

# **North Carolina American Shad Sustainable Fishery Plan**

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## **INTRODUCTION**

American shad (*Alosa sapidissima*) are currently managed under Amendment 3 to the Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fishery Management Plan for Shad and River Herring. Amendment 3 requires all states and jurisdictions without an approved sustainable fishery plan to close their fisheries (with the exception of catch and release fisheries) for American shad by January 1, 2013 (ASMFC 2010). A sustainable fishery is defined in Amendment 3 as one that “demonstrates their stock could support a commercial and/or recreational fishery that will not diminish future stock reproduction and recruitment”. The purpose of this plan is to identify and implement sustainable management measures that will allow for maintenance and rebuilding of American shad populations in North Carolina.

The most recent stock assessment of American shad stated that populations in the Albemarle Sound and Roanoke River are stable and low, whereas a determination of stock status could not definitively be assigned for the Tar-Pamlico, Neuse and Cape Fear rivers due to limited information (ASMFC 2007a). It should be noted that areas south of Albemarle Sound form a zone where stocks transition from iteroparity to semelparity, which can also impact the ability to determine stock status.

Sustainable fishery parameters are being submitted for consideration for the following areas: Albemarle Sound/Roanoke River, Tar-Pamlico River, Neuse River, and Cape Fear River.

## **EXISTING MANAGEMENT**

American shad are jointly managed by the North Carolina Marine Fisheries Commission (MFC) and the North Carolina Wildlife Resources Commission (WRC). The Division of Marine Fisheries (DMF) implements MFC rules for American shad in the Atlantic Ocean as well as the Coastal and Joint waters of North Carolina, while the WRC manages American shad in the state’s recreational fishery in Inland Waters. The known extent of American shad in North Carolina river systems is shown in Figure 1.

### Commercial Seasonal Restrictions (statewide)

From the 1950s to 1965, a January 1 through May 1 commercial season existed in Coastal Waters, while a January 1 through June 1 season existed in Inland Waters throughout the state. From 1966 through 1994, no seasonal restrictions existed for the commercial fishery. Since 1995, a commercial season of January 1 through April 15 has been in place in Coastal and Joint waters although the fishery is rarely opened prior to February 1 each year. Implementation of this seasonal restriction greatly reduced harvest, as historically a large portion of the commercial American shad harvest occurred after April 15 and into May.

### Commercial Gear Restrictions

#### *Albemarle Sound*

Beginning in 1988, western Albemarle Sound (also referred to as Batchelor Bay) has been closed to the use of gill nets from February through mid-November. While the purpose of the closure is striped bass (*Morone saxatilis*) conservation, this measure has also afforded protection for American shad. From 1988 through 1990, limits of 1,000 to 2,000 yards were implemented for 5.25-inch stretched mesh and larger gill nets in Albemarle Sound, and nets could only be set 5 days per week. Again, these measures were implemented for striped bass conservation, but it is likely they had positive impacts on American shad.

Since 1998, commercial restrictions in Albemarle Sound have been consistent and include a prohibition on the use of gill nets with a mesh size of 3.5–5.0 inches stretched mesh and a limit of 1,000 yards on the use of 5.25-inch stretched mesh during the open shad season (generally mid-February through April 15). When the season closes, these nets are removed from the water. The Albemarle Sound is the only system for which mesh size restrictions and yardage limits exist during the shad season.

### *Tar-Pamlico River, Neuse River*

There is a statewide rule limiting the amount of large mesh (5.0-inch and greater) gill net set in internal coastal waters to no more than 3,000 yards per vessel. However, this rule has been suspended in the majority of internal coastal waters as a result of sea turtle conservation measures that allow no more than 2,000 yards per vessel of 4.0–6.5-inch gill net in the Tar-Pamlico and Neuse systems. Nets can be set in lengths no greater than 100 yards and must have at least a 25-yard space between each individual length of net. Only single overnight sets are allowed; nets can be set one hour prior to sunset and must be retrieved within one hour of sunrise, with no sets allowed Friday, Saturday or Sunday evenings. Additionally, in certain sections of the Tar-Pamlico and Neuse rivers, gill nets with a mesh size less than five inches must be attended at all times.

Interim management measures implemented in November 2011 for spotted seatrout (*Cynoscion nebulosus*) conservation make it unlawful to use gill nets of any mesh size in Joint Waters on weekends. These measures will reduce American shad harvest since they will likely remain in effect throughout the spring 2012 fishing season.

### *Cape Fear River*

The same statewide rule limiting the amount of large mesh gill net in internal coastal waters that has been suspended in the Tar-Pamlico and Neuse systems has also been suspended in the Cape Fear as a result of sea turtle conservation measures. All the same restrictions described above for the Tar-Pamlico and Neuse systems (i.e. mesh lengths, spacing, set/retrieval days and times) apply in the Cape Fear system with the exception of the maximum yardage allowed; a 1,000-yard limit per vessel has been imposed in the Cape Fear.

The same interim management measures implemented in November 2011 for spotted seatrout conservation in the Joint Waters of the Tar-Pamlico and Neuse systems are also in place in the Cape Fear, making it unlawful to use gill nets of any mesh size on weekends.

### Recreational Restrictions

Prior to 1995, no recreational restrictions existed. Beginning in 1995, it became unlawful to take American shad and hickory shad (*Alosa mediocris*) by any method except hook-and-line from April 15–December 31 in Coastal Waters. Additionally, from 1995 through 1998, there was a recreational season during January 1 through April 14. Beginning in 1999, it became unlawful to possess more than 10 American shad and hickory shad in the aggregate in both Coastal and Inland Waters.

### *Albemarle Sound/Roanoke River*

In 2010, the WRC implemented a 1-fish American shad limit within the 10-fish aggregate creel limit for American and hickory shad in the Inland Waters of the Roanoke River.

### *Neuse River*

A rule implementing a 1-fish limit for American shad in the Inland Waters of the Neuse River will become effective in August 2012 and applicable to the spring 2013 fishing season.

### *Tar-Pamlico River, Cape Fear River*

The 10 American and hickory shad aggregate creel limit applies throughout the waters of the Tar-Pamlico and Cape Fear rivers.

## **REQUEST FOR FISHERIES**

A sustainable fishery is defined in Amendment 3 as one that demonstrates shad stocks could support a commercial and/or recreational fishery that will not diminish future stock reproduction and recruitment. A suite of potential sustainability parameters were considered for North Carolina and it was decided to

develop sustainability parameters for each river system based on relative abundance and relative fishing mortality rate. Relative abundance was calculated using available fisheries-independent survey data that were considered appropriate for measuring the abundance of American shad and were expressed in terms of catch-per-unit-effort (CPUE). The standard deviations of the annual CPUE index values were also calculated to demonstrate the variability of these values. Environmental conditions on the spawning grounds, especially flow rates, are a major source of the variability associated with these indices.

Relative fishing mortality rate is calculated by dividing catch by a fisheries-independent index of relative abundance. Imprecision in the survey index can cause estimates of relative  $F$  to be noisy. The noise can be dampened by using an average of the survey index over adjacent years in place of point estimates in the denominator. Here, relative  $F$  was computed by dividing commercial landings by a centered 3-year average of a survey index. Note that relative  $F$  in the first and last year of the time series will be based on only two years of data. In each system, the survey data used in the calculations of relative  $F$  were subset to reflect conditions in the commercial fishery.

Indices of relative abundance and estimates of relative  $F$  were calculated for each system using available data. The objective was to select a minimum of one abundance index and one series of relative  $F$  estimates to serve as sustainability parameters in each system. Where multiple data sources were available in a system to calculate relative abundance or relative  $F$ , a tiered approach was taken to select the most appropriate data source for deriving the sustainability parameter. Sources of data that were not considered reflective of conditions in the system of interest were eliminated from consideration. Data sources that were available for a minimum of ten years were preferred. Also, data sources associated with extreme variability or a large amount of imprecision were not considered reliable for deriving sustainability parameters. Finally, sustainability parameters based on the female segment of the stock were preferred because the commercial fishery targets roe shad; roe landings can account for as much as 90% of the total American shad landings in a year.

