and Herke (1978) (Table 11.3). Estimated daily increase in length ranged from 0.22 to 0.42 mm for the length frequency method and 0.47 to 0.99 for mark recapture studies. Higher growth rates indicated by mark-recapture studies reflect seasonal variations in growth rates and the short time-span (1-4 months) over which growth was measured. Knudsen and Herke (1978) reported that growth rate estimates increased from January through May as water temperature increased from 8.7°C to 28.0°C. Hansen (1969) noted that growth of juveniles averaged from 0.30-0.36 mm/day from January through August with maximum growth of 0.10 mm/day in July.

Warlen (1980) determined the age and growth of larval croaker in North Carolina from daily growth increments on their otoliths. A Laird-Gompertz growth model, $L_{(t)} = 0.926e^{2.876(1-e^{-0.0428t})}$ where $L_{(t)}$ = length at time (t), described the growth of larvae to 62 days old. The age specific growth rate showed a decline in daily growth rate from 12.3% at day-0 to 0.9% at day-60.

11.3.5 Behavior

Seasonal movements and migrations of Atlantic croaker from tagging studies were reported by Wallace (1940) and Haven (1957) for the Chesapeake Bay, Pearson (1932) and DeVries (1986) for North Carolina, Bearden (1964) for South Carolina, and Music and Pafford (1984) for Georgia. Results of these tagging studies indicated that Atlantic croaker generally move out of estuaries in the fall and south along the coast.

Haven (1957) reported that in Chesapeake Bay most croaker migrated up-river or up-bay in spring and early summer, moved more or less at random in summer, and shifted down-river or down-bay in fall. Croaker tagged in August in the upper Chesapeake Bay were recaptured a short time later in the lower Bay. Tag recoveries off the North Carolina coast in winter from fish tagged in Delaware Bay (Pearson 1932) and the Maryland-Virginia coast (Haven 1959) in fall indicate a coastwide migration to the south in late fall.

A three year tagging project in North Carolina, in which 98,000 croaker were tagged, revealed that during October-December, croaker in southern Pamlico Sound move out of the tributaries into deeper, more open water, into nearshore ocean waters south of Cape Hatteras, and south along the coast at least as far as Savannah, Georgia. Cape Lookout, N.C. appeared to be a primary over-wintering area for yearling fish. In spring croaker moved back into Pamlico Sound to areas of moderate salinities although a few moved to estuaries to the south as far as the Georgia-Floria border and to the north as far as Chesapeake Bay. There was little movement of croaker from northern to southern Pamlico Sound (DeVries 1986).

In a Georgia tagging study, 82% of the croaker which left the estuaries moved southward and few creel-size fish remained in the estuaries during

Table 11.3. First year Atlantic croaker growth estimates from the literature, prorated to daily growth increments [modified from Knudsen and Herke (1975)].

Area and habitat	Standard length at 1 year (mm)	Computed daily increase (mm)	Method	Source
Atlantic coast-open water	120	0.33	length frequency	Welsh and Breder (1923)
Chesapeake Bay and tributaries	140-144	0.38-0.39		Haven 1957
Pamlico Sound, North Carolina	144	0.39	length frequency	Higgins and Pearson (1928)
North Carolina-sounds and ocean	115	0.32	length frequency	Hildebrand and Cable (1930)
North Carolina-ocean and estuary		0.156-0.272	daily growth increments on otoliths	Warlen (1980)
North Carolina estuaries		0.035g/day	length frequency (Mar-Oct)	Currin et al. (1984)
North Carolina-ocean and sounds	121	0.33	length frequency	Ross (in press)
South Carolina-tidal creeks, bays, ocean	120	0.33	length frequency	Bearden 1964
Georgia-sound and ocean	150	0.41	length frequency	Hoese 1973
Florida-Pensacola estuary	86-104	0.24-0.28	length frequency	Hansen (1969)
Northern Gulf of Mexico-ocean	96	0.26	length frequency	Roithmayr (1965)
Northern Gulf of Mexico offshore	128	0.35	length frequency	Juhl et al. (1975)
Alabama-Mobile Bay	94	0.26	length frequency	Nelson (1969)
Louisiana-marsh bays, Gulf	84-116	0.23-0.32	length frequency	Suttkus (1955)
Louisiana-stocked 0.04 ha brackish ponds	172	0.47	stocking	Avault et al. (1969)
Louisiana-natural and semi-impounded marsh	200	0.56	mark-recapture	Herke (1971)

Table 11.3. (continued)

Area and habitat	Standard length at 1 year (mm)	Computed daily increase (mm)	Method	Source
Louisiana-marsh and open water	112-120	0.31-0.33	length-frequency	Wagner (1973)
Louisiana-semi-impounded marsh		0.47	mark-recapture	Arnoldi et al. (1974)
Louisiana-marsh	110-120	0.30-0.33	Tarbox (1974)	
Louisiana-semi-impounded marsh		0.51-0.99	mark-recapture	Knudsen and Herke (1978)
Texas and Louisiana-Gulf and bays	126-132	0.35		White and Chittenden (1976)
Texas-open water	120	0.33	length frequency	Pearson (1929)
Texas coast-open water	82-138	0.22-0.38	length frequency	Gunter (1945)
Texas - Galveston Bay	113-114	0.31	length frequency	Parker (1971)

* Total lengths were converted to standard lengths by multiplying by 0.8.

winter (Music and Pafford 1984). A South Carolina study also revealed a southward migration along the coast in fall (Bearden 1964).

Hettler (1977) measured maximum sustained swimming speed of five species of estuarine fish, including juvenile croaker, to predict impingement on power plant intake screens. Swimming speeds for croaker and spot were lower than for pinfish, menhaden, and striped mullet. Perez (1969) determined the average swimming speed of croaker (63.0-118.8 mm) under a constant and a changing salinity regime. Croaker moved faster under 5 and 10°/₀₀ change/hr as compared to the fixed salinity regime.

11.3.6 Contaminants

Trace element levels were determined for 15 elements in Atlantic croaker to provide baseline data to help identify potential problems involving elements or locations (Hall et al. 1978). Doyle et al. (1978) investigated depuration of the organochloride Kepone in croaker from the James River, Virginia, and found that no substantial depuration occurred until the water temperature exceeded 15°C. Total PCBs (polychlorinated biphenyls) in Atlantic croaker from Texas ranged from 0.09 to 0.31 ppm with a mean of 0.18 ppm, a level well below the FDA limit of 5 ppm and the proposed 2 ppm standard (Gadbois and Maney 1983). Larval croaker were exposed to sea water extracts of sediment (reported to contain high concentrations of lead, copper, zinc, and chromium) from one site in Charleston Harbor, S.C., and after 96 h survival did not differ from controls (Hoss et al. 1974). Larvae of other species, including pinfish, menhaden, and flounders, were affected in other tests using sediment extracts from different sites.

11.4 Population

11.4.1 Structure

Sex ratio data for Atlantic croaker populations are scarce. Reported sex ratios for croaker collected in Chesapeake Bay and the ocean off North Carolina varied seasonally (Wallace 1940). The sex distribution was about equal in spring when croaker moved into the bay; however, females outnumbered males from July through October, indicating that males may begin the seaward spawning migration earlier than females. Fall and winter sex ratios of croaker collected in the ocean were about equal.

Atlantic croaker have been aged using eye lens weight (Mericas 1977), scales (White and Chittenden 1977; Barger and Johnson 1980; Music and Pafford 1984; Ross in press) and otoliths (Barger and Johnson 1980; Music and Pafford 1984; Barger 1985). White and Chittenden (1977) reported that two scale marks formed annually on croaker from the northwestern Gulf of Mexico; the first was more or less indistinct and formed in warm periods, and the second mark formed in cold periods and was considered the true annulus. Formation of a single annulus occurred from December to May on otoliths in the Gulf of Mexico (Barger 1985), March-May on scales and otoliths in Georgia croaker (Music and Pafford 1984), and April-June in North Carolina fish (Ross in press). Ross (in press) stated that the formation of two marks in the northwestern gulf was problematic, given the environmental similarities of that region to North Carolina, but that it might be related to croaker age specific movements between estuaries and the Gulf. More extensive aging studies using otoliths, scales, and length frequencies from several different areas are needed to clarify croaker mark formation.

The age composition of Atlantic croaker population varies throughout its range (Table 11.4). Age VII was the maximum age reported for North Carolina, although most fish were <3-4 years old (Ross in press). Ages V-VII were mainly collected from the offshore winter trawl fishery and were rare in estuarine waters. Length frequency data indicated that three age classes (YOY, I, II) of croaker were present in a trawl survey of the South Atlantic Bight (Wenner 1987a). Age I fish were most abundant and 4% were age II, using White and Chittenden's (1977) size at age data. Five age groups of croaker were reported for Georgia; however, only ages I-II were common (Music and Pafford 1984). Eight age groups were reported from the northern Gulf of Mexico, but most fish sampled belonged to age groups 0 and I (Barger 1985). White and Chittenden (1977) observed two age classes in the northwestern Gulf of Mexico, but only age I was abundant.

