Impacts of Hurricanes on North Carolina Fisheries

By

Christine C. Burgess
Alan J. Bianchi
Josh Murauskas
Scott Crosson, Ph.D.

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North Carolina Department of Environment and Natural Resources
Division of Marine Fisheries
PO Box 769
Morehead City, NC 28557

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GLOSSARY OF ACRONYMS

ACCSP – Atlantic Coastal Cooperative Statistics Program
ASMFC – Atlantic States Marine Fisheries Commission
FMP – Fishery Management Plan
ICAAT – International Commission for the Conservation of Atlantic Tunas
MAFMC – Mid Atlantic Fishery Management Council
NCDMF – North Carolina Division of Marine Fisheries
NMFS – National Marine Fisheries Service
NOAA – National Oceanographic and Atmospheric Administration
SAFMC – South Atlantic Fishery Management Council

EXECUTIVE SUMMARY

Little research exists on the relationships between tropical cyclones, commercial and recreational fisheries, and the socioeconomic characteristics of coastal communities. Previous studies have generally focused on individual species with little regard to the social and economic importance of the fishery. The recent increase in hurricane activity and the devastation from the 1999 hurricane season has prompted further examination of tropical storms and their influence on marine fisheries to improve management of stocks and mitigation of natural disasters. The objectives are to determine the impact of hurricanes on North Carolina fisheries by:

1. Analyzing commercial fishery landings data;
2. Analyzing hurricane impacts for 1999 compared to hurricane impacts in previous years including possible acute and chronic impacts;
3. Establishing linkages between commercial fishery landing, recreational harvest, and fishery-independent and dependent biological data;
4. Analyzing historical and future commercial fishery landing, recreational harvest, and fishery-independent and dependent biological data; and
5. Determining the socioeconomic impact.

Fishery-independent and dependent biological data were not examined in this study due to time and personnel constraints.

Commercial Fishing

The impacts of hurricanes on commercial fishing depend largely on the individual nature of a given hurricane. Generally speaking, hurricanes do not appear to have long-term consequences on the fish stocks themselves most of the time; however, hurricanes can affect fishermen by causing damage to gear, vessels, and personal property which keep people from actively fishing leading to a reduction in harvest and fishing mortality and a loss of income for fishermen. Hurricanes may also redistribute fish or cause them to migrate, also affecting fishermen's harvest.

Occasionally, environmental conditions could be right for a hurricane to cause a lasting impact on a particular fishery. The 1999 hurricane season was likely a contributor to the significant decline in hard blue crab landings observed following 1999 and left a lasting impression that persisted throughout the end of the time series. The 1999 hurricane season was the only season found to coincide with the decline seen in the hard blue crab fishery; however, since the hard blue crab fishery is the largest and most economically important fishery in the state of North Carolina, any factors that could potentially negatively influence this fishery are cause for concern.

The red tide of 1987-88 decreased bay scallop population levels below a minimum stock size threshold that is needed to maintain recruitment levels large enough to supply adequate numbers of larvae for the next generation. Bay scallop populations are likely currently at such low levels that any external influence such as hurricanes, habitat loss, poor water quality, or predators increases the vulnerability of the population. They may continue to be negatively affected by environmental disturbances (including hurricanes) until the spawning stock can reach large enough levels to overcome these events as they have in the past.

Fisheries that occur primarily in the fall during the peak of hurricane season, such as striped mullet and the southern flounder pound net fishery, have a large risk for a reduction in overall harvest. The striped mullet fishery likely suffers, not from a stock reduction, but simply from the inability of fishermen to harvest striped mullet roe during the peak of the season causing short-term impacts to landings.

This study also provides evidence that hurricanes may impact estuarine and nearshore commercial fisheries (e.g., hard blue crabs, bay scallops, and striped mullet) more than offshore fisheries (e.g., groupers). In addition, the hard clam fishery may experience short-term decreases in landings due to shellfish closures associated with fecal coliform runoff, particularly during years in which there are multiple storm events.

Forecasting

Forecasting models developed in this study consistently overestimated actual future harvest, because the models assume that all factors affecting the behavior of the series remain unchanged; however, trends in commercial landings, effort, and participation have been decreasing for the past several years due to socioeconomic factors. In addition, the inherent variability within the time series causes forecast estimates to have large confidence intervals indicating a high degree of uncertainty. Furthermore, it would be difficult to predict the impact of a notable hurricane on a particular fishery because no two storms are alike and each storm affects the ecosystem differently. Therefore, given the tendency for model overestimation, a large degree of uncertainty, and the individual nature of each storm, these models would be unreliable for predicting the effect of another notable storm on a given fishery.

Recreational Fishing

Out of the 10 recreational fisheries examined in this study, hurricanes had apparent negative impacts on the harvest of dolphinfish, king mackerel, Spanish mackerel, and spotted seatrout. Anglers fish for these species using boats almost exclusively, and the majority of their harvest typically overlaps with hurricane season. When a hurricane is approaching, many fishermen remove their boats from the water to prevent damage resulting in a loss of harvest time. Large storms also often result in damage to docks, vessels, channel markers, and present hazards to navigation, any of which could take several weeks or more to repair resulting in further reductions in effort and harvest. In addition, hurricanes may also redistribute fish or cause them to migrate affecting the catchability of these fish. Based on these results, it is likely that the impact of hurricanes is minimal, or nonexistent, on the harvest of species by anglers fishing from shore or man-made structures; however, hurricanes may limit the opportunities for anglers to make trips when using boats. Species with the majority of their harvest outside of the hurricane season are also not likely to be influenced by hurricane activity. Based on the time series of recreational harvest, there do not appear to be any long-term impacts on harvest of any of the recreational species discussed. A longer time series is needed in order to perform further statistical tests.

The recent history of recreational fishing data collection does not provide an adequate time series for more detailed statistical tests such as intervention analysis. Further, the current data collection program is not designed to provide the detailed information needed to answer questions regarding the short-term impacts of hurricanes on recreational fisheries. Lastly, other influential factors, such as fish population dynamics, management efforts, and angler demographics, add inseparable dimensions increasing variation in effort and harvest estimates.

Economic Impact

Sectors of the economy most likely to be affected by a decrease in commercial fishing activity are dwellings (essentially fishermen's mortgages), wholesale trade, food service/drinking (restaurants and bars), doctors and dentists, the real estate industry, and hospitals. The hard blue crab fishery is the most economically important fishery in the state, and the hurricanes of 1999 likely caused a significant blow to those closely linked to this fishery. Any factors that could potentially disrupt this fishery are cause for concern. Although bay scallops are currently not contributing to the North Carolina economy, this fishery reached over $1 million in ex-vessel value prior to the red tide event. If the population levels of bay scallops return to sustainable levels, this fishery could once again increase in economic importance to the state because it provides income to fishermen during the winter months when other fisheries are slow. The striped mullet fishery should also be noted for its importance to the state's fishing economy; however, disruptions to the striped mullet fishery will likely only have a temporary impact that lasts one fishing season.

Unfortunately, we currently do not have any data from which to derive a measure of the economic impact of the recreational fishery on the economy of North Carolina; however, with an increasing trend and an estimated 7 million trips in 2004, the impact is likely to be significant and continue to increase in the near future.

INTRODUCTION

Hurricanes are the most destructive of all atmospheric storms, frequently causing catastrophic damage to coastal regions of the eastern United States (Elsner and Kara 1999). Although many of these consequences are well documented, little research exists on the relationships between tropical cyclones, commercial and recreational fisheries, and the socioeconomic characteristics of coastal communities. Previous studies have generally focused on individual species with little regard to the social and economic importance of the fishery. Some research has demonstrated immediate and localized effects on fish communities, though most have concluded no long-term impacts (Tabb and Jones 1962; Fenner 1991; Bythell et al. 1993; Bell and Hall 1994; Dolloff et al. 1994; McBride 2001). North Carolina ranks sixth in Atlantic coast commercial fishery landings with 79 million pounds worth over $60 million and second in marine saltwater anglers, with over two million participants annually (NMFS 2005; NCDMF 2005b). The state also has experienced nearly one-sixth of all United States landfalling hurricanes through recorded history (Blake et al. 2005). The recent increase in hurricane activity and the devastation from Hurricane Floyd has prompted further examination of tropical storms and their influence on marine fisheries to improve management of stocks and mitigation of natural disasters.

Tropical Cyclones[1]

A tropical cyclone is a closed cyclonic low-pressure system powered by the release of latent heat. These warm core storm systems are notorious for high winds, torrential rains, storm surges, and tornadoes that lead to catastrophic damage. Hurricanes may last as long as 30 days and grow to 1,300 km in diameter (Elsner and Kara 1999). Nearly all of these storms form within 20 degrees of the equator in a worldwide band of thunderstorm activity known as the Intertropical Convergence Zone. The Atlantic basin affecting the eastern United States includes the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. The most intense hurricanes tend to originate near the Cape Verde Islands off the west coast of Africa (Elsner and Kara 1999).

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[1] Data used frequently throughout the following sections are taken from HURDAT, which is considered the most complete and reliable source of all North Atlantic hurricane information (Elsner and Kara 1999).

The National Hurricane Center (NHC) classifies three types of tropical cyclones: tropical depressions, tropical storms, and hurricanes. Tropical depressions have winds less than 38 mph and usually lack an eye and the organization seen in more powerful storms. Tropical storms are more organized with maximum sustained winds of 39–73 mph. Hurricanes are intense tropical cyclones with sustained winds greater than 74 mph and are the most destructive of all atmospheric storms (Elsner and Kara 1999). Hurricanes are ranked according to the Saffir-Simpson scale based on wind speed and intensity, ranging from a category 1 storm (74–95 mph) to a category 5 storm (> 155 mph) (Table 1). Hurricanes of a category 3 or greater are considered major hurricanes by the NHC. The Atlantic hurricane season officially starts on June 1st and continues through November 30th of each year. The peak of hurricane season in the Atlantic Basin occurs in mid-September. Tropical storms and hurricanes in the Atlantic Basin are relatively common, though major hurricanes are relatively infrequent. An average hurricane season in the Atlantic basin will see roughly 8.5 tropical storms, 5.2 hurricanes, and 1.8 United States landfalling hurricanes (averages from 1851 to 2004 (Blake et al. 2005)).

Table 1. The Saffir-Simpson hurricane scale (Simpson and Riehl 1981).

Category	Barometric Pressure	Wind Speed	Storm Surge	Damage Potential
1 weak	980.2 mb or more	75–95 mph	4–5 ft	Minimal damage to vegetation
2 moderate	965.12–979.68 mb	96–110 mph	6–8 ft	Moderate damage to houses
3 strong	945.14–964.78 mb	111–130 mph	9–12 ft	Extensive damage to small buildings
4 very strong	920.08–944.80 mb	131–155 mph	13–18 ft	Extreme structural damage
5 devastating	< 920.08 mb	> 155 mph	> 18 ft	Catastrophic building failures

Although not reaching the intensity of a hurricane, tropical storms have the potential to be very destructive. For example, Tropical Storm Allison produced catastrophic flooding over portions of Texas in 2001. Allison stalled over Houston, causing massive flooding in the greater metropolitan area with some areas receiving over 30 inches of rain causing nearly $5 billion in damage and 23 deaths (Stewart 2002). Tropical storms that have made direct landfall in North Carolina include Dennis (1999), Arthur (1996), and Doria (1971), among others. Arthur caused little damage, though Dennis caused $60 million in property damage and $37 million in agricultural losses throughout North Carolina and Virginia (Beven 2000). Doria was by far the most powerful storm to impact the United States in 1971. Doria made landfall in North Carolina on August 27th near Morehead City, and total damages throughout Doria's path exceeded $147 million in the United States. Flooding, mudslides, and damage to water, sewer, and power systems across the eastern seaboard resulted from the storm, and six fatalities were reported (Simpson and Hope 1972). Tropical storms also have been shown to have great ecological impacts. For example, Tropical Storm Agnes impacted bacteria, plankton, vegetation, invertebrates, and fish populations throughout the Chesapeake Bay in 1972 (Andrews 1973; Boesch et al. 1976).

Table 2. Tropical cyclones in the Atlantic Basin (1944-2003) and the United States coastline (1899-2003) (Landsea 2004).

Category	Maximum	Minimum
Tropical storms/hurricanes	19* (1995)	4 (1983)
Hurricanes	12 (1969)	2 (1982)
Major Hurricanes	7 (1950)	0 (many, 1994 last)
USA landfalling storms/hurricanes	8 (1916)	1 (many, 1997 last)
USA landfalling hurricanes	6** (1916,1985)	0 (many, 2001 last)
USA landfalling major hurricanes	3*** (1909,1933,1954)	0 (many, 2003 last)

(*) As a footnote, 1933 is recorded as being the most active of any Atlantic basin season on record (reliable or otherwise) with 21 tropical storms and hurricanes.
(**) 1886 is recorded as the most active hurricane season for the continental USA with 7 landfalling hurricanes.
(***) 1893 tied three years in the 20th Century with 3 landfalling major hurricanes in the continental United States.

Table 3. Tropical storms and hurricanes in the Atlantic basin by month (1944-2005) (data from (Blake et al. 2005)).

Month	Total	Average
January–April	4	0.1
May	8	0.1
June	35	0.6
July	58	0.9
August	173	2.8
September	224	3.6
October	114	1.8
November	33	0.5
December	7	0
All	656	10.4

Hurricanes are believed to come in cycles of active seasons. Periods of heightened activity usually take place in multidecadal oscillations that last 20 to 30 years or longer, often referred to as the Atlantic Multidecadal Oscillation (AMO). The current period of hurricane activity (1995–present) is similar to previous eras of increased activity (i.e., 1950 to 1969). Every season has been above average during the current cycle, except the two El Niño years of 1997 and 2002. The increase is attributed to warmer ocean waters, low wind shear, and favorable mid-level easterly winds. El Niño and La Niña cycles play a large role in determining these conditions in addition to convective rainfall variability (Landsea and Gray 1992; Bove et al. 1998; Pielke and Landsea 1999; Kerr 2000; Enfield et al. 2001; Elsner et al. 2006; Bell and Chelliah 2006). In contrast, periods of below-normal activity occur, such as the period from 1970 to 1994. During this 24-year period, just three seasons had activity slightly above average and about half were below (Bell and Chelliah 2006). Another period of below average activity occurred in 1900–1925 following years of intense storms from 1870 to 1899. These multidecadal oscillations have a significant correlation with rainfall, severe droughts, and tropical storms. The Dustbowl of the 1930s and the 1950s drought occurred during a positive AMO, and inflow to Lake Okeechobee due to rainfall in Florida increased as much as 40% during AMO extremes (Enfield et al. 2001). Hurricane development during warm phases is at least twice as numerous as during cold phases of the AMO. Studies of paleoclimate proxies suggest that these changes have been occurring for at least the past millennium (Kerr 2000).

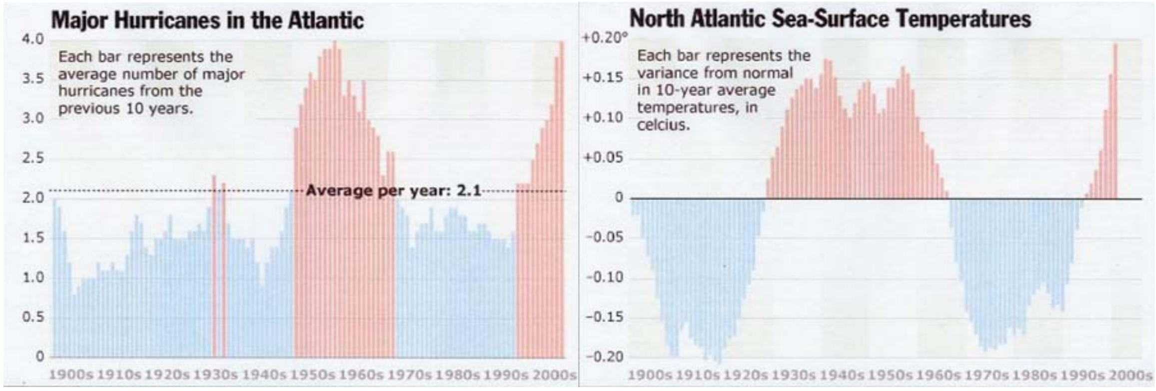

Figure 1. Major hurricanes in the Atlantic basin (left) and north Atlantic sea-surface temperatures (source: Unisys, prepared by J. Duchneskie for the Philadelphia Inquirer).

Questions surrounding global warming and hurricane strength and activity have come about in recent years (Walsh 1983; Emanuel 2005; Elsner et al. 2006; Anthes et al. 2006). Some scientists suggest that increasing temperatures resulting from anthropogenic-induced greenhouse gases have increased hurricane frequency and intensity. Although many models and predictions support this idea, virtually all climatologists agree there is no reasonable evidence that hurricane activity is linked to global warming. Changes are not large enough to indicate significant differences, "thus any increase in hurricane intensity that may have already occurred as a result of global warming is inconsequential compared to natural variability" (Emanuel et al. 2004; Pielke et al. 2005; Pielke et al. 2006). The National Oceanic and Atmospheric Administration has stated, "It is highly unlikely that global warming has (or will) contribute to a drastic change in the number or intensity of hurricanes" (Pielke et al. 2006). Some scientists, however, question this notion and suggest that warming above naturally occurring oscillations will "lead to an upward trend in tropical cyclone destructive potential" (Emanuel 2005).

As previously mentioned, research has indicated that the multidecadal oscillation has been in an amplified phase since 1995, leading to increased hurricane frequency. Hurricane activity in the 2004 and 2005 seasons was exceptionally high. There were 15 named storms in 2004, including nine hurricanes, six of which were major hurricanes. Nine systems struck the United States, five of them making landfall in Florida (Bonnie, Charley, Frances, Ivan, and Jeanne). The season went down as one of the deadliest and most costly on record, with over 3,000 deaths and record property damage in the United States (Levinson 2005; Franklin et al. 2005). The 2005 season was even more extraordinary, with three category 5 storms, a record-setting 27 total storms, and the costliest hurricane in recorded history, Katrina (> $100 billion in associated losses). Two tropical storms, two minor hurricanes, and four major hurricanes struck the United States in 2005—the most in recorded history (Shein et al. 2006). The destruction from these storms has raised awareness and provoked re-examination of consequences associated with tropical storm activity.

Hurricane Activity in North Carolina[2]

An average of 2.3 tropical cyclones have come within 200 nautical miles of North Carolina annually since 1851. A category 5 hurricane has never impacted the state in recorded history, and category 4 hurricanes are rare. Larger systems are typically confined to the southern part of the Atlantic Basin, and rarely occur north of the Florida/Georgia border. Only one category 4 storm has made direct landfall, and ten have entered North Carolina's Exclusive Economic Zone (EEZ), 3–200 nautical miles from the coast, since 1851 (Blake et al. 2005). Category 3 storms have approached North Carolina's EEZ 35 times, with four of those making landfall. Nearly 200 category 1 and category 2 storms have come within North Carolina's EEZ, 34 of which made landfall (Blake et al. 2005). Over 200 tropical storms have approached the state, many making direct landfall. Tropical storm activity in North Carolina increases from mid August to October, peaking in mid to late September about a week later than the rest of the Atlantic basin (Figure 2), while hurricane activity in North Carolina is similar to that of the Atlantic basin (Figure 3). Hurricanes are most likely to occur in September and October in North Carolina (Figure 4).

Meso-scale tropical weather expert Dr. William Gray, along with research associate Phil Klotzbach introduced the United States Landfalling Hurricane Probability Project and launched a website in 2004 (www.e-transit.org/hurricane). The project provides high wind probabilities for the entire east coast based on historical landfalls of the 20th century. Climatological probabilities of tropical storms, minor, and major hurricanes have been calculated for 11 regions, 55 subregions, and 205 coastal and near-coastal counties (Klotzbach 2006). The majority of North Carolina is located in region eight and a few of the northern counties are in region nine (Figure 5). Region eight (the Carolinas) ranks fourth in total coastal population (behind Texas, Florida, and Louisiana). Based on calculated probabilities of experiencing a tropical storm, minor, or major hurricane, region eight ranks fourth, behind regions six, one, and three, respectively (Table 4).

In coastal North Carolina, southern counties are the most populated, have the longest coastline, and the greatest calculated probability of tropical storm activity, followed by central and northern counties in all categories, respectively (Table 5). Southern counties have an 8.1%

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[2] Tropical storm frequency and locations for the following section originate from Unisys reformatting of the HURDAT database. Downloads can be found at: http://weather.unisys.com/hurricane/atlantic/index.html

annual chance of tropical storm-force winds, 2.3% of hurricane-force winds, and a 0.4% chance of major hurricane-force winds. Based on 50-year probabilities, these chances increase to 98.5%, 68.6%, and 16.3%, respectively. Central counties have roughly one-third of annual and two-thirds of 50-year calculated probabilities observed in southern counties. Northern counties have even fewer chances, roughly less than 10% of annual and 50-year probabilities of southern counties (Table 5).

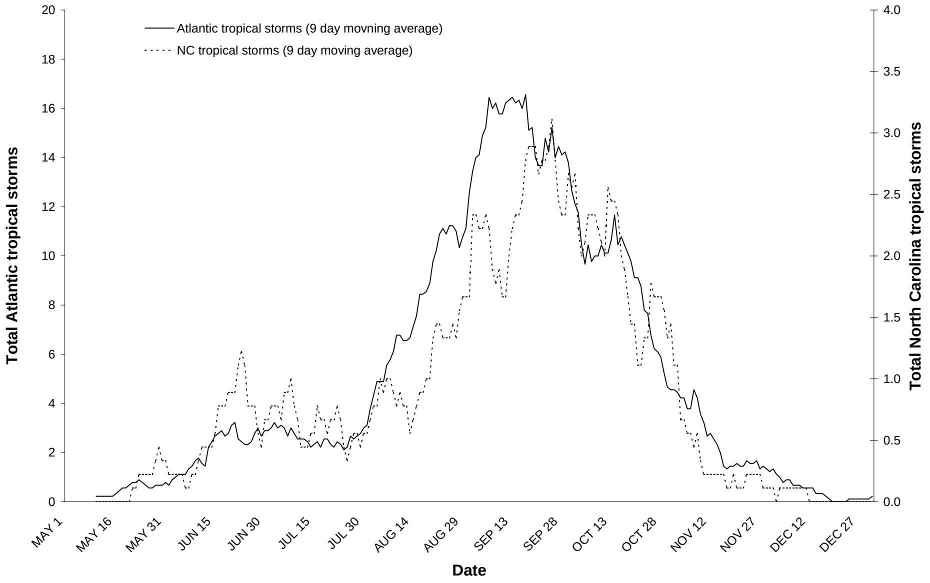

Figure 2. Tropical storm activity in the Atlantic basin and those affecting North Carolina by date and total occurrence, 1851–2004 (source: Unisys).

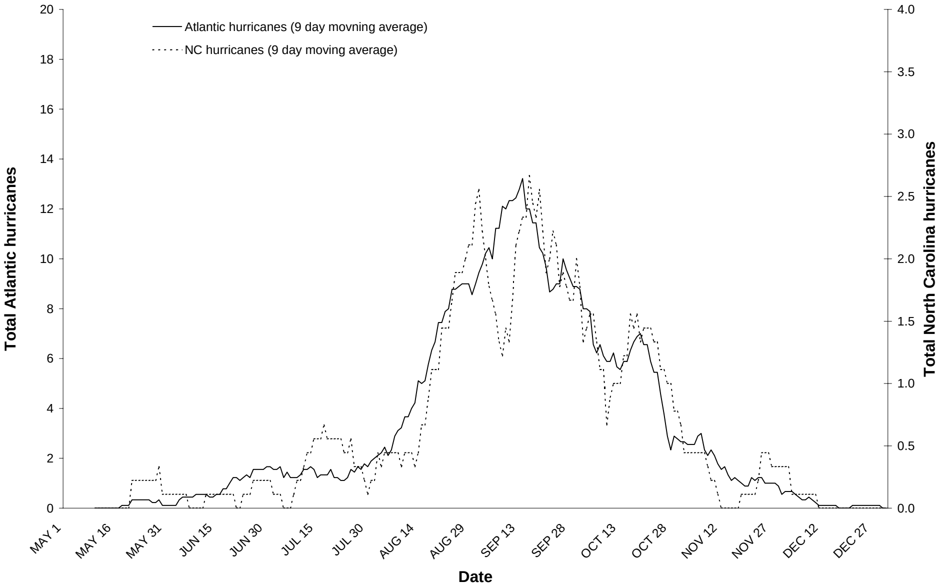

Figure 3. Hurricane activity in the Atlantic basin and those affecting North Carolina by date and total occurrence, 1851–2004 (source: Unisys).

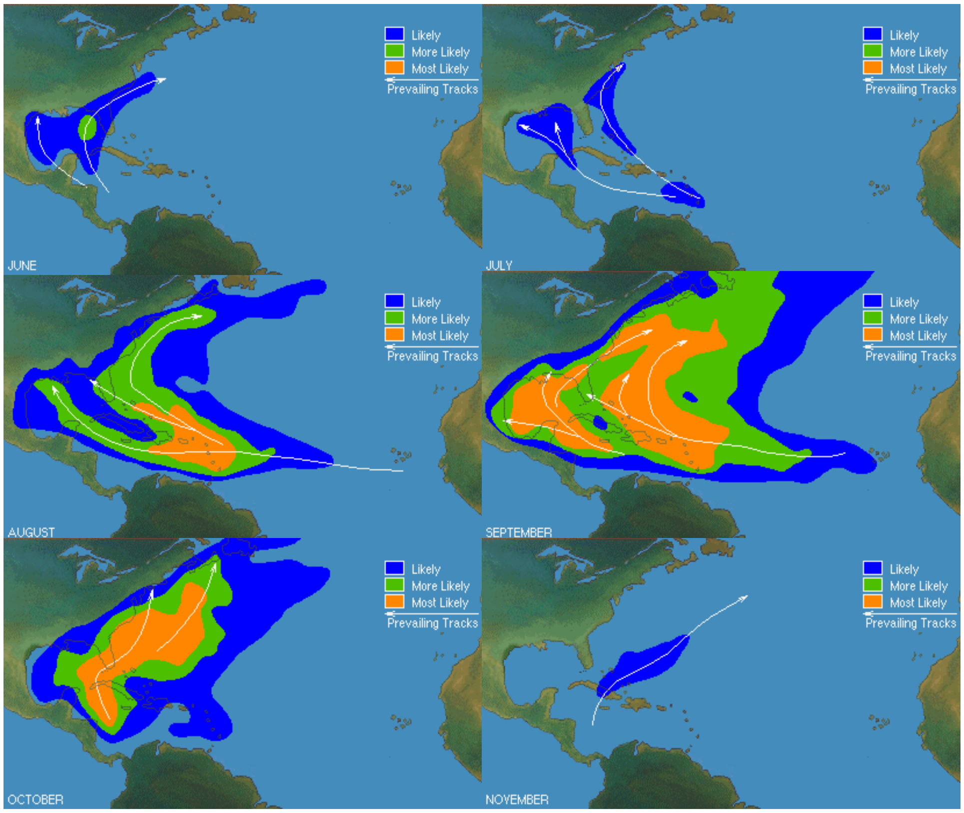

Figure 4. Probability of hurricane tracks from June to November (figures from NOAA (no date)).

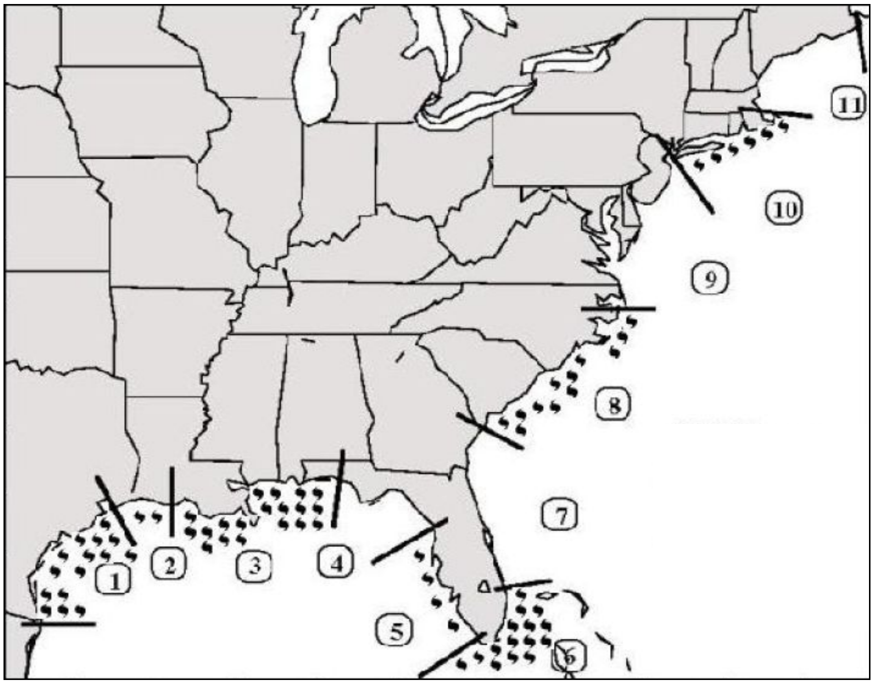

Figure 5. U.S. Landfalling Hurricane Probability Project map with eleven coastal regions for which probabilities were calculated. Symbols indicate the 73 major hurricanes that occurred from 1900–1999 (Klotzbach 2006).

Table 4. United States Landfalling Hurricane Project (2006) climatological probabilities by region and storm type (regions including NC are shaded gray).

			Annual Probability			50-Year Probability		
Region	Coastline (km)	2000 Population	Tropical Storm	Hurricane	Intense Hurricane	Tropical Storm	Hurricane	Intense Hurricane
Region 1	503	5,899,658	28.9	8.2	1.9	100.0	98.6	61.7
Region 2	257	818,946	17.0	4.2	0.7	100.0	88.3	29.6
Region 3	666	3,851,241	26.6	6.9	1.7	100.0	97.2	57.6
Region 4	382	759,731	17.6	4.0	0.3	100.0	87.0	13.9
Region 5	373	3,819,848	12.7	2.7	0.7	99.9	74.6	29.6
Region 6	483	5,213,884	28.9	8.9	2.4	100.0	99.1	70.3
Region 7	574	4,454,373	7.3	1.8	0.3	97.7	59.7	13.9
Region 8	673	1,770,948	20.4	5.8	0.9	100.0	95.0	36.4
Region 9	527	4,025,812	3.1	0.5	<0.1	79.3	22.2	<0.1
Region 10	426	14,325,512	9.7	2.6	0.6	99.4	73.2	26.0
Region 11	447	4,705,129	2.6	0.6	<0.1	73.2	26.0	<0.1

Table 5. United States Landfalling Hurricane Project (2006) climatological probabilities for North Carolina by region, county, and storm type (region totals within North Carolina are shaded gray).

			Annual Probability			50-Year Probability		
Region / County	Coastline (km)	2000 Population	Tropical Storm	Hurricane	Intense Hurricane	Tropical Storm	Hurricane	Intense Hurricane
Northern Counties	48	71,340	0.3	<0.1	<0.1	13.2	2.3	<0.1
Camden	-	6,885	0.2	<0.1	<0.1	8.9	1.5	<0.1
Currituck	48	18,190	0.3	<0.1	<0.1	13.2	2.3	<0.1
Pasquotank	-	34,897	0.2	<0.1	<0.1	11.4	1.9	<0.1
Perquimans	-	11,368	0.2	<0.1	<0.1	8.0	1.3	<0.1
Central counties	121	98,623	3.7	0.2	0.2	84.6	40.8	7.8
Beaufort	-	44,958	0.8	0.2	<0.1	32.2	10.4	1.7
Dare	93	29,967	2.8	0.8	0.1	76.1	33.1	6.0
Hyde	28	5,826	0.8	0.2	<0.1	34.7	11.4	1.9
Tyrrell	-	4,149	0.7	0.2	<0.1	30.6	9.8	1.6
Washington	-	13,723	0.9	0.3	<0.1	36.7	12.1	2.0
Southern counties	266	653,770	8.1	2.3	0.4	98.5	68.6	16.3
Brunswick	54	73,143	1.6	0.5	0.1	56.2	20.8	3.5
Carteret	99	59,383	3.0	0.9	0.1	78.2	34.8	6.4
Columbus	-	54,749	1.4	0.4	0.1	51.4	18.5	3.1
Craven	-	91,436	0.6	0.2	<0.1	26.5	8.4	1.3
Jones	-	10,381	0.3	0.1	<0.1	12.8	3.8	0.6
New Hanover	42	160,307	1.3	0.4	0.1	47.3	16.6	2.8
Onslow	45	150,355	1.4	0.4	0.1	49.7	17.7	3.0
Pamlico	-	12,934	1.3	0.4	0.1	47.3	16.6	2.8
Pender	26	41,082	0.8	0.2	<0.1	32.7	10.6	1.7

Notable Storms in North Carolina, 1950–2004

North Carolina has had many prominent storms throughout history. Since 1851, 46 of the 273 (17%) landfalling hurricanes in the U.S. have struck coastal North Carolina (Blake et al. 2005). Some years of increased activity have produced notable storms, such as the 1996 season when Tropical Storm Arthur, Hurricane Bertha, and Hurricane Fran landed within months of each other. Since 1950, North Carolina had 42 storms come within the EEZ (Table 6). The following describes the state's more notable storms in greater detail.

Hazel (1954)

Three major hurricanes struck the Atlantic states during the 1954 season. Hurricane Hazel—probably the most powerful storm to ever hit North Carolina—made landfall about one month after Hurricanes Edna and Carol passed near the North Carolina coast (Davis 1954). Hazel made landfall on the North Carolina/South Carolina border on October 15th as a borderline category 3/category 4 hurricane. Wind estimates from several points between Myrtle Beach and Cape Fear ranged between 130 and 150 mph (Davis 1954; Barnes 2001). Every pier within 170 miles of Hazel's landfall was destroyed, as were thousands of homes. The state's greatest storm surge in recorded history was observed at Calabash, where floodwaters reached 18 feet above mean low water. Incomparable devastation occurred throughout Brunswick and New Hanover beaches. Hazel caused $163 million in damage in the Carolinas, with $36 million throughout North Carolina beaches and the remainder in South Carolina and the interior of both states. Twenty deaths were reported in North Carolina, mostly from drowning (Davis 1954; Barnes 2001).

1955 Season

The 1955 hurricane season was the most active season in North Carolina's history, and for the second consecutive year broke all previous records for damage. Hurricanes Connie, Diane, and Ione all made landfall within 6 weeks of each other. Hurricane Diane was undoubtedly the nation's worst natural disaster prior to the 1950s, and earned the distinction as the "first billion dollar hurricane" (Dunn et al. 1955). The resulting devastation from the three storms was unparalleled in eastern North Carolina, especially following the damages caused by Hazel during the previous year (Barnes 2001). Together, the 1954–1955 hurricane seasons led to

Table 6. Hurricanes affecting North Carolina, 1950–2004*.

Year	Month	Day	Storm Name	Category	Wind speed (kts)	Wind speed (mph)	Pressure (mm Hg)	Speed	Location of Landfall in NC
1950	8	20	ABLE	H4	120	140	.	21.4	-
1950	9	11	DOG	H2	85	100	.	16.2	-
1951	5	21	ABLE	H3	100	115	.	13.5	-
1951	10	4	HOW	H2	95	110	.	10.5	-
1952	8	31	ABLE	H1	70	80	.	15.1	-
1953	8	14	BARBARA	H2	90	105	987	13.2	Ocracoke
1954	8	31	CAROL	H2	85	100	.	39.8	-
1954	9	11	EDNA	H3	105	120	.	19.2	-
1954	10	15	HAZEL**	H3	110	125	937	46.2	NC/SC Border
1955	8	12	CONNIE**	H1	70	80	965	9.4	Core Banks
1955	8	17	DIANE**	H1	75	85	.	10.4	Carolina Beach
1955	9	19	IONE**	H2	90	105	.	10.4	Atlantic Beach
1956	8	16	BETSY	H2	85	100	.	20.3	-
1958	8	28	DAISY	H3	110	125	955	18.4	-
1958	9	27	HELENE**	H4	115	135	943	19.2	-
1959	9	29	GRACIE	H3	105	120	.	15.4	-
1960	9	12	DONNA**	H2	95	110	958	24.2	Bogue Inlet
1961	9	20	ESTHER	H4	120	140	949	15.2	-
1963	10	26	GINNY	H2	85	100	.	12.0	-
1964	9	23	GLADYS	H1	75	85	980	8.0	-
1964	10	16	ISBELL	H1	65	75	994	17.3	Core Banks
1968	10	20	GLADYS	H1	70	80	985	23.4	-
1969	9	9	GERDA	H1	70	80	991	29.0	-
1971	9	30	GINGER	H1	65	75	984	5.3	Emerald Isle
1976	8	9	BELLE	H2	95	110	963	25.7	-
1984	9	13	DIANA**	H1	80	90	978	4.0	Cape Fear
1984	10	13	JOSEPHINE	H1	70	80	973	7.1	-
1985	9	27	GLORIA**	H2	90	105	942	26.8	Cape Hatteras
1986	8	17	CHARLEY	H1	65	75	991	12.1	Core Banks
1989	9	22	HUGO**	H4	120	140	935	25.3	-
1991	8	19	BOB	H2	95	110	957	23.1	-
1993	8	31	EMILY**	H3	100	115	962	13.0	-
1994	11	18	GORDON	H1	70	80	984	6.1	-
1995	8	17	FELIX	H1	65	75	968	3.4	-
1996	7	12	BERTHA**	H2	90	105	974	16.8	Cape Fear
1996	9	6	FRAN**	H3	100	115	954	18.5	Long Beach
1998	8	27	BONNIE**	H2	95	110	963	6.1	Surf City
1999	9	16	FLOYD**	H2	90	105	956	25.6	Surf City
1999	10	18	IRENE	H1	80	90	976	26.5	-
2003	9	18	ISABEL**	H2	90	105	956	19.7	Core Banks
2004	8	3	ALEX	H2	85	100	974	17.0	-
2004	8	14	CHARLEY	H1	65	75	988	29.6	NC/SC Border

* Data reflect conditions when storm was closest to North Carolina coastline.

** Indicates notable storms that had a large impact on North Carolina.

economic hardship of unprecedented proportions, responsible for $326 million in damages throughout North Carolina. Several groups provided relief, and President Eisenhower approved federal financial assistance (Barnes 2001). The season inflicted over 200 fatalities throughout the United States (Dunn et al. 1955).

Connie (1955)

Hurricane Connie was the first of three hurricanes to strike North Carolina's coast during the 1955 Atlantic Hurricane Season. Connie made landfall on August 12th in Carteret County as a category 1 storm, causing major damage from the Outer Banks to Raleigh. Tornado activity was reported in Pender County, and seven-foot storm surges caused extensive damage and beach erosion from Southport to Nags Head. Roughly $40 million in damages from severe flooding occurred throughout the state, though no deaths or serious injuries were reported. Hurricane Diane exaggerated these impacts 5 days later (Dunn et al. 1955; Barnes 2001).

Diane (1955)

Hurricane Diane made landfall just after Hurricane Connie near Carolina Beach on August 17th as a category 1 hurricane. The storm caused record floods from the Carolinas to Maine, and Diane became the first "billion dollar hurricane" (Dunn et al. 1955; Barnes 2001). Several inches of rain and a 6–8 foot storm surge saturated North Carolina, causing severe flooding. Extreme flooding was reported in New Bern, Belhaven, Washington, the Cape Fear River, and thousands of acres of eastern farmlands. Hurricane Diane caused $80 million in damages in North Carolina, though no deaths were reported (Barnes 2001).

Ione (1955)

Hurricane Ione hit the North Carolina coast about one month after Hurricane Diane. Ione was the third hurricane to pass through eastern North Carolina in six weeks, and the fourth within eleven months—the most ever recorded in such a short time period (Dunn et al. 1955). Ione made landfall on September 19th on Salter Path as a category 2 storm. A combination of tidewaters from the east and floodwater from the west inundated large areas of the state. Roads and bridges were closed, flooded, or washed out, isolating thousands of residents in several counties. Sand dunes along the 25-mile stretch from Cape Hatteras to Drum Inlet were swept away by the combined effects of Ione, Diane, and Connie. Ione was responsible for seven deaths and roughly $88 million in damages throughout North Carolina (Dunn et al. 1955; Barnes 2001).

Helene (1958)

Hurricane Helene never made landfall on North Carolina, but it passed just offshore of Cape Fear and Cape Lookout on September 27th as a category 4 storm. Gusts of 135 mph were recorded in Wilmington, exceeding all previous records. Some have considered Helene to be stronger than Hazel in 1954, though North Carolina was spared as the storm's eye passed 20 miles offshore. Strong winds, high tides, torrential rains, and moderate flooding occurred throughout coastal North Carolina. Southport was devastated and Wilmington received heavy damage. Resorts in Wrightsville and Carolina beaches were also heavily impacted. Hurricane Helene was responsible for $11 million in damages, though no deaths were reported throughout the state (Barnes 2001).

Donna (1960)

Hurricane Donna was the one of only four hurricanes that developed in the 1960 season, and the only storm to reach major intensity near North Carolina. Donna was among the most destructive ever to hit the United States and caused hurricane-strength winds over a greater proportion of the coast than any other known storm at the time (Dunn 1961). After demolishing parts of Florida, Donna re-intensified over the Atlantic 80 miles southeast of Charleston, then passed through Bogue Inlet and made landfall in North Carolina near Cape Carteret late on September 12th as a category 2 storm. Winds exceeding 100 mph and tides 8 feet above normal damaged many areas along the coast, especially in northeastern parts of the state where residents considered the damage to be greater than any storm within recent decades (Dunn 1961; Barnes 2001). Total costs were believed to exceed 1 billion dollars across the United States, and eight deaths were reported in North Carolina (Barnes 2001).

Diana (1984)

Hurricane Diana was the first major hurricane to hit the east coast in nearly 20 years. Diana quickly became the strongest storm of the season with category 4 winds just 15 miles off of New Hanover County. Diana's center looped offshore and dropped to a borderline category

1/category 2 storm just before making landfall on Cape Fear on September 13th. Widespread flooding occurred in New Hanover, Brunswick, Pender, Columbus, Bladen, Sampson, and Duplin counties, causing dam failures at three locations and considerable damage throughout coastal North Carolina. Substantial beach erosion and power outages occurred throughout New Hanover and Pender counties, extensive wind damage along the barrier islands, and the Brunswick Nuclear Power Plant experienced a direct hit—the first nuclear power plant struck by a hurricane (Gerrish 1984). Roughly $65 million in damages were reported in the Wilmington and Myrtle Beach areas, and three deaths occurred in North Carolina (Gerrish 1984; Barnes 2001).

Gloria (1985)

Hurricane Gloria was one of the 11 named storms in the Atlantic basin during the 1985 hurricane season (Case 1986). Gloria made landfall on Hatteras Island early on September 27th as a category 3 storm (Barnes 2001). The Outer Banks was most affected by the storm, with severe beach erosion and flooding throughout Dare County (Case 1986; Barnes 2001). Although damages exceeded $1 billion and 6 deaths throughout the U.S., Gloria's impact on North Carolina was minimal and largely restricted to the Outer Banks. Only one death was reported in North Carolina (Barnes 2001). Despite the limited damage within the state, Gloria caused substantial alarm, approaching the state as the second category 4 hurricane in two years. Evacuations occurred with greater intensity and warnings were more threatening than experienced in the past (Barnes 2001).

Hugo (1989)

Hurricane Hugo was one of the most destructive and costly storms in United States history. Hugo made landfall just north of Charleston, South Carolina on September 22nd as a category 4 storm. Even though the eye of the storm hit 100 miles south of the border, damage in North Carolina was severe, especially on the beaches of Brunswick County and western parts of the state (Barnes 2001). Damages to Brunswick County totaled $75 million. Over one billion dollars worth of damage occurred throughout the rest of the state, with twenty-nine counties declared federal disaster areas (Barnes 2001). Much of this damage occurred in Charlotte about 200 miles inland where Hugo still maintained category 2 strength. Seven deaths were reported in

North Carolina and Hugo remains one of the costliest hurricanes in United States history (Barnes 2001).

Emily (1993)

Emily was the season's only major hurricane, reaching peak intensity (category 3) while passing just east of Hatteras Island on August 31st (Pasch and Rappaport 1995). The communities of Hatteras, Frisco, Buxton, and Avon were heavily impacted. Over 500 homes were deemed uninhabitable, and the tourism industry suffered tremendously when about 160,000 people were evacuated from North Carolina's barrier islands during this Labor Day storm (Lawrence 1993; Pasch and Rappaport 1995). About 25% of the population on Cape Hatteras was left homeless, and Dare County was declared a federal disaster area. Hurricane Emily caused $35 million in damages throughout the Outer Banks, and two deaths were reported in Nags Head (Lawrence 1993; Pasch and Rappaport 1995).

1995-96 Seasons

The 1995 season was extremely active, with 19 tropical storms of which 11 became hurricanes – second only to the 1933 season. Only one of these affected North Carolina, when the extratropical system Allison passed near Nags Head on June 7th causing minor damages (Lawrence et al. 1998). In 1996, tropical storm activity in the Atlantic Basin was above average for the second year in a row. The 20 hurricanes between the seasons was the highest two-year count since reliable recording began. The latter is considered by some to be the busiest major hurricane season since 1950 (Pasch and Avila 1999). During this year, Hurricane Bertha, Hurricane Fran, Tropical Storm Arthur, and the extratropical Josephine all struck the United States near Wilmington, North Carolina. The damage from these storms exceeded $3 billion and caused 34 direct deaths (Pasch and Avila 1999).

Bertha (1996)

Hurricane Bertha made landfall on July 12th, in the Cape Fear area as a category 2 storm. Beaches between Cape Fear and Cape Lookout were the hardest hit, especially those north of Wrightsville Beach (Barnes 2001). Over 5,000 homes were damaged and an estimated 750,000 people were evacuated from the Carolinas (Lawrence 1996; Pasch and Avila 1999). Beach erosion, wind damage, storm surge flooding, pier destruction, fallen trees, and crop damage occurred through several coastal counties (Lawrence 1996). Bertha caused $270 million in damages and two deaths in North Carolina, and was remembered as the forerunner to Hurricane Fran that struck the same area later in the season (Pasch and Avila 1999).

Fran (1996)

Hurricane Fran was a powerful Cape Verde hurricane that made landfall on September 6th over the Cape Fear area as a category 3 storm. Fort Fisher, Kure Beach, Carolina Beach, Wrightsville Beach, Figure Eight Island, and the rest of New Hanover County experienced the brunt of the hurricane (Barnes 2001). Fran was the most powerful hurricane of the season and related damages aggravated problems from the recent Hurricane Bertha. Due to the large size of the storm, hurricane force winds were experienced throughout Brunswick, New Hanover, Pender, Onslow, and Carteret counties (Mayfield 1996). Millions were left without power and about 500,000 people were evacuated from the Carolinas. Hurricane Fran was by far the most powerful storm of the season, causing over $1 billion in damages and 14 deaths in North Carolina alone (Mayfield 1996; Pasch and Avila 1999).

Bonnie (1998)

Hurricane Bonnie was the third hurricane to hit North Carolina in three years, making landfall August 27th as a category 2 hurricane near Surf City. North Carolina and Virginia were most affected with widespread power outages and extensive wind damage. An unusual fisheries-related event occurred when Bonnie washed ashore thousands of automobile tires used to construct artificial reefs in the 1970s (Barnes 2001). Several counties in North Carolina were declared federal disaster areas. Hurricane Bonnie was responsible for $240 million in damages throughout North Carolina and one death in Currituck County (Avila 1998).

1999 Season

The 1999 hurricane season was perhaps the worst hurricane season experienced in North Carolina History. The season produced 12 named storms, including one of the deadliest storms to ever hit the United States—Hurricane Floyd. This also was the second time in three years that the Carolinas were impacted by multiple hurricanes in a single season. After Hurricanes Dennis and Floyd, Hurricane Irene contributed six more inches of rain to the still-saturated area just four weeks later. These combined storms inflicted over $1 billion in damage and at least 35 deaths in North Carolina alone (Lawrence et al. 2001).

Dennis (1999)

Hurricane Dennis was the first storm in 1999 to impact the east coast of the United States. After passing 60 miles off of the North Carolina Coast on August 30th as a category 2 storm, Dennis lingered offshore 100 miles east of Cape Hatteras before making landfall September 4th near Cape Lookout as a tropical storm. The rainfall from the slow moving storm and winds pushing water upstream saturated the soils and caused localized flooding, especially in Craven, Beaufort, and Pamlico counties. Both the Neuse and Pamlico rivers reported heights 3 m above normal levels (Lawrence et al. 2001; Barnes 2001). Damages from Tropical Storm Dennis totaled $157 million in North Carolina and Virginia (Beven 2000). The rainfall and saturated grounds from Dennis set up conditions for the catastrophic flood disaster caused by Hurricane Floyd—one of the state's worst natural disasters.

Floyd (1999)

Hurricane Floyd hit the North Carolina coast on September 16th two weeks after Dennis. Floyd made landfall as a category 2 storm near Surf City. The torrential rainfall from Floyd over saturated ground triggered 500-year floods in all of the North Carolina's river basins east of Raleigh (Bales et al. 2000). Floyd caused the largest peacetime evacuation in United States history up until that time, with roughly 2.6 million people leaving Florida, Georgia, and the Carolinas (Ross 2000). Over 75,000 homes were damaged, 500,000 lost electricity, and much of Duplin and Greene counties were under water (Ross 2000). The flooding caused further environmental concerns regarding pollution from hog waste lagoons, waste-water treatment plants, petroleum, pesticides, and other unknown toxins (Bales et al. 2000). Several counties were declared federal disaster areas, and the Secretary of Health and Human Services stated that "nothing since the Civil War has been as destructive to families" in the state (Ross 2000). Hurricane Floyd was responsible for billions of dollars in damages and at least 35 deaths in North Carolina (Ross 2000; Lawrence et al. 2001).

Isabel (2003)

Isabel made landfall along Core Banks on September 18th as a category 2 hurricane. Storm surges and high winds caused significant coastal flooding, with extensive damage occurring in Bertie, Carteret, Dare, and Pamlico counties (Beven and Cobb 2003). Northeastern parts of the state had not seen as much damage from a hurricane since Hazel (1954) and the Chesapeake-Potomac Hurricane (1933). Hurricane Isabel was responsible for $170 million in damages and one death in North Carolina (Beven and Cobb 2003).

Effects of Hurricanes

Physical Impacts

Hurricanes generally have profound influences on coastal areas, from geomorphologic alterations to changes in water quality, especially turbidity, salinity, and chemical composition (Lodge and McDowell 1991; Mallin et al. 1999). These changes may be natural (i.e., loading stained swamp waters into river systems) or anthropogenic (inundated hog waste lagoons) (Mallin et al. 1999). Geomorphologic changes may include landslides, shoreline migration, sedimentation, overwash deposits, scouring of river channels, dune/berm aggradation or degradation, and wind effects; all of which may last for decades (Scatena and Larsen 1991; Dolloff et al. 1994; Nyman et al. 1995; Boose et al. 2001; Stone et al. 2004). Hurricane Hugo caused blowdowns and hundreds of landslides, affecting 14 percent of a study area in Puerto Rico. Some landslides moved as much as 30,000 m^3 of material into nearby rivers (Scatena and Larsen 1991). Hurricane Fran leveled miles of protective dunes along the North Carolina coast in 1996 (NIEHS 1997).

Water quality degradation is among the most prevalent and damaging effects of hurricanes. Increased sedimentation and watercolor decreases phytoplankton and benthic algal primary production (Mallin et al. 1999). Substantial release of organic matter, sometimes accompanied with strong salinity stratification, causes low dissolved oxygen levels and large fish and invertebrate kills (NIEHS 1997; Mallin et al. 1999; Paerl et al. 2001). Hurricane Fran (1996) caused several hog waste lagoons and septic systems to release large quantities of raw sewage into the Cape Fear River, contributing to an 80% drop in dissolved oxygen levels and marked increases in ammonium and phosphorus (NIEHS 1997; Mallin et al. 1999). Hog waste in combination with human sewage diverted from wastewater treatment plants, urban runoff, and agricultural runoff caused water in the lower Neuse River to become "not safe for human contact" (NIEHS 1997). A significant amount of sediments and organic matter from these river systems end up in marine waters, sometimes exceeding annual inputs and coastal primary productivity and causing a major perturbation for benthic communities (Goñi et al. 2006).

Effects of unfavorable water quality are even more detrimental in water bodies with long residence time, such as the Pamlico Sound. The three hurricanes that made landfall in North Carolina during 1999 caused freshwater inflow to the sound to increase six-fold. Roughly half of the average annual input of freshwater occurred during a six-week period following the storms (Paerl et al. 2001). Salinities dropped 10-13 practical salinity units (psu), creating freshwater conditions from the headwaters to the mouths of major tributaries. Strong stratification (> 3 psu), bottom water hypoxia (< 4 mg liter^{-1} O_2), and increased nutrient loading lasted for approximately three weeks until Hurricane Irene re-aerated and destratified the sound. The sound subsequently restratified and high freshwater inflow continued to alter the ecosystem for several weeks (Paerl et al. 2001).

Biological Impacts

Hurricanes often cause considerable alterations in local and regional ecosystems. Effects range from mortality and displacement of plant and animal communities, to the spread of disease and exotic species (Scatena and Larsen 1991; Lodge and McDowell 1991; Mallin et al. 1999; White 2000). Further, many of the aforementioned physical effects alter habitats, behaviors, or both for many species (Waide 1991; Dolloff et al. 1994; Locascio and Mann 2005). Responses from animals may be excessive or non-existent, depending on timing, prevailing conditions, and life histories of affected species (Letourneur et al. 1993; Dolloff et al. 1994; Livingston et al. 1999; Adams and Ebersole 2004; Locascio and Mann 2005). Secondary effects from species interactions following a hurricane may lead to localized invasions, extinctions, and reorganization of plant and animal communities (Waide 1991).

The change in water quality resulting from hurricanes has a direct and occasionally fatal effect on finfish and shellfish. Dissolved oxygen levels < 2 mg liter^{-1} are extremely stressful to motile species and fatal to most sessile biota (Paerl et al. 2001). Poor water quality from North

Carolina’s 1999 hurricane season increased lesions, sores, sloughing skin, and systemic bacterial infections in several coastal fishes (Paerl et al. 2001). Hurricane Fran (1996) caused North Carolina clam harvests throughout September to fall to nearly 10% of the previous September’s harvest (NIEHS 1997). Decreased salinity sent migratory fish prematurely offshore, and anoxic conditions caused dozens of fish kills (NIEHS 1997). Hurricanes have shown to cause temporary displacement of shrimp, followed by increased detrital food supplies and rapid population increases (Waide 1991; Covich et al. 1991). Water quality, sedimentation, and altered hydrology characteristics tend to change terrestrial and aquatic plant communities (Nyman et al. 1995). Vegetation, soils, nutrient cycling, and water chemistry of inundated coastal wetlands can change dramatically in response to hurricanes. Secondary effects, such as salt stress, disease, insect infestations, fire, and habitat modification have profound impacts on biotic communities (Chabreck and Palmisano 1973; Michener et al. 1997).

Both artificial and natural reef communities are affected by hurricanes, with varying consequences. Impacts may include movement of material, structural damage, burial or subsidence, scouring, and altering biotic communities (Bythell et al. 1993; Bell and Hall 1994). Hurricanes have shown to have drastic effects on oyster reefs and, in some cases, completely decimating coral reef flats fish communities (Letourneur et al. 1993; Livingston et al. 1999). In contrast, some research has indicated little or no change in reef communities following a hurricane. Turpin and Bortone (2002) suggested that reductions in faunal biomass of reef communities following a hurricane could be nothing more than natural reductions in species richness occurring at that time of year. This study also suggested that changes in fish communities were more likely caused by redistribution and changes in fishing pressure, and that long-term effects were difficult to assess due to confounding factors, such as food supply and ecological interactions. Likewise, a study on the immediate effects of a hurricane found no substantial depletions or loss of intertidal benthic taxa off O’ahu, Hawaii following Hurricane Iniki in 1992. Previous studies showing less than catastrophic mortalities of infaunal species may actually be effects less than annual variability (Dreyer et al. 2005).

Socioeconomic Impacts

Hurricanes can impact fishermen and fishing communities at two levels. The first, and most direct, is the loss of catch due to species being dislocated from their normal habitat or fishermen being physically prevented from attempting to harvest them because of stormy weather. The second, and perhaps greater, impact descends from secondary effects of the storm such as damaged gear, boats, property, and infrastructure, all of which affects the coastal economies.

Commercial fishermen landed almost 80 million pounds of seafood in North Carolina in 2005, worth $64.9 million in ex-vessel value (see Economic Impact Analysis Section). Recreational fishermen landed an unknown, though doubtlessly significant, quantity more; although we are not able to accurately estimate the economic impact of recreational fishermen on the state. Storms may cause a species to migrate to seek better conditions or give a species an early cue to migrate offshore to join in spawning aggregations. If the timing of a fishery coincides with the peak of hurricane season, the fishery may be particularly at risk. Species that are harvested primarily in the fall include striped mullet and southern flounder. Commercial boats will not venture far from port, if at all, when hurricane warnings are posted.

Tropical cyclones also have the potential to alter recreational activity in coastal areas, especially fishing and other water sports. North Carolina possesses one of the greatest amount of Atlantic coast saltwater anglers in the United States, with over two million participants annually (NCDMF2005b). Hurricanes often inflict damage to private and charter boats, piers, boat launches, marinas, live bait dealers, and tackle shops. Navigable waters, buoy and marker systems, and access roads are frequently ruined during intense storms, as are ecological structures (e.g., artificial reefs) (Harper et al. 2000; Buerger et al. 2003; Posadas 2005; Buck 2005). Many coastal areas impacted by hurricanes rely heavily on tourism as a major source of recreational participants, and many business owners depend on revenue from tourism during the hurricane season to support their businesses through the slow winter months. Reports on the impacts of hurricanes on recreational fishing suggest significant losses, with damages often exceeding millions of dollars (Posadas 2005; Kirkley et al. 2005).

On the other hand, hurricanes can result in temporary increases in fishing, as was seen in the blue crab fishery in Pamlico Sound following Hurricane Floyd. However, this increased harvest led to localized intensive fishing pressure that may have contributed to a decrease in blue crab harvest for the following several years, producing an overall negative result. A follow-up survey conducted by Cheuvront (2005) to assess the impact of the 1999 hurricane season on North Carolina fishermen found that all fishermen interviewed experienced significant negative effects after the storms; although most managed to stay in business, 12% left fishing altogether. Fishermen did not attribute their reduced fishing efforts entirely to hurricane activity, but considered it among the many factors currently threatening their livelihood (e.g., pollution, imports, competition for resources, and regulatory actions). Generally, fishermen see the direct environmental impacts from hurricanes as short-term problems. According to Cheuvront (2005):

> "They do clean things up," said one fisherman, "but they also create a lot of silt and pollution. All the fresh water from the rain holds things farther down the sounds. That usually only lasts for one or two months."

Fishermen on the coast have always dealt with hurricanes, and it is considered part of the natural order of an ocean-dependent life.

The secondary effects from hurricanes are the ones fishermen fear more. It is known that commercial fishermen experience damage or loss of fishing gear and vessels that prevent them from actively fishing following a hurricane. Hurricane Katrina, which caused massive devastation along the Gulf coast region in 2005, is an extreme example of what can happen to fishermen following an intense hurricane. The physical damage experienced by fishermen, seafood dealers, and seafood processors along with long-term power outages, flooding, impassible roads, and lack of available gasoline led to a collapsed infrastructure. Even if a local fisherman was able to harvest some seafood after the storm, there was no one to buy it. This, of course, leads to a loss of income and a major economic impact to the region.

Hurricanes can also cause a loss to the tourism-dependent economy, as was found on the outer banks along Hatteras Island after Hurricane Emily just before Labor Day in 1993 (Barnes 2001). Seafood related businesses both directly and indirectly depend on tourism. For example, Carter and Letson (Draft) found that increased hurricane activity significantly decreased head boat effort in Florida. Without tourism, local restaurants and businesses suffer. It is important to understand the effects of hurricanes on our fishery resources and fishery infrastructure to initiate proper management following a hurricane to mitigate the effects of a disaster. Berrigan (1988) describes how a comprehensive management plan was successfully developed following Hurricane Elena along Florida's northern Gulf Coast in 1985 that protected surviving resources and promoted recovery of oyster reefs devastated by the storm while mitigating economic hardships. Regulatory strategies were redefined to include specific area restrictions, limiting harvest times, establishing bag limits, and requiring that harvesters pass through checkpoints before landing their catch. In addition, cooperation between state and federal agencies produced successful programs to sustain the shellfish-dependent economy and benefit the resource over the long term. A good way to anticipate the impacts of future hurricanes on North Carolina's fisheries is to understand how hurricanes have influenced target species in the past.

Project Objectives

The purpose of this study is to better understand how commercial and recreational fisheries, fishermen, and fishing communities are impacted by hurricanes. The objectives are to determine the impact of hurricanes on North Carolina fisheries by:

(1) Analyzing commercial fishery landings data;
(2) Analyzing hurricane impacts for 1999 compared to hurricane impacts in previous years including possible acute and chronic impacts;
(3) Establishing linkages between commercial fishery landing, recreational harvest, and fishery independent and dependent biological data;
(4) Analyzing historical and future commercial fishery landing, recreational harvest, and fishery independent and dependent biological data; and
(5) Determining the socioeconomic impact.

Deviations

The biologist in charge of the project accepted another position with the North Carolina Division of Marine Fisheries (NCDMF) in April 2006. It was evident that there was not enough time remaining on the project to rehire the position and bring a new biologist up to speed on the project in enough time for that person to complete the final report. As a result, the biologist agreed to continue to coordinate the project and complete the final draft with the help of other personnel at NCDMF. As a result of the personnel change, we were not able to examine fishery-independent or fishery-dependent data from the NCDMF biological database as proposed in jobs 3 and 4. We did, however, present analyses of both commercial and recreational landings data for those jobs.

QUANTITATIVE COMMERCIAL ANALYSIS

Methods

Data Used

North Carolina landings data were collected by the National Marine Fisheries Service (NMFS) prior to 1978. From 1978 to 1993, commercial landings in North Carolina were acquired on a monthly basis from licensed seafood dealers via the NCDMF/NMFS cooperative statistics program. Reporting up until this time was not mandatory. Mandatory reporting of commercial landings began in 1994 via the NCDMF Trip Ticket Program, which is a dealer-based reporting program that obtains a trip-level census of commercial landings in North Carolina. Annual landings are available by water body back to 1962 and can be summarized by month from 1972 to the present. All water bodies referenced are defined by the NCDMF Trip Ticket Program and include those waters that make up the Albemarle-Pamlico estuarine system, all of the inshore waters in the southern part of the state, and the Atlantic Ocean (Figure 6 through Figure 9). Species and gears were grouped for analyses as reported in the NCDMF License & Statistics Annual Report (NCDMF 2005b) (Table 7 and Table 8).

The annual numbers of pounds landed were used for all quantitative analyses. Catch per unit effort (CPUE) would provide a better unit of measure to estimate the relative abundance of a stock; however, CPUE for landings data (harvest per trip) have only been available since the trip ticket program was instituted in 1994. Unfortunately, a longer time series is needed prior to the intervention event to establish the underlying normal variability (noise) in order to effectively evaluate whether the intervention had a significant impact on the fishery.

There are some biases associated with using fishery-dependent data to “sample” a population. For instance, data are only collected when landings are reported or fishermen may not go out during storms and adverse weather conditions. In addition, economic factors such as market demand, gas prices, and ex-vessel value of a fishery all influence the amount of effort that fishermen put forth to actively fish. Fishery-independent data limits many of these biases, but reliable estimates are often not available for a long, continuous time series

Table 7. Major species groupings used in analyses.

Species Group	Common Name	Scientific Name
Amberjacks	Greater Amberjack	*Seriola dumerili*
	Lesser Amberjack	*Seriola fasciata*
Bass, Striped	Striped Bass	*Morone saxatilis*
Blue Crab	Blue Crab	*Callinectes sapidus*
Bluefish	Bluefish	*Pomatomus saltatrix*
Catfishes	White Catfish	*Ameiurus catus*
	Bullheads	*Ameiurus* spp.
	Channel Catfish	*Ictalurus punctatus*
	Blue Catfish	*Ictalurus furcatus*
Clam, Hard	Northern Quahog	*Mercenaria mercenaria*
Croaker, Atlantic	Atlantic Croaker	*Micropogonias undulatus*
Dolphinfish	Dolphinfish	*Coryphaena hippurus*
Drum, Red	Red Drum	*Sciaenops ocellatus*
Eel, American	American Eel	*Anguilla rostrata*
Flounder, Southern	Southern Flounder	*Paralichthys lethostigma*
Flounder, Summer	Summer Flounder	*Paralichthys dentatus*
Goosefish	Goosefish	*Lophius americanus*
Groupers	Longtail Bass	*Hemanthias leptus*
	Speckled Hind	*Epinephelus drummondhayi*
	Rock Hind	*Epinephelus adscensionis*
	Snowy Grouper	*Epinephelus niveatus*
	Yellowedge Grouper	*Epinephelus flavolimbatus*
	Red Grouper	*Epinephelus morio*
	Marbled Grouper	*Dermatolepis inermis*
	Misty Grouper	*Epinephelus mystacinus*
	Black Grouper	*Mycteroperca bonaci*
	Gag	*Mycteroperca microlepis*
	Scamp	*Mycteroperca phenax*
	Yellowmouth Grouper	*Mycteroperca interstitialis*
	Yellowfin Grouper	*Mycteroperca venenosa*
	Atlantic Creolefish	*Paranthias furcifer*
	Graysby	*Cephalopholis cruentata*
	Coney	*Cephalopholis fulva*

Species Group	Common Name	Scientific Name
	Warsaw Grouper	*Epinephelus nigritus*
Herring, River	Alewife	*Alosa pseudoharengus*
	Blueback Herring	*Alosa aestivalis*
Herring, Thread	Atlantic Thread Herring	*Opisthonema oglinum*
Hogfish	Hogfish	*Lachnolaimus maximus*
Kingfishes	Southern Kingfish	*Menticirrhus americanus*
	Northern Kingfish	*Menticirrhus saxatilis*
	Gulf Kingfish	*Menticirrhus littoralis*
Mackerel, King	King Mackerel	*Scomberomorus cavalla*
Mackerel, Spanish	Spanish Mackerel	*Scomberomorus maculatus*
Menhaden, Atlantic	Atlantic Menhaden	*Brevoortia tyrannus*
Mullet, Striped	Striped Mullet	*Mugil cephalus*
Oyster	Eastern Oyster	*Crassostrea virginica*
Perch, White	White Perch	*Morone americana*
Perch, Yellow	Yellow Perch	*Perca flavescens*
Porgies	Longspine Porgy	*Stenotomus caprinus*
	Red Porgy	*Pagrus pagrus*
	Saucereye Porgy	*Calamus calamus*
	Whitebone Porgy	*Calamus leucosteus*
	Knobbed Porgy	*Calamus nodosus*
	Littlehead Porgy	*Calamus proridens*
Scallop, Bay	Bay Scallop	*Argopecten irradians*
Scup	Scup	*Stenotomus chrysops*
Sea Basses	Black Sea Bass	*Centropristis striata*
	Rock Sea Bass	*Centropristis philadelphica*
Seatrout, Spotted	Spotted Seatrout	*Cynoscion nebulosus*
Shad, American	American Shad	*Alosa sapidissima*
Shad, Gizzard	Gizzard Shad	*Dorosoma cepedianum*

Species Group	Common Name	Scientific Name
Shad, Hickory	Hickory Shad	*Alosa mediocris*
Sharks	Bull Shark	*Carcharhinus leucas*
	Sand Tiger	*Carcharias taurus*
	Atlantic Sharpnose shark	*Rhizoprionodon terraenovae*
	Blacktip Shark	*Carcharhinus limbatus*
	Atlantic Angel Shark	*Squatina dumeril*
	Shortfin Mako	*Isurus oxyrinchus*
	Longfin Mako	*Isurus paucus*
	Thresher Shark	*Alopias vulpinus*
	White Shark	*Carcharodon carcharias*
	Sandbar Shark	*Carcharhinus plumbeus*
	Dusky Shark	*Carcharhinus obscurus*
	Tiger Shark	*Galeocerdo cuvier*
	Bonnethead	*Sphyrna tiburo*
	Lemon Shark	*Negaprion brevirostris*
Sharks, Dogfishes	Smooth Dogfish	*Mustelus canis*
	Spiny Dogfish	*Squalus acanthias*
Shrimp	Brown Shrimp	*Farfantepenaeus aztecus*
	Pink Shrimp	*Farfantepenaeus duorarum*
	White Shrimp	*Litopenaeus setiferus*
Snappers	Blackfin Snapper	*Lutjanus buccanella*
	Silk Snapper	*Lutjanus vivanus*
	Cubera Snapper	*Lutjanus cyanopterus*
	Gray Snapper	*Lutjanus griseus*
	Mutton Snapper	*Lutjanus analis*
	Red Snapper	*Lutjanus campechanus*
	Vermillion Snapper	*Rhomboplites aurorubens*
	Yellowtail Snapper	*Ocyurus chrysurus*
	Ballbat Snapper	*Etelis oculatus*
Spadefish	Atlantic Spadefish	*Chaetodipterus faber*
Spot	Spot	*Leiostomus xanthurus*
Swordfish	Swordfish	*Xiphias gladius*
Tilefishes	Tilefish	*Lopholatilus chamaeleonticeps*
	Blueline Tilefish	*Caulolatilus microps*
	Sand Tilefish	*Malacanthus plumieri*
Triggerfishes	Gray Triggerfish	*Balistes capriscus*
	Queen Triggerfish	*Balistes vetula*
	Rough Triggerfish	*Canthidermis maculata*

Species Group	Common Name	Scientific Name
	Ocean Triggerfish	*Canthidermis sufflamen*
	Sargassum Triggerfish	*Xanthichthys ringens*
Tunas	Atlantic Bonito	*Sarda sarda*
	Little Tunny	*Euthynnus alletteratus*
	Albacore	*Thunnus alalunga*
	Bluefin Tuna	*Thunnus thynnus*
	Skipjack Tuna	*Katsuwonus pelamis*
	Yellowfin Tuna	*Thunnus albacares*
	Bigeye Tuna	*Thunnus obesus*
	Blackfin Tuna	*Thunnus atlanticus*
Wahoo	Wahoo	*Acanthocybium solandri*
Weakfish	Weakfish	*Cynoscion regalis*

Table 8. List of major gear groupings.

Gear Group	Gear
By Hand	By Hand
Channel Net	Channel Net
Dip Nets	Dip Net
	Scallop Scoop
Dredges	Hydraulic Escalator Dredge
	Hydraulic Pump Dredge
	Clam Dredge (hydraulic)
	Clam Dredge
	Crab Dredge
	Oyster Dredge
	Scallop Dredge (bay)
	Scallop Dredge (sea)
Fyke Net	Fyke Net
Gill Nets	Gill Net Set (float)
	Gill Net Set, < 5" mesh
	Gill Net Set, >= 5" mesh
	Gill Net (drift)
	Gill Net (runaround)
	Gill Net Set (sink)
Haul Seines	Beach Seine
	Haul Seine
	Common Seine
Hook-and-Line	Rod-and-Reel
	Trolling
Longlines	Longline Surface
	Longline Bottom
	Longline Shark
	Trotline
	Turtle Hooks
Pots	Conch Pot
	Crab Pot
	Peeler Pot
	Eel Pot
	Fish Pot
	Lobster Pot
	Shrimp Pot
	Turtle Pot
Pound Nets	Pound Net
	Shrimp Pound
Purse Seine	Purse Seine
Rakes	Power Rake
	Bull Rake
	Hand Rake
Tongs	Mechanical Tongs
	Hand Tongs
	Patent Tongs
Trawls	Butterfly Net
	Skimmer Trawl
	Crab Trawl
	Flounder Trawl
	Scallop Trawl
	Shrimp Trawl
	Clam Trawl Kicking
	Flynet

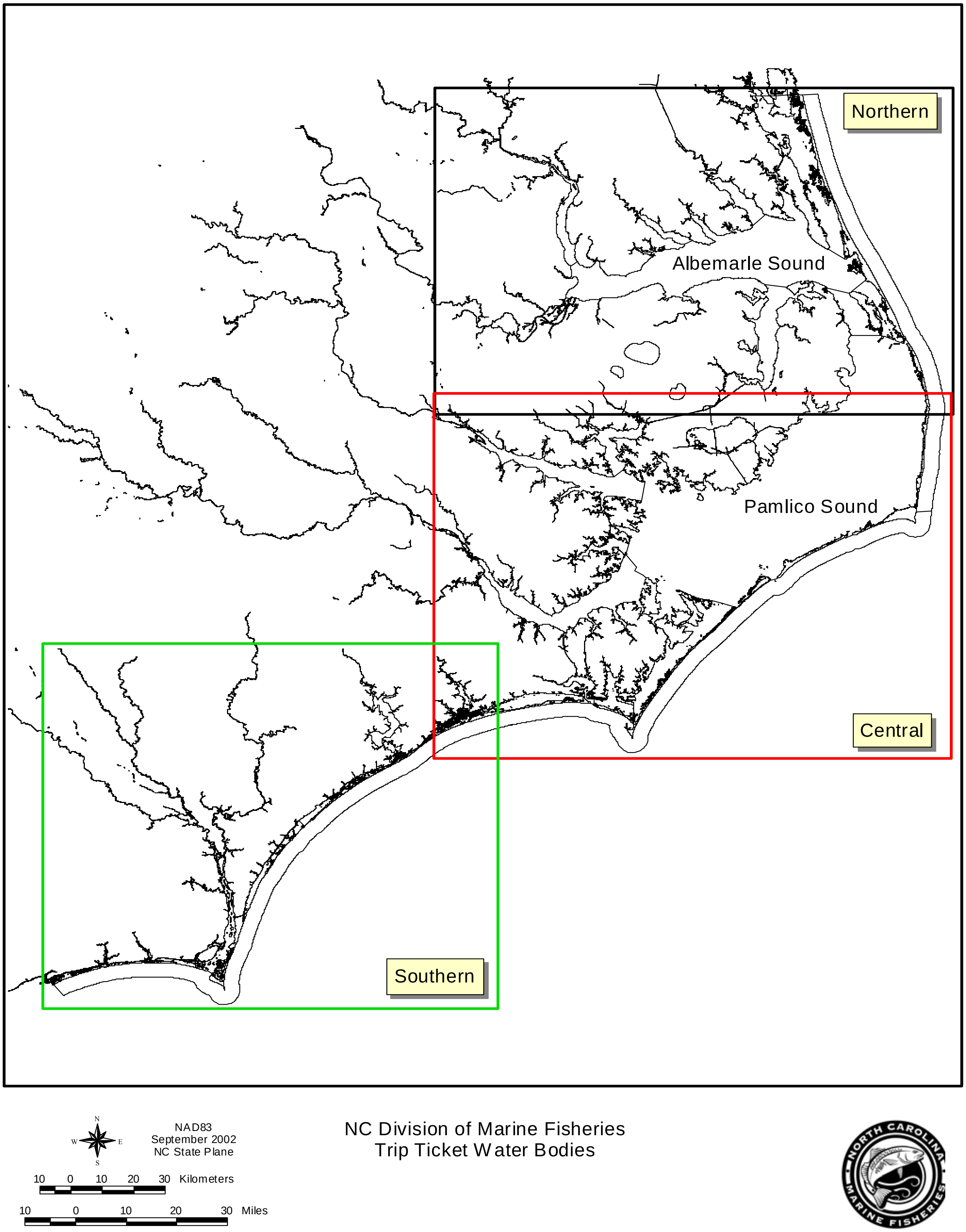

Figure 6. NCDMF trip ticket water body regions.