While scales have been collected for aging from both fisheries-dependent and fisheries-independent programs since 1972, there was concern regarding the reliability of scales for determining age for the following reasons: first, the scouring that allows for identification of spawning marks could result in loss of annuli and therefore inconsistent scale readings; and second, although increases in average age and percent of older individuals were observed, these were also associated with decreases in average length and weight. Because of these concerns and continued discrepancies between NCDMF and NCWRC in the determination of age and spawning marks, age data were not considered for sustainability parameters in any of the systems (See Appendix 1 for additional detail).

The sustainability parameters evaluated and selected are described below for each system. The selected sustainability parameters will be reported in annual compliance reports and any management actions will be noted. Potential management actions are included in a separate section to eliminate repetition within each of the river system sections, although any action or suite of actions could be specific to and independent of each system.

## **Albemarle Sound**

### Stock Status

The 2007 ASMFC stock assessment stated that American shad stocks in the Albemarle Sound and Roanoke River were low but stable and suggested a benchmark total mortality rate ( $Z_{30}$ ) of 1.01 (ASMFC 2007b). Annual estimates of  $Z$  from the assessment indicate that values have fluctuated around the benchmark since 2000.

### Commercial Fisheries

The Albemarle Sound area has traditionally accounted for the largest proportion of the state's commercial harvest (Figure 2). The 2010 American shad landings in North Carolina totaled 233,267 pounds, and the

Albemarle Sound area accounted for 79.3% of those landings. Landings from gill nets comprised 97.3% of the overall harvest.

### Recreational Fisheries

A recreational fishery for striped bass and hickory shad has existed on the Roanoke River for many years, with little effort, catch or harvest of American shad in annual creel surveys. However, creel surveys conducted by the WRC have traditionally focused on striped bass effort and harvest; therefore, estimates of American shad harvest could be inherently biased. The spring 2006 Roanoke River creel report estimated a directed harvest of 103 American shad and release of 541 fish (McCargo et al. 2007). As noted in the previous section, a 1-fish limit on American shad within the aggregate 10-fish creel for American and hickory shad became effective July 1, 2008 on the Roanoke River. This regulation was implemented to provide additional protection for American shad on the Roanoke River and to complement restoration and stocking efforts (see “Future Considerations” section.).

### Sustainability Parameters

Data used in the development of sustainability parameters include independent gill net survey (IGNS) data collected by DMF, electrofishing data collected on the spawning grounds by WRC, and commercial landings data collected through the DMF Trip Ticket Program (see the “Stock Monitoring Programs” section for complete descriptions of these surveys).

Although DMF has conducted a fixed-station alosine seine survey since 1972 for calculation of a juvenile abundance index (JAI), the survey was specifically developed for river herring and is not a reliable indicator of shad juvenile abundance. Further analysis determined that the survey lacked the persistence needed to provide an unbiased index of abundance. For these reasons, the JAI is not being used as a sustainability parameter even though this information is updated annually in compliance reports.

Although a *Z* benchmark of 1.01 was calculated for the Albemarle Sound from the 2007 stock assessment, there was concern that the total mortality estimate for a population in which the age distribution is contracting will not necessarily show an increase if there is no change in the slope that the *Z* estimate is based upon. In addition, continued concerns regarding the reliability of scales for determining age highly influenced the workgroup’s decision not to use age data for sustainability parameters. Because of this, the *Z* benchmark was not considered for a sustainability parameter.

The following sustainability parameters and thresholds were evaluated for the Albemarle Sound area:

*Female CPUE (DMF IGNS):* The female CPUE index based on the DMF IGNS was calculated as the number of fish per haul using data collected during January through May (Figure 3).

- Time series: 2000–2011. Although the IGNS has been conducted since 1991, use of the 2000–2011 time series will allow for more consistent comparison with the female CPUE index from the Roanoke River electrofishing survey, which has been conducted annually since 2000.
- Threshold: Three consecutive years of values below the 25<sup>th</sup> percentile (where 75% of all values are greater).

*Female CPUE (WRC electrofishing survey):* The female CPUE index based on the WRC electrofishing survey was calculated as the number of fish per minute (Figure 3). Data from the 2000 electrofishing survey were unavailable for analysis due to database construction but will be included when parameters are updated for the annual compliance report.

- Time series: 2001–2011.
- Threshold: Three consecutive years of values below the 25<sup>th</sup> percentile (where 75% of all values are greater).

*Female Relative F (DMF IGNS):* Female relative  $F$  based on the DMF IGNS was calculated using commercial gill net landings of roes in Albemarle Sound (February through April) and a female index derived from data collected in the 5.0, 5.5 and 6.0-inch mesh sizes of the IGNS (February through April; Figure 4). The February through April timeframe was used to reflect the period during which the commercial fishery is prosecuted. The mesh sizes selected most accurately reflect those used by the commercial fleet.

- Time series: 2000–2011. See description of time series for female CPUE based on the DMF IGNS.
- Threshold: Three consecutive years of values above the 75<sup>th</sup> percentile (where 25% of all values are greater).

*Female Relative F (WRC electrofishing survey):* Female relative  $F$  based on the WRC electrofishing survey was calculated using commercial landings of roes by all gear types in Albemarle Sound and the female CPUE index from the Roanoke River electrofishing survey (Figure 5). Because the survey occurs during the months of March through May, landings data from only those months were used in the calculations. As noted above, data from the 2000 electrofishing survey were unavailable for analysis.

- Time series: 2001–2011.
- Threshold: Three consecutive years of values above the 75<sup>th</sup> percentile (where 25% of all values are greater).

*Total Relative F (DMF IGNS):* Total relative  $F$  based on the DMF IGNS was calculated the same way that female relative  $F$  based on the DMF IGNS was calculated except that all sexes were included (male, female, unknown) in computing relative abundance, and commercial landings included both bucks and roes (Figure 6).

- Time series: 1998–2011. This time period was chosen because commercial regulations in the Albemarle Sound have been consistent during these years.
- Threshold: Three consecutive years of values above the 75<sup>th</sup> percentile (where 25% of all values are greater).

The sustainability parameters selected for Albemarle Sound were female CPUE based on the IGNS, female CPUE based on the electrofishing survey and female relative  $F$  based on the IGNS. Relative  $F$  based on the IGNS was chosen over relative  $F$  based on the electrofishing survey because the electrofishing survey is limited to the Roanoke River and so was not considered representative of Albemarle Sound as a whole. The majority of the commercial fishery occurs in Albemarle Sound and because a reliable IGNS exists for this area, use of relative  $F$  based on the IGNS rather than the electrofishing index was determined to be a more appropriate sustainability parameter. Exceeding the threshold for any of the selected parameters will trigger management action (see “Potential Management Measures”).

The IGNS index of female relative abundance for Albemarle Sound showed little variation over time (Figure 3). This index has been above the threshold from 2005-2010, and fell below the threshold in 2011. The female abundance index derived from the electrofishing survey was above the threshold throughout most of the time series (Figure 3). This index demonstrated an increase from 2006 to 2008 but decreased in 2009 and dropped below the threshold in 2010. The index increased slightly above the threshold in 2011.

Estimates of female relative  $F$  derived from the IGNS also varied with time and exceeded the threshold in 2010 and 2011 (Figure 4). Relative  $F$  estimates for female American shad derived from the electrofishing survey demonstrated a decline from 2003 to 2008 followed by an increase through 2011. (Figure 5). Trends in total relative  $F$  derived from the IGNS (Figure 6) were similar to trends in female relative  $F$  derived from the same survey (Figure 4).