Estimates of length at age vary over the geographic range (Table 11.4); however, comparisons between studies may be misleading due to such things as varying collection and ageing techniques, the prolonged spawning season, and annual variations in growth. Mean back-calculated total lengths at first annulus formation were greatest for croaker in the northern Gulf of Mexico (204 mm TL, Barger 1984) and North Carolina (181 mm TL, Ross in press). However, croaker in North Carolina were larger than Gulf of Mexico fish at each successive age. White and Chittenden (1977) reported a mean length of 165 mm at age I for croaker in the northwestern Gulf of Mexico which was similar to Music and Pafford's (1984) results for croaker in Georgia (164 mm TL).

Von Bertalanffy growth parameters were estimated for croaker in North Carolina (Ross in press) and the Gulf of Mexico (Chittenden 1977; Barger 1985) (Table 11.5). Predicted lengths at ages I-VI for North Carolina fish were 176.6, 261.5, 331.0, 388.0, 434.5, and 472.7 mm TL, respectively. Chittenden's (1977) estimate of growth parameters was calculated using average total lengths of 160 and 275 mm at ages I and II, respectively, from White and Chittenden (1977) and 3 mm TL to represent the average length of croaker at age 0. Using length at age 0 assumes that the von Bertalanffy equation approximately describes growth throughout life, rather than just growth during the second stanza (Ricker 1975). If this assumption is wrong, K may be an under-estimate and L_∞ may be an over-estimate (Chittenden 1977). Estimates of L_∞ ranged from 419 to 645 mm TL.

Length-weight relationships were reported for croaker in North Carolina (Hester and Copeland 1975; Ross in press), Georgia (Shipman 1983; Music and Pafford 1984) and the Gulf of Mexico (Dawson 1965; Avault et al. 1969; Parker 1971; White and Chittenden 1977; Barger 1985) (Table 11.6).

Differences in the life history of Atlantic croaker found north and south of Cape Hatteras, North Carolina were discussed by White and Chittenden (1977). Fish north of Cape Hatteras have a spawning season that starts earlier and may end earlier, reach maturity about 1 yr

Table 11.4. Mean back-calculated and observed total lengths (TL in mm) and growth increments for Atlantic croaker as reported in the literature.

Location and Reference	Age	N	Mean observed TL (mm)	Mean back-calculated lengths at time of annulus formation: 1	2	3	4	5	6	7	8
North Carolina (Ross in press)	0	292	144								
	I	936	192	168							
	II	537	271	179	251						
	III	358	320	188	265	305					
	IV	133	371	206	283	332	356				
	V	67	430	217	304	359	398	409			
	VI	16	473	232	324	378	425	452	488		
	VII	2	514	249	351	408	455	484	499		
	Total N	2341		1702	915	405	130	35	3		
	Weighted mean TL			181	266	326	388	433	495		
				181	76	46	35	19	22		
Georgia (Music and Pafford 1984)	0	137	148								
	I	82	248	169							
	II	27	268	149	233						
	III	1	297	161	214	263					
	IV	0									
	V	1	389	183	270	316	346	362			
	Weighted mean TL			164	233	290	346	362			
	Annual increment			164	69	57	56	16			
Northern Gulf of Mexico (Barger 1985)	I	320	219	199							
	II	70	269	211	251						
	III	23	304	216	254	289					
	IV	16	344	215	261	300	330				
	V	6	358	219	262	393	321	346			
	VI	3	385	229	265	300	333	360	376		
	VII	2	416	227	281	309	345	366	390	406	
	VIII	3	374	220	260	299	315	331	349	362	369
	Weighted mean TL			204	255	295	328	249	370	380	369
	Annual increment			204	51	40	33	21	21	10	-11

Table 11.5. Von Bertalanffy growth parameters as reported in the literature (total length in mm).

Location	Reference	L_∞	t_0	K
North Carolina	Ross (in press)	645	-0.60	.20
Northwestern	Chittenden (1977)	590	-0.0162	.3113
Gulf of Mexico	Barger (1985)	419	-1.405	0.273

Table 11.6. Published total length-weight relationships for Atlantic croaker (weight is in g and length in mm).

Location	Reference	N	Length range (mm TL)	Log a	b	r
North Carolina	Hester and Copeland (1975)	2,368	15-220	-5.29	3.15	0.99
North Carolina	Ross (in press)	1,947	81-533	-8.49	3.23	0.99
Georgia	Shipman (1983)	296		-4.91	2.99	0.90
Georgia	Music and Pafford (1984)	260	84-389	-5.37	3.20	0.96
Northern Gulf of Mexico	Dawson (1965)	1,123	50-200	-5.28	3.15	
Louisiana ponds	Avault et al. (1969)	362	165-264	-5.25	3.17	
Galveston Bay, Texas	Parker (1971)	2,645	40-198	-5.21	3.10	.99
Northwestern Gulf of Mexico	White and Chittenden (1977)	2,081	90-360	-5.26	3.15	0.98
Northern Gulf of Mexico	Barger (1985)	1,291	113-417	-5.28	3.13	0.99

later, and typically have larger sizes at age and greater maximum age. The observed differences in population dynamics north and south of Cape Hatteras may be largely the result of different temperature regimes that offset age at maturation, spawning-associated somatic weight loss, and the magnitude of a subsequent post-spawning mortality, or regionally differentiated genetic stocks of croaker may exist. Electrophoretic analyses of 11 genetic systems in croaker found potentially useful genetic variation in four enzyme/protein systems (phosphoglucose isomerase, hemoglobin, transferrin and parvalbumin) representing 10 loci (Sullivan 1986). Separation occurs among small juveniles, but the genetic systems showing heterogeneity (hemoglobin loci) could not be monitored because the adult genes had not been activated.

11.4.2 Abundance, Density, Mortality, and Dynamics

Juvenile croaker abundance peaked from fall through early summer in various estuaries along the Atlantic coast. In the York River estuary, Virginia, abundance peaked in late fall-early winter (Chao and Musick 1977) although in some years a peak occurred in late winter and spring (Haven 1957). In North Carolina estuaries, peak juvenile recruitment generally occurred from April to July (Benedict et al. 1984; Epperly 1984; DeVries 1985; Ross and Epperly 1985), although Tagatz and Dudley (1961) reported that abundance peaked in August in the Neuse River, N. C. A second peak in juvenile croaker abundance was reported in the fall in northern Pamlico Sound, N. C. (Ross and Epperly 1985). Abundance of juveniles in South Carolina estuaries peaked in late spring-early summer in South Carolina (Bearden 1964; Shealy et al. 1974; Miglarese et al. 1982) and Georgia (Mahood et al. 1974).

Catch per unit effort (CPUE) indexes for juvenile Atlantic croaker are available for different time periods along the coast and indicate that annual recruitment is highly variable. A croaker index from the Maryland striped bass seine survey, 1962-1984, indicated that abundance was high in 1974 and 1975 and lower peaks occurred in 1978 and 1983. A Maryland crab trawl survey, 1980-1985, indicated that croaker abundance peaked in 1983 with a lesser peak in 1985[5]. A trawl survey in Virginia waters, 1951-1982, also indicated that juvenile croaker abundance peaked in 1974 and 1975 and again in 1979 (Norcross and Shaw 1983). In Pamlico Sound, N. C., CPUE from a 1979-1984 trawl survey was highest in 1983 (DeVries 1985). Regressions of juvenile CPUE data on northern Pamlico Sound long haul seine croaker catches three years later yielded high correlations (0.978-0.993), but because of the few degrees of freedom, probabilities ranged from 0.053 to 0.0943. CPUE in a South Carolina survey between 1953 and 1962 peaked in 1956, 1959, and 1962 (Bearden 1964). Although the surveys are not directly comparable, similar trends in abundance are apparent from the Maryland, Virginia, and North Carolina surveys.

Commercial landings statistics may sometimes reflect long term trends in abundance of adult croaker. However, landings also are the result of

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[5]Pers. commun. Charles Frisbie, Maryland Department of Natural Resources, Annapolis, MD.

changes in fishing effort, area and gear restrictions, as well as market conditions, and thus not a precise nor accurate measure of abundance. Commercial landings data have been collected since 1880. From 1880-1927 a survey was conducted on the average of once every five years. Annual surveys were conducted from 1927 to 1956, and since then commercial landings statistics have been collected on a monthly basis. It should be noted that commercial statistics, when biased, tend to be underestimated due to reporting failures inherent in their collection.

Atlantic coast commercial foodfish landings of Atlantic croaker have fluctuated greatly during the past 50 years (Figure 11.6). A period of high landings was recorded from the mid-1930s throughout the 1940s, with peak catches of 26,665 mt and 29,121 mt landed in 1938 and 1945, respectively (Table 11.7). A sharp decline in croaker catches followed in the late 1940s to a low of 2,768 mt in 1952. Landings increased in the mid-1950s to 9,000 mt but declined again in the 1960s and reached an all-time low of 460 mt in 1970. Croaker catches increased in the 1970s with peak landings exceeding 13,000 mt in 1977 and 1978, and have since declined.

Shifts in the geographic distribution of foodfish catches of Atlantic croaker have occurred during the past 40 years (Figure 11.7). In the 1940s catches were primarily from the Chesapeake region, probably due to the great emphasis placed on nearshore and estuarine fisheries during World War II (Wilk 1981). The most recent peak in landings in the 1970s can be attributed to increases in North Carolina landings and somewhat to the Chesapeake region. The Middle Atlantic region has not contributed significantly to the total foodfish catch since the 1940s.