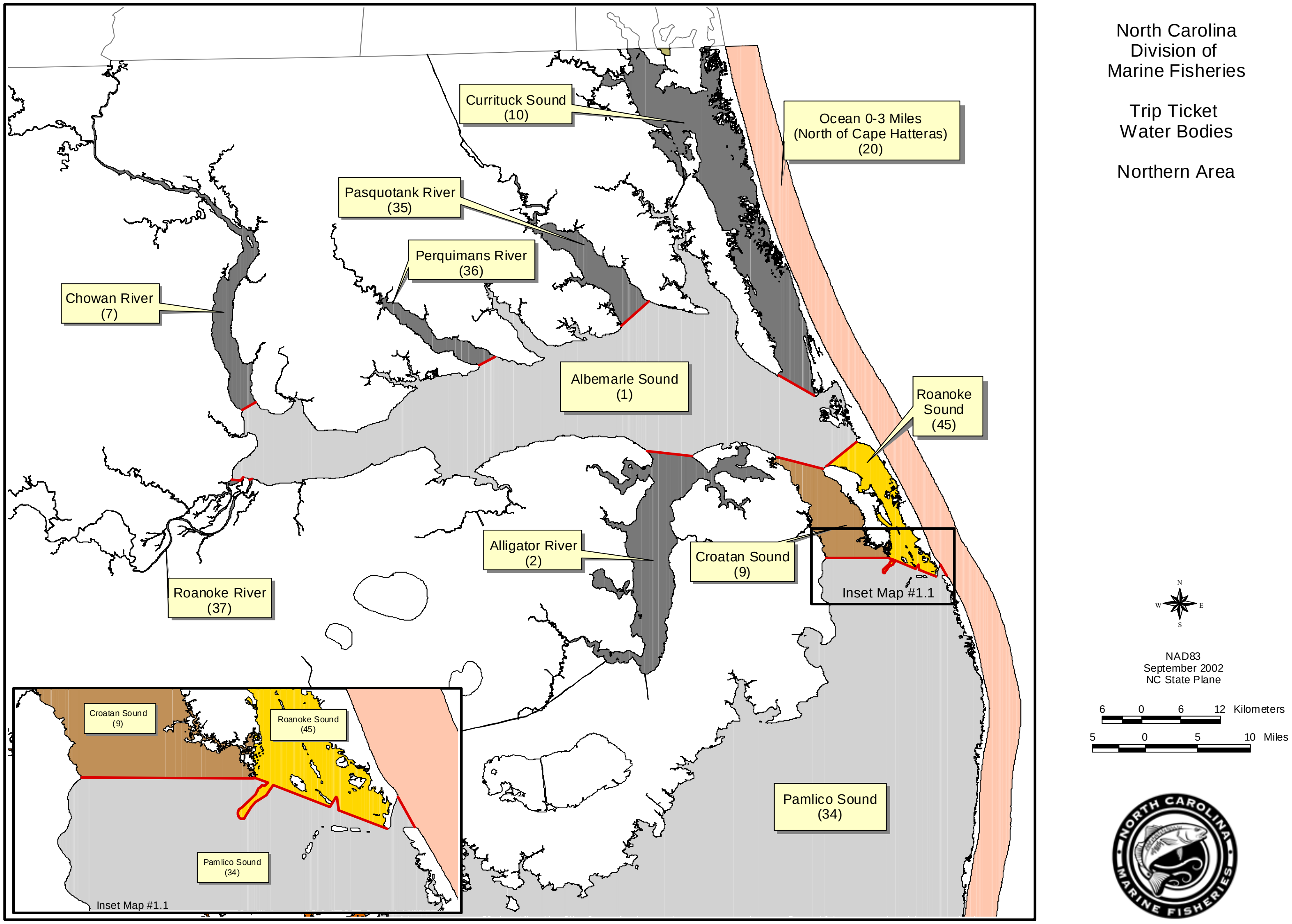

Figure 7. NCDMF trip ticket water bodies in the northern region.

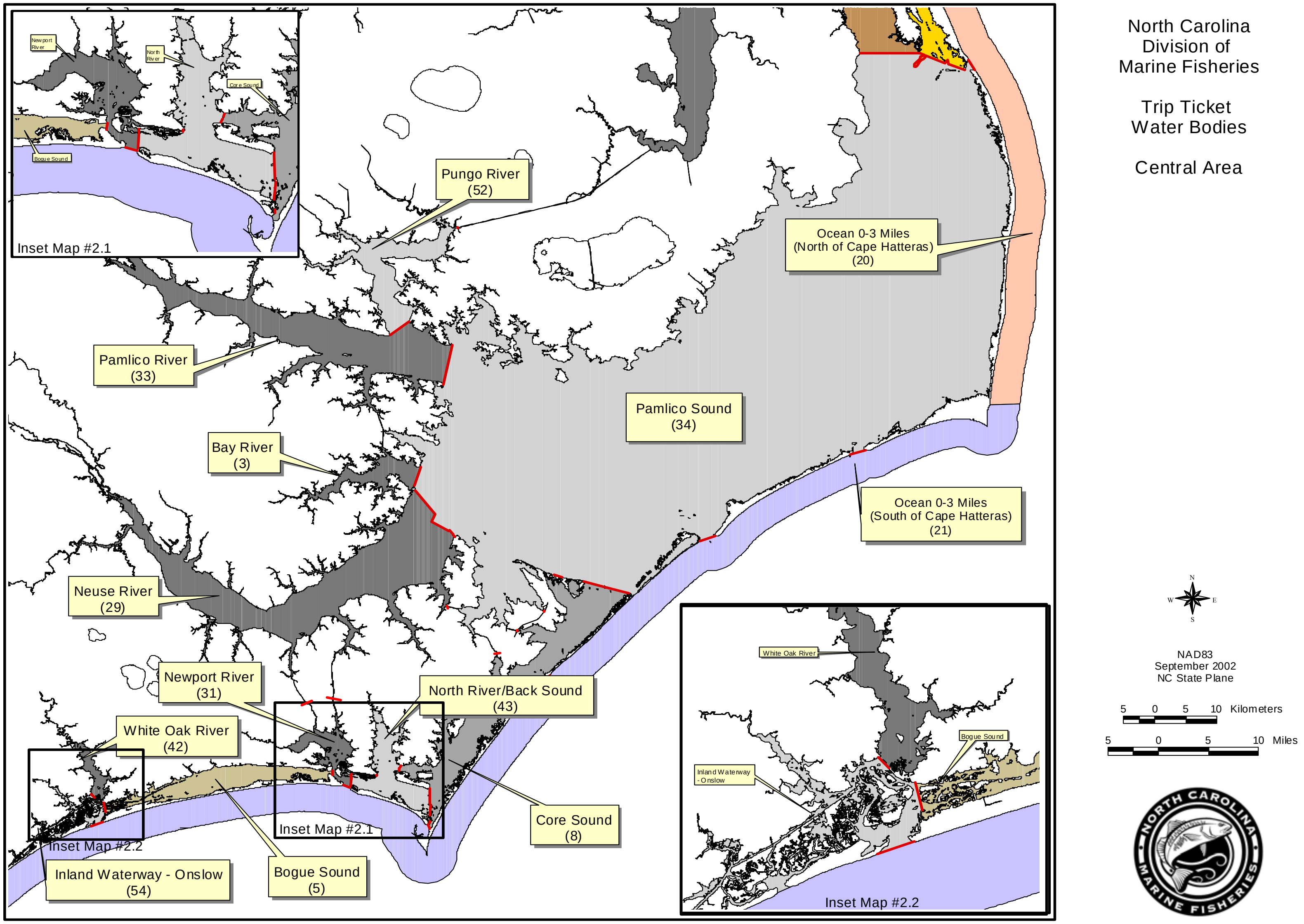

Figure 8. NCDMF trip ticket water bodies in the central region.

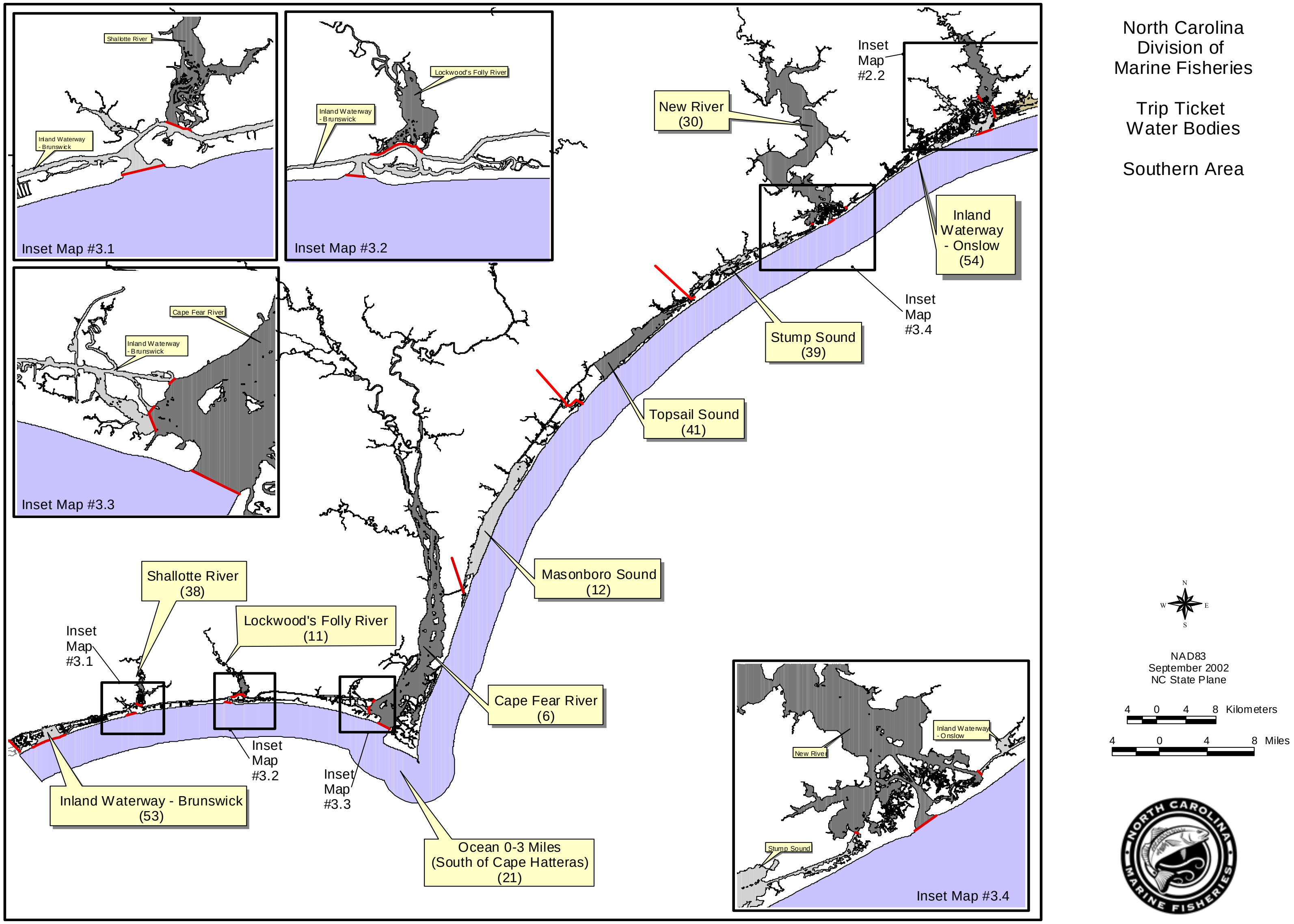

Figure 9. NCDMF trip ticket water bodies in the southern region.

or are only available in certain locations or for certain age classes and were therefore not examined in this report. Landings data may not always reflect actual population densities of a given species, but can provide a reasonable estimate of the state of the fishery when considering socioeconomic factors.

Introduction to Time Series Analysis

The ability to quantify the impacts of man-induced or natural interventions on a fishery provides decision makers with information that allows for more effective resource management. Understanding how past interventions have affected a particular fishery can help managers anticipate changes that may occur should a similar event occur in the future. Intervention analysis, a type of time series analysis, is a statistical technique used to detect nonrandom changes in the mean level of a time series that may have been caused by a particular event (e.g., hurricane, regulations, etc.). The analysis answers the question: was there a significant reduction or increase in landings, and if so, what was the magnitude?

Intervention analysis can be used in the fisheries realm to detect changes resulting from a variety of external influential events such as hurricanes, red tide, pollution events, seafood market developments, and regulation changes. Carpenter (1990) suggests using intervention analysis for large-scale experiments when replication is impossible. Chan et al. (2003) states that intervention analysis provides a valuable tool for studying the impact of an environmental disturbance on a stable dynamic system. This technique is not familiar to most fishery biologists, because it is not typically taught as part of the curriculum in most fishery programs. Nonetheless, intervention analysis can give valuable insight into the effects that external influences have on a particular fishery of interest and can be used where a long time series of data is available prior to the intervention. Noakes (1986) illustrates the usefulness of intervention analysis in the management of fishery resources. Intervention analysis has been used successfully to detect changes in a wide variety of fisheries issues (Thompson et al. 1982; Noakes 1986; Noakes and Campbell 1992; Hare and Francis 1995; Pace et al. 1998; Lloret et al. 2000; Madenjian et al. 2000; Chan et al. 2003).

ARIMA Models

Before the intervention can be evaluated, the underlying "noise" or general pattern present in the time series must be modeled. This is done using Box-Jenkins models, which are commonly referred to as Autoregressive Integrated Moving Average (ARIMA) models. ARIMA models require a long-term observational time series to establish the patterns of normal variation. There is some debate on the minimum number of observations required, but most authors recommend at least 30 to 50 observations (Yaffee and McGee 2000). Data must be collected at equal time intervals and it is essential that there are no missing values. ARIMA models are constructed using only data contained in the series itself where current values of the response variable are related to observations in the past. That is, each value of a response is linearly related to or has a "memory" of what has happened in the past plus any random shocks (errors). ARIMA models can be summarized as (*p,d,q*) where *p* is the autoregressive (AR) order of the model, *d* is the level of differencing (I), and *q* is the moving average (MA) order of the model.

In an autoregressive process (*p*), each value in a series is a linear function of one or more of the previous values. In effect, an observation at time *t* is related linearly to the observation(s) before time *t*. A first order autoregressive process would be represented as (1,0,0). In this example, only the single preceding value is used to formulate the current value. A second order autoregressive process (2,0,0) uses the two preceding values and so on. The formula for a first order autoregressive process can be represented as

$$value_t = disturbance_t + \phi_1 \times value_{t-1}$$

where *value* represents the response of the series at a particular point in time, and *disturbance* represents a random error term. The parameter, ϕ, is estimated from the observed series and indicates how strongly each value depends on the preceding value. A value of 1 represents a perfect memory of the previous value and a value of 0 represents no memory. A second order autoregressive process would simply add an additional term to the previous equation.

$$value_t = disturbance_t + \phi_1 \times value_{t-1} + \phi_2 \times value_{t-2}$$

ARIMA models require a series to be stationary with constant variance, that is, vary about a mean with constant variance. Time series data are also frequently not stationary meaning that the series may exhibit drift from the mean, random walk, or a trend in a series. In this case, differencing may resolve the effect. The "I" in ARIMA stands for integrated and represents the level of differencing (d). Differencing transforms the series by subtracting (taking the difference of) the response variable at time t from the value at time t-1. A series that is differenced once could be represented as (0,1,0). Transformation of a series can used to stabilize the variance.

In a moving average (MA) process, the observation at time t is the average of the current disturbance and one or more previous disturbances. The order of the process determines how many previous disturbances are averaged and is expressed in terms of the previous errors. The formula for a first order moving average process can be represented as

$$value_t = disturbance_t - \theta_1 \times disturbance_{t-1}$$

where value represents the response of the series at a particular point in time, and disturbance represents a random error term. The parameter, θ, is estimated from the observed series and indicates how strongly each value depends on the preceding disturbance. As with an autoregressive process, a second order moving average process would simply add an additional term to the model

$$value_t = disturbance_t - \theta_1 \times disturbance_{t-1} - \theta_2 \times disturbance_{t-2}$$

A complete stationary, nonseasonal ARIMA model can be expressed conceptually as

Response + autoregressive components = moving average + white noise components where the response refers to the value of the time series at a specified time, the autoregressive components reflect the dependence of the response to time series values at previous times, the moving average components determine how the response depends on the white noise terms at previous times, and white noise is the random (that is, independently distributed) portion of the response.

There are three steps to model construction: identification of the model, estimation of the parameters, and diagnosis of the model. The goal of model identification is to develop a model that gives a good statistical fit of the data. It is of utmost importance to keep the model as simple as possible while adequately describing the data. This is known as parsimony. Using an unnecessarily complex model in intervention analysis can impair your ability to detect a change (Lettenmaier et al. 1978). All time series analysis was performed using SPSS Trends 12.0 (SPSS Inc., Chicago, Illinois).

Creating a sequence plot of the data along with Autocorrelation function (ACF) and partial autocorrelation (PACF) plots help identify candidates for the correct model. Potential models were tested by comparing ACF and PACF plots with theoretical plots (Yaffee and McGee 2000). Model parameters were estimated using the maximum likelihood method.

Models were diagnosed by first checking to see if parameter estimates were significant ($\alpha = 0.05$). If parameters were significant, an ACF was run on the residuals. Box-Ljung statistics were calculated for each lag to determine if they were reduced to “white noise” (i.e., not autocorrelated). If several models are possible, the model with the lowest value for the Akaike’s Information Criterion (AIC) was selected as the most appropriate model. The AIC balances statistical fit with parsimony (Akaike 1974). The formula used to calculate the AIC is

$$\text{AIC} = (-2) \log (\text{maximum likelihood}) + 2k$$

where k is the number of parameters estimated.

Intervention Analysis

Intervention analysis was used to determine if there was a significant change in landings due to the presence of a hurricane. This statistical technique determines whether or not an external event, such as a hurricane, causes a significant change in the mean level of a time series. It can be used to model a system when the natural variation in the time series (system) is disrupted by a major event (e.g., hurricane, regulation change, red tide, hazardous waste spill, market shift, etc.). Intervention analysis was performed on the commercial landings data for a few species to provide an example of what can be accomplished by further research. All other species were examined qualitatively to look for trends associated with hurricane activity.

Time series data are often serially dependent, exhibiting autocorrelation (lack of independence between successive observations), often nonstationary, and frequently seasonal. That is, one observation is dependent on a set of previous observations. This is often the case in fisheries with species that are not annual crops and harvest levels depend on the strength of previous year classes. Conventional statistical techniques, such as t-tests, regression, and ANOVAs, are often inappropriate to analyze time series data because these tests are only valid if observations are independent of one another. Their assumptions are often violated when using time series data. Madenjian et al. (1986) found that an impact assessment based on ANOVA can result in detection of impact when actually there was no effect (type I error) when observations were serially correlated.

Intervention analysis is a technique used to quantitatively analyze whether or not a specific event in time, such as a hurricane, coincided with a significant change in the mean level of the time series. The analysis takes into account autocorrelation and natural variability of the series when evaluating the change in system response. Note, if a significant change is detected, this does not actually determine that a particular event *caused* the change, merely that it was *coincident* with the change and *could* have caused the observed change. In order to determine if an event is actually responsible for a change, an experiment would have to be conducted under controlled conditions, which is logistically impossible for hurricane activity and oceanic and estuarine systems of such a large scale. Intervention analysis merely shows that a significant change is coincident with a particular intervention. Establishing the relationship between the dynamic series and the intervention should be based on a plausible ecological mechanism (Carpenter 1990).

Intervention analysis is an extension of the ARIMA model with an additional term representing the intervention added to the model. The formula for intervention analysis can be represented conceptually as:

$$\text{Response} = \text{noise} + \text{intervention effect}$$

Where the response is the value of the series at time t, noise is the ARIMA model representing the underlying patterns normally present in the system, and the intervention effect contains the model parameters reflecting the influence of the intervention(s) on the response. The parameter for this term will indicate the magnitude and direction of any change in the mean level of the series. More than one intervention can be modeled at a time. All types of interventions that could possibly influence the time series must be considered (e.g., market, disease, red tide, water quality, regulation changes, etc.) and not limited to hurricane activity.

First, an ARIMIA model was developed using the pre-intervention series to establish the underlying noise (natural variability) of the system. Then, both the pre and post intervention series were modeled together to detect any change in the mean level of the series. A significance level of $\alpha = 0.05$ was used for all analyses.

All assumptions that apply to ARIMA models also apply to intervention analysis. The background noise modeled by ARIMA is assumed to persist throughout the time series even after the intervention. It is also assumed that the intervention is the only source affecting a change in the series.

The input series for the intervention is coded using dummy variables of 1 and 0 to represent presence and absence of an effect respectively. A permanent change caused by an intervention is referred to as a step change. The input series for a step change is represented by a 0 until the intervention begins at time T. At the onset of the event, the input series is set equal to 1.

$$S(t) = \begin{cases} 0 \text{ when } t < T \\ 1 \text{ when } t \geq T \end{cases}$$

where S(t) is the input series for a step function, t is the current time observation, and T is the timing of the intervention. An example of a step change would be the discovery for a new market for a type of seafood.

A temporary change caused by an intervention is referred to as a pulse function. The input series for a pulse function is represented by a 0 prior to the timing of the intervention, changes to a 1 during the influence of the intervention, and returns to 0 following the intervention.

$$P(t) = \begin{cases} 0 \text{ when } t \neq T \\ 1 \text{ when } t = T \end{cases}$$

where P(t) is the input series for a pulse function. An example of a pulse function would be a temporary rule limiting harvest imposed on a fishery. A graph of the time series was examined initially for potential changes coinciding with years of notable hurricane activity, and the appropriate step or pulse intervention was subsequently modeled and tested for significance. In the case where there was no autocorrelation detected, standard regression analysis with forward selection was used with the same dummy variables used as intervention terms. The time series for all remaining major species were examined qualitatively for apparent annual and seasonal trends following hurricanes.

Time series analysis (ARIMA and intervention models) can also be used to forecast landings. Intervention models can be used to predict what would happen if a similar hurricane or other significant event were to occur in the future. Forecasts are generated based on the assumption that the past history can be used to predict future values and that future events will respond similarly to past events. Forecasts are typically only good for the short term (next one or two time steps) because models become less precise as confidence intervals tend to become wider the further the forecast moves into the future.

Results

All Species Combined

North Carolina's unique geographical location supports one of the most diverse commercial fishing industries of any state in the United States. The cold waters of the Labrador Current from the north meet the warm waters of the Gulf Stream from the south near Cape Hatteras, which marks the southern range for many coldwater species and the northern range for many warm water species. This has contributed to over 150 species having been commercially harvested in North Carolina (A. Bianchi, NCDMF, personal communication).

In general, commercial landings for all species combined peak in December, reach a low in February and March, and reach a secondary peak in July with fishing activity continuing throughout the fall (Figure 10). Most of the total commercial landings for the state are harvested with purse seines (52%) followed by pots (16%), trawls (14%), and gill nets (7%) (Figure 11). The majority of total commercial landings are from the largest bodies of water led by the Atlantic Ocean less than three miles (52%), the Atlantic Ocean greater than three miles (12%), Pamlico Sound (12%), and Core Sound (7%) (Figure 12). From 1994 to 2001, the majority of seafood in North Carolina was landed in Carteret County (46%) and Dare County (21%) followed by Hyde (7%), Pamlico (6%), and Beaufort (6%) counties (Bianchi 2004). However, note that most of the trends seen when all species are combined are greatly influenced by the menhaden fishery, which made up 50% of the landings on average from 1972 to 2004.

Commercial landings of all species combined peaked in 1959 at 342.6 million pounds and declined to an all time low of 105.2 million pounds in 1966 (Figure 13). Landings increased for the next 15 years reaching an all time high for recorded landings of 432.0 million pounds in 1981. Landings declined drastically over the next 5 years and stabilized averaging 182.1 million pounds from 1986 to 1997. Since that time, landings have been on a decline ending at 134.1 million pounds in 2004. There were no discernable patterns detected in the overall commercial landings of all species combined with respect to hurricane activity.

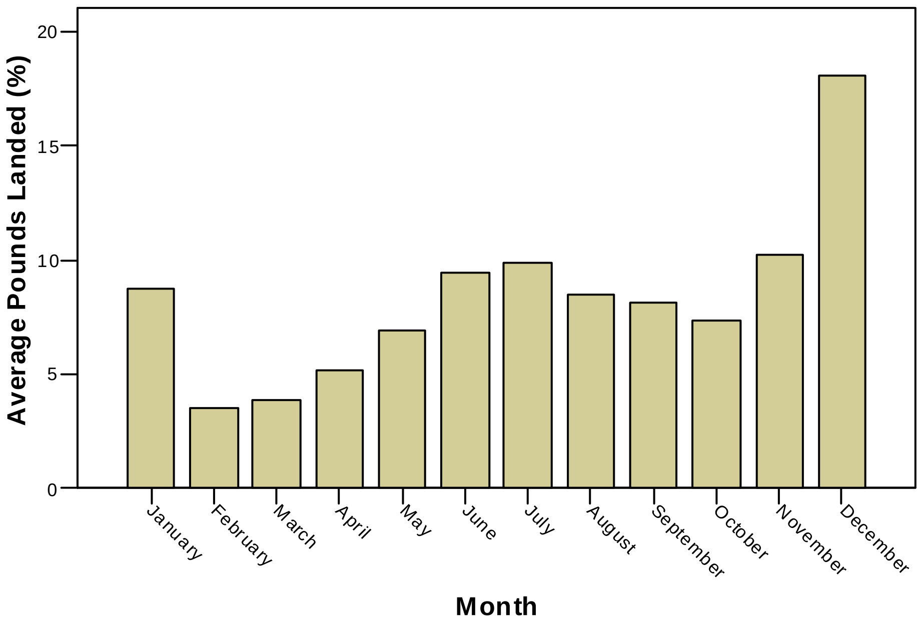

Figure 10. Average monthly landings of all species harvested commercially in North Carolina, 1972–2004.

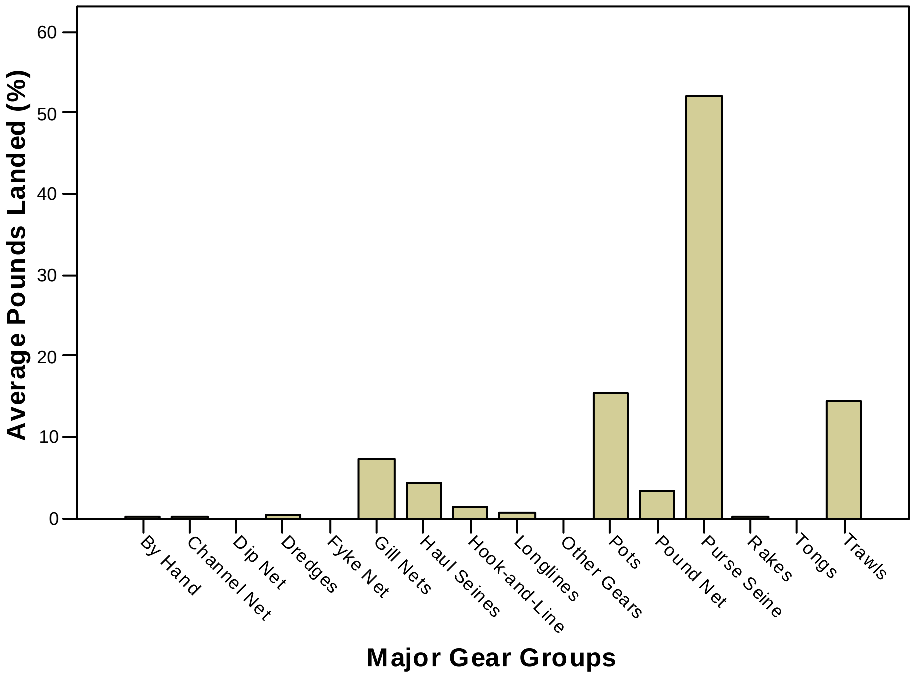

Figure 11. Average landings of all species harvested commercially in North Carolina by gear type, 1972-2004.

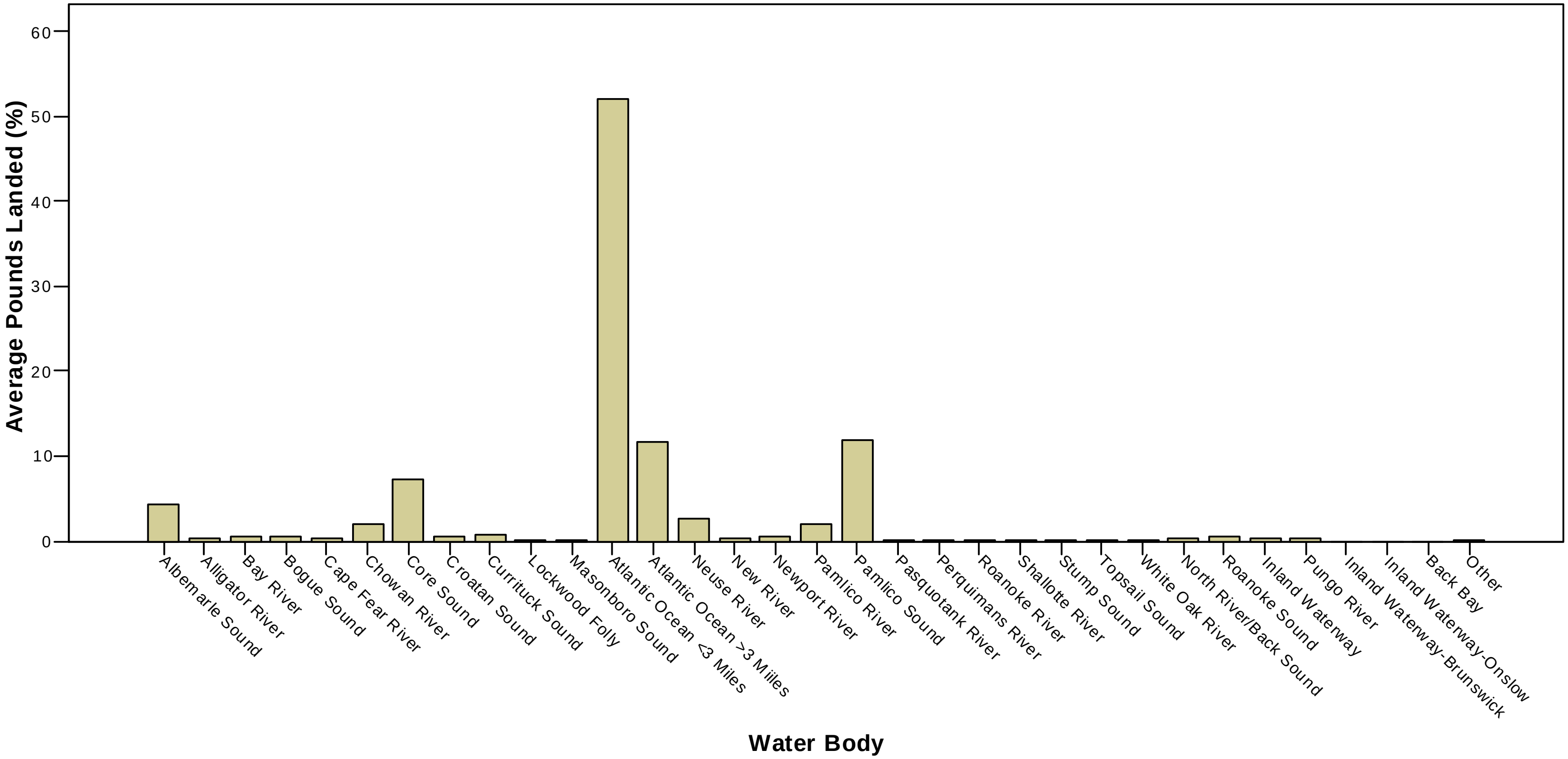

Figure 12. Average annual landings of all species commercially harvested in North Carolina by water body, 1972–2004.

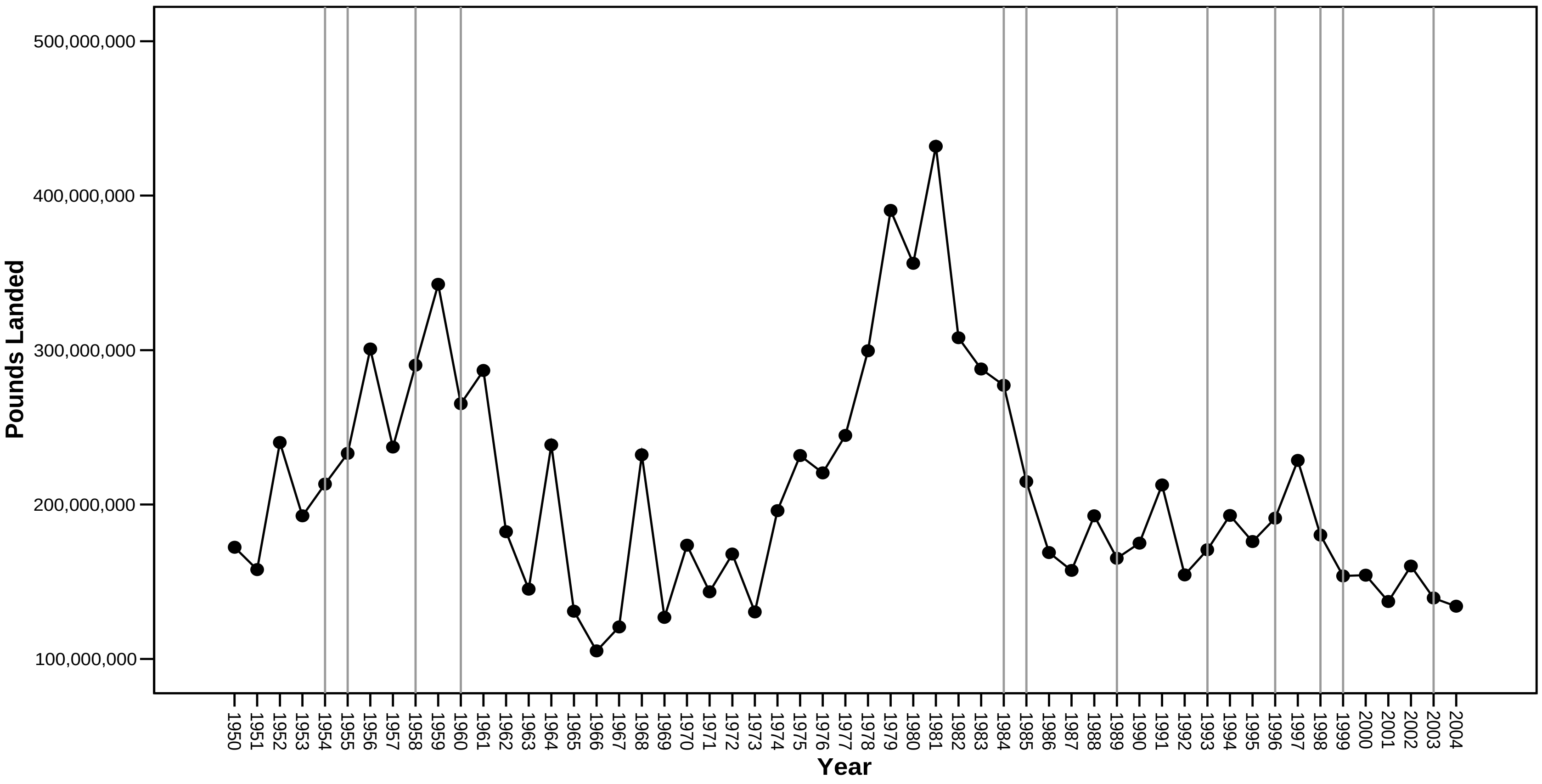

Figure 13. Total annual landings of all species commercially harvested in North Carolina, 1950–2004. Grey bars represent notable hurricane years.

All Species Combined (Excluding Menhaden)

Since the trends observed for all species combined were greatly influenced by activity in the menhaden fishery, landings were also analyzed for all commercial species combined while excluding menhaden. On average, these landings were relatively consistent throughout much of the year with a small increase in landings seen in July through October (Figure 14). The majority of these landings were made with pots (31%), trawls (29%), gill nets (14%), haul seines (9%), and pound nets (7%) (Figure 15). Landings for this subset were greatest in Pamlico Sounds (24%), the Atlantic Ocean greater than three miles (20%), the Atlantic Ocean less than three miles (19%), Albemarle Sound (9%), and Core Sound (6%) (Figure 16).

Commercial landings for all species combined, excluding menhaden, steadily increased from an all time low of 47.3 million pounds at the beginning of the time series in 1950 to 86.6 million pounds in 1977 (Figure 17). After that time, landings increased sharply reaching a peak of 159.3 million pounds in 1980 after which they varied between 100 and 120 million pounds. A second peak of 137.2 million pounds was reached in 1996 followed by a persistent decline in landings, which bottomed out in 2001 and has averaged 86.5 million pounds from 2001 to 2004.

There were no discernable patterns detected in the overall commercial landings of all species combined excluding menhaden with respect to hurricane activity. One period of concern was the continuous decline from 1996 to 2001 totaling a loss of 56.1 million pounds with an average decline of 11.2 million pounds per year. Although there were hurricanes present during this period, intervention analysis did not show any significant effects due to notable hurricane years. Instead, the decline is more likely due in large part to a combination of other factors during that time period. Overfishing and the threat of impending regulations in the spiny dogfish fishery led to a decline from 13.2 million in 1996 to less than 500 pounds in 2001 (C. Batsavage, NCDMF, personal communication). Thread herring peaked at 13.3 million pounds in 1997 and declined to 9 pounds within two years averaging only just over 236,000 pounds from 1999 to 2001. Regulations imposed on the flynet fishery between 1994 and 1996 also resulted in a decline of 4.2 million pounds of flynet landings from 1997 to 1998 and remained stable until 2002. A considerable reduction in landings also occurred in the long haul and sciaenid pound net fisheries in inside waters (NCDMF (2004b)), and regulatory changes limiting finfish bycatch from shrimp and crab trawls and fish sold as bait may have contributed to the decline in harvest during this time period (NCOAH (2005) [15A NC Admin Code 3J .0104(a), 3J .0202 (5)(a), 3M .0102]). Furthermore, the number of fishermen participating in commercial fishing in North Carolina has declined from 1994 to 2004 (Bianchi 2005). In addition, the CPUE (pounds per trip) declined by nearly 200 pounds per trip from 1996 to 2001 (A. Bianchi, NCDMF, personal communication).

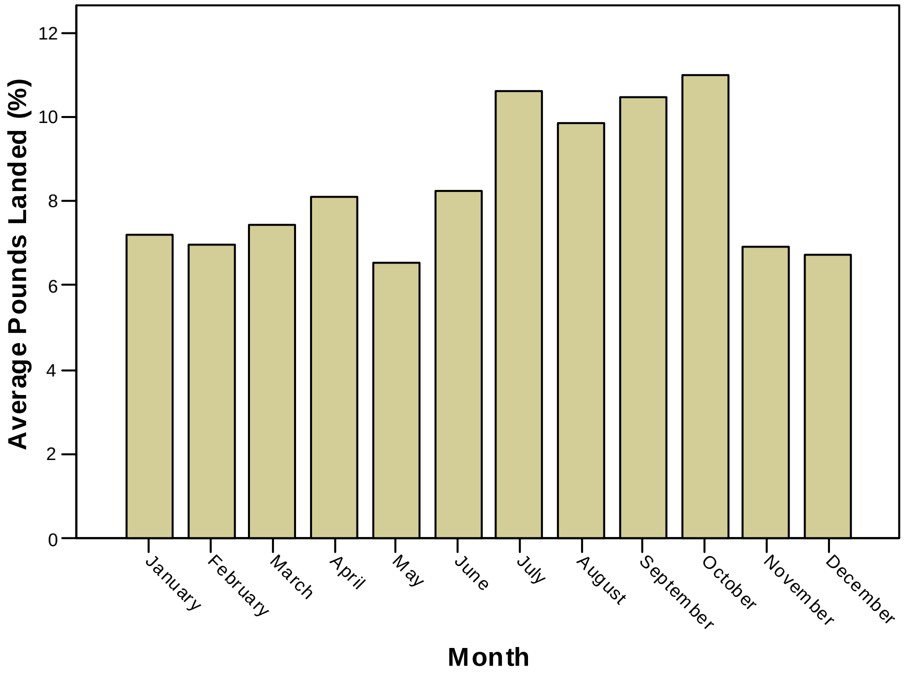

Figure 14. Average monthly landings of all species harvested commercially in North Carolina excluding Atlantic menhaden, 1972–2004.

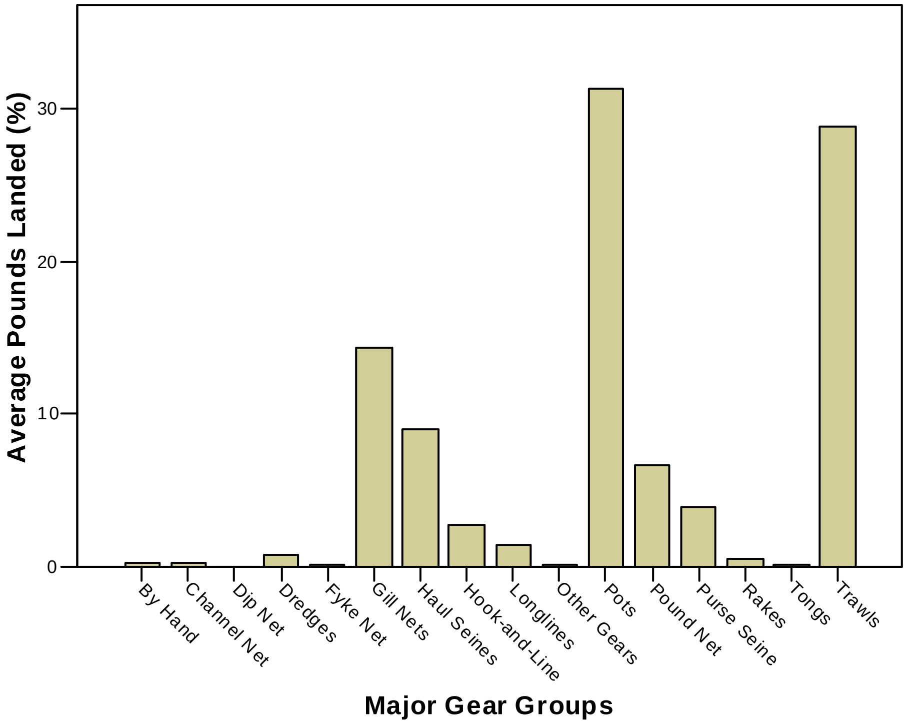

Figure 15. Average landings of all species harvested commercially in North Carolina excluding menhaden by gear type, 1972-2004.

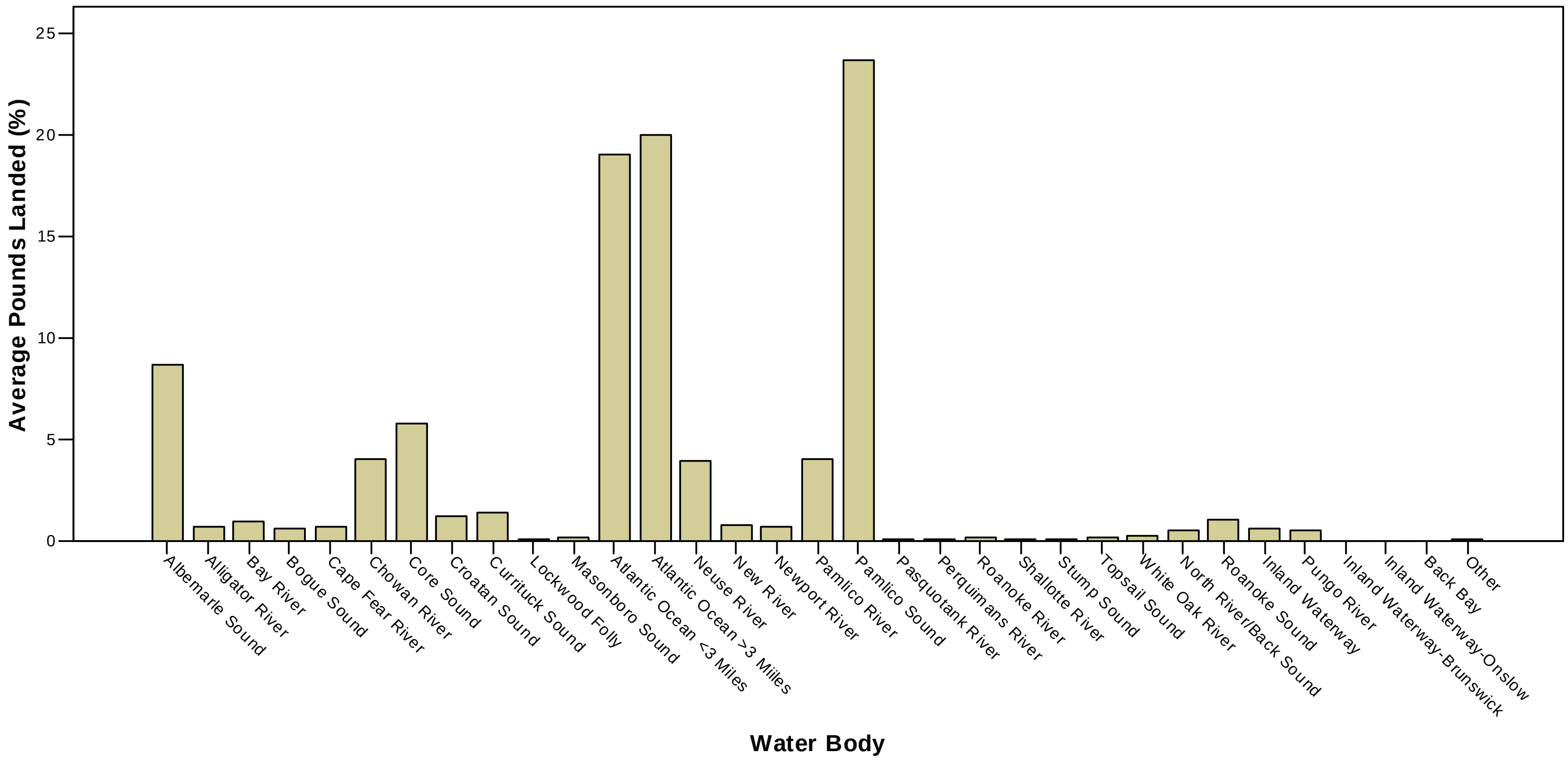

Figure 16. Average annual landings of all species commercially harvested in North Carolina excluding menhaden by water body, 1972–2004.

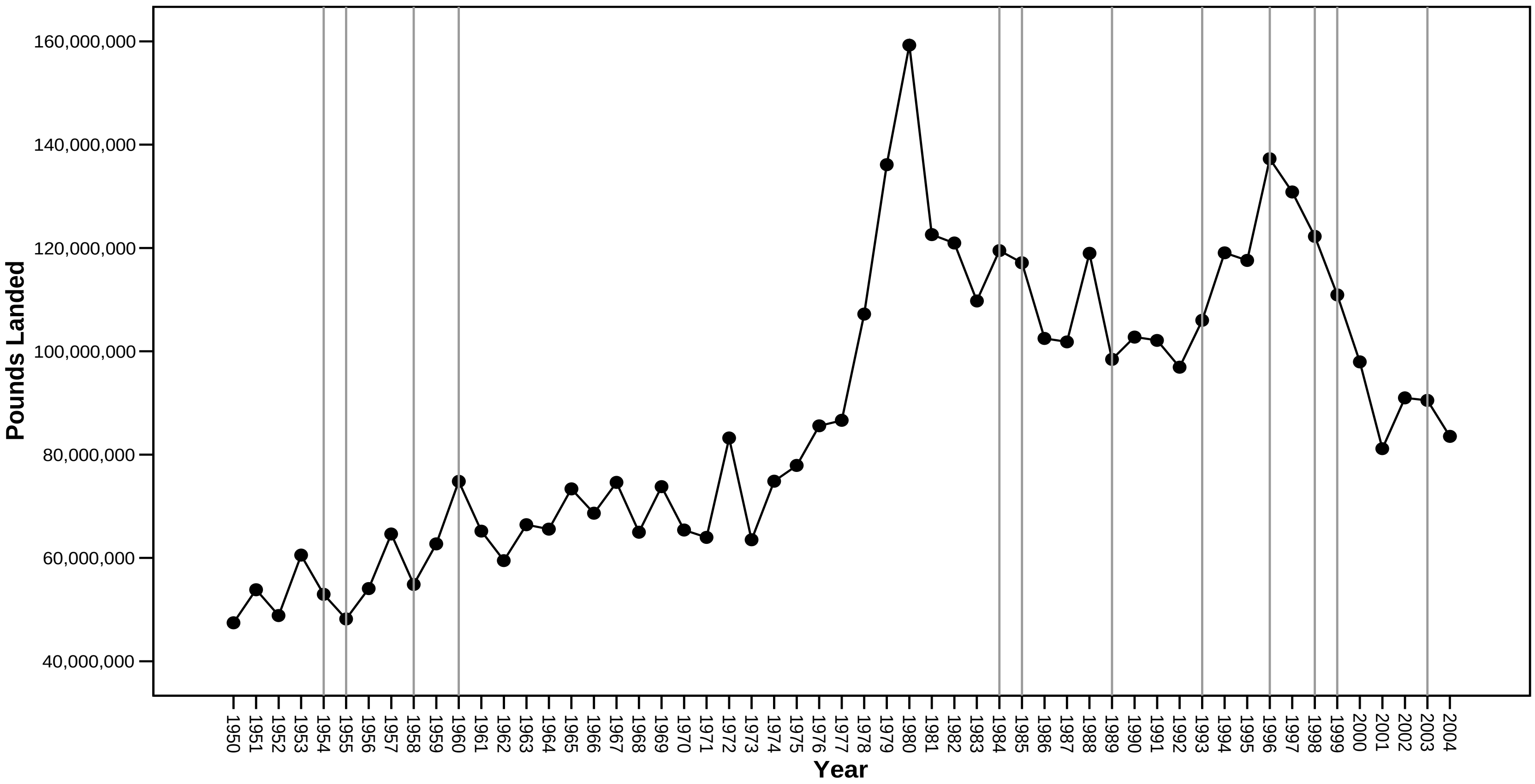

Figure 17. Total annual landings of all species commercially harvested in North Carolina excluding Atlantic menhaden, 1950–2004. Grey bars represent notable hurricane years.

Blue Crabs (Hard)

The blue crab (*Callinectes sapidus*) fishery is the most economically important commercial fishery in North Carolina (Burgess and Bianchi 2004). The commercial harvest of blue crabs is grouped into three categories: hard, peeler, and soft based on molting (shedding) phase. Blue crabs that have a thick carapace are considered hard, those that are beginning to molt are considered peelers, and those that have recently molted and have not yet formed a thick carapace are considered soft. Peeler and soft blue crabs are primarily harvested in May and were not considered for this analysis.

Blue crabs are currently managed under the North Carolina Blue Crab Fishery Management Plan (FMP) (NCDMF 2004c). Hard blue crabs are generally harvested throughout much of the year from April through November with the peak in harvest typically occurring in July (Figure 18). Almost all hard blue crabs are harvested with pots (91%) followed by trawls (8%) (Figure 19). The majority are harvested from Pamlico Sound (38%) followed by Albemarle Sound (19%), the Pamlico River (10%), and the Neuse River (9%) (Figure 20). On average, Beaufort County landed the greatest amount of hard blue crabs from 1994 to 2003 followed by Dare, Hyde, Pamlico, Tyrrell, Carteret, Pasquotank, Currituck, Camden, and Perquimans counties, each landing at least one million pounds (Bianchi 2004).

The commercial fishery has been steadily increasing since 1950 (Figure 21). The number of pounds of hard blue crabs landed in North Carolina ranged from a low of 6.2 million pounds in 1952 to a peak of 65.7 million pounds in 1996; however, landings experienced a significant drop after 1999 that exists until the end of the time series. Participation, effort, and landings also began to decline after 1999; however, the number of dealers has remained relatively stable (Bianchi 2004). Given the number of dealers still participating in the hard blue crab fishery and the relatively high price per pound still seen after 1999, it is evident that a large market for hard blue crabs still existed during that time despite the drop in landings.

Intervention analysis was modeled as a step change beginning in 2000 and revealed that landings significantly decreased by 21.2 million pounds in the years following the 1999 hurricane season (Table 9). As a result of the heavy rainfall received from both Dennis and Floyd in 1999, the Pamlico and Neuse River systems experienced massive flooding, reduction in salinities, and anoxic conditions (Paerl et al. 2001). This flooding caused a "flushing" effect that forced blue crabs out of the rivers and downstream into Pamlico Sound where the crabs formed large aggregations and were subsequently harvested in record numbers. The 1999 hurricane season resulted in an increase in statewide catch efficiency that was 369% above the average from 1987 to 1998 (Eggleston et al. 2004).

A recent stock assessment of North Carolina blue crabs indicated that average landings were near or above the upper range of the estimates of annual maximum sustainable yield (MSY) of 51.7 million pounds from 1994 to 1999 (Eggleston et al. 2004). Eggleston et al. (2004) further stated that 2000 and 2001 represented years with the two lowest estimates of spawning stock biomass on record and reported that the low biomass was likely due to the interacting effects of floodwaters in the fall of 1999 and intense fishing pressure that occurred as a result of the flushing effect. Etherington and Eggleston (2000) found that tropical cyclones generally assist in widely distributing early juvenile blue crabs throughout the Croatan-Albemarle-Pamlico Estuarine System (CAPES); however, the floodwaters from the 1999 hurricane season may have disrupted across-sound transport mechanisms and disrupted secondary pelagic dispersal of early juvenile crabs from initial settlement areas near inlets into the CAPES which, along with the high levels of harvest from 1994 to 1999 and the intense harvest of the spawning stock in 1999 and 2000, contributed to a recruitment failure (Etherington and Eggleston 2003; Burkholder et al. 2004). These effects have contributed to the significant drop observed in hard blue crab landings from which the fishery is still trying to recover years later.

There were no other apparent impacts on hard blue crab landings during other years with notable hurricane activity (Figure 21). Hard blue crab landings increased slightly in 2002 and 2003 but decreased again in 2004. Hurricane Isabel hit North Carolina in 2003, and the eye of the storm passed directly over Pamlico Sound, Pamlico River, and near the Neuse River (Appendix, Figure A50), which make up the areas supporting the majority of the hard blue crab harvest (Figure 20). Several major fishing communities along those areas were affected by damage to vessels, fishing gear, and personal property and likely suspended fishing activities in the area for a limited time; however, it is unclear if Hurricane Isabel had an impact on landings at this time. Addition of more years to the time series will provide enough data to test if an additional shift has occurred using intervention analysis.

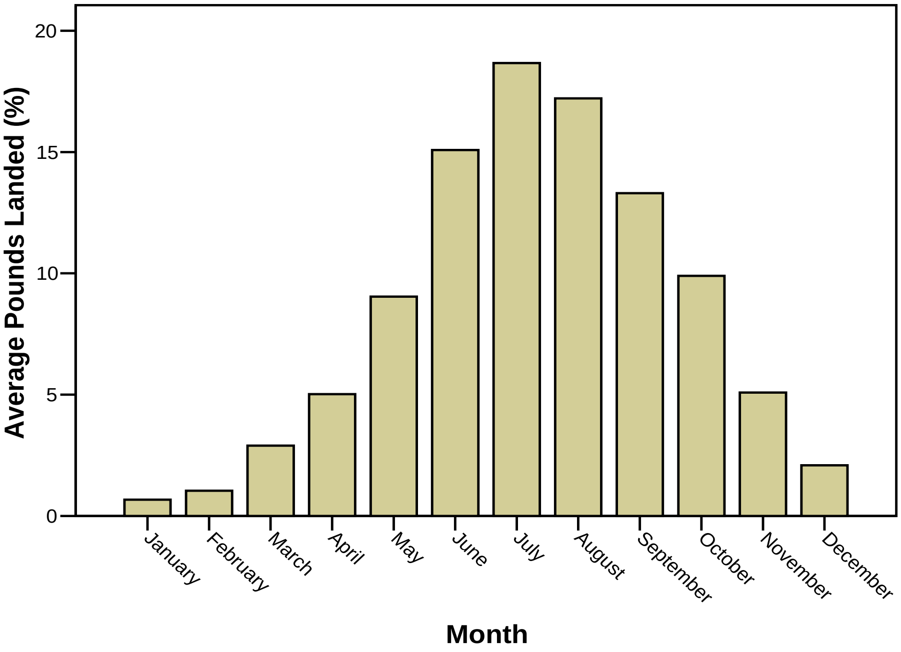

Figure 18. Average monthly landings of hard blue crabs harvested commercially in North Carolina, 1972–2004.

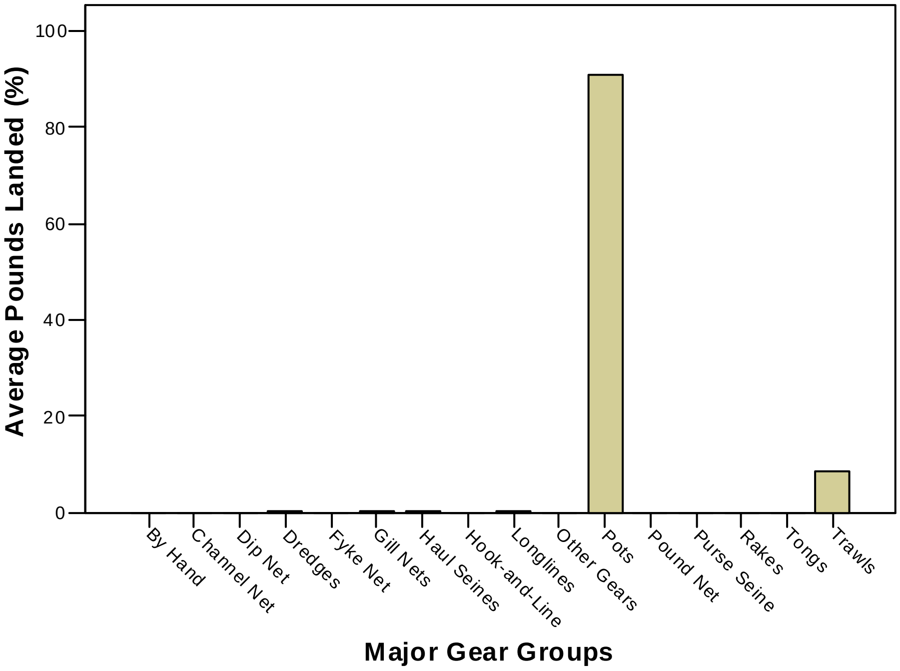

Figure 19. Average landings of hard blue crabs harvested commercially in North Carolina by major gear groups, 1972–2004.

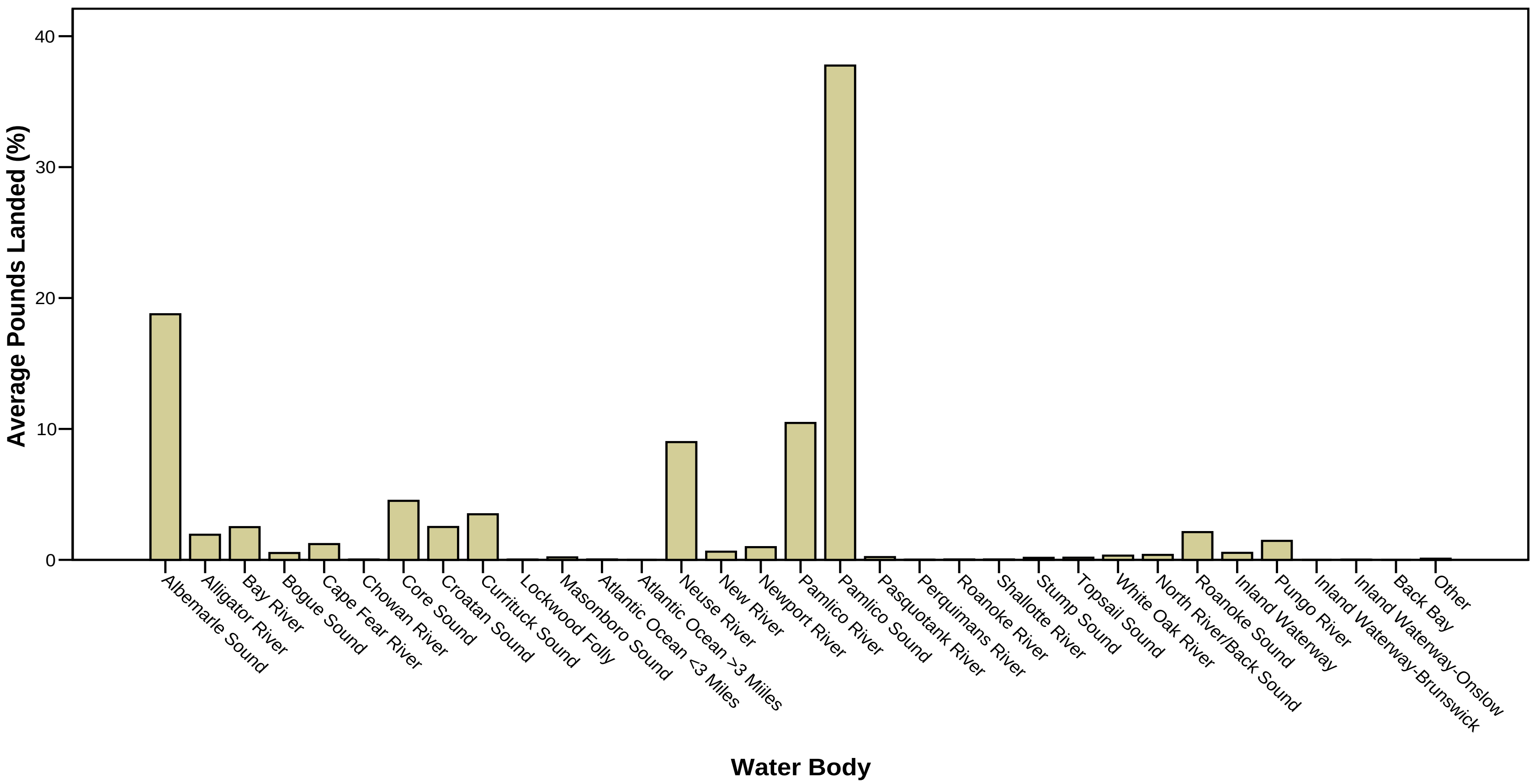

Figure 20. Average annual landings of hard blue crabs commercially harvested in North Carolina by water body, 1950–2004.

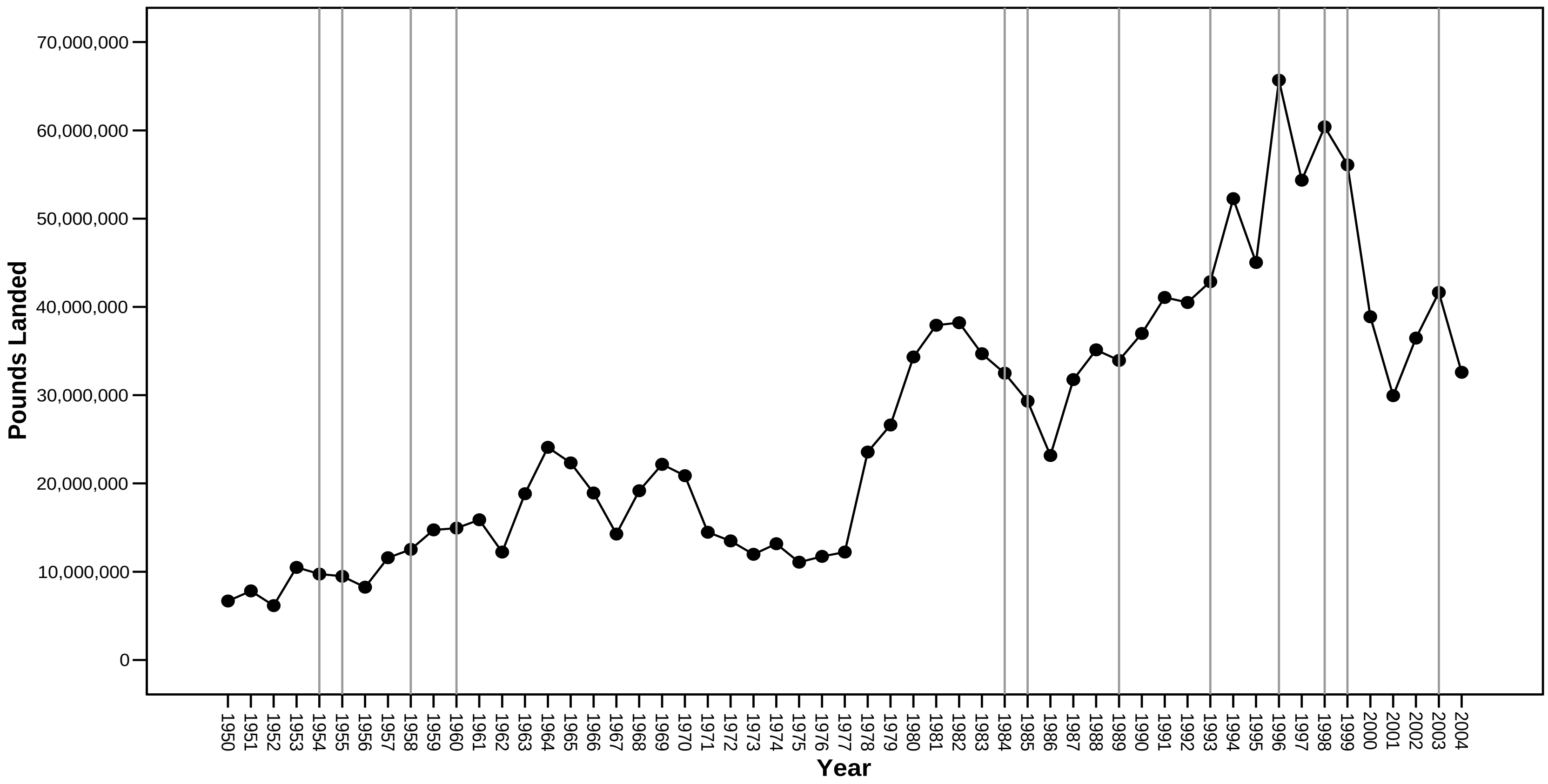

Figure 21. Total annual landings of all hard blue crabs commercially harvested in North Carolina, 1950–2004. Grey bars represent notable hurricane years.

Table 9. Results from intervention analysis of hard blue crab commercial landings data using a (1,1,0) ARIMA noise model and a step intervention beginning in 2000.

Parameter	Estimate	Standard Error	t-ratio	*p*-value
$\square_1$	-0.338	0.132	-2.558	0.013
1999	-21,223,342.419	5,014,161.143	-4.233	< 0.001

Groupers

The grouper category consists of 17 species including Longtail bass (*Hemanthias leptus*), Speckled hind (*Epinephelus drummondhayi*), Rock hind (*Epinephelus adscensionis*), Snowy grouper (*Epinephelus niveatus*), Yellowedge grouper (*Epinephelus flavolimbatus*), Red grouper (*Epinephelus morio*), Marbled grouper (*Dermatolepis inermis*), Misty grouper (*Epinephelus mystacinus*), Black grouper (*Mycteroperca bonaci*), Gag (*Mycteroperca microlepis*), Scamp (*Mycteroperca phenax*), Yellowmouth Grouper (*Mycteroperca interstitialis*), Yellowfin Grouper (*Mycteroperca venenosa*), Atlantic Creolefish (*Paranthias furcifer*), Graysby (*Cephalopholis cruentata*), Coney (*Cephalopholis fulva*), and Warsaw Grouper (*Epinephelus nigritus*) (Table 7). Snowy grouper, scamp, gag, and red grouper are the four most commonly landed grouper species in North Carolina (Bianchi 2004).

Groupers are currently managed by the SAFMC (South Atlantic Fishery Management Council) under the Snapper-Grouper FMP (SAFMC 2003). Groupers are generally harvested throughout much of the year with the majority of the harvest occurring from May to August (Figure 22). Almost all groupers are harvested with hook-and-line gear (93%) followed by longlines (6%) (Figure 23). The majority are harvested from the Atlantic Ocean greater than three miles (99.7%) (Figure 24). On average, Carteret, Brunswick, and New Hanover counties landed just over 170,000 pounds of groupers from 1994 to 2003 followed by Onslow, Pender, and Dare counties which each landed near 50,000 pounds (Bianchi 2004).

The grouper fishery was virtually non-existent until 1978 when a market quickly developed; since that time, grouper have been landed in large numbers (Figure 25). Intervention analysis revealed a significant increase of 589,740 pounds after modeling a step change in 1978 (Table 10). Two main factors were responsible for the sudden market development. First, several fishermen from Florida came north to fish in North Carolina waters; second, increases in technology (upgrading from LORAN-A to LORAN-C) allowed fishermen to locate areas that groupers inhabited more efficiently (J. Holland, NCDMF, personal communication). Grouper landings ranged from a low of 0 pounds during several of the early years to a peak of 949,547 pounds in 1983 (Figure 25).

Since that time, landings have decreased slightly. There were no significant changes as a result of years with notable hurricane activity.

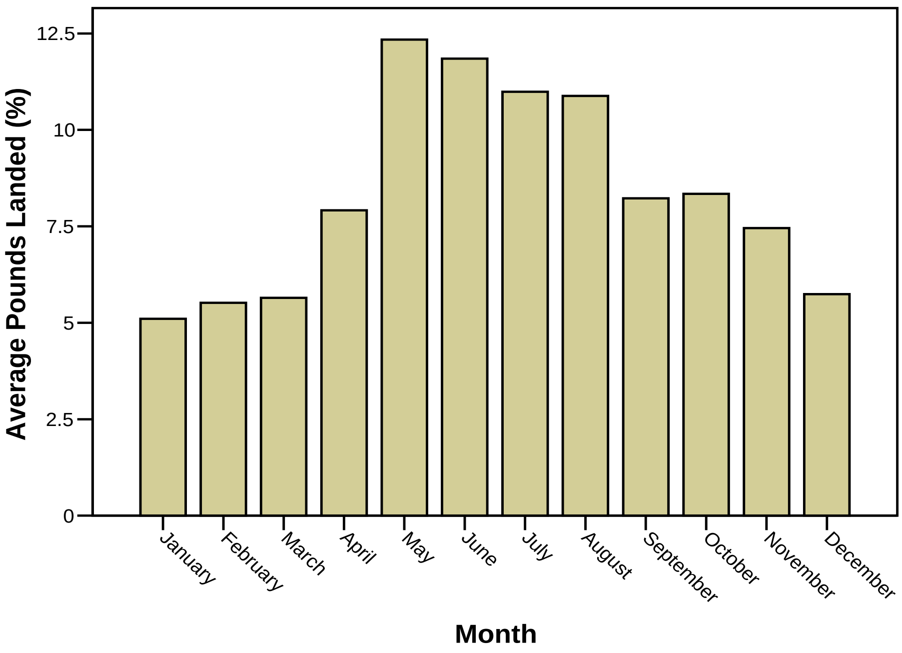

Figure 22. Average monthly landings of groupers harvested commercially in North Carolina, 1972–2004.

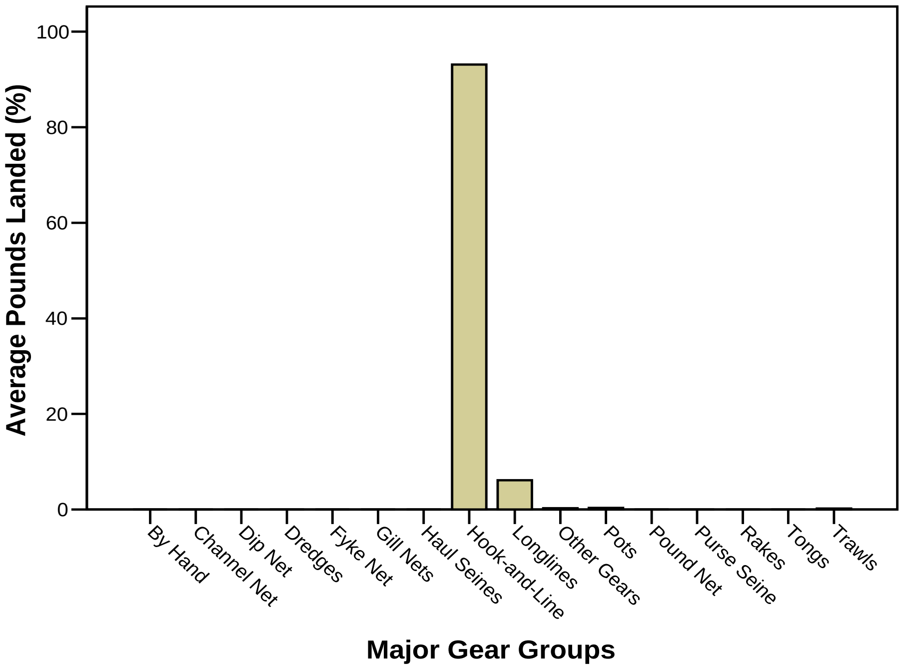

Figure 23. Average landings of groupers harvested commercially in North Carolina by major gear groups, 1972–2004.

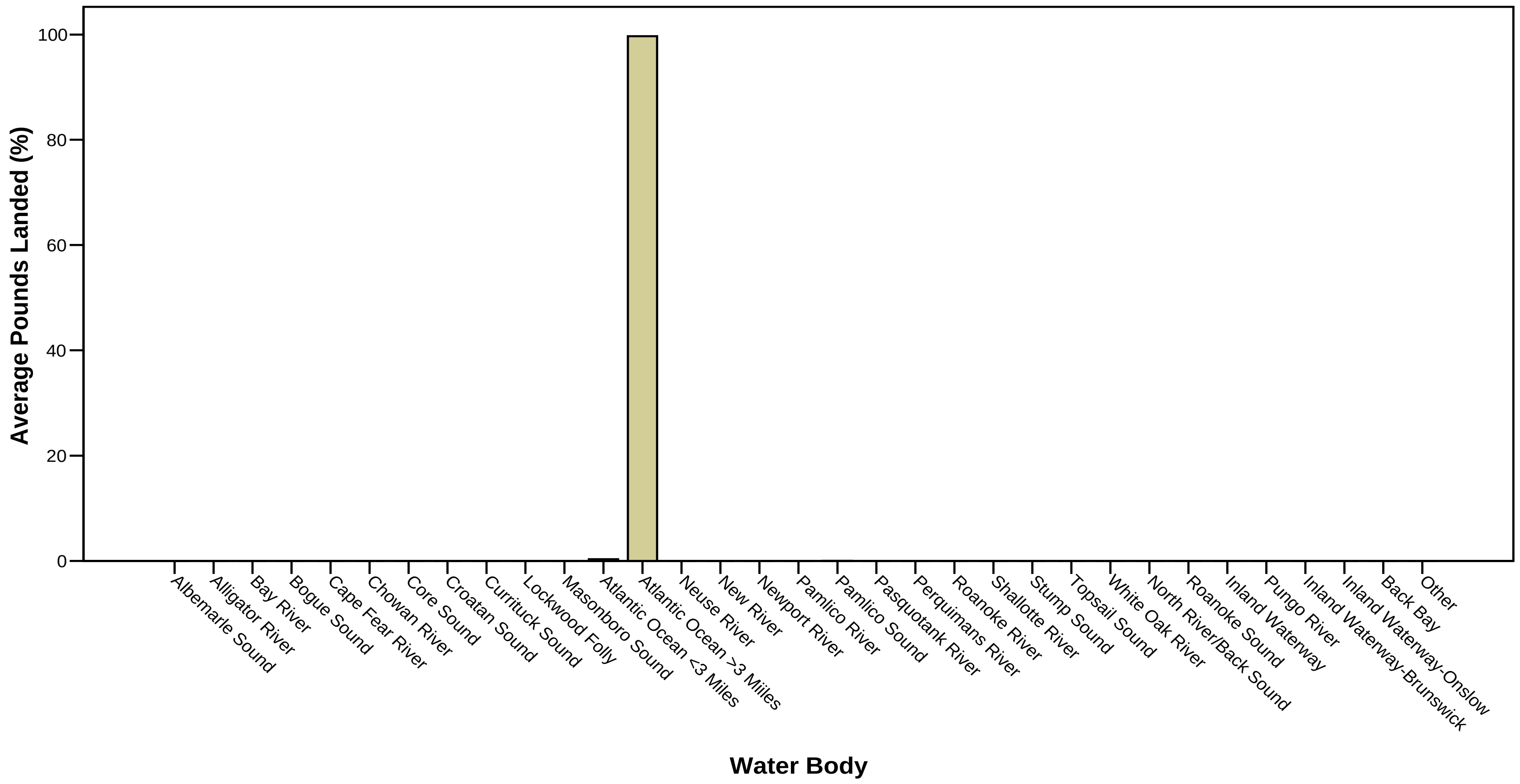

Figure 24. Average annual landings of groupers commercially harvested in North Carolina by water body, 1950–2004.