### Future Considerations

Since 1998, American shad fry have been stocked in the Roanoke River downstream of Kerr (US Army Corps of Engineers), Gaston (Dominion Power) and Roanoke Rapids (Dominion Power) reservoirs at Weldon, NC as well as upstream of these reservoirs at Altavista and Clover Landing, VA. These stocking activities serve as migratory obstruction mitigation required by Federal Energy Regulatory Commission (FERC) relicensing of the Gaston and Roanoke Rapids hydropower dams. This restoration effort is coordinated by a Diadromous Fish Restoration Technical Advisory Committee (DFRTAC; includes representatives from U.S. Fish and Wildlife Service (FWS), National Marine Fisheries Service (NMFS), Virginia Department of Game and Inland Fisheries (VDGIF), WRC, DMF and Dominion Power) and has a target of two annual population estimates of 20,000 adult American shad present below the base of the Roanoke Rapids Dam. The two population estimates do not have to occur in consecutive years. The target was developed based on a combination of 1/10<sup>th</sup> of the projected run size (using the 50 shad per acre rule of thumb for riverine habitat between the dam and the river mouth (St. Pierre 1979)) and very limited historic landings information.

The contribution of these enhancement efforts to the overall population in the Albemarle Sound system, as well as the potential impact of fishery removals on these efforts, are issues that need to be resolved for possible inclusion in future revisions to this plan. Additional efforts in the Albemarle region include prioritization of roadway culvert replacements. DMF is pursuing a grant opportunity to restore river herring habitat through removal of priority culverts within the region. While this is specifically focused on river herring habitat, there may likely be benefits to shad habitat as well should the grant be awarded.

With regard to the Roanoke River creel survey, additional effort will be made in the future to target locations closer to the spawning grounds near Gaston, where there may be a higher encounter rate of American shad by anglers. This creel survey occurs annually, and collection of effort data related to American shad is somewhat dependent on location. Also, existing methods do not capture effort, harvest and catch from bank anglers although efforts are underway to do so in upcoming surveys.

Finally, DMF just completed a research prioritization process for all managed species. A top priority was expansion of existing surveys to meet the need for more accurate JAIs for species of importance. Depending on funding and staff resources, expansion of the alosine seine survey may be able to meet this need.

### **Tar-Pamlico River**

#### Stock Status

Stock status could not be determined for the Tar-Pamlico River based on the 2007 ASFMC stock assessment (ASFMC 2007b). There were no definitive trends in abundance, although it was noted that the electrofishing CPUE for the Tar River was higher than in other North Carolina rivers since 2000. A total mortality benchmark ( $Z_{30}$ ) of 1.01 was suggested.

#### Commercial Fisheries

Commercial landings of American shad have declined significantly since the mid-1980s and have remained low and variable without trend since 1994 (Figure 2). Almost all harvest occurs in gill nets. There has been sporadic harvest by pound nets over the years.

#### Recreational Fisheries

A recreational fishery does exist, and estimates of angler effort and catch are calculated through the use of a creel survey that rotates among the Tar, Neuse, and Cape Fear rivers. The most recent creel survey on the Tar River was conducted in 2005 and determined recreational harvest to be 1,212 American shad out of a total estimated catch of 7,575 American and hickory shad combined (Homan et al. 2006). The recreational creel limit is 10 American and hickory shad in the aggregate. While DMF has recently expanded creel surveys further upstream in the central region (Pamlico Sound area) of the state, estimates

of harvest are highly variable and inherently have a large error associated with them, similar to creel surveys conducted by WRC in Inland Waters.

### Sustainability Parameters

Data used in the development of sustainability parameters for the Tar-Pamlico system include electrofishing data collected by WRC and commercial landings data collected through the DMF Trip Ticket Program (see the “Stock Monitoring Programs” section for complete descriptions of these surveys). There is no directed JAI survey for the Tar-Pamlico system. An IGNS has been conducted consistently in the Neuse, Pamlico, and Pungo river tributaries of Pamlico Sound since 2004, but the survey has an average annual catch of only 24 American shad in the Tar-Pamlico River. American shad captured in this IGNS are not sexed; therefore, an independent estimate of female relative abundance could not be calculated from this survey.

The following sustainability parameters and thresholds were evaluated for the Tar-Pamlico River system:

*Female CPUE (WRC electrofishing survey):* The female CPUE index based on the WRC electrofishing survey was calculated as the number of fish per minute (Figure 7).

- Time series: 2000–2011. The electrofishing survey has been conducted annually since 2000 on the Tar River.
- Threshold: Three consecutive years of values below the 25<sup>th</sup> percentile (where 75% of all values are greater).

*Female Relative F (WRC electrofishing survey):* Female relative  $F$  based on the WRC electrofishing survey was calculated using commercial landings of roes by all gear types from the Pamlico River and the female CPUE index from the Tar River electrofishing survey (Figure 8). Because the electrofishing survey primarily occurs during March through April, only commercial landings from those months were used in the calculations.

- Time series: 2000–2011. The electrofishing survey has been conducted on the Tar River annually during these years.
- Threshold: Three consecutive years of values above the 75<sup>th</sup> percentile (where 25% of all values are greater).

*Total Relative F (DMF IGNS):* Total relative  $F$  based on the DMF IGNS was calculated using commercial gill net landings (February through April) from the Pamlico River and an abundance index derived from data collected in the 4.5, 5.0, 5.5, 6.0, and 6.5-inch mesh sizes of the IGNS in the Pamlico River (February through April; Figure 9). Because the IGNS occurs during February through April in the Pamlico River, only commercial landings from those months were used in the calculations. The mesh sizes selected most accurately reflect those used by the commercial fleet in this system.

- Time series: 2004–2011. This time period reflects the years that the IGNS has been conducted in the Pamlico Sound and its tributary rivers (Neuse, Pamlico).
- Threshold: Three consecutive years of values above the 75<sup>th</sup> percentile (where 25% of all values are greater).

The sustainability parameters selected for the Tar-Pamlico River were the female CPUE index and female relative  $F$ , both derived from the WRC electrofishing survey. Although the IGNS is generally considered to be more representative of conditions in the commercial shad fishery, there are currently only 8 years of data available from the IGNS in the Pamlico River while 12 years are currently available from the Tar River electrofishing survey. Exceeding the threshold for any of the selected parameters will trigger management action (see “Potential Management Measures”).

Female relative abundance of American shad derived from the electrofishing survey in the Tar River was above the threshold in most years of the time series (Figure 7). The index fell just below the threshold in 2009 but increased to a level slightly above the threshold in 2010 and 2011. Estimates of relative  $F$  for female American shad derived from the electrofishing survey were below the threshold during 2000 to 2006, with the exception of 2003 where relative  $F$  was slightly above the threshold (Figure 8). These estimates of female relative  $F$  exceeded the threshold in 2007 and 2009 and were only slightly below the threshold in 2008 and 2010. The 2011 estimate is well below the threshold. The estimates of total relative  $F$  based on the IGNS were variable over time but were generally similar to the female relative  $F$  estimates derived from the electrofishing survey (Figure 9).

### Future Considerations

There is potential to improve upstream passage in this system. The WRC, FWS and the Pamlico-Tar River Foundation have engaged in conversations with the Rocky Mount Mills Dam owner and hydroelectric operator. In addition to interest in providing American shad access to potential spawning habitat upstream of Rocky Mount Mills Dam, concern exists that periodic downward spikes in flow below Rocky Mount Mills Dam compromise the quality of existing spawning habitat.

With regard to creel surveys, DMF and WRC have engaged in a cooperative effort to improve the frequency and design of surveys on the Tar and Neuse rivers beginning in spring 2012. Creel surveys will occur annually and include increased coverage on both rivers, which should improve estimates of recreational harvest. These efforts will continue for at least the next five years.

As noted previously, DMF recently completed a research prioritization exercise for all managed species. One of the top priorities was expansion of existing surveys to provide accurate JAIs for all commercially and recreationally important species. Depending on future funding and protected resources concerns, expansion of the IGNS in the rivers may be able to serve this need.

## **Neuse River**

### Status of Stocks

Stock status could not be determined for the Neuse River based on the 2007 ASFMC stock assessment (ASMFC 2007b). There were no definitive trends in abundance over the most recent five to ten years of the assessment. A total mortality benchmark ( $Z_{30}$ ) of 1.01 was suggested (ASMFC 2007a).