The Atlantic croaker is a southern species which is only caught in great abundance north of Chesapeake Bay when conditions are particularly favorable, or when populations are high (McHugh 1981). Commercial landings of croaker were reported from as far north as Massachusetts in the 1930s, but presently are reported from the Middle Atlantic region (New York, New Jersey, Delaware) south (Table 11.7). New Jersey croaker landings are exclusively from the more southerly winter trawl fishery and were highest from 1935 to 1944 (1,635-3,342 mt). Delaware is the most northerly location where croaker are caught in inshore fisheries, although catches there are irregular. Delaware landings were highest in 1930 (510 mt) and 1955 (303 mt) but have not exceeded 5 mt since 1957.

Historically, the Chesapeake region (Maryland and Virginia) accounted for the majority of Atlantic coast croaker landings. Virginia landings peaked at 25,036 mt in 1945 and then declined steadily to a low of 3 mt in 1968. Landings increased in the early 1970s, peaked at 3,901 mt in 1977 and then declined. Maryland landings followed a similar trend but only reached a high of 2,264 mt in 1944.

South Atlantic landings (North Carolina, South Carolina, Georgia, Florida east coast) have fluctuated since 1930 with peaks in 1937 (4,546 mt), 1958 (3,216 mt) and 1980 (9,619 mt). North Carolina landings account for 98-99% of the South Atlantic croaker catch. South Carolina and Georgia landings have not exceeded 50 mt and 10 mt, respectively. Florida landings are somewhat higher, ranging from 18 to 150 mt.

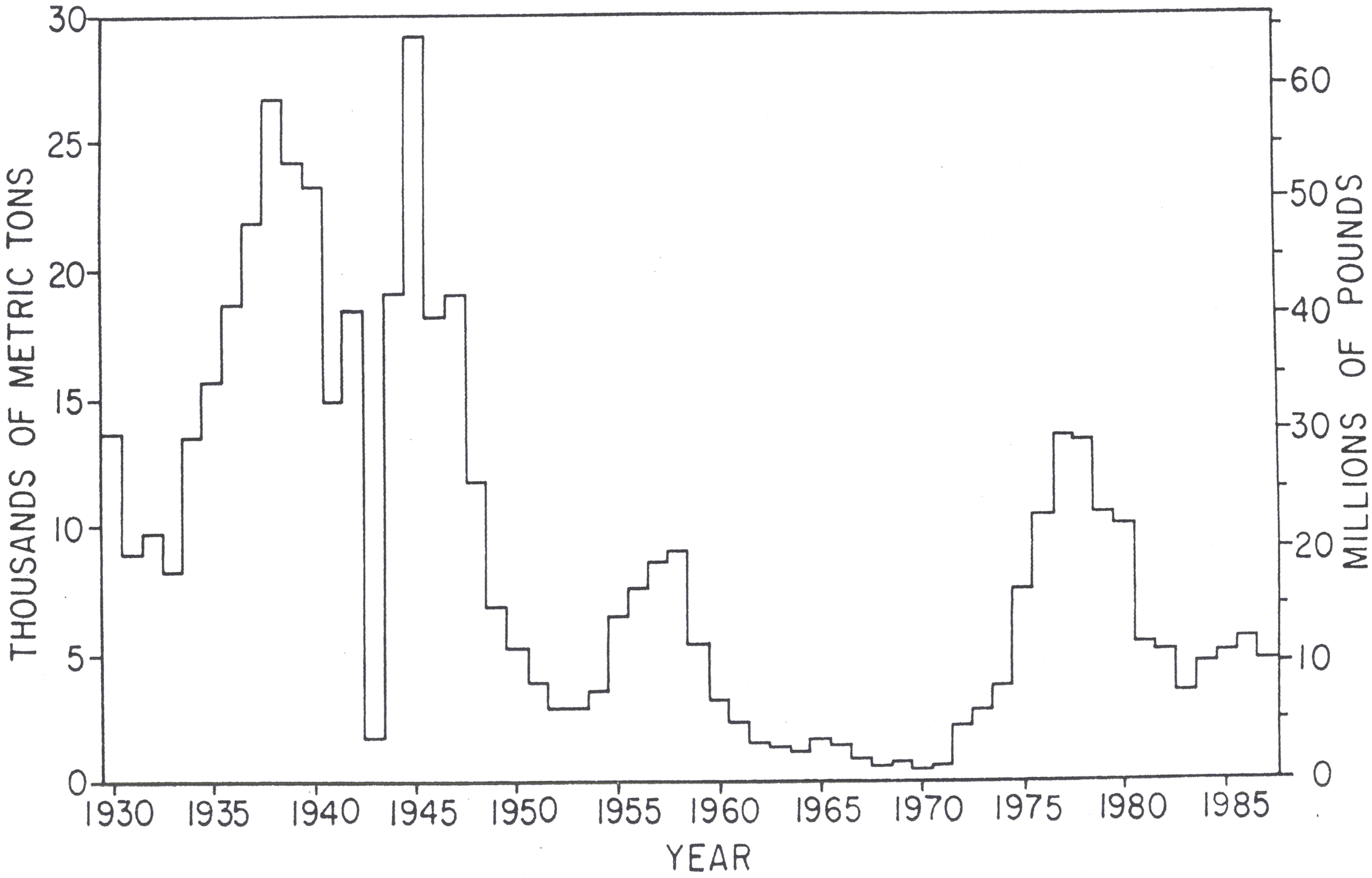

Figure 11-6. U.S. commercial landings of Atlantic croaker, 1930-1987.

Table 11.7. Commercial landings (mt) of Atlantic croaker by state, 1930-1987.

Year	New York	New Jersey	Delaware	Maryland	Virginia	North Carolina	South Carolina	Georgia	Florida east coast	Total
1930	147	653	510	959	9,030	2,317	1	7	6	13,631
1931	19	694	137	408	5,624	1,955	-	4	15	8,857
1932	30	328	30	600	6,665	2,059	-	4	12	9,728
1933	36	862	30	820	6,457	+	+	+	+	8,205
1934	+	+	+	967	9,046	3,485	-	3	20	13,521
1935	38	3,342	268	1,542	10,450	+	+	+	+	15,639
1936	+	+	85	1,276	12,901	4,419	-	2	16	18,700
1937	14	1,784	123	446	15,019	4,530	*	1	15	21,934
1938	*	2,612	103	1,372	19,634	2,937	*	1	5	26,665
1939	89	1,842	224	1,134	18,623	2,294	-	9	5	24,219
1940	182	1,981	186	1,557	17,369	1,955	-	3	11	23,245
1941	+	+	+	1,999	12,898	+	+	+	+	14,896
1942	77	2,419	137	2,703	12,108	+	+	+	+	17,444
1943	6	1,677	90	+	+	+	+	+	+	1,773
1944	10	1,635	117	2,264	15,072	+	+	+	+	19,098
1945	1	777	139	1,139	25,036	1,912	46	5	66	29,121
1946	*	+	+	1,279	16,929	+	+	+	+	18,208
1947	-	403	3	869	17,718	+	+	+	+	18,992
1948	-	154	15	1,006	10,502	+	+	+	+	11,675
1949	-	39	40	1,067	5,616	+	+	+	+	6,761
1950	-	17	3	1,142	3,027	951	13	*	27	5,181
1951	-	23	2	840	1,916	953	10	-	55	3,798
1952	-	38	4	386	1,652	611	10	-	68	2,768
1953	-	71	20	210	1,842	650	3	-	43	2,839
1954	-	167	27	414	2,324	461	2	-	57	3,453
1955	-	336	303	773	4,423	450	15	-	92	6,392
1956	-	35	12	793	4,385	2,190	34	-	63	7,512
1957	-	47	76	635	6,440	1,323	1	-	59	8,581
1958	-	*	1	299	5,378	3,139	5	*	72	8,894
1959	-	1	4	380	3,472	1,387	4	-	39	5,287
1960	-	4	*	266	1,784	949	9	*	64	3,076
1961	-	26	-	22	1,398	796	6	-	65	2,312
1962	-	2	-	5	587	754	15	*	73	1,437
1963	-	-	-	1	55	1,032	16	*	52	1,157
1964	-	-	-	1	179	847	5	*	46	1,077
1965	-	-	-	*	694	796	1	1	49	1,541
1966	-	-	-	*	664	575	*	2	150	1,392
1967	-	-	-	*	147	582	-	3	65	797
1968	-	-	-	*	3	545	-	-	32	579
1969	-	-	-	*	29	621	*	1	23	673
1970	-	*	-	*	58	366	1	4	30	460
1971	-	*	-	*	120	430	1	*	41	592
1972	-	*	-	*	220	1,864	*	1	46	2,131
1973	*	17	-	17	616	1,961	1	7	47	2,666
1974	-	20	-	54	681	2,759	18	4	29	3,566
1975	-	401	*	290	2,141	4,650	2	2	28	7,516
1976	-	318	1	485	2,675	6,821	*	6	35	10,343
1977	-	671	4	314	3,901	8,616	*	3	23	13,532
1978	-	297	3	271	3,674	9,047	*	*	18	13,310
1979	3	41	2	44	969	9,325	3	9	18	10,414
1980	*	5	-	3	323	9,592	2	2	23	9,952
1981	*	10	-	1	195	5,083	1	*	33	5,323
1982	-	*	-	1	54	4,910	*	1	43	5,009
1983	-	-	-	*	68	3,289	1	*	37	3,396
1984	1	26	-	12	370	4,160	2	*	55	4,627
1985	-	22	*	4	985	3,953	*	-	70	5,034
1986	-	48	*	62	1,074	4,275	*	*	42	5,501
1987	-	162	*	NA	1,226	3,306	*	*	98	4,792