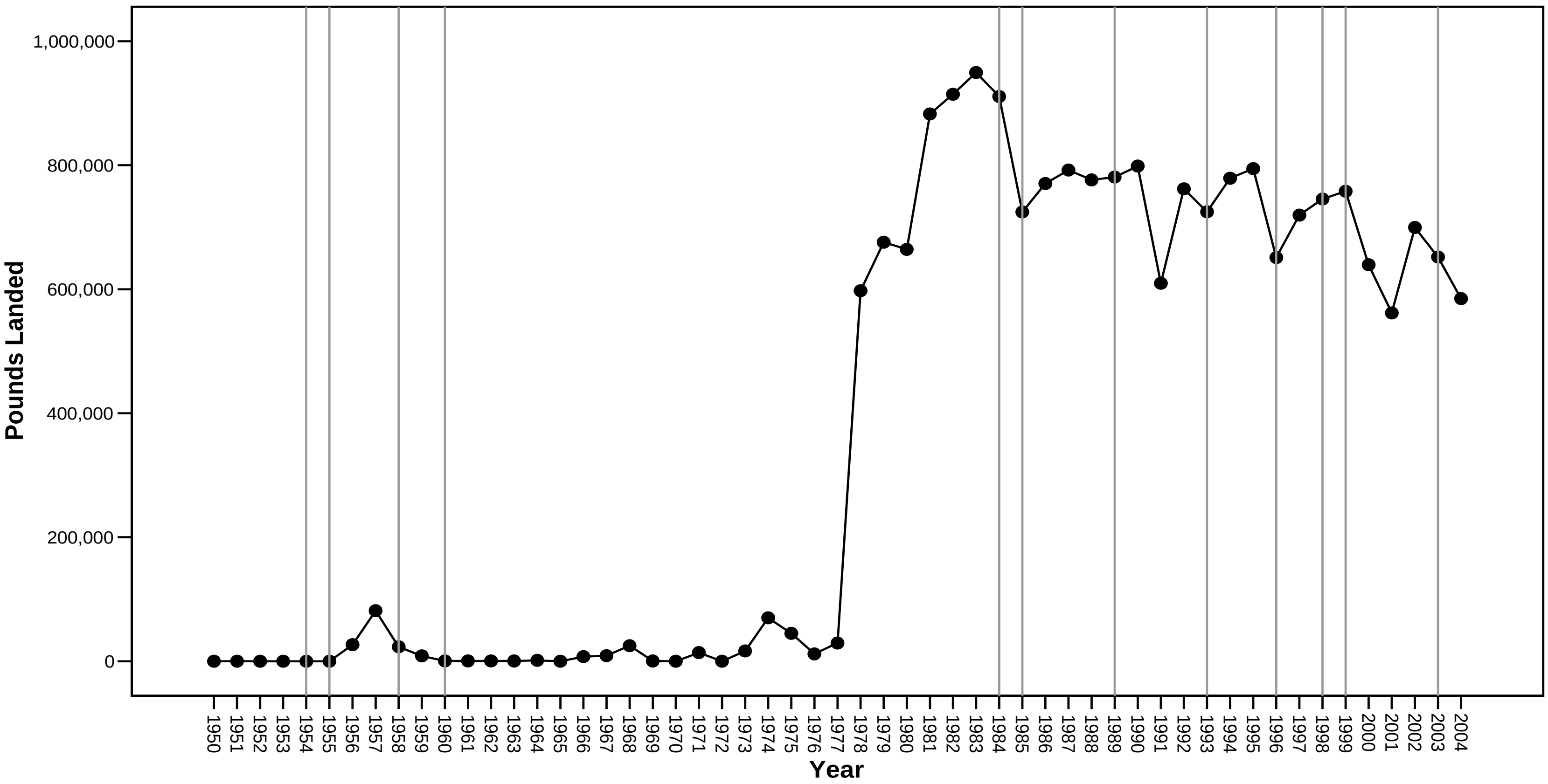

Figure 25. Total annual landings of all groupers commercially harvested in North Carolina, 1950–2004. Grey bars represent notable hurricane years.

Table 10. Results from intervention analysis of grouper commercial landings data using a (0,0,1) ARIMA noise model and a step intervention representing the market development beginning in 1978. Estimates are square root transformed.

Parameter	Estimate	Standard Error	t-ratio	*p*-value
μ	82.520	18.056	4.570	< 0.001
θ_1	-0.467	0.124	-3.777	< 0.001
Market	767.945	25.491	30.126	< 0.001

Striped Mullet

Striped mullet (*Mugil cephalus*) are currently managed under the North Carolina striped mullet FMP (NCDMF 2006b). Historically, 67% of the average annual striped mullet harvest occurs in the fall months peaking in October: September (13%), October (35%), and November (19%) (Figure 26). Most striped mullet are harvested with gill nets (70%) followed by haul seines (29%) (Figure 27). The majority of striped mullet are harvested from the Atlantic Ocean less than three miles from shore (34%), Pamlico Sound (12%), and Core Sound (11%) (Figure 28). On average, Carteret, Dare, Pamlico, and Onslow counties landed at least 100,000 pounds annually from 1994 to 2003 (Bianchi 2004).

Landings of striped mullet declined from an all time high of 4,013,000 pounds in 1951 to an all time low of 713,000 pounds in 1971 and have been have been highly variable but without a trend since 1985 (Figure 29). Based upon the behavior of the time series, years with notable hurricane activity were modeled as one-year pulse events in the intervention analysis. Results showed inconsistent significant changes in landings during years in which hurricanes Donna (1960), Hugo (1989), Emily (1993), and Dennis, Floyd, and Irene (1999) occurred. Landings showed significant increases in 1960 (+985,829) and 1993 (+1,279,787) and significant decreases in 1989 (-923,975) and 1999 (-1,642,169) (Table 11). Results may have been confounded by trends in landings by market grade.

Information on market grades have only been available since 1994 and are categorized as either mixed, red roe, or white roe for this analysis. Since market grade has been recorded, the majority of the landings have been composed of red roe, which is harvested primarily in October and November (Figure 30) during striped mullet spawning aggregations, which also overlaps with a period of increased hurricane activity in North Carolina (Figure 3 and Figure 4).

Unfortunately, a relatively long time series is needed to establish historic variability in the time series in order to perform intervention analysis. Because information on market grade has only been recorded since 1994, it is not possible to perform intervention analysis by market grade; however, based on trends, it is likely that hurricanes generally have had a significant impact on striped mullet, particularly on the red roe fishery. The striped mullet red roe fishery experienced large decreases in three out of the four years of notable hurricane activity in 1996 (-60.3%), 1999 (-48.4%), and 2003 (-58.7%) when compared to the previous year (Figure 31). Although white roe is not landed in as large quantities, trends were similar to that of red roe with large decreases also in 1996 (-73.1%), 1999 (-46.0%), and 2003 (-63.2%) (Figure 31). The mixed market grade for striped mullet, however, does not show a clear trend with the largest decline being only a drop of -20.0% in 1999, which may have been due to normal variability (Figure 31). The mixed market grade likely confounds the results of the intervention analysis, and based on market grade trends, masks the combined striped mullet landings from showing significant changes in the roe fisheries resulting from hurricanes Fran (1996) and Isabel (2003) in the intervention analysis.

Those fisheries that primarily occur in the fall during the peak of hurricane season have the greatest risk for a reduction in overall harvest. The striped mullet fishery likely suffers, not from a stock reduction, but simply from the inability of fishermen to harvest striped mullet roe during the peak of the season. The species itself may actually even experience an increase in spawning stock biomass due to reduced fishing mortality during a hurricane year. Hurricanes appear to have an impact on fishermen targeting striped mullet, but it does not appear to be detrimental to the species itself.

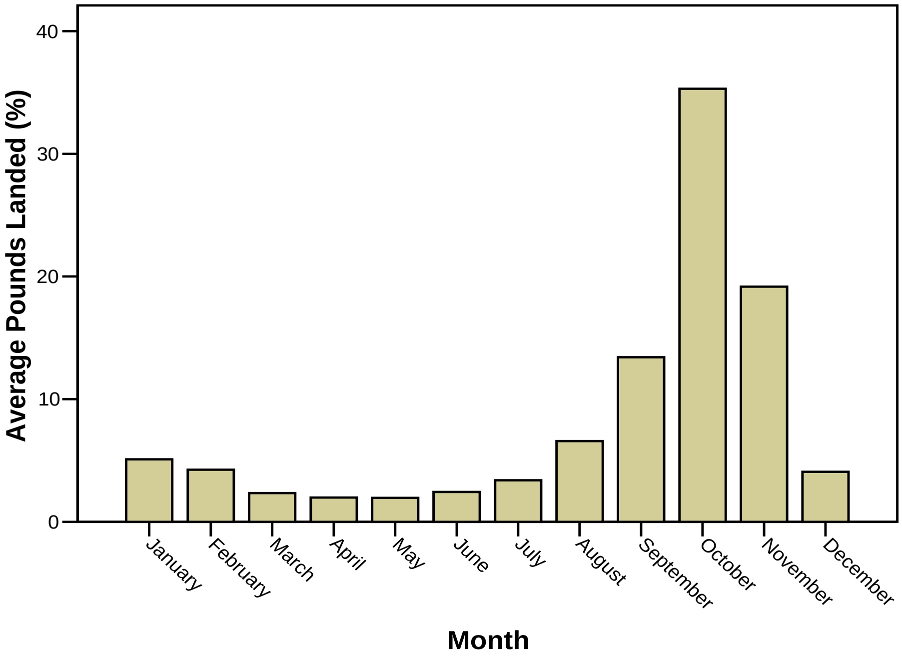

Figure 26. Average monthly landings of striped mullet harvested commercially in North Carolina, 1972–2004.

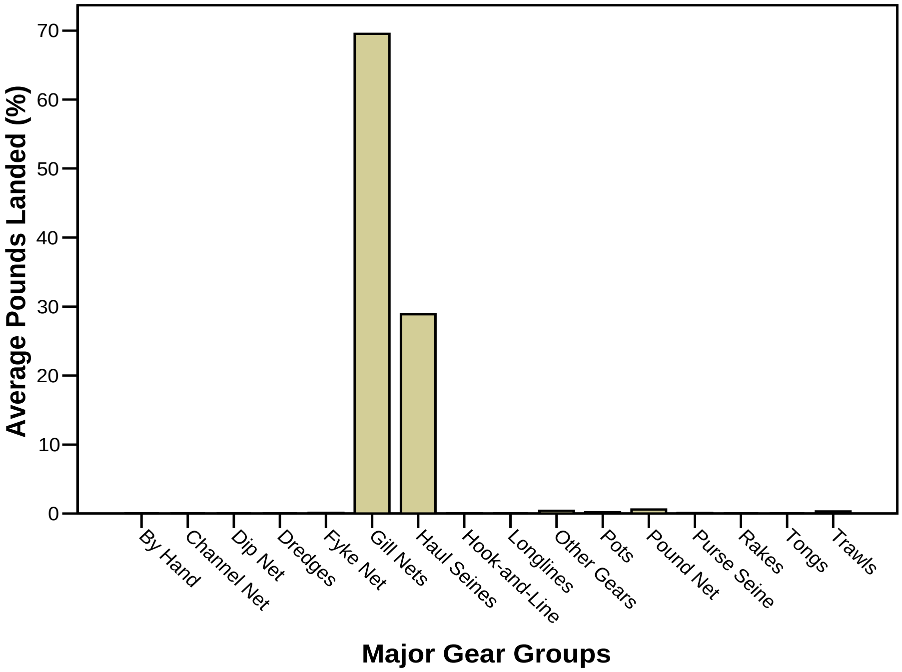

Figure 27. Average landings of striped mullet harvested commercially in North Carolina by major gear groups, 1972–2004.

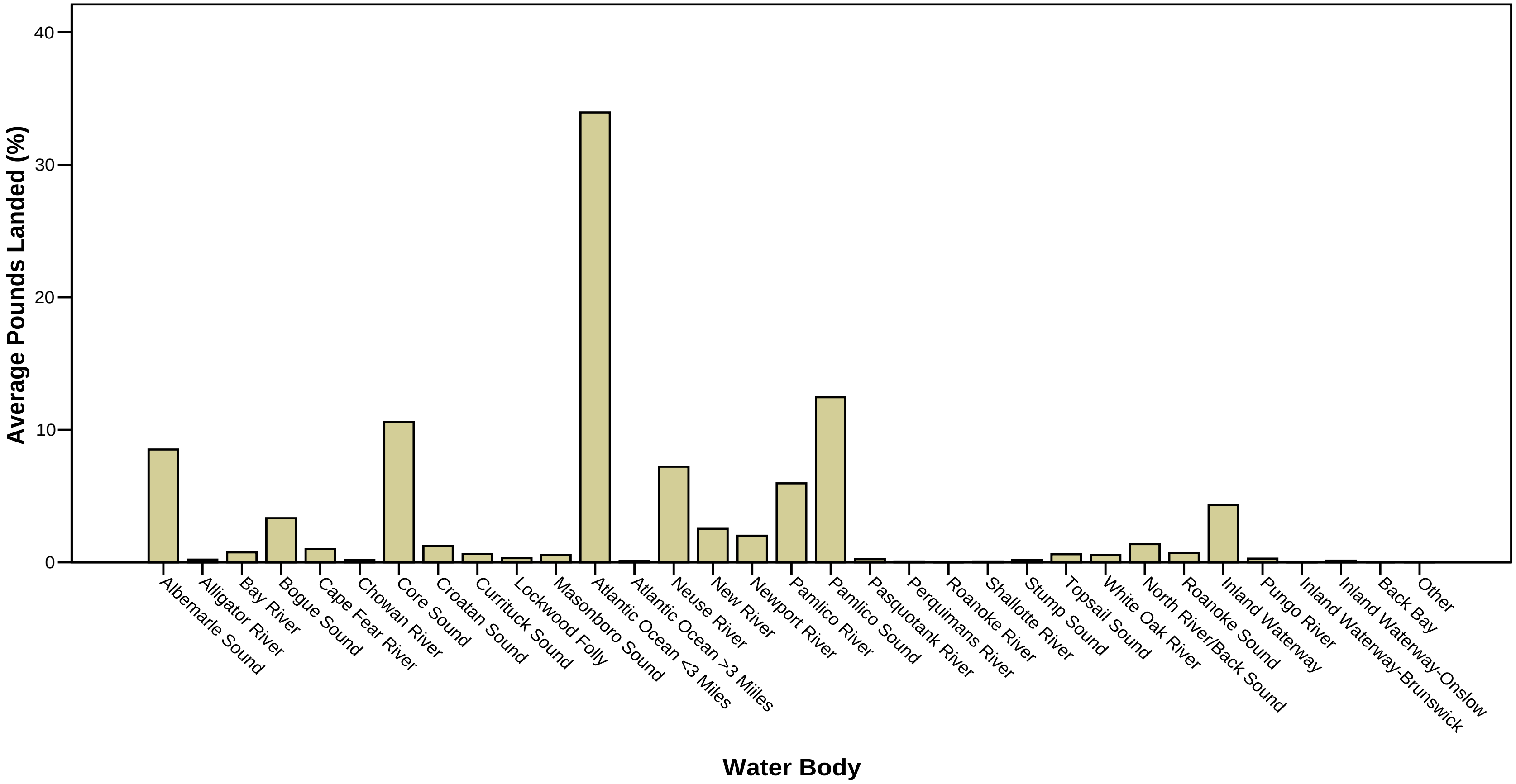

Figure 28. Average annual landings of striped mullet commercially harvested in North Carolina by water body, 1950–2004.

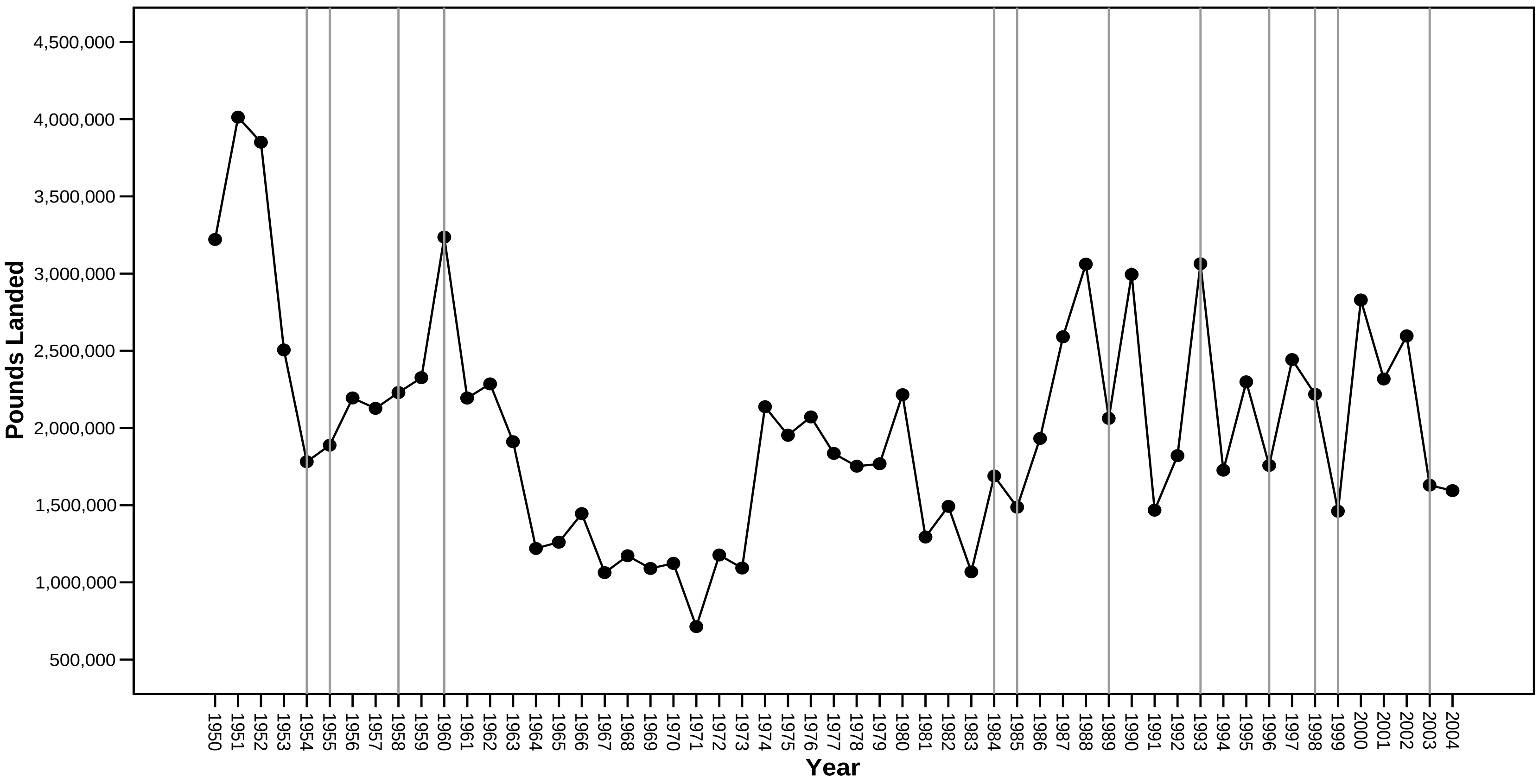

Figure 29. Total annual landings of all striped mullet commercially harvested in North Carolina, 1950–2004. Grey bars represent notable hurricane years.

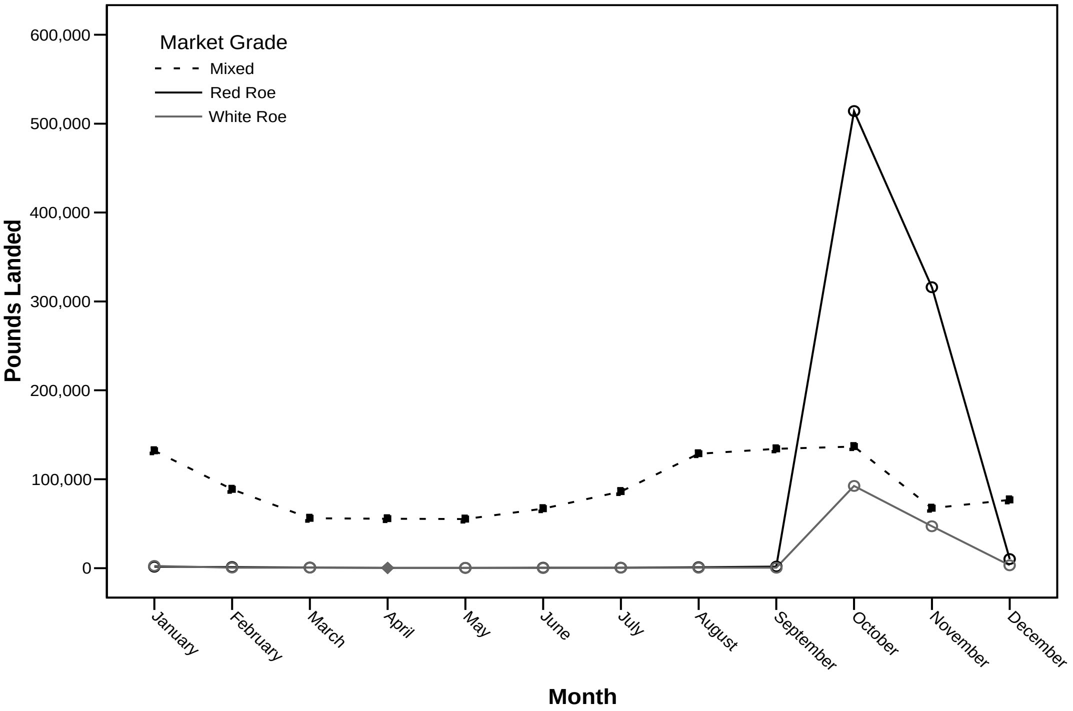

Figure 30. Commercial landings of striped mullet by market grade in North Carolina, 1994–2004.

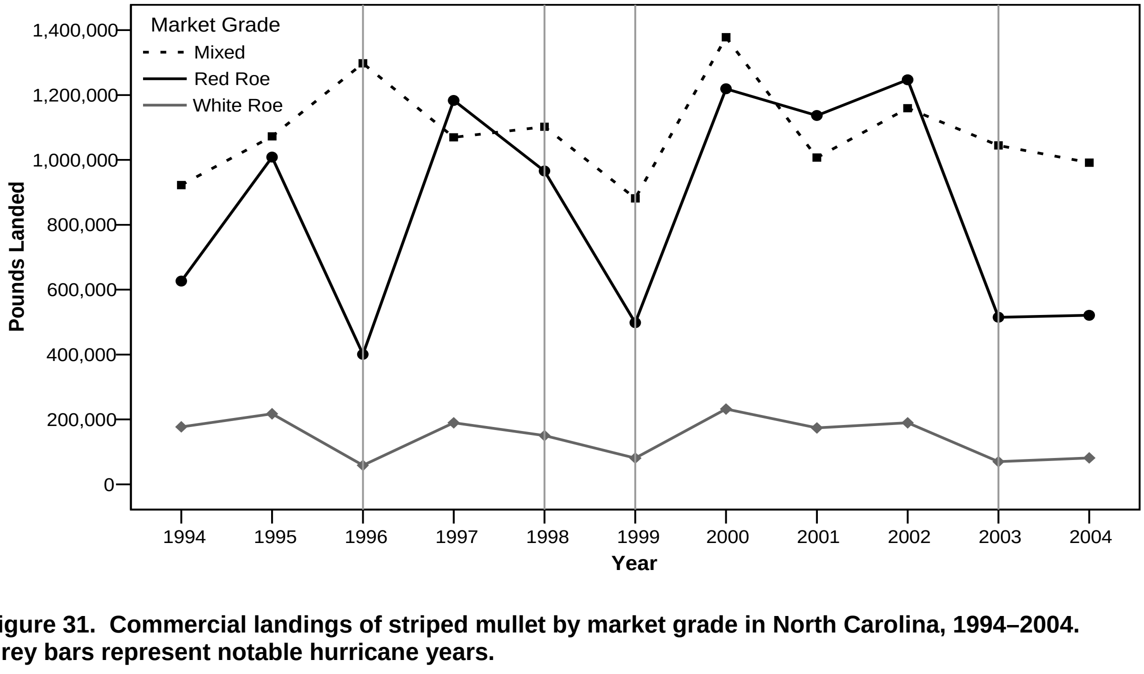

Figure 31. Commercial landings of striped mullet by market grade in North Carolina, 1994–2004. Grey bars represent notable hurricane years.

Table 11. Results from intervention analysis of striped mullet commercial landings data using a (1,0,0) ARIMA noise model and single-year pulse interventions for each hurricane year.

Parameter	Estimate	Standard Error	t-ratio	*p*-value
μ	2,029,992.3	247,218.8	8.211	< 0.001
θ_1	0.745	0.093	8.058	< 0.001
1960	985,828.5	393,362.3	2.506	0.015
1989	-923,974.7	393,362.3	-2.349	0.023
1993	1,279,786.6	393,362.3	3.253	0.002
1999	-1,042,168.6	393,362.3	-2.649	0.011

Bay Scallops

An FMP for bay scallops (*Argopecten irradians*) is currently under development by the state of North Carolina (NCDMF Draft). Bay scallops are generally harvested from December to March with the peak in harvest typically occurring in January (Figure 32). Almost all bay scallops are harvested with dredges (85%) followed by rakes (9%) (Figure 33). The majority of bay scallops are harvested from Core Sound (44%) and Bogue Sound (43%) (Figure 34). On average, most bay scallops are landed in Carteret County with a few also landed in Onslow and Craven counties (Bianchi 2004).

The bay scallop fishery experienced a large increase in landings during the 1960s peaking at 638,700 pounds of meats in 1968 (Figure 35). Landings declined dramatically in 1970 increasing and peaking again in 1977 and 1985. A red tide occurred in the fall of 1987 causing a dramatic decline in the availability of bay scallops. Landings have been very low since that time reaching a less than 150 pounds of meats in 2004. Landings beyond 2004 were not considered in the analysis, but no bay scallops were landed in 2005 despite an open season. The season was not reopened in 2006 due to lack of bay scallop population abundance.

Bay scallops are sensitive to several types of environmental disturbances such as loss of seagrass, pollution, extreme temperature changes, reductions in salinity, predation, increases in turbidity, red tides, and hurricanes (Gutsell 1930; Mercaldo and Rhodes 1982; Tettelbach et al. 1985; Peterson et al. 1989; Summerson and Peterson 1990). The fishery is typically opened in December or January when bay scallops have completed spawning and reach an adequate meat weight. The harvest season generally continues until catch rates decline and it is no longer economically viable to continue fishing. Because of the nature of this fishery on an annual crop, landings are considered to be a fairly good reflection of the actual population abundance. Based on landings data, populations declined dramatically following a red tide in 1987.

A red tide is a harmful algal bloom that occurs when *Karenia brevis*, a naturally occurring microscopic planktonic organism, increases to higher than normal concentrations. *K. brevis* produces a potent neurotoxin that kills fish and bay scallops, contaminates shellfish, and can cause neurotoxic shellfish poisoning and respiratory distress in humans. In the United States, red tides occur frequently in Gulf of Mexico waters off the west coast of Florida. A red tide typically originates offshore and is occasionally driven inshore and transported into estuaries by wind and currents. When conditions are favorable, *K. brevis* can multiply rapidly reaching bloom concentrations causing the water to take on a reddish-brown color creating a "red tide" event. Red tides can last for as little as a few days or as much as several months depending on environmental conditions. In the Gulf of Mexico, red tides generally occur in the late summer or early fall. Red tides are most common along the southwestern coast of Florida where most blooms last from three to five months and can affect hundreds of square miles. However, red tides are much less common along the southeastern Atlantic Coast.

The first, and only, red tide in North Carolina's recorded history persisted from October 1987 to February 1988. The following summary of events was taken from Tester et al. (1991) and summarized by Summerson and Peterson (1990). A warm-water Gulf Stream filament that was first detected on October 19, 1987 and likely contained *K. brevis* transported from Florida presumably seeded North Carolina's red tide. By late October, bloom conditions were present in the Atlantic Ocean near Bogue Banks. By early November, bloom concentrations were present throughout Bogue and Back sounds from New River Inlet to Barden's Inlet at Cape Lookout resulting in the closure of shellfish beds. For the first few weeks, the red tide was restricted to Bogue and Back sounds, particularly around ocean inlets, but soon spread northward into Core and Pamlico sounds. The effect of the red tide was more severe in Bogue and Back sounds versus Core Sound. *K. brevis* was not detected in the center of Core Sound until mid November. Bogue and Back sounds were consistently found to have higher bloom concentrations than Core Sound, with particularly high levels near Bogue, Beaufort, and Barden's Inlets. *K. brevis* concentrations in Core Sound were consistently lower than in Bogue or Back sounds by a factor of ten or more. As a result, the waters of Core Sound were closed to shellfishing later and opened earlier than those of Bogue and Back sounds (Tester and Fowler 1990). *K. brevis* disappeared from Core Sound by late December, while it persisted in Bogue and Back sounds until the first week of February.

Hurricanes can cause several unfavorable environmental conditions to occur simultaneously. Rainfall associated with hurricanes can lead to reductions in salinity (also referred to as freshets) that causes mortality in bay scallops (Gutsell 1930). Tettelbach et al. (1985) documented a mass mortality of bay scallops in Long Island Sound caused by reductions in salinity following a heavy rainfall event. Mercaldo and Rhodes (1982) found that bay scallops are particularly prone to reductions in salinity at high temperatures, such as those seen in the summer and fall months during the peak of hurricane season. Hurricanes can also cause destruction of seagrass habitat required by bay scallops. Additionally, Peterson et al. (1989) proposed that storms assist in increasing mortality by transporting bay scallops into shallow, non-vegetated areas where they become susceptible to predation by gulls at low tides.

Autocorrelation was not detected in the bay scallop commercial landings time series, probably because bay scallops have a short life span and are considered an annual crop; therefore, linear regression was used instead of intervention analysis to detect significant changes in the time series. The value for 2004 was considered an influential outlier and was therefore eliminated from the analysis. A short-term pulse event was modeled from 1963 to 1969, and step changes were modeled for the red tide (1988+) and the 1999 hurricane season (2000+). The time series was transformed using the natural log to stabilize the variance.

The long-term average of overall statewide landings of bay scallops during typical years was 148,662 pounds (Figure 36). Years not exhibiting significant change from the overall mean of the series were considered typical. From 1963 to 1969, there was a temporary increase of 186% above the typical average ($p < 0.001$) (Table 12). The cause of this increase is not clear, but these appear just to have been particularly good years for bay scallops. Landings decreased significantly following the red tide event in 1987-1988 to 61% below the typical average ($p < 0.001$). A further reduction in harvest was also seen following the 1999 hurricane season dropping the average landings to 93% below the typical average ($p < 0.001$). Even further reduction may have also occurred as of 2004 since landings were less than 150 pounds of meats in 2004 and no landings were reported in 2005. This additional reduction could be due to Hurricane Isabel which made landfall near the northern part of Core Sound in September 2003 as a category 2 storm, predation of cownose rays on bay scallops, or a combination of these factors.

The red tide resulted in the closure of 1,480 km^2 of North Carolina waters to shellfish harvesting and an economic impact of over $24 million (Tester and Fowler 1990). Affected waters were closed to the harvest of shellfish because toxins produced by *K. brevis* accumulate in the bodies of filter feeders such as clams and oysters and can cause neurotoxic shellfish poisoning when consumed. Even though only the adductor muscle of bay scallops is eaten and this tissue does not generally retain toxins, the harvest of bay scallops was also prohibited because they were found to contain much larger concentrations of toxins in their bodies than clams or oysters (P. Fowler, North Carolina Division of Environmental Health, personal communication). The red tide had a particularly large impact on shellfishermen since waters were closed to any harvest from as early as November to as late as May.

The red tide did not cause mortality in clams or oysters; however, there was a significant loss of bay scallops. Those bay scallops that remained had emaciated meats and were not getting good prices at market. The cause of bay scallop mortality is not entirely clear. The red tide killed both adult and newly recruited bay scallops resulting in a recruitment failure. Summerson and Peterson (1990) found that recruitment was virtually eliminated from Bogue and Back sounds where densities of new recruits were found to average 2% of pre-red tide years. The trend continued in the two years following the red tide, with average recruitment rates about 29% of normal in Back Sound and about 5% of normal in Bogue Sound (Peterson and Summerson 1992). A similar problem was found during a brown tide event in Long Island Sound, NY that caused mortality and severe reduction in tissue weights of adult bay scallops and a subsequent recruitment failure (Kuenster and Bricelj 1988). Summerson and Peterson (1990) found that juvenile densities during the red tide were near normal in central Core Sound, and a later study found that recruitment rates remained normal in Core Sound (Peterson and Summerson 1992).

Low population abundances are likely to continue until the spawning stock increases. Peterson and Summerson (1992) stated that Bogue Sound may be slow to recover from the effects of the red tide because the spawning stock for that basin was too depleted to provide an adequate supply of larvae for population recovery and further suggested that recruitment limitation exists on a basin scale for bay scallop populations in North Carolina. This means that larvae from Core Sound may not be able to replenish populations in Bogue Sound because of hydrological and geographical isolation and a relatively short planktonic larval stage (5-11 days). Further research is needed to determine if Core and Bogue sounds are genetically distinct populations.

Other events, such as severe winter freezes and previous hurricanes, were also examined but found not to have a significant impact. Prior to the red tide, some localized reductions in abundance may have occurred; however, either the events were not severe enough or of a large enough scale to affect the overall population abundance. Prior to the red tide, it appears that there was a large enough spawning stock to overcome any noteworthy events.

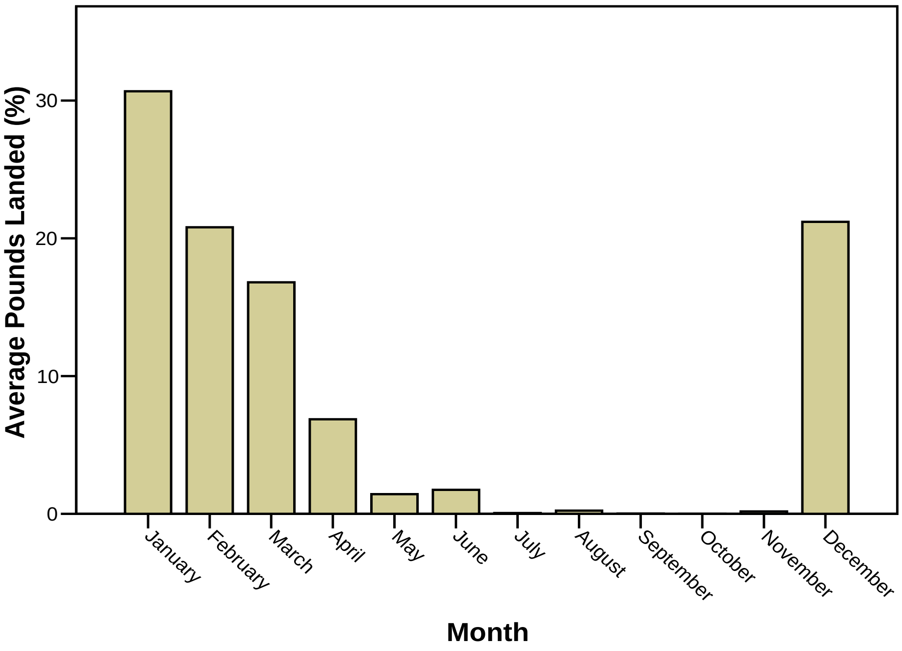

Figure 32. Average monthly landings of bay scallops harvested commercially in North Carolina, 1972–2004.

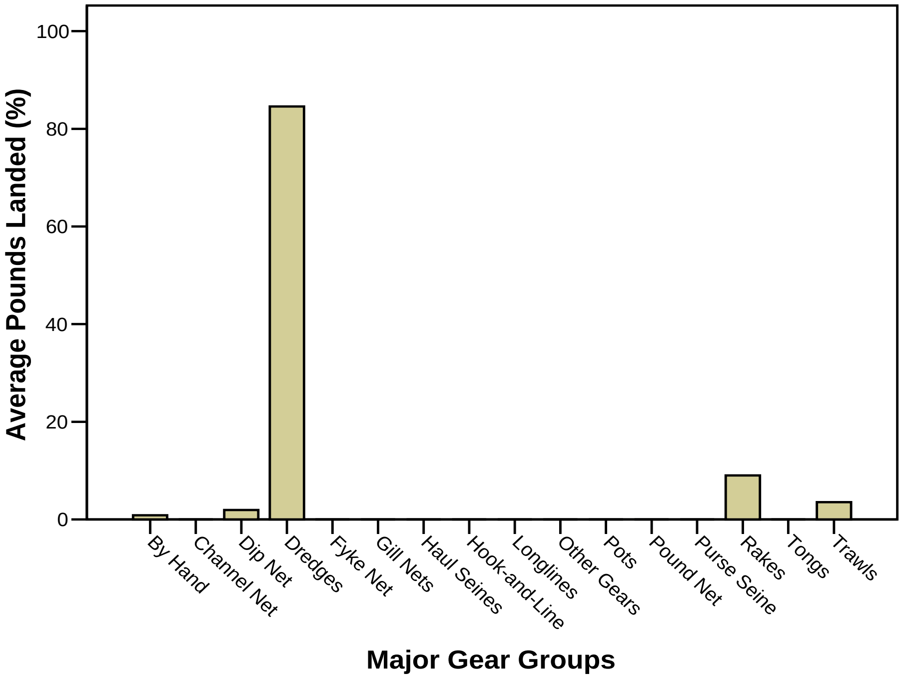

Figure 33. Average landings of bay scallops harvested commercially in North Carolina by major gear groups, 1972–2004.

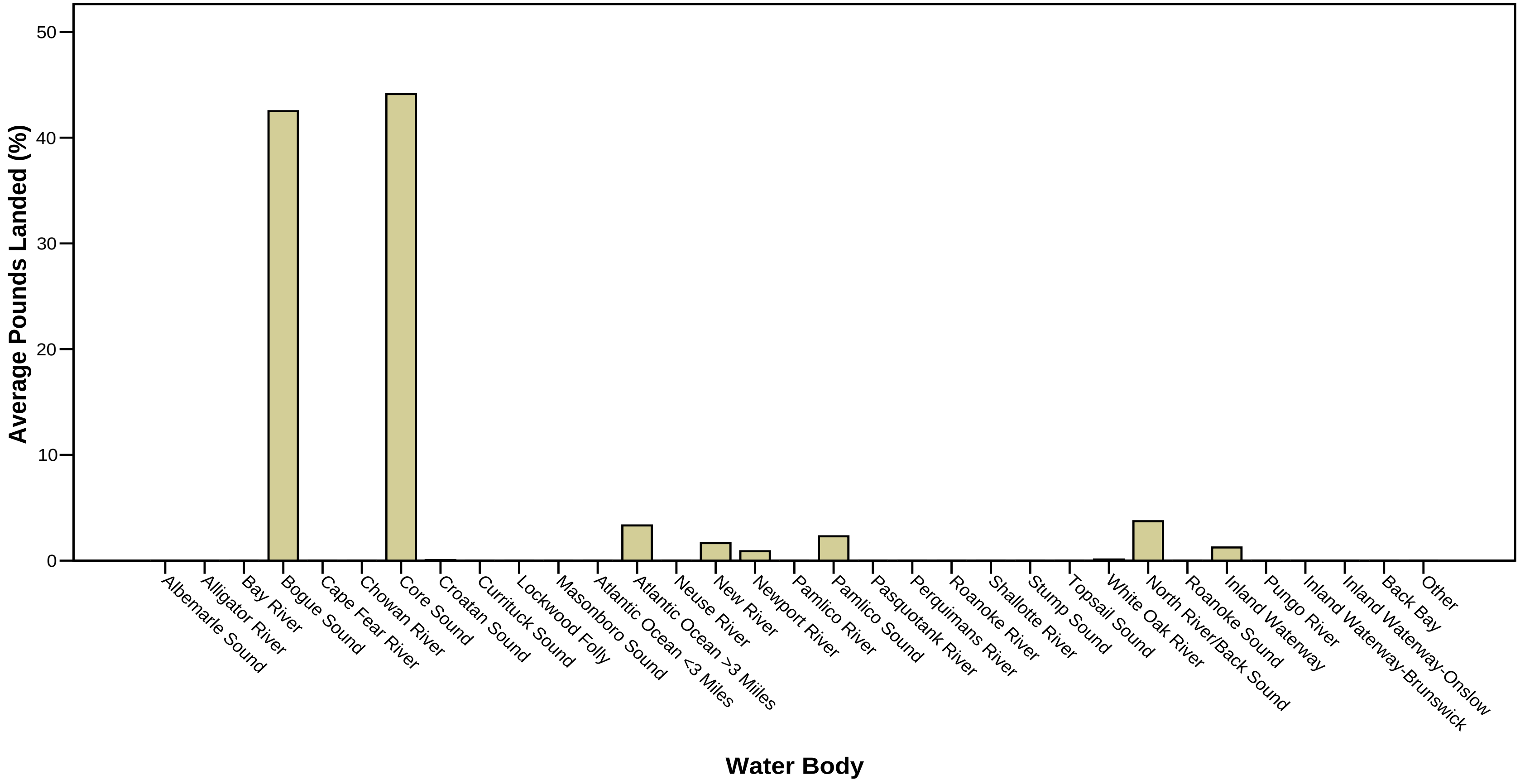

Figure 34. Average annual landings of bay scallops commercially harvested in North Carolina by water body, 1950–2004.

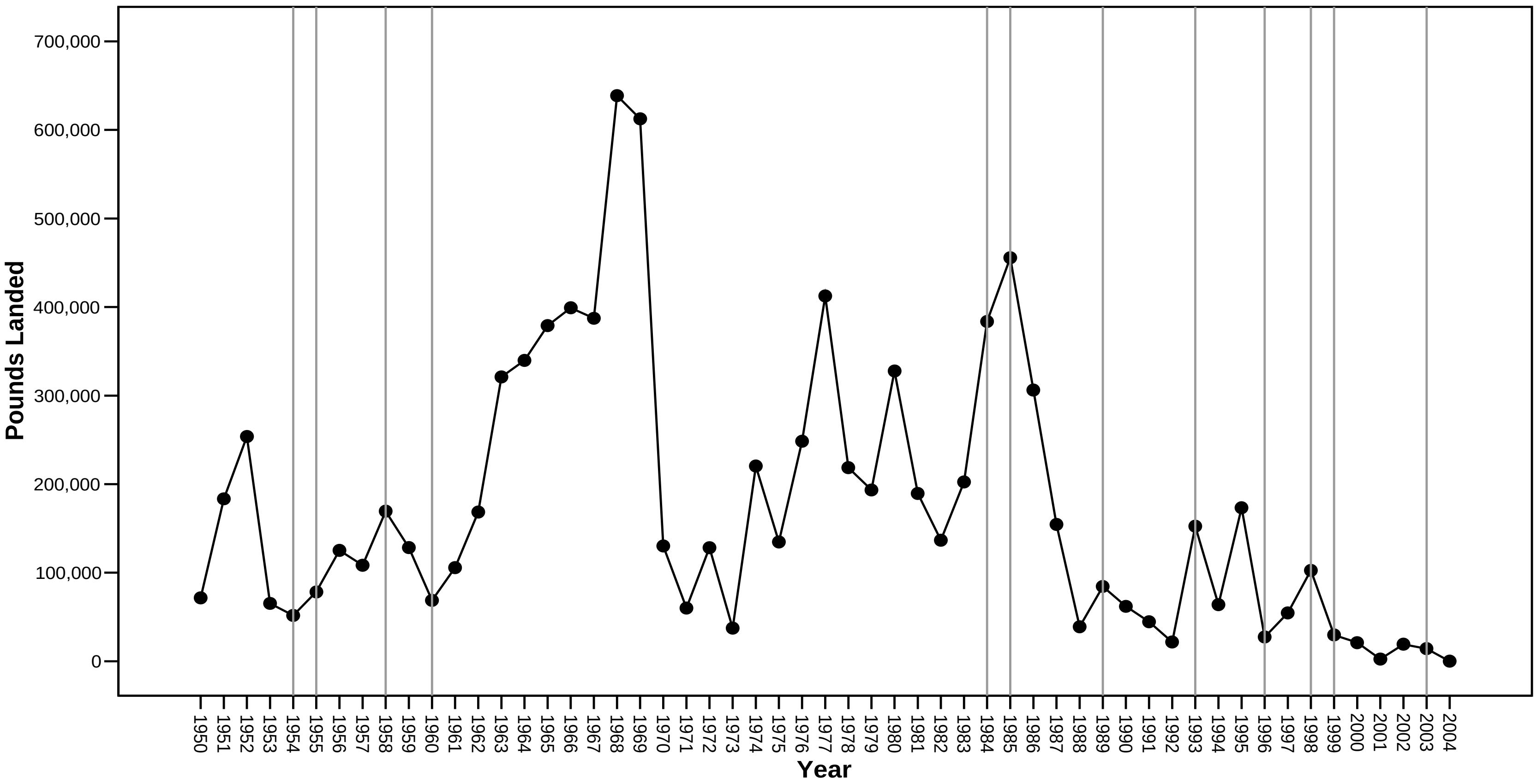

Figure 35. Total annual landings of bay scallops commercially harvested in North Carolina, 1950–2004. Grey bars represent notable hurricane years.

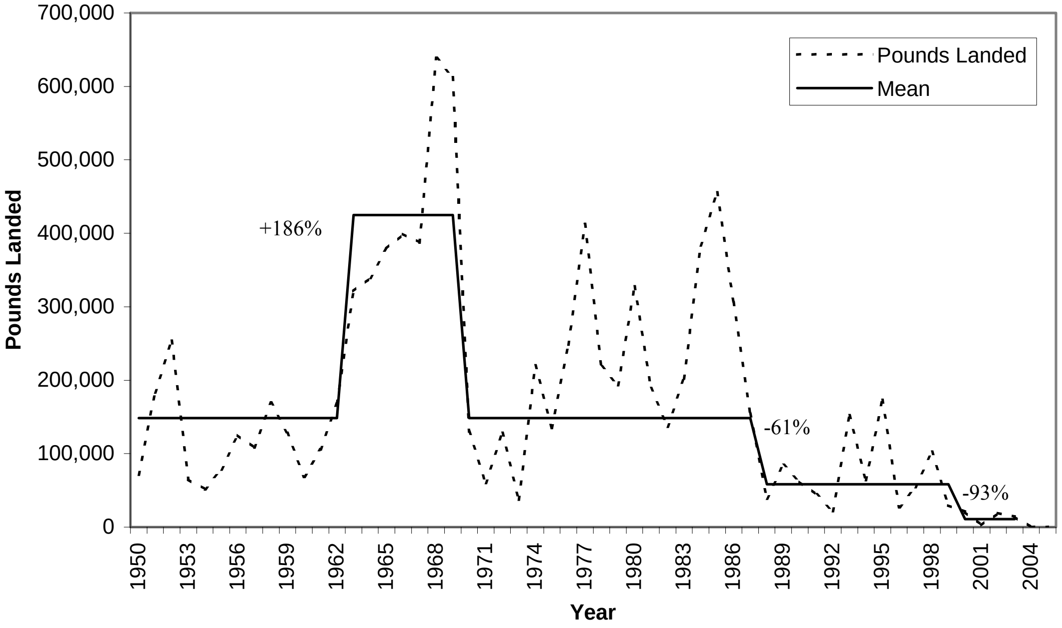

Figure 36. Overall statewide landings of bay scallops from 1950 to 2005 showing significant deviations from the "typical" mean of 148,662 pounds of meats.

Table 12. Results from the regression analysis of bay scallop commercial landings data using a short-term pulse event for 1963-1969 and step changes for the red tide (1988-2004) and the 1999 hurricane season (2000-2004). Estimates are natural log transformed.

Parameter	Estimate	Standard Error	t-ratio	*p*-value
μ	11.909	0.114	104.499	< 0.001
Red Tide (1988+)	-0.937	0.216	-4.345	< 0.001
1999 Hurricanes (2000+)	-1.670	0.366	-4.558	< 0.001
1963-1969	1.050	0.266	3.955	< 0.001

Shrimp

Shrimp are currently managed under the North Carolina Shrimp FMP (NCDMF 2006a). For this analysis "shrimp" include all of the penaeid species: brown (*Farfantepenaeus aztecus*), pink (*Farfantepenaeus duorarum*), and white shrimp (*Litopenaeus setiferus*) (Table 7). Shrimp are generally harvested from June through October with the peak in harvest typically occurring in July (Figure 37). Almost all shrimp are harvested with trawls (97%) followed by channel nets (3%) (Figure 38). The majority of shrimp are harvested from Pamlico Sound (44%) followed by the Atlantic Ocean less than three miles (22%), and Core Sound (15%) (Figure 39). On average, Carteret County landed more than 1.1 million pounds of shrimp from 1994 to 2003 followed by Pamlico and Hyde counties which each landed more than 500,000 pounds (Bianchi 2004).

Shrimp are an annual crop, and as a result, landings fluctuate greatly from year to year (Figure 40). Landings reached an all time high of 14,645,100 pounds in 1953 and declined to an all time low of 2,518,100 in 1958 (Figure 40). Since that time, landings have been highly variable, but relatively consistent over the long term. The time series for shrimp was found to exhibit no autocorrelation probably because they have a short life span and are considered an annual crop. The series exhibits no discernible pattern and is merely exhibiting erratic or random variation probably due to changes in environmental conditions from year to year. No impacts were detected due to hurricane activity outside of the normal variation.

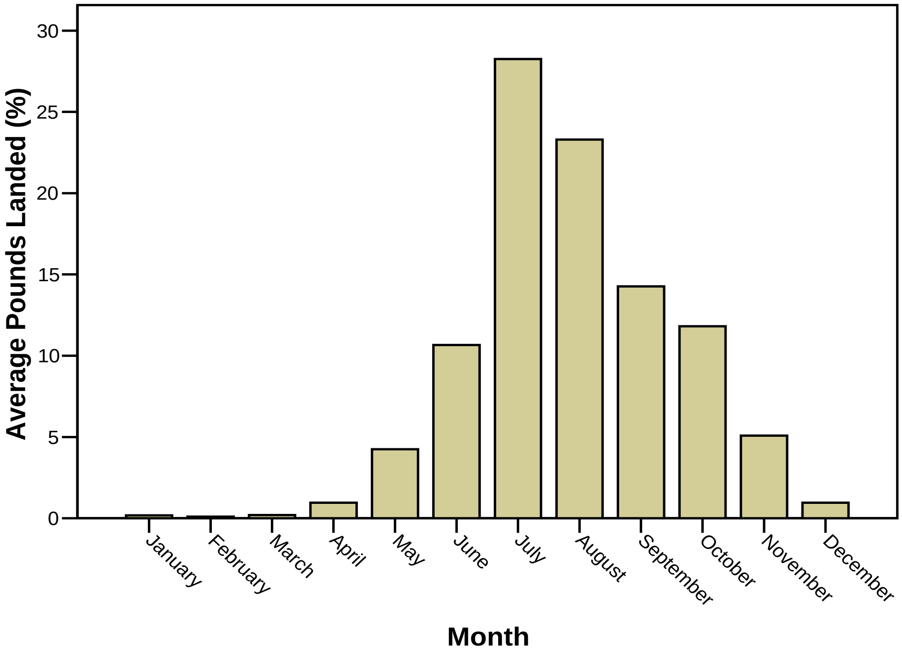

Figure 37. Average monthly landings of shrimp harvested commercially in North Carolina, 1972–2004.

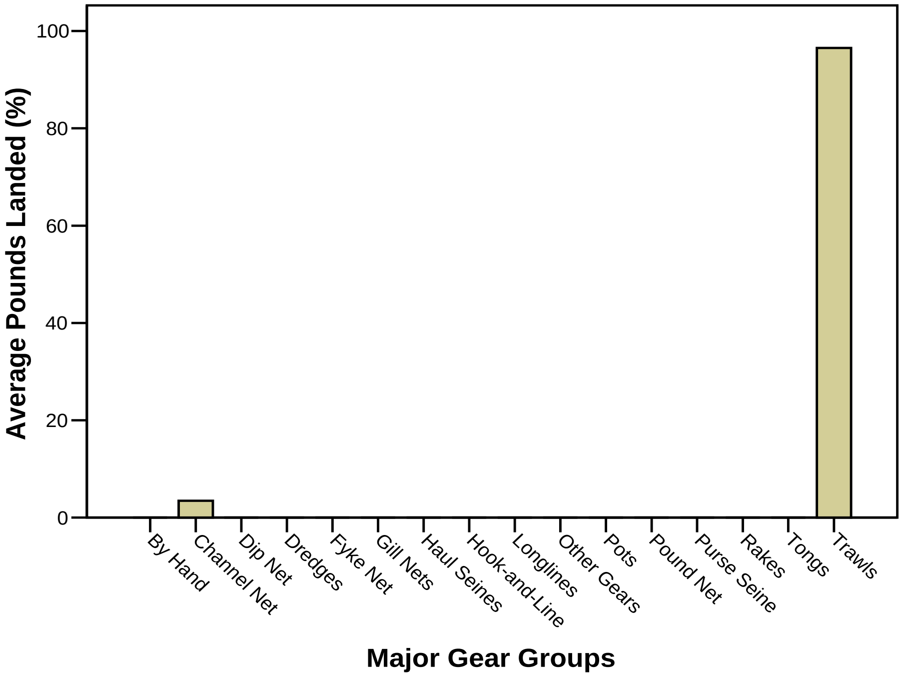

Figure 38. Average landings of shrimp harvested commercially in North Carolina by major gear groups, 1972–2004.

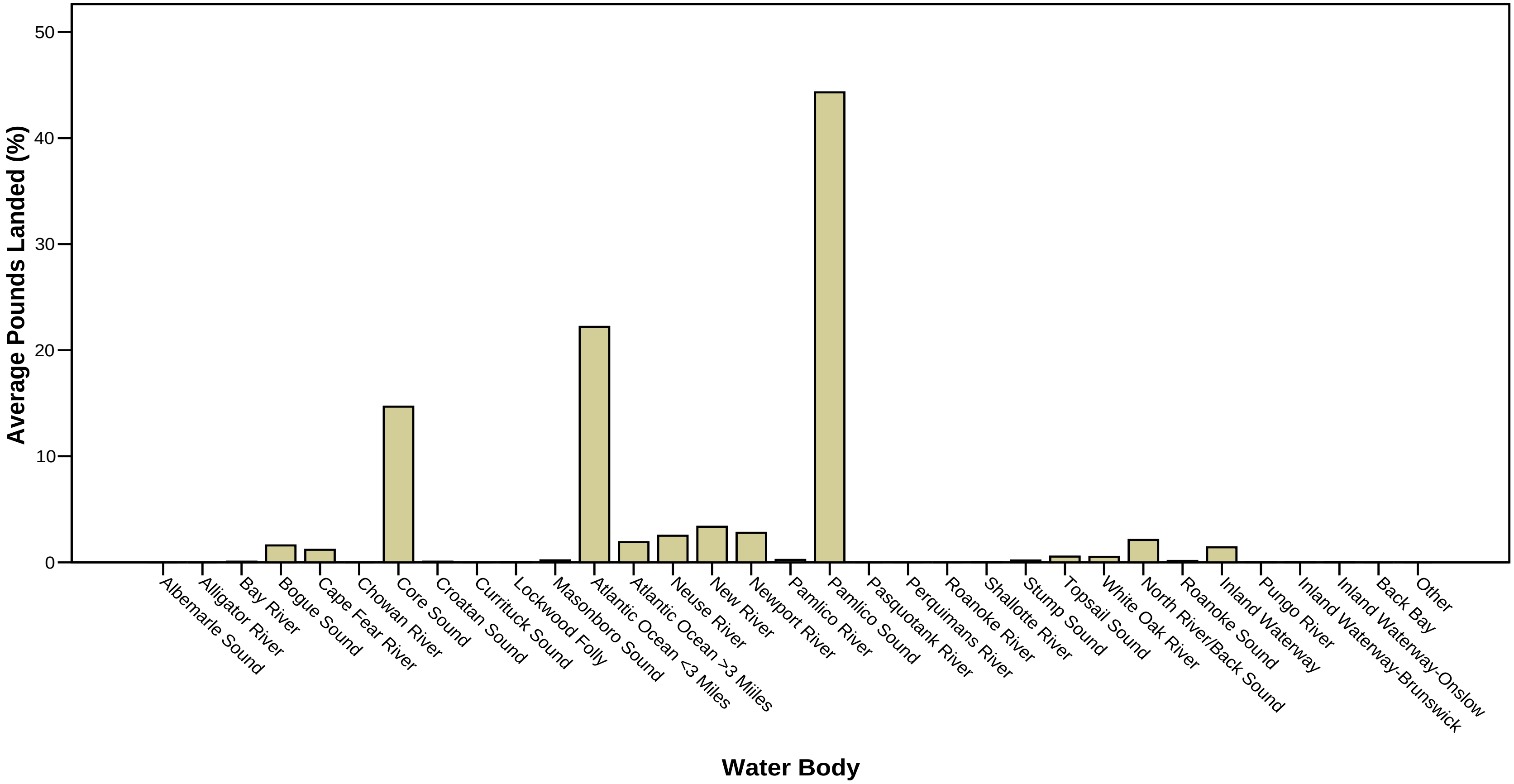

Figure 39. Average annual landings of shrimp commercially harvested in North Carolina by water body, 1950–2004.

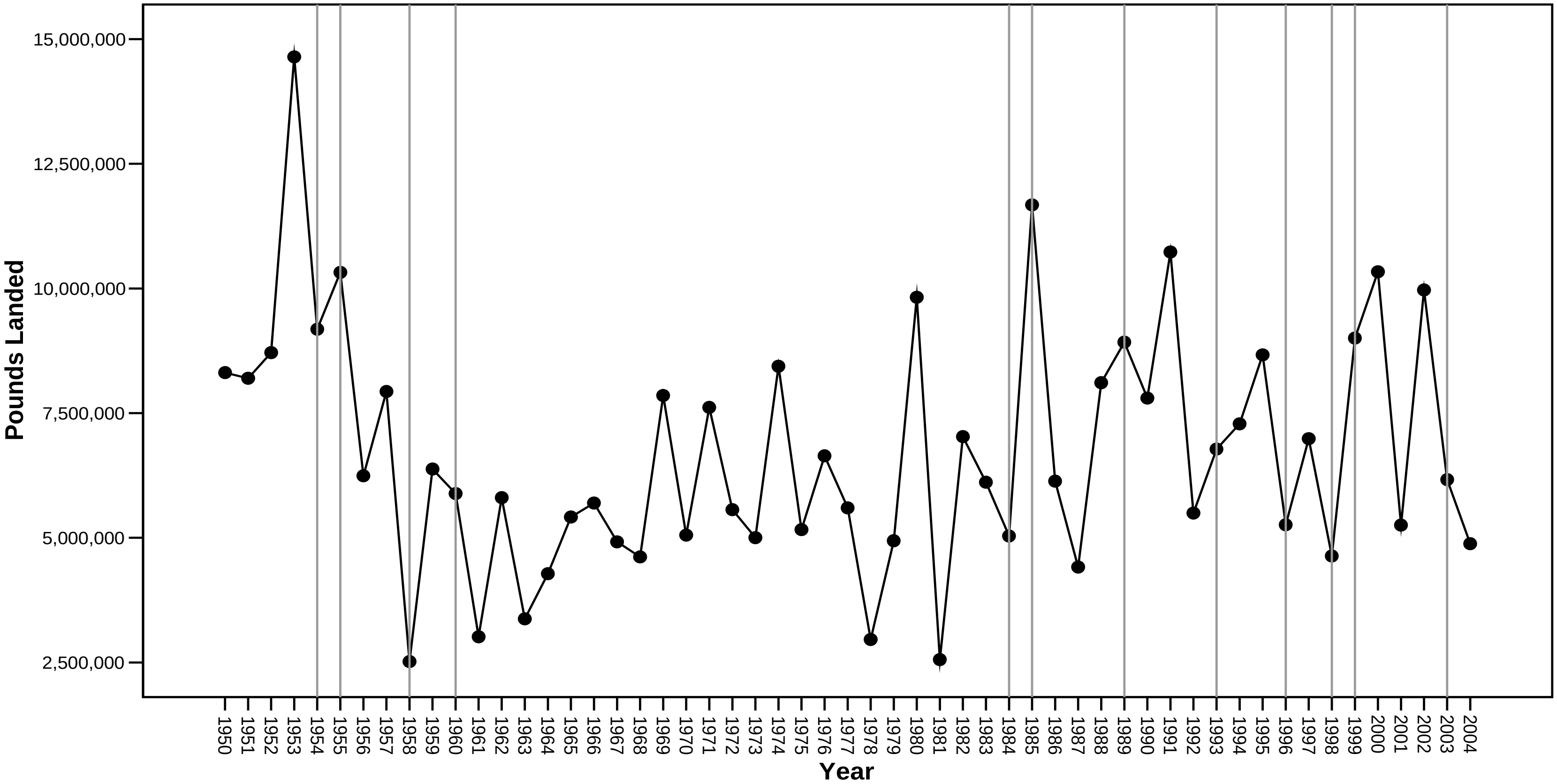

Figure 40. Total annual landings of shrimp commercially harvested in North Carolina, 1950–2004. Grey bars represent notable hurricane years.

Landings Forecasts

Attempts were made to forecast 2005 commercial landings using the models produced in this section. Forecasts were made assuming no external events occurred to effect 2005 commercial landings. Forecast estimates were then compared to the actual observed values for 2005 to assess model accuracy. Forecasts worked best for striped mullet and Groupers, which were only overestimated by 5.2% and 16.6% respectively; however, all other models were inaccurate when compared to observed values (Table 13).

Forecasts always overestimated landings for all species. These models assume that all factors affecting the behavior of the series remain unchanged; however, commercial landings, effort, and participation has been decreasing for the past several years because of factors affecting trip costs such as, increases in fuel prices, competition with imported seafood, and stricter regulations (B. Cheuvront, NCDMF, personal communication). Unless these factors are accounted for in the model, estimates are likely to be consistently high.

Because of the inherent variability in the time series, forecast estimates have large confidence intervals resulting in a high degree of uncertainty. In addition, predicting the impact of a notable hurricane on a particular fishery is difficult because no two storms are alike and each storm affects the ecosystem differently. Each storm is individual with respect to factors such as overall strength, wind speed, rainfall, forward momentum, barometric pressure, storm surge, and direction of travel. For example, Hurricane Floyd was only a category 2 storm at the time of landfall in North Carolina, but because Tropical Storm Dennis made landfall just two weeks earlier and saturated the landscape, Hurricane Floyd became one of the most destructive storms in North Carolina's history. Other category 2 storms to hit the coast did not have similar results. Therefore, given the tendency for model overestimation, a large degree of uncertainty, and the individual nature of each storm, these models would be unreliable for predicting the effect of another notable storm on a given fishery.

Table 13. Forecasts of 2005 commercial landings for selected species using intervention analysis and regression models developed in the quantitative analysis section. All estimates represent untransformed values.

Species	Forecasted Landings (lb)	(+/-) 95% Confidence Interval (lb)	Actual Landings (lb)	Difference (lb)	% Over/ Underestimated
Total Landings	154,412,384	101,364,271	79,162,659	75,249,725	+95.1
Total Landings w/o Menhaden	84,192,488	24,912,212	65,853,764	18,338,724	+27.8
Scallops, Bay	80	Ranged from 23 to 273*	0	80	**
Groupers	675,510	203,920	579,307	96,203	+16.6
Blue Crabs, Hard (with Floyd pulse)	35,649,045	10,620,087	23,560,168	12,088,877	+51.3
Blue Crabs, Hard	56,872,388	14,629,527	23,560,168	33,312,220	+141.4
Shrimp	6,326,450	613,760	2,354,611	3,971,839	+168.7
Mullet, Striped	1,704,953	993,658	1,620,034	84,919	+5.2

*Unequal confidence interval due to log transformation.

**Division by zero is undefined.

QUALITATIVE COMMERCIAL ANALYSIS

Methods

Not all of North Carolina's commercially important species could be analyzed with intervention analysis due to personnel and time constraints. Therefore, a qualitative analysis was conducted to determine whether hurricanes may have an impact on several other fisheries. Annual landings trends from 1950 to 2004 for each species were overlaid with annual plots of hurricane activity in which notable hurricanes occurred (
Table 6). Landings trends were during the hurricane season (June to November) from 1972 to 2004 were also overlaid with yearly plots of hurricane activity in which notable hurricanes occurred to account for any effort that occurs outside of the hurricane season. Landings trends and comparisons were made between years with and without notable hurricanes to determine whether hurricanes may have had an effect on the commercial fishery.

Results and Discussion

Amberjack

The South Atlantic Fisheries Management Council (SAFMC) manages amberjacks under the Snapper-Grouper Fishery Management Plan (SAMFC 1983b). Four amberjack species are included in the snapper-grouper management complex: greater amberjack (*Seriola dumerili*), lesser amberjack (*S. fasciata*), Almaco jack (*S. rivoliana*) and banded rudderfish (*S. zonota*). This analysis contains landings for only the greater and lesser amberjacks. The majority of amberjacks landed in North Carolina are caught in the ocean more than three miles offshore primarily with rod-n-reel gears (Bianchi 2004). The majority of amberjack landings occur during the late spring through late fall and are primarily landed in Brunswick and Carteret counties.

Annual landings of amberjack increased from the early 1980s to a peak in 1997 (Figure 41). Landings declined in 1998 but have remained relatively stable since that time. Two years, 1996 and 1998, stand out when the annual landings of amberjack are overlaid with hurricane activity. Amberjack landings declined sharply in 1996 and in 1998 and remained low after 1998.

Amberjack landings during the hurricane season show the same trends but also show a decline in landings in 1989 and an increase in landings in 2003 (Figure 42).

These trends suggest that the hurricanes of 1989, 1996, and 1998 may have had a negative impact on the amberjack fishery. Three of these storms made landfall in the Cape Fear region (Hurricanes Bertha, Fran, and Bonnie), and Hurricane Hugo made landfall in Charleston, South Carolina during months in which amberjacks are typically harvested. These storms may have forced participants to spend more time in preparations and relief instead of fishing for amberjack. The landings during 2003 occurred mostly during the summer months prior to Hurricane Isabel. In comparison to 2002, landings in 2003 were higher in the months of June through August but actually lower in September, which was the same month that Hurricane Isabel made landfall.

However, other factors could also have contributed to these trends. During this time period, an annual quota and a trip limit were put in place for greater amberjack, which accounts for the majority of North Carolina’s amberjack landings.

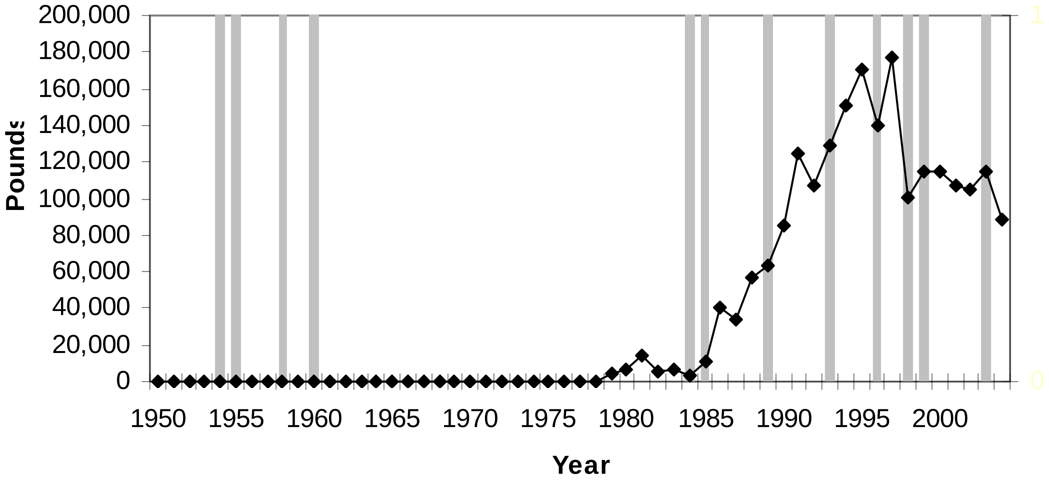

Figure 41. Annual landings of amberjacks, 1950-2004. Grey bars represent notable hurricane years.

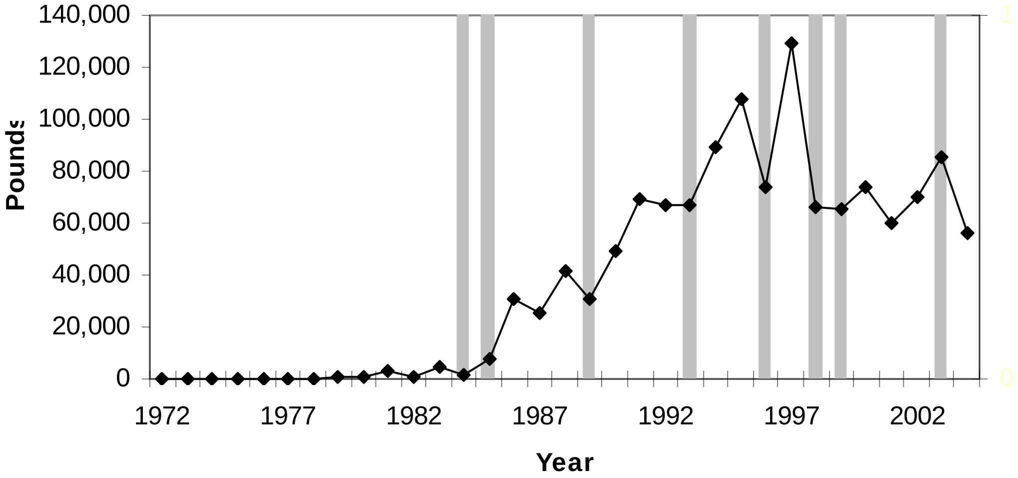

Figure 42. Landings of amberjacks during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

American Eel

The American eel (*Anguilla rostrata*) is managed under the American Eel Fisheries Management Plan approved by the Atlantic States Marine Fisheries Commission (ASMFC) in 1999 (ASMFC 2000; NCDMF 2002). American eels are primarily caught in Albemarle Sound, Currituck Sound, and Pamlico River primarily with eel pots. Landings of American eels occur mainly during the spring (March-April) and fall (September-December) in Pamlico, Carteret, Currituck, Tyrrell, and Dare counties (Bianchi 2004).

Landings of American eel increased significantly from the early 1970s to 1980 but have declined overall since 1980 (Figure 43). A few years stand out when the annual landings are overlaid with hurricane activity: 1984, 1985, 1989, and 2003. American eel landings increased in 1984, 1989, and 2003 from the previous years. Only in 1985 did American eels show a large decline from the year before. Also, since 1985 the annual landings of American eel have remained low. The same trends are observed in the landings of American eel during the hurricane season (
Figure 44).

The most significant change in landings occurred in 1985 with a 68% decrease in landings from the previous year. Hurricane Gloria could have contributed to this as the storm system skirted the Outer Banks in September possibly making fishing impractical because of bad weather conditions. The increase in landings in 1989 and 2003 occurred primarily after Hurricanes Hugo and Isabel in the months of October and November, while the increase in landings in 1984 occurred throughout the year (prior and after Hurricane Diana). It is possible that the resulting inland flooding from these storms caused American eels to become more accessible to harvest after the storm event by displacing them further downstream but there is no biological or ecological evidence to support this.

These trends suggest that hurricanes may have an effect on the American eel fishery. However, it is likely that other factors have contributed to these trends as well. After 1984, landings of American eel declined steadily and have remained low. A combination of factors has probably led to this event including hurricane activity, changes in the fishery, changes in the fish stock, and regulation changes.

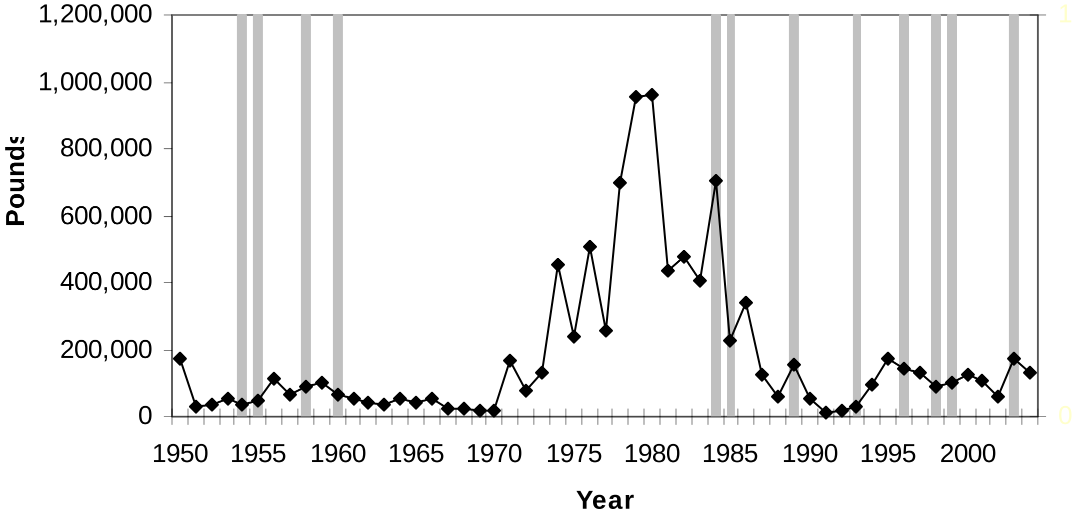

Figure 43. Annual landings of American eel, 1950-2004. Grey bars represent notable hurricane years.

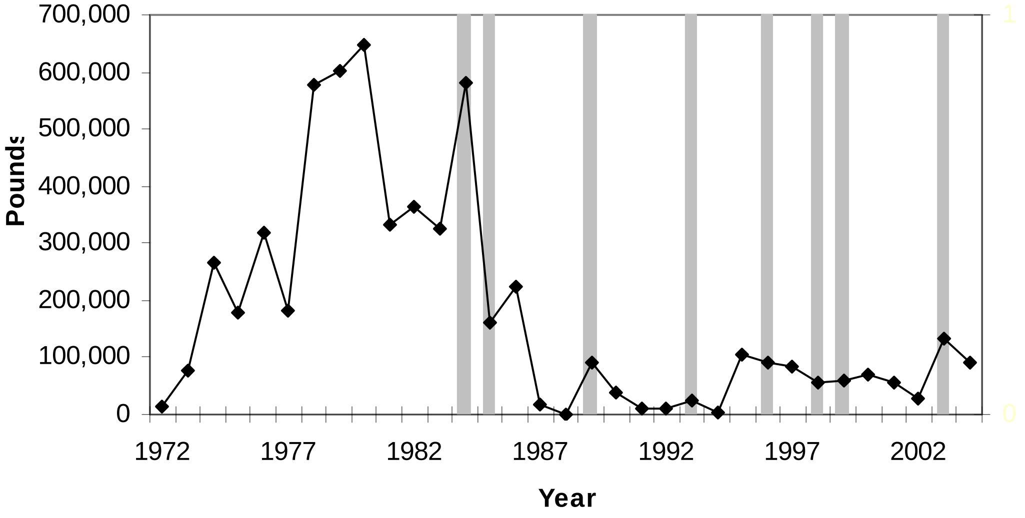

Figure 44. Landings of American eel during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Atlantic Croaker

The ASMFC adopted the Atlantic Croaker (*Micropogonias undulatus*) FMP in 1987 (ASMFC 1987b; NCDMF 2002). This species has a wide range, occurring in waters from Massachusetts to northern Mexico, excluding southern Florida. Atlantic croaker can obtain a length of almost 20 inches and a weight of 4 pounds. The majority of Atlantic croaker landings are from the Atlantic Ocean. Atlantic croaker are primarily harvested in trawls, gill nets, and seines during the winter (January-March) and fall (October-December) seasons. Three counties account for the majority of the landings: Dare, Hyde, and Carteret (Bianchi 2004).

The annual landings of Atlantic croaker increased during the 1950s but declined after 1958 and remained relatively constant until the early 1970s (Figure 45). Landings of croaker then increased dramatically and peaked in 1980, then declined sharply until 1992,and have since increased and remained relatively stable. When the annual landings data are overlaid with hurricane activity none of the years appear to show an impact. Landings do increase in 1996 and again in 2003; however, when the landings of croaker during the hurricane season are overlaid with years of notable hurricane activity, only 1996 showed an increase (Figure 46). The majority of this increase occurs during October and November with a small increase in September when compared to 1995.

The trends in the Atlantic croaker landings seem not to be impacted by hurricane activity. Although the landings increased in 1996, the majority of these landings occurred well after the two hurricanes made landfall in North Carolina and the majority of the fishery is prosecuted in counties north of their landfall. In addition, because this fishery is primarily an ocean fishery, displacement of this species due to inland flooding would not make these fish more accessible to the fishery. These trends are most likely due to changes in effort, management, and availability of the stock.

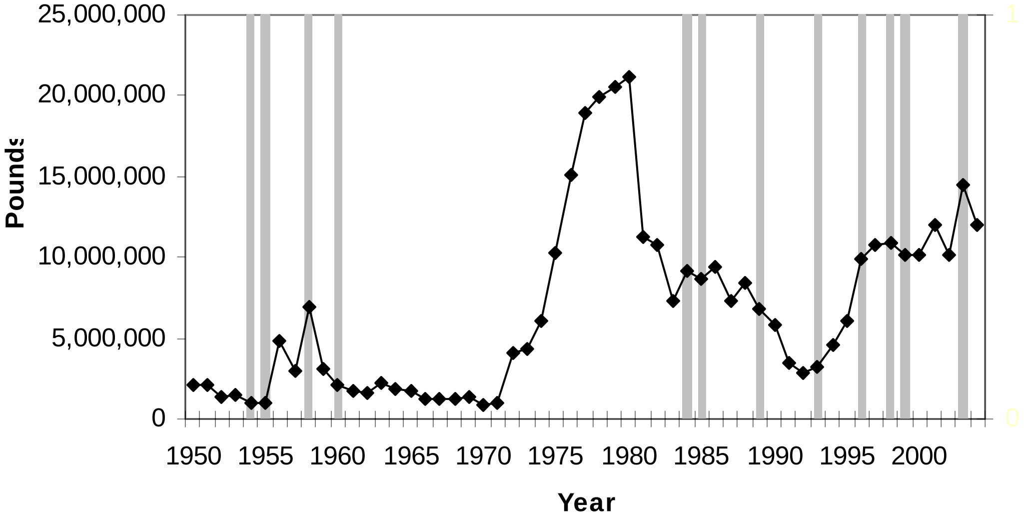

Figure 45. Annual landings of Atlantic croaker, 1950-2004. Grey bars represent notable hurricane years.