### Commercial Fisheries

Commercial landings of American shad have declined since 1972. There have been several peaks throughout the time series, but landings have remained low and variable without trend since the early 2000s (Figure 2). Harvest occurs almost entirely from gill nets. There have been minimal contributions from pound nets over the years.

### Recreational Fisheries

Estimates of angler effort and catch are calculated through the rotating creel survey noted in previous systems. A confounding factor in the creel survey is that American and hickory shad co-occur in the Neuse and responses to creel clerks indicated only that anglers were fishing for “shad”. The most recent survey occurred in 2003. An estimated 318 American shad were caught during the month of April, 274 of which were harvested (Rundle et al. 2004). A 1-fish limit on American shad within the aggregate 10-fish recreational creel limit for American and hickory shad has been proposed for the Inland Waters of the Neuse River. Unlike the 1-fish limit for American shad on the Roanoke River, this measure is being implemented in response to recent declines in electrofishing indices and creel data and will become effective in 2012.

### Sustainability Parameters

Data used in the development of sustainability parameters for the Neuse River system include electrofishing data collected by WRC and commercial landings data collected through the DMF Trip Ticket Program (see the “Stock Monitoring Programs” section for complete descriptions of these surveys). There is no directed JAI survey for the Neuse River. As noted previously, there is an IGNS in the tributaries of Pamlico Sound. However, the IGNS for the Neuse River area of the survey has an average annual catch of only 17 American shad. Because American shad captured by this IGNS are not sexed, an independent estimate of female relative abundance could not be calculated from this survey.

The following sustainability parameters and thresholds were evaluated for the Neuse River system:

*Female CPUE (WRC electrofishing survey):* The female CPUE index based on the WRC electrofishing survey was calculated as the number of fish per minute (Figure 10).

- Time series: 2000–2011. The electrofishing survey has been conducted consistently since 2000 on the Neuse River.
- Threshold: Three consecutive years of values below the 25<sup>th</sup> percentile (where 75% of all values are greater).

*Female Relative F (WRC electrofishing survey):* Female relative  $F$  based on the WRC electrofishing survey was calculated using commercial landings of roes by all gear types from the Neuse River and the female CPUE index from the Neuse River electrofishing survey (Figure 11). Because the electrofishing survey primarily occurs during March through April, only commercial landings from those months were used in the calculations.

- Time series: 2000–2011. This time period reflects the years the electrofishing survey has been conducted on the Neuse River.
- Threshold: Three consecutive years of values above the 75<sup>th</sup> percentile (where 25% of all values are greater).

*Total Relative F (DMF IGNS):* Total relative  $F$  based on the DMF IGNS was calculated using commercial gill net landings (February through April) from the Neuse River and an index derived from data collected in the 4.5, 5.0, 5.5, 6.0, and 6.5-inch mesh sizes of the IGNS (February through April) in the Neuse River (Figure 12). Because the IGNS in the Neuse River occurs during February through April, only commercial landings from those months were used in the calculations. The mesh sizes selected most accurately reflect those used by the commercial fleet.

- Time series: 2004–2011. This time period reflects the years that the IGNS has been conducted in the Pamlico Sound and its tributary rivers (Neuse, Pamlico).
- Threshold: Three consecutive years of values above the 75<sup>th</sup> percentile (where 25% of all values are greater).

The sustainability parameters selected for the Neuse River were the female CPUE index and female relative  $F$ , both derived from the WRC electrofishing survey. Although the IGNS is generally considered to be more representative of conditions in the commercial shad fishery, there are currently only 7 years of data available from the IGNS in the Neuse River while 11 years are currently available from the Neuse River electrofishing survey. Exceeding the threshold for any of the selected parameters will trigger management action (see “Potential Management Measures”).

The electrofishing index of relative abundance for female American shad in the Neuse River has been variable and remained above the threshold throughout most of the time series, but did fall below the threshold in 2010 (Figure 10) and increased above the threshold again in 2011. Relative  $F$  estimates for female shad derived from the electrofishing survey have been variable but were below the threshold from

2008 to 2011 (Figure 11). The estimates of total relative  $F$  based on the IGNS demonstrate a similar trend to female relative  $F$  estimates derived from the electrofishing survey during 2007 through 2011 (Figure 12).

### Future Considerations

Lack of adequate flow during the spring spawning season is a major concern on the Neuse River. The largest dam on this river is the Falls Lake Dam, which forms the drinking water supply for the city of Raleigh and other municipalities. While flow regimes have been negotiated on the Roanoke River for spawning and ecological needs, similar considerations do not formally exist on the Neuse River. The variability in timing and strength of flows can impact restoration efforts, particularly spawning success and subsequent recruitment (e.g., there may be sufficient numbers of spawning adults but flows are insufficient for successful spawning activity or downstream transport of larvae and juveniles to favorable nursery habitat). Periodically limited stream flow and associated navigability issues also impact the ability to conduct electrofishing surveys.

As noted in the previous section, a more frequent creel survey rotation as well as efforts by DMF to expand creel surveys upstream should hopefully provide improvements in future recreational effort and catch/harvest estimates. Similarly, a representative JAI for American shad may be a future possibility depending on resources available to expand or reconfigure existing independent surveys.

## **Cape Fear River**

### Stock Status

Similar to the Tar-Pamlico and Neuse rivers, the stock status on the Cape Fear River is unknown, although a total mortality benchmark ( $Z_{30}$ ) of 1.01 was recommended in the latest assessment (ASMFC 2007a, 2007b). Of all the river systems in North Carolina, the Cape Fear is likely to have the highest proportion of fish that are semelparous.

### Commercial Fishery

Commercial landings have displayed several cyclical peaks since 1972, although each successive peak has been slightly lower than the previous. Landings have been somewhat low throughout the 2000s. As with the other river systems, the vast majority of landings are from gill nets. There has been very little harvest from other gears.

### Recreational Fishery

The rotating creel survey used in the river systems took place during the spring of 2011 on the Cape Fear River, from mid-March through mid-May. Estimates of total catch and harvest were 22,312 and 14,888 American shad respectively. The creel limit remains at 10 American and hickory shad in the aggregate.

### Sustainability Parameters

Data used in the development of sustainability parameters for the Cape Fear system include electrofishing data collected by WRC and commercial landings data collected through the DMF Trip Ticket Program (see the “Stock Monitoring Programs” section for complete descriptions of these surveys). There is no directed JAI survey for the Cape Fear River. While there was an IGNS from 2003–2007, it was a fixed-station survey rather than a stratified random design and was therefore not used in any sustainability parameter calculations.

The following sustainability parameters and thresholds were evaluated for the Cape Fear River system:

*Female CPUE (WRC electrofishing survey):* The female CPUE index based on the WRC electrofishing survey was calculated as the number of fish per minute (Figure 13).

- Time series: 2001–2011. The electrofishing survey has been conducted annually since 2001 on the Cape Fear River.
- Threshold: Three consecutive years of values below the 25<sup>th</sup> percentile (where 75% of all values are greater).

*Female Relative F (WRC electrofishing survey)*: Female relative  $F$  based on the WRC electrofishing survey was calculated using commercial landings of roes by all gear types from the Cape Fear River and the female index from the WRC Cape Fear River electrofishing survey (Figure 14). Because the electrofishing survey primarily occurs during March through May, only commercial landings from those months were used in the calculations.

- Time series: 2001–2011. This time period reflects the years the electrofishing survey has been conducted on the Cape Fear River.
- Threshold: Three consecutive years of values above the 75<sup>th</sup> percentile (where 25% of all values are greater).

*Total Relative F (WRC electrofishing survey)*: Total relative  $F$  based on the WRC electrofishing survey was calculated using commercial landings by all gear types from the Cape Fear River and an index of total abundance from the WRC Cape Fear electrofishing survey (Figure 15). Because the electrofishing survey is conducted during March through May, only commercial landings from those months were used in the calculations.

- Time series: 2001–2011. The electrofishing survey has been conducted annually on the Cape Fear River since 2001.
- Threshold: Three consecutive years of values above the 75<sup>th</sup> percentile (where 25% of all values are greater).