- No landings reported
+ Landings data was not collected
* <1 mt reported
NA not available

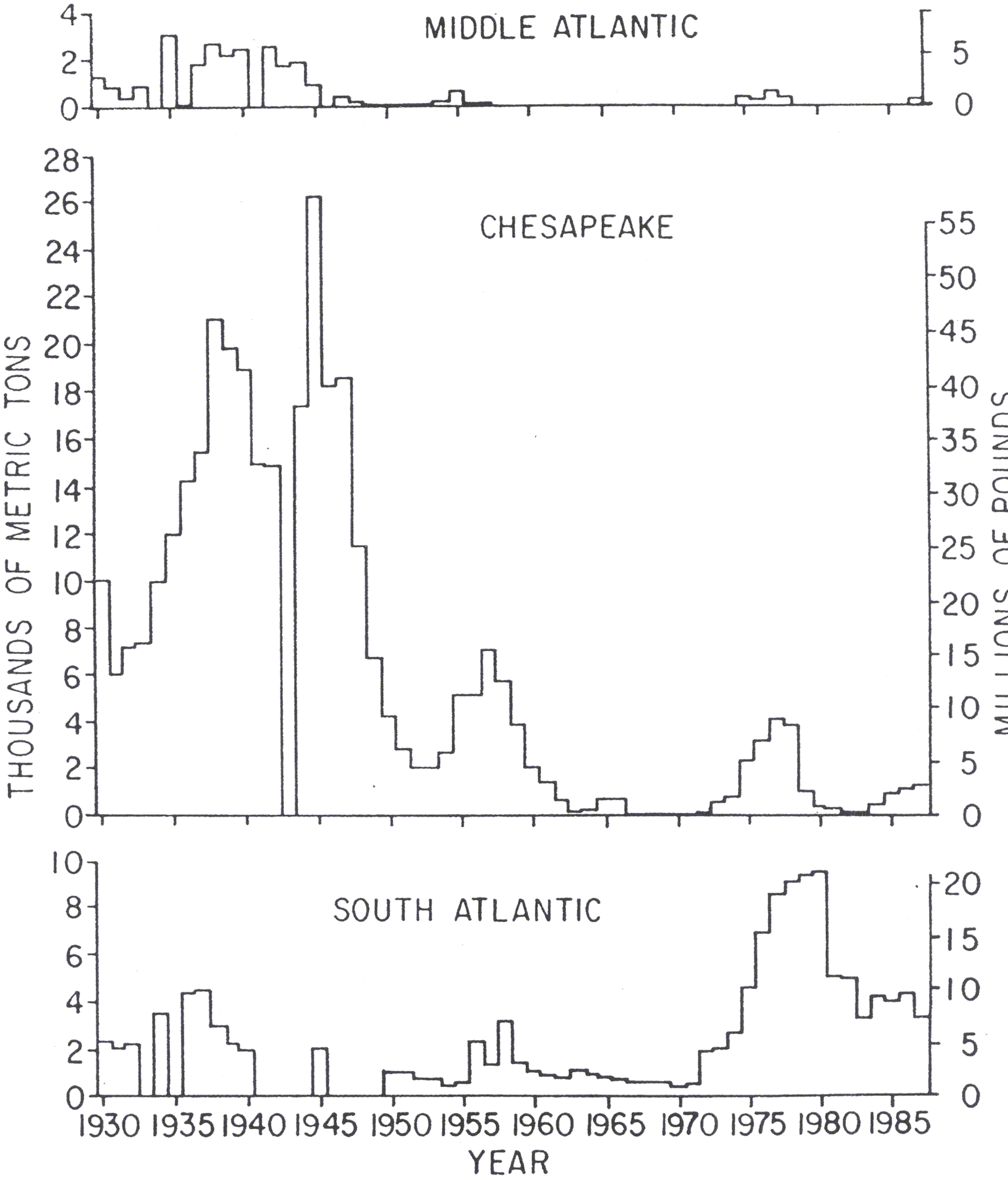

Figure 11-7. U.S. commercial landings of Atlantic croaker by geographic region, 1930-1987.

Recreational fishery statistics have been collected annually since 1979 by the National Marine Fisheries Service (Anonymous 1984, 1985a, b, 1986, 1987). Estimates of total number of fish caught were calculated from the estimated total number of fishing trips by mode obtained from a telephone survey, and the average number of fish caught per trip obtained from the intercept survey. Weights were obtained by sampling the fish caught and brought ashore in whole form by intercepted fishermen (Catch Type A). Estimated weights of the recreational catch presented in Table 11.8 were calculated by multiplying the average weight of Catch Type A times the number of fish caught in each region. Recreational landings fluctuated in both regions between 1979 and 1986 with the lowest catches in 1982 and 1985 and highest catches in 1979, 1984 and 1986 (Table 11.8). Estimated recreational catches of Atlantic croaker were less than commercial landings for all years.

Fluctuations in croaker landings appear to be related to variations in climate and fishing pressure (Perlmutter 1959). Joseph (1972) and more recently Norcross (1983) related trends in croaker landings to climatological trends. The warming trend of the first half of the 20th century appears to be linked to the increases in croaker landings and to the northward range extension of adult croaker as far north as Delaware in 1880 (McHugh 1981), New Jersey in 1900 (McHugh 1977b) and New York in 1920 (McHugh 1977b). Commercial landings of croaker were reported for Connecticut in 1935. While the 1940s was a period of unusual abundance, it was also one of heavy exploitation (Perlmutter 1959; McHugh 1977b). The combination of increased effort, a sharp downward climatic trend and a series of cold winters from 1958 to 1971 reduced the total Atlantic catch to <3,000 mt from 1961 to 1973. Massmann and Pacheco (1960) reported the disappearance of post-larval and juvenile croaker from the York River, Virginia nursery grounds in January-February 1958 following a period of unusually low temperatures and noted that this 1958 year class never contributed to future catches of croaker. McHugh (1977b) noted that croaker had made a partial recovery in abundance in the mid-1970s and suggested that degradation of estuarine areas was partially responsible for past population fluctuations. The resurgence in commercial landings of croaker in the 1970s and expansion of the range northward was attributed to the combination of warm winters and interannual increases in temperature. The short-lived warming trend and accompanying increased fishing effort, were followed by a fall in landings at the end of the 1970s (Norcross 1983).

Environmental factors controlling fluctuations in abundance of Atlantic croaker were investigated and quantified to produce a model predicting year class strength (Norcross 1983; Norcross and Austin 1981; Norcross and Shaw 1983; Norcross et al. 1985). Adult spawning and larval distribution on the continental shelf, and juvenile over-wintering within the Chesapeake Bay were identified as key periods of environmental vulnerability. The model encompases interactions of time of cessation of the summer wind regime in the Mid-Atlantic Bight, distribution of warm ($\geq 6°C$) bottom waters, and croaker spawning time, location and migration; effect of wind-induced transport of larval croaker on recruitment to the Chesapeake Bay; effect of low temperatures on subsequent summer recruitment of juvenile croaker in Chesapeake Bay; and the importance of year-class strength to the commercial catch of croaker.

Table 11.8. Atlantic croaker recreational catch statistics from National Marine Fisheries Service Marine Recreational Fishery Statistics Surveys, 1979-1987.

Survey year	Region	Number	Catch Estimated Weight* lb	kg	Average Weight* lb	kg
		--THOUSANDS--				
1979[1]	Middle Atlantic	1,805	2,053	931	1.1	0.5
	South Atlantic	8,306	4,643	2,106	0.6	0.3
	Total	10,111	6,695	3,037		
1980[1]	Middle Atlantic	1,781	703	319	0.4	0.2
	South Atlantic	4,141	2,363	1,072	0.6	0.3
	Total	4,100	2,260	1,025		
1982[2]	Middle Atlantic	1,557	855	388	0.5	0.2
	South Atlantic	2,543	1,404	637	0.6	0.3
	Total	11,447	1,764	800		
1983[3]	Middle Atlantic	7.071	1,792	813	0.3	0.1
	South Atlantic	4,376	1,576	715	0.4	0.2
	Total	3,681	3,369	1,528		
1984[3]	Middle Atlantic	7,553	2,247	1,019	0.3	0.1
	South Atlantic	11,275	4,566	2,071	0.4	0.2
	Total	18,828	6,814	3,091		
1985[4]	Middle Atlantic	5,553	944	428	0.2	0.1
	South Atlantic	5,869	1,174	532	0.2	0.1
	Total	11,422	2,118	960		
1986[5]	Middle Atlantic	12,988	4,248	1,927	0.3	0.1
	South Atlantic	6,088	3,137	1,423	0.5	0.2
	Total	19,076	7,385	3,350		
1987[+]	Middle Atlantic	7,748	1,550	703	0.2	0.1
	South Atlantic	12,114	2,181	989	0.2	0.1
	Total	19,862	3,731	1,692		

* from Catch Type A
1 Anonymous 1984
2 Anonymous 1985a
3 Anonymous 1985b
4 Anonymous 1986
5 Anonymous 1987
\+ preliminary data

Mortality estimates for Atlantic croaker indicate a lower rate of mortality at the northern end of the range. Ross (in press) estimated the total instantaneous rate of mortality (Z) from a catch curve analysis of the North Carolina long haul seine fishery. Based on five age groups with age I croaker fully recruited to the fishery, Z=1.3 and the total annual mortality rate (A) was 73%. The total annual mortality rate for croaker in the northwestern Gulf of Mexico where the typical maximum life span is 1-2 yr was 96% (White and Chittenden 1977).