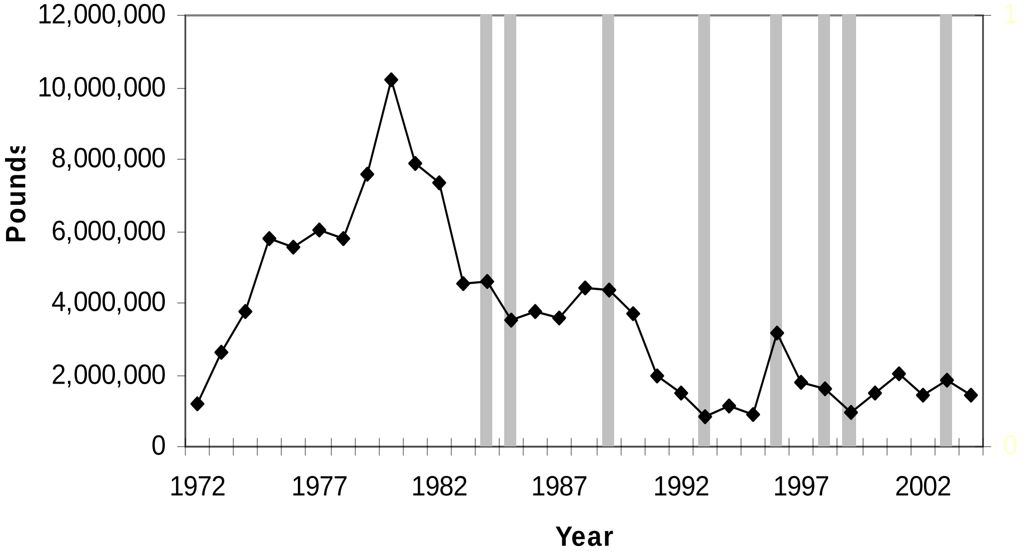

Figure 46. Landings of Atlantic croaker during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Atlantic Menhaden

Atlantic menhaden (*Brevoortia tyrannus*) are currently managed by the ASMFC under the Atlantic Menhaden FMP (ASMFC 2001; NCDMF 2002). Atlantic menhaden have a range extending from Nova Scotia to Florida. Menhaden can obtain a length of 14 inches. Menhaden are most commonly harvested from Core Sound and the Atlantic Ocean less than 3 miles offshore. The menhaden fishery is composed up of two sectors: the bait and industrial fisheries. The bait fishery is primarily conducted with gill nets while the industrial fishery is prosecuted with purse seines. The vast majority of menhaden landings are due to the industrial fishery. Menhaden are typically harvested all year long, with fall having the largest amount of landings, particularly in November and December (Bianchi 2004). The majority of menhaden landings occur in Carteret, Dare, and Hyde counties although there were significant landings in the southern part of the state as well in the early 1980s.

Menhaden landings increased throughout the 1950s and then declined from the early 1960s to the mid 1970s (Figure 47). Landings then increased dramatically during the mid 1970s until they reached a peak in 1981. Landings sharply declined until the mid to late 1980s and have remained stable since. Overlaying the years of notable hurricane activity on top of the annual landings of menhaden does not show any significant trends or correlations. However, when landings during the hurricane season are examined, 1985 stands out (Figure 48). Examining the monthly landings between 1984 and 1985, September and October landings were actually higher in 1985, but the landings in November were considerably less (99% decrease) in 1985 compared to 1984.

The trends in menhaden landings suggest that hurricanes are not a significant factor in this fishery. The landings trends observed in this fishery are most likely due to changes in the market and infrastructure of the industrial component. Over the years, a number of the larger purse seine operations of have closed down which has significantly affected the landings of menhaden over the years.

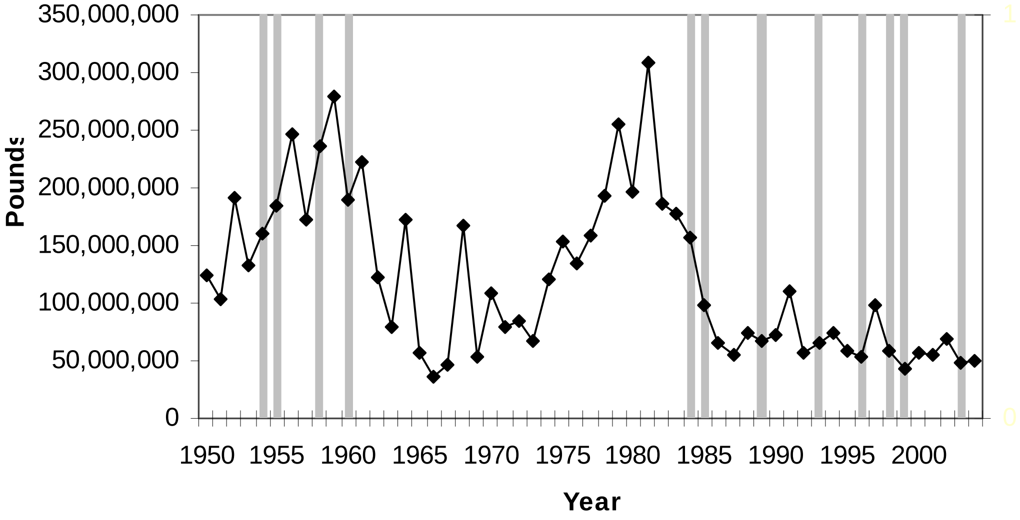

Figure 47. Annual landings of Atlantic menhaden, 1950-2004. Grey bars represent notable hurricane years.

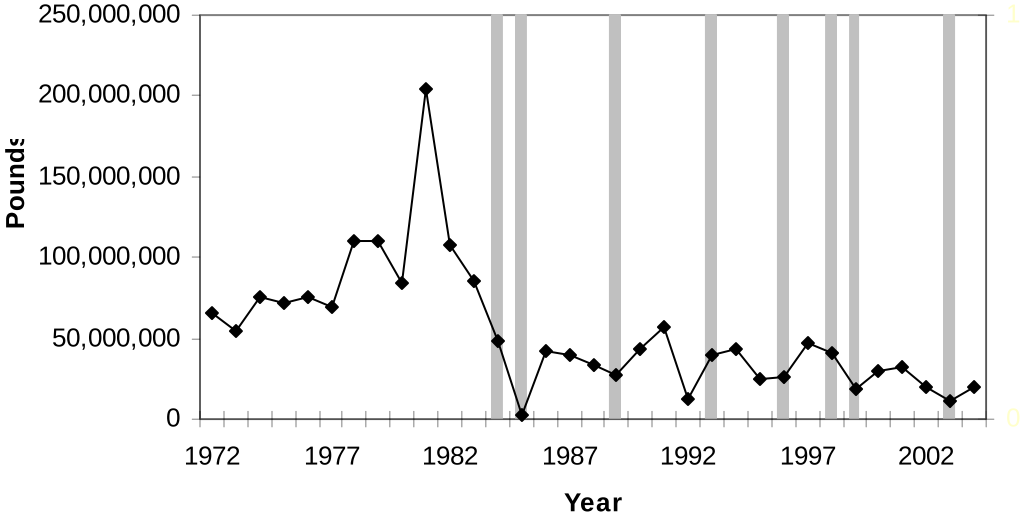

Figure 48. Landings of Atlantic menhaden during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Bluefish

The ASMFC and the Mid Atlantic Fisheries Management Council (MAFMC) manage bluefish (*Pomatomus saltatrix*) under a joint Bluefish FMP (ASMFC 1989; NCDMF 2002). Bluefish are a migratory species with a wide range extending from Nova Scotia to Bermuda. Bluefish can reach a length of 45 inches and a weight of 27 pounds. In North Carolina, bluefish are most often harvested from the ocean and Pamlico Sound. Bluefish are primarily harvested with gill nets, seines, and trawls during the winter and spring (December through May). Three counties account for the majority of bluefish landings: Dare, Hyde, and Carteret (Bianchi 2004).

Bluefish landings declined steadily during the early 1950s and then increased from 1955 to 1960 (Figure 49). Landings of bluefish remained relatively stable until the 1970s and then increased sharply through mid 1980s. Landings have since fluctuated through 2004. Three years stand out when the annual landings of bluefish are overlaid with the hurricane activity: 1984, 1989, and 2003. During 1984 and 1989, the landings of bluefish declined while in 2003 the landings of bluefish increased. However, these same trends are not apparent in the landings of bluefish during the hurricane season (Figure 50). This suggests that landings of bluefish were not affected by hurricanes in those years and were most likely due to changes in landings in the winter months. However, 1998 year stands out when looking at the landings during hurricane season. In 1998, a large decline in bluefish landings occurred during and after the month Hurricane Bonnie made landfall in comparison to 1997. Hurricane Bonnie could have had a negative impact on the inshore bluefish fishery by displacing fish and forcing fishermen to make preparations prior to and after the storm that could have prevented them from participating in the fishery.

Bluefish landings are highly variable, especially in recent years. Hurricanes most likely play a minor role in these trends. These trends are most likely driven by changes in participation over time and market conditions.

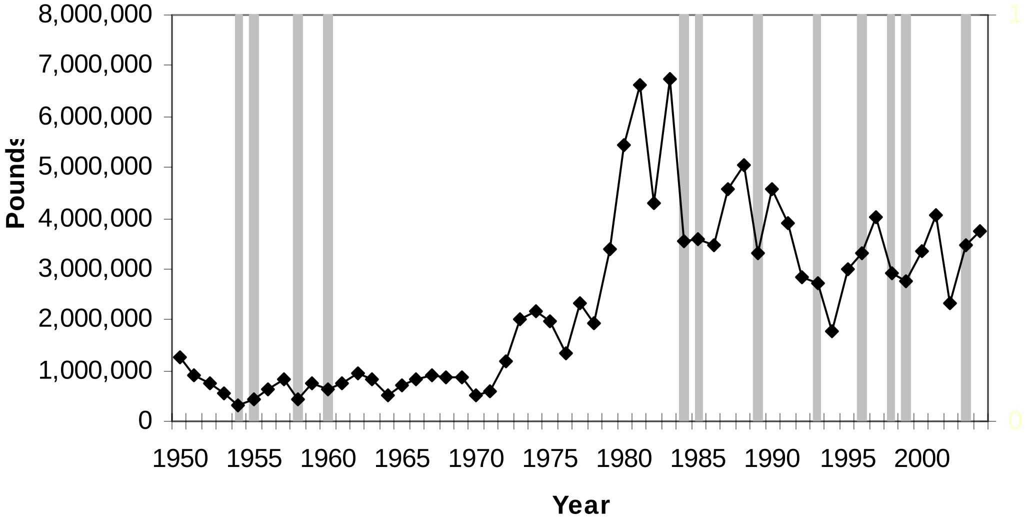

Figure 49. Annual landings of bluefish, 1950-2004. Grey bars represent notable hurricane years.

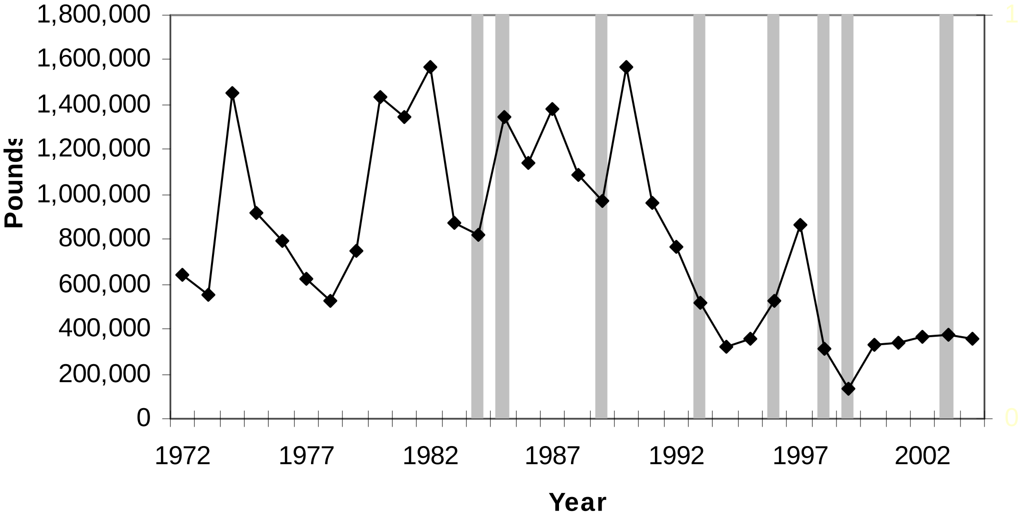

Figure 50. Landings of bluefish during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Catfishes

There are two commercially important genera of catfishes, *Amerius* and *Ictalurus*. Within these genera, commercially important species of catfishes include white catfish (*A. catus*), blue catfish (*I. furcatus*), channel catfish (*I. punctatus*), and other bullheads. The majority of the catfishes in North Carolina are harvested from Albemarle Sound and its tributaries primarily with gill nets, fyke nets, fish pots, and pound nets. The majority of catfishes are harvested during the early spring and fall months. Catfishes are primarily landed in the northern counties, most notably in Chowan, Pasquotank, and Tyrell counties (Bianchi 2004).

Two trends are evident in the annual landings of catfish from 1950 to 2004 (Figure 51). Catfish landings increased overall from 1950 to 1972 but since have declined overall since reaching that peak. Overlaying hurricane activity on top of the annual landings trends of catfishes does not indicate any type of correlation between the two. Although, there are increases and decreases in landings in some years that had hurricane activity these changes seem to be within the range of variability of the other years, no years stand out with a strong decline or increase. The landings of catfishes during the hurricane season also show the same type of trends (Figure 52).

These trends suggest that hurricanes have little effect on the catfish fishery overall. The fishery is mainly prosecuted in the northern part of the state, which is not impacted as often by hurricanes, and a large portion of this fishery is conducted outside of the hurricane season; however, fish kills have, on occasion, been reported in the Albemarle Sound area following some hurricanes (e.g., Hurricane Isabel in 2003) that affected species that can only tolerate relatively low salinities, including catfish, that is thought to be caused by low levels of dissolved oxygen and increases in salinity caused by the storm surge (M. Loeffler, NCDMF, personal communication).

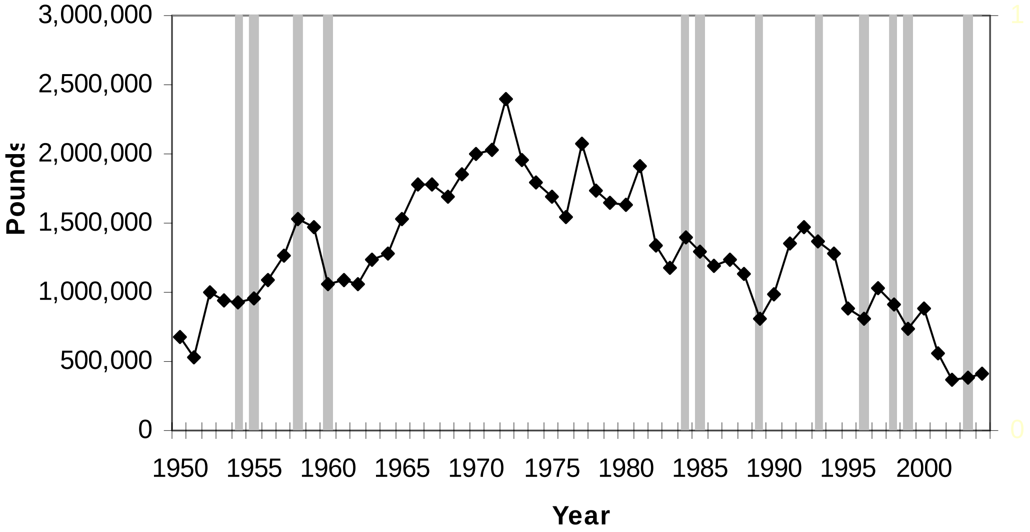

Figure 51. Annual landings of catfishes, 1950-2004. Grey bars represent notable hurricane years.

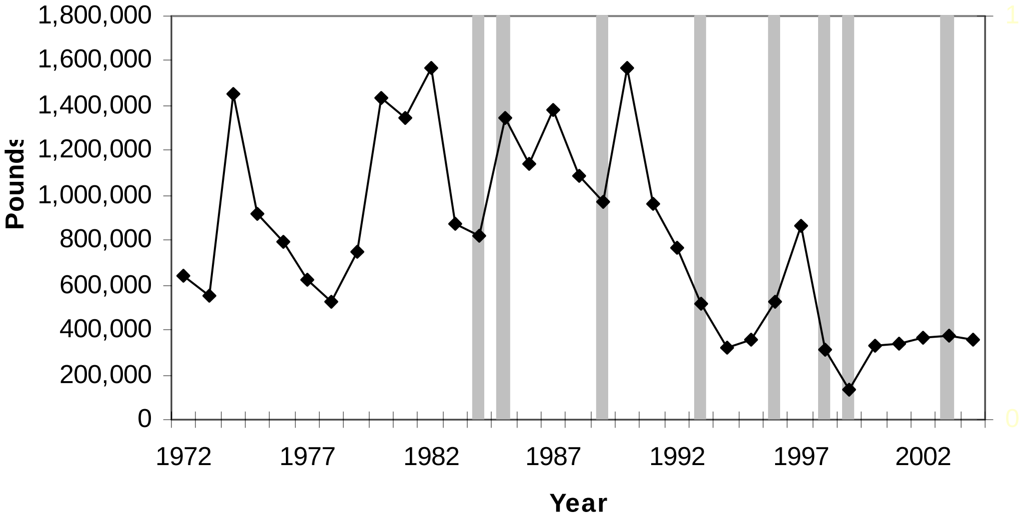

Figure 52. Landings of catfishes during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Hard Clams

Hard clams (*Mercenaria mercenaria*) are currently managed under the North Carolina Hard Clam FMP (NCDMF 2001a). Hard clams are harvested primarily from Core and Bogue sounds south to the South Carolina border with hand gears (rakes, tongs, and by hand) and mechanical gears (dredges, trawl kicking). Clams are harvested throughout the year peaking in the summer months. Carteret, Onslow, New Hanover, and Brunswick counties account for the vast majority of the state's landings (Bianchi 2004).

Landings of hard clams declined sharply through the mid-1950s and then increased from 1955 to 1961 (Figure 53). Hard clam landings then remained stable until the mid-1970s when landings rose significantly through the early 1980s. Landings of hard clams have since declined overall from the early 1980s to 2004. Only one year stands out when hurricane activity is overlaid on top of the landings of hard clams: 1955. This year is notable because it happens to be the year in which the lowest landings of clams occurred for the time series. However, this decline began well before that year and shortly after 1955 landings increased suggesting that the 1955 hurricanes did not have a significant impact on the fishery. When the landings during the hurricane season are plotted with hurricane activity, three years are stand out: 1984, 1996, and 1999 (Figure 54). During these years, clam landings are down during September and through the rest of fall.

The trends in hard clam landings and hurricanes indicate that there is most likely a short-term negative impact on the fishery primarily during the hurricane season, most likely due to shellfish closures from high fecal coliform runoff (NIEHS 1997). In addition, a negative impact is most likely to occur when multiple storms affect the state (Hurricanes Fran and Bertha in 1996 and Tropical Storm Dennis and Hurricane Floyd in 1999) because of commercial fishermen having to prepare for the storm, possible loss of infrastructure after the storms, and mortality of clams due to heavy turbidity from sedimentation in addition to prolonged shellfish closures. However, because the fishery occurs throughout the year hurricanes appear to be a rather minor component affecting the fishery.

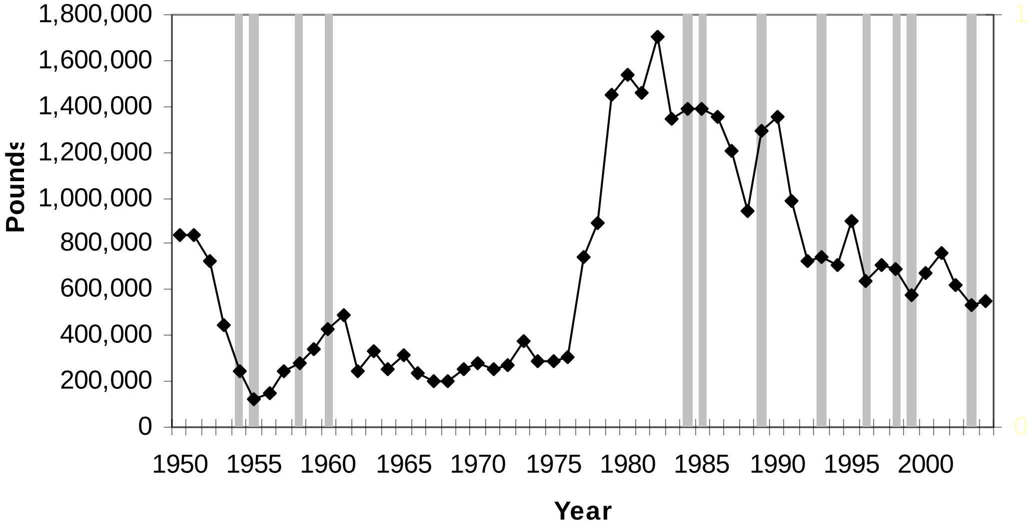

Figure 53. Annual landings of hard clams, 1950-2004. Grey bars represent notable hurricane years.

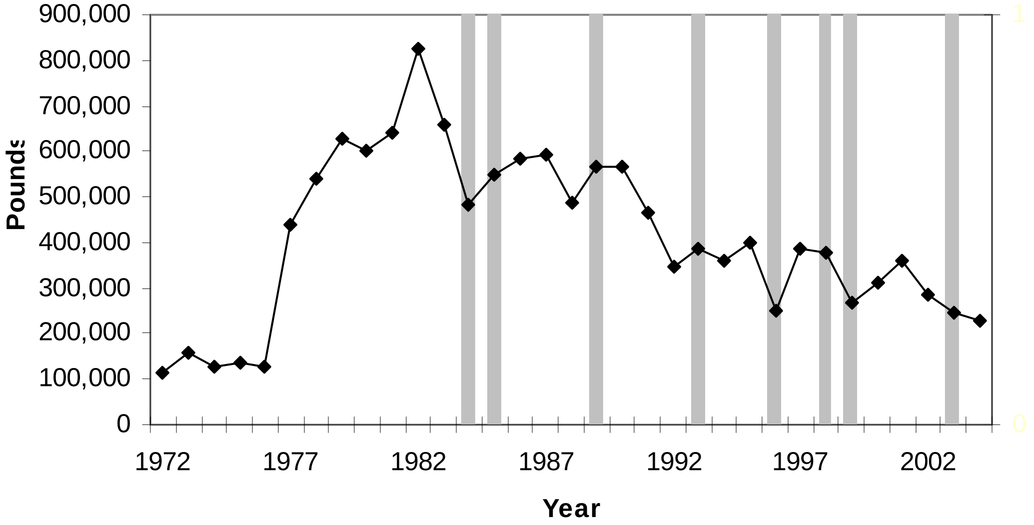

Figure 54. Landings of hard clams during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Hogfish

Hogfish (*Lachnolaimus maximus*), also known as hog snapper, are managed under the snapper-grouper complex of the Snapper-Grouper FMP developed by the SAFMC (SAFMC 1983b). This species is typically harvested in the ocean greater than three miles offshore with rod and reel and diving spears. Hogfish are primarily harvested during the summer and throughout the fall months with landings occurring mostly in Brunswick, New Hanover, and Carteret counties (Bianchi 2004).

The hogfish fishery in North Carolina did not develop until the early 1980s when landings increased steadily from 1980 to 1995 (Figure 55). Landings declined after 1995 and have remained relatively stable since that time. When landings and hurricane activity are overlaid, the only notable year is 1996 where landings of hogfish drop considerably. The same trend is observed with the landings during the hurricane season (Figure 56). Hogfish landings declined appreciably in the months of July and September during 1996 when compared to 1995, the months in which Hurricanes Bertha and Fran impacted North Carolina. Landings of hogfish have also remained low since 1996.

The landings trends in hogfish suggest that the 1996 Hurricanes may have had an impact on the fishery. These two storms made landfall in the general area in which the majority of this fishery is operated and they occurred during peaks months for this fishery. Participants in the fishery may have been making preparations for the storms instead of prosecuting the fishery. This would result in a short-term decline in the fishery in 1996 but landings in the fishery have remained low since this period. This is most likely due to a decline in participation in the fishery and not a result of hurricane activity. In 1995, 125 licensed fishermen recording landings of hogfish and by 2003 this had dropped down to only 51 fishermen (Bianchi 2004) suggesting that changes in participation and markets also have impacted this fishery.

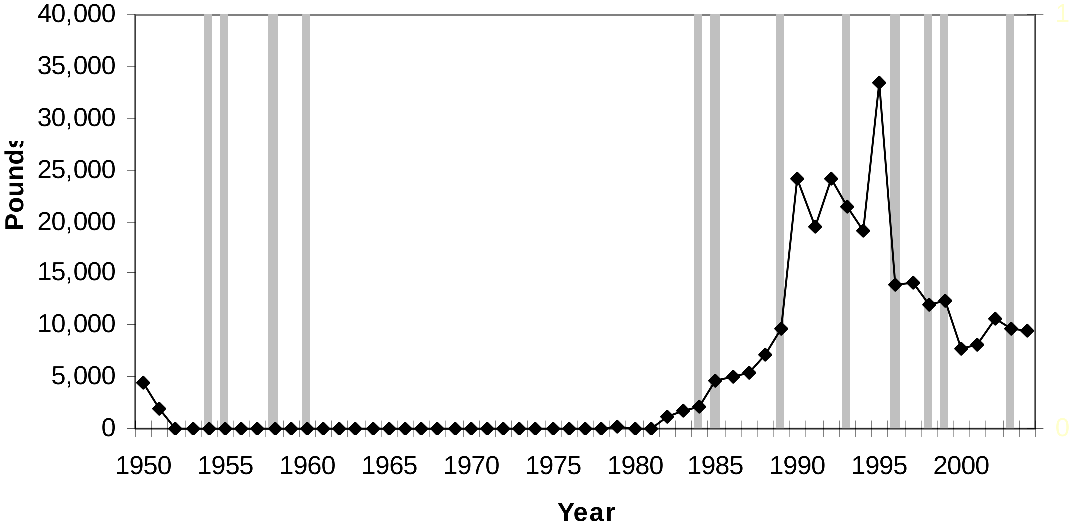

Figure 55. Annual landings of hogfish, 1950-2004. Grey bars represent notable hurricane years.

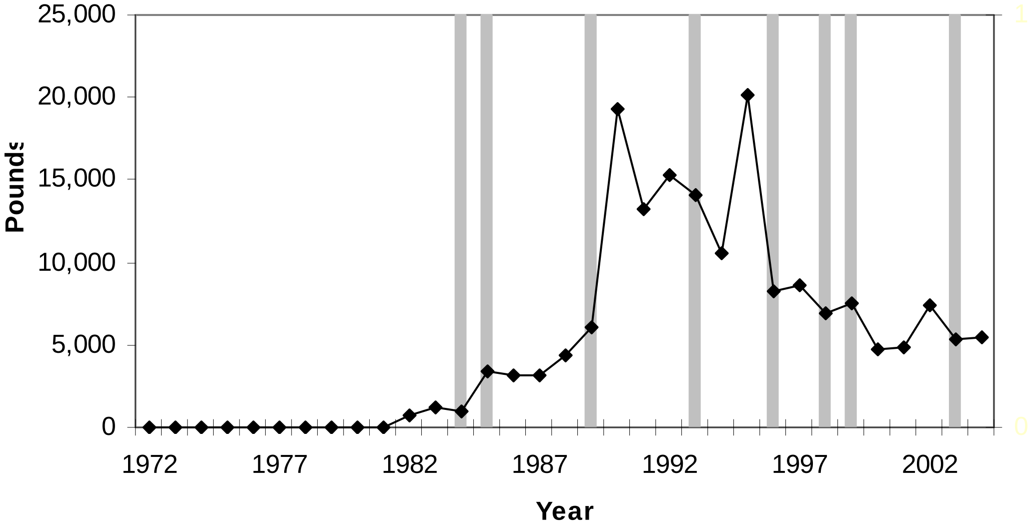

Figure 56. Landings of hogfish during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

King Mackerel

King mackerel (*Scomberomorus cavalla*) are managed under the Coastal Migratory Pelagics FMP of the SAFMC (SAFMC 1983a; NCDMF 2002). The majority of king mackerel are harvested from ocean waters greater than three miles offshore with rod and reel, trolling, and gill net gears. Landings typically occur during the late fall through spring (October to April). The majority of king mackerel are landed in Dare and New Hanover counties (Bianchi 2004). The king mackerel fishery did not develop in North Carolina until the mid to late 1970s (Figure 57). Landings increased dramatically from the early 1970s to the late 1980s and have fluctuated since that time.

When the annual landings of king mackerel are overlaid with hurricane activity a noticeable trend is observed. Since the landings the development of the fishery, landings have generally declined during years that had notable hurricane activity. The same trends are observed when looking at the landings during the hurricane season (Figure 58).

The correlations observed in the king mackerel landings and hurricane activity suggests that hurricanes could have a negative impact on the fishery. This could be due to the inability of the fleet to leave port to participate in the fishery due to bad weather conditions and hurricane preparations. Other factors also contribute to the trends observed in the landings of king mackerel. Regulations (trip limits and quotas) have also impacted this fishery as well as changes in market conditions (methyl mercury, etc.). It is likely that all of these have contributed to the landings trends observed in king mackerel.

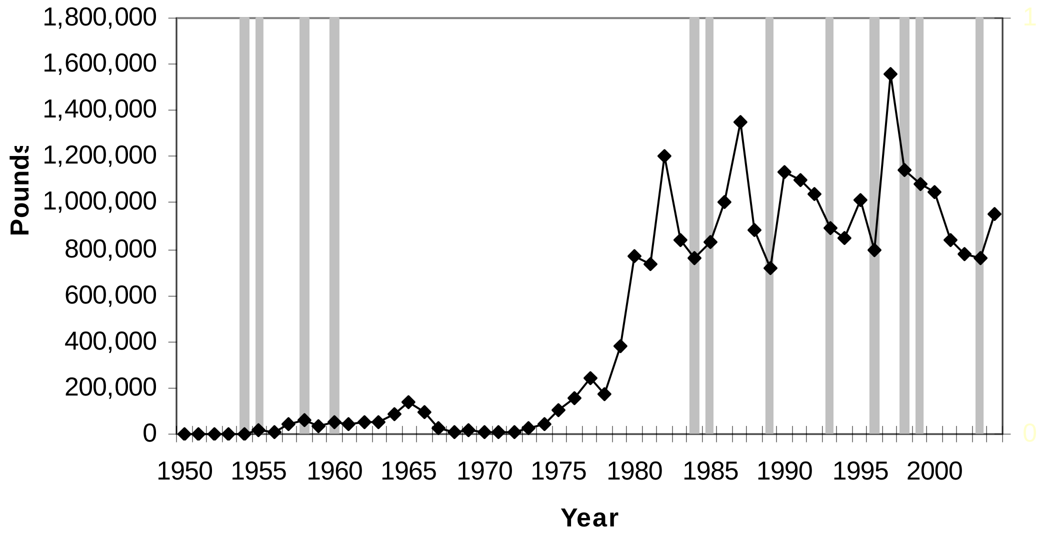

Figure 57. Annual landings of king mackerel, 1950-2004. Grey bars represent notable hurricane years.

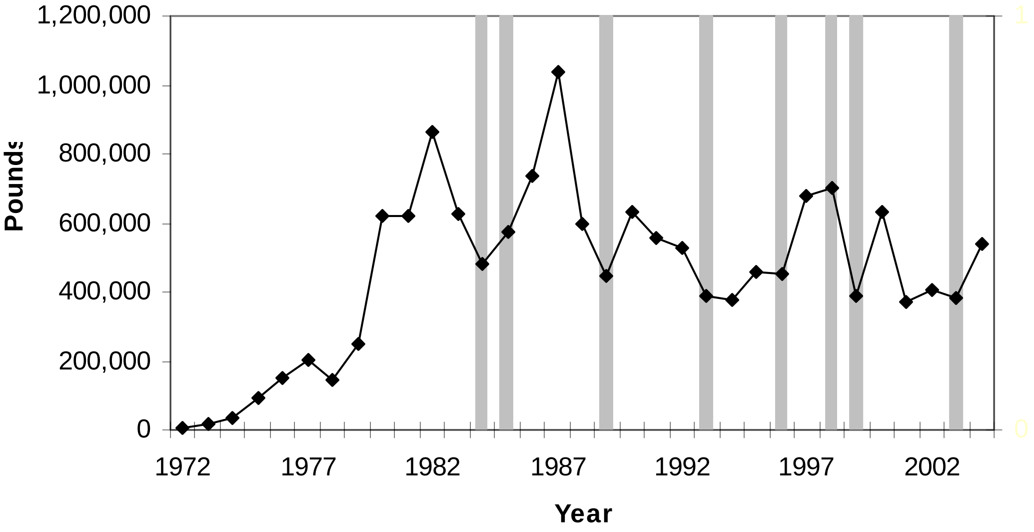

Figure 58. Landings of king mackerel during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Kingfishes (Sea Mullets)

Three species of kingfishes, also known as sea mullets, whiting, or Virginia mullet, are known to inhabit the coastal waters of North Carolina: southern kingfish (*Menticirrhus americanus*), northern kingfish (*M. saxatilis*), and gulf kingfish (*M. littoralis*). In North Carolina, kingfishes are primarily harvested from the Atlantic Ocean, Pamlico Sound, and Core Sound with gill nets, trawls, and seines. Kingfishes are typically harvested during the late fall through spring (November to April) with most landings occurring Carteret, Dare, Onslow, New Hanover, and Brunswick counties (Bianchi 2004).

The kingfish was productive during the early 1950s but landings started to decline in 1965 and remained low through the early 1980s (Figure 59). Landings increased through the late 1980s and have remained relatively stable through the mid 1990s. Landings declined in 1996 and remained at that level through the rest of the time series. When the annual landings of kingfish are compared to hurricane activity both increasing and decreasing trends during years of hurricane activity are observed. Landings increased in 1954 and 1993 and declined in 1955, 1996, and 1998. However, activity the same trends are not entirely observed (Figure 60). Instead, kingfish landings increased in 1993 and declined in 1989, 1998, and 2003. This suggests that the trends seen 1996 occurred outside of the hurricane season and was most likely do to another factor.

These trends suggest that hurricanes could have a negative impact on the kingfish fishery, probably by decreasing effort just before and after the storm as fisherman make their preparations and trawling may be difficult if large amounts of debris are produced as a result of the storm. However, other factors have also contributed to these trends. Management strategies have been implemented during the 1990s to limit catch from fish trawls (a closure south of Cape Hatteras) and shrimp trawls (50:50 ratio bycatch rule). In addition, participation in some of the fisheries in which kingfishes are typically harvested in has declined, primarily haul seines. Likewise, market conditions have also resulted in fewer landings of kingfish in recent years.

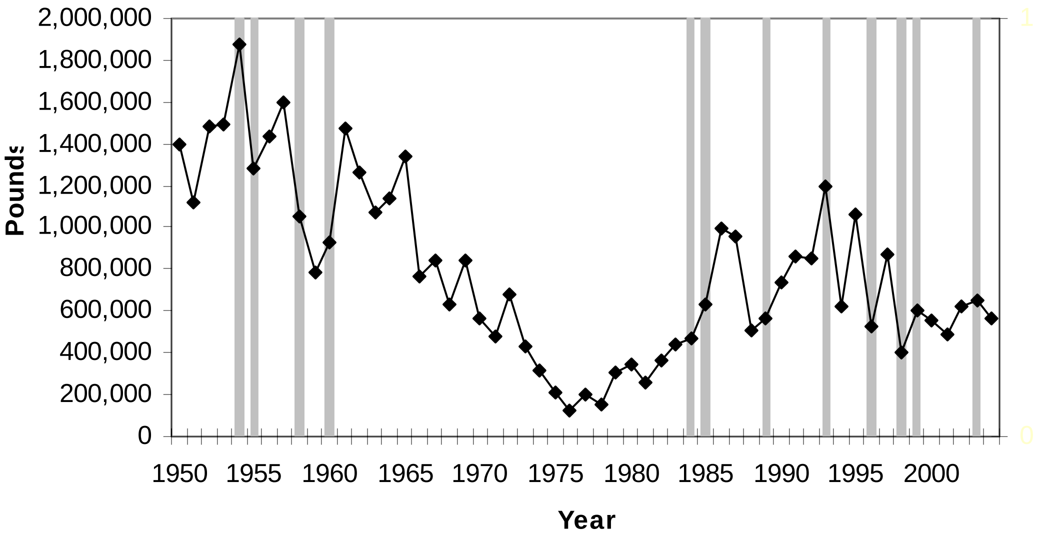

Figure 59. Annual landings of kingfishes, 1950-2004. Grey bars represent notable hurricane years.

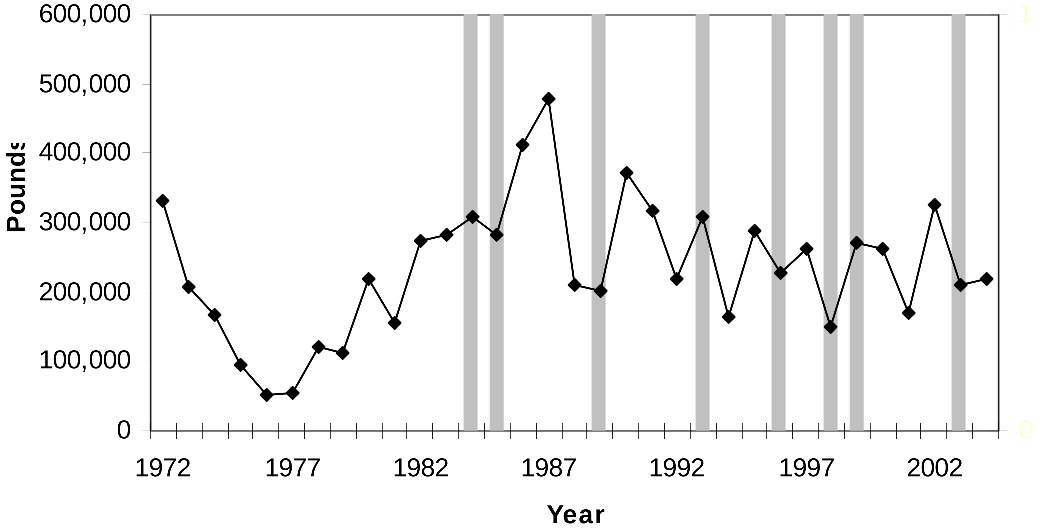

Figure 60. Landings of kingfishes during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Oysters

Eastern oysters (*Crassostrea virginica*) are currently managed under the North Carolina Oyster FMP (NCDMF 2001b). Historically, oysters were harvested in large quantities from Pamlico Sound but disease has caused the stock to decline. Currently, oysters are mainly harvested from Pamlico Sound and south with hand gears (by hand, rakes, tongs) and oyster dredges. Oysters are mainly landed during the fall and winter months with most landings occurring in Carteret, Onslow, Brunswick, and New Hanover counties (Bianchi 2004).

The oyster fishery was very productive in the early 1950s but landings declined steadily from the mid 1950s to the mid 1970s (Figure 61). Oyster production increased throughout the mid 1980s. Oyster landings then sharply declined after 1988 and have remained relatively consistent but low since that time, primarily due to disease. A few correlations are seen when the annual landings of oysters are compared to years of notable hurricane activity. Oyster landings declined notably in 1954, 1955, 1985, and 1989. Comparing the landings of oysters during the hurricane season to hurricane activity shows that landings were down in the hurricane years of 1985, 1989, and 1999 (Figure 62).

These trends suggest that hurricanes could have a negative impact on the oyster fishery. This could be due to a number of factors such as a decline in participation because fishermen are tending to preparations and repairs before and after hurricanes, oyster mortality due to sedimentation, declining water quality, and subsequent harvest closures after the storm from runoff. However, these trends are not entirely driven by hurricane activity. Oysters are susceptible to disease and management measures have changed over time that have also impacted the fishery.

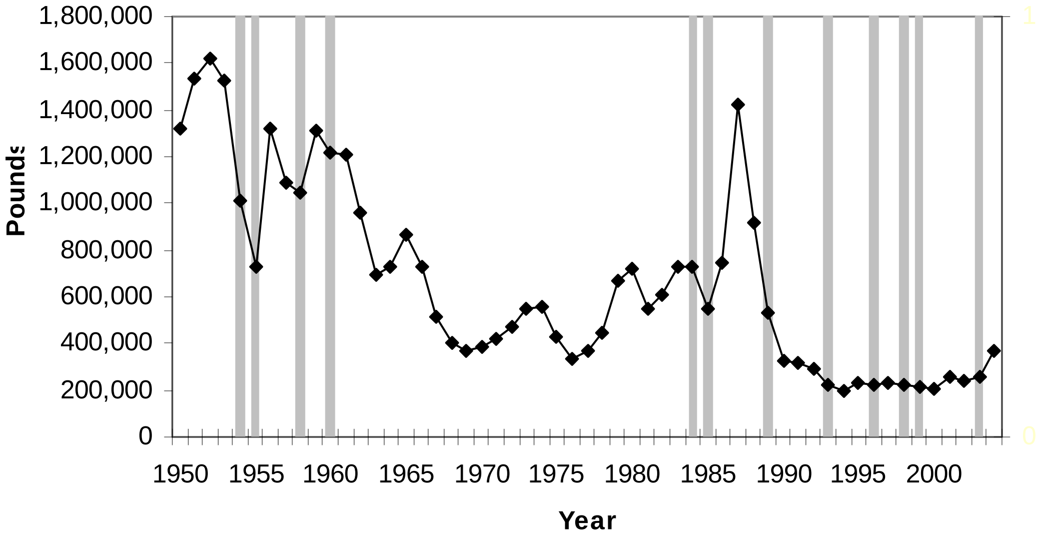

Figure 61. Annual landings of oysters, 1950-2004. Grey bars represent notable hurricane years.

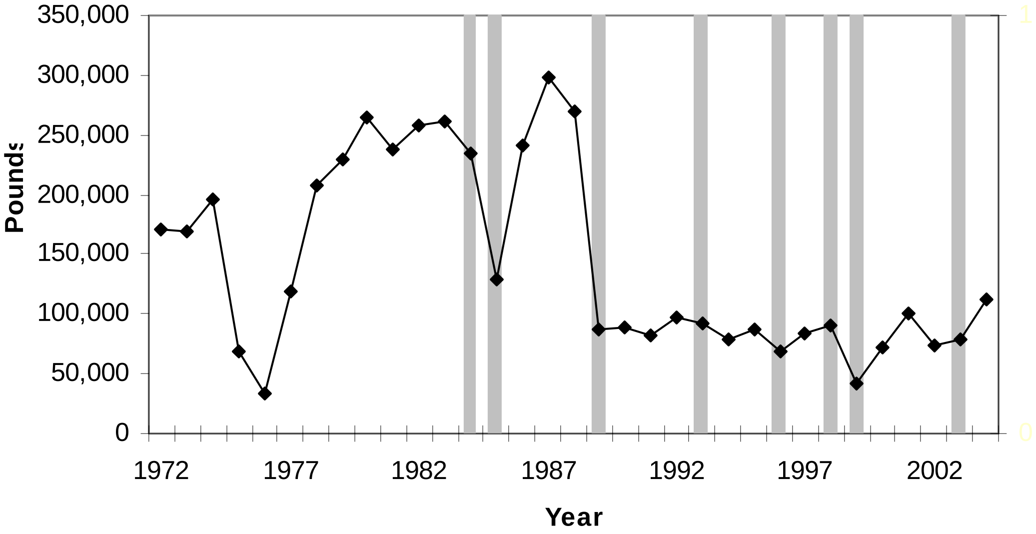

Figure 62. Landings of oysters during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Red Drum

Red drum (*Sciaenops ocellatus*) are currently managed by the ASMFC under the Red Drum FMP in addition to a state level FMP (NCDMF 2001c; ASMFC 2002a). Red drum are primarily harvested in Pamlico Sound with gill nets and seines. The majority of red drum landings occur in Dare, Carteret, Hyde, and Pamlico counties during the summer and fall months with smaller landings occurring during the winter and spring (Bianchi 2004).

The red drum fishery was fairly productive in the early 1950s with landings reaching a peak of 285,000 pounds in 1953 (Figure 63). Landings then declined throughout the rest of the 1950s and into the late 1960s. The landings of red drum then increased steadily until 1975 and have been highly variable since that time. Comparing the landings of red drum with hurricane activity did not show any consistent trends with landings increasing during some active years (1960, 1989, 1993, 1998, and 1999) and declining in others (1955, 1958, 1985, and 1996). Inconsistent trends also appear when landings during the hurricane season are compared to hurricane activity (Figure 64). Landings of red drum declined in 1984, 1985, and 1996 and increased in 1993, 1998, and 1996.

The inconsistent trends in landings data for red drum suggest that other factors influence the fishery. Hurricanes likely do impact the fishery but probably not to the same extent as other factors. Management measures have been put in place to rebuild the red drum stock since the mid 1990s including size limits, trips limits, and a harvest cap, but these measures have changed over this time period making the cause of landings trends difficult to determine.

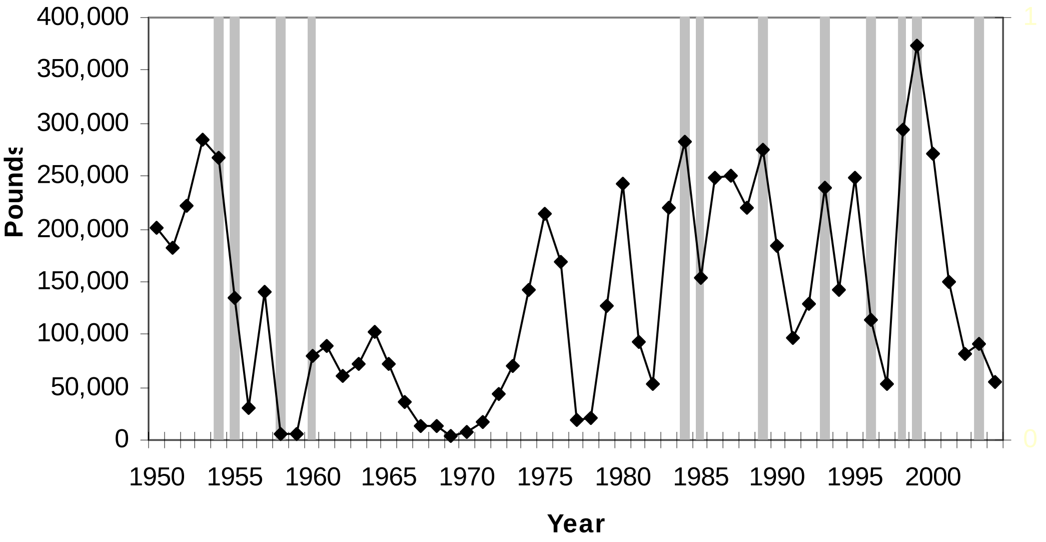

Figure 63. Annual landings of red drum, 1950-2004. Grey bars represent notable hurricane years.

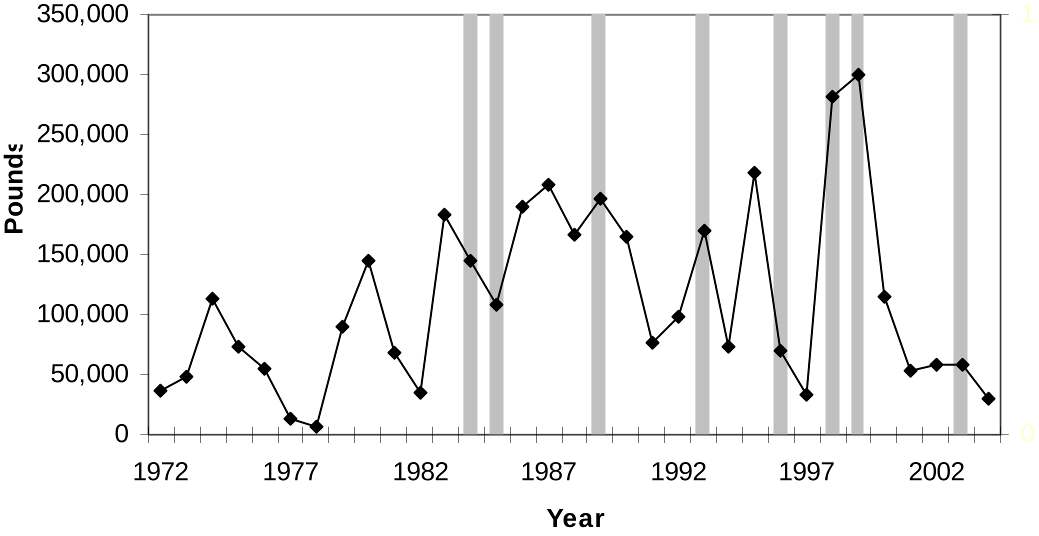

Figure 64. Landings of red drum during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Sea Basses

Two species of sea basses are generally landed in North Carolina, the black sea bass (*Centropristis striata*) and the rock sea bass (*C. philadelphica*) with black sea bass comprising the majority of the landings. Black sea bass north of Cape Hatteras are managed under the joint Summer Flounder, Scup and Black Sea Bass FMP of the ASMFC and MAFMC (ASMFC 1996; NCDMF 2002). Black sea bass south of Cape Hatteras and rock sea bass are managed under the Snapper-Grouper FMP of the SAFMC as part of the snapper-grouper complex (SAFMC 1983b; NCDMF 2002). Sea bass are primarily harvested from the ocean greater than 3 miles offshore. North of Cape Hatteras, sea basses are mainly harvested with trawls while south of Cape Hatteras fish pots and rod and reel account for the majority of the landings. The fishery primarily occurs during the late fall through spring months (November to April). Five counties account for the majority of landings: Onslow, Dare, New Hanover, and Carteret (Bianchi 2004).

Landings of sea basses were relatively minor through the 1950s (Figure 65). The fishery flourished in the 1960s with landings peaking in 1967 at almost 2 million pounds. Landings declined throughout the early 1970s and then varied widely from the mid 1970s to early 1990s. Landings remained relatively constant throughout the rest of the time period. When landings of black sea bass are compared to hurricane activity, no trends are apparent. There are years that decline or increase during years in which notable hurricanes occurred; however those trends are not unique and remain within the normal variability of the fishery. The same trends are seen when looking at the landings of black sea bass during the hurricane season (Figure 66).

The time of year in which this fishery occurs does not lend itself to be affected by hurricanes. The trends in this fishery are probably due to changes in regulations over time and stock availability.

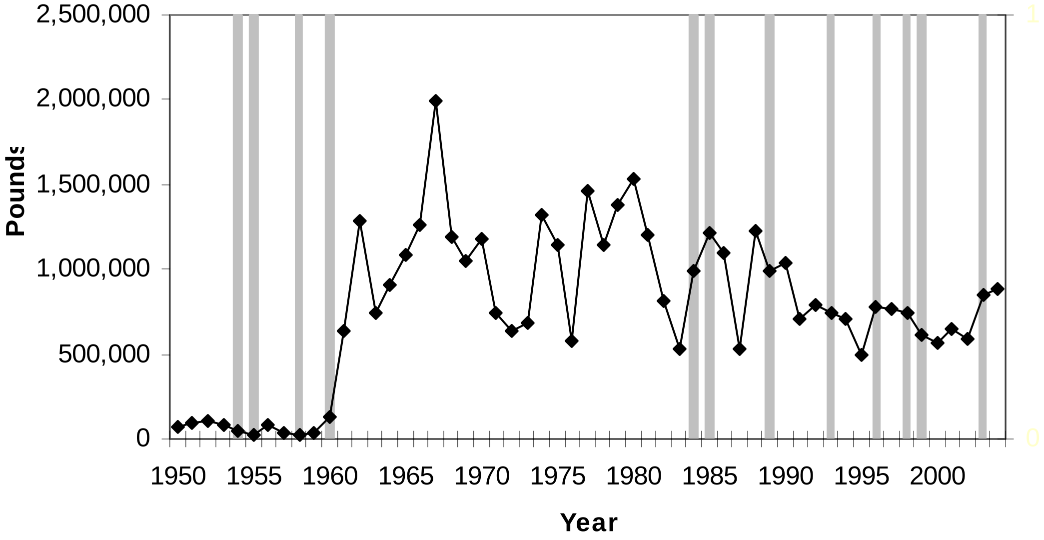

Figure 65. Annual landings of sea basses, 1950-2004. Grey bars represent notable hurricane years.

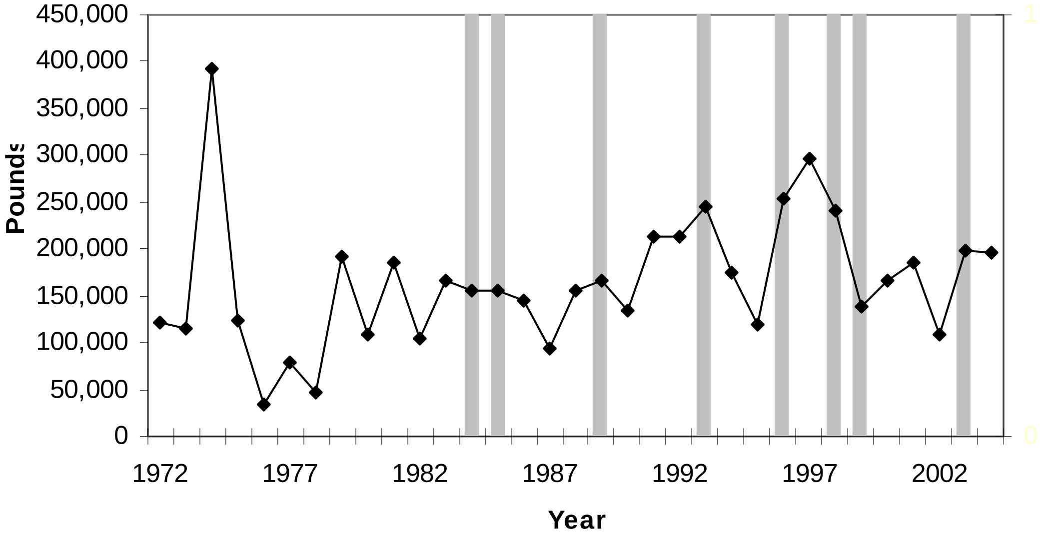

Figure 66. Landings of sea basses during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Snappers

Snappers are managed by the SAFMC under the Snapper-Grouper FMP (SAFMC 1983b; NCDMF 2002). The most common snapper landed in North Carolina is the vermilion snapper (*Rhomboplites aurorubens*). Other snappers landed in North Carolina include red snapper (*Lutjanus campechanus*), silk snapper (*L. vivanus*), and mutton snapper (*L. analis*). Snappers are generally landed in the ocean more than 3 miles offshore with rod and reel and trolling gears. Snappers are harvested throughout the year and are mainly landed in Brunswick and Carteret counties (Bianchi 2004).

Landings of snapper were relatively minor until the mid to late 1970s when the fishery started to develop (Figure 67). Landings peaked in 1982 and have fluctuated since that time with a slight declining trend observed overall. When the landings trends are compared to hurricane activity, only two years stand out: 1958 and 2003. During these years, landings of snapper decreased dramatically. The same trend is also seen when landings of snapper during the hurricane season are compared to hurricane activity (Figure 68).

These trends suggest hurricanes may have an impact on the snapper fishery but it is likely a minor impact. There may be a very short-term impact because of fishermen's inability to fish in rough sea conditions for a few days before and after a storm. However, these landings trends are also driven by other factors such as management strategies and market conditions. Landings of snapper declined significantly in 1992 when there was no notable hurricane activity in North Carolina indicating that other factors also influence the fishery.

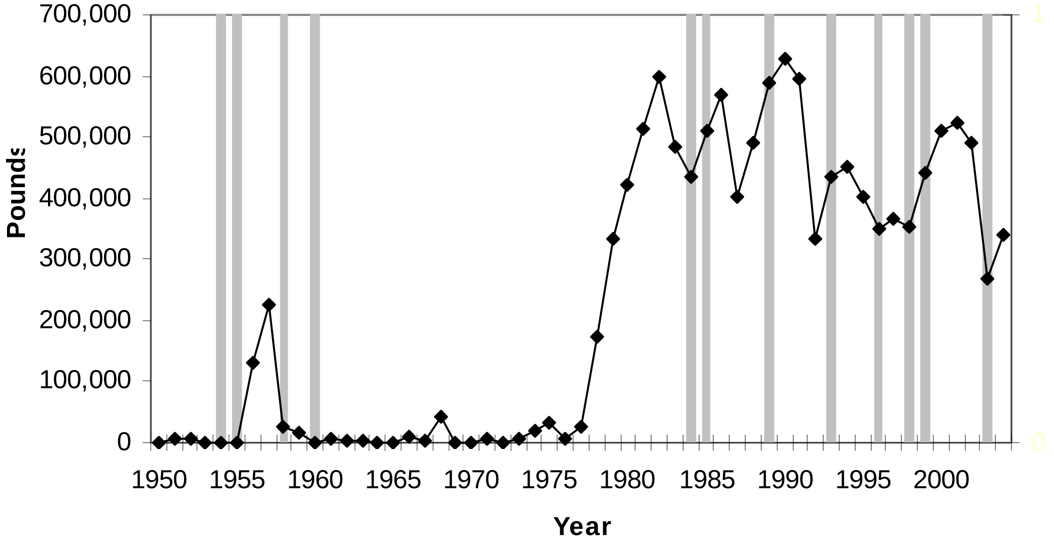

Figure 67. Annual landings of snappers, 1950-2004. Grey bars represent notable hurricane years.

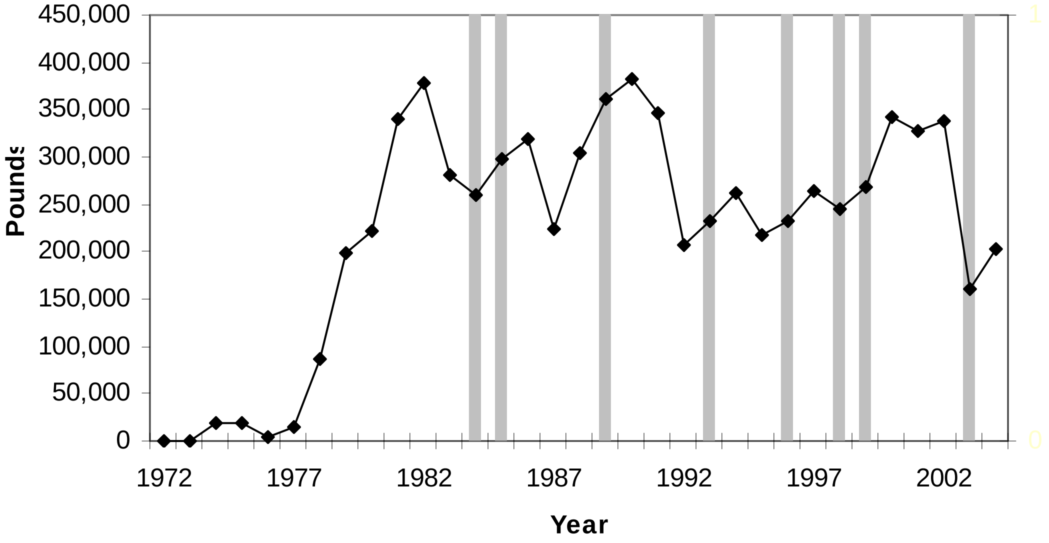

Figure 68. Landings of snappers during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Southern Flounder

Southern flounder (*Paralichthys lethostigma*) are currently managed under the North Carolina Southern Flounder FMP (NCDMF 2005a). The majority of southern flounder are harvested from the Albemarle-Pamlico Sound estuarine system with gill nets, pound nets, and trawls. Southern flounder are harvested throughout the year but landings peak in the fall months. The majority of southern flounder landings occur in Dare, Carteret, Hyde, Pasquotank, Beaufort, Perquimans, Chowan, and Tyrrell counties (Bianchi 2004).

The southern flounder fishery remained relatively stable during the 1950s and 1960s with annual landings averaging around 430,000 pounds (Figure 69). Landings increased steadily in the 1970s and eventually peaked in 1994. Since 1994, landings have declined overall. When the annual landings of southern flounder are overlaid with hurricane activity, two years stand out: 1999 and 2003. Southern flounder landings declined noticeably in both of those of years. These same trends are also seen when the landings during the hurricane season are examined (Figure 70).

These trends suggest hurricanes may have a negative impact on the southern flounder fishery. A large portion of the southern flounder fishery is conducted with pound nets during the fall. Hurricanes impacting North Carolina during late September and October disrupt these fisheries by forcing fishermen to remove their gear from the water. Those fishermen that do not remove their gear from the water prior to a hurricane often lose their gear resulting in less effort in the fishery. At the same time, fishermen are also making preparations to protect their belongings resulting in a decline in effort. Southern flounder may respond to the presence of a storm by migrating out to the ocean sooner than they would in non-hurricane years. However, other factors also contribute to the trends observed in southern flounder such as changes in the stock and management strategies. In addition, each hurricane has different characteristics with respect to wind speed, storm direction, location of landfall, and rainfall and, as a result, would likely not affect the fishery in a consistent manner.

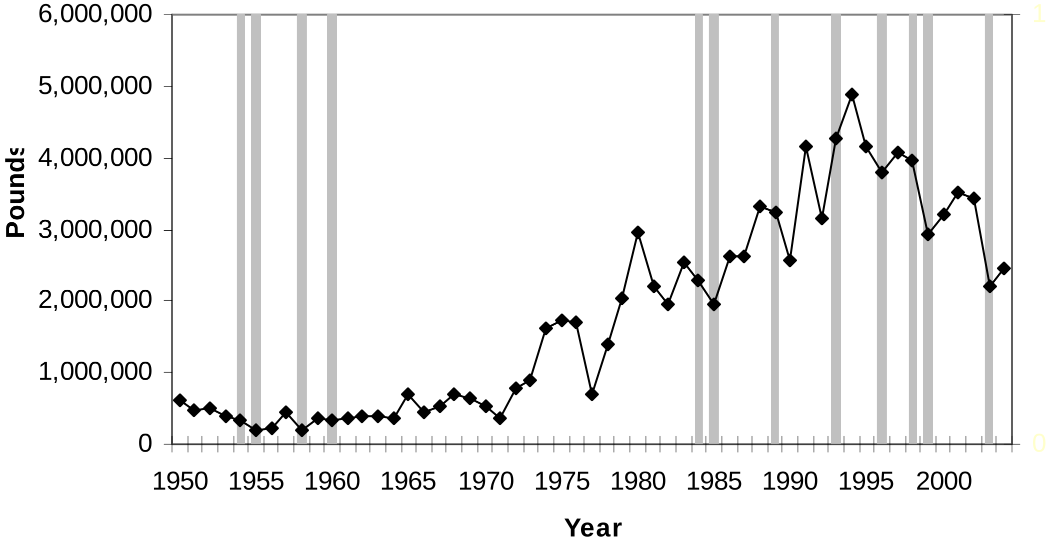

Figure 69. Annual landings of southern flounder, 1950-2004. Grey bars represent notable hurricane years.

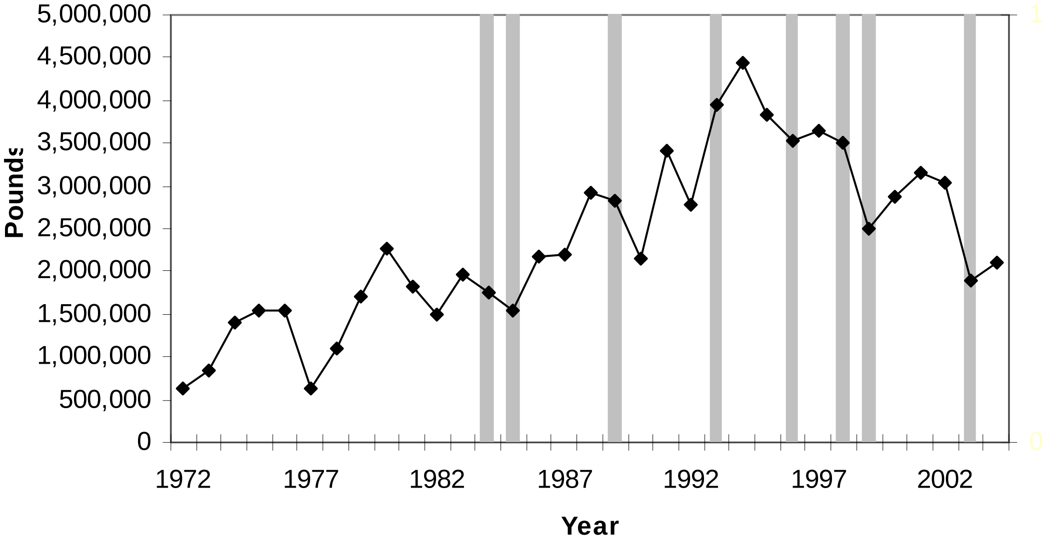

Figure 70. Landings of southern flounder during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Spadefish

Spadefish (*Chaetodipterus faber*) are currently managed by the SAFMC under the Snapper-Grouper FMP (SAFMC 1983b). Spadefish are primarily harvested from Pamlico and Core Sounds with pound nets and gill nets. Landings typically occur during the summer and fall months with landings peaking in September and October. Carteret, Dare, and Hyde account for the majority of the landing (Bianchi 2004).

Landings of spadefish were low (under 20,000 lb per year) and fluctuated from the late 1950s to the mid 1980s (Figure 71). Spadefish landings increased sharply in 1985 but declined the following year. Landings then remained stable and increased in 1996 and fluctuated for the rest of the period. Five years are noteworthy when the landings of spadefish are overlaid with hurricane activity: 1984, 1985, 1996, 1998, and 2003. Harvest of spadefish increased in 1984, 1985, and 1996 but years even occurring during notable hurricane activity. Spadefish is not a high dollar fishery and declined in 1998 and 2003. The same trends are observed when looking at the landings during the hurricane season (Figure 72).

The landings trends for spadefish suggest that hurricanes do not have an impact on this fishery. The spadefish fishery is mainly driven by changes in effort. In years when landings were high, so were the number of trips (NCDMF 2006c) with some of these fish bringing in approximately \$0.20 to \$0.30 per pound (Bianchi 2004). It is likely that spadefish are bycatch in the pound net and gill net fisheries for flounder and other high dollar species. Therefore, spadefish are probably brought to dock only when abundances of the higher dollar species are low.

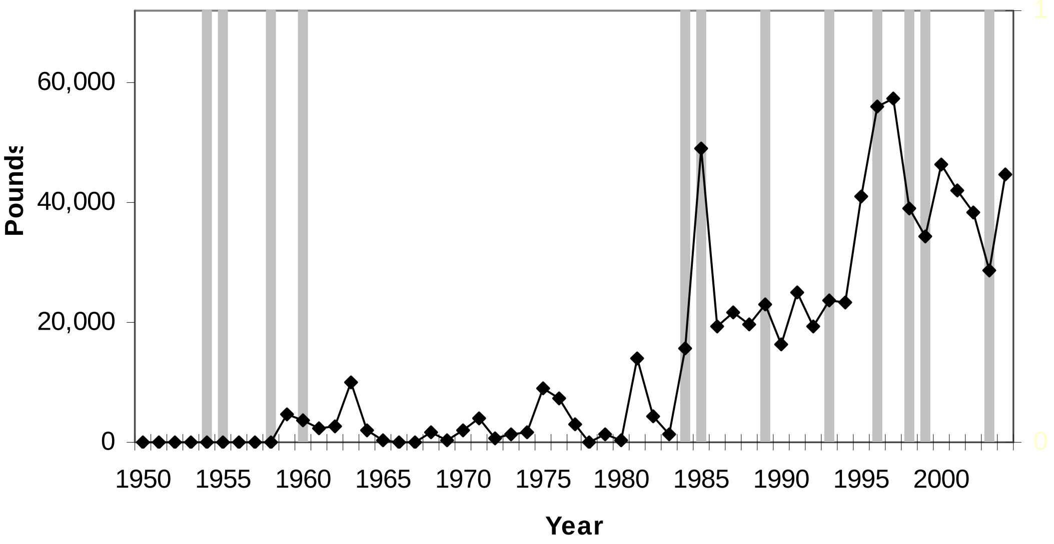

Figure 71. Annual landings of spadefish, 1950-2004. Grey bars represent notable hurricane years.

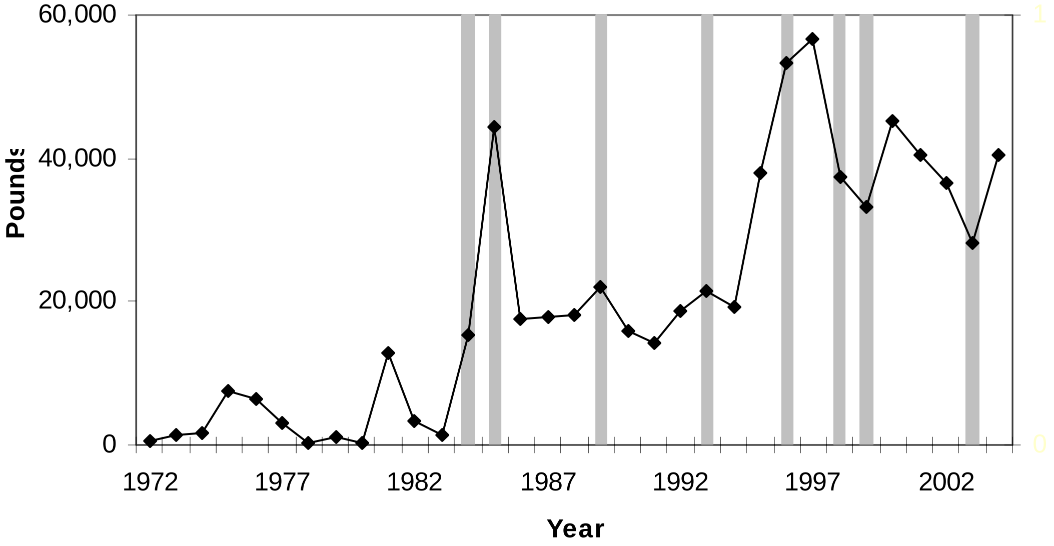

Figure 72. Landings of spadefish during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Spanish Mackerel

Spanish mackerel (*Scomberomorus maculatus*) are currently managed by the ASMFC under the Spanish Mackerel FMP and by the SAFMC under the Coastal Migratory Pelagics FMP (SAFMC 1983a; ASMFC 1990; NCDMF 2002). Commercial harvest of Spanish mackerel mostly occurs in the ocean and in Pamlico Sound with gill net and pound net gears. Spanish mackerel are harvested during the summer and fall months with landings peaking in September and October. The majority of landings occur in Dare County with Hyde and Carteret counties ranking second and third (Bianchi 2004).

Spanish mackerel landings increased from 1950 to 1956 and then declined overall through until the mid 1980s. Landings increased starting in 1985 and throughout the early 1990s. Landings fluctuated during the rest of the time period (Figure 73). When the landings data are compared to hurricane activity, some years had an increase in landings from the year before (1954 and 1989) while others showed a decline (1955, 1993, 1998, and 2003). The same trends are observed when looking at landings during the hurricane season (Figure 74).

The landings trends of Spanish mackerel suggest this fishery can be negatively impacted by hurricanes. The fishery is mainly conducted during the summer and fall months when hurricanes typically form. Although during some active years the landings of Spanish mackerel actually increased when compared to the prior year, the increase in landings occurred after the storms impacted the coast. During the months of hurricane activity, fishermen are probably preparing for the storms and removing gear out of the water therefore reducing effort. However, it is also likely that other factors contribute to these trends such as changes in management and species availability.

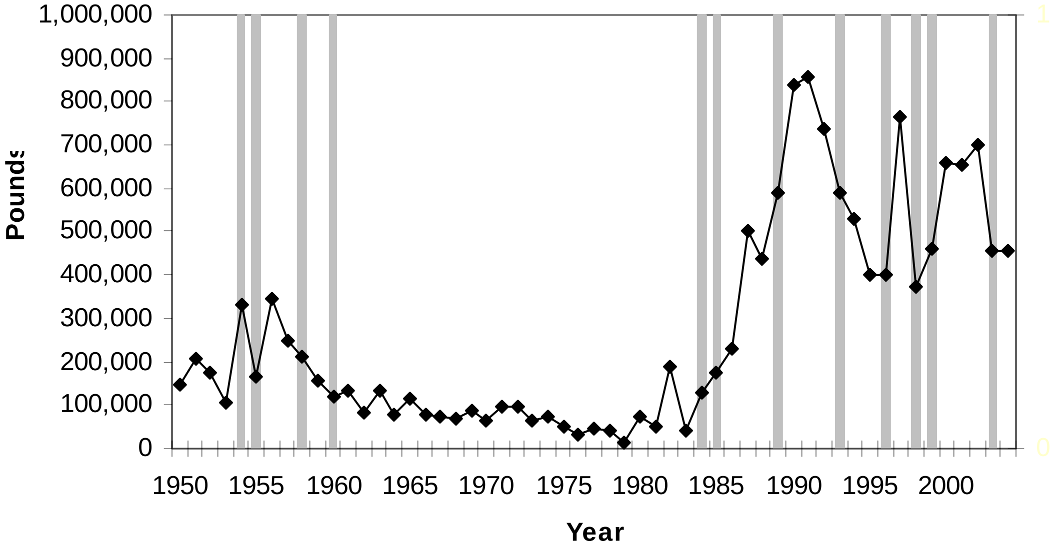

Figure 73. Annual landings of Spanish mackerel, 1950-2004. Grey bars represent notable hurricane years.

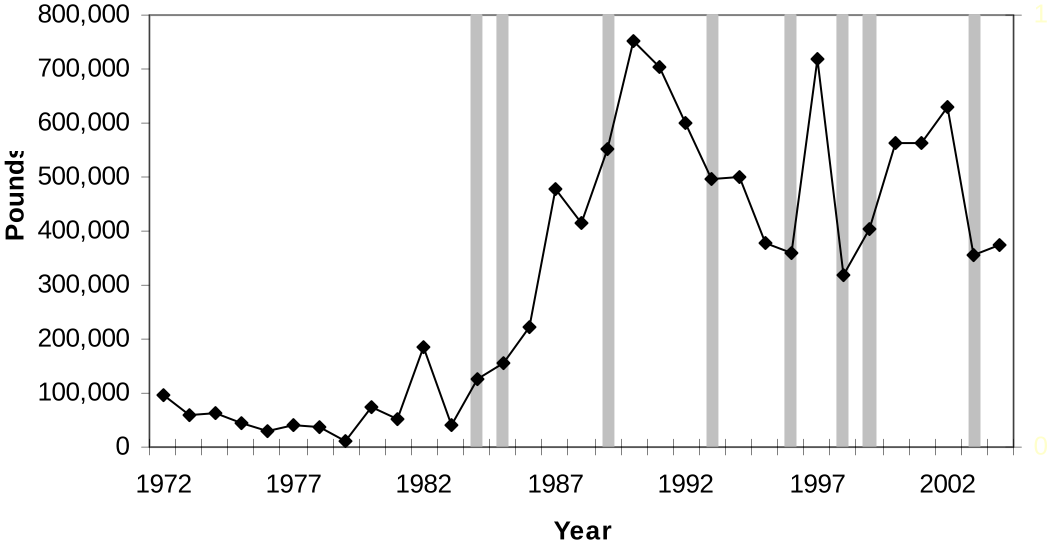

Figure 74. Landings of Spanish mackerel during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Spot

Spot (*Leiostomus xanthurus*) are currently managed by the ASMFC under the Spot FMP (ASMFC 1987a; NCDMF 2002). Commercial harvest of spot mainly occurs in Core Sound, Pamlico Sound, and the Atlantic Ocean with gill nets and seines. Spot are mainly landed during the summer and fall months with landings peaking during October. Five counties account for the majority of the state's landings: Carteret, Dare, Brunswick, Onslow, and New Hanover (Bianchi 2004).

The spot fishery was productive during the early 1950s but then landings declined through the mid 1950s to the late 1960s overall (Figure 75). Landings then increased dramatically in the early 1970s with landings peaking in 1975. However, since 1975 landings steadily declined overall, except for 1979 and 1980. There is no apparent trend when landings are compared to hurricane activity during the time period. The lack of correlation is also seen when looking at the landings of spot during the hurricane season (Figure 76). These trends suggest that hurricanes do not have a large impact on the spot fishery, but rather that other factors have an impact on the fishery such as changes in effort over time, fish availability, or changes in market conditions.