The sustainability parameters selected for the Cape Fear River were the female CPUE index and female relative  $F$ , both derived from the WRC electrofishing survey. Although the IGNS is generally considered to be more representative of conditions in the commercial shad fishery, the IGNS conducted on the Cape Fear River consisted of a fixed-station design and data are currently available for a limited number of years (2003–2007); therefore, it was not considered appropriate for developing abundance indices or calculating relative  $F$  estimates. Exceeding the threshold for any of the selected parameters will trigger management action (see “Potential Management Measures”).

Relative abundance of female American shad in the Cape Fear River has been low since 2004 as compared to the early 2000s, based on the electrofishing survey (Figure 13). The index values have remained near the threshold since 2004 and were below the threshold in 2010 and 2011. Estimates of female relative  $F$  gradually increased from the beginning of the time series in 2001 to a peak in 2007 (Figure 14). These estimates then decreased in 2008 and increased to levels above the threshold in 2010 and 2011. Total relative  $F$  estimates show a nearly identical pattern (Figure 15).

### Future Considerations

The Cape Fear River is currently the site of a major reconstruction effort for fish passage (Lock and Dam #1 rock arch ramp). This is scheduled for completion by the 2013 spawning season. Based on the construction efforts and changing conditions, DMF and WRC recommend a two-year review of the 75<sup>th</sup> percentile threshold for female relative  $F$ . Calculation of this parameter is likely to be heavily influenced by drought, floods, and changes in fish passage and may require revision sooner than other systems. Restoration efforts may also influence electrofishing catch rates because fish passage may improve with completion of the rock arch ramp.

## **Potential Management Measures**

The environmental circumstances under which a sustainability threshold may be reached can vary among systems. Therefore, different management measures may be used for each system in addressing the triggers. A suite of potential measures to be implemented is presented here and may be used singly or in conjunction with one another:

- Restrictions on length of season to reduce effort (e.g., March 1–April 15)—not to extend beyond the estuarine striped bass quotas being filled (avoids waste of striped bass and shad)
- Trip limits (this may result in discards)
- Reduce allowable amount of yards (the 1,000-yard limit in Albemarle Sound could be considered in other areas)
- Area/season closure (e.g., area closure at mouth of Roanoke River from February–mid-November since 1988)
- Only allow fishing certain days of the week (lift days)
- Creel reduction—complement WRC rules in the Roanoke and Neuse Rivers in Coastal Waters
- Commercial harvest quota (although possible, this could be difficult to implement given existing resources)
- If two years of sustainability parameters exceeding thresholds are observed, a suite of management measures could be proactively developed and presented to Finfish and Regional Advisory Committees

## **Proposed Management Measures for 2013**

### Albemarle Sound, Tar-Pamlico River, Neuse River

As noted in the “Commercial Gear Restrictions” section, management measures implemented in November 2011 for spotted seatrout conservation (prohibition on the use of gill nets in Joint Waters on weekends) are likely to reduce commercial harvest of American shad during the upcoming 2012 fishing season. The following management measures are proposed to be effective January 1, 2013:

- Commercial season of March 1, 2013 through April 15, 2013
- Recreational creel limits of 1-fish for American shad in the Joint and Coastal Waters of the Roanoke and Neuse rivers to complement the WRC 1-fish limit in the Inland Waters of these rivers

While none of the selected sustainability parameters for any of the river systems have exceeded the triggers for management, the above measures are considered prudent given the results of the 2007 stock assessment as they pertain to North Carolina. Future changes to creel limits for American shad in the Inland Waters of the other river systems will also be complemented by DMF for Joint and Coastal Waters.

Although harvest is an obvious potential contributor to population declines, significant habitat degradation has also occurred in all of the river systems. It is unlikely that American shad populations in North Carolina will recover and expand without considerable resources being dedicated to habitat restoration for this species. Our management goals, however, are intended to sustain population levels as additional habitat is protected or improved through aquatic habitat conservation measures and increased passage opportunities of American shad beyond impediments that block migration to historic spawning grounds.

### Cape Fear River

At the request of the ASMFC Shad and River Herring Technical Committee, additional analysis was conducted for the Cape Fear River. This was based on the female relative  $F$  parameter being over the 75<sup>th</sup> percentile threshold for two consecutive years, as well as the female CPUE from the electrofishing survey being very close to the threshold for the past six years. First, the percent reduction in commercial harvest required to bring female relative  $F$  down to the threshold was calculated. This reduction (commercial harvest only) was determined to be 11.2%. Again, this reduction would only result in female relative  $F$  decreasing to the threshold, not below it.

Additional analyses were conducted to determine the commercial and recreational reductions in harvest that would provide an additional conservation buffer. Recall that the relative  $F$  parameter is based on the ratio of commercial roe harvest *only* to the female index from the electrofishing survey; it does not include recreational harvest. It should be noted that commercial harvest and estimated recreational harvest for 2011 are roughly equivalent, and in several years, recreational harvest is greater (note that recreational harvest is listed in numbers of fish). It was determined that equivalent reductions in harvest for both commercial and recreational sectors would provide the greatest benefit. Management options that resulted in a 25% reduction in harvest for each sector were calculated as described below.

For the commercial sector, it was determined that a shortened season would provide the greatest benefit to the resource rather than a trip limit. Seasonal reductions will result in fewer discards, as well as additional protection for protected species such as Atlantic sturgeon. Reductions were calculated from the beginning of the season (January 1) and the end of the season (April 15) that would equate to a 25% reduction in commercial harvest. Calculations included the weekend lift days for gill nets in Joint Waters that were implemented in November 2011 and noted above. It was determined that an opening date of February 20 and closing date of April 11 would result in a 25% reduction.

For the recreational sector, a series of bag limit reductions and associated percent reductions in harvest were calculated based on the 2011 Cape Fear creel survey (see Appendix 2). A 3% catch-and-release mortality was applied based on Hillard (2003). It was determined that a 5-fish bag limit came closest to meeting a 25% reduction in recreational harvest, with an actual reduction of 23%.

Based on the *minimum* required reduction in *commercial harvest only* to reach the female relative threshold of 11.2%, reductions of 25% for both commercial and recreational harvest are proposed for 2013. Given that the minimum required reduction is based only on commercial harvest and that commercial and estimated recreational harvest are roughly equivalent, a 25% reduction in both sectors should provide a sufficient conservation buffer to account for potential changes in fishing behavior. As noted in the “Future Considerations” subsection of the Cape Fear section on page 12, construction on the Cape Fear to remove impediments to upstream passage at Lock & Dam 1 will be completed for the 2013 spawning season and are expected to result in 80% upstream passage. Construction activities resulted in the closure of the boat launch at Lock & Dam 1 in late 2011, which is the most popular launch for both commercial and recreational fishermen. It is anticipated that this closure will displace effort further upstream on the Cape Fear.

### **Ancillary Information**

The focus on female indices for the sustainability parameters in all systems is based on the conclusion that changes in female abundance combined with impacts from various environmental parameters could prove challenging to stock improvement given that the commercial fishery targets roe shad. Major fluctuations in female abundance could potentially impact future recruitment and landings. The use of sex ratios as a sustainability parameter was considered, but it was determined that the sex ratios from both the IGNS (in the Albemarle system and potentially the other systems) and the electrofishing surveys were

more suitable for use as long-term trends rather than short-term (i.e., three year) indicators of stock health due to the impact of environmental variability on the data. The intent of the agencies is to monitor the sex ratios from each of the surveys for trends and use this information to help inform future management.

The use of repeat spawning data was also considered as a potential sustainability parameter. However, inconsistencies in determination of repeat spawning marks made it difficult to set a target or threshold. Because repeat spawning continues to be tracked annually as part of the required monitoring program, it will also be used as ancillary information for determining future management. Should greater confidence in repeat spawning data be attained in the future, they may be considered for developing a formal sustainability parameter.

Finally, while sustainability parameters will be updated annually in compliance reports, DMF and WRC will conduct a review of this plan once every five years as new data and information become available and may elect to change or update sustainability parameters at that time.