Parameters of the Beverton-Holt yield equation were estimated to assess the effects of harvesting croaker in the northern Gulf of Mexico (Chittenden 1977) (Table 11.9). Simulations of the effects of fishing on croaker suggest: (1) the magnitude of maximum sustainable yield (MSY) critically depend on instantaneous natural mortality (M); (2) for the most likely ranges of M and mean selection age (t_c , yield per recruit (Y/R) is an asymptotic function of instantaneous fishing mortality (F), F_{MSY} is at least 1.5; (3) curves of eumetric fishing and MSY at given t_c are asymptotic in the most likely ranges of M and t_c, thus either management strategy requires a t_c range of about 0.5-1.0 years, and the required F is extremely sensitive to change in t_c; (4) in terms of MSY, overfishing currently occurs only if M is <1.0-1.5; and (5) in terms of eumetric fishing, overfishing now occurs unless M is at least 1.5-2.0 or more depending upon t_c. An exact assessment of the current impact of fishing is not possible because M is unknown. Maximum values of Y/R range from about 3-40 g and are inversely related to the magnitude of M. These simulations apply only to croaker of the warm temperate Carolinean Province; they do not apply to populations of the cold temperate waters north of there whose population dynamics differ. Chittenden[6] continued these simulations for croaker north of the Carolinean Province using a typical maximum size and age of 400 mm TL and age IV, respectively and a suggested value of about 8% for the total annual mortality rate (Z=1.15). Based on these estimates the simulations resulted in values of Y/R at MSY of 32-91 g for t_c = 1.5 years and 25-125 g for t_c = 3.0 years. It must be noted that these estimates for parameters are admittedly crude so that the results of the simulations may not be exact.

11.5 Exploitation

11.5.1 Commercial Exploitation

Aspects of the commercial fisheries for Atlantic croaker were discussed by Higgins and Pearson (1928), Hildebrand and Cable (1930), Pearson (1932), Roelofs (1951), Gutherz (1977), McHugh (1977 a, b), and Wilk (1981).

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[6]Chittenden, M.E., Jr. 1977. Management implications of zoogeographic variation in population dynamics of the Atlantic croaker, *Micropogon undulatus*. Presented at Annual Meeting of AFS, Vancouver, B.C., Canada.

Table 11.9. Summary of the estimated values for the parameters of the Beverton-Holt yield equation.

I. Growth-Related Parameters

$W = 2491$ grams

$K = 0.3113$

$t_o = -0.0162$ years

II. Mortality Coefficients

$Z = 3.0$

$M = 0.5 - 2.5$

$F = 0.5 - 2.5$

III. Time Parameters

$t_L = 2.0$ years

$t_r = 0$ years

$t_c = 0.50 - 0.85$ years

11.5.1.1 Fishing Equipment

Atlantic croaker are primarily caught by a variety of methods in mixed species fisheries. The major methods of harvesting Atlantic croaker include pound nets (Higgins and Pearson 1928; Rothschild et al. 1981), haul seines (Higgins and Pearson 1928; DeVries 1981; Rothschild et al. 1981), otter trawls (Pearson 1932), and gill nets. Trammel and fyke nets account collectively for approximately 1% of the foodfish catch of croaker. Industrial catches of croaker are made in the near-shore waters of the Gulf of Mexico with modified otter trawls (Gutherz 1977; Wilk 1981).

11.5.1.2 Areas Fished

Croaker are caught off the coast of North Carolina in winter in the trawl and gill net fisheries (Pearson 1932; Ross et al. 1986). The primary fishing grounds for croaker lie in the vicinity south of Cape Hatteras from 3 to 30 mi offshore in water from 18 to 55 m (10 to 30 fm) in depth. Large catches are made further north in the fall and spring as the fish are migrating.

Croaker are caught inshore in estuaries from spring through early fall. Hildebrand and Schroeder (1928) reported that in Chesapeake Bay the first catches are made with pound nets operated near the entrance to the bay. The fish migrate gradually up the bay and are common throughout the summer in the shallower shore waters. As cool weather arrives late in September and in October, the fish become scarce along the shores as they move into deeper water. Croaker are caught in North Carolina in the long haul seines which operate on the shallow, sandy bottoms of Pamlico and Core sounds and in pound nets in the deeper waters (5-6 m) of Pamlico Sound and its tributaries on muddy bottom (Higgins and Pearson 1928; DeVries 1981).

11.5.1.3 Fishing Seasons

The coastal and sound fisheries for Atlantic croaker are conducted from April through October. As water temperatures decline in fall, croaker move offshore and become the target of the winter trawl and gill net fisheries.

11.5.1.4 Fishing Operations and Results

Rothschild et al. (1981) examined trends in Chesapeake Bay fisheries which included Atlantic croaker. Time trends in pound nets and haul seines indicate a decline in units of both gears in the post-war years.

The efficiency of a 4.9-m (16-ft) otter trawl in capturing Atlantic croaker was estimated using mark-recapture experiments (Loesch et al. 1976). Trawl efficiency was determined to be approximately 26% for croaker, based on only one sample, compared with 6.5% for spot (3 samples).

Mean selection lengths (l_c) and ages (t_c) were estimated by Chittenden (1976) for shrimp trawls in the Gulf of Mexico. Estimates of t_c were about 0.50-0.85 and l_c were 91-142 mm TL for stretched-mesh sizes of 38.1-44.5 mm (1.5-1.75 in). Trent and Pristas (1977) calculated mean selection lengths of 22.4 to 26.9 cm (8.8 to 10.6 in) for gill net stretched-mesh sizes of 6.3 to 8.2 cm (2.5 to 3.2 in). Roelofs (1950) reported escapement for croaker (7->16 cm in length) of 12.2, 42.8, and 50.5%, respectively, from trawls with cod-end mesh 11 sizes of 5.1 cm (2 in), 5.7 cm (2¼), and 6.4 cm (2½ in).

11.5.1.5 Incidental Catches

Industrial or scrap landings of Atlantic croaker were reported annually by NMFS for 1966 in the Chesapeake region, 1966-1973 in the South Atlantic region, and 1966-1977 in the Gulf region (Table 11.9). Since 1973 scrap landings of croaker on the Atlantic coast are included in the category of "unclassified, for bait, reduction and animal food." Scrap landings in the Chesapeake region were 42 mt (92,000 lb) in 1966 and were chiefly derived from the pound net fishery (McHugh 1960; Joseph 1972). South Atlantic scrap landings ranged from 241 to 1,471 mt (0.5-3.2 million lb) over the 8-yr period and were derived chiefly from the trawl fishery with lesser amounts caught incidentally in the long haul seine and pound net fisheries (Fahy 1966; Wolff 1972). The Gulf industrial fish fishery is much larger and is supplied by a fleet operating solely for industrial species (Gutherz 1977; Austin et al. 1978). Landings of small croaker (115-200 mm) ranged from 23,192 to 28,729 mt (51-63 million lb) and accounted for 70% of the industrial catch in the Gulf of Mexico.

Studies of the North Carolina industrial fish fishery in 1962 and 1964 revealed that croaker accounted for 42.6 and 30.3% by weight, respectively, of the trawl landings or 1,558 mt (3.4 million lb) and 1,540 mt (3.4 million lb) (Fahy 1966). Wolff (1972) reported that croaker accounted for 20.3% by weight of the trawler-caught scrap fish from 1969-1971, or approximately 215 mt (0.5 million lb). Croaker <210 mm were generally discarded as scrap.

A more serious scrapfish problem may be the destruction of undersized fish by fisheries that cull the fish "at sea" rather than land them, especially the shrimp fishery (Roelofs 1950). Examination of finfish discarded in the North Carolina shrimp fishery in 1969-1971 indicated that croaker accounted for 24.2% of the discard, which amounted to approximately 808 mt (17,381,193 lb) of croaker based on a discard ratio of 5.4:1 (Wolff 1972). Keiser (1976) determined that the overall median fish/shrimp weight ratio in South Carolina was 1.94:1 and that 146-6,624 mt (0.3-1.5 million lb) of croaker were caught incidental to shrimping in 1975. Knowlton (1972) reported that croaker comprised 20.9% by weight of the finfish discard from Georgia shrimp trawl samples from July 1969 to June 1971. Croaker accounted for 10.5% of the total catch of fishes taken during shrimp trawling along the South Atlantic coast (Anderson 1968). Largest catches occurred in August and September while smallest catches were reported for February and March.