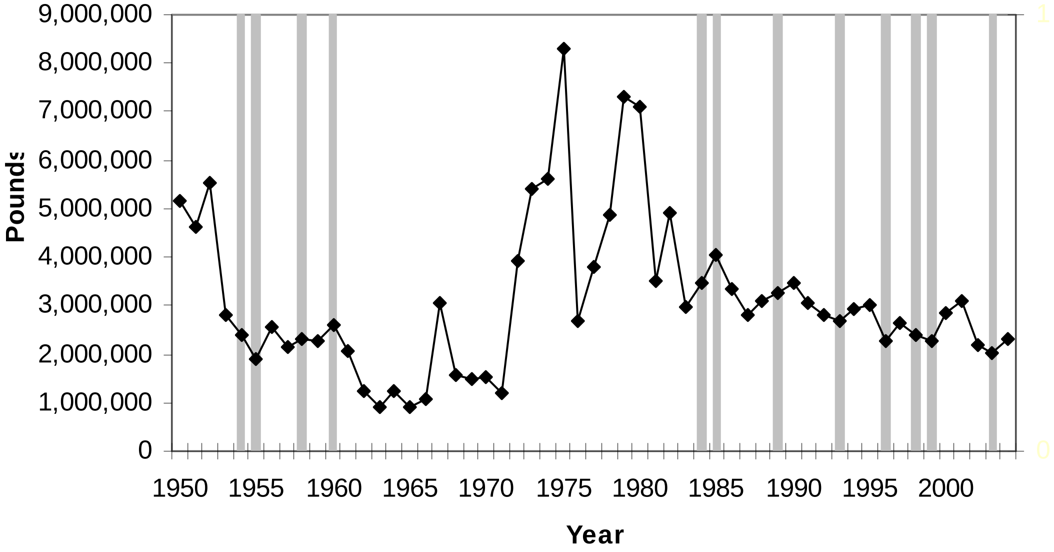

Figure 75. Annual landings of spot, 1950-2004. Grey bars represent notable hurricane years.

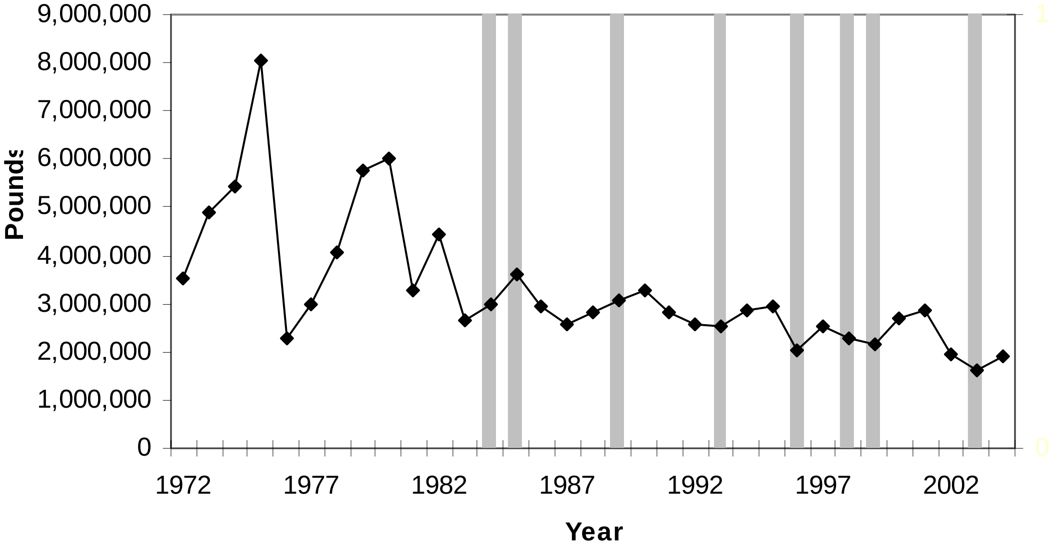

Figure 76. Landings of spot during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Spotted Seatrout

Spotted seatrout (*Cynoscion nebulosus*) are currently managed by the ASMFC under the Spotted Seatrout FMP (ASMFC 1984; NCDMF 2002) and are selected to be managed under a future state-level FMP. Spotted seatrout are commercially harvested throughout the Albemarle-Pamlico estuarine system and the Atlantic Ocean. Gill nets and seines account for the majority of the landings. Commercial harvest occurs throughout the year with harvest peaking in late fall and winter. Dare, Carteret, and Pamlico counties account for the majority of the landings (Bianchi 2004).

Spotted seatrout landings declined overall from the mid 1950s until the late 1960s (Figure 77). Landings then increased dramatically during the early and mid 1970s with landings reaching a peak in 1974. Spotted seatrout harvest declined sharply after this peak and remained low throughout the early 1980s. Harvest increased through the mid 1980s and early 1990s and has fluctuated widely since. When the landings trends for spotted seatrout are compared to the trends of hurricane activity, inconsistent trends are observed. Landings declined in 1955, 1958, 1960, and 1996 and increased in 1989 and 1999. However, these trends are not all observed when the landings of spotted seatrout during the hurricane season are compared to hurricane activity (Figure 78). Only two years stand out in this comparison: a decrease in landings in 1996 and an increase in landings in 1999.

These trends suggest that hurricanes have a minor impact on the spotted seatrout fishery, if any at all. A large portion of this fishery is conducted during the winter months when hurricane activity is negligible. Other factors also affect this fishery, primarily changes in effort.

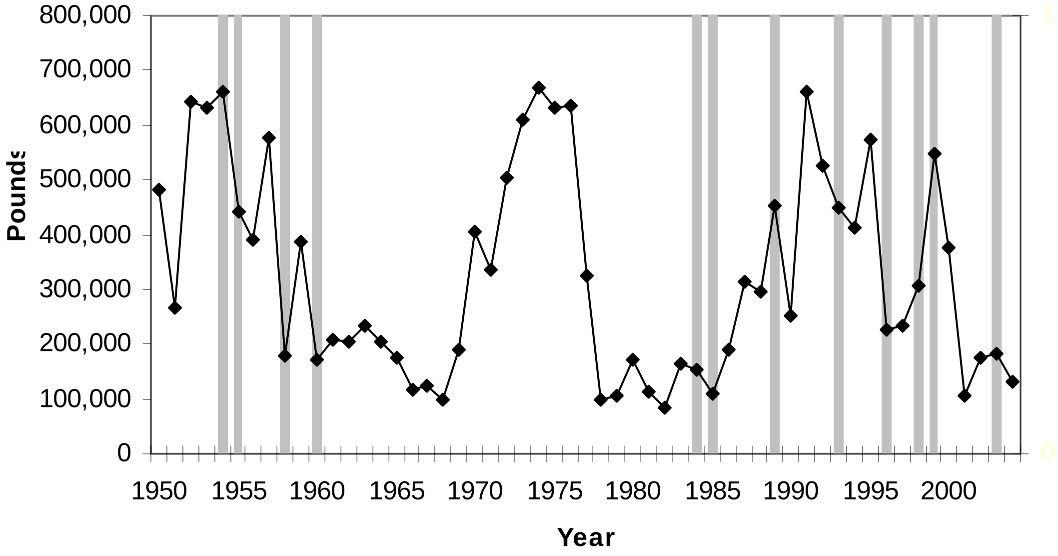

Figure 77. Annual landings of spotted seatrout, 1950-2004. Grey bars represent notable hurricane years.

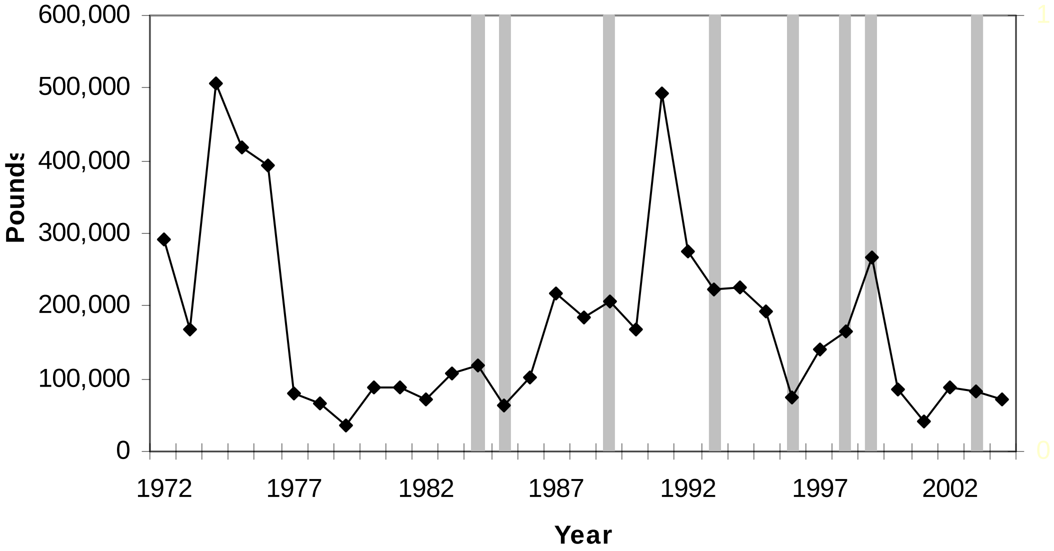

Figure 78. Landings of spotted seatrout during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Striped Bass

Striped bass (*Morone saxatilis*) are currently managed under the NC Estuarine Striped Bass FMP and the Striped Bass FMP of the ASMFC (ASMFC 2003; NCDMF 2004a). The commercial striped bass fishery primarily occurs in the nearshore ocean and the Albemarle Sound Management Area during the late fall through spring (November to April). Gill nets, seines, and trawls are the primary gears used to commercially harvest striped bass. The majority of commercial striped bass landings occur in Dare County (Bianchi 2004).

The commercial harvest of striped bass fluctuated through 1950s and mid 1960s and then increased dramatically in the late 1960s and early 1970s (Figure 79). Landings peaked in 1970 and then declined steadily until the early 1990s. Since the early 1990s, landings have increased overall through the rest of the time period. When the trends of hurricane activity are compared to the landings of striped bass an inconsistent correlation is observed. In some years with active hurricane seasons the landings increased (1954 and 1958), while in others the landings declined (1955 and 1996). These trends also differ when landings of striped bass during the hurricane season are compared to hurricane activity (Figure 80). Landings of striped during the hurricane season increased in 1984 and then declined sharply in 1985 while in other years, landings were not recorded.

Comparing the landings trends of striped bass with hurricane activity shows that hurricanes do not have a significant effect on the striped bass fishery. The fishery occurs during the winter when hurricanes would have little impact on any fishery. The trends observed in this fishery are mainly due to management strategies to help rebuild the stock. Striped bass has been managed under a strict trip limit and quota limit since the late 1990s and this has been the main influence on striped bass landings trends.

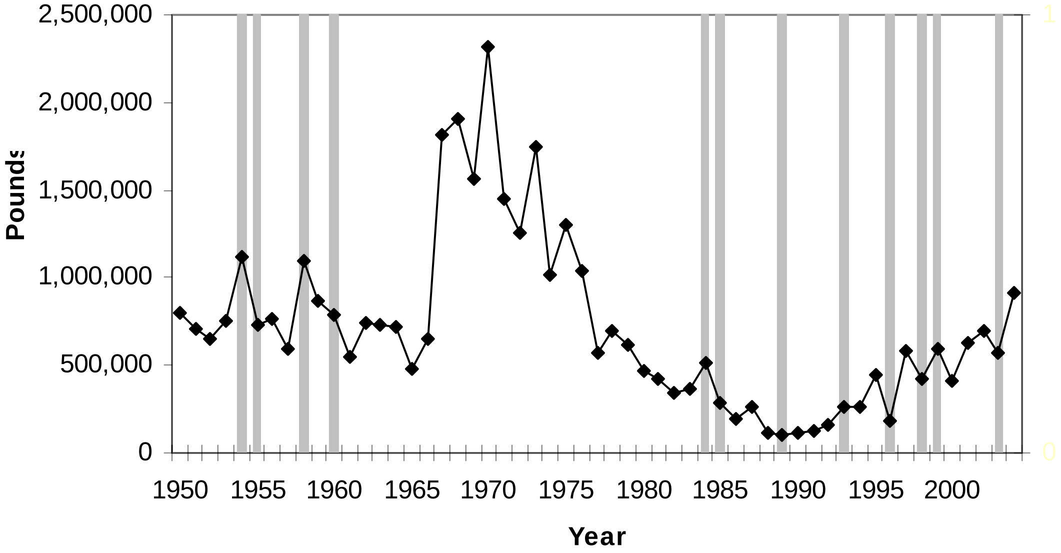

Figure 79. Annual landings of striped bass, 1950-2004. Grey bars represent notable hurricane years.

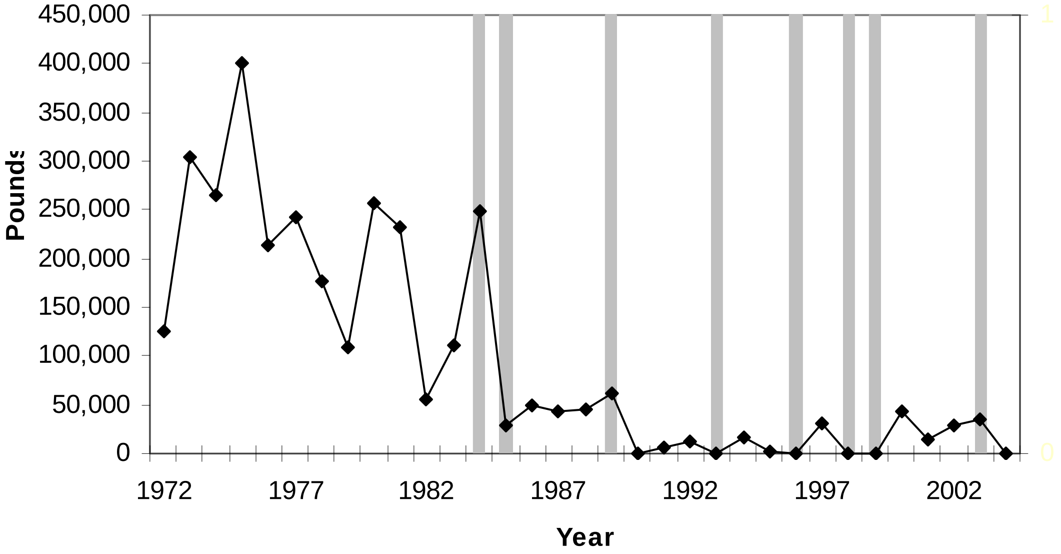

Figure 80. Landings of striped bass during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Summer Flounder

Summer flounder (*Paralichthys dentatus*) are currently managed under the joint Summer Flounder, Scup and Black Sea Bass FMP of the ASMFC and MAFMC (NCDMF 2002). Commercial harvest of summer flounder typically occurs from late fall through spring (November to April). Flounder trawls are the primary gear used to commercially harvest summer flounder. Summer flounder is commercially harvested from the Atlantic Ocean from North Carolina to southern New England with the majority of landings occurring in Dare, Carteret, Pamlico, and Hyde counties (Bianchi 2004).

Commercial harvest of summer flounder was fairly consistent throughout the 1950s, with landings averaging around 1.8 million lb (Figure 81). Landings then began to increase throughout 1960s and 1970s and reached a peak in 1979 at over 16 million pounds. Landings then declined overall (except for a peak in 1984 at around 13 million pounds) through the 1980s and mid 1990s. Coastwide commercial quotas were implemented in 1993; however, landings have increased overall since 1996. When landings of summer flounder are compared to hurricane activity two years stand out: 1984 and 1985. Landings increased in 1984 compared to the previous year and declined in 1985. These same trends are not observed when looking at the landings of summer flounder during the hurricane season (Figure 82). Landings increased in 1984 and 1993 and declined in 1989 and 1998. There were also some years without any landings

The trends in the landings suggest that hurricanes have little impact on the summer flounder fishery. The summer flounder fishery is highly seasonal with landings primarily occurring from late November to April, which are periods with little or no hurricane activity. The trends observed in this fishery are primarily due to changes in management over the years to rebuild the stock. Summer flounder are currently managed under a trip limit and quota system, which has had the largest impact on the trends observed in the fishery.

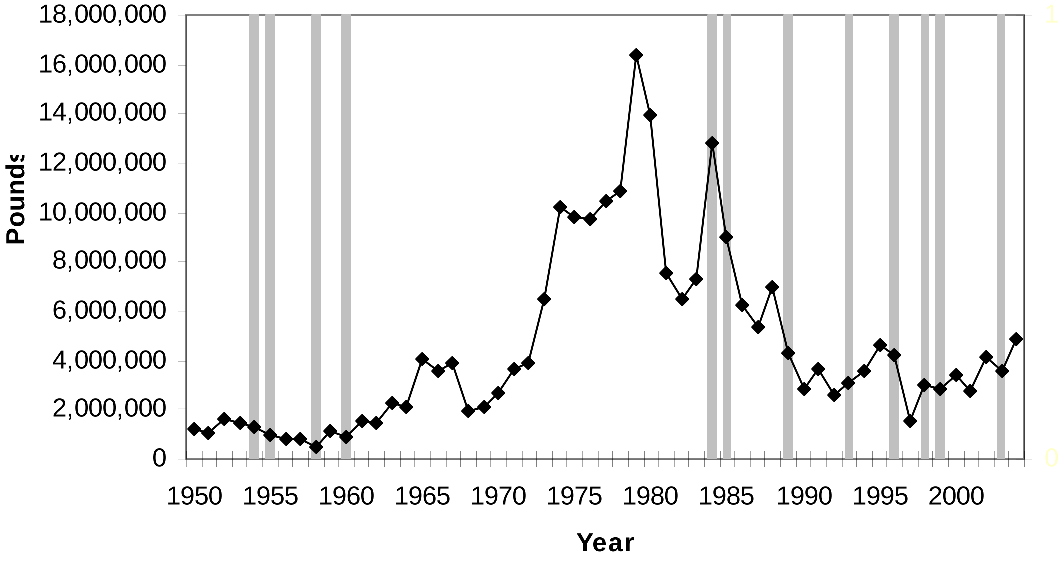

Figure 81. Annual landings of summer flounder, 1950-2004. Grey bars represent notable hurricane years.

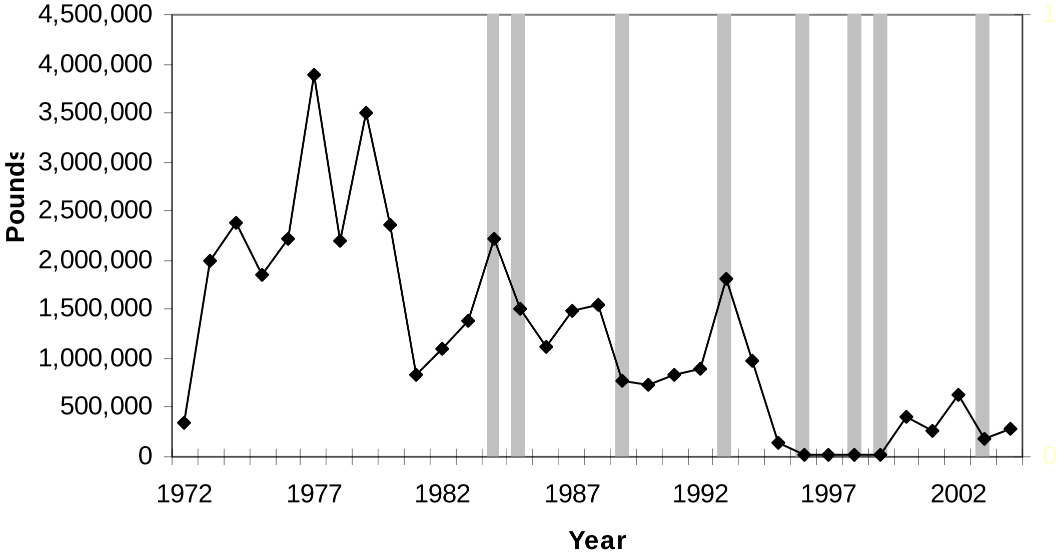

Figure 82. Landings of summer flounder during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Thread Herring

The thread herring (*Opisthonema oglinum*) fishery is an industrial fishery, similar to the menhaden purse seine fishery. The fishery primarily occurs during the fall with landings peaking in September and October. Thread herring are mainly harvested with purse seines in the Atlantic Ocean. Carteret County accounts for the majority of the landings (Bianchi 2004).

The annual landings of thread herring have been sporadic over the years with some years having zero landings and other years having over 20 million pounds of landings (Figure 83). Landings of thread herring fluctuated during the 1950s and early 1960s and then increased steadily until reaching a peak in 1972. Landings then declined overall through 1980s. Thread herring landings increased until 1997 and have declined since that time. When the landings of thread herring are overlaid with hurricane activity some trends are observed. Landings of thread herring were low in 1954, 1955, 1958, 1960 1989, 1998, 1999, and 2003. When the landings of thread herring during the hurricane season are compared to hurricane activity, the same types of trends are observed (Figure 84).

The thread herring fishery is a very sporadic (hit or miss) fishery even during low hurricane active years. The correlations between thread herring landings and active hurricane years suggest that the fishery could be impacted by hurricanes. This impact would likely be due to the inability of the fleet to leave port to participate in the fishery due to bad weather conditions and hurricane preparations. However, it is also just as likely that the schooling behavior of thread herring (e.g. schooling further offshore during some years) could have limited the fishery as well.

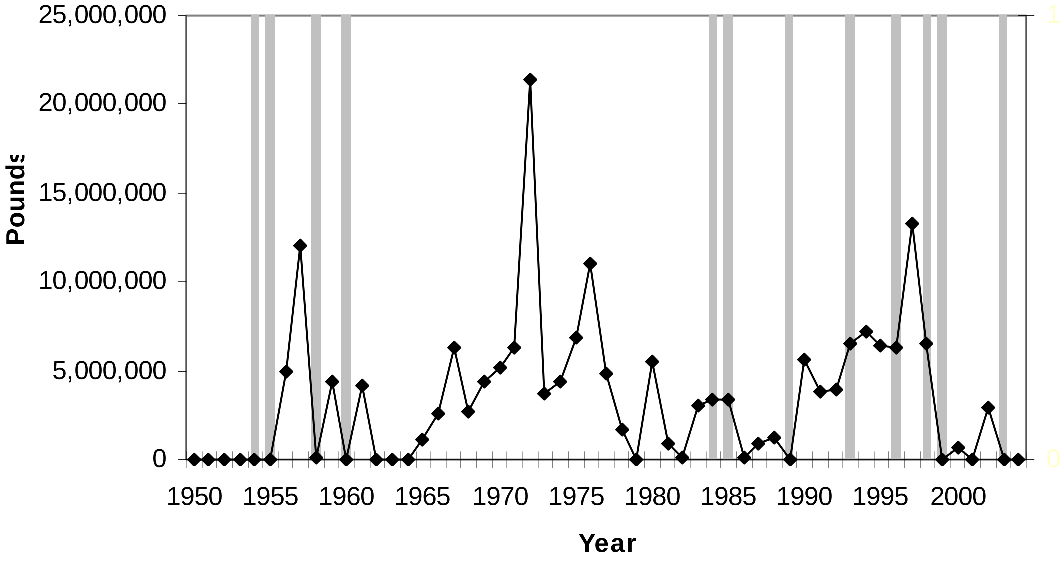

Figure 83. Annual landings of thread herring, 1950-2004. Grey bars represent notable hurricane years.

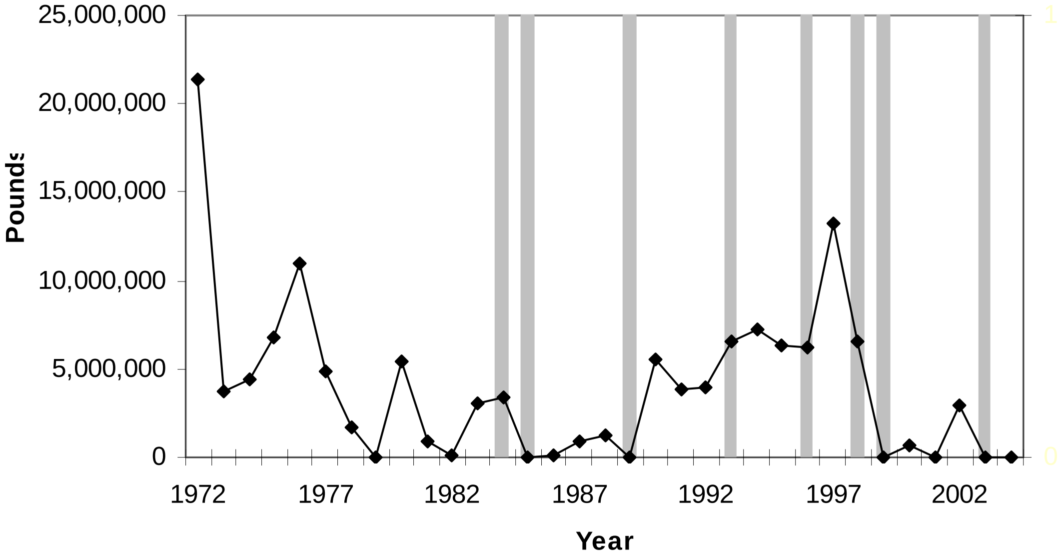

Figure 84. Landings of thread herring during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Tilefish

Tilefish are managed under the Snapper-Grouper FMP of the SAFMC (SAFMC 1983b). Three species of tilefish are landed in North Carolina, the golden tilefish (*Lopholatilus chamaeleonticeps*), the blueline tilefish (*Caulolatilus microps*) and the sand tilefish (*Malacanthus plumieri*). Tilefish is commercially harvested throughout the year with landings peaking during the summer months (May thru September). Longlines and rod and reel gears are typically used to commercially harvest tilefish. Four counties account for most of the landings: Dare, Brunswick, New Hanover, and Carteret (Bianchi 2004).

Similar to other species within the snapper-grouper complex, the tilefish fishery did not become productive until the late 1970s and early 1980s in North Carolina (Figure 85). Landings increased steadily from 1978 to 1992 but then declined overall after peaking in 1992 until 1999. Landings increased from 1999 to 2002 but then declined noticeably in 2003 and 2004. Comparing the annual landings trends to hurricane activity shows five years of interest: 1984, 1985, 1993, 1996, and 1999. In all of these years, except for 1984, landings of tilefish declined. Landings of tilefish during the hurricane season do not show the same pattern when compared to hurricane active years (Figure 86). Although the landings do increase in 1984 and decline in 1985, landings remain within the normal variation during that time period. However, landings show a sharp decline in 1993, 1998, and 2003.

Comparing the landings data with hurricane activity suggests that hurricanes might have a negative impact on the fishery. However, this impact is most likely minor and would be most likely due to vessels not being able to get to leave port due to bad weather. The increase in landings during 1985 was mostly during non-hurricane season months. This fishery is mainly affected by changes in regulations and stock abundance and not hurricane activity.

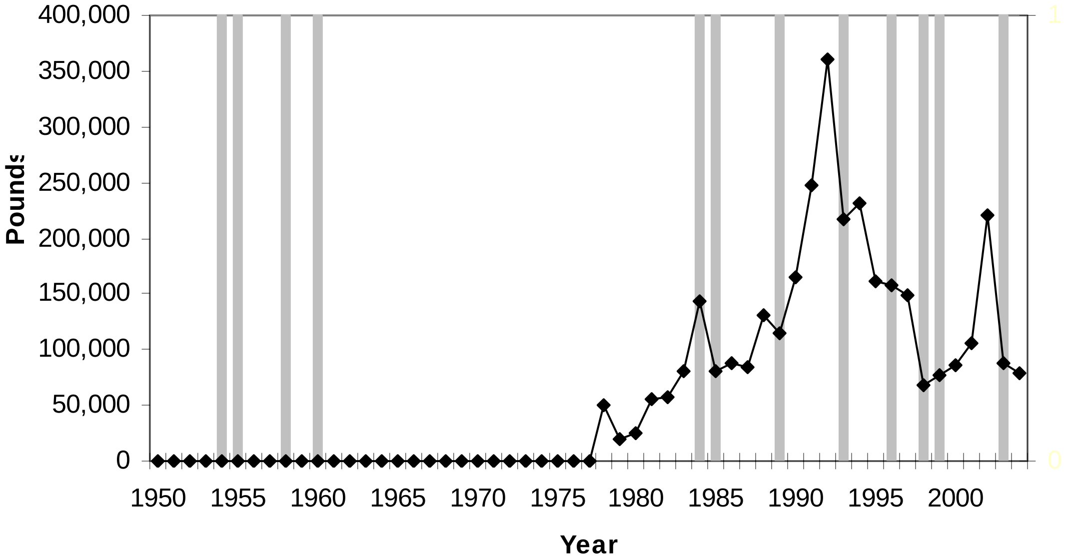

Figure 85. Annual landings of tilefishes, 1950-2004. Grey bars represent notable hurricane years.

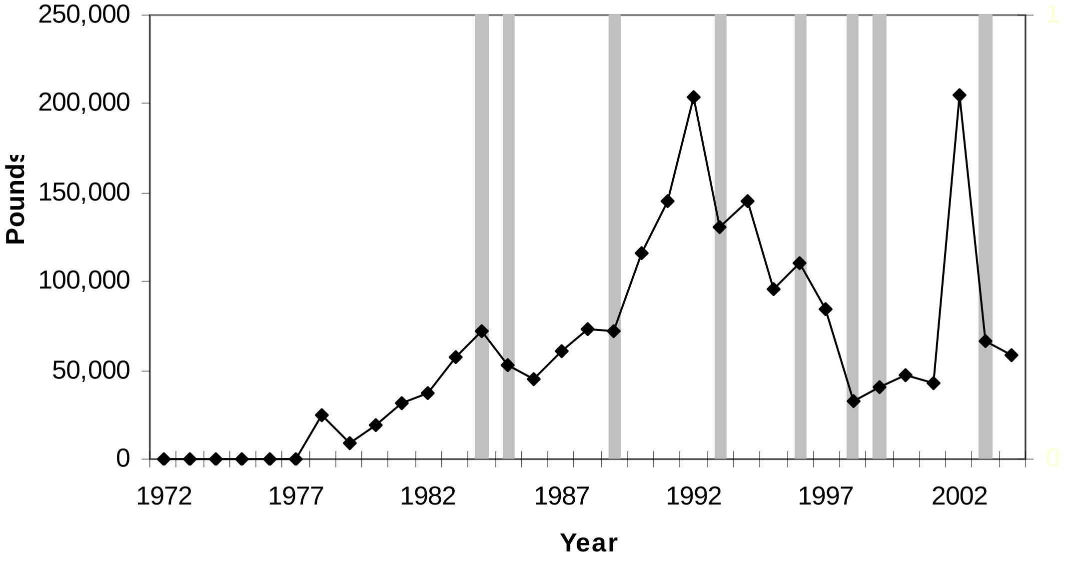

Figure 86. Landings of tilefishes during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Triggerfishes

Triggerfishes are managed under the Snapper-Grouper FMP of the SAFMC (SAFMC 1983b). Triggerfish species that occur in North Carolina waters include gray triggerfish (*Balistes capriscus*), queen triggerfish (*B. vetula*), rough triggerfish (*Canthidermis maculata*), ocean triggerfish (*C. sufflamen*), and sargassum triggerfish (*Xanthichthys ringens*). Triggerfish are commercially harvested throughout the year with landings peaking during the late summer and fall (August thru November) in the ocean greater than three miles offshore. The triggerfish fishery is mainly prosecuted with rod and reel gears and the majority of the landings occur in Brunswick and Carteret counties (Bianchi 2004).

The triggerfish fishery did not start until the early 1980s with landings averaging around 40,000 lb per year (Figure 87). Landings then increased sharply in the 1990s and peaked in 1997. Landings then declined until 2000 and have remained relatively stable since then. Three years are notable when the annual landings of triggerfish are compared to hurricane activity, 1993, 1998, and 1999. During 1993, the landings of triggerfish increased while in 1998 and 1999 landings declined. When the landings of triggerfish during the hurricane season are compared to the trends in hurricane activity the same general trend is observed (Figure 88). Landings are low during the 1980s and peak in the 1990s and then decline again. However, the increase in landings in 1993 is not as large but the declining trends in 1998 and 1999 are still present.

The comparison of landings to hurricane activity suggests that hurricanes do not have a large impact on the fishery. Although the landings increased in 1993, a large portion of that increase occurred outside of the hurricane season and during a period of time when the fishery was expanding. The decline in landings in 1998 and 1999 may have been impacted by the hurricanes during those years but landings never did increase back to the levels of the mid 1990s. These trends were most likely driven by changes in effort during that time period.

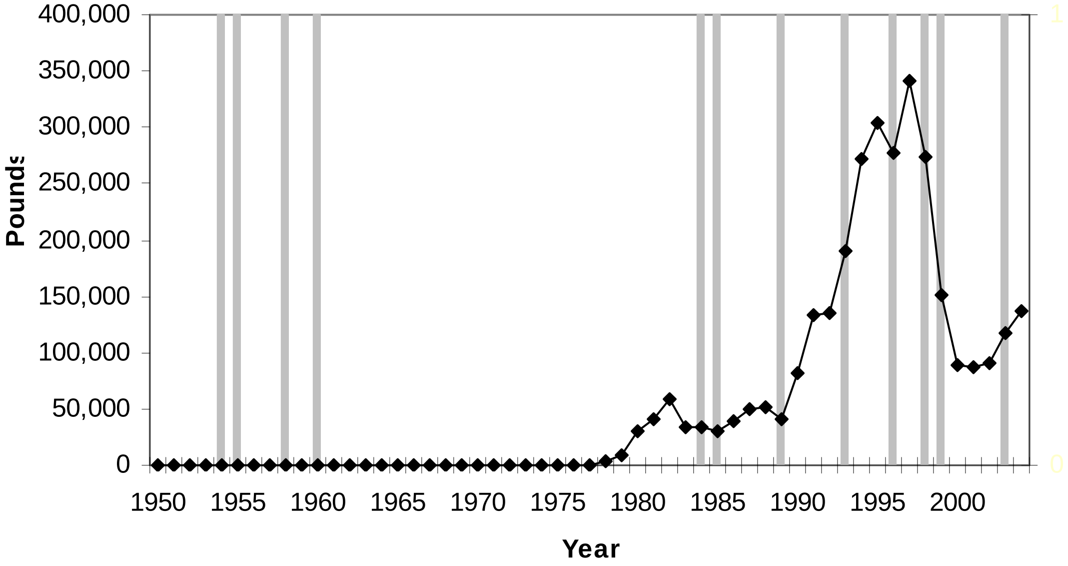

Figure 87. Annual landings of triggerfish, 1950-2004. Grey bars represent notable hurricane years.

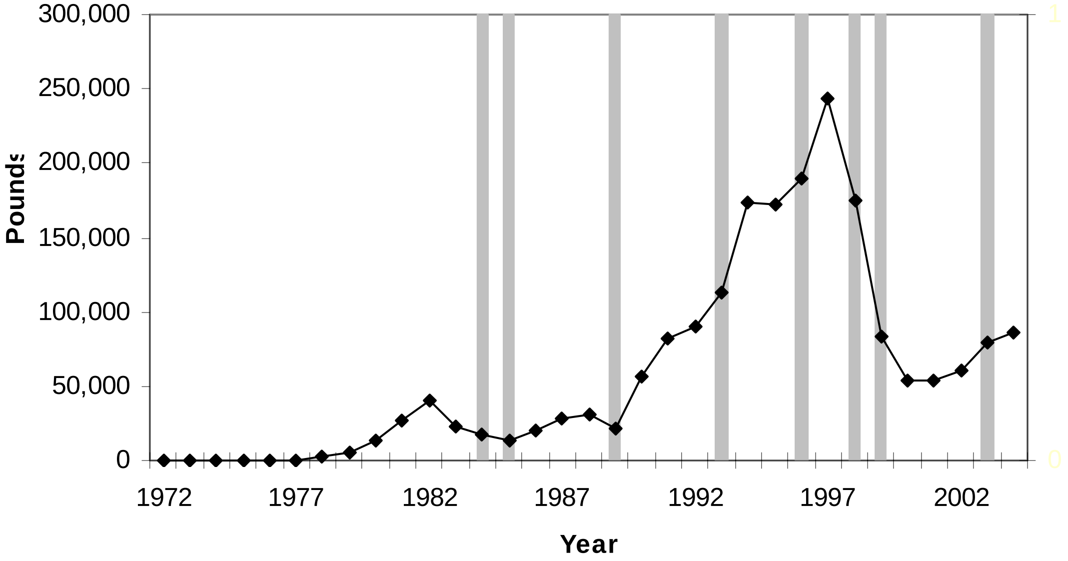

Figure 88. Landings of triggerfish during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Tunas

Tunas are managed internationally by the International Commission for the Conservation of Atlantic Tunas (ICAAT) and nationally by NMFS under the Highly Migratory Species FMP (NMFS 1999). Tunas commonly landed in North Carolina include bonito (*Sarda sarda*), albacore tuna (*Thunnus alalunga*), bluefin tuna (*T. thynnus*), little tuna (*Euthynnus alletteratus*), yellowfin tuna (*T. albacares*), bigeye tuna (*T. obesus*), skipjack tuna (*E. pelamis*), and blackfin tuna (*T. atlanticus*). The majority of North Carolina tuna landings are composed of yellowfin tuna. Tunas are commercially harvested throughout the year with landings peaking in late spring and during the fall. Tunas are primarily harvested with three gears: longlines, rod and reel, and trolling gears. The majority of tuna are harvested in the ocean greater than three miles offshore and are primarily landed in Dare and Carteret counties (Bianchi 2004).

Landings of tuna were low from 1950 to 1980 (Figure 89). The tuna fishery expanded in the early 1980s with landings increasing overall from 1980 to a peak in 1995. Landings have fluctuated since then. When the annual landings of tuna are compared to the trends in hurricane activity no noticeable trends are detected. The same trends are observed when the landings of tuna during the hurricane season are compared to hurricane activity (Figure 90).

The trends in landings and hurricane activity suggest other factors besides hurricanes impact the tuna fishery. The tuna fishery is conducted throughout the year and is heavily regulated. Trends observed in the landings data are most likely driven by changes in effort over time (e.g. such as the relative increase in blue fin tuna effort and landings in recent years) and changes in regulations.

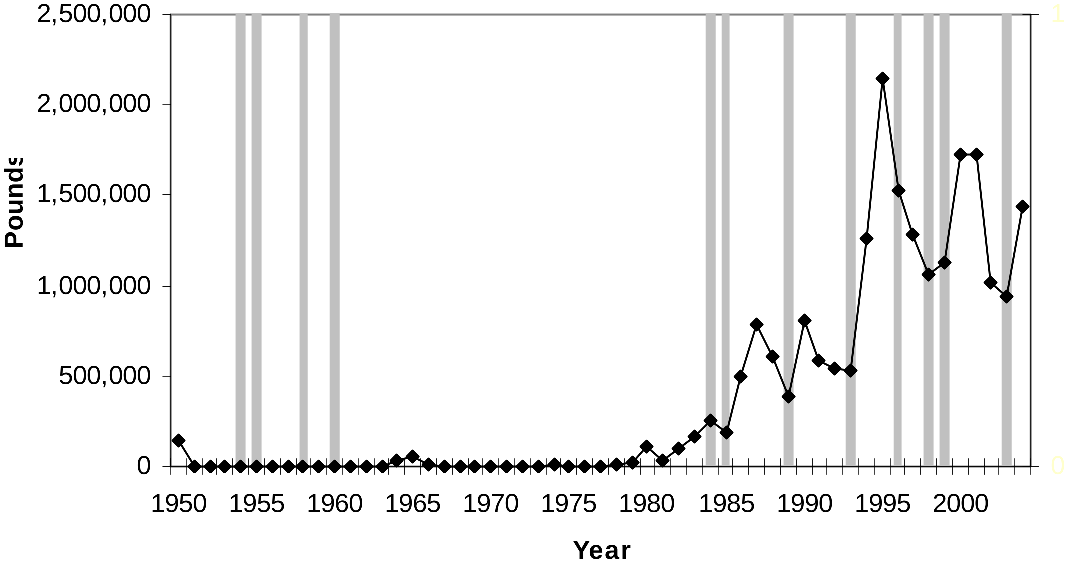

Figure 89. Annual landings of tuna, 1950-2004. Grey bars represent notable hurricane years.

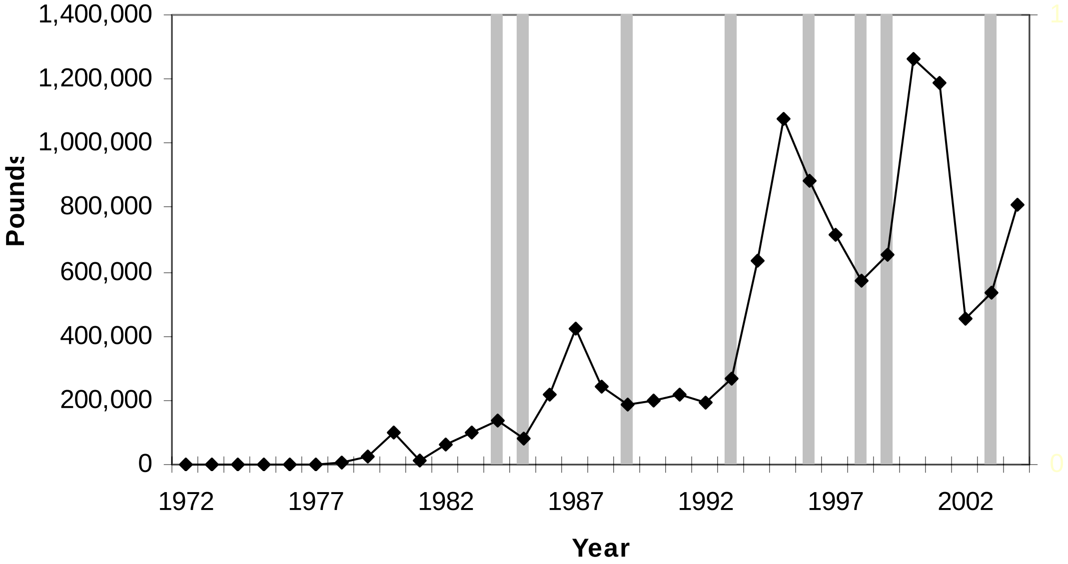

Figure 90. Landings of tuna during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

Wahoo

The SAFMC manages wahoo (*Acanthocybium solandri*) under the Wahoo-Dolphin FMP (NCDMF 2002; SAFMC 2003). Wahoo are commercially harvested throughout the year with landings mostly occurring from spring through fall (March to November). Three gears account for the majority of the landings of wahoo: trolling, rod and reel, and longlines. Wahoo are commercially harvested in the ocean greater than three miles from shore with most harvest occurring south of Cape Hatteras. Four counties account for the majority of the wahoo landings: Dare, Carteret, New Hanover, and Brunswick (Bianchi 2004).

The commercial fishery for wahoo did not begin until the late 1970s (Figure 91). Landings of wahoo increased overall from 1978 to 1995. Landings then declined overall from 1995 to 2000 but have remained relatively constant from 2000 to 2004. Four years are noticeable when the annual landings are compared to trends in hurricane activity: 1989, 1993, 1996, and 1999. Landings of wahoo increased in 1993 and 1999 and decreased in 1989 and 1996. These same trends are also apparent when the landings of wahoo during the hurricane season are compared to hurricane activity except for the increase in 1999 (Figure 92).

The landings trends suggest that the commercial wahoo fishery may be negatively impacted by hurricanes but the impact is probably minor. Although the landings of wahoo did increase during two notable hurricane years: 1993 and 1999, the increase in landings either occurred primarily during the summer months before a hurricane impacted the coast or outside of the hurricane season. These trends suggest that other factors (e.g. changes in effort and management) have a greater impact on the wahoo fishery than hurricanes.

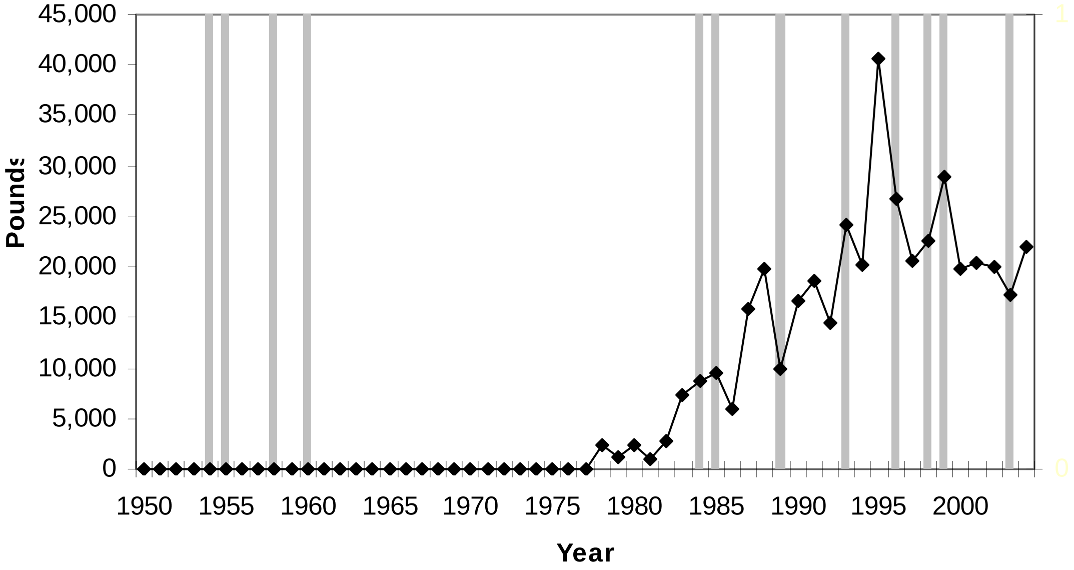

Figure 91. **Annual landings of wahoo, 1950-2004. Grey bars represent notable hurricane years.**

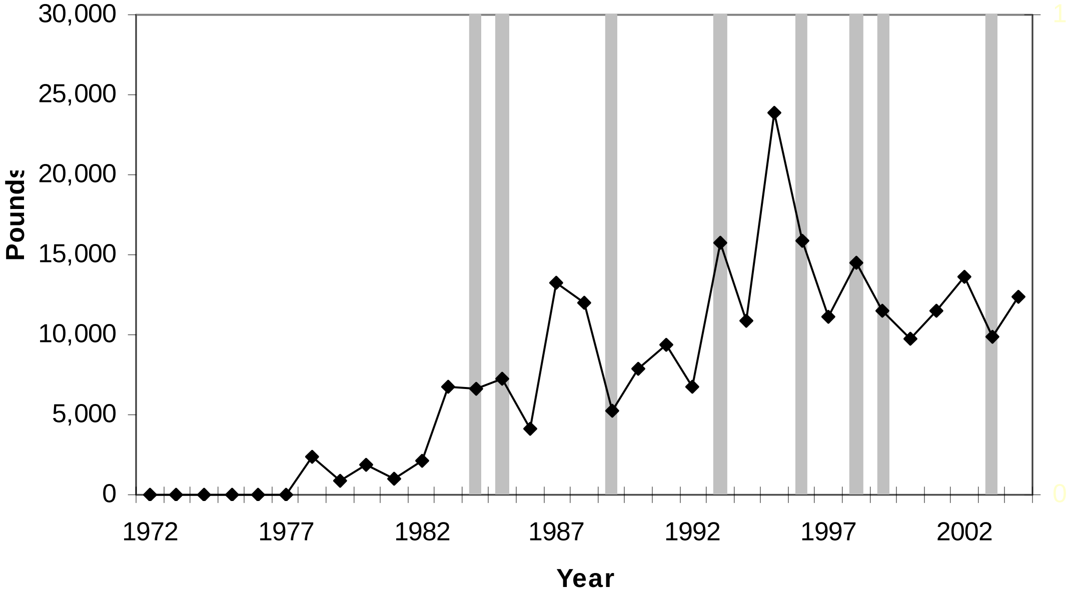

Figure 92. **Landings of wahoo during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.**

Weakfish

Weakfish (*Cynoscion regalis*) are currently managed under the Weakfish FMP of the ASMFC (NCDMF 2002; ASMFC 2002b). Weakfish are commercially harvested year round but landings peak in the late fall and through the early spring (November to May). Weakfish are primarily harvested with gill nets, trawls, seines and pound nets. Weakfish are commonly harvested out of the ocean, Pamlico Sound and Core Sound. Three counties account for most of the weakfish landings in North Carolina: Dare, Carteret, and Hyde (Bianchi 2004).

The annual landings of weakfish were relatively stable from the early 1950s through the 1960s, averaging about 2 million pounds per year (Figure 93). Landings then increase steadily through the 1970s and peak in 1980 at around 20 million pounds. However, since 1980 the landings have declined overall with landings declining significantly during the 1990s. Only 1989 is notable when the landings of weakfish are compared to hurricane activity. During 1989, weakfish landings declined noticeably. These same trends are seen in the landings of weakfish during the hurricane season (Figure 94).

These trends suggest that weakfish are not affected that much by hurricanes. The peak time of harvest for this species occurs outside of the hurricane season thus minimizing the impact hurricanes would have on the fishery. The trends observed in this fishery are primarily due to changes in the stock and changes in management over time including the ban of flynets south of Cape Hatteras.

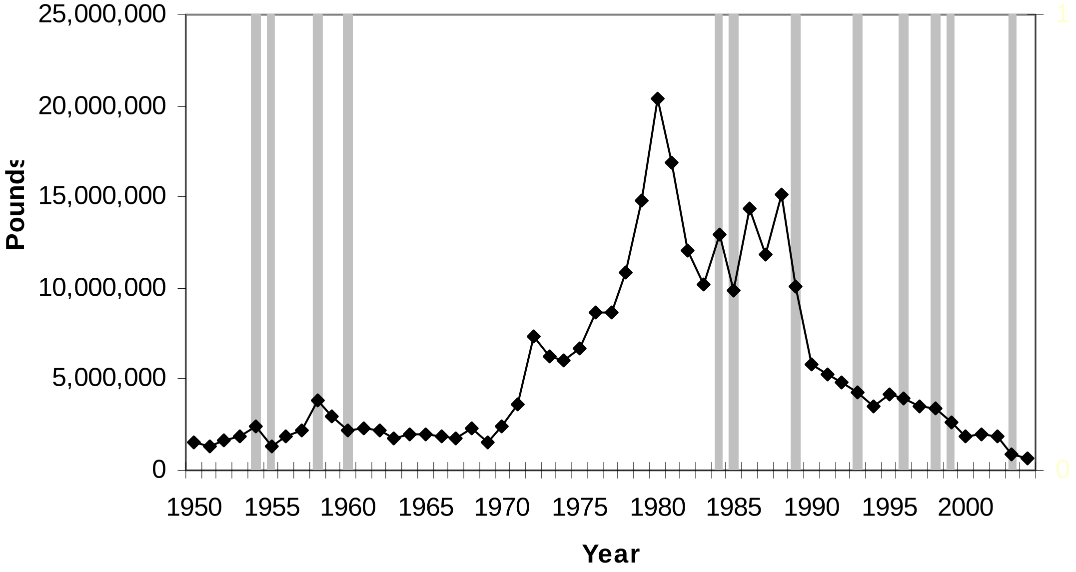

Figure 93. Annual landings of weakfish, 1950-2004. Grey bars represent notable hurricane years.

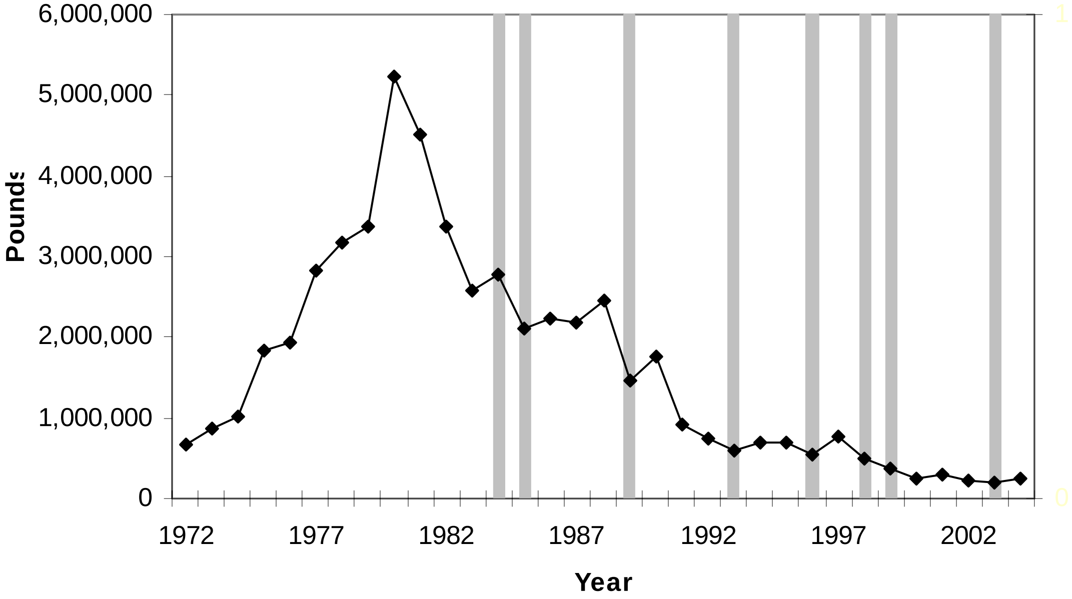

Figure 94. Landings of weakfish during hurricane season (June-November), 1972-2004. Grey bars represent notable hurricane years.

HURRICANES AND RECREATIONAL FISHERIES

Methods

Hurricanes have been closely observed over the past century, though recreational fishing statistics for North Carolina have only been monitored since 1981. This 24-year period (1981–2004) was examined to determine if differences in recreational fishing effort and harvest may exist among years with and without notable hurricanes. The timeline examined for each species ranged from 1989 to 2004 because sample sizes were increased dramatically in North Carolina in 1989 allowing for more reliable estimates at the species level.

Data source[3]

The Marine Recreational Fishery Statistics Survey (MRFSS) was established in 1981 by the National Marine Fisheries Service (NMFS). The program is designed to obtain standardized and comparable estimates of participation, effort, and catch by recreational anglers to identify the impact of recreational fishing on marine resources. MRFSS data are currently used to aid management of numerous species, and the North Carolina Division of Marine Fisheries (NCDMF) receives roughly 400 data requests for information on recreational fishing activity annually (NCDMF2005b).

MRFSS data are collected through two complementary surveys: a telephone survey of households in coastal counties, and an intercept (i.e., interview) survey of anglers at fishing access sites. Estimates of fishing effort, catch, and participation are produced from the results of the two independent surveys. These estimates are calculated for six two-month periods (waves) in each year. Resulting data fall into three categories: 1) number of fishing trips taken (fishing effort); 2) number of finfish caught and harvested or released (number and weight); and, 3) number of participants in recreational fishing activities. Fishing effort is defined as "the estimated number of fishing trips taken by individual anglers" (NMFS, Fisheries Statistics Division, personal communication). Estimates of trips are produced for each state, fishing mode, and bimonthly wave. Catch estimates for each finfish species are produced for each subregion,

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[3] Much of the following is derived from NOAA Fisheries, by John F. Witzig and M. Osborn. Full text and additional information can be found at: http://www.st.nmfs.gov/st1/recreational/overview/overview.html

state, fishing mode, primary fishing area, and wave. Annual participation estimates are produced at the state level.

Precision of MRFSS data are measured by calculating the proportional standard error (PSE). The PSE expresses the standard error as a percentage of the estimate (standard error/estimate*100), providing a useful measure in comparing the relative precision of two estimates. A small PSE indicates a more precise estimate than does a large PSE, with PSE values ≤ 20% considered acceptable in fisheries data (NMFS, Fisheries Statistics Division, personal communication).

Effort

Estimates of recreational fishing effort provided by creel surveys have long been used for management purposes (Guthrie et al. 1991; Pollock et al. 1994). Effort consistently shows strong correlations with harvest, mortality, and catch rates (Hoenig et al. 1998; Bernard et al. 1998). Effort data (number of trips) is available extending back to 1981 for North Carolina and is reasonably precise, and 8 of the 25 years coincided with hurricanes that had a large impact on North Carolina (

Table 6). Effort was also broken down further and examined by mode of fishing (i.e., fishing from the beach or river bank, charter boats, manmade structures, and private or rental boats). Effort data were not available by species when the data were being analyzed for this report. The Atlantic Coastal Cooperative Statistics Program (ACCSP) has recently developed a method for estimating the number of angler trips as a measure of effort by species.

Catch

Ten species were selected for comparison of harvests (number of fish, type A + B1[4]) among years with notable hurricane activity and years without (

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[4] Type A catch are fish brought back to the dock in a form that can be identified; type B1 catch are fish not brought to the dock, previously identified by the angler.

Table 6). Species were selected according to recreational importance, precision of estimates, and likelihood of interactions with hurricane activity. Catch estimates for individual species vary extensively, and data prior to 1989 often lacks precision needed for accurate assessment[5]; therefore, data for a particular species only extends back to 1989.

Table 14. Time periods represented by each wave of MRFSS surveys.

Wave	Months
1	January-February
2	March-April
3	May-June
4	July-August
5	September-October
6	November-December

Table 15. Average PSE values for MRFSS harvest estimates in North Carolina, 1989-2004.

Species	Average Annual PSE			Average Wave 4 PSE		Average Wave 5 PSE	
	Harvest (numbers)	Harvest (pounds)	Released Alive	Harvest (numbers)	Harvest (pounds)	Harvest (numbers)	Harvest (pounds)
Atlantic croaker	10.5	11.6	8.4	15.3	15.6	20.3	21.2
Bluefish	8.0	11.3	9.1	14.5	15.6	13.2	14.2
Dolphinfish	10.9	11.5	31.3	16.9	17.4	22.9	23.3
King mackerel	12.1	13.8	33.5	18.9	20.8	30.0	22.4
Red drum	16.6	20.3	16.4	35.1	38.3	24.2	25.8
Spanish mackerel	9.3	9.8	13.5	13.8	14.6	21.2	23.6
Spot	9.8	10.8	9.3	17.4	17.6	14.0	14.2
Spotted seatrout	13.6	13.9	17.3	26.7	28.1	22.0	22.6
Weakfish	15.6	16.1	19.1	34.8	35.5	22.9	24.1
Yellowfin tuna	12.6	12.8	33.9	20.3	21.1	22.6	22.8

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[5] Beginning in 1987, NCDMF increased the annual number of angler interviews by approximately six times and implemented control measures to improve the quality of MRFSS data.

Results

Effort

Since the establishment of MRFSS in 1981, marine recreational fishing effort has increased over 300% at a rate of roughly 200,000 trips per year; however, it does not appear to show any clear trends with regard to hurricane activity (Figure 95). Estimates of total effort were within acceptable levels averaging 5.4% from 1981 to 2004. Fishing effort was also within acceptable PSE levels when separated by mode averaging 11.7% for beach/bank, 11.4% for

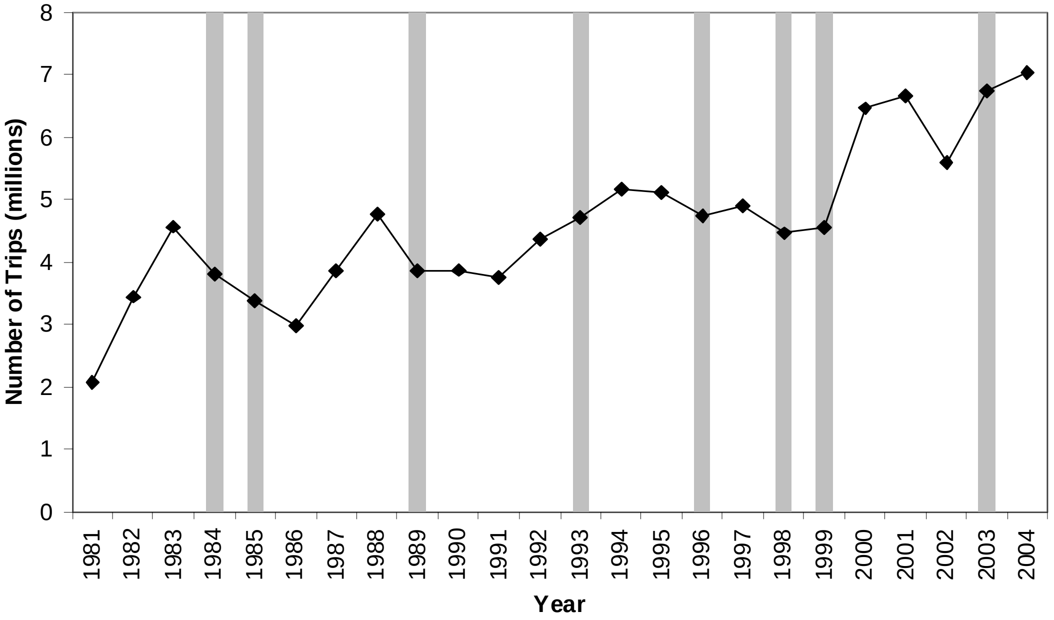

Figure 95. Coastal recreational fishing trips (millions) in North Carolina, 1981–2004. Grey bars represent notable hurricane years.

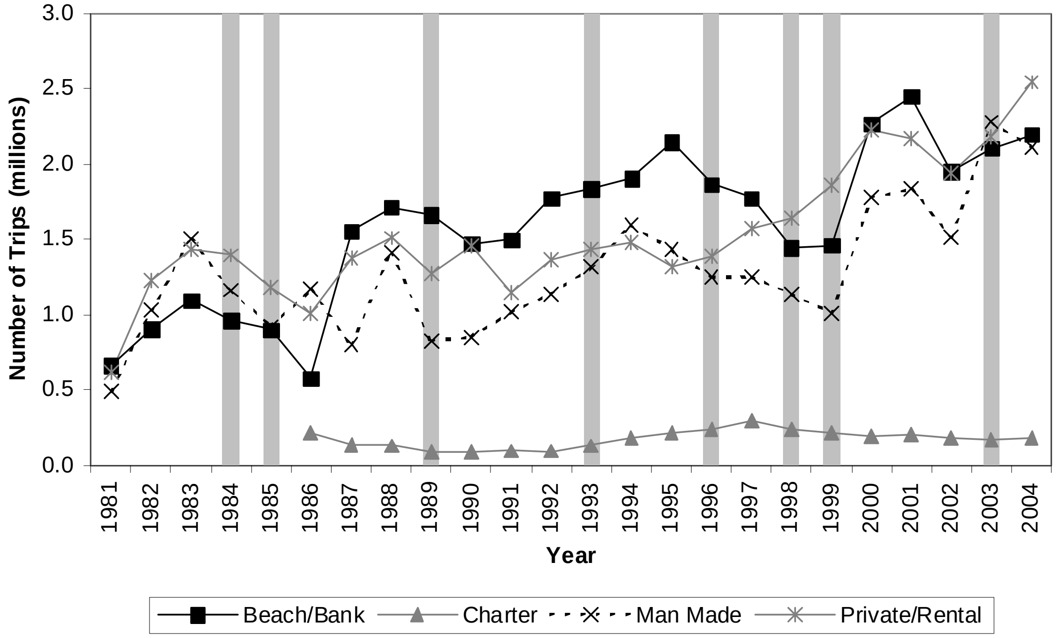

Figure 96. Coastal recreational fishing trips (millions) in North Carolina by mode, 1981–2004. Grey bars represent notable hurricane years.

charter, 9.9% for man-made structures, and 6.0 for private/rental boats. The number of trips made by recreational charter boats is much smaller—roughly four percent of the total effort—than trips made by fishermen fishing from the beach or banks, manmade structures, or private and rental boats (Figure 96). There are no clear indications that hurricane activity influences the number of trips taken by each mode.

Catch

Average PSE values for both harvest in numbers and harvest in pounds were within acceptable limits (≤ 20%) for all species (Table 15). The average PSE values for fish released alive was somewhat high for dolphinfish (31.3%), king mackerel (33.5%), and yellowfin tuna (33.9%), while PSEs for all other species were within acceptable limits.

Atlantic Croaker

The majority of Atlantic croaker are harvested during wave 4 (44%), and large amounts are also harvested during waves 3 (27%) and 5 (19%) (Figure 97). Atlantic croaker are harvested in roughly equal numbers by each mode of fishing (Figure 98). Both the number and pounds of Atlantic croaker harvested were high in 1989 and dropped, remaining fairly steady, for the remainder of the time period (Figure 99). The number released alive also remained fairly steady throughout the time period with an exception of a large peak in 1994 (Figure 99). Even though a large portion of the harvest occurs during the hurricane season, examination of the time series by year and by waves 4 and 5 showed no discernable patterns with regard to hurricane activity (Figure 100 & Figure 101).

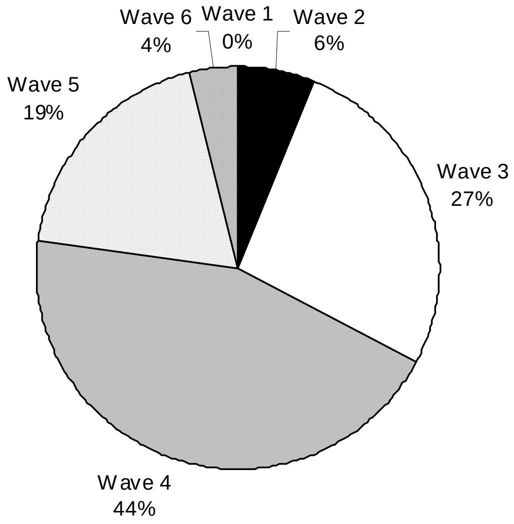

Figure 97. Average percent of Atlantic croaker harvest by wave, 1989–2004.

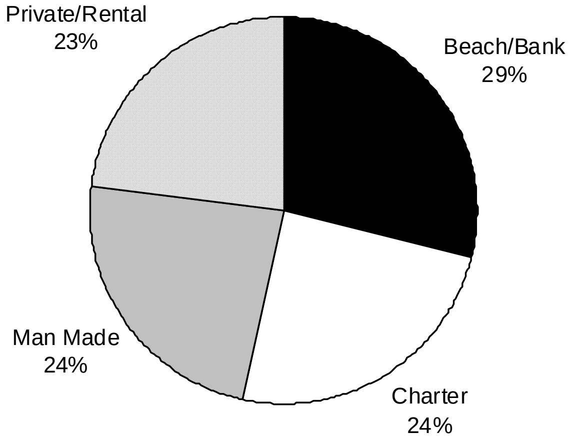

Figure 98. Average percent of Atlantic croaker recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

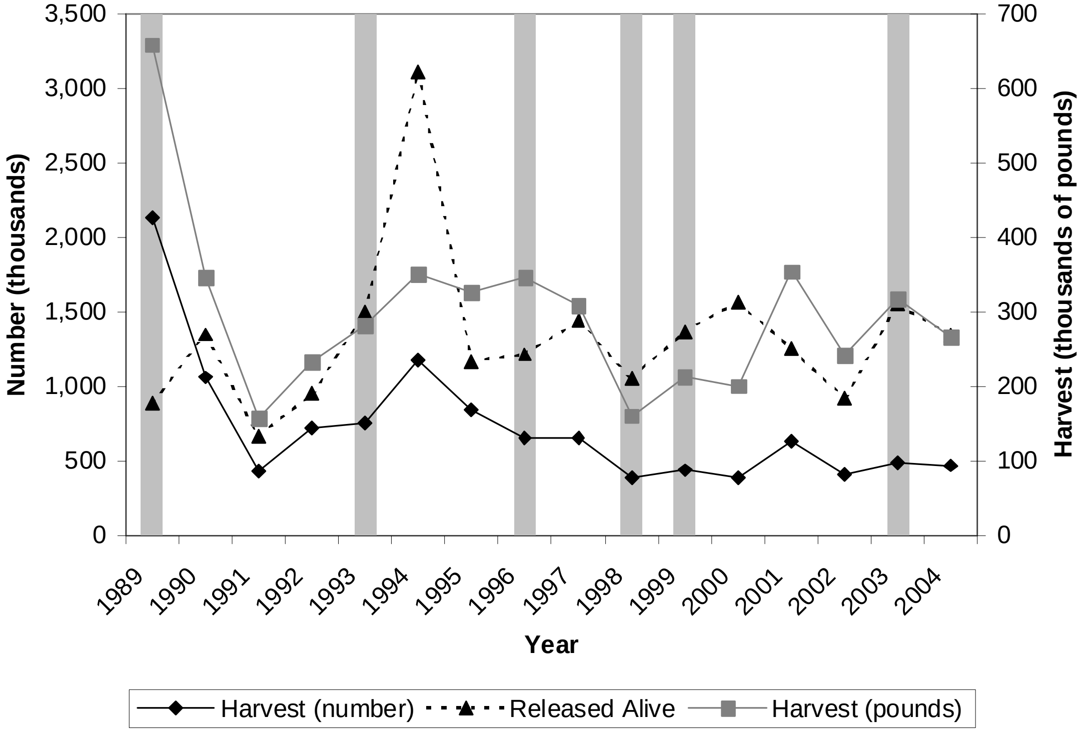

Figure 99. Atlantic croaker recreational catch in North Carolina by year, 1989–2004. Grey bars represent notable hurricane years.

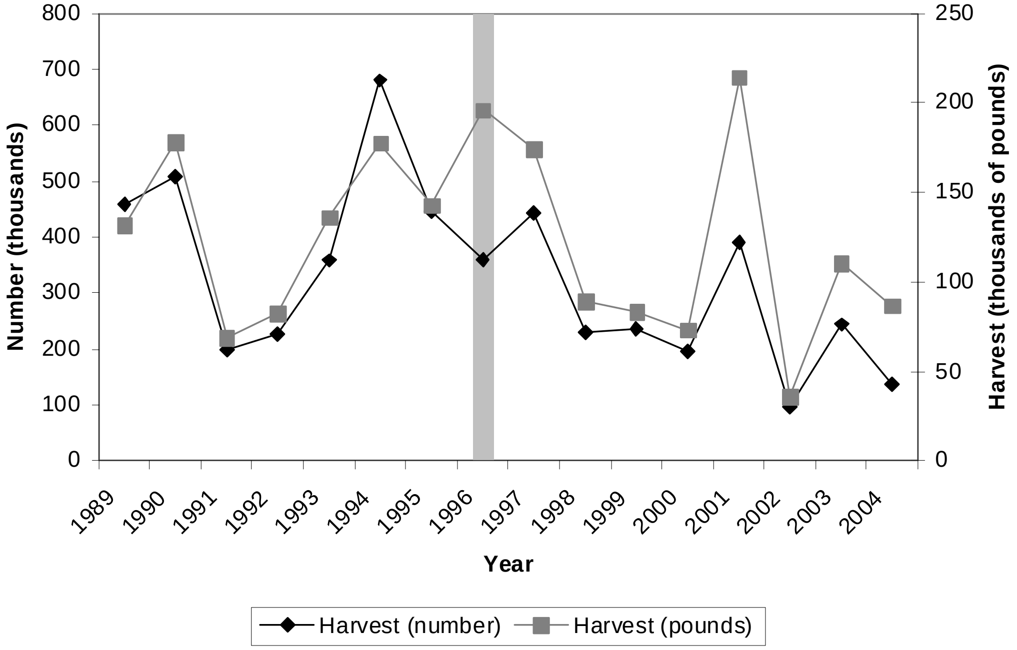

Figure 100. Atlantic croaker recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

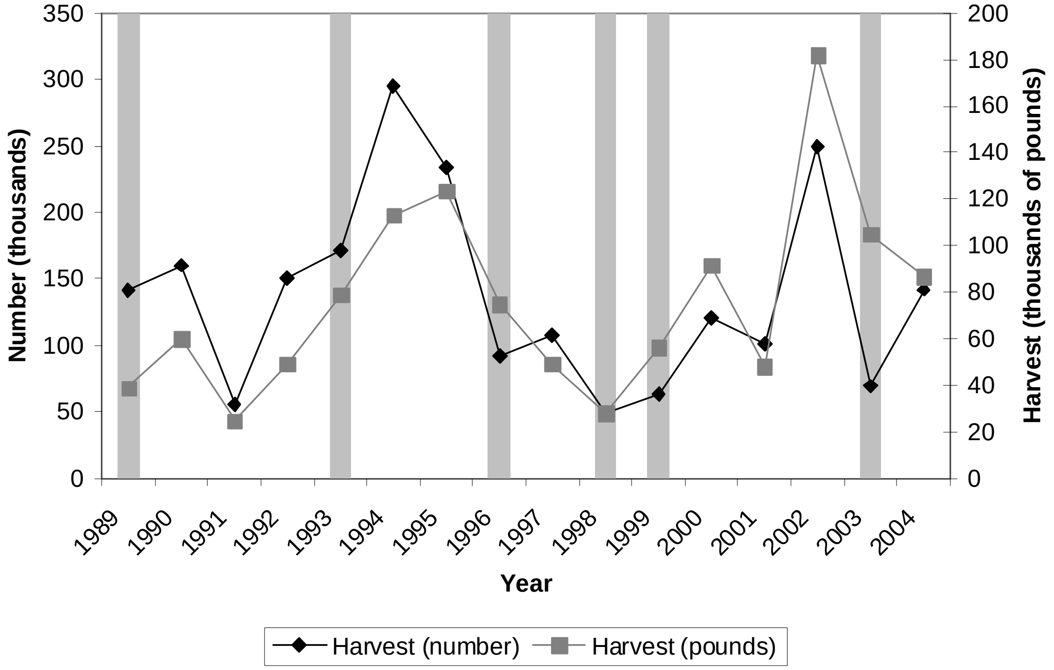

Figure 101. Atlantic croaker recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

Bluefish

Bluefish are harvested in similar numbers throughout the year, except during wave 1, in nearly equal numbers by each fishing mode (Figure 102 & Figure 103). Both the number and pounds of bluefish harvested were high in 1989 and 1990 and dropped varying around a lower mean for the remainder of the time series (Figure 104). The number released alive has been relatively high since 2000 (Figure 104). There were no consistent patterns with regard to hurricane activity seen by year or harvest by waves 4 and 5 (Figure 105 & Figure 106).

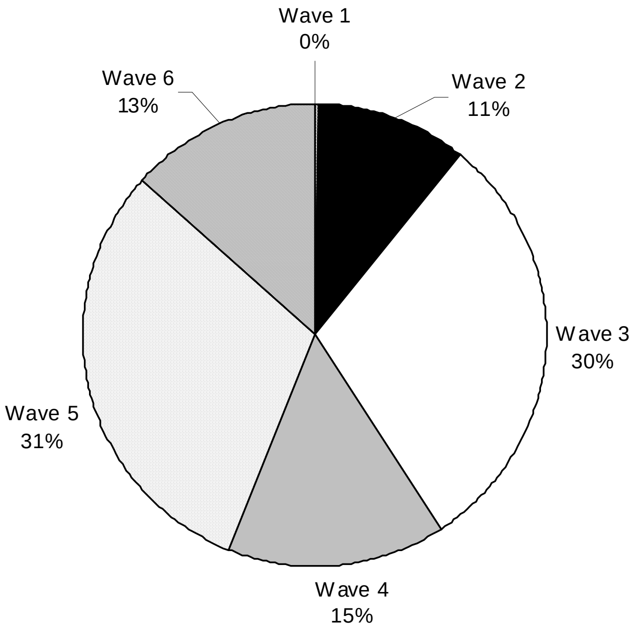

Figure 102. Average percent of bluefish harvest by wave, 1989–2004.

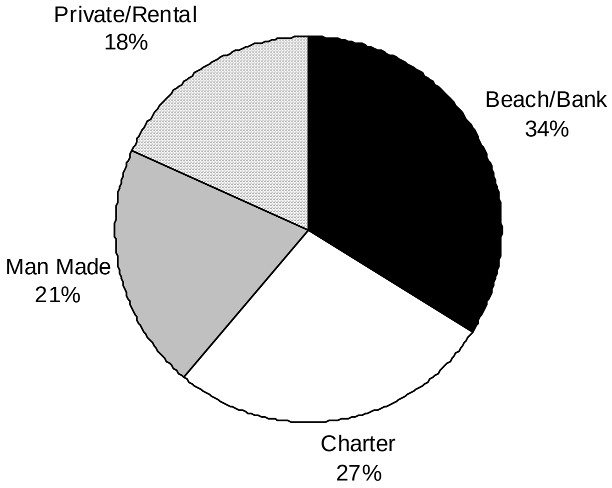

Figure 103. Average percent of bluefish recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

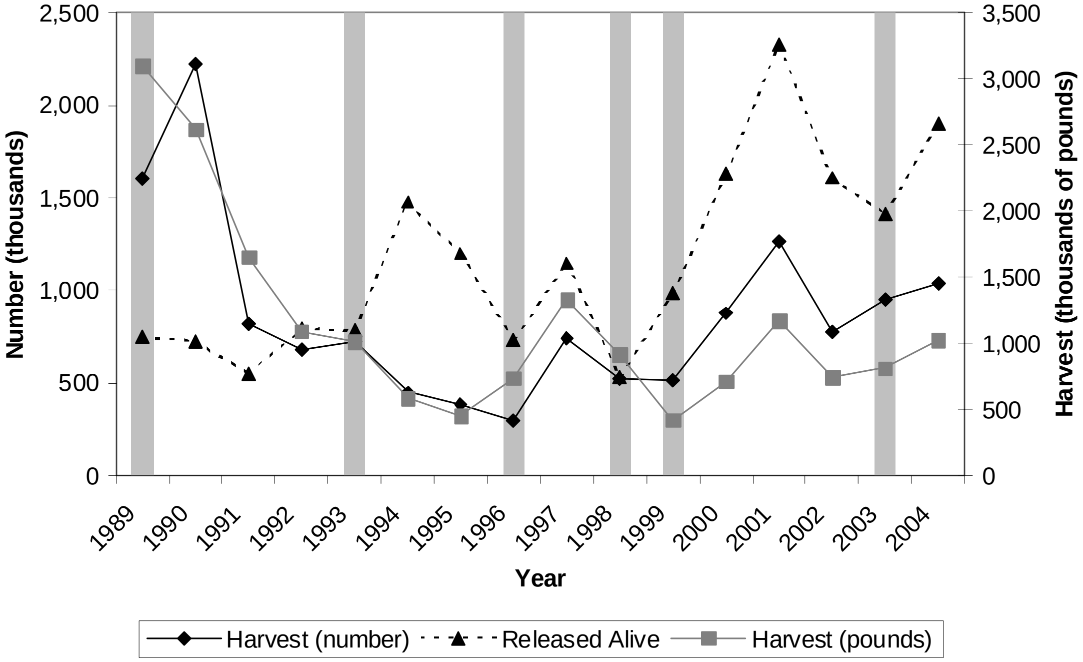

Figure 104. Bluefish recreational catch in North Carolina by year, 1989–2004.