## **STOCK MONITORING PROGRAMS**

The following descriptions represent the entirety of stock monitoring programs used to assess the health of American shad in North Carolina. All programs are included in annual compliance reports and as noted in the program descriptions, specific details can be found in past compliance reports.

### **Fishery-Independent Monitoring**

#### Juvenile Abundance

A juvenile abundance index is calculated for Albemarle Sound area using data from the alosine seine survey that has been conducted annually since 1972. Eleven core seine stations are sampled monthly in the western Albemarle Sound area during June–October of each year. During September, thirteen additional seine samples are taken to determine distribution and annual variations of alosines in the nursery area. All stations are sampled with an 18.5-m (60-ft) bag seine. Relative abundance data are collected for blueback herring, alewife, American shad and hickory shad from the 11 core stations.

Samples are sorted by species and 30 randomly selected individuals of each alosine species present are measured. Other species present are also noted. Water temperature, salinity, and other environmental characteristics are counted, measured, and recorded. As noted previously, this survey was designed specifically for blueback herring and is not considered a reliable indicator of juvenile American shad abundance.

No juvenile abundance indices exist for the Tar-Pamlico, Neuse and Cape Fear river systems.

#### Adult Stock Monitoring

##### *Spawning Area Survey*

An annual spawning stock survey and representative sampling for biological data is required from Albemarle Sound and its tributaries, Tar-Pamlico, Neuse, and Cape Fear rivers for American shad. Sampling in these areas was initiated in 2000.

WRC personnel collect American shad from the Roanoke, Tar, Neuse and Cape Fear systems annually during March–May. A boat-mounted electrofishing unit (Smith-Root 7.5 GPP) is used (1 or 2 dip netters) to capture fish during daylight hours and electrofishing times are recorded. To minimize size selection during sampling, shad are picked up as they are encountered regardless of size. Relative abundance of each year-class is indexed by CPUE expressed as the number of fish captured per hour of electrofishing. American shad broodstock collections are not included in calculations of CPUE. Size, age and sex data are collected for all captured fish.

### *Independent Gill Net Survey (IGNS)*

Since 1991, DMF has been conducting an independent gill net survey throughout the Albemarle Sound area. The survey was designed for striped bass data collection and occurs November through May each year. However, American shad are captured during the survey and size, age and sex data are collected. Forty-yard segments of gill net from 2.5- through 7.0-inch stretched mesh, in half-inch increments, as well as 8.0, and 10.0-inch stretched mesh are utilized. The sound is divided into zones and grids and random sites are selected within these areas. Lines of float and sink nets are set in both shallow and deep strata if they are present in the grid.

The IGNS in the Pamlico Sound area (including Pamlico, Pungo and Neuse rivers) began in 2000. The survey runs from February through mid-December and utilizes a slightly different methodology than that conducted in the Albemarle Sound. Thirty-yard segments of gill net are used, ranging from 3.0-inch stretched mesh through 6.5-inch stretched mesh in half-inch increments. Similar to the Albemarle Sound, each set of nets is fished in both shallow and deep strata, and sites are selected at random from within a set of zones and grids.

An IGNS was conducted in the Cape Fear River from 2003–2007 but used a fixed-station design rather than a stratified random design.

### Size, Age and Sex Determination

#### *Spawning Area Survey*

Sex is determined for each captured fish by applying directional pressure to the abdomen toward the vent and observing the presence of milt or eggs. Each fish is measured for total length in millimeters. Scales are removed from the left side of each fish between the lateral line and the dorsal fin. To estimate age, scales are examined at 33X magnification on a microfiche reader and annuli are counted. Spawning marks are recorded separately. Shad that cannot be aged are assigned ages based on the gender specific age-length key developed for each river and included in CPUE and size-distribution analyses. Beginning in 2011, American shad will be aged using otoliths. Up to 10 fish per 10-mm size bin (by sex) will be sacrificed for otolith extraction.

#### *Independent Gill Net Survey*

Each fish is measured for fork length and total length. Sex is determined only for fish captured in the Albemarle Sound IGNS. Each fish is sexed by applying directional pressure to the abdomen toward the vent and observing the presence of milt or eggs. Scales are collected from the left side of each fish between the lateral line and the dorsal fin. Scales are prepared and aged according to the DMF/WRC American Shad Ageing Guidelines.

### Total Mortality Estimates

Survival estimates are calculated using the Robson and Chapman (1961) method. Robson and Chapman showed that estimates of annual rates of survival can be made from the catch curve of a single season if the population is exposed to unbiased fishing gear beyond the age of recruitment and if year-class strength and survival rate remain constant from year to year. Annual mortality rates are calculated based on observed samples of individuals at age. Only age groups that are fully recruited to the gear are included in the calculations and the resulting estimates only apply to the fully recruited individuals.

### **Hatchery Evaluation**

#### Roanoke River American Shad Restoration Project

American shad fry reared at the FWS Edenton National Fish Hatchery and at the WRC Watha State Fish Hatchery have been stocked annually into the Roanoke River since 1998. This restoration project was initiated by the WRC and funded by the North Carolina Department of Transportation as mitigation for aquatic habitat damages resulting from highway bridge construction on the Roanoke River (see North

Carolina's 1999 Shad and River Herring Report for full details). The project has since evolved into a cooperatively managed restoration partnership (see earlier text in the Albemarle Sound section under "Future Considerations") as required by FERC relicensing of the Gaston and Roanoke Rapids hydropower projects.

Initial attempts in 1998 at field collection and fertilization of American shad eggs met with limited success. In 1999, both hatcheries began developing hormone injection/tank spawning techniques in efforts to increase fry production. Also in 1999, WRC began coordination of marking fry with oxytetracycline (OTC) marking and stocking activities with the ad hoc interstate OTC Marking Task Force.

Following protocols of other states involved in American shad restoration efforts, brood stock for fry production are obtained from nearby rivers having adequate shad stocks. American shad brood fish are collected by electrofishing from the Tar, Neuse, Cape Fear, and Roanoke rivers. Upon collection, brood fish are placed in circular tanks with oxygen and continuously circulating water onboard the electrofishing boats and are then transferred to large circular, trailer-mounted tanks for transport to the hatcheries. In 2009, for the first time, no brood fish were injected with hormone (LHRHa or sGnRHa pellets) upon arrival at the hatcheries and prior to being transferred to circular spawning tanks. In 2011, broodstock endemic to the system intended for fry stockings were utilized for production. Broodstock will be genotyped for future genetic analysis of returning adults to identify hatchery contribution.

For additional detail and information regarding OTC marking, please refer to the 2009 North Carolina Shad and River Herring Compliance Report.

#### Evaluation of Hatchery Contribution

Since 2000, the annual contribution of returning adult American shad to the Roanoke River spawning stock collected in independent sampling gears has ranged between 0% and 3.1%. Because Roanoke River American shad return to the spawning grounds 3 to 6 years after hatching or stocking, recent American shad fry stockings since 2007 are likely still at-large. The WRC will continue stocking and recovery efforts of the Roanoke River American shad restoration program to assess the contribution of hatchery-origin American shad. Please see previous compliance reports for data (e.g., number of fry stocked, number of hatchery origin fish recovered) and additional details regarding hatchery contribution.

### **Fishery-Dependent Monitoring**

#### Commercial Fishery

##### *Total Catch, Landings and Effort*

American shad landings data are collected through the North Carolina Trip Ticket Program. The number of participants by gear utilized and the total number of positive trips can be determined. For the Albemarle Sound area, the following assumptions are made: (1) trips landing over 100 pounds of shad are considered directed trips, and (2) the maximum yardage used in directed trips is 1,000 yards. The total yardage for each area is determined by multiplying the number of participants by the maximum yardage per area. The catch-per-yard (CPY) is determined by dividing the number of pounds harvested by the total yardage estimate of gill nets fished and multiplied by 1,000 yards. This will result in the pounds landed per 1,000 yards. Catch estimates for other areas are determined similarly.