Great concern from environmentalists has been raised in recent years about the incidental catches and subsequent mortality of sea turtles and the large volume of finfish by-catch in the South Atlantic and Gulf shrimp fisheries. In order to reduce the mortality of threatened and endangered sea turtles, NMFS designed and tested a device, called the Turtle Excluder Device (TED), that was placed in the net in front of the codend to deflect sea turtles out through a trap door in the top of the net. The first TEDs were not well received by the shrimping industry because of their large size and heavy weight. They were redesigned, made lighter in weight, modified to increase their ability to exclude finfish and other organisms caught incidentally to trawling, and renamed to Trawl Efficiency Device. Several models of TEDs have been designed and tested by NMFS, various Gulf of Mexico and South Atlantic States and Sea Grant. Implementation of regulations requiring the use of these devices in the Gulf and South Atlantic is now occurring.

Results of tests conducted on two different TEDs (the NMFS-TED and the Georgia-Jumper), in South Carolina coastal waters were presented by Wenner (1987 b). In the July-August brown shrimp portion of the study, the total number of fishes in the by-catch was reduced by 49.7% while the total weight was 54.5% less in the NMFS-TED. Reductions in the catch of Atlantic croaker were 43.3% in number and 45.8% in weight. The Georgia-Jumper showed at 24.8% and 37.2% reduction in finfish by-catch in numbers and weight, respectively. Atlantic croaker were reduced by 58.3% and 62.8% in number and weight, respectively. Similar results in finfish by-catch reduction were obtained in the October-November white shrimp study. Reductions in the number and weight of Atlantic croaker were 70.6% and 73.7%, respectively.

TEDs have been shown to be effective in eliminating a sizeable portion of the by-catch encountered during shrimp trawling operations. Many finfish species of commercial and recreational interest, including the Atlantic croaker, weakfish, spot, kingfish, summer flounder, bluefish, and Spanish mackerel, were removed; however, the catch of shrimp was reduced by 2.5-15.8% in nets with TEDs. TEDs were also shown to be effective in reducing the catch of blue crabs (28.4-42.5% by weight) and horseshoe crabs (87.9-100%) by weight. While TEDs have not been readily accepted by fishermen, mainly because of their expense and handling problems, the results of field tests indicated that TEDs would be effective in reducing the bycatch and mortality of finfishes in the southern shrimp fishery.

11.5.2 Recreational Exploitation

11.5.2.1 Fishing Equipment

Atlantic croaker are caught bottom fishing, jigging, and live lining from anchored or drifting boats, or from shore. Baits include shrimp, squid, worms, clams, soft or shedder crabs, and cut fish. Artificial lures such as small jigs and weighted bucktails are also used (Freeman and Walford 1974, 1976a, b, c, d).

11.5.2.2 Areas Fished

Atlantic croaker are caught from ocean beaches and the banks of bays and rivers, as well as from man-made structures such as piers, bridges, jetties, and causeways. They are also taken while fishing nearshore and in estuarine waters from party, charter, and private boats of every description. According to the Marine Recreational Fisheries Statistics Survey, 1979-1987, the private-rental mode accounts for the majority of the recreational catch of croaker (Anonymous 1984, 1985 a, b, 1986, 1987) (Table 11.10). This species is usually taken from a few feet below the high tide line to depths of 14 m (45 ft) or more, over all types of bottoms, including mud, sand, gravel or rock bottom and around shellfish beds, rock piles, and wrecks. The majority of the recreational catch is derived from inland (estuarine) waters (Anonymous 1984, 1985a, b) (Table 11.11).

11.5.2.3 Fishing Seasons

The fishing season is progressively longer, proceeding south along the coast (Freeman and Walford 1974, 1976a, b, c, d). In Chesapeake Bay the fishing season extends from mid-April or May to late September or October, with best fishing in June to early July (Richards 1962; Williams et al. 1982, 1983). The fishing season from False Cape, Virginia to Altamaha Sound, Georgia extends from mid-April or May to late November with best fishing in August and September (Freeman and Walford 1976b). Hammond and Cupka (1978) reported that monthly catch per unit of effect for croaker caught on the South Carolina Pier fishery peaked in April. Most croaker are caught from March or April to November from Altamaha Sound, Georgia to Fort Pierce Inlet, Florida, with best fishing from July to September (Freeman and Walford 1976c). The fishing season is all year further south, with best fishing from November to March (Freeman and Walford 1976d).

11.5.2.4 Fishing Operations and Results

Recreational landings of Atlantic croaker apparently paralleled commercial landings trends in Virginia waters between 1955 and 1962. Richards (1962) reported a severe decline in the Chesapeake Bay croaker catch from 2.2 fish/man-hour in 1955 to 0.2 fish/man-hour in 1960. The Eastern Shore charter boat catch rate of croaker declined from 2.48 fish/man-hour in 1956 to 0.05 fish/man-hour in 1960 (Richards 1965). A croaker catch of 7,650 fish was reported in that study for 1956, while only 112 were reported landed during the 4-year period, 1959-1962.

11.6 Social and Economic Implications

11.6.1 Values

Croaker are second most valuable sciaenid landed in the U.S., behind weakfish (Cato 1981). The dockside value of croaker landings increased in the mid-1950s to over $2 million in 1956, declined in the early 1960s, and increased steadily after 1967. Croaker landings were valued at $5.8 million in 1979.

The dockside price of croaker has been highest in the Chesapeake region where it peaked at 25 cents per pound in 1963. South Atlantic prices have remained fairly stable at less than 10 cents per pound. Lack of price increases in the 1970s appears to be associated with the increased landings (Cato 1981).

Table 11.10. Estimated total number of Atlantic croaker caught by marine recreational fishermen by mode and subregion, 1979-1987.

Year	Region	Shore	Party/ charter	Private/ rental	All
		- - - - -T H O U	S A N D S -	- - - -	
1979[1]	Middle Atlantic	231	41	1,533	1,805
	South Atlantic	1,207	1	7,098	8,306
	Total	1,528	42	8,631	10,111
1980[1]	Middle Atlantic	178	65	1,538	1,781
	South Atlantic	1,807	1	2,333	4,141
	Total	1,985	66	3,871	5,922
1981[2]	Middle Atlantic	53	65	1,439	1,557
	South Atlantic	1,068	*	1,475	2,543
	Total	1,121	65	2,914	4,100
1982[2]	Middle Atlantic	222	*	128	350
	South Atlantic	1,408	267	1,656	3,331
	Total	1,630	267	1,784	3,681
1983[3]	Middle Atlantic	2,087	103	4,881	7,071
	South Atlantic	2,277	36	2,063	4,376
	Total	4,364	139	6,944	11,447
1984[3]	Middle Atlantic	1,218	2,323	4,013	7,553
	South Atlantic	2,332	2,940	6,003	11,275
	Total	3,550	5,263	10,016	18,828
1985[4]	Middle Atlantic	410	309	4,833	5,553
	South Atlantic	2,391	303	3,175	5,869
	Total	2,801	613	8,008	11,422
1986[5]	Middle Atlantic	383	698	11,906	12,988
	South Atlantic	5,129	3	956	6,088
	Total	5,512	701	12,862	19,076
1987[+]	Middle Atlantic	623	91	7,035	7,748
	South Atlantic	9,725	1	2,388	12,114
	Total	10,348	92	9,423	19,862

* denotes none reported

[1] Anonymous 1984
[2] Anonymous 1985a
[3] Anonymous 1985b
[4] Anonymous 1986
[5] Anonymous 1987
[+] preliminary data

Table 11.11. Estimated total number of Atlantic croaker caught by marine recreational fishermen by area of fishing within subregions, 1979-1987.

Year	Region	Inland	Ocean (≤3 mi)	Ocean (>3 mi)	Undefined	All areas
		-THOUSANDS-				
1979[1]	Middle Atlantic	1,537	217	22	28	1,805
	South Atlantic	6,992	825	486	3	8,306
	Total	8,529	1,042	508	31	10,111
1980[1]	Middle Atlantic	971	434	9	367	1,781
	South Atlantic	3,000	97	28	1,016	4,141
	Total	3,971	531	37	1,383	5,922
1981[2]	Middle Atlantic	471	640	386	59	1,557
	South Atlantic	1,175	1,140	*	228	2,543
	Total	1,646	1,780	386	287	4,100
1982[2]	Middle Atlantic	14	336	*	*	350
	South Atlantic	2,179	797	40	315	3,331
	Total	6,086	2,222	1,481	1,658	11,447
1983[3]	Middle Atlantic	3,724	522	1,441	1,384	7,071
	South Atlantic	2,362	1,700	40	274	4,376
	Total	2,193	1,133	40	315	3,681
1984[3]	Middle Atlantic	3,695	3,259	599	*	7,553
	South Atlantic	8,944	1,429	34	868	11,275
	Total	12,639	4,688	633	868	18,828
1985[4]	Middle Atlantic	3,972	1,235	346	*	5,553
	South Atlantic	3,784	876	1,209	*	5,869
	Total	7,756	2,111	1,555	0	11,422
1986[5]	Middle Atlantic	9,081	459	259	3,189	12,988
	South Atlantic	5,590	422	6	*	6,088
	Total	14,671	951	265	3,189	19,076
1987[+]	Middle Atlantic	5,644	999	1,105	*	7,748
	South Atlantic	11,372	685	57	*	12,114
	Total	17,016	1,684	1,162	*	19,862

* denotes none reported

[1] Anonymous 1984 [2] Anonymous 1985a [3] Anonymous 1985b [4] Anonymous 1986
[5] Anonymous 1987 [+] preliminary data

11.6.2 Employment

There is little information available on employment in the fisheries for croaker which are mixed species fisheries. Austin et al. (1978) presented information on employment in the fisheries for croaker in the Gulf of Mexico. The industrial fishery, which is the major fishery for croaker in the Gulf, employed about 50 fishermen as of January, 1978. There were about 300 persons directly employed by the industrial groundfish processors, 35 in Louisiana and 265 in Mississippi.