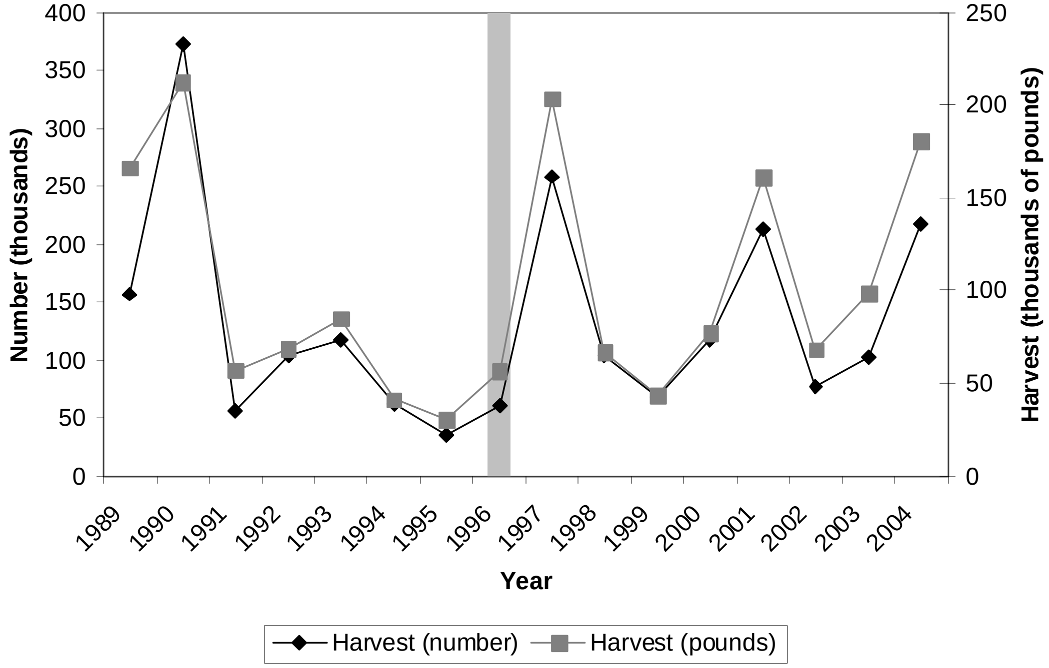

Figure 105. Bluefish recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

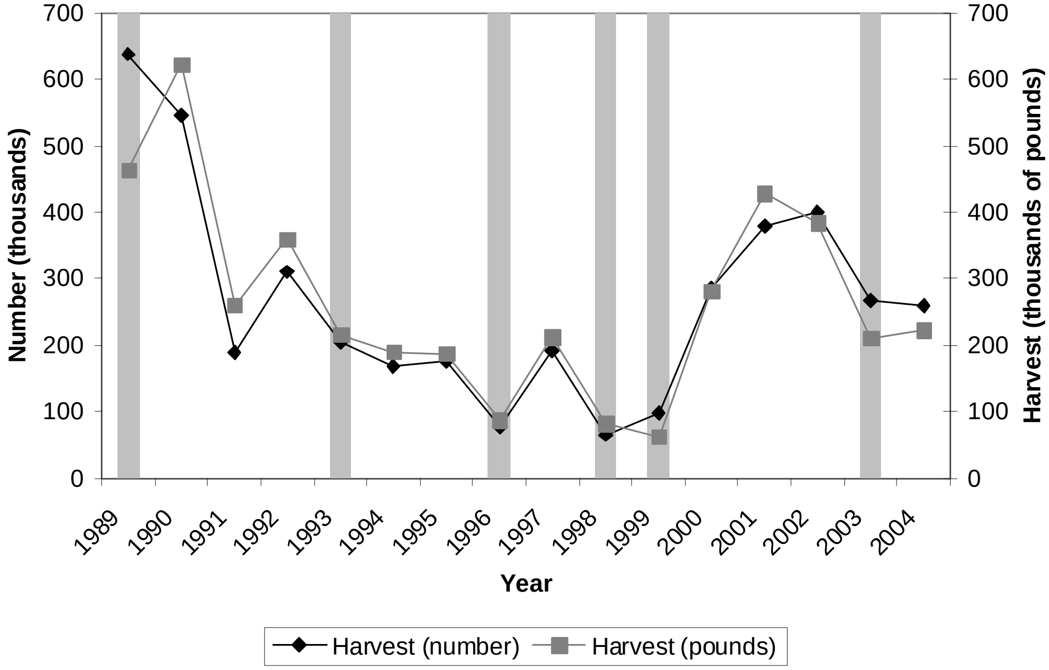

Figure 106. Bluefish recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

Dolphinfish

Dolphinfish are found in offshore waters during waves 3 through 5 with nearly half of the recreational harvest occurring in wave 4 (Figure 107). Most are harvested with charter boats (71%) and the remainder with private or rental boats (29%) (Figure 108). The number of dolphinfish harvested steadily increased from 1992 to 2000, and the pounds harvested increased steadily from 1992 to 2002 (Figure 109). Most of the dolphin caught are kept and are not released alive (Figure 109).

There were decreases in both pounds and the number dolphinfish harvested during several hurricane years, whereas increases were usually seen in non-hurricane years. Decreases coincided with hurricane years in 1996 (Hurricanes Bonnie and Fran), 1998 (Hurricane Bertha), and 2003 (Hurricane Isabel) but not during 1993 (Hurricane Emily) or 1999 (Tropical Storm Dennis and Hurricane Floyd). Breaking down harvest by wave further supports evidence of potential hurricane impacts. Hurricane Bertha occurred in July of 1996 during wave 4, harvest was somewhat lower than the preceding or following years (Figure 110). However, this decrease does not appear to be outside of the normal variation present in the years prior to the storm. Hurricane Fran in September 1996, Hurricane Bonnie at the end of August in 1998, and Hurricane Isabel in September of 2003 all could have impacted landings during wave 5. Large decreases in dolphinfish harvest coincided with these periods, and it is likely that hurricanes have negatively affected harvest during these waves (Figure 111). Low levels of dolphinfish were also seen in wave 5 when Hurricane Hugo impacted the state in September of 1989. It is difficult to determine the potential impact of Hugo since it is at the beginning of the time period, and there are no previous years with which landings can be compared. There were no apparent impacts during other notable hurricane years.

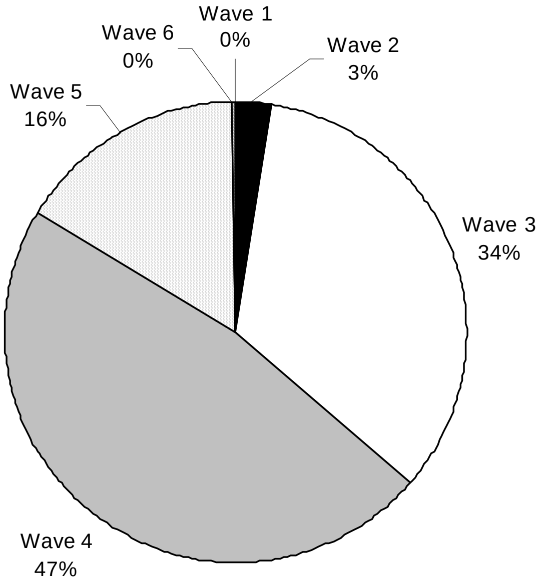

Figure 107. Average percent of dolphinfish harvest by wave, 1989–2004.

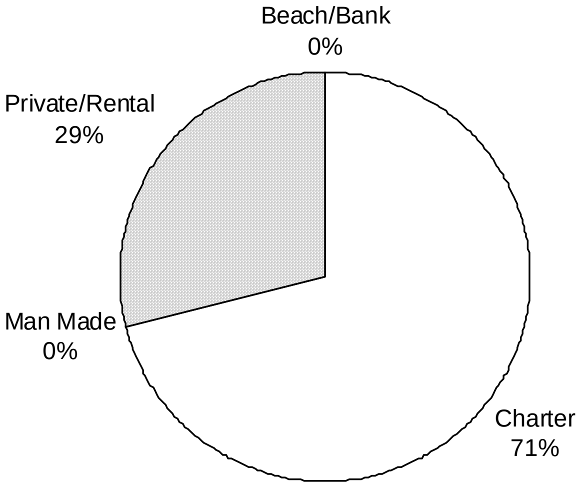

Figure 108. Average percent of dolphinfish recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

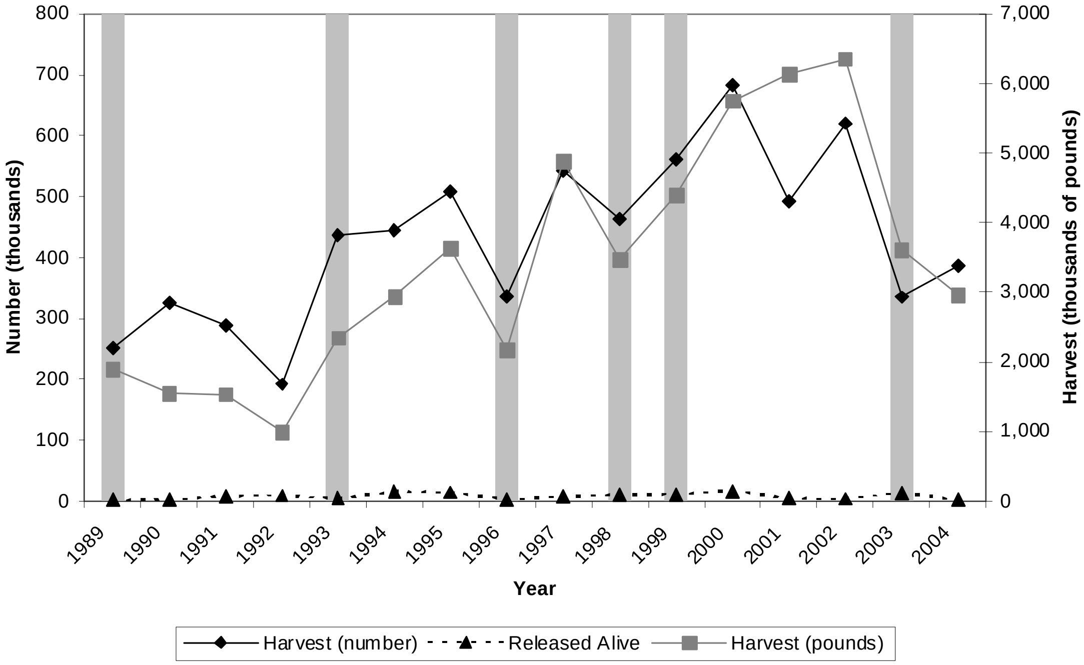

Figure 109. Dolphinfish recreational catch in North Carolina by year, 1989–2004.

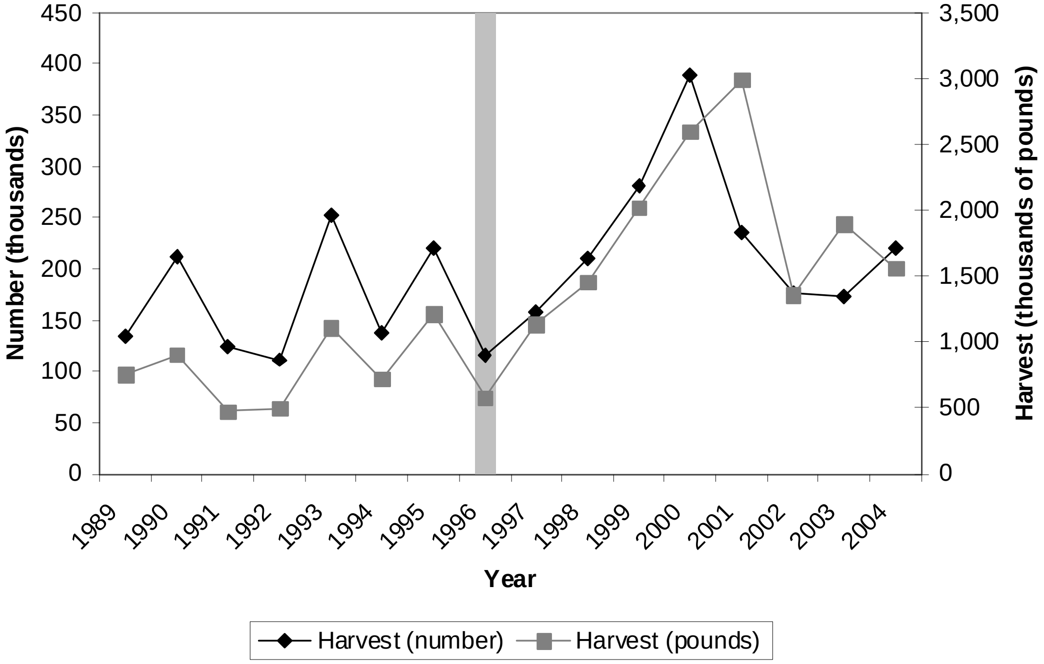

Figure 110. Dolphinfish recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

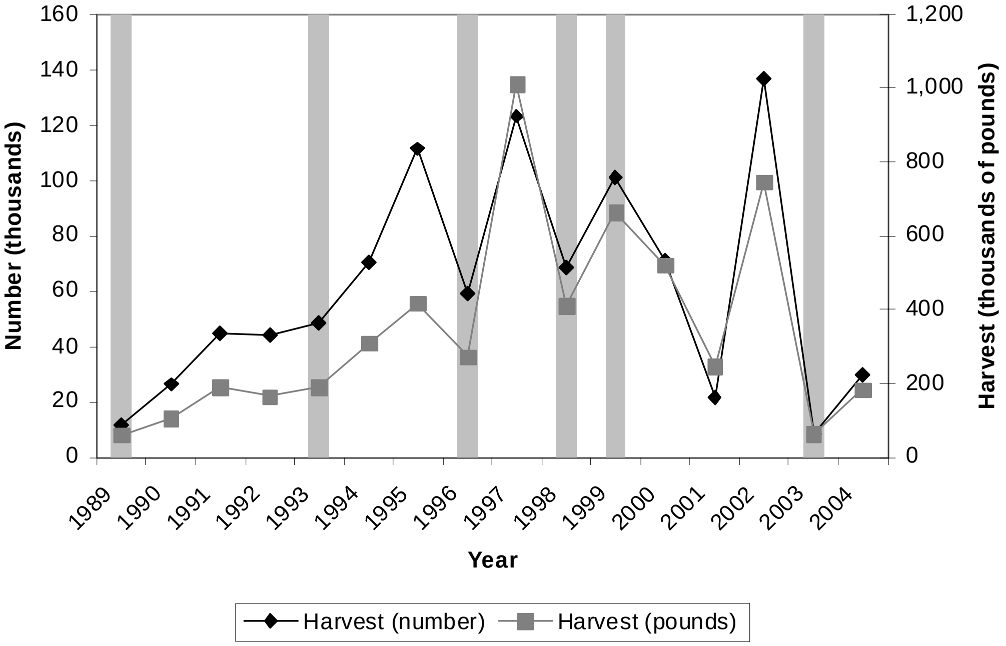

Figure 111. Dolphinfish recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

King Mackerel

King mackerel occur offshore and are landed year-round, excluding wave 1, in relatively equal amounts (Figure 112). The majority are harvested by private or rental boats (60%) with the remainder harvested mostly by charter boats (38%) (Figure 113). Almost all of the king mackerel caught are kept and are not released alive (Figure 114). Declines in harvest coincided with all notable hurricane years except Hurricane Isabel in 2003 (Figure 114). A decline was seen in during wave 4 coinciding with Hurricane Bertha in July of 1996, but the decline does not appear to be outside of the variation exhibited in other years (Figure 115). Harvest in wave 5 shows declines during all years with notable hurricanes except Hurricane Isabel in 2003; however, the harvest during 2003 in wave 5 was low when compared to other years without notable storms (Figure 116).

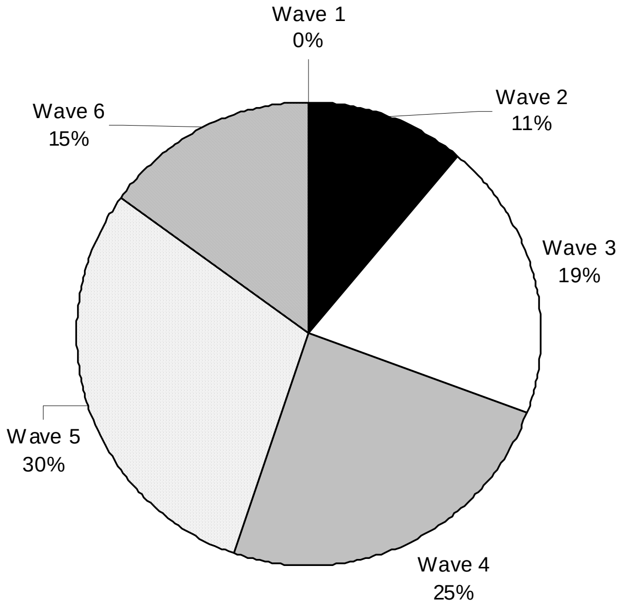

Figure 112. Average percent of king mackerel harvest by wave, 1989–2004.

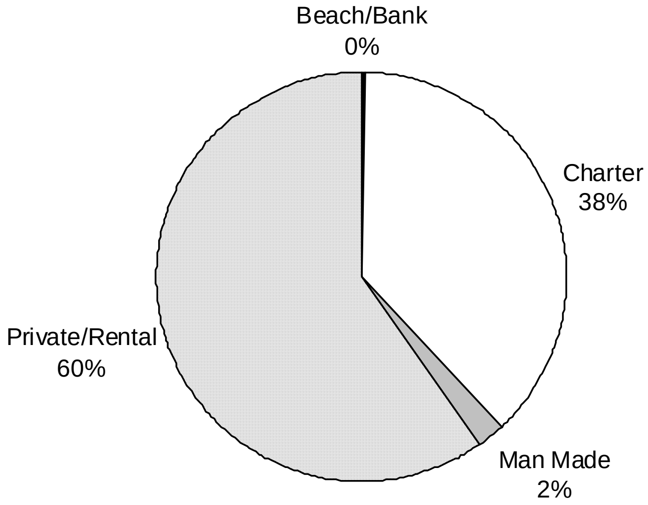

Figure 113. Average percent of king mackerel recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

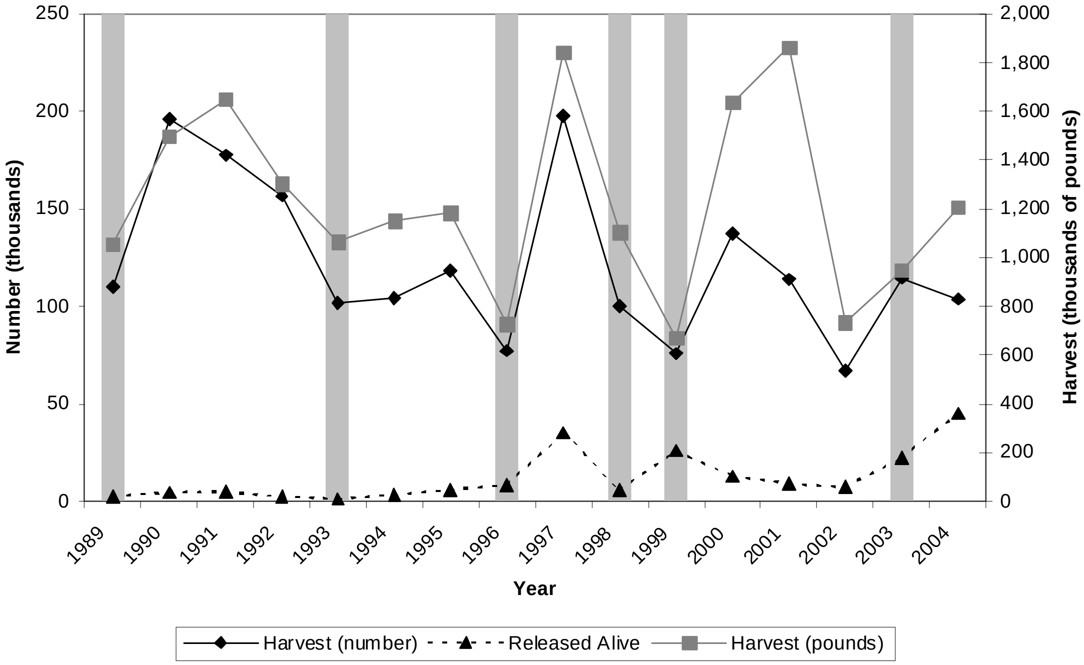

Figure 114. King mackerel recreational catch in North Carolina by year, 1989–2004.

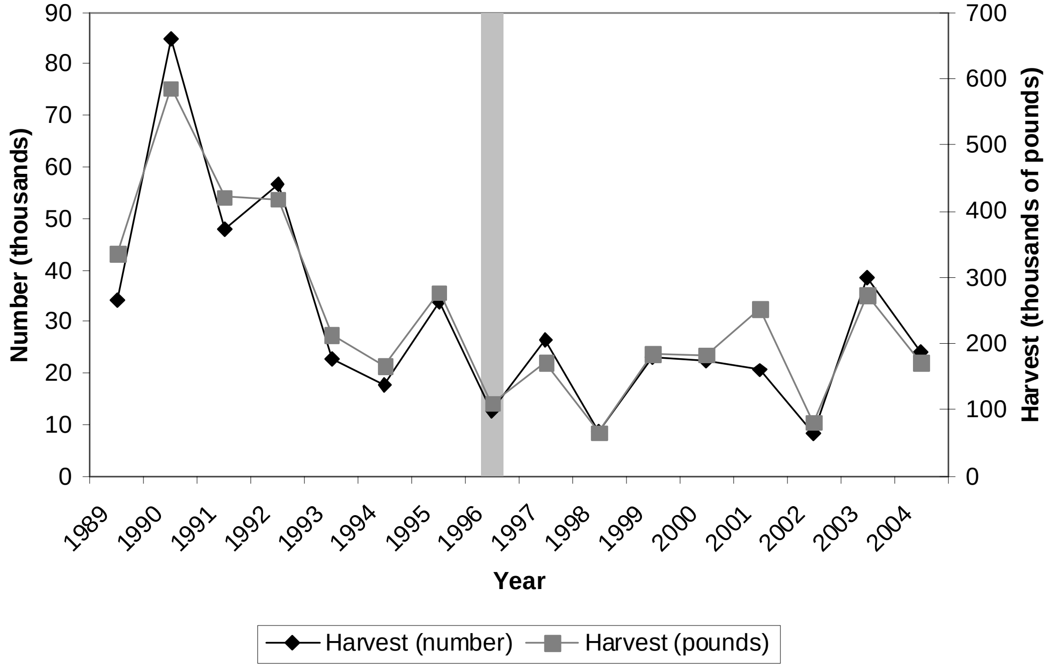

Figure 115. King mackerel recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

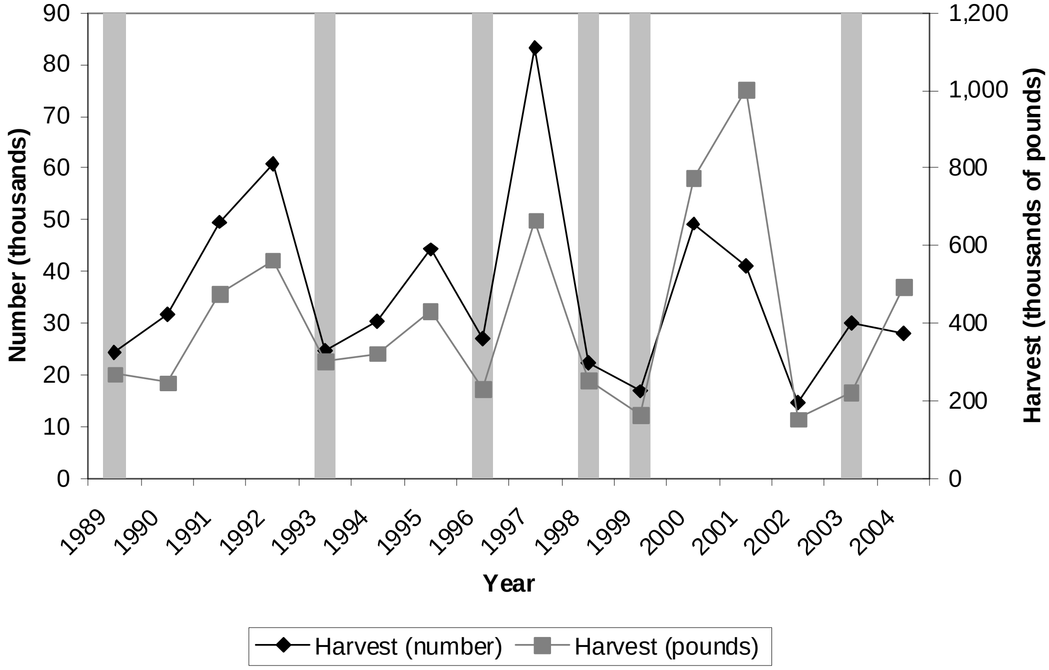

Figure 116. King mackerel recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

Red Drum

Red drum are harvested from estuarine waters throughout the year, excluding wave 1, but nearly half are harvested during wave 5 which is the peak of hurricane season (Figure 117). Most red drum are caught by anglers in private or rental boats (46%) or from anglers fishing from the beach or bank (42%) (Figure 118). The harvest in numbers is relatively low—usually less than 100,000—throughout the time series (Figure 119). Most of the red drum harvested are released alive with a peak occurring in 2002 (Figure 119). Examination of the time series for annual plots and that of waves 4 and 5 show no patterns with regard to hurricanes outside of the normal variability seen even though the majority of the harvest occurs during the peak in hurricane season (Figure 120 & Figure 121).

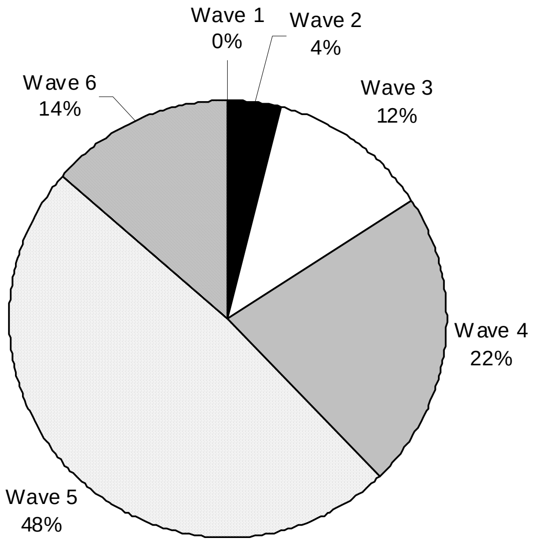

Figure 117. Average percent of red drum harvest by wave, 1989–2004.

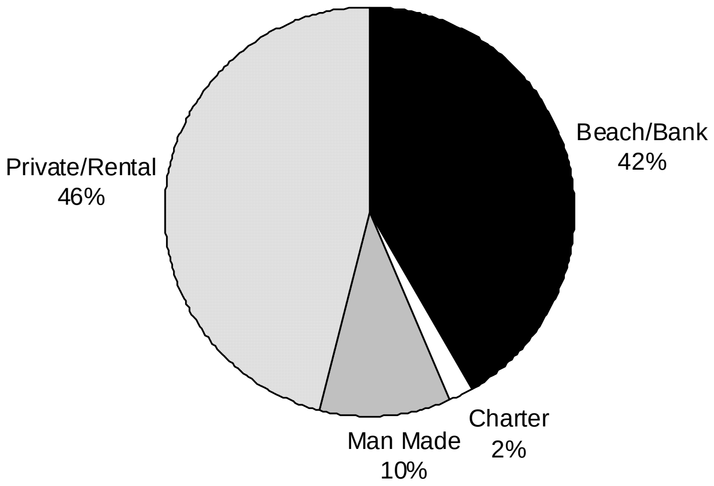

Figure 118. Average percent of red drum recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

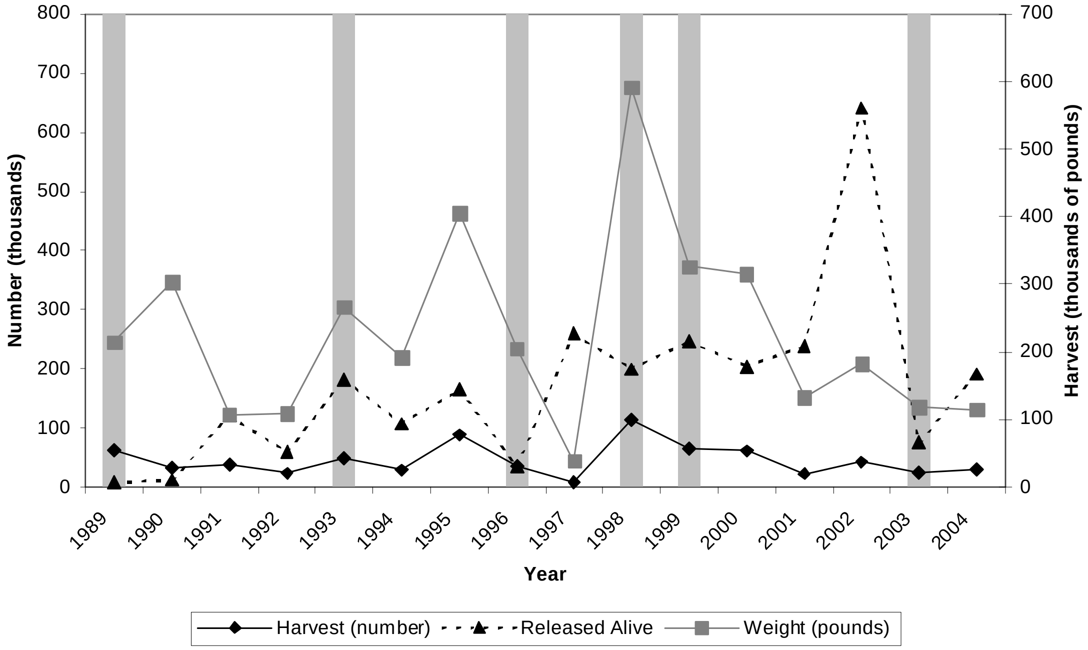

Figure 119. Red drum recreational catch in North Carolina by year, 1989–2004.

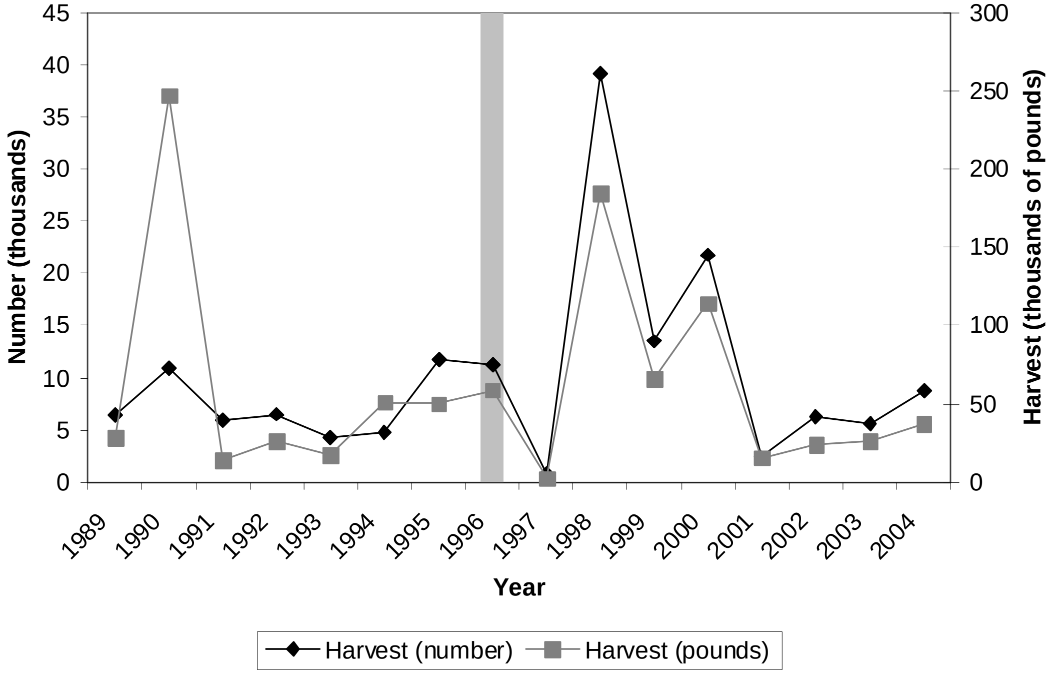

Figure 120. Red drum recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

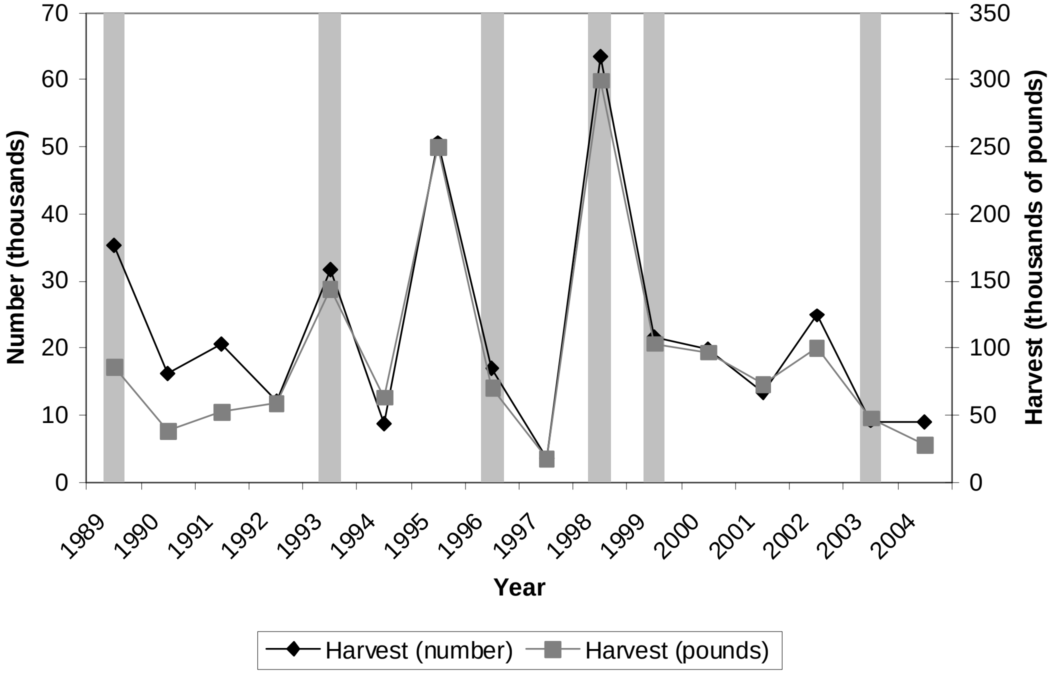

Figure 121. Red drum recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

Spanish Mackerel

Spanish mackerel are harvested during waves 3 and 4 in roughly equal amounts (38 and 41% respectively) with a the remainder landed primarily in wave 5 (20%) (Figure 122). Most Spanish mackerel are caught offshore by anglers using private or rental boats (70%), a few from charter boats (15%) and some from manmade structures (11%) (Figure 123). Harvest of Spanish mackerel declined from 1990 to 1995, was sporadic from 1996 to 2001, and leveled out after that time (Figure 124). The number of Spanish mackerel released alive has remained fairly consistent over the period (Figure 124).

Annual harvest of Spanish mackerel decreased during notable hurricane years in 1993, 1998, and a small amount in 2003 (Figure 124). Harvest in 1989 is difficult to interpret without prior years for comparison, but it may have been low. There was no apparent impact during the storm coinciding with wave 4 in 1996 (Figure 125). However, low landings were observed in 5 of the 6 years that coincided with hurricanes during wave 5 (Figure 126).

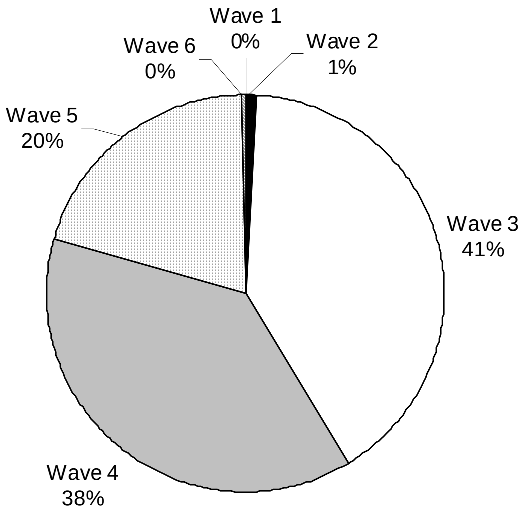

Figure 122. Average percent of Spanish mackerel harvest by wave, 1989–2004.

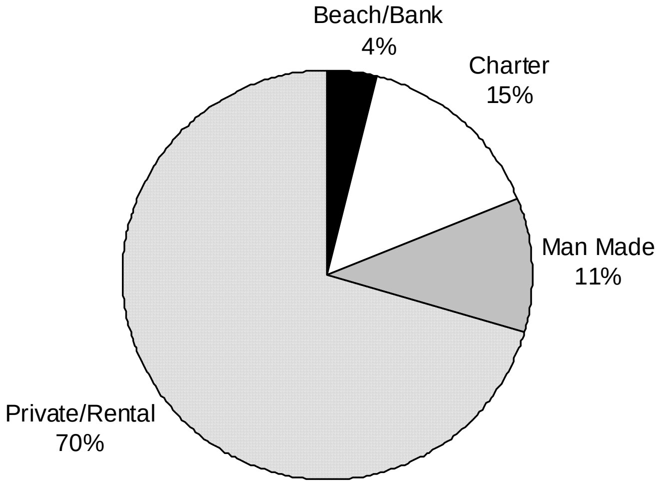

Figure 123. Average percent of Spanish mackerel recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

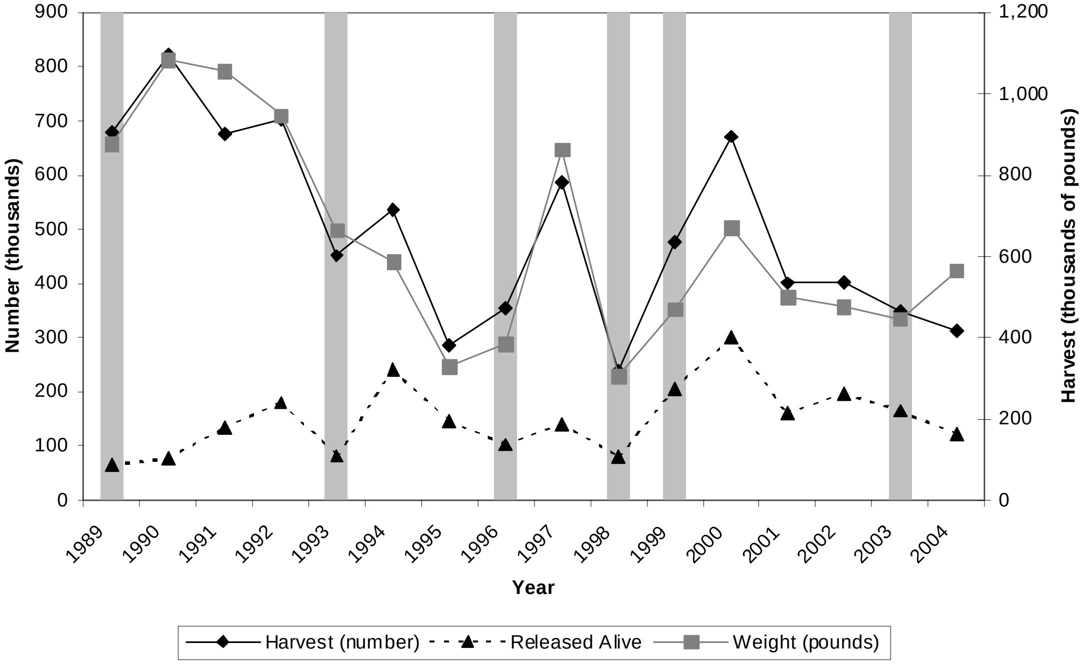

Figure 124. Spanish mackerel recreational catch in North Carolina by year, 1989–2004.

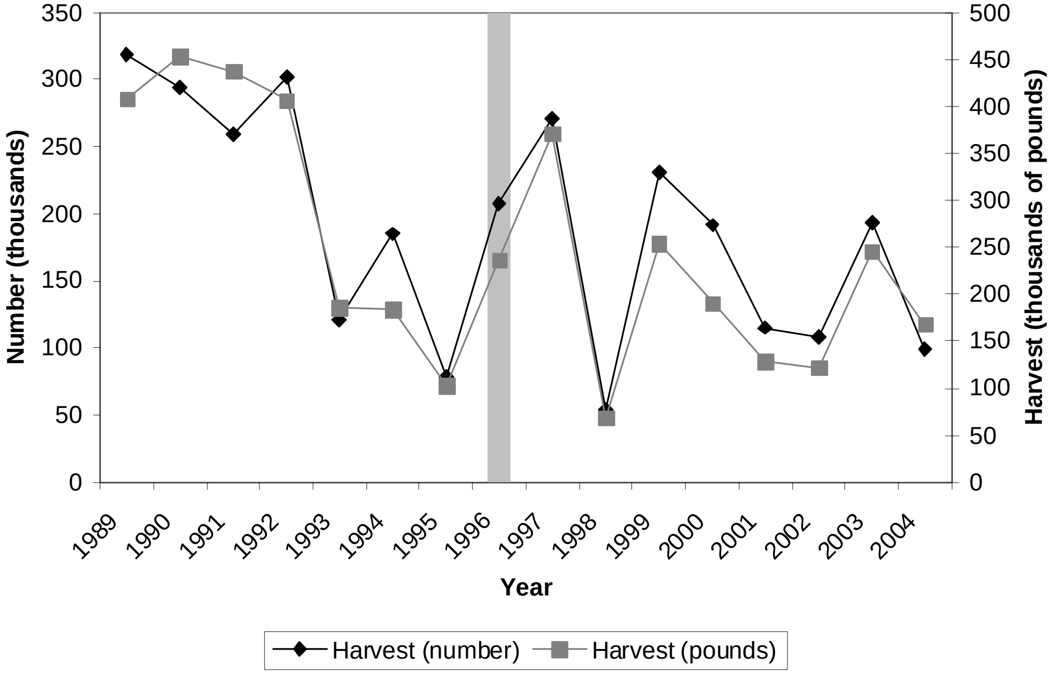

Figure 125. Spanish mackerel recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

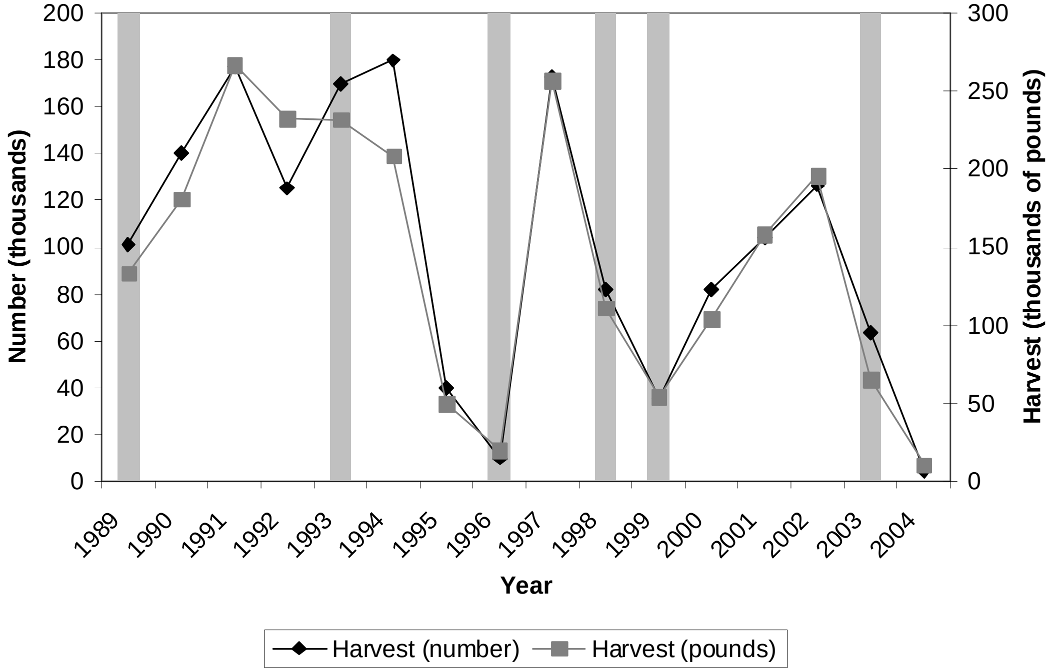

Figure 126. Spanish mackerel recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

Spot

Spot are predominantly harvested in wave 5 during the peak of hurricane season (62%) (Figure 127). The majority of spot (55%) are harvested from man-made structures such as bridges and piers, followed by private or rental boats (37%) (Figure 128). The amount of spot harvested has been highly variable since the beginning of the time period (Figure 129). The number of spot released alive is a little less than half the number harvested (Figure 129). Examination of the time series by year and by waves 4 and 5 shows no apparent influence outside the normal variation with regard to hurricane activity even though the majority of the harvest occurs during the peak of hurricane season (Figure 130 & Figure 131).

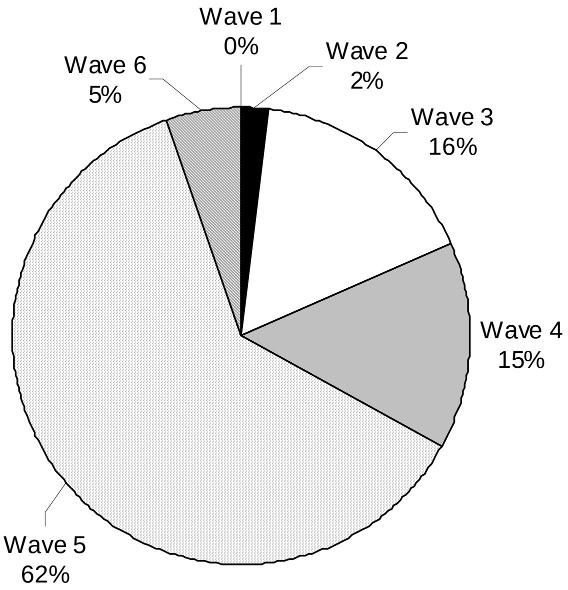

Figure 127. Average percent of spot harvest by wave, 1989–2004.

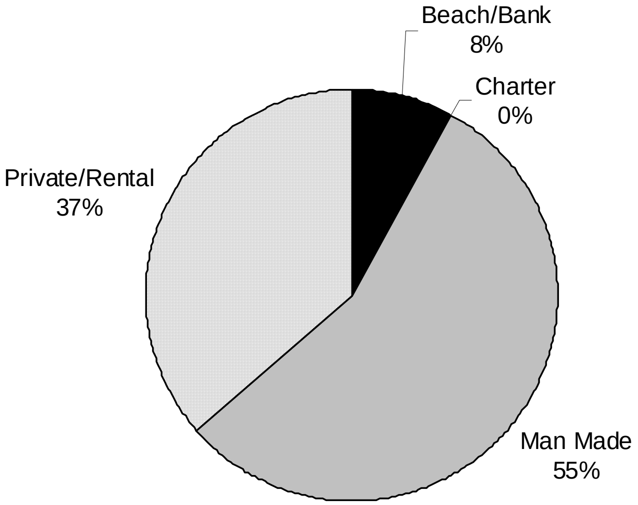

Figure 128. Average percent of spot recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

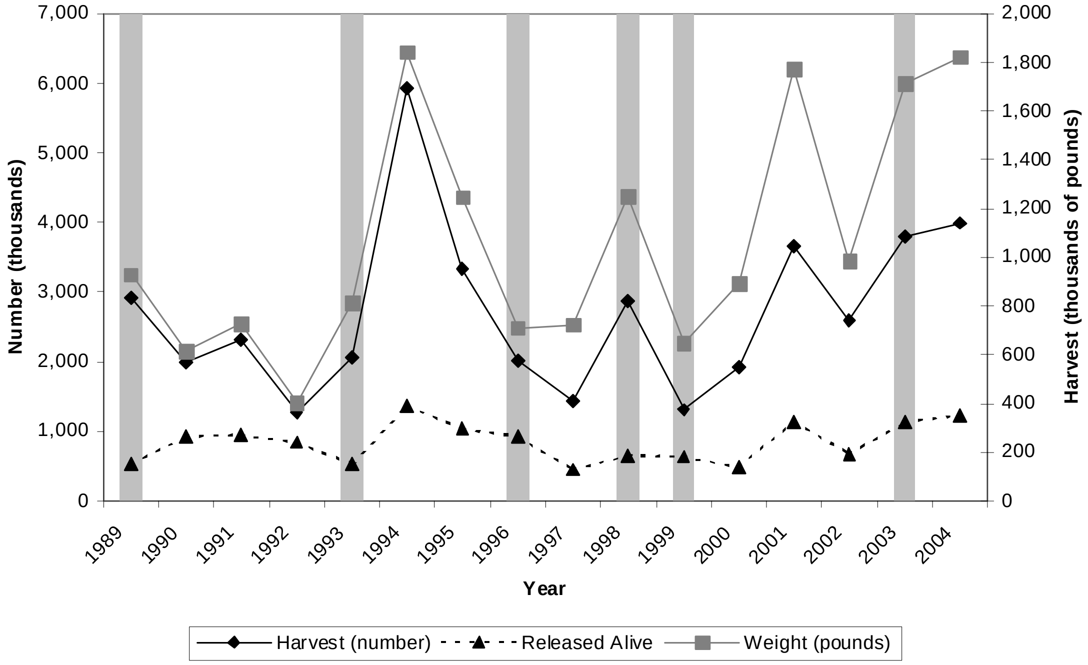

Figure 129. Spot recreational catch in North Carolina by year, 1989–2004.

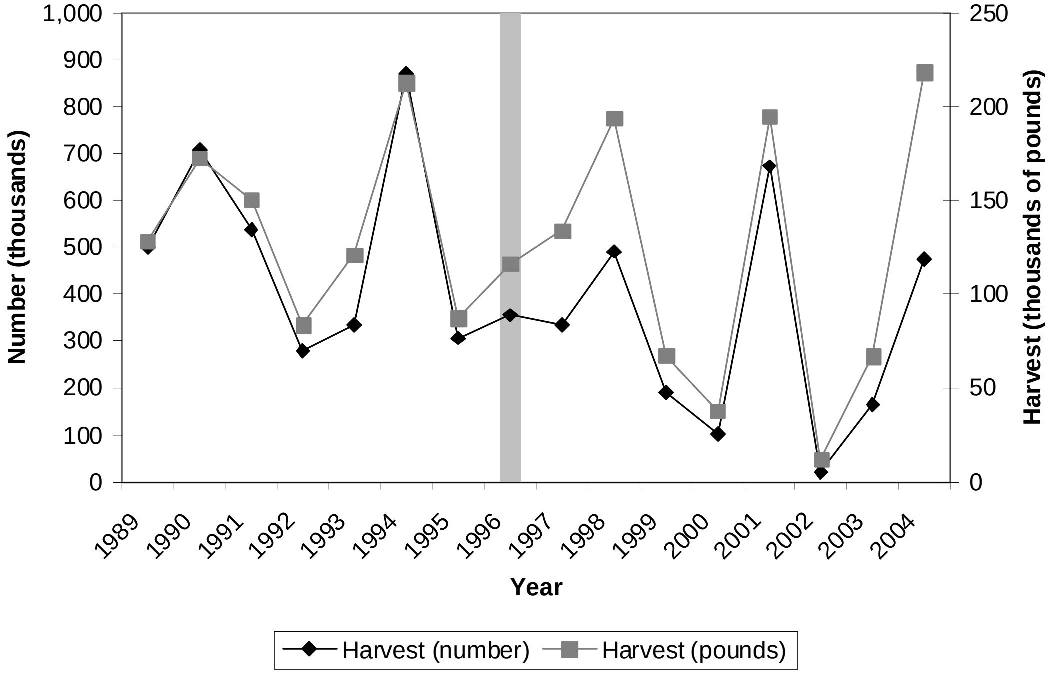

Figure 130. Spot recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

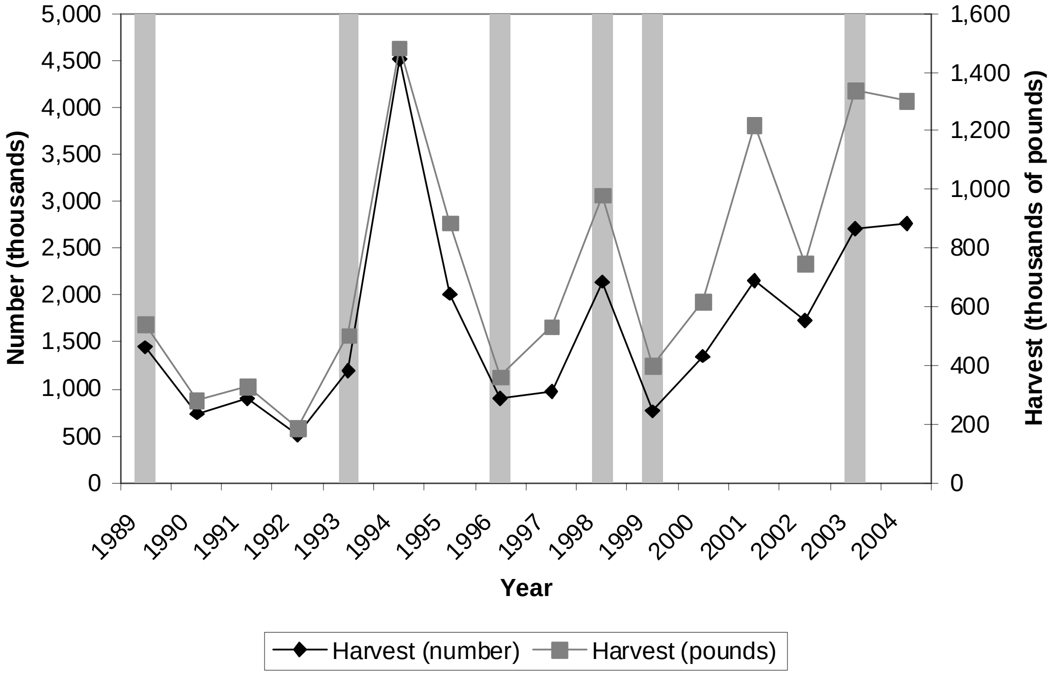

Figure 131. Spot recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

Spotted Seatrout

Spotted seatrout are predominantly caught during waves 5 (30%) and 6 (38%) (Figure 132). The overwhelming majority are caught by anglers fishing from private or rental boats (78%) with some fishing from man-made structures (14%) and a few from the beach or banks (8%) (Figure 133). The annual harvest and number released alive are highly variable for the time period (Figure 134). Harvest of spotted seatrout was low during 4 of the 6 notable hurricane years in 1989, 1993, 1996, and 2003. Examination of the time series for wave 4 shows a dramatic dip in the harvest coinciding with Hurricane Bertha in July of 1996 (Figure 135). The time series for wave 5 shows low landings coinciding with Hurricane Hugo in September of 1989, a large decrease with Hurricane Emily in 1993, low landings with Hurricane Fran in 1996 and a large drop with Hurricane Isabel in 2003 (Figure 136). However, there does not appear to be an impact during Hurricane Bonnie in 1998, and landings were extremely high during the 1999 hurricane season (Figure 136). Spotted seatrout are also known to be susceptible to winter freezes resulting in high mortality (B. Burns, NCDMF, personal communication), which may have contributed to the reduction in harvest experienced in 2003.

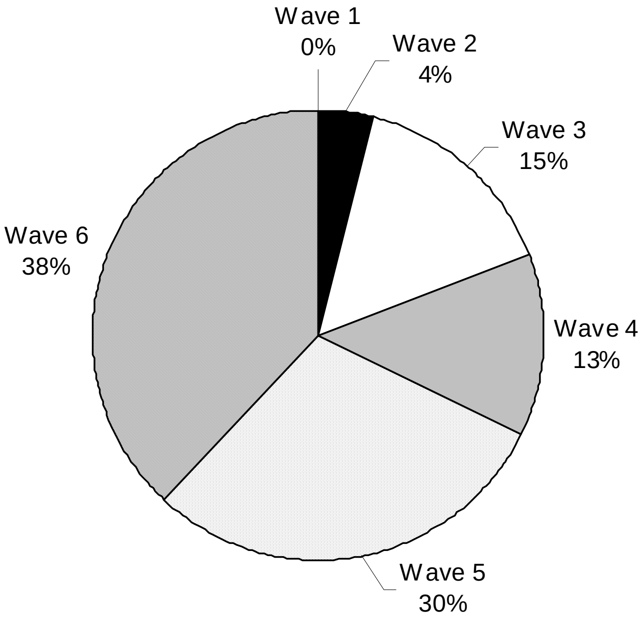

Figure 132. Average percent of spotted seatrout harvest by wave, 1989–2004.

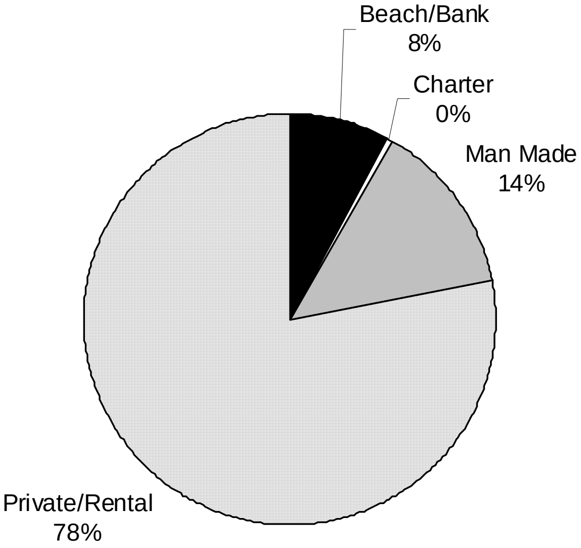

Figure 133. Average percent of spotted seatrout recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

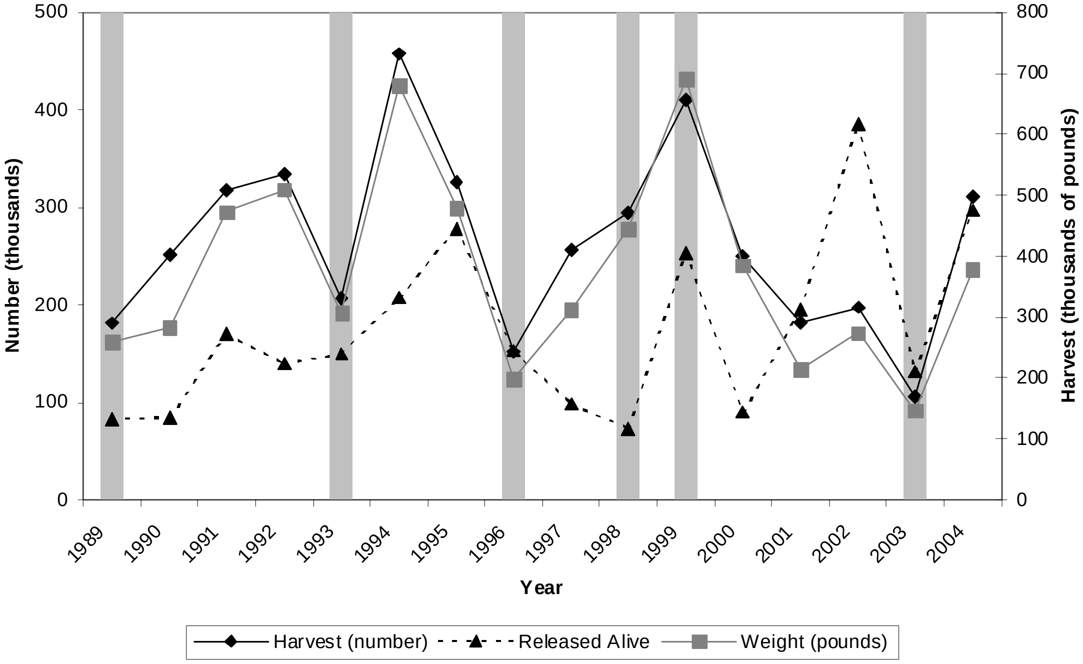

Figure 134. Spotted seatrout recreational catch in North Carolina by year, 1989–2004.

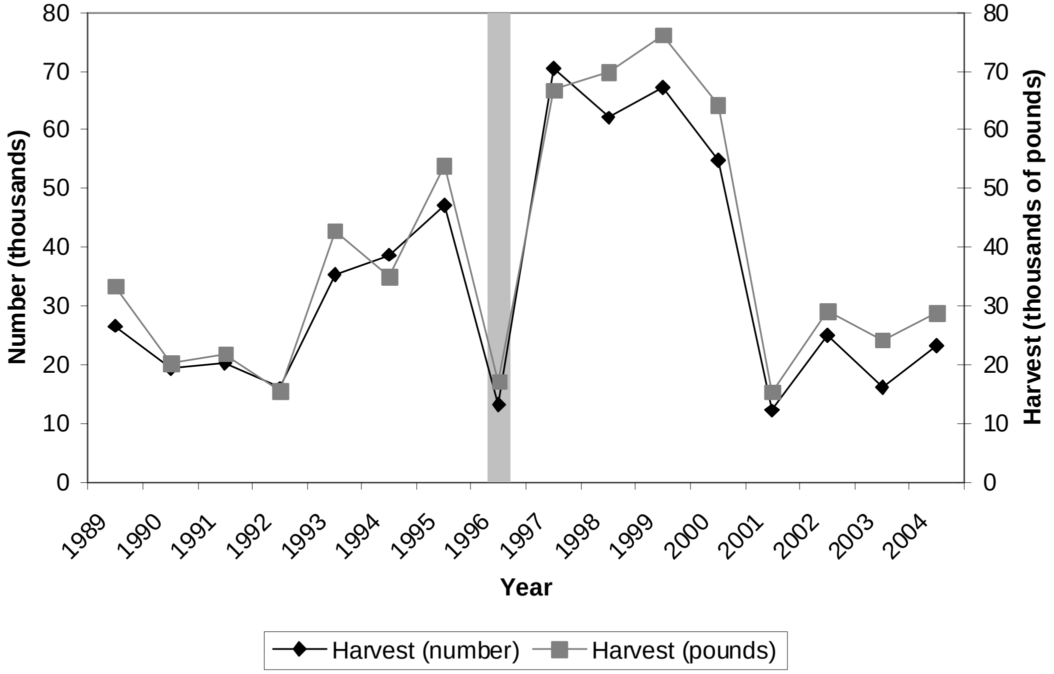

Figure 135. Spotted seatrout recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

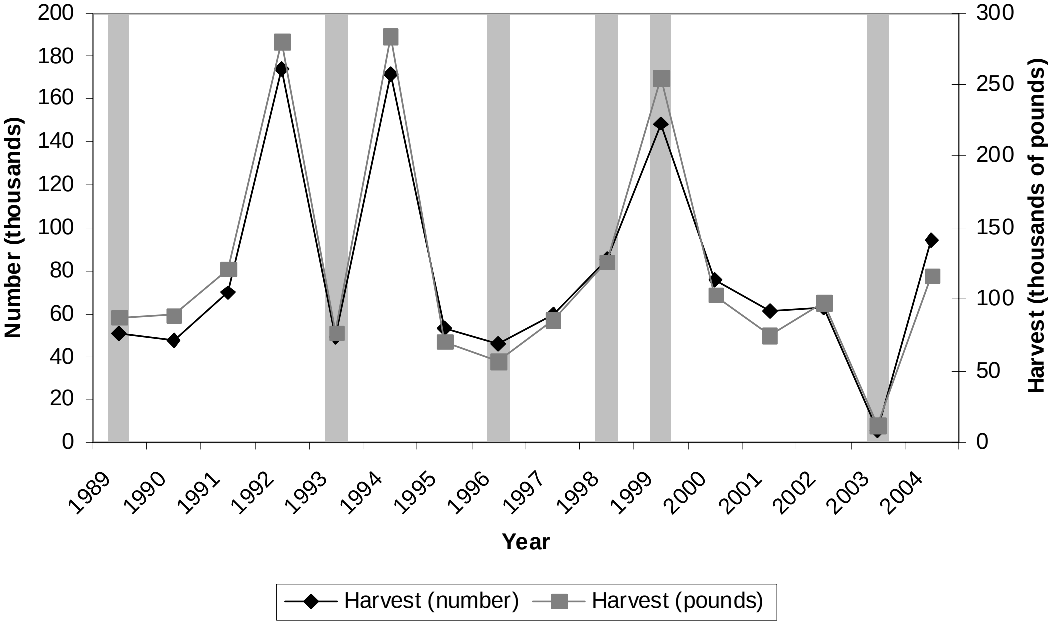

Figure 136. Spotted seatrout recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

Weakfish

Weakfish are harvested in roughly equal numbers in all waves except wave 1 (Figure 137). The overwhelming majority of weakfish are harvested by anglers using private or rental boats (78%), while a few are harvested by anglers fishing from man-made structures (12%) or the beach or bank (9%) (Figure 138). The harvest of weakfish has remained variable, but fairly consistent for most of the period, but has increased through 2004 (Figure 139). The number released alive was fairly low from 1989 to 1993, increased in 1994 and remained consistent until 1999, and spiked in 2001 (Figure 139). Examination of the time series by year and by waves 4 and 5 showed no discernable patterns with regard to hurricane activity (Figure 140 & Figure 141).

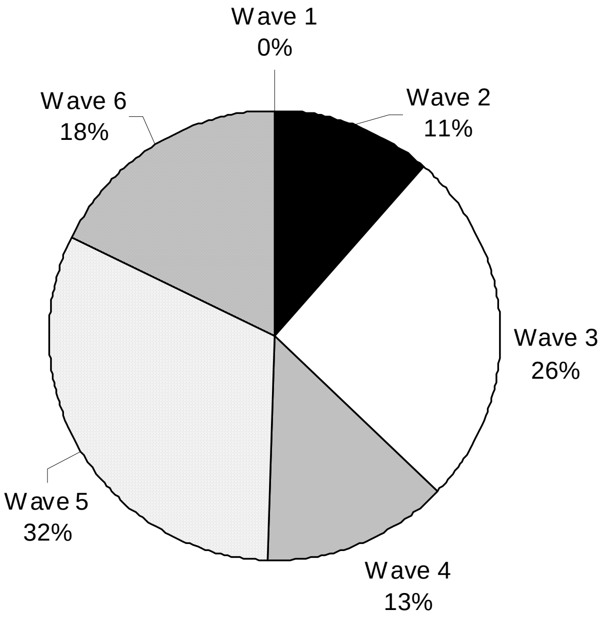

Figure 137. Average percent of weakfish harvest by wave, 1989–2004.

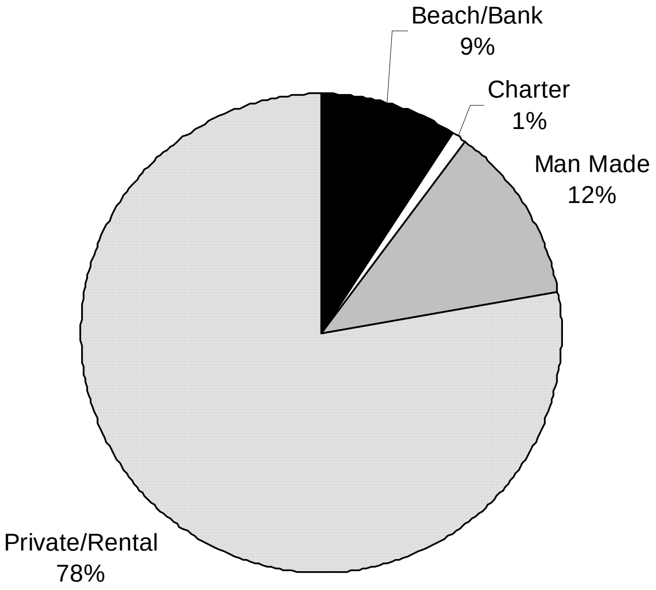

Figure 138. Average percent of weakfish recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

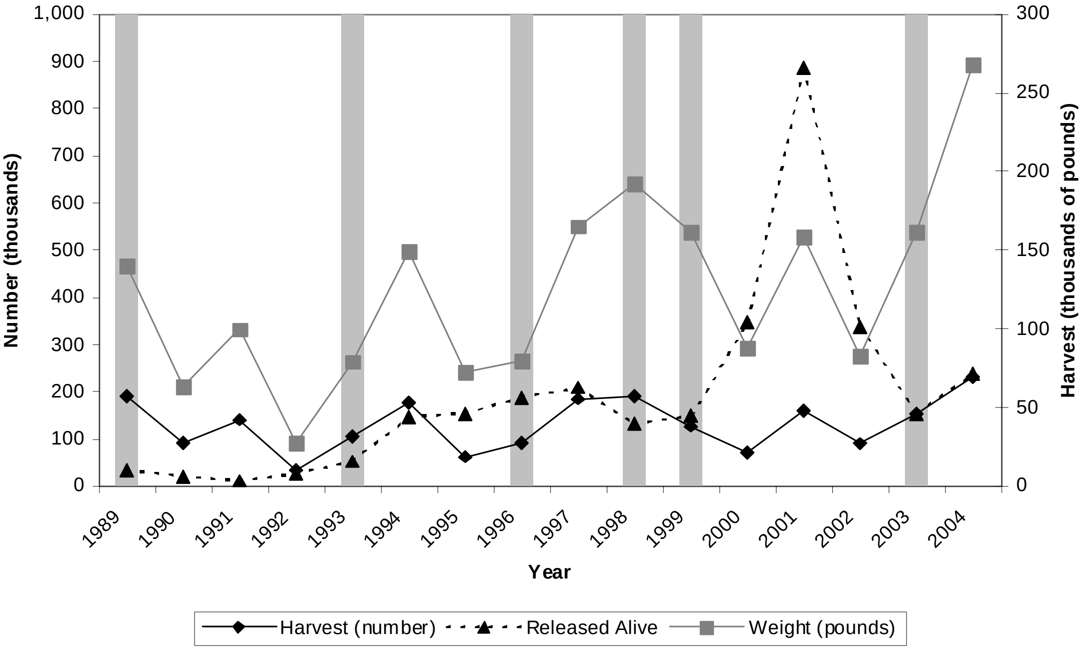

Figure 139. Weakfish recreational catch in North Carolina by year, 1989–2004.

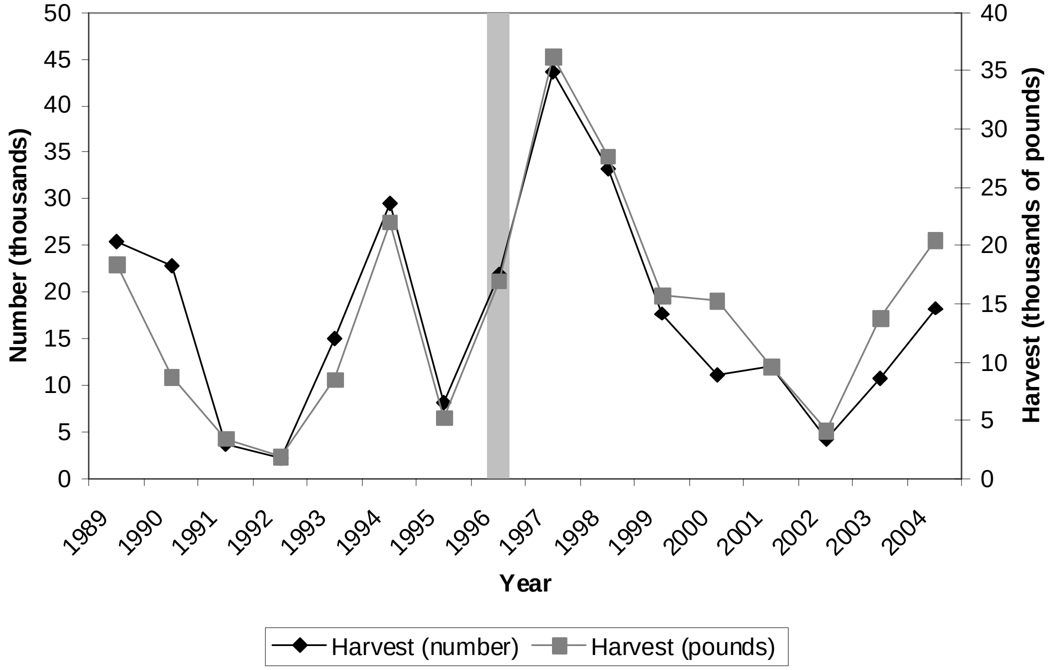

Figure 140. Weakfish recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

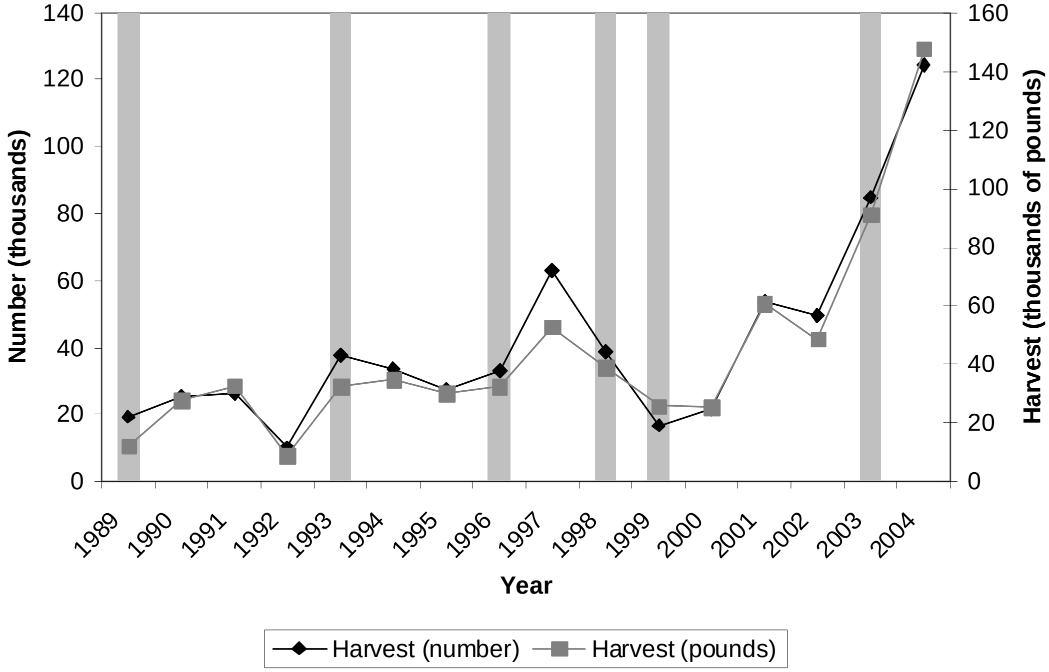

Figure 141. Weakfish recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

Yellowfin Tuna

Yellowfin tuna are predominantly harvested in waves 2 (23%) and 3 (34%) with roughly equal amounts harvested during waves 4 (12%), 5 (18%), and 6 (13%) (Figure 142). All yellowfin tuna are found in offshore waters and are therefore harvested primarily by charter boats (74%) or private or rental boats (26%) (Figure 143). Harvest was fairly low from 1989 to 1993 and increased in 1994 and remained fairly consistent for the remainder of the time period (Figure 144). Most of the yellowfin tuna caught are kept and not released alive (Figure 144). Examination of the time series by year and by waves 4 and 5 showed no discernable patterns with regard to hurricane activity (Figure 145 & Figure 146).