##### *Size, Age and Sex Composition of Catch*

Commercial landings from all four systems (Albemarle Sound, Tar-Pamlico River, Neuse River and Cape Fear River) are sampled to obtain size, age, sex and repeat spawning information. A target of 200 samples from each system has been in place since 1999. For specific information regarding exact number of samples collected per area, please see previous compliance reports.

## Recreational Fishery

### *Total Catch, Landings and Effort*

The North Carolina Fisheries Reform Act of 1997 required the MFC to establish limits on recreational use of commercial fishing gear. An individual holding a Recreational Commercial Gear License (RCGL) is allowed to use limited amounts of specified commercial gear to catch seafood for personal consumption or recreational purposes. The holder of the RCGL must comply with the recreational size and creel limits, and RCGL catch cannot be sold. During 2002, DMF began a RCGL survey to estimate the harvest by these license holders. The survey was discontinued in 2009 due to budget reductions.

In the Coastal, Joint, and Inland Waters of North Carolina the American shad and hickory shad hook-and-line creel limits are 10 fish per person per day in the aggregate. In the Inland Waters of the Roanoke River—effective July 1, 2008—the limit for American shad was reduced to one fish per person per day. In the Inland Waters of the Neuse River, the limit for American shad will be reduced to one fish per person per day effective August 1, 2012.

An annual creel survey occurs on the Roanoke River each year. The survey targets striped bass catch and effort but also collects information on American shad and other species. A rotating creel survey occurs on the Tar, Neuse and Cape Fear rivers. For specific information regarding catch and harvest of American shad, please see previous compliance reports.

### Bycatch and Discards

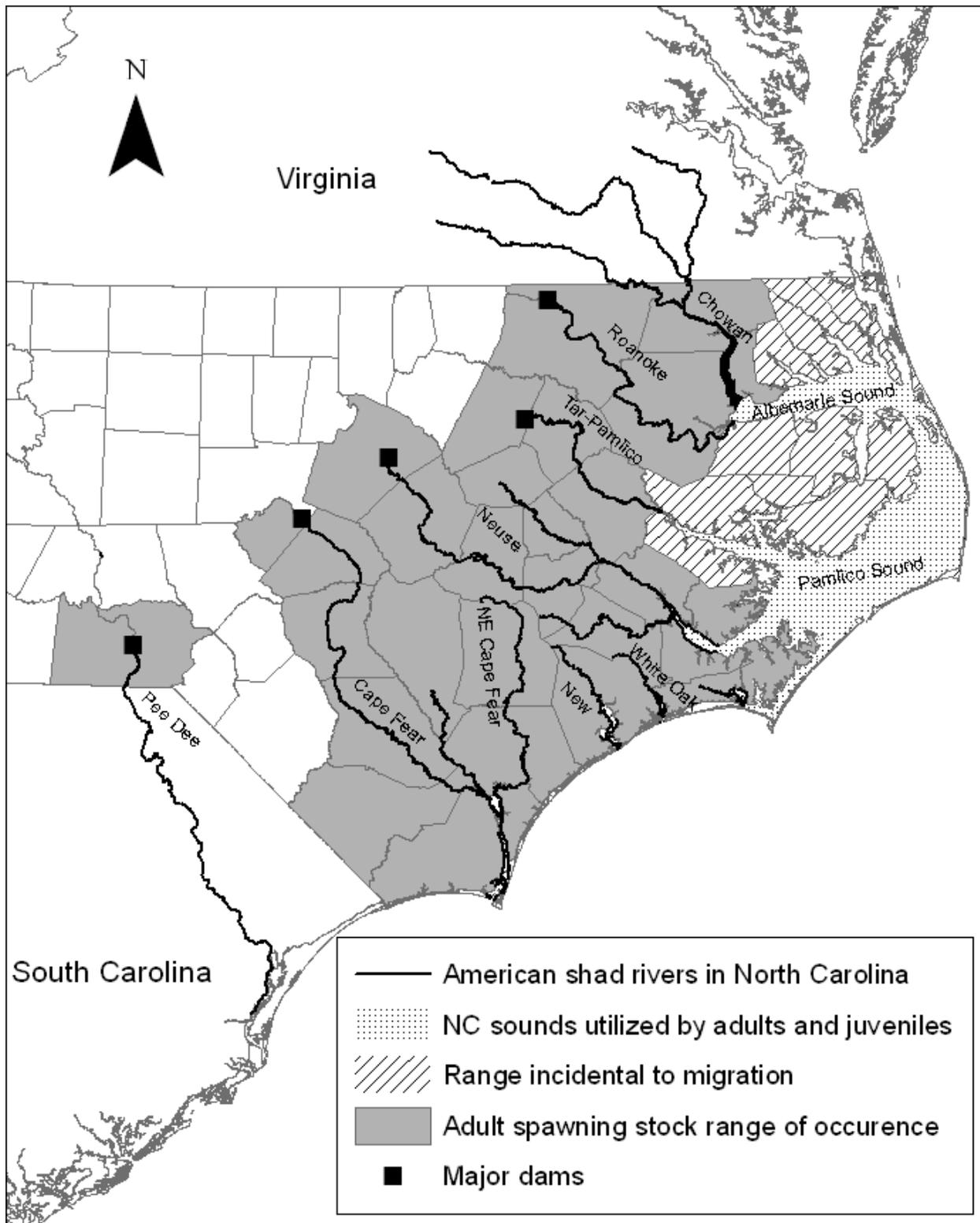
Bycatch and discard information are not currently collected on commercial trip tickets. The only mechanism that exists to capture commercial bycatch and discards of American shad in other fisheries is an observer program conducted by DMF to monitor sea turtle interactions in gill nets. Because there are very few encounters with sea turtles in the areas and times of year where and when directed American shad fishing occurs (i.e., western Albemarle Sound and the rivers), these areas have little observer coverage. However, current gill net restrictions in the Albemarle Sound and tributaries allows for the use of floating gill net webbing only during the open shad season. Once the shad season closes, the gill net webbing used to target shad is removed from the water.

The creel surveys conducted by the WRC in Inland Waters do capture discard and release information of non-target species. Please see previous compliance reports for this information.