11.6.3 Participation

User groups include commercial fishermen, processors and dealers, food consumers, recreational fishermen, marinas, and bait shops. Little data exists on number of participants in these various user groups. Estimates of participation in marine recreational fishing by residents of the Mid-Atlantic states between 1979 and 1986 fluctuated between 2.0 to 4.3 million residents. Estimates for the South Atlantic ranged from 1.5 to 2.5 million residents for those same years (Anonymous 1984, 1985a, b, 1986, 1987).

11.6.4 Processors and Product Forms

Foodfish landings of croaker are primarily sold freshly iced, whole, through local fish houses (Gutherz 1977; Cato 1981). Summey (1977) reported that 52% of the North Carolina croaker catch was marketed in-state, primarily to coastal area markets. The primary out-of-state market was South Carolina, with smaller amounts going to Pennsylvania, Virginia, Maryland, and New York. The major in-state and out-of-state markets were wholesalers and distributors. A study of inland channels of distribution for fresh iced croaker found that 36.9% was purchased from in-state suppliers and 64.1% from two major out-of-state suppliers, Alabama (41.3%) and Virginia (21.8%) (Summey 1979). Out-of-state sources were used when croaker was out of season in North Carolina. Croaker appears to be primarily a home consumption item.

The industrial catch of croaker is processed into cat food, frozen crab bait, and, recently, surimi (Austin et al. 1978). There are three processors of industrial bottom fish along the northern Gulf coast. Croaker and black marlin are considered the best raw material for surimi (Okada et al. 1973). Pilot surimi plants are operating in Louisiana (Austin et al. 1978).

11.6.5 Import/Export

Small amounts of croaker fillets, probably a congeneric species, are recorded from Argentina, Brazil, Surinam, Venezuela, and Uruguay (Cato 1981); however, these are undoubtedly a different species. Croaker imports into Gulf of Mexico ports have been as high as 183 mt (headed and gutted weights) (Cato 1981).

11.6.6 Gear Conflicts

A large increase in the number of crab and eel pot fishermen in North Carolina sounds has resulted in confrontations with haul seiners, who cannot haul in areas filled with pots (DeVries 1981).

11.6.7 Commercial-Recreational Conflicts

A growing problem in the Pamlico-Pungo River area of North Carolina is a conflict with recreational anglers who fear long haulers are depleting stocks of sport fish (DeVries 1981). Similar conflicts probably have occurred in other states.

11.7 Management and Protection

11.7.1 Regulatory Measures

Croaker occur mainly in the territorial waters of the coastal states from Maryland to Florida. Each state exercises jurisdiction over the fisheries within its waters to three nautical miles from shore. The regulations and methods of promulgating them vary between states and are summarized in Table 11.12. The Magnuson Fishery Conservation and Management Act (MFCMA) provides for the conservation and exclusive management of all fishery resources within the U.S. Exclusive Economic Zone (EEZ) which extends from the territorial sea to 200 nautical miles from shore. There are no national or international laws or policies dealing with croaker.

11.7.2 Habitat Protection

Atlantic croaker utilize both estuarine and coastal oceanic waters at various life history stages and times of the year. Coastal marshes with their relative shallowness and dense stands of vegetation, provide protection from predators for juvenile fish, such as croakers, and the network of channels common to marshes provides ready access to food resources (Thayer et al. 1978). Marshes serve as a source of nutrients to the entire estuarine system as a result of tidal flushing animal migration. Habitat alterations within estuarine areas are probably the most damaging to croaker stocks since these areas are utilized as nursery grounds.

Most estuarine areas of the United States have been altered to some degree by such activities as agricultural drainage, flood control and development. The National Estuary Study, completed in 1970, indicated that 73% of the nation's estuaries had been moderately or severely degraded. Damage and/or destruction of estuaries have largely been by filling, dredging of navigation channels, and pollution (Gusey 1978, 1981). In the Atlantic coast states (Maine-Florida), containing 3,152,800 acres of estuarine habitat, an estimated 129,700 acres (4.1%) were lost to dredging and filling from 1954-1968 (Table 11.13). Unfortunately, the effects of habitat alterations such as channel dredging, filling of wetlands, increased turbidity associated with dredging, boating, loss of wetlands, and storm runoff, industrial pollutants, and sewage, have rarely been quantified.

Table 11.12. Synoptic overview of present state management systems.

State	Maryland	Virginia
Administrative organization	Maryland Department of Natural Resources	Virginia Marine Resources Commission
Legislative organization	Natural Resources Article, Annotated Code of Maryland Title 4, Subtitle 1, Title 08, Subtitle 02, Chapter 05 Fish	Marine Resources of the Commonwealth Code of Virginia of 1950, Title 28.1
Licenses	Otter trawl - $100 Bean trawl - $100 Fyke or hoop nets - $50 Gill nets - <200 yds $100 >200 yds $200	Commercial
Size restrictions	None	None
Limits	None	None
Gear	Trawling prohibited within 1 mile of Maryland shoreline in Atlantic Ocean. Numerous gear and area restrictions	Trawling prohibited in Chesapeake Bay. Pound net mesh <2" (s.m.) prohibited. 3" mesh (s.m.) requirement for haul seines.
Conservation regulations	Secretary of Natural Resources has authority to adopt rules and regulations relating to taking, possession, transportation, exporting, processing, sale or shipment necessary to conservation.	

Table 11.12. (continued)

State	North Carolina
Administrative organization	North Carolina Department of Natural Resources and Community Development Division of Marine Fisheries
Legislative organization	North Carolina Administrative Code, Title 15, Chapter 3.
Licenses	Vessels without motors, any length, when used with other licensed vessel - no license Vessels, <18'5" - $1.00/foot Vessels, 18'6" to 38'5" - $1.50/foot Vessels, >38'3" - $3/foot Non-resident vessels - $200 in addition to above fee requirement Finfish processor - $100 Unprocessed finfish dealer - $50
Size restrictions	None
Limits	None
Gear restrictions	Trawling for finfish prohibited in internal coastal waters. No purse seine for food fish. Many specific net regulations for areas and seasons.
Conservation regulations	Secretary, acting upon advise of Director of Marine Fisheries, may close any area to trawling if in coastal fishing waters, samples become composed primarily of juvenile finfish of major economic importance.

Table 11.12. (continued)

State	South Carolina	Georgia
Administrative organization	South Carolina Wildlife and Marine Resources	Georgia Department of Natural Resources
Legislative organization	Section 50-5-20	Georgia Code 27-4-110
Licenses	Land and sell - $25 Commercial boat licenses <18' - $20 >18' - $25 Gill nets haul seines - $10/100 yds	Commercial fishing license (personal)- $10.25 for any sales of catch Nontrawler license <18' - $5 >18' - $5 + $.50/ foot Trawler license-$50 for 18' + $3/ additional foot No license for seines >300' unless catch is sold.
Size restriction	None	None
Limits	None	None
Gear	Seine mesh less than <2½" prohibited. Purse seining for food fish permitted in ocean >300 yds from beach	Gill netting prohibited in Georgia waters. Seine mesh restrictions: minimum of 1¼" for seines <100'; minimum mesh size of 2½" (s.m.) for 100 - 300' maximum length.
Conservation regulations	None	None

Table 11.12. (continued)

State	Florida
Administrative organization	Marine Fisheries Commission
Legislative organization	Chapter 370, Florida Statutes; additional 220 state laws that apply on a local level; all local laws will become Rules of the Marine Fisheries Commission by July 1, 1985.
Licenses	Licenses to sell: Resident - \$25 annually Non-resident - \$100 annually Alien - \$150 annually Wholesale seafood dealer Resident - \$300 annually Non-resident - \$500 annually Alien - \$750 annually Retail seafood dealer Resident - \$25 annually Non-resident - \$200 annually Alien - \$250 annually
Size restrictions	None
Limits	None
Gear	Purse seining and stop netting prohibited. Numerous local gear and area restrictions.
Conservation regulations	None

Table 11.13. Acres of shoal water habitat and loss in Atlantic coastal states from 1954 - 1968 (from Gusey 1978, 1981).

State	Total Area	Basic area of important habitat	Area of basic habitat lost by dredging and filling	Percent loss of habitat
Massachusetts	207,000	31,000	2,000	6.5
Rhode Island	94,700	14,700	900	6.1
Connecticut	31,600	20,300	2,100	10.3
New York	376,600	132,500	10,800	15.0
New Jersey	778,400	411,300	53,900	13.1
Delaware	395,500	153,400	8,500	5.6
Maryland	1,406,100	376,300	1,000	0.3
Virginia	1,670,000	428,100	2,400	0.6
North Carolina	2,206,600	793,700	8,000	1.0
South Carolina	427,900	269,400	4,300	1.6
Georgia	170,800	125,000	800	.6
Florida, E. coast	525,600	398,100	35,000	8.8
TOTAL	8,290,800	3,152,800	129,700	4.1

In recent years, the coastal states have enacted coastal zone management laws to regulate dredge and fill activities and shoreline development. The federal government also regulates dredging and spoil disposal, water pollution, and creation of marine sanctuaries through the U. S. Army Corps of Engineers (PL 92-500; 1899 R&H Act), the National Marine Fisheries Service (F&W Coordination Act; PL 92-500), the U. S. Fish and Wildlife Service (F&W Coordination Act; PL 92-500), and the Environmental Protection Agency (PL 92-500). State regulations are summarized in Table 11.14.