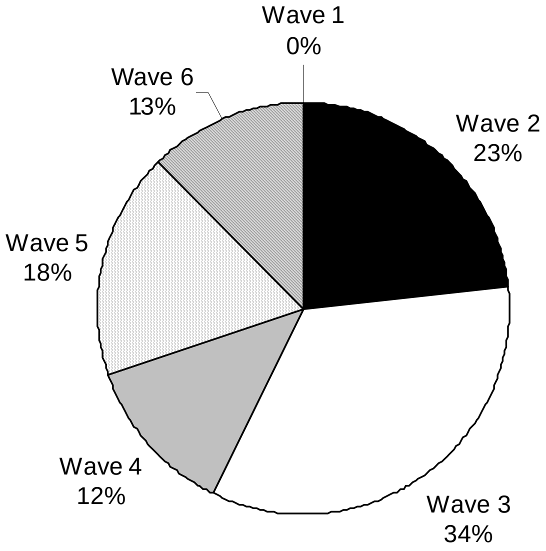

Figure 142. Average percent of yellowfin tuna harvest by wave, 1989–2004.

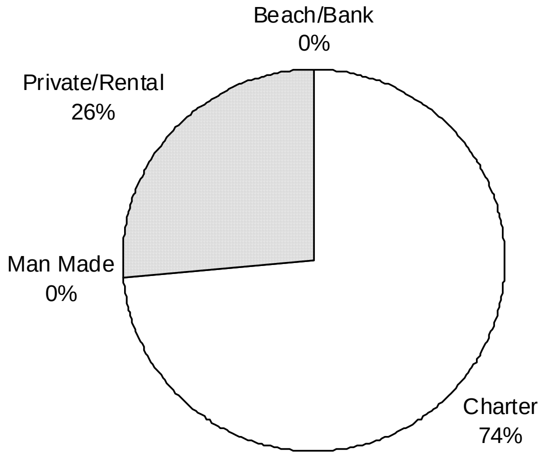

Figure 143. Average percent of yellowfin tuna recreational harvest (numbers) in North Carolina by fishing mode, 1989–2004.

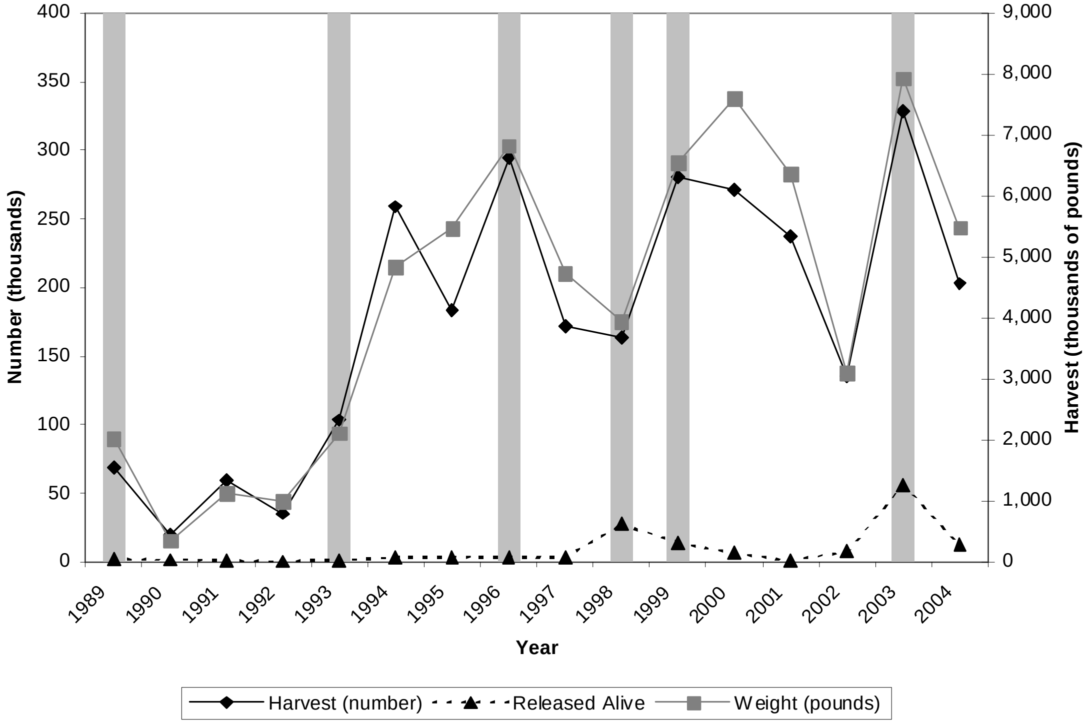

Figure 144. Yellowfin tuna recreational catch in North Carolina by year, 1989–2004.

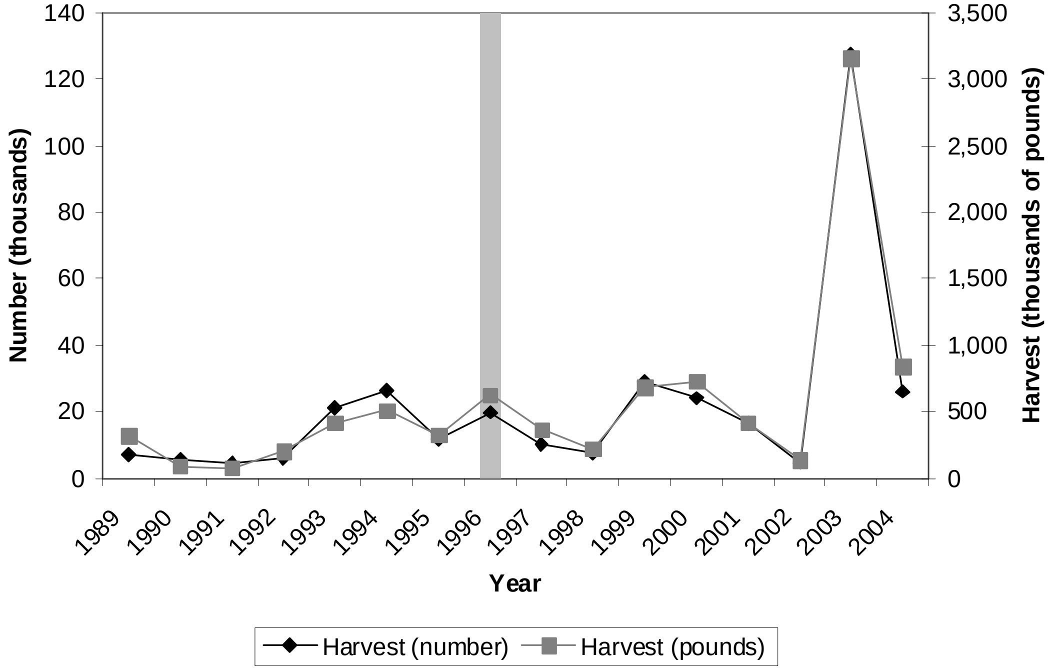

Figure 145. Yellowfin tuna recreational catch for wave 4 (July-August) of the MRFSS survey in North Carolina, 1989–2004.

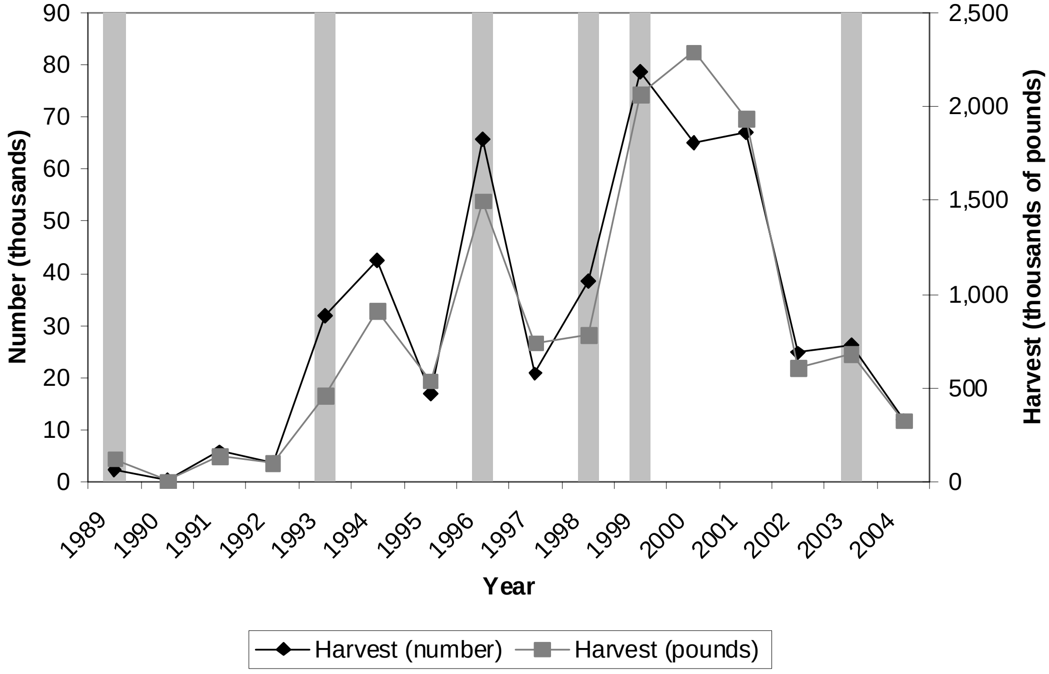

Figure 146. Yellowfin tuna recreational catch for wave 5 (August-September) of the MRFSS survey in North Carolina, 1989–2004.

Discussion

Out of the 10 fisheries examined in this study, hurricanes had apparent negative impacts on the harvest of dolphinfish, king mackerel, Spanish mackerel, and spotted seatrout. Anglers fish for these species using boats almost exclusively, and the majority of the harvest typically overlaps with hurricane season. When a hurricane is approaching, many fishermen remove their boats from the water to prevent damage. Charter boats can lose as much as two weeks of fishing time (R. Gregory, NCDMF, personal communication). Large storms often result in damage to docks, vessels, channel markers, and present hazards to navigation, any of which could take several weeks or more to repair resulting in reduced effort and harvest. Based on the results, it is likely that the impact of hurricanes is minimal, or nonexistent, on the harvest of species by anglers fishing from shore or man-made structures. Species with the majority of their harvest outside of the hurricane season are also not likely to be influenced by hurricane activity.

Tourists make up a large portion of anglers contributing to harvest and may avoid making trips to the coast to fish after a large storm, particularly if there has been a lot of damage to the area.

Declines were observed during many, but not all, of the storms examined. Each storm is unique with respect to characteristics such as wind speed, location, rainfall, storm diameter, and storm surge. As a result, the harvest for a specific fishery may or may not be influenced by a particular storm depending on these characteristics causing inconsistent results. Past studies have often revealed similar conclusions or inconsistent results (acknowledged in Turpin and Bortone 2002).

There is no evidence that hurricanes cause reductions in biomass of target species. Instead, it is more probable that hurricanes limit the opportunities for anglers to make trips out to go fishing when using boats. Based on the time series of recreational harvest, there do not appear to be any long-term impacts on harvest of any of the species discussed.

Apparent changes in harvest distribution of valuable recreational fisheries throughout years of hurricane activity are likely to exist; however, it is important to realize that several limitations prevent us from providing a decisive conclusion. Factors such as population dynamics, habitat alteration, species popularity with anglers, and changes in management strategies all have confounding influences on harvest; therefore the dynamic nature of each fishery limits the capability to attribute changes in harvest to any single cause, such as hurricanes, with absolute certainty. It is possible that any trends observed are merely coincident with hurricane activity by chance with changes in harvest.

Based on the MRFSS estimates, hurricanes do not appear to effect harvests of Atlantic croaker, bluefish, red drum, spot, weakfish, or yellowfin tuna. However, the MRFSS survey was designed to obtain estimates of participation, effort, and catch by recreational anglers over a greater spatial and temporal scale than would be required for a more detailed analysis of hurricane impacts. These impacts may be restricted to a more specific region (e.g., Core Sound) over a period much shorter than a two-month wave. Further, reliable estimates of recreational harvests in North Carolina are only available for a 16-year period consisting of 6 years with notable hurricane activity. A longer time series is needed to perform intervention analysis to test the potential impacts of hurricane activity for statistical significance.

A large problem with analyzing recreational fishing effort in response to hurricane activity is that current estimates are for longer periods than would be needed for reliable analysis. For example, decreased effort during a hurricane on September 1st would not be detected should increased effort during the following 8 weeks (all in wave 5) offset or eliminate the reduction. Current data collection was not designed to answer short-term questions, but rather provide long-term estimates for management at the regional level. Another problem in detecting and comparing differences among modes and hurricane activity are the socioeconomic aspects of each fishery. For example, private boat fisheries may consist of a greater percentage of local anglers than charter boat fisheries; or, anglers who fish from man-made structures may be of a different income level than those of rental fisheries. These groups of anglers may respond differently to hurricane impacts, possibly offsetting or increasing measurable impacts by mode.

ECONOMIC IMPACT ANALYSIS

Methods

The economic impact of commercial fishing on the state of North Carolina was estimated for 2005 using IMPLAN Pro 2.0 (Minnesota IMPLAN Group 2000). The IMPLAN Pro package is composed of a database and software that models regional economic activity. In this study, the ex-vessel value and the average crew size (including the captain) was determined for each fishery using data provided by the North Carolina Trip Ticket Program. The data were used to compute the secondary effects within the North Carolina economy. Secondary effects include indirect impacts generated by the inter-industry purchases of goods and services by fishermen and the induced impact from the household expenditures of persons employed in both the direct and indirect activities. In other words, as fishing businesses and crews spend their earnings, these dollars continue to impact the state as they flow through the economy until leaving the state's borders. Money generated throughout this process is considered the "economic impact" on North Carolina. At this time, the economic impact can be estimated for commercial fishing but not for recreational fishing.

In general, IMPLAN gives a good sense of the overall economic impact of commercial fishing on the state. However, there are a few limitations with the IMPLAN Pro package that should be realized. IMPLAN Pro treats the commercial fishing industry as one generalized category; therefore, the full economic impact is underestimated since there are no specific data available to track the flow of dollars between different commercial fishing businesses. The economic impact is underestimated further when a fishery is analyzed at the species level because the economic impact of property and other business taxes is not available for each type of fishery at this time. Lastly, IMPLAN Pro treats employment in a single industry as the total number of people who are working in the industry, regardless of whether those people work full or part time (Minnesota IMPLAN Group 2000). Due to the tremendous diversity in commercial fisheries that occur along the coast of North Carolina, it is unlikely that fishermen operate full time harvesting only one species.

Results

The value of commercial fishing landings as a whole in 2005 was nearly $65 million (Table 16). These dollars are significantly magnified as they flow into the local economy, eventually generating $122.8 million in total economic impacts inside the state. The hard blue crab fishery had the largest economic impact of a single species on the state producing just over $27 million and creating 117.9 jobs. The summer flounder fishery came in second producing about half the impact seen in the crab fishery with just over $13 million and creating 57.6 jobs. The shrimp fishery came in third producing a little more than half that of summer flounder with just under $8 million and 33.8 jobs.

Some businesses are more affected than others by the commercial fishing industry. The largest target of fishermen's landings dollars is their own homes (essentially, their mortgages) followed by wholesale trade, food service/drinking, and doctors and dentists (Table 17). These dollars also generate additional, non-fishing jobs in the community. The vast majority of jobs are created in the food service/drinking sector with 67.0 jobs (Table 18). Doctors/dentists come in second with less than half of that with 26.8 jobs followed closely by wholesale trade with 23.5 jobs.

Discussion

The sustained reduction of commercial landings in the commercial hard blue crab fishery seen after the 1999 hurricane season has likely caused a significant blow to those closely tied to the industry. After the storms of 1999, the state established the hurricane assistance program, funded by both state and federal dollars, to assist fishermen who were adversely affected by the 1999 storms. This program was open to all fishermen, not just crab fishermen, although crab fishermen made up a large percentage of those impacted (personal communication, D. Lupton, NCDMF). A Blue Crab Economic Assistance Program was later established, funded by federal dollars, to provide relief to fishermen adversely affected by market conditions and imports that also affected the blue crab fishery from 2000 to 2002 (personal communication, G. Kemp, NCDMF).

Table 16. Economic impact of the commercial fisheries in North Carolina, 2005. NCDMF Trip Ticket Program, IMPLAN Pro.

		2005			
Species	Pounds	Value	Fishermen (w/crew)	Total Impact*	Jobs Created
Blue Crabs, Hard	23,554,876	$ 15,351,439	1,666	$ 27,271,303	117.9
Flounder, Summer	4,064,464	$ 7,500,273	575	$ 13,324,265	57.6
Shrimp	2,354,611	$ 4,403,318	603	$ 7,822,462	33.8
Flounder, Southern	1,870,044	$ 3,453,449	1,489	$ 6,134,883	26.5
Tunas	1,328,179	$ 3,419,687	958	$ 6,075,500	26.3
Croaker, Atlantic	11,490,704	$ 3,278,759	1,054	$ 5,825,079	25.2
Clams, Hard	412,995	$ 2,777,957	1,047	$ 4,935,231	21.3
Mackerel, King	1,246,092	$ 2,053,711	862	$ 3,648,767	15.8
Oysters	378,221	$ 1,683,564	1,017	$ 2,991,295	12.9
Striped Bass	849,904	$ 1,645,053	1,282	$ 2,922,498	12.6
Groupers	579,231	$ 1,474,038	415	$ 2,618,695	11.3
Sea Basses	690,201	$ 1,332,261	605	$ 2,366,646	10.2
Menhaden, Atlantic	13,308,895	$ 1,215,339	575	$ 2,158,867	9.3
Snappers	432,829	$ 1,116,056	377	$ 1,982,705	8.6
Spot	1,713,847	$ 904,678	1,383	$ 1,607,470	7.0
Mullet, Striped	1,620,034	$ 801,038	1,097	$ 1,423,068	6.2
Bluefish	2,827,222	$ 787,627	1,269	$ 1,399,562	6.1
Mackerel, Spanish	444,975	$ 585,525	618	$ 1,040,595	4.5
Weakfish	421,469	$ 356,783	1,163	$ 634,018	2.7
Kingfishes	296,243	$ 271,713	999	$ 482,164	2.1
Seatrout, Spotted	129,595	$ 173,526	1,063	$ 308,649	1.3
Drum, Red	128,770	$ 173,040	904	$ 307,387	1.3
Triggerfish	145,639	$ 162,533	308	$ 289,114	1.3
Eel, American	49,278	$ 106,769	57	$ 189,862	0.8
Catfishes	401,516	$ 91,165	604	$ 161,833	0.7
Amberjack	103,376	$ 60,151	350	$ 106,745	0.5
Tilefishes	44,212	$ 52,827	132	$ 93,985	0.4
Wahoo	14,980	$ 32,814	327	$ 58,441	0.3
Hog Snapper	8,445	$ 19,433	120	$ 34,188	0.1
Spadefish	35,445	$ 9,059	304	$ 16,048	0.1
Herring, Thread	7,489	$ 3,195	10	$ 5,525	0.0
Scallop, Bay	0	$ -	0	$ -	0.0
All species**	79,183,439	$ 64,896,645	5,524	$122,833,226	564.4

* Individual species estimates do not include the economic impact of property and other business taxes. The “all species” estimate does include those factors.

** The “all species” category includes species not listed in this table.

Table 17. Largest monetary impacts from commercial fishing in North Carolina, 2005. NCDMF Trip Ticket Program, IMPLAN Pro.

Sector	Impact (millions)
Dwellings	$ 6.9
Wholesale trade	$ 3.5
Food service/drinking	$ 2.9
Doctors/dentists	$ 2.9
Real estate	$ 2.6
Hospitals	$ 2.1
Commercial building repair	$ 1.7
Banks	$ 1.4
Insurance	$ 1.3
Auto sales and parts	$ 1.3

Table 18. Largest secondary job impacts from commercial fishing in North Carolina, 2005. NCDMF Trip Ticket Program, IMPLAN Pro.

Sector	Impact (jobs)
Food service/drinking	67.0
Doctors/dentists	26.8
Wholesale trade	23.5
Real estate	20.9
Hospitals	20.8
Commercial building repair	18.9
Nursing/residential care	18.8
Food/beverage stores	17.1
Retail stores	16.8
Private household employment	15.0

CONCLUSION

Commercial Fishing

The impacts of hurricanes on commercial fishing depend largely on the individual nature of a given hurricane. No two storms are the same with respect to factors such as overall strength, wind speed, rainfall, forward momentum, barometric pressure, storm surge, and direction of travel. Hurricanes of similar strength can have very different impacts on commercial fishing depending on specific conditions. Generally speaking, hurricanes do not appear to have long-term consequences on the fish stocks themselves most of the time; however, hurricanes can affect fishermen by causing damage to gear, vessels, and personal property which keep people from actively fishing leading to a reduction in harvest and fishing mortality and a loss of income for fishermen.

Occasionally, environmental conditions could be right for a hurricane to cause a lasting impact on a particular fishery. The 1999 hurricane season was likely a contributor to the significant decline in hard blue crab landings observed following 1999 and left a lasting impression that persisted throughout the end of the time series. Tropical Storm Dennis had saturated the ground two weeks prior to Hurricane Floyd making landfall, and the additional rainfall from Hurricane Floyd resulted in severe flooding causing a “flushing” effect that triggered blue crabs to migrate out of the Pamlico and Neuse rivers and into Pamlico Sound where they were subsequently harvested in large numbers. The 1999 hurricane season was the only season found to coincide with the decline seen in the hard blue crab fishery; however, since the hard blue crab fishery is the largest and most economically important fishery in the state of North Carolina, any factors that could potentially negatively influence this fishery are cause for concern.

The red tide of 1987-88 decreased bay scallop population levels below a minimum stock size threshold that is needed to maintain recruitment levels large enough to supply adequate numbers of larvae for the next generation. Recruitment levels in Core Sound were found to be near normal following the red tide. However, it appears that bay scallop populations in North Carolina may be recruitment limited on a basin scale, and the spawning stock from Core Sound was not able to replenish populations in Bogue Sound. Bay scallop populations are likely currently at such low levels that any external influence such as hurricanes, habitat loss, poor water quality, or predators increases the vulnerability of the population. They may continue to be negatively affected by environmental disturbances (including hurricanes) until the spawning stock can reach large enough levels to overcome these events as they have in the past.

Fisheries that occur primarily in the fall during the peak of hurricane season, such as striped mullet and the southern flounder pound net and gill net fishery, have a large risk for a reduction in overall harvest. The striped mullet fishery likely suffers, not from a stock reduction, but simply from the inability of fishermen to harvest striped mullet roe during the peak of the season causing short-term impacts to landings. The species itself may actually even experience an increase in spawning stock biomass due to reduced fishing mortality during a hurricane year.

This study also provides evidence that hurricanes may impact estuarine and nearshore commercial fisheries (e.g., hard blue crabs, bay scallops, and striped mullet) more than offshore fisheries (e.g., groupers). The impacts of hurricanes were easier to detect with quantitative compared to qualitative analysis, as changes were difficult to detect outside of normal variability without objective statistical tests. However, trends seen from the qualitative analysis of commercial data also support evidence that fisheries that occur primarily in the fall, such as the southern flounder pound net fishery, are at risk for a decrease in landings during years with notable hurricane activity. The hard clam fishery may also experience short-term decreases in landings due to shellfish closures associated with fecal coliform runoff, particularly during years in which there are multiple storm events. Additionally, the catfish fishery could experience declines in future landings resulting from fish kills associated with hurricanes affecting Albemarle Sound.

Intervention analysis was quite informative for those species analyzed using this method. Future research would benefit by performing this analysis on additional species (e.g., hard clams) and particular fisheries (e.g., flounder pound net fishery) to clarify results that were unclear in the qualitative analysis section. In addition, a seasonal ARIMA model can be performed using intervention analysis to detect differences at a monthly level, essentially comparing harvest during a month in which a hurricane occurred to harvest during that same month in previous years when no hurricanes occurred.

Forecasting

Forecasting models developed in this study consistently overestimated actual future harvest, because the models assume that all factors affecting the behavior of the series remain unchanged; however, trends in commercial landings, effort, and participation have been decreasing for the past several years due to socioeconomic factors. Unless these factors are measured and accounted for in the model, estimates are likely to be consistently high. In addition, the inherent variability within the time series causes forecast estimates to have large confidence intervals indicating a high degree of uncertainty. Furthermore, it would be difficult to predict the impact of a notable hurricane on a particular fishery because no two storms are alike and each storm affects the ecosystem differently. Therefore, given the tendency for model overestimation, a large degree of uncertainty, and the individual nature of each storm, these models would be unreliable for predicting the effect of another notable storm on a given fishery.

Recreational Fishing

Out of the 10 recreational fisheries examined in this study, hurricanes had apparent negative impacts on the harvest of dolphinfish, king mackerel, Spanish mackerel, and spotted seatrout. Anglers fish for these species using boats almost exclusively, and the majority of their harvest typically overlaps with hurricane season. When a hurricane is approaching, many fishermen remove their boats from the water to prevent damage resulting in a loss of harvest time. Large storms also often result in damage to docks, vessels, channel markers, and present hazards to navigation, any of which could take several weeks or more to repair resulting in further reductions in effort and harvest. Based on the results, it is likely that the impact of hurricanes is minimal, or nonexistent, on the harvest of species by anglers fishing from shore or man-made structures. Species with the majority of their harvest outside of the hurricane season are also not likely to be influenced by hurricane activity.

As is sometimes the case in commercial fisheries, there is no evidence that hurricanes cause reductions in biomass of recreational target species. Instead, it is more probable that hurricanes limit the opportunities for anglers to make trips out to go fishing when using boats. Based on the time series of recreational harvest, there do not appear to be any long-term impacts on harvest of any of the recreational species discussed. A longer time series is needed in order to perform further statistical tests.

It is highly probable that hurricane activity influences recreational fisheries in coastal North Carolina to some extent. The magnitude of the state's marine recreational fisheries, amount of shoreline, and frequency of hurricane activity suggests that impacts are inevitable. Physical, biological, and socioeconomic consequences of hurricanes all have the potential to alter fishing effort and harvests. The recent history of recreational fishing data collection does not provide an adequate time series for more detailed statistical tests such as intervention analysis. More data points are needed before this test can be done. Further, the current data collection program is not designed to provide the detailed information needed to answer questions regarding the short-term impacts of hurricanes on recreational fisheries. Lastly, other influential factors, such as fish population dynamics, management efforts, and angler demographics, add inseparable dimensions adding variation to effort and harvest estimates. In spite of these limitations, continued evaluations of recreational fishing dynamics in response to hurricane activity is suggested to better understand these interactions for management and mitigation purposes.

Economic Impact

Sectors of the economy most likely to be affected by a decrease in commercial fishing activity are dwellings (essentially fishermen's mortgages), wholesale trade, food service/drinking (restaurants and bars), doctors and dentists, the real estate industry, and hospitals. The hard blue crab fishery is the most economically important fishery in the state, and the hurricanes of 1999 likely caused a significant blow to those closely linked to this fishery. Any factors that could potentially disrupt this fishery are cause for concern. Although bay scallops are currently not contributing to the North Carolina economy, this fishery reached over $1 million in ex-vessel value prior to the red tide event. If the population levels of bay scallops return to sustainable levels, this fishery could once again increase in economic importance to the state. The striped mullet fishery is also an important fishery in North Carolina. Disruptions to the striped mullet fishery will likely only have a temporary impact that lasts one fishing season.

Unfortunately, we currently do not have any data from which to derive a measure of the economic impact of the recreational fishery on the economy of North Carolina; however, with an increasing trend and an estimated 7 million trips in 2004, the impact is likely to be significant and continue to increase in the near future.

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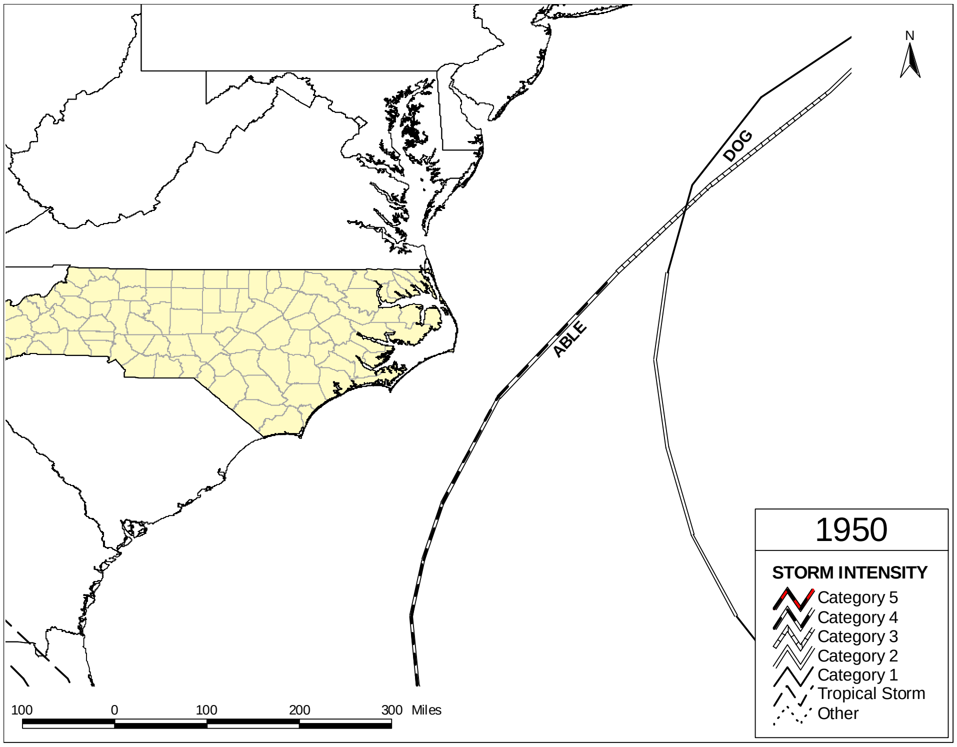
APPENDIX

Tracks of tropical cyclones near the North Carolina coast, 1950-2004.



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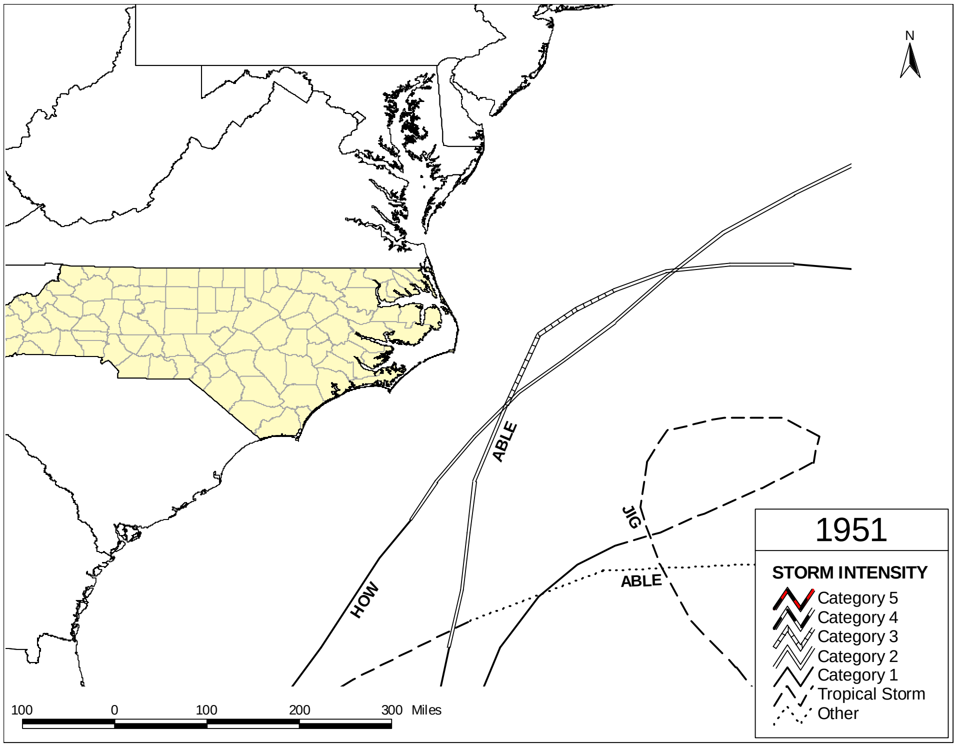

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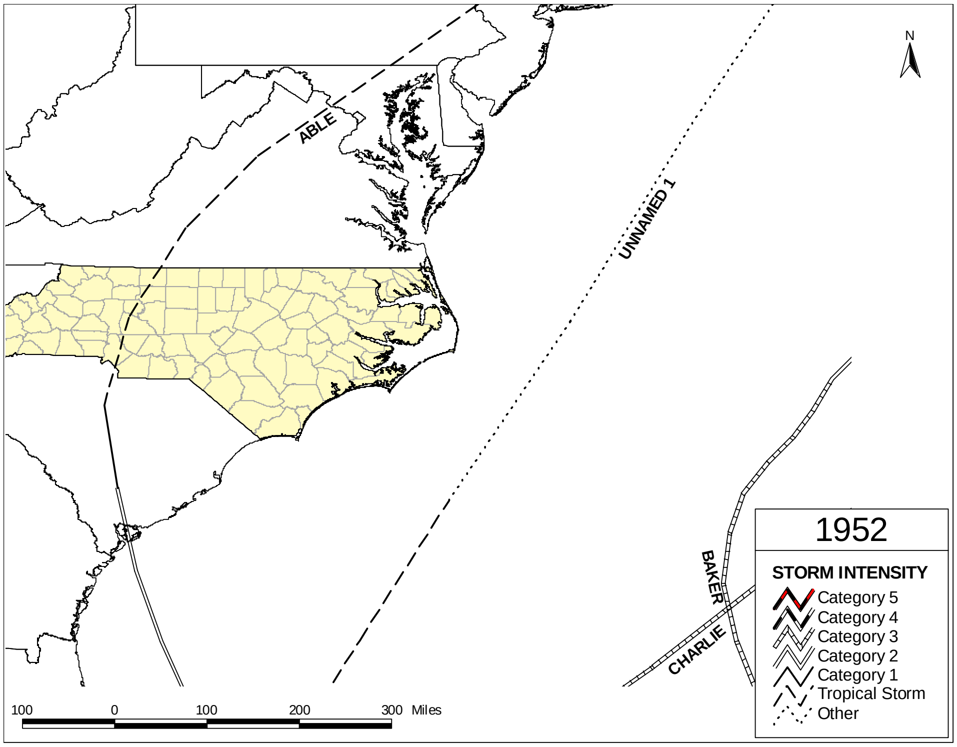

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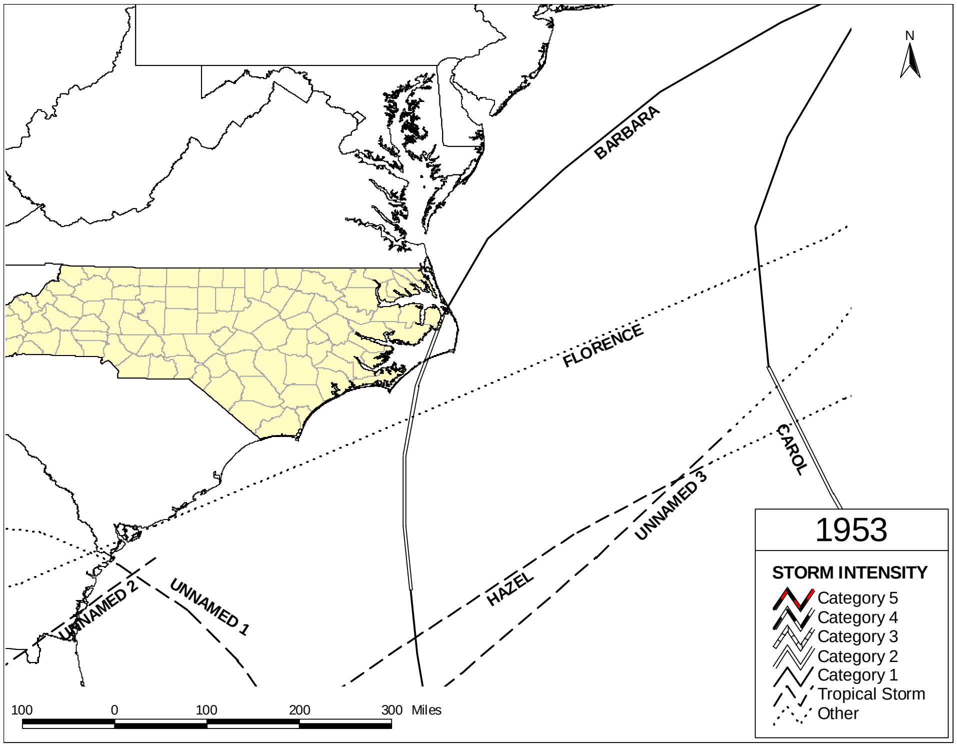

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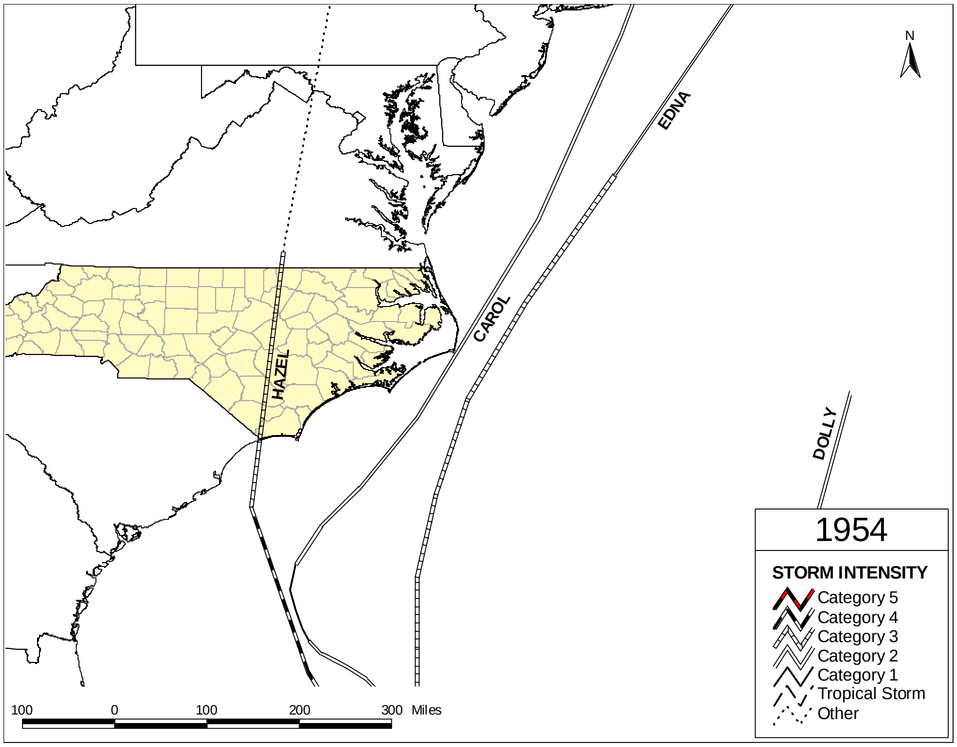

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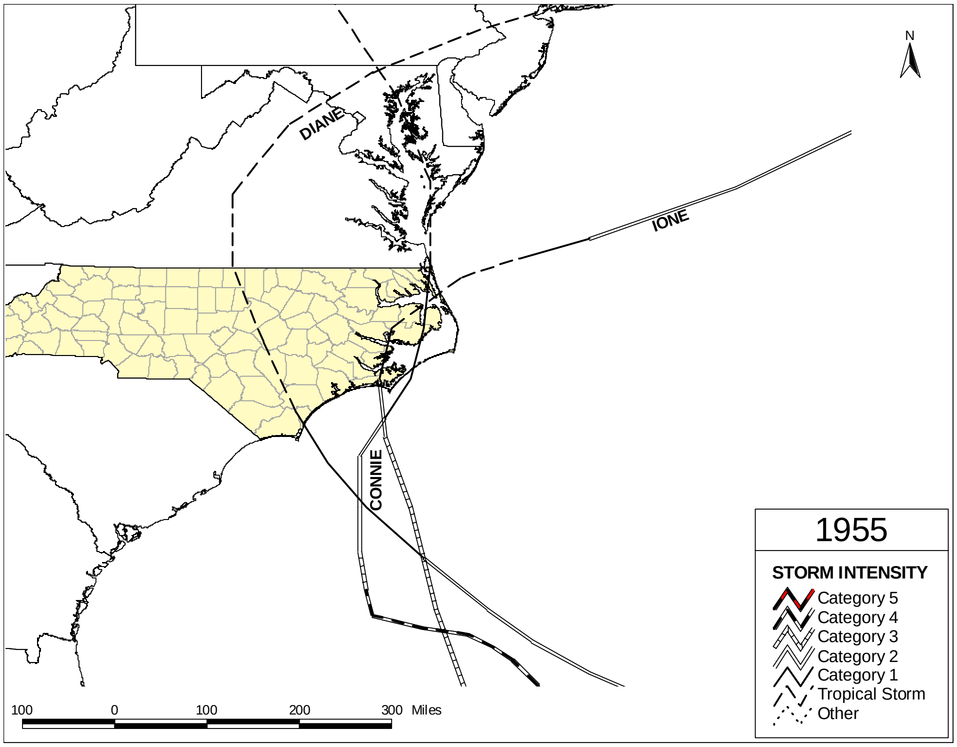

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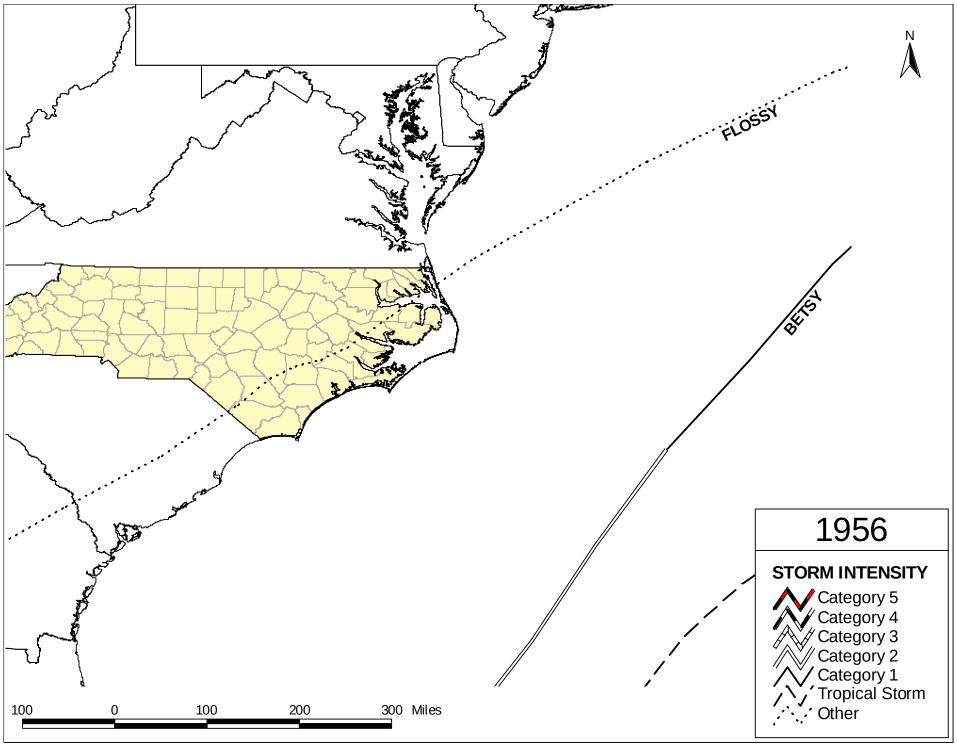

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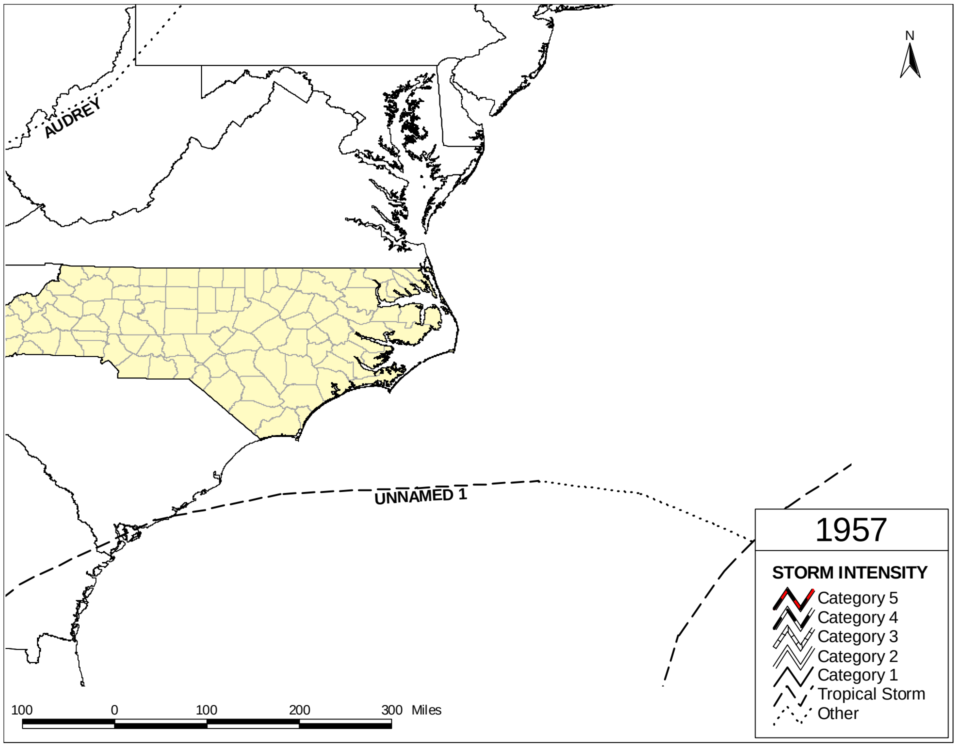

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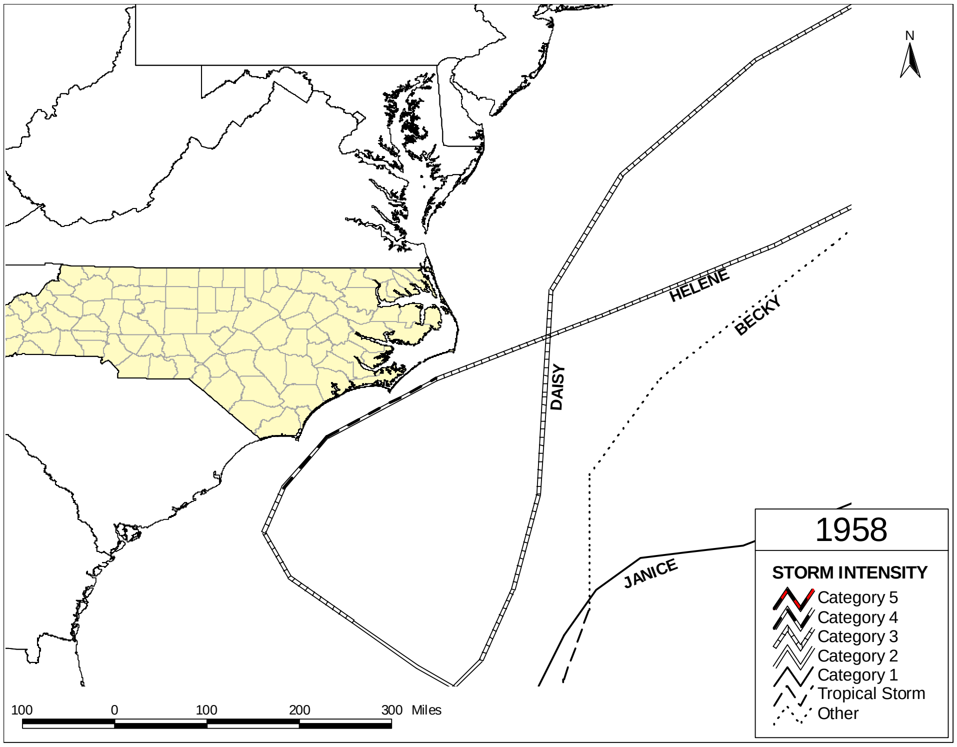

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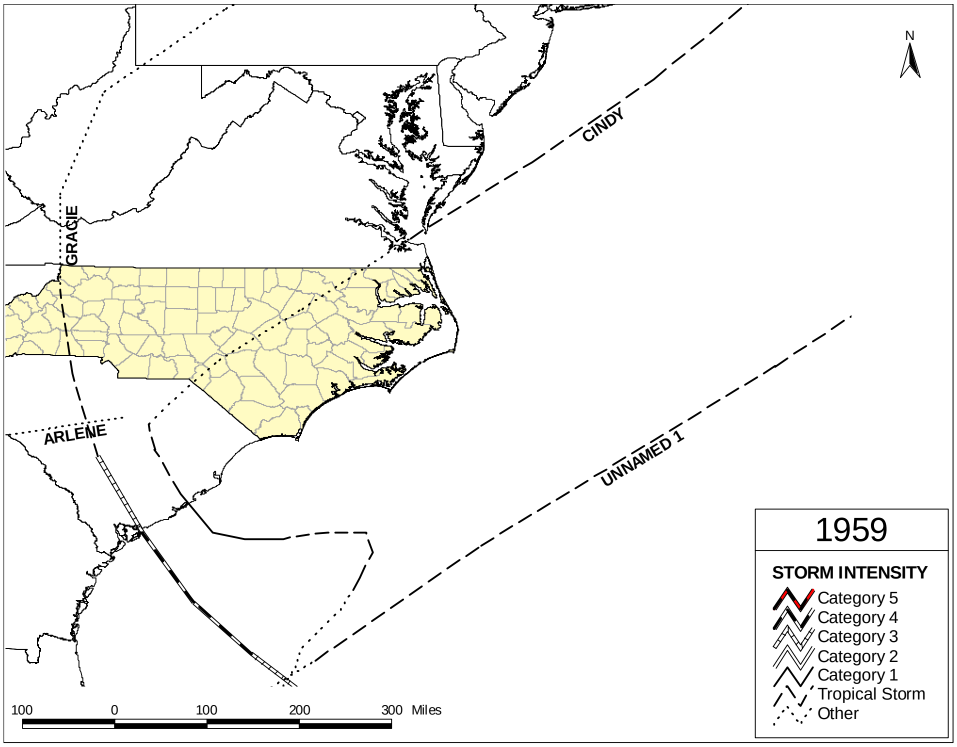

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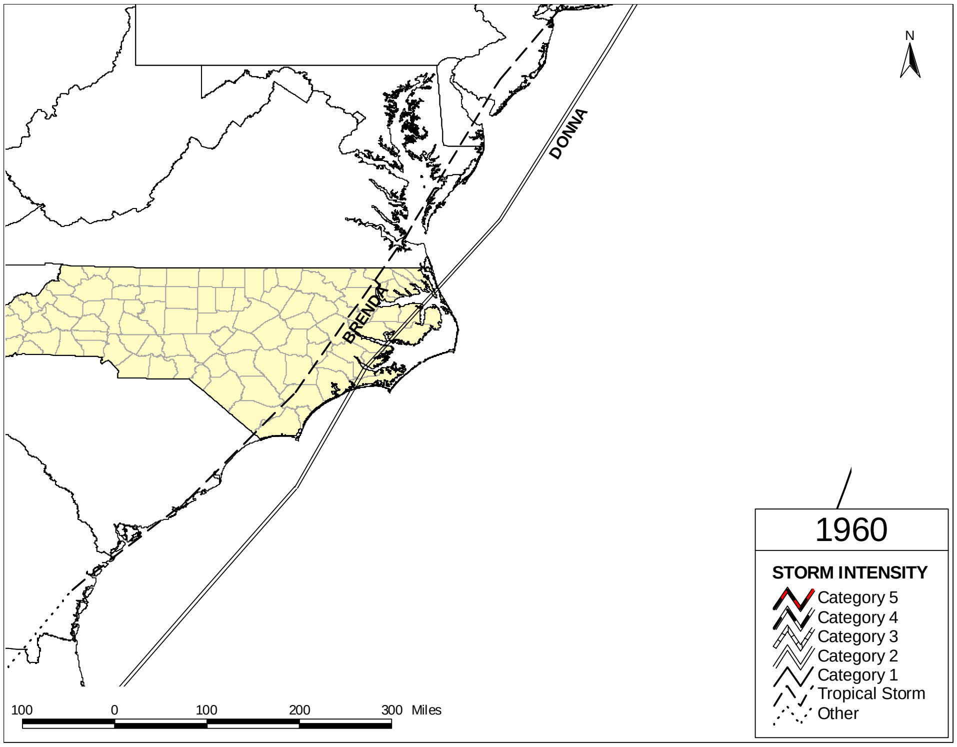

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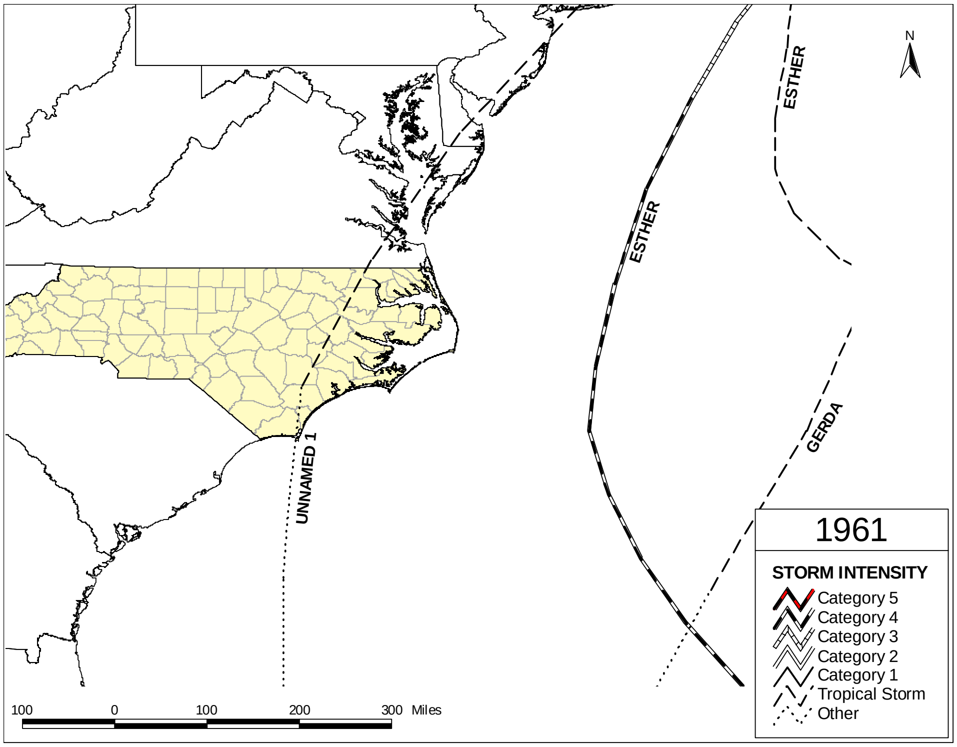

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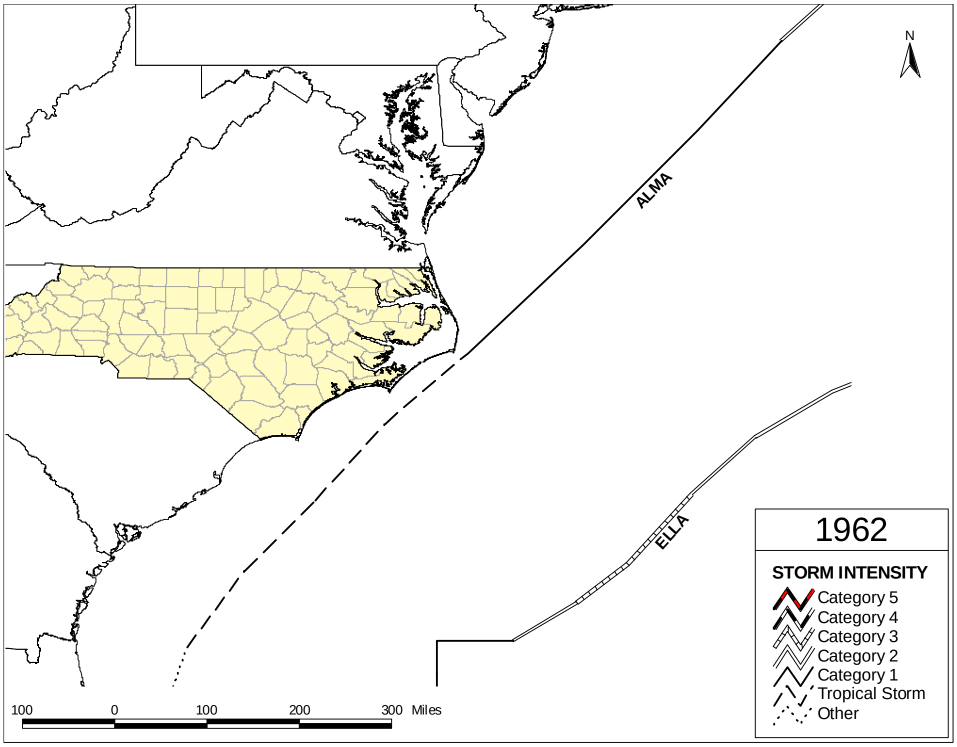

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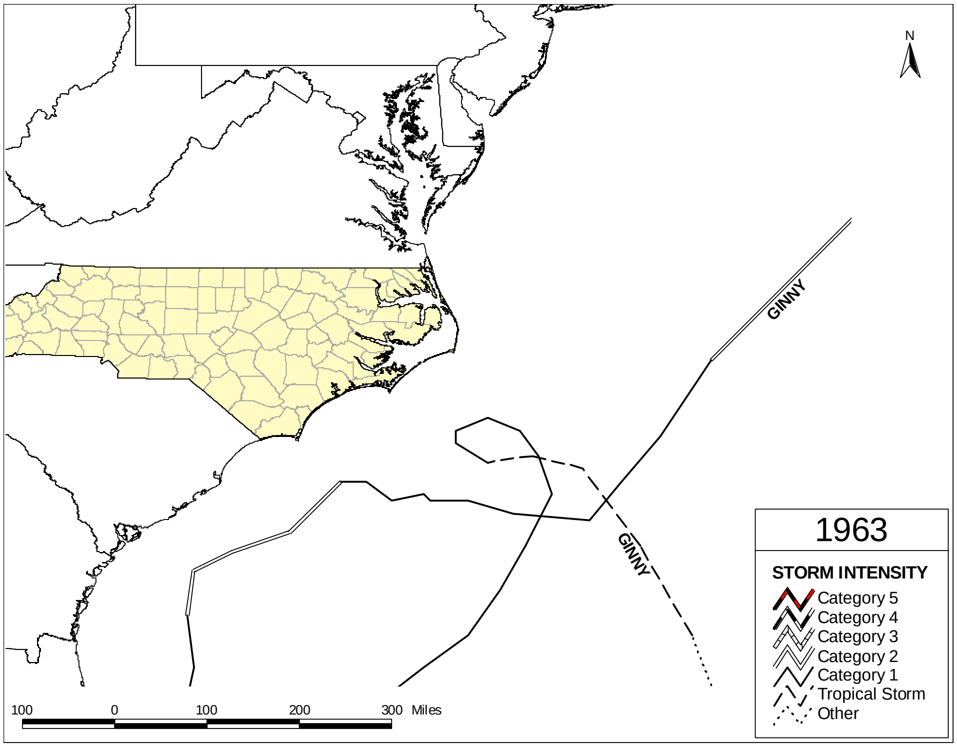

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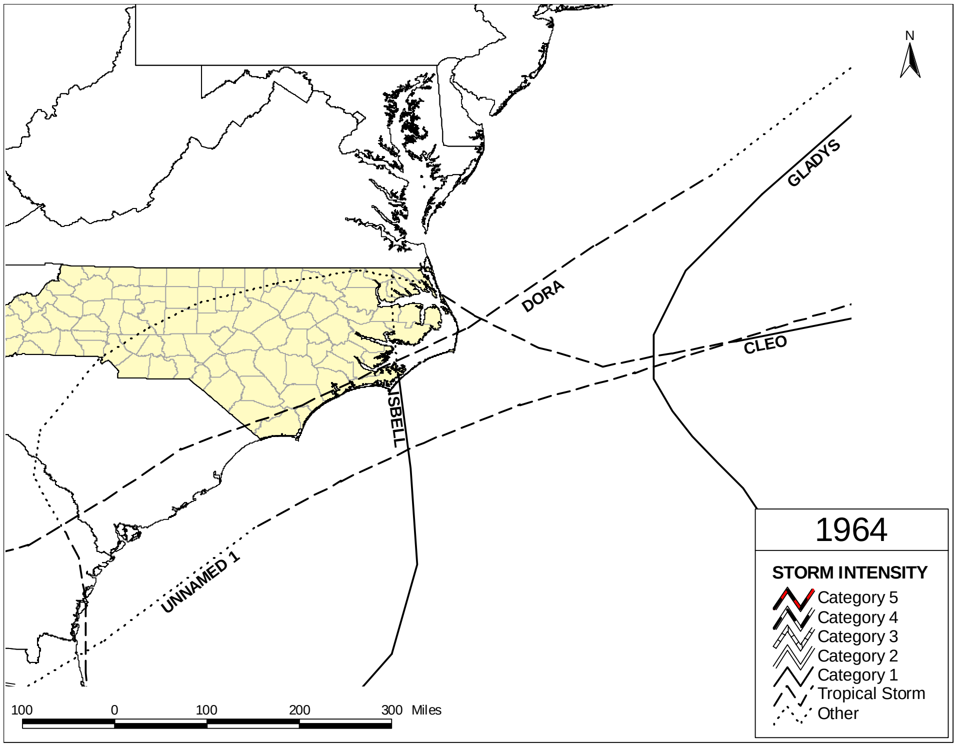

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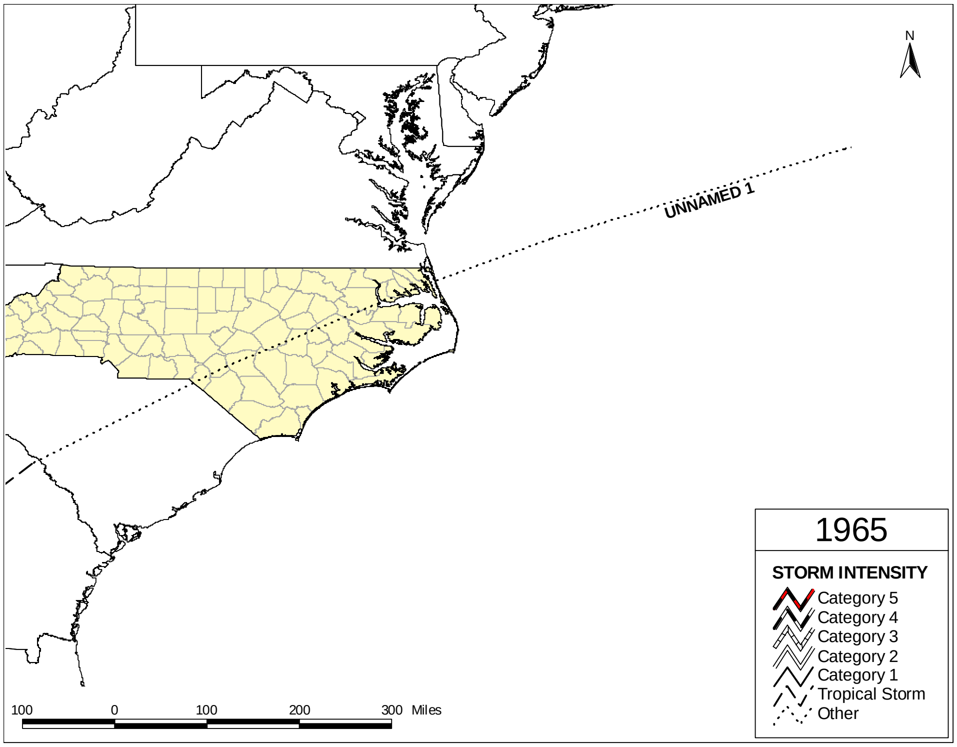

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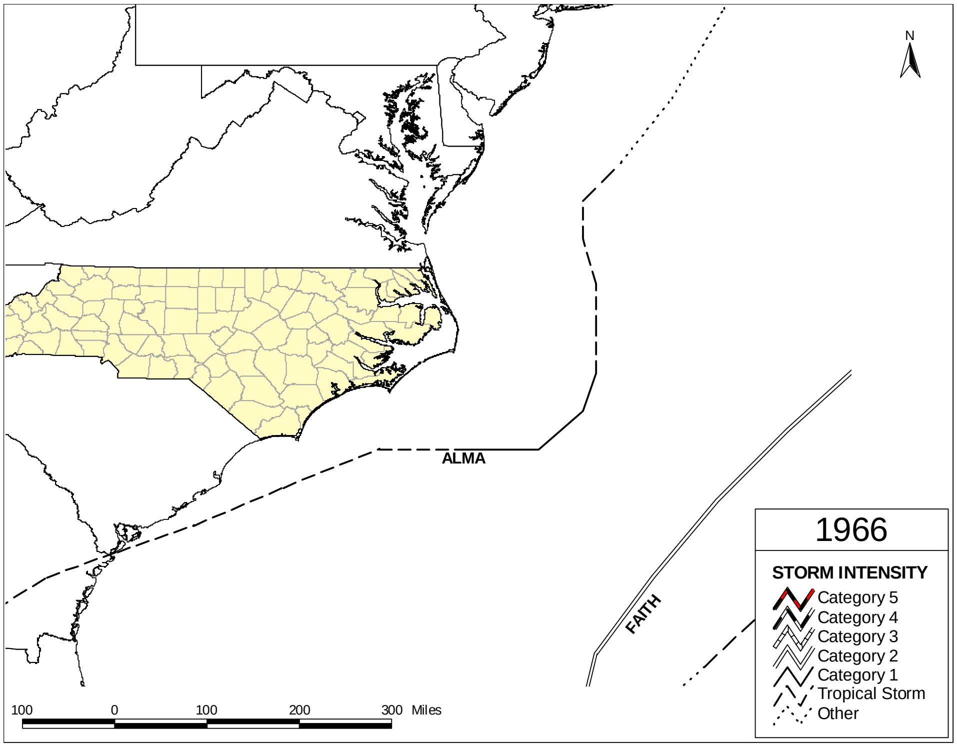

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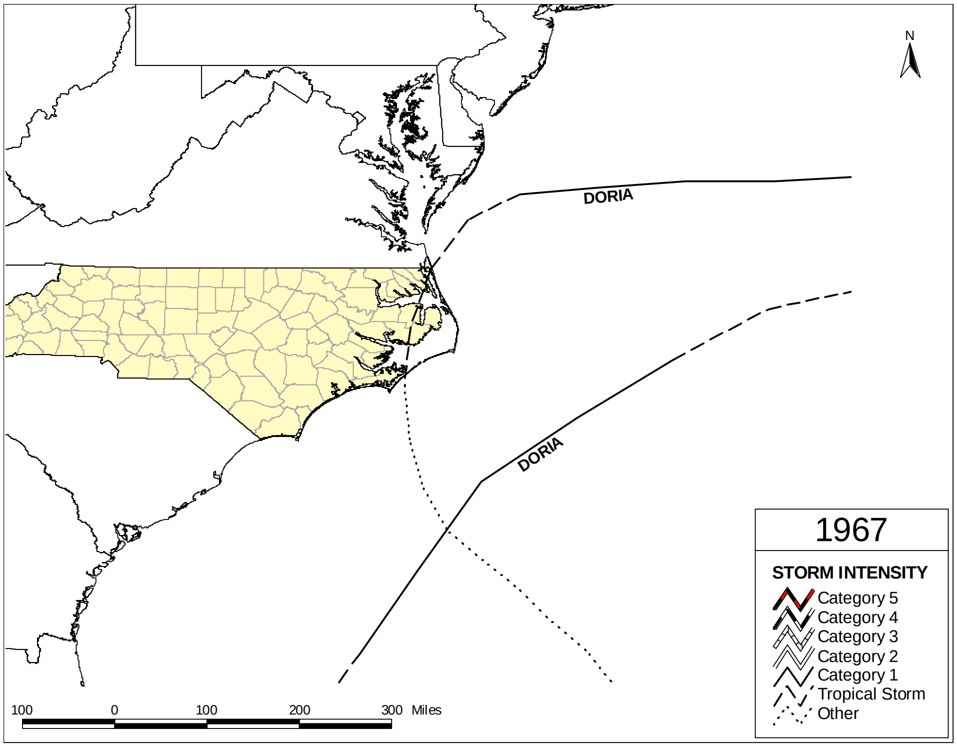

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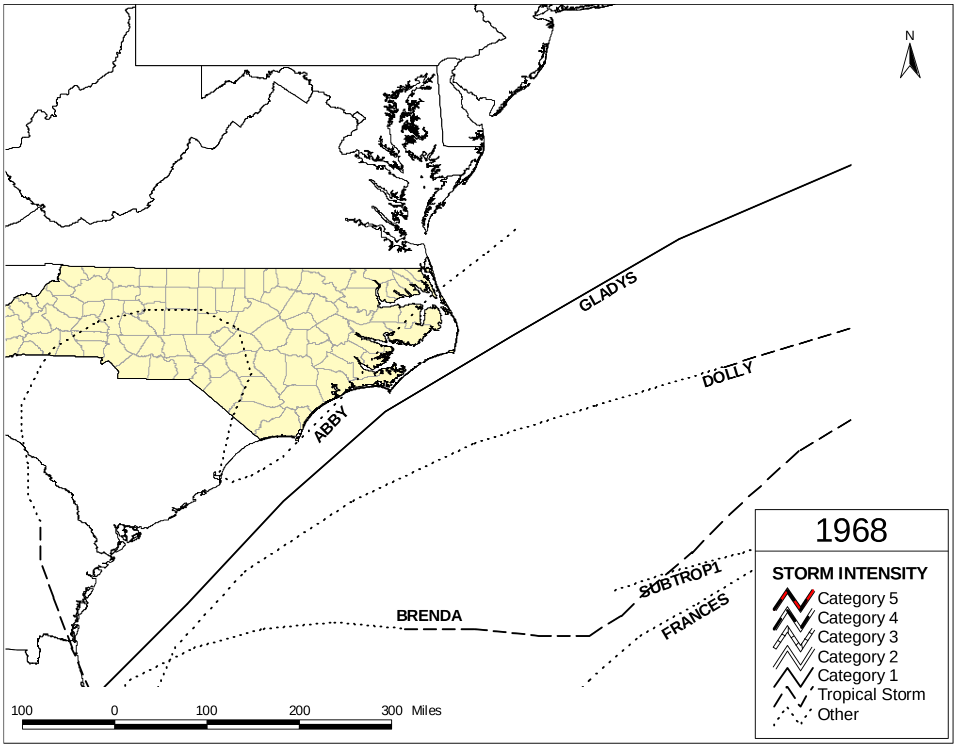

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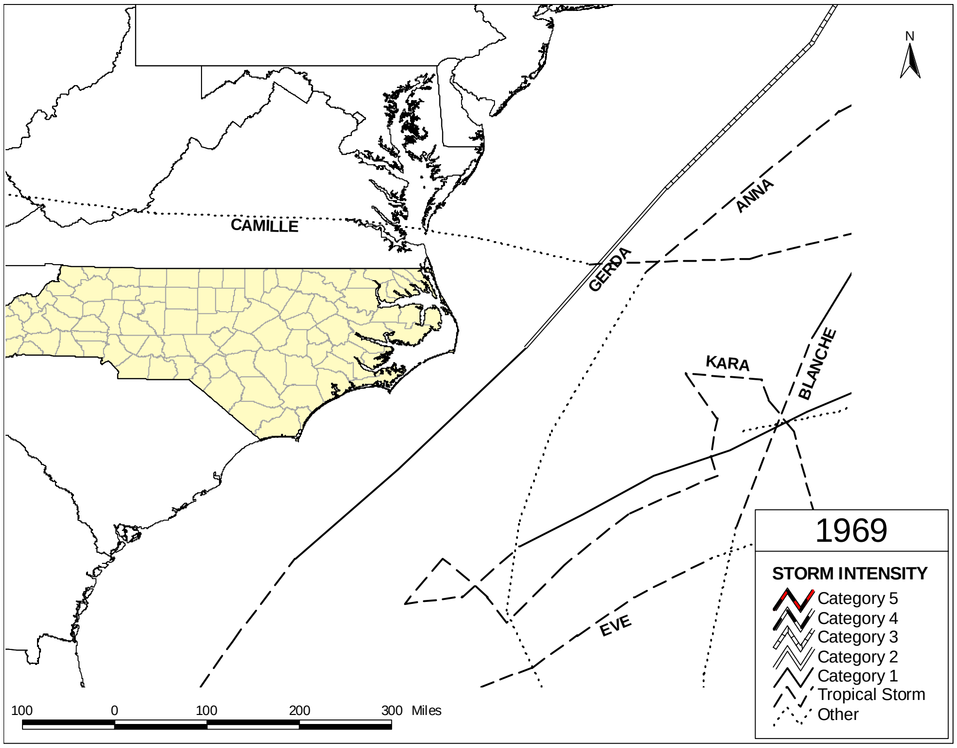

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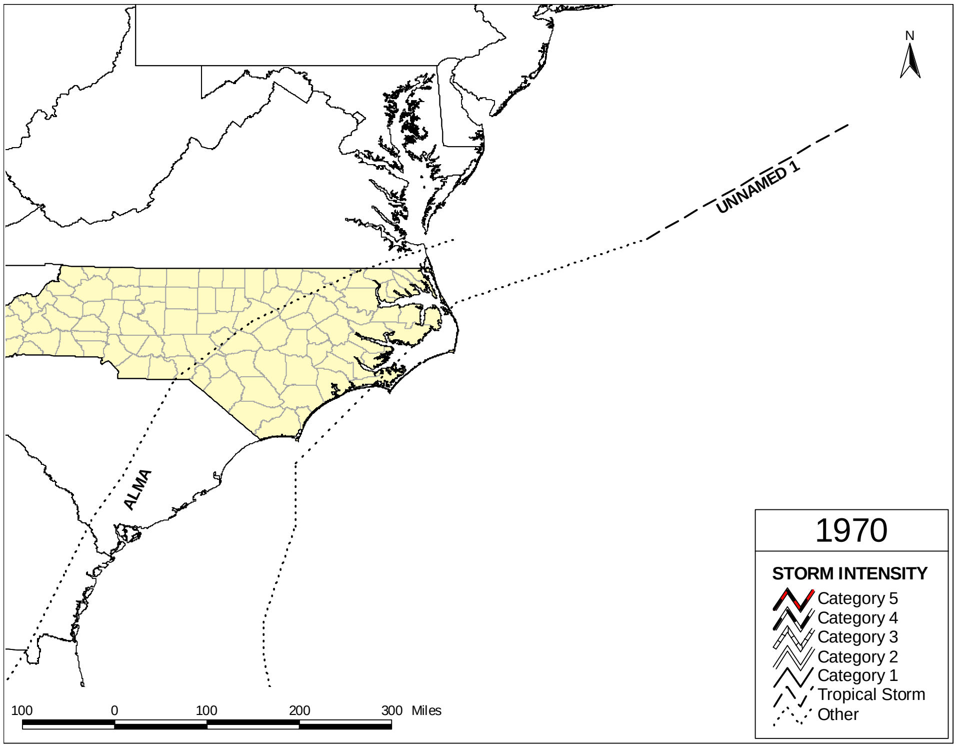

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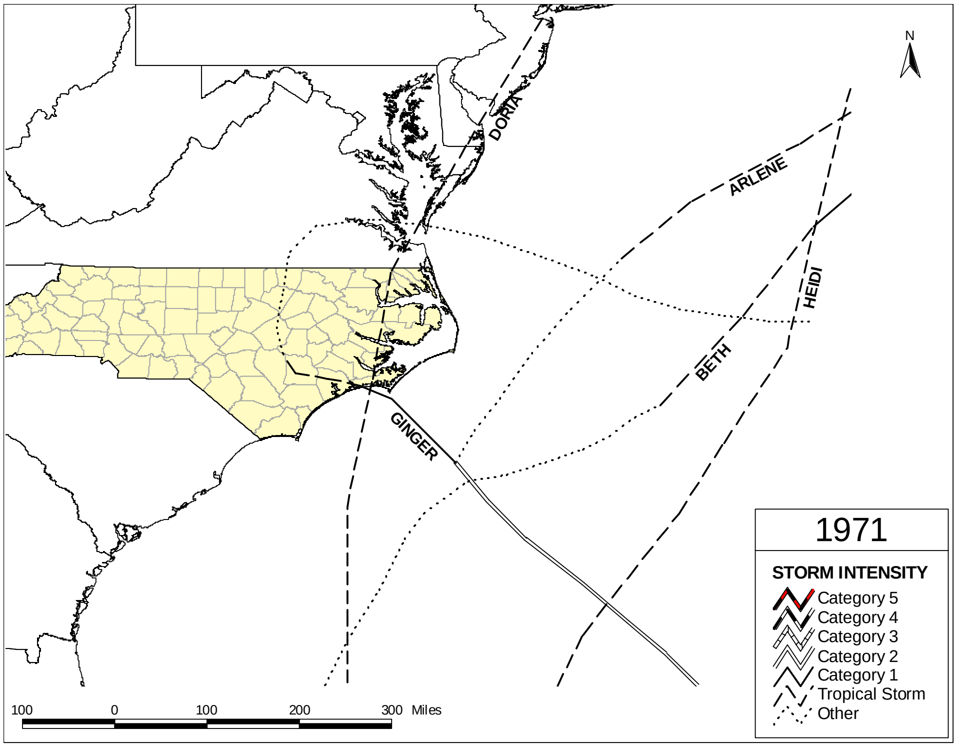