11.8 Current Research

Croaker research and monitoring activities were discussed at the Sciaenid Assessment Workshop (Wilk and Austin 1981) and by the Sciaenid Technical Committee. Several states monitor juvenile and adult abundance of croaker in estuarine surveys. The Delaware Division of Fish and Wildlife conducts annual recruitment surveys of sciaenids and adult groundfish surveys in Delaware Bay. Data has also been collected on the recreational fishing in Delaware since 1955. The Maryland Department of Natural Resources has conducted an annual blue crab and finfish population survey in Chesapeake Bay and Chincoteague Bay since 1980. The University of Maryland's Chesapeake Biological Laboratory (CBL) conducted a trawl survey from 1965 to 1975. Juvenile croaker abundance in Chesapeake Bay and its tributaries has been monitored in monthly trawl surveys since 1954 by the Virginia Institute of Marine Science (VIMS). Beginning in 1988, VIMS and CBL, under coordination of the Chesapeake Bay Stock Assessment Committee (CBSAC), will undertake a Chesapeake Bay-wide trawl survey using high rise trawls. The Virginia Marine Resources Commission will begin a fishery dependent sampling program in 1988. The North Carolina Division of Marine Fisheries (NCDMF) has collected data on juvenile croaker abundance from March through November annually in a trawl survey that was standardized in 1978. A quarterly stratified random survey of fishes of Pamlico Sound was initiated in 1987. The NCDMF also conducts monthly sampling of the major commercial fisheries for size and age composition of the fisheries. A number of studies on recruitment of larval and juvenile croaker in Pamlico Sound and its tributaries and food resource partitioning by juvenile spot and croaker have been conducted by Dr. John Miller and graduate students of North Carolina State University. The National Marine Fisheries Service (NMFS) Beaufort Laboratory conducts an annual recruitment survey of larval fishes at two estuarine sites in the vicinity of Beaufort North Carolina. NMFS conducts an annual coastwide survey of contaminants in estuarine finfish. The Carolina Power and Light Company's Southport Laboratory conducts a monthly monitoring survey of the Cape Fear River. A seasonal coastal groundfish trawl survey from Cape Fear, North Carolina to Cape Canaveral, Florida was recently completed by the South Carolina Marine Resources Research Institute. The Georgia Department of Natural Resources has performed fishery-independent monitoring of finfish abundance in northern, central, and southern sectors of Georgia coastal waters since 1984, including tagging and age and growth studies. The Florida Department of Natural Resources is conducting a food chain study of croaker and other finfishes in the mangroves. Commercial landings statistics are col-

Table 11.14. Summary of state habitat protection regulations.

State	Administrative organization	Legislative authorization	Regulations
Maryland	Maryland Department of Natural Resources, Tidewater Administration; Maryland Department of Health and Mental Hygiene, Office of Environmental Programs	Natural Resources Article, Code of Maryland	Regulates activities in tidal wetlands areas.
Virginia	Virginia Marine Resources Commission; County wetlands boards	Section 62.1-13.4, Code of Virginia, Wetlands Act.	Regulates alterations to tidal marshes, sand and mud flats, subaqueous bottoms, and sand dunes.
North Carolina	North Carolina Department of Natural Resources and Community Development Office of Coastal Management; Coastal Resources Commission; Coastal Resources Advisory Council	NC Dredge and Fill Law (GS 113-229), Coastal Area Management Act (CAMA) (GS 113A100)	Requires permits to dredge or fill in or about estuarine waters. Established areas of environmental concern. Permits required for coastal zone development.
	Division of Marine Fisheries	NC Administrative Code Code, Chap. 3, Sect. .1400	Prohibits the use of bottom - disturbing gears and severely restricts or prohibits excavation and/or filling activities in nursery areas for young finfish and crustaceans.
Georgia	Georgia Department of Natural Resources, Coastal Resources Division,	Coastal Marshlands Protection Act of 1970 (Gs. L. 1970, p. 939, §1.)	Requires permits to dredge, fill, remove, drain, or otherwise alter any marsh-lands.

Table 11.14. (continued)

State	Administrative organization	Legislative authorization	Regulations
Georgia	Georgia Department of Natural Resources, Coastal Resources Division,	Coastal Marshlands Protection Act of 1970 (Gs. L. 1970, p. 939, <1.)	Requires permits to dredge, fill, remove, drain, or otherwise alter any marsh-lands.
		Shore Assistance Act o 1979 (Gs. L. 1979, <1.)	Required permits for a structure, shoreline engineering activity, or land alteration in beaches, sand bars, and sand dunes in Georgia.
Florida	Florida Department of Natural Resources	Chapter 253, Florida Statutes	Regulates dredge, fill, and structures on state submerged lands)below mean high water). Provides for acquisition of conservation lands and tidally influenced areas.
		Chapter 258. F.S.	Established aquatic preserves and regulates activities within perserves.
	Florida Department of Environmental Regulation	Chapter 403, F.S.	Permitting of activities (including dredge and fill) which affect water quality.

Table 11.14. (continued)

State	Administrative organization	Legislative authorization	Regulations
	Florida Department of Community Affairs	Chapter 380, F.S.	Administer and set standards for "Development of Regional Impact". Protects regional or statewide resources from poorly conceived development activities.

lected monthly by all states and NMFS and recreational catch statistics are being collected cooperatively between individual states and NMFS.

11.9 Research Needs

Croaker research needs, as indicated by this review of the literature, by discussions at the Sciaenid Assessment Workshop (Wilk and Austin 1981), and by the ISFMP Sciaenid Technical Committee, include stock identification, determination of migratory patterns through tagging studies, monitoring long term changes in abundance, growth rates and age structure, and determination of the onshore vs offshore components of the fishery. Continued monitoring of juvenile croaker populations in major spawning areas is necessary to predict year-class strength. Improved catch and effort statistics from the commercial and recreational fisheries are needed, along with size and age structure of the catch, in order to develop production models. The optimum utilization (economic and biological) of a long-term fluctuating population such as croaker needs to be determined.

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14.0 APPENDIX

14.1 Listing of members of Sciaenid Technical Committee and South Atlantic State-Federal Fisheries Management Board.

<u>Sciaenid Technical Committee</u>

Richard Seagraves
DE Div. Fish. & Wildlife
Edward Tatnal Bldg.
P.O. Box 1401
Dover, DE 19901
(301) 736-4782

Louis Rugolo
MD Dept. Nat. Resources
Tidewater Administration
580 Taylor Avenue
Annapolis, MD 21401
(301) 269-3786

Mark Chittenden, Jr.
VA Institute of Marine Science
Gloucester Point, VA 23062
(804) 642-7000

Douglas DeVries
NC Div. Mar. Fish.
P.O. Box 769
Morehead City, NC 28557
(919) 726-7021

Glenn Ulrich
SC Wildl. & Mar. Res. Dept.
P.O. Box 12559
Charleston, SC 29412
(803) 795-6350

John Pafford
GA Dept. Nat. Resources
Coastal Resources Div.
1200 Glynn Avenue
Brunswick, GA 31523
(912) 264-7221

Roy Williams
FL Dept. Nat. Resources
100 8th Ave., SE
St. Petersburg, FL 33701
(813) 896-8626

John Merriner
NMFS-Southeast Fisheries Center
Beaufort Lab.
Beaufort, NC 28516
(919) 728-4595

Harry Mears
NMFS
State Fish Pier
Gloucester, MA 01930
(617) 281-3600

Paul Perra
Atlantic States Marine Fisheries Commission
1717 Massachusetts Ave., NE
Suite 310
Washington, DC 20036
(202) 387-5330

South Atlantic State-Federal Fisheries Management Board

Dennis Spitsbergen*
Div. of Marine Fisheries
P.O. Box 769
Morehead City, NC 28557
(919) 726-7021

Edwin B. Joseph
SC Wildlife & Mar. Resources Dept.
P.O. Box 12559
Charleston, SC 29412
(803) 795-6350

Duane Harris, Director
GA Coastal Resources Div.
Dept. Natural Resources
1200 Glynn Avenue
Brunswick, GA 31520
(912) 264-7128

Tom Gardner
FL Dept. of Natural Resources
3900 Commonwealth Blvd.
Tallahassee, FL 32303
(904) 487-2256

Joseph Angelovic
NMFS, SE Region
9450 Koger Bovd.
St. Petersburg, FL 33702
(813) 893-3161

Frank Richardson
U.S. Fish & Wildlife
Richard B. Russell Fed. Bldg.
75 Spring Street, SW
Atlanta, GA 30303
(202) 387-5330

Dr. Edwin B. Joseph
GA Dept. of Natural Resources
Coastal Resources
1200 Glynn Avenue
Brunswick, GA 31523-9990
(912) 264-7218

* Board Chairman