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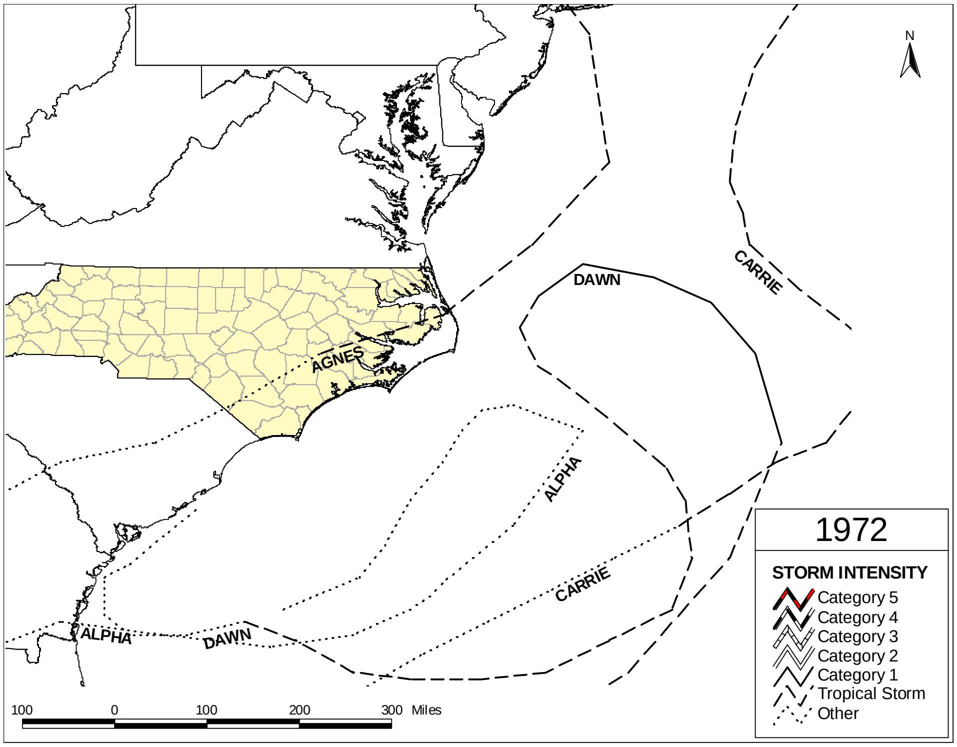

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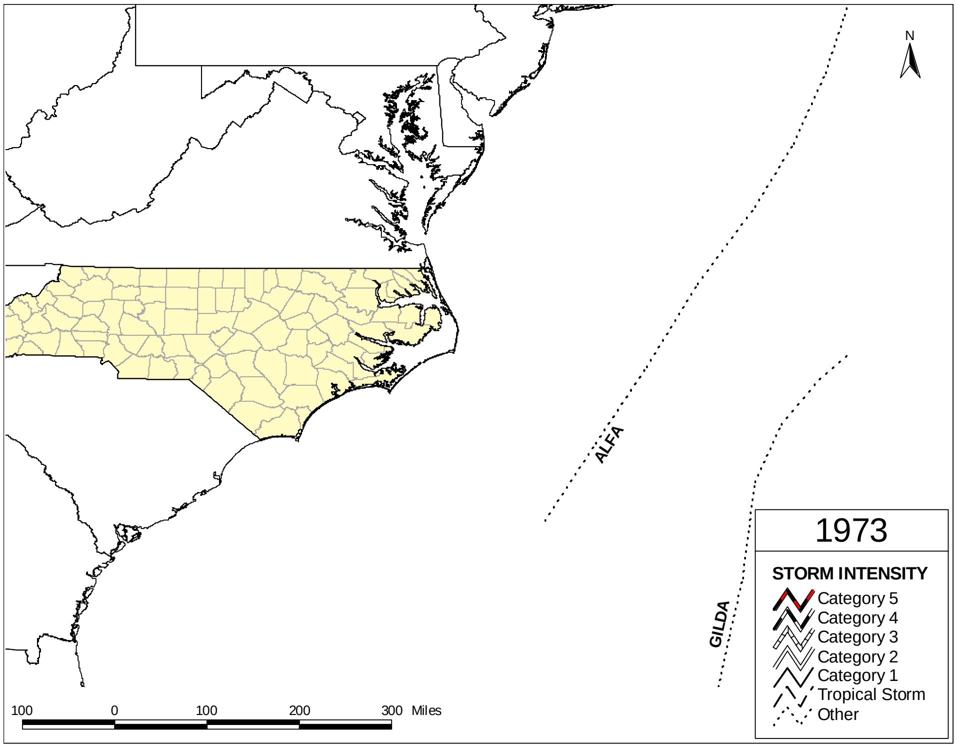

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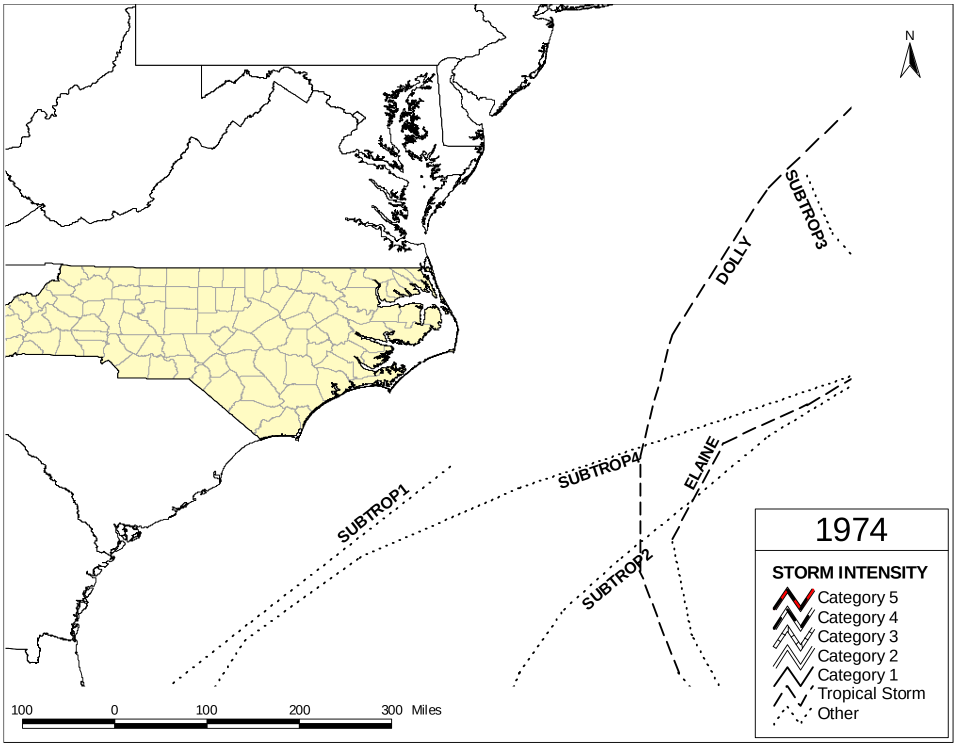

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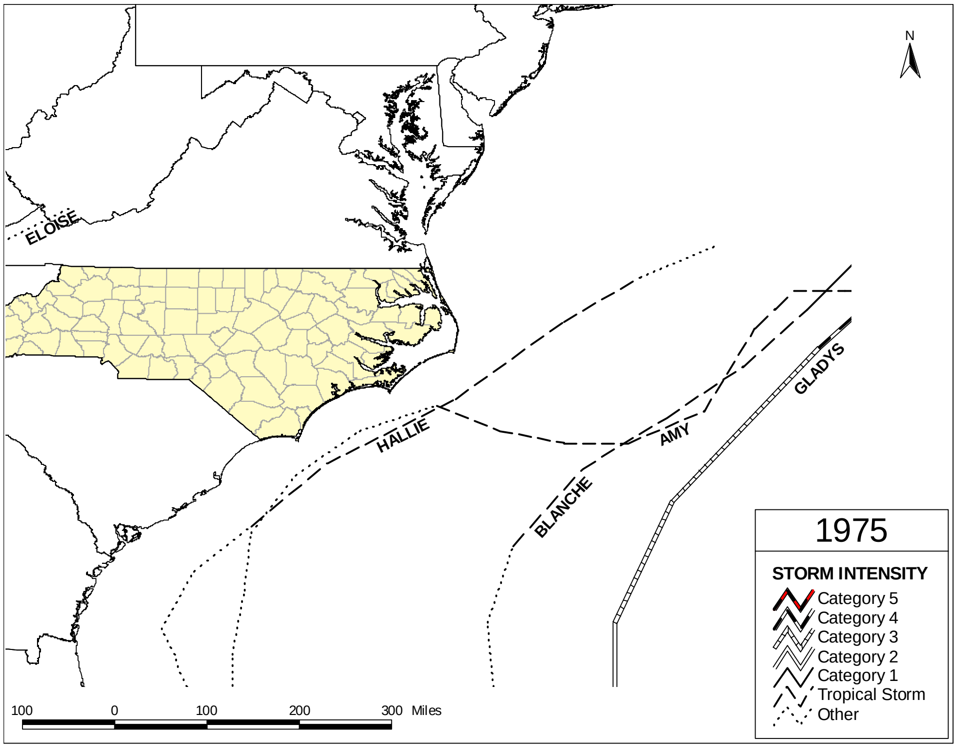

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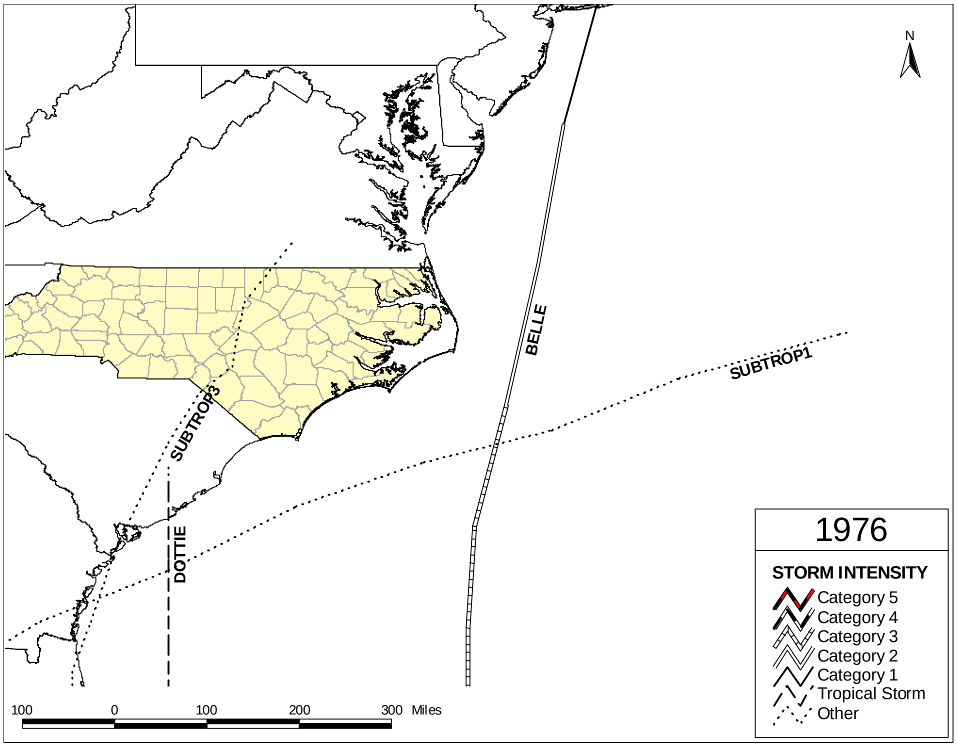

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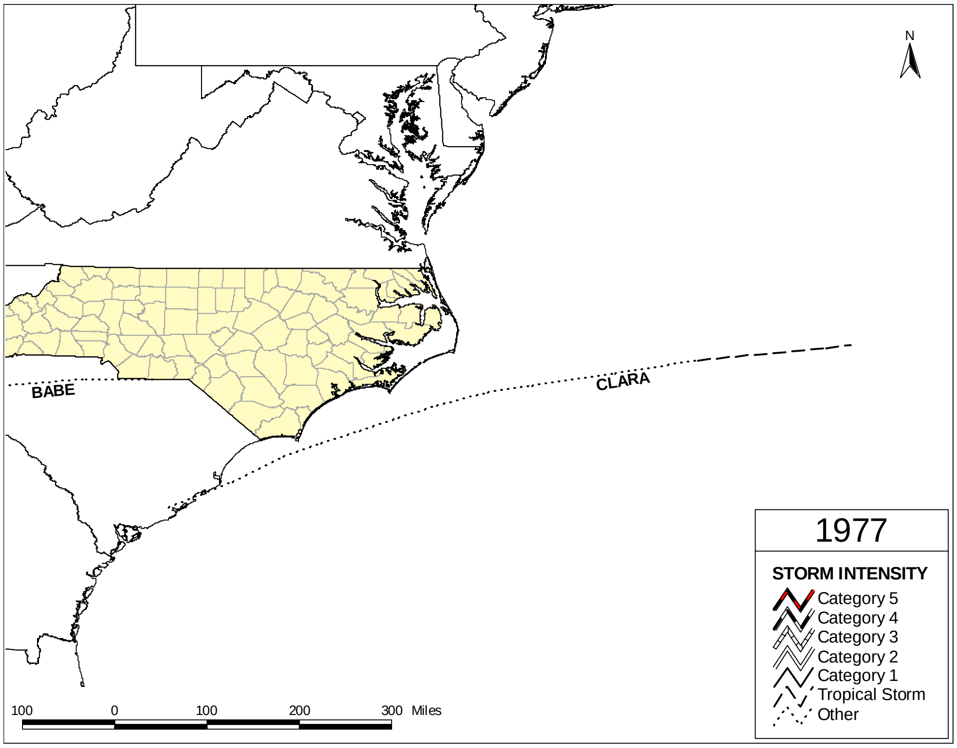

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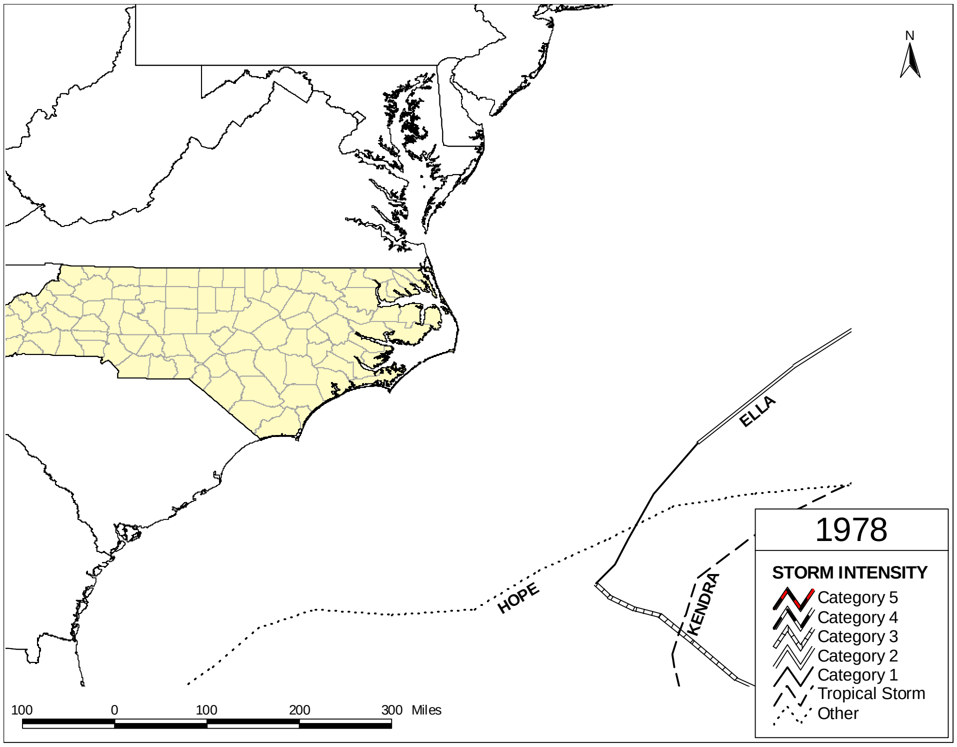

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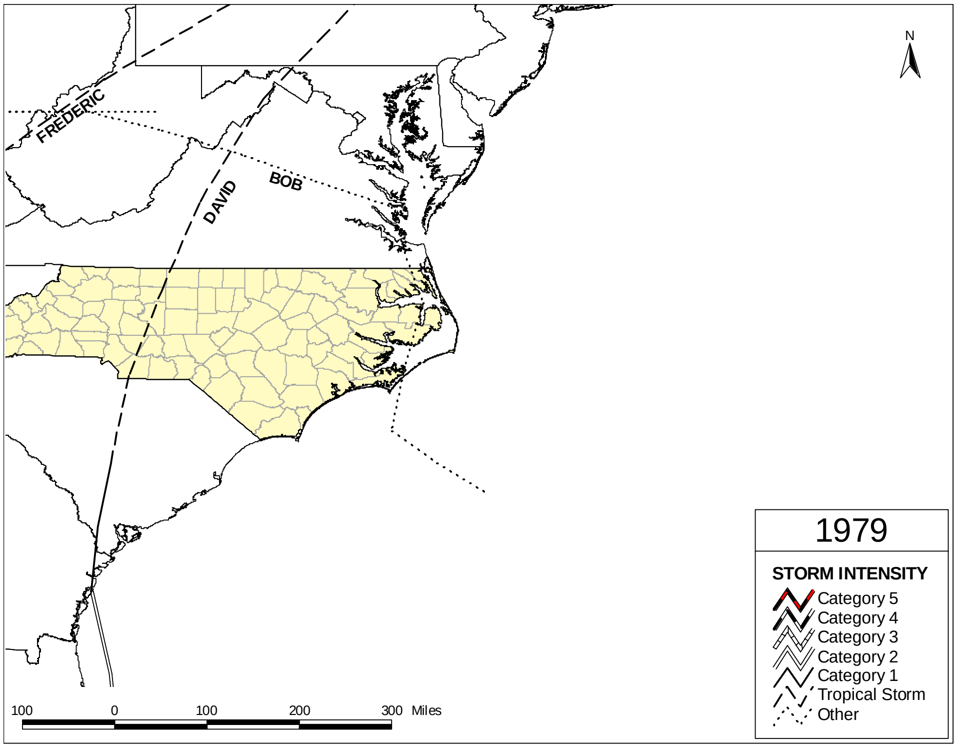

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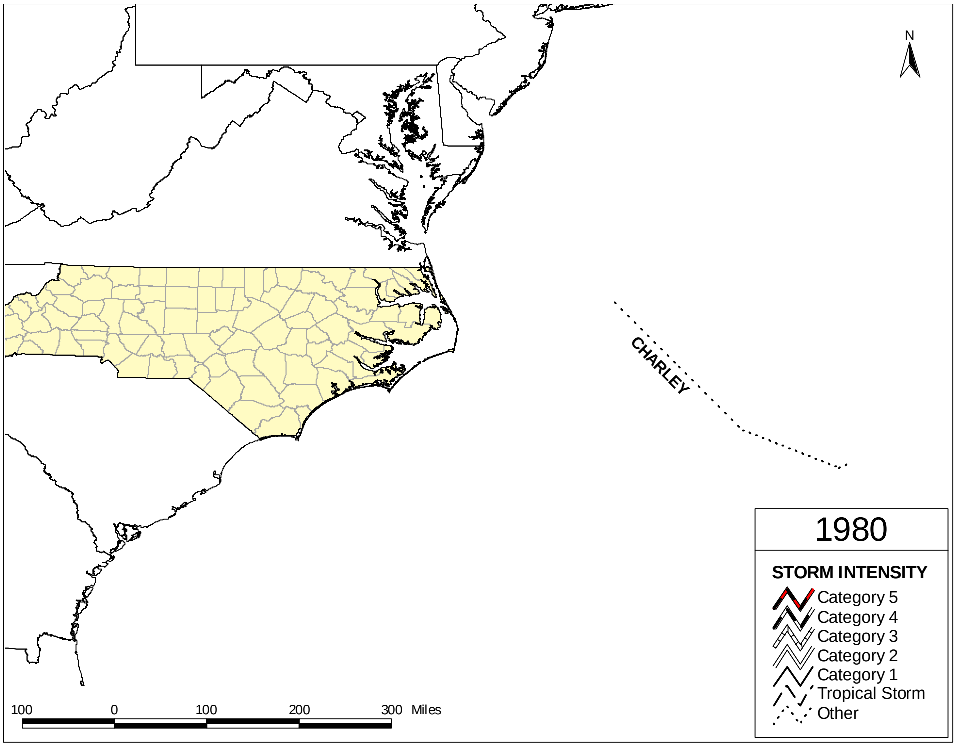

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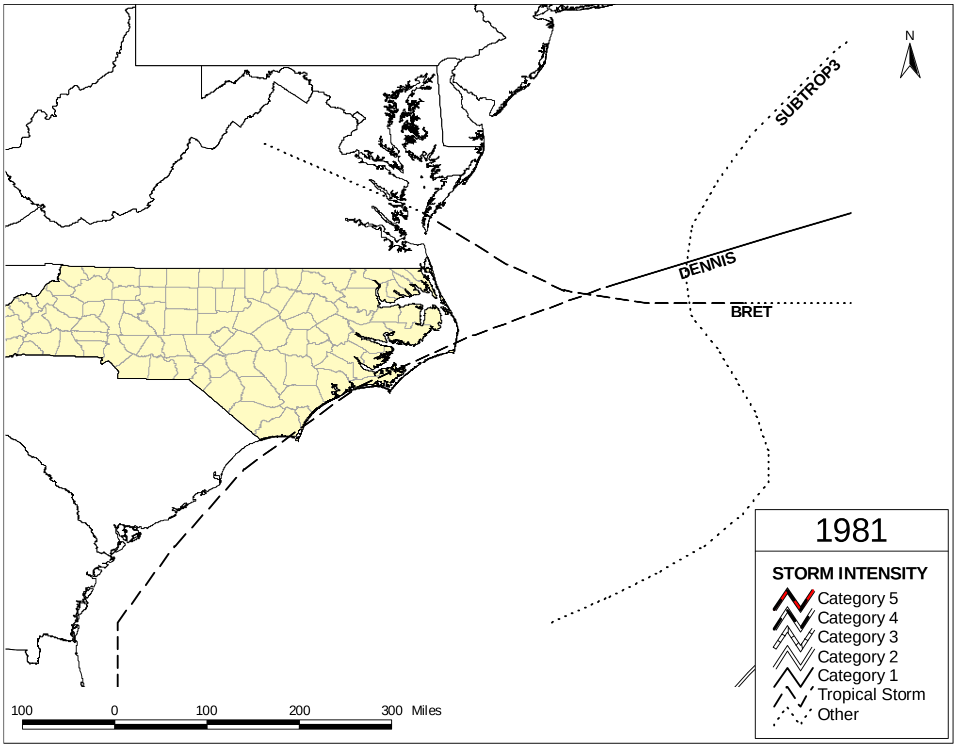

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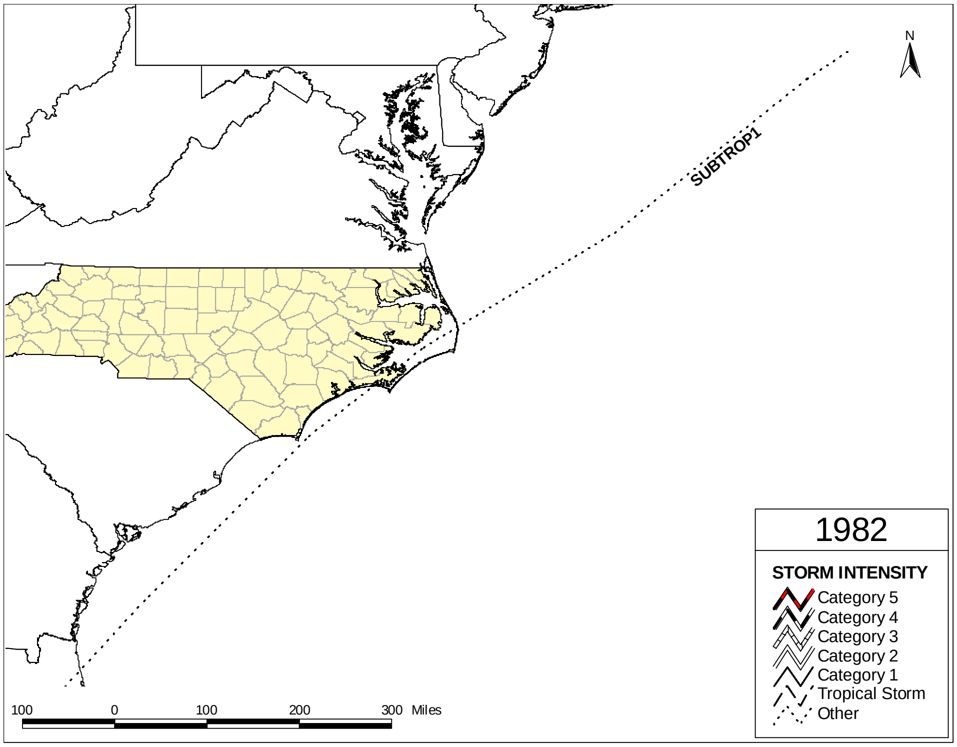

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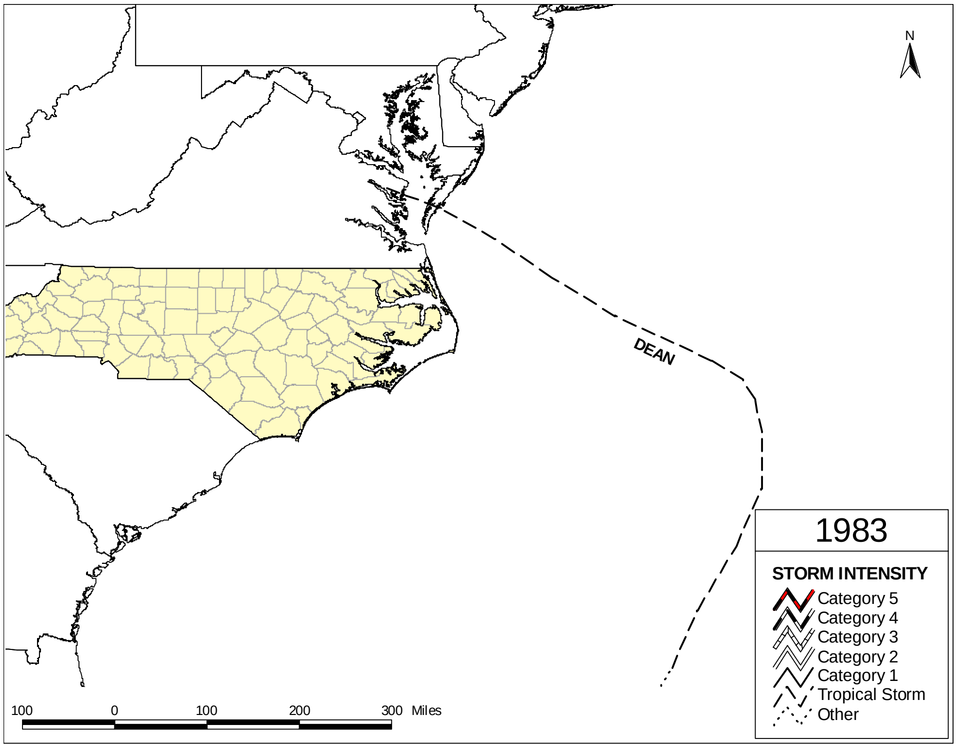

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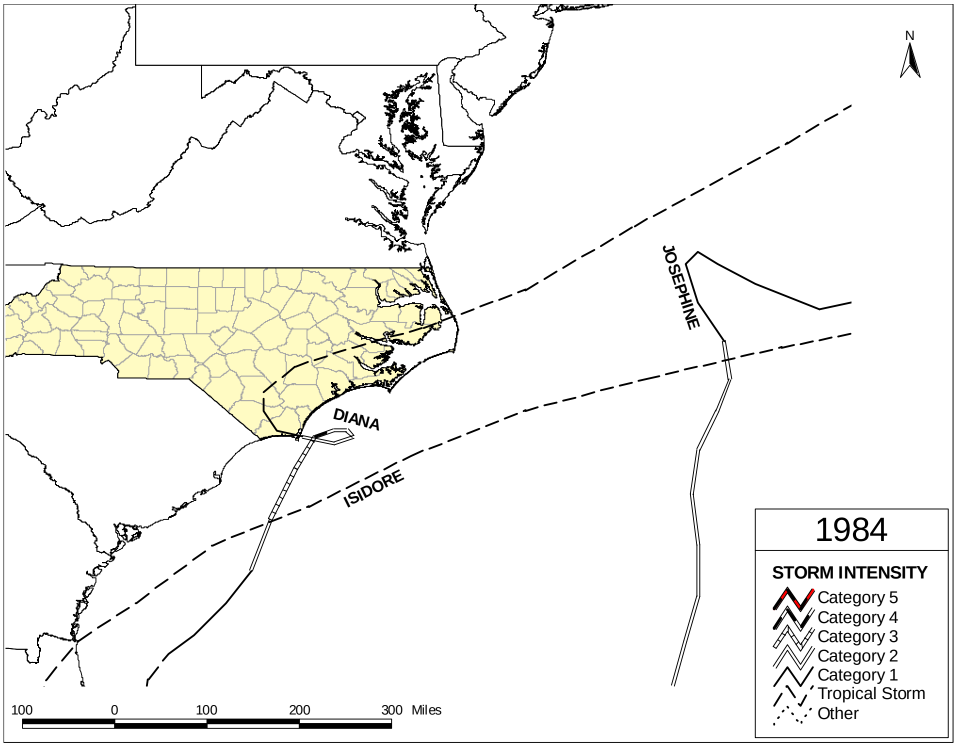

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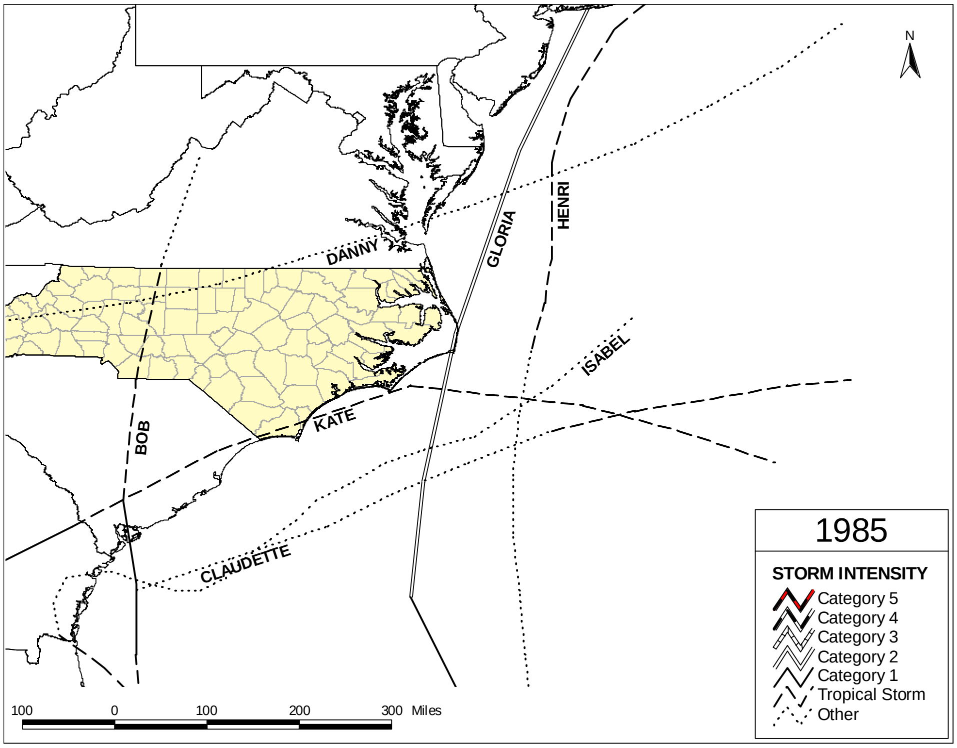

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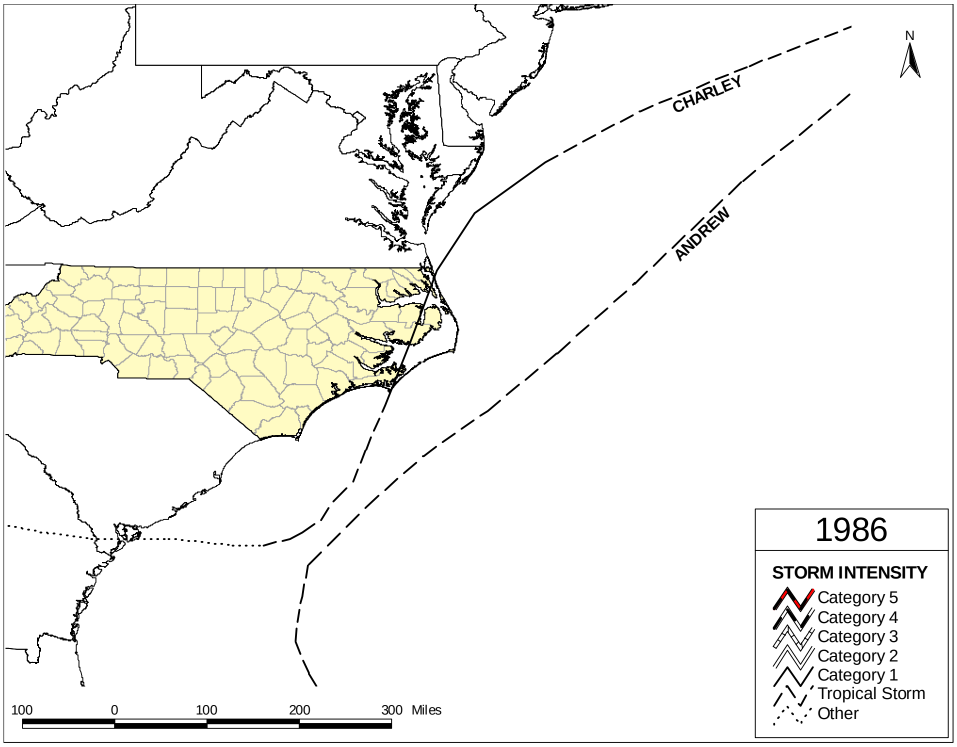

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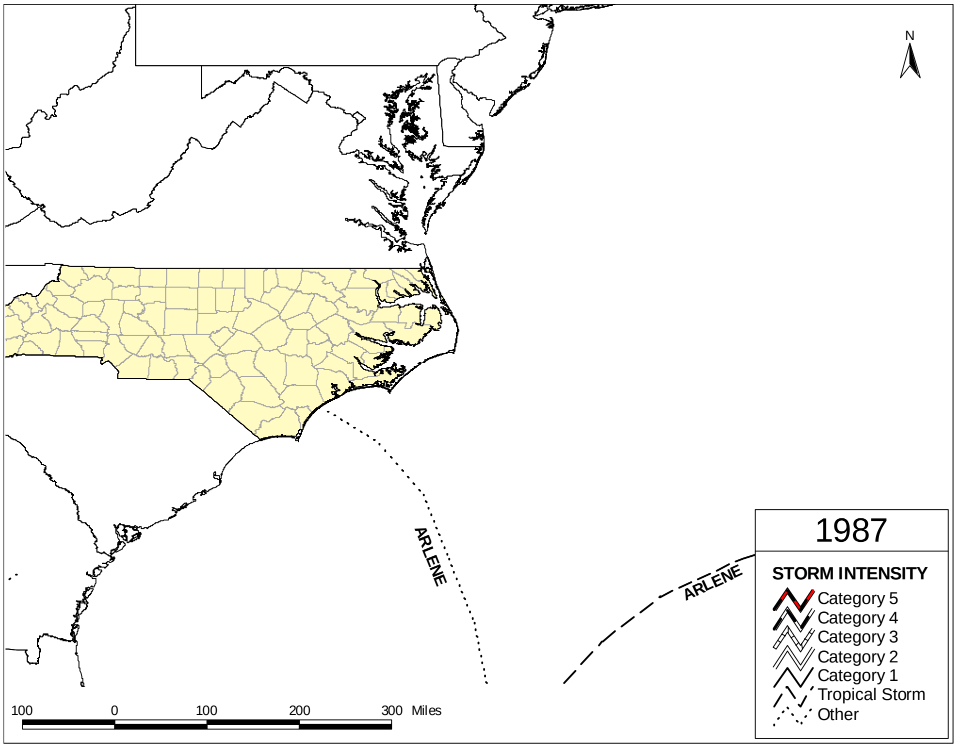

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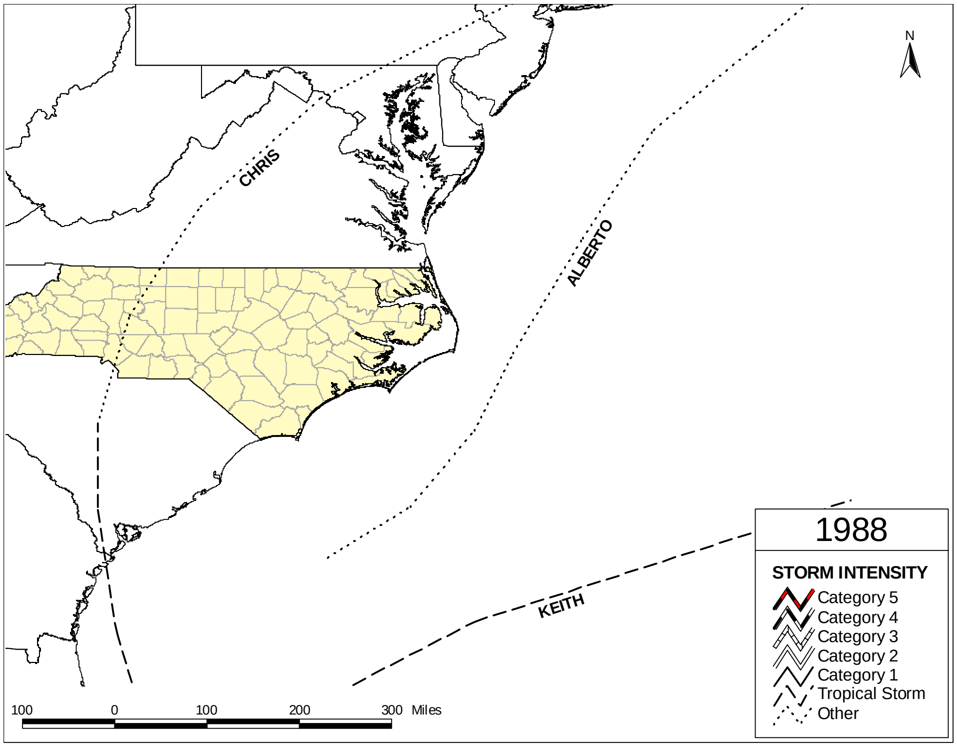

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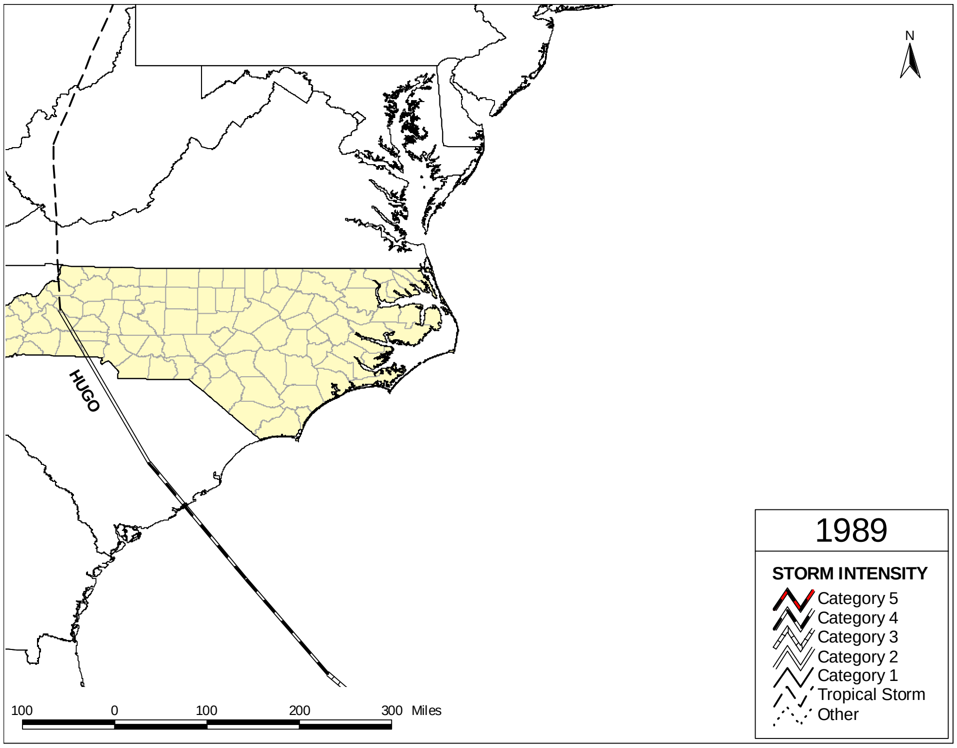

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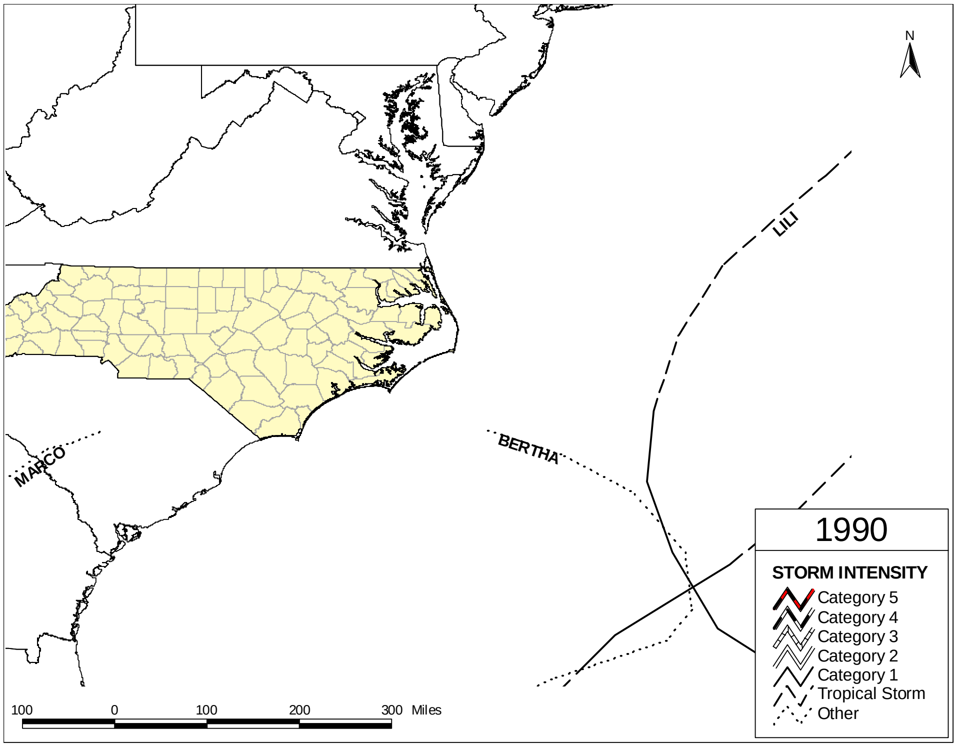

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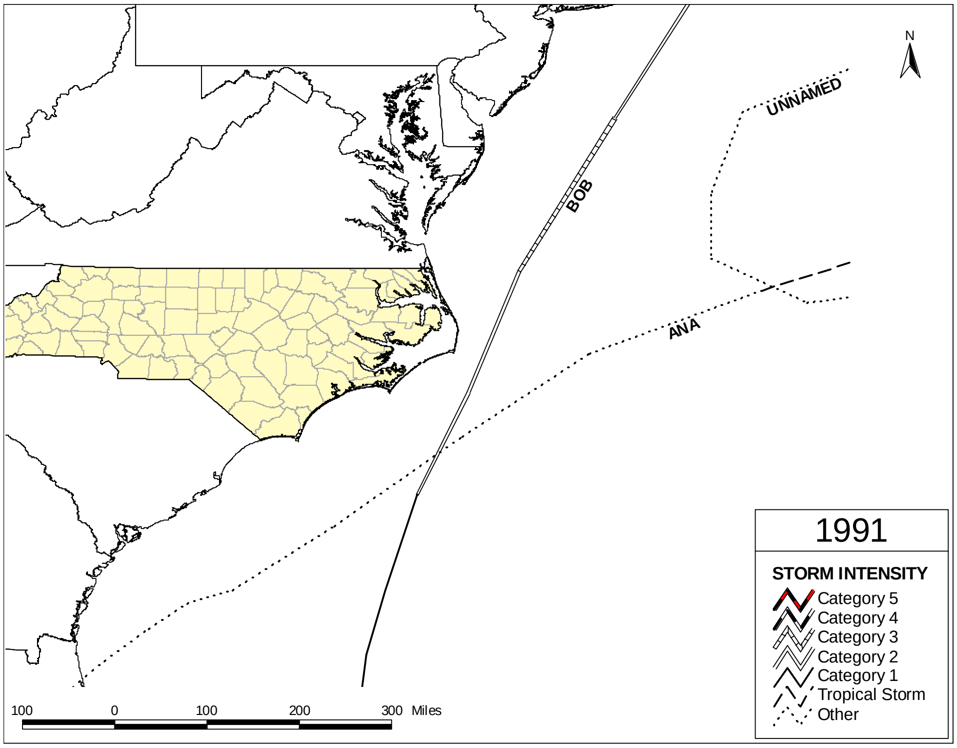

Figure A42. Tracks of tropical cyclones near the North Carolina coast, 1991.

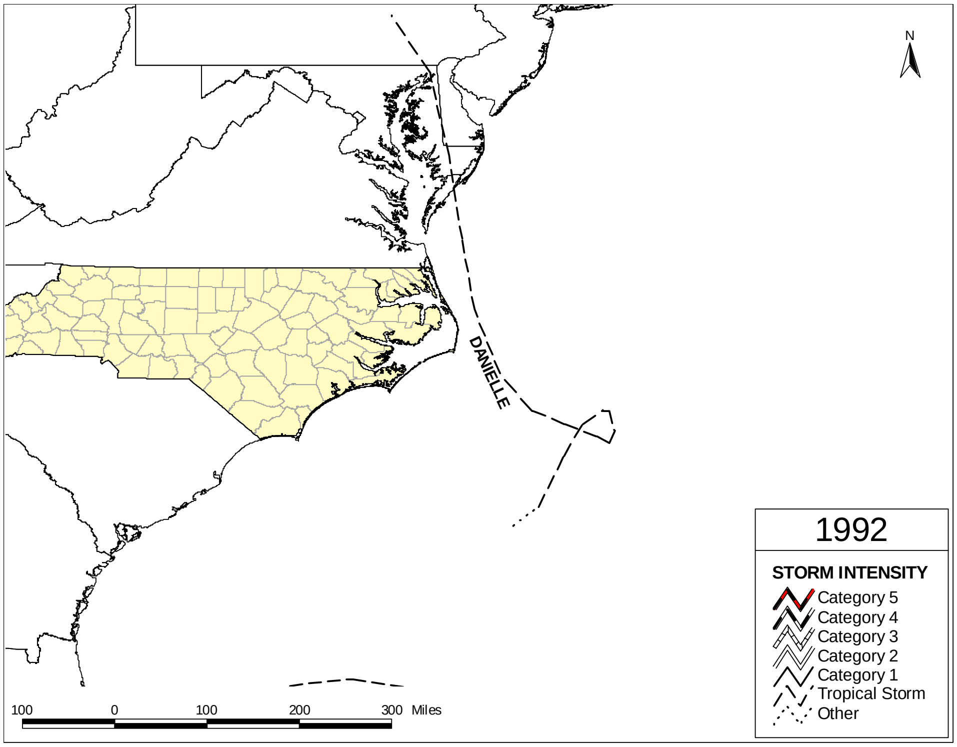

Figure A43. Tracks of tropical cyclones near the North Carolina coast, 1992.

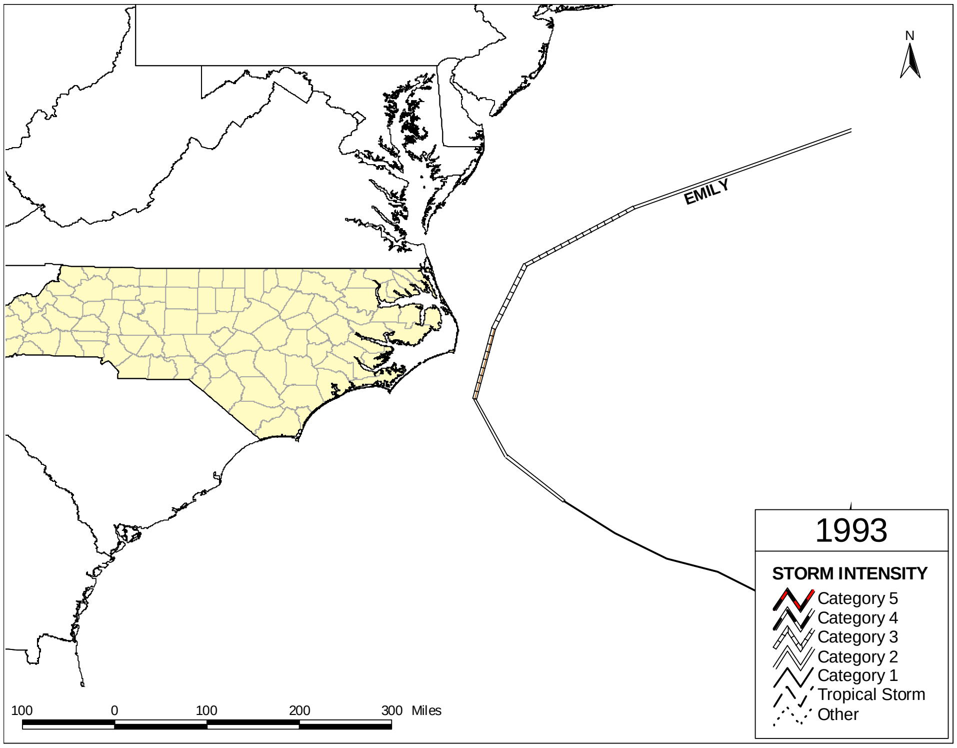

Figure A44. Tracks of tropical cyclones near the North Carolina coast, 1993.

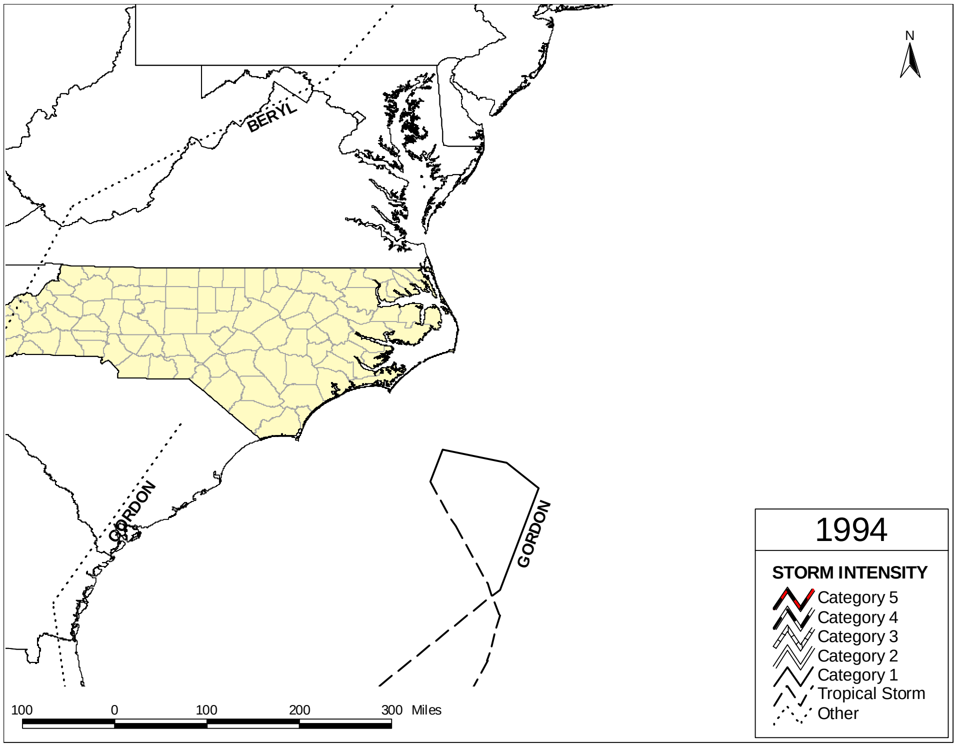

Figure A45. Tracks of tropical cyclones near the North Carolina coast, 1994.

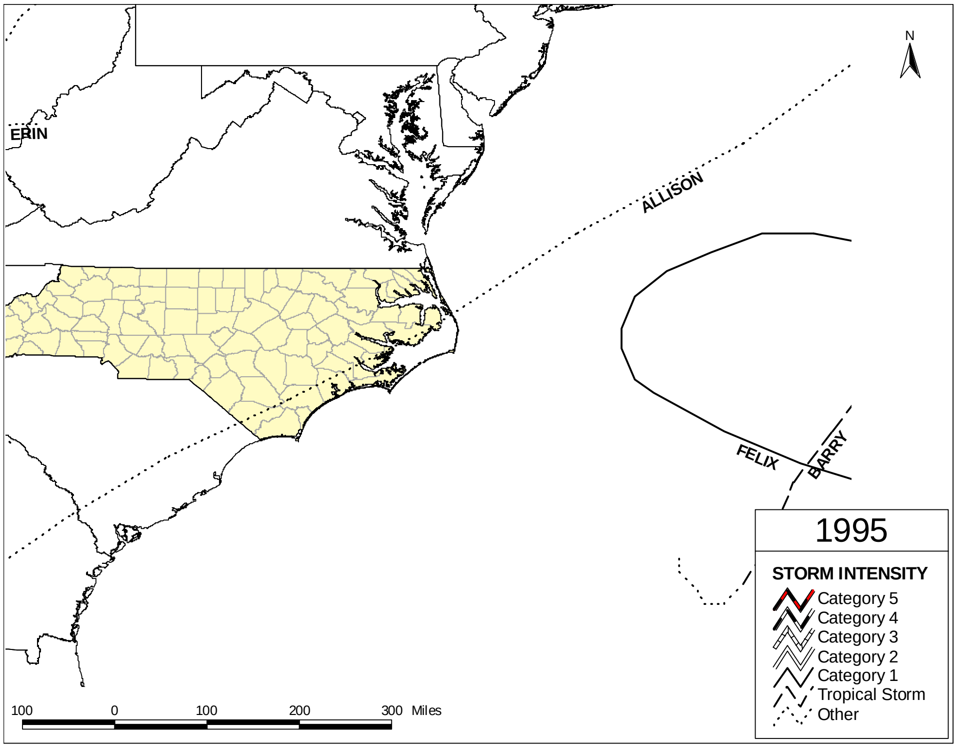

Figure A46. Tracks of tropical cyclones near the North Carolina coast, 1995.

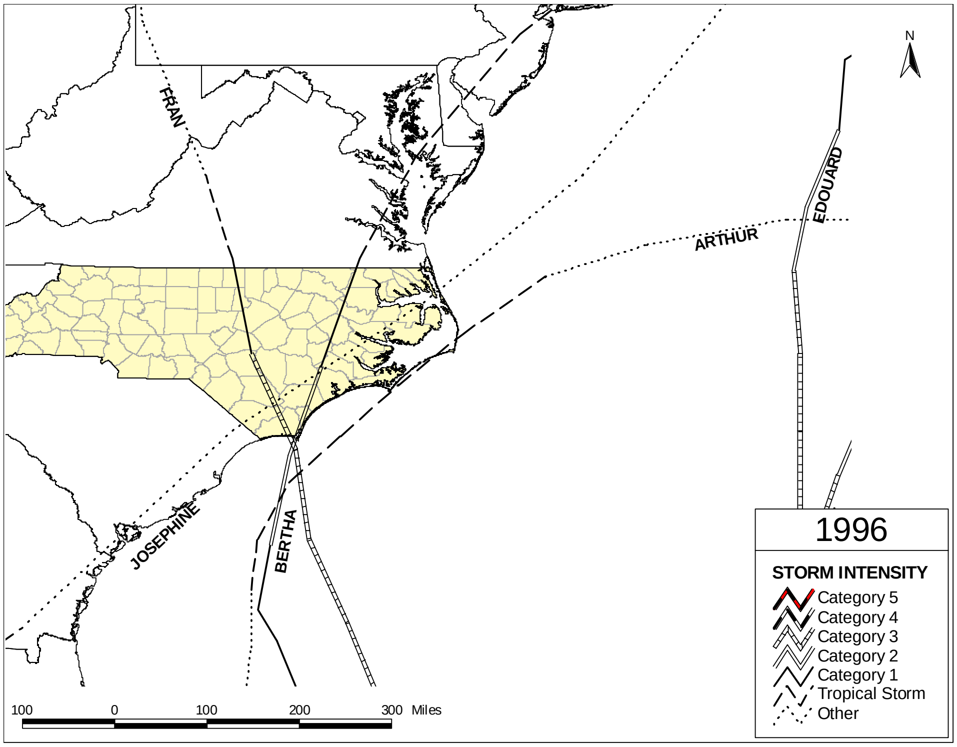

Figure A47. Tracks of tropical cyclones near the North Carolina coast, 1996.

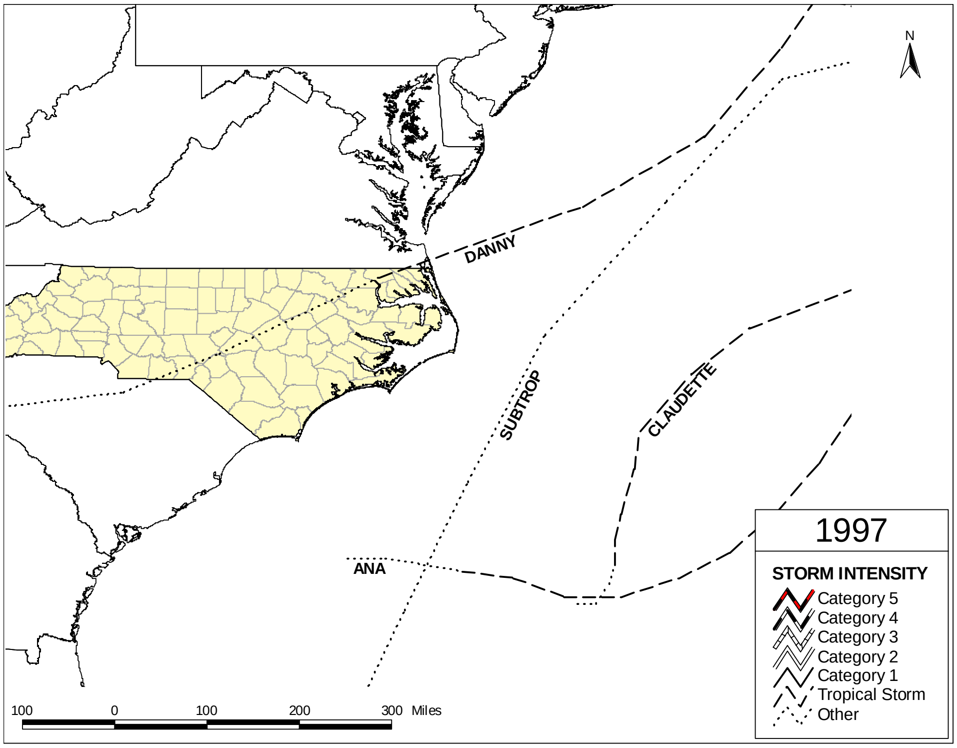

Figure A48. Tracks of tropical cyclones near the North Carolina coast, 1997.

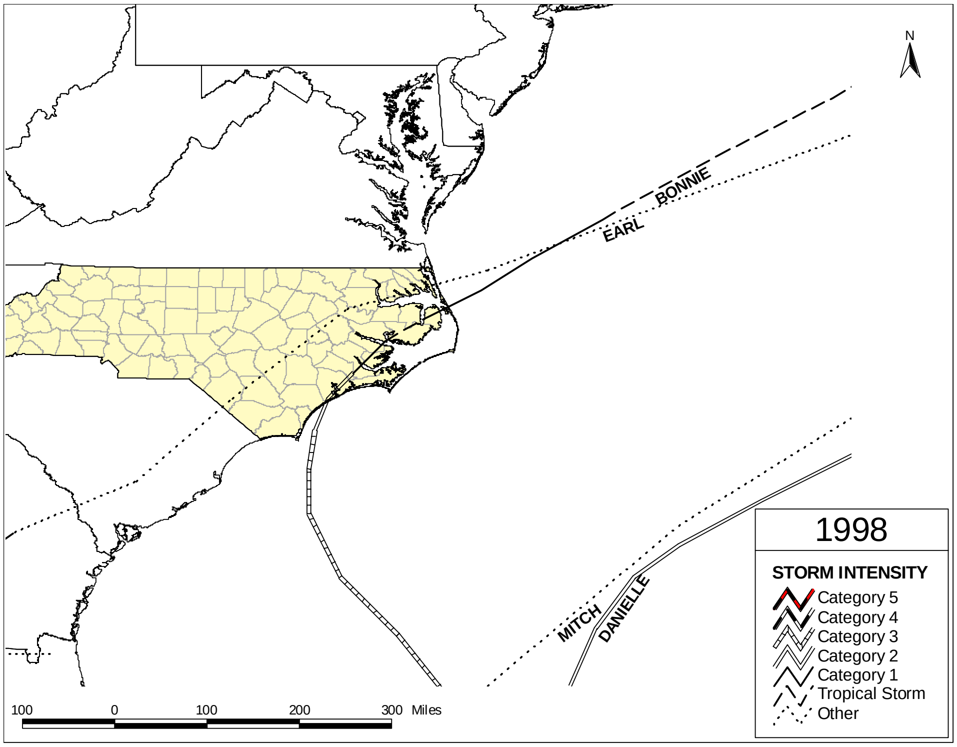

Figure A49. Tracks of tropical cyclones near the North Carolina coast, 1998.

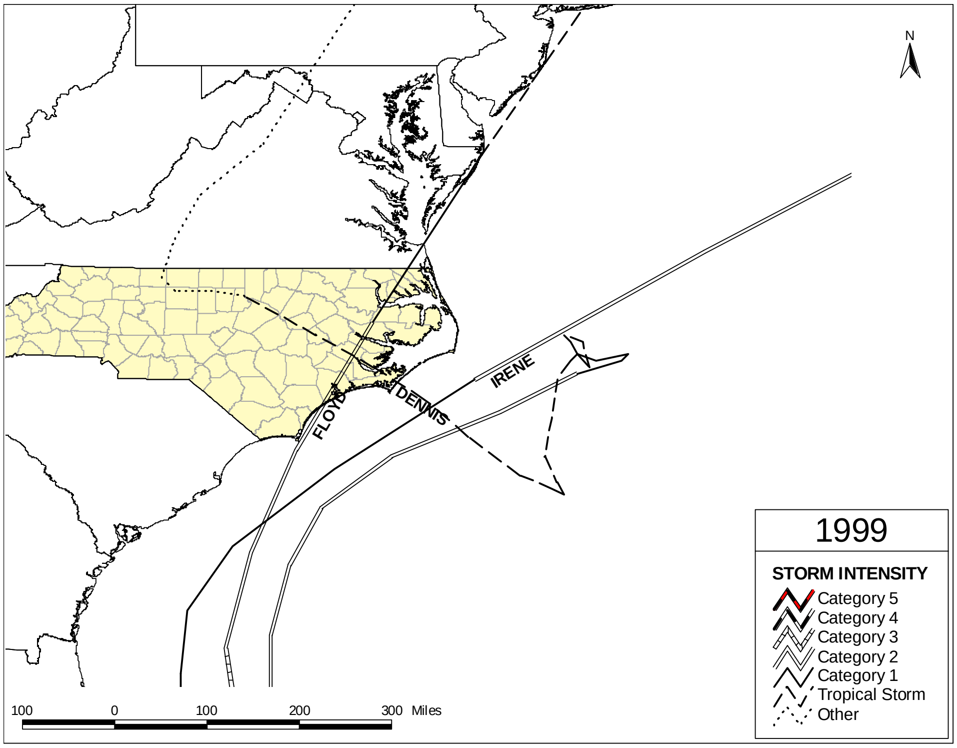

Figure A50. Tracks of tropical cyclones near the North Carolina coast, 1999.

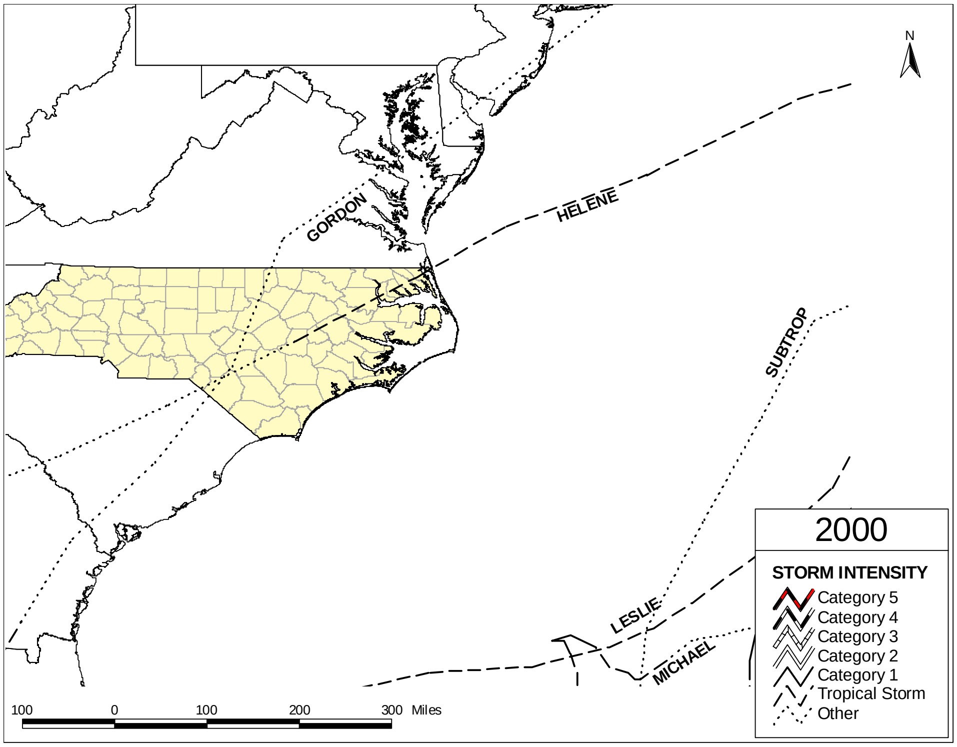

Figure A51. Tracks of tropical cyclones near the North Carolina coast, 2000.

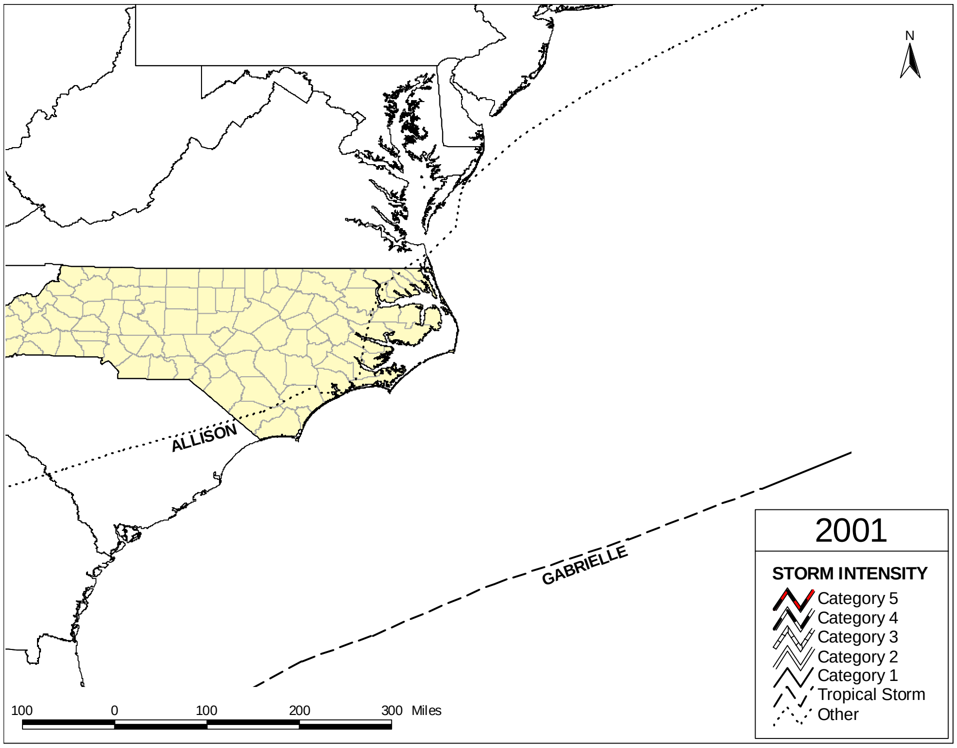

Figure A52. Tracks of tropical cyclones near the North Carolina coast, 2001.

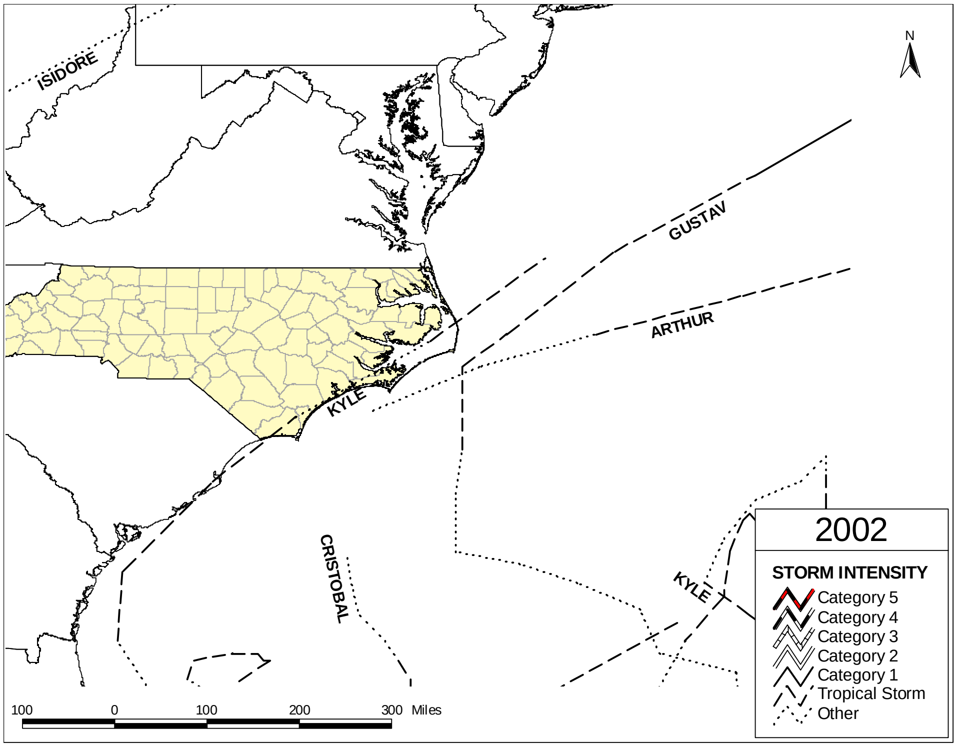

Figure A53. Tracks of tropical cyclones near the North Carolina coast, 2002.

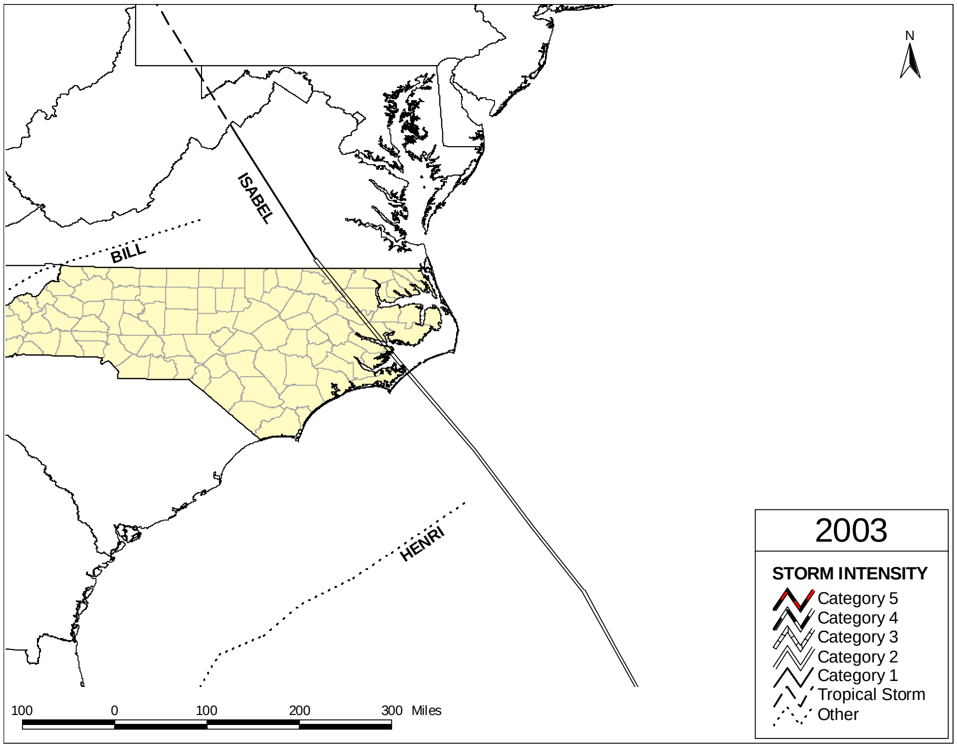

Figure A54. Tracks of tropical cyclones near the North Carolina coast, 2003.

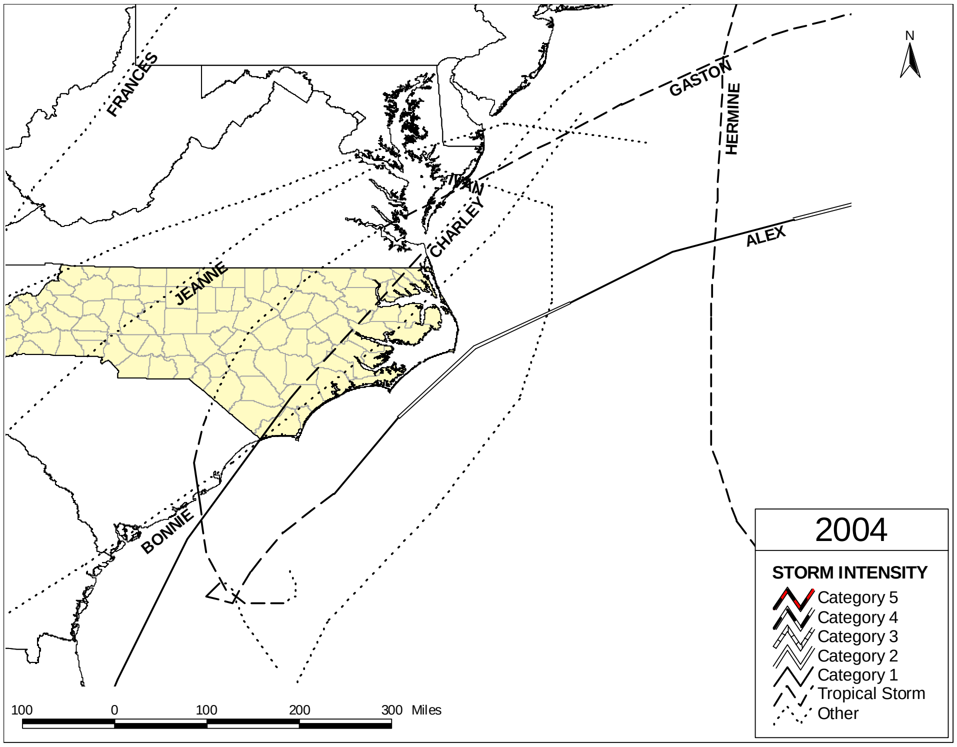

Figure A55. Tracks of tropical cyclones near the North Carolina coast, 2004.