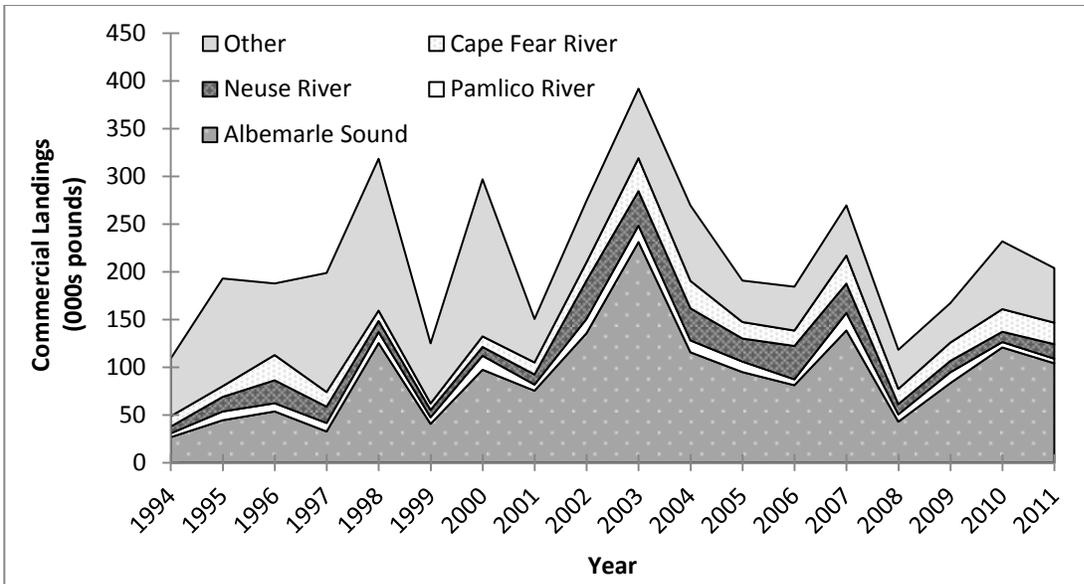
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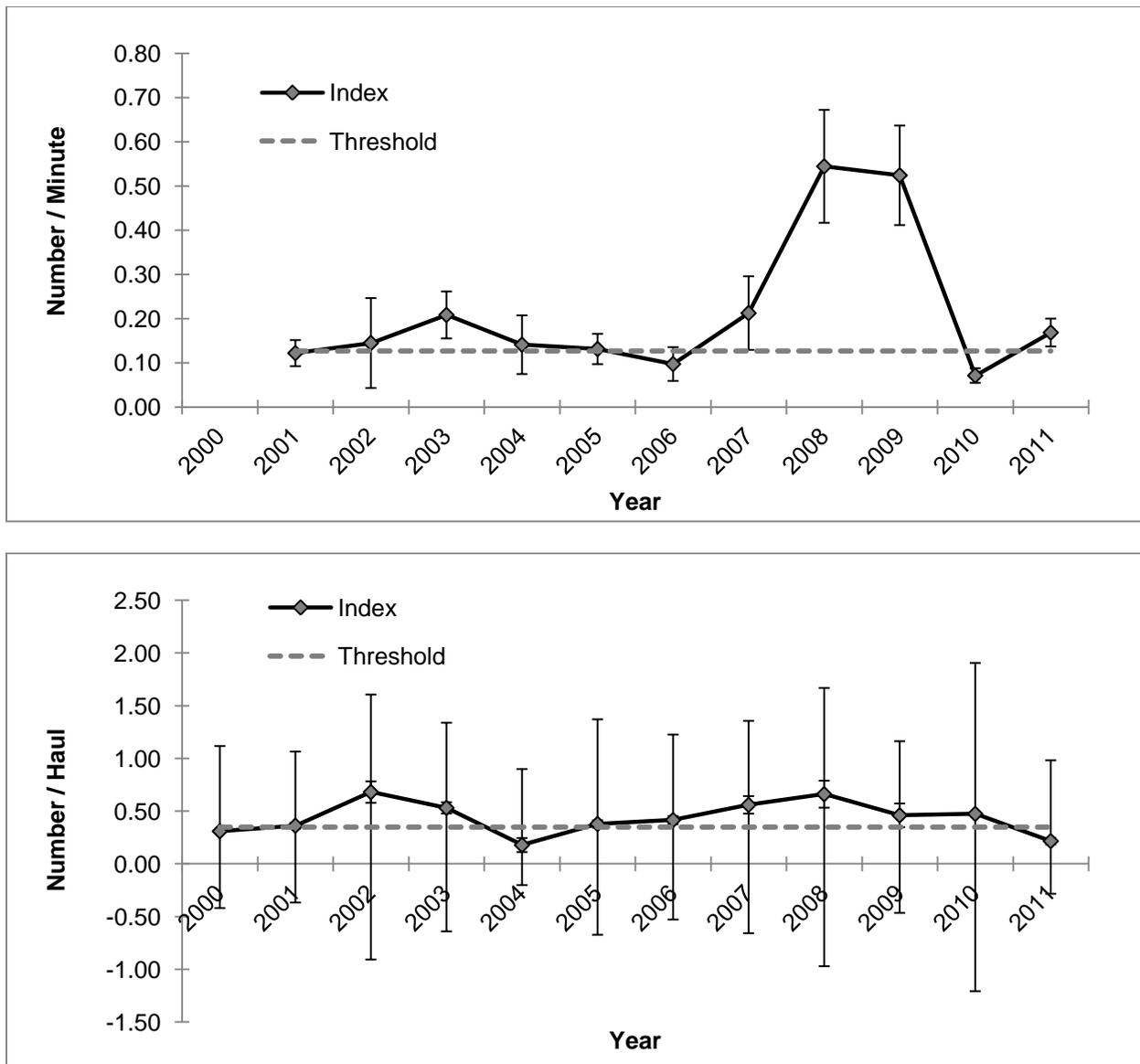
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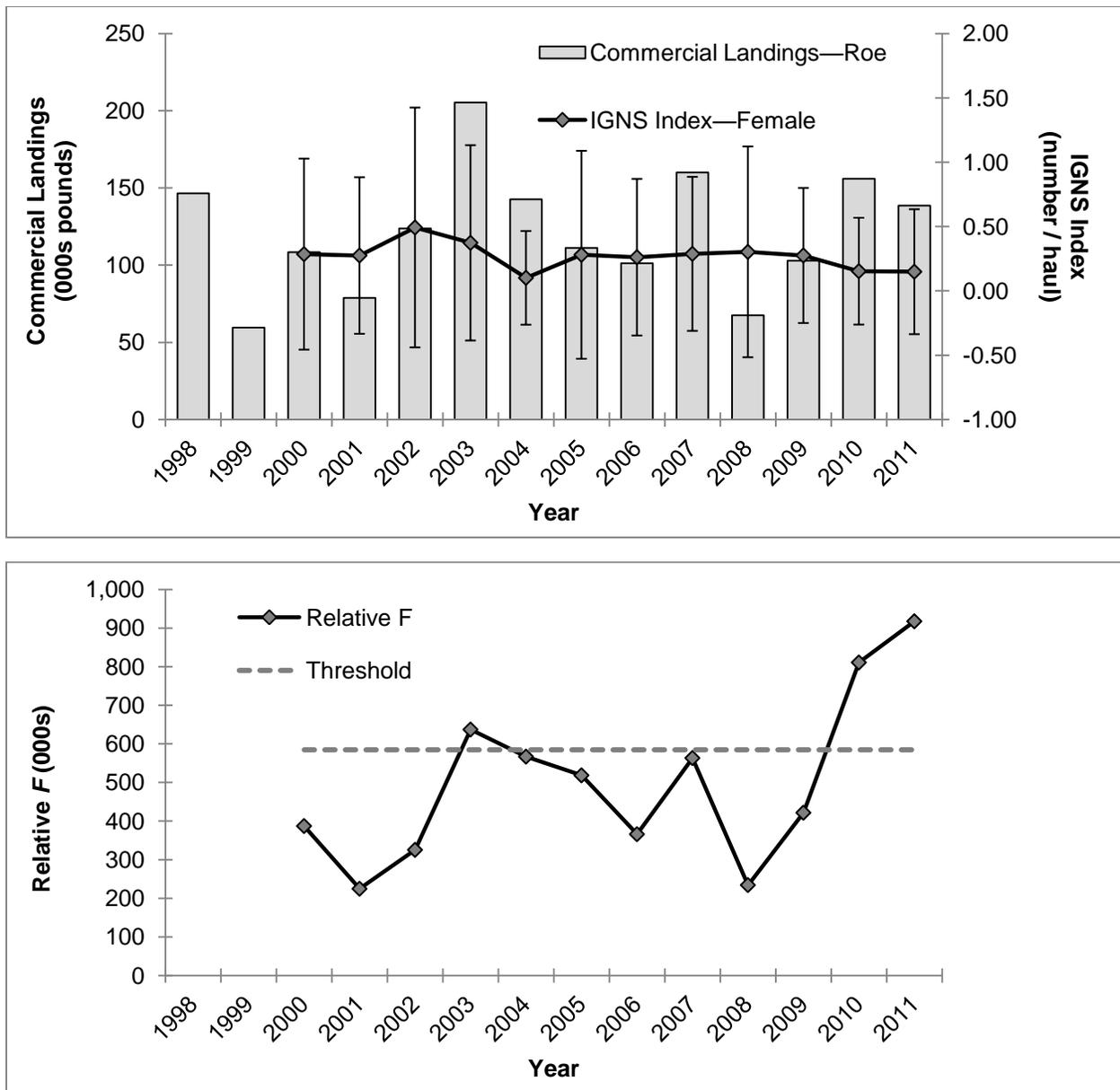
**Figure 1.** North Carolina river systems depicting the extent of American shad occurrence and habitat use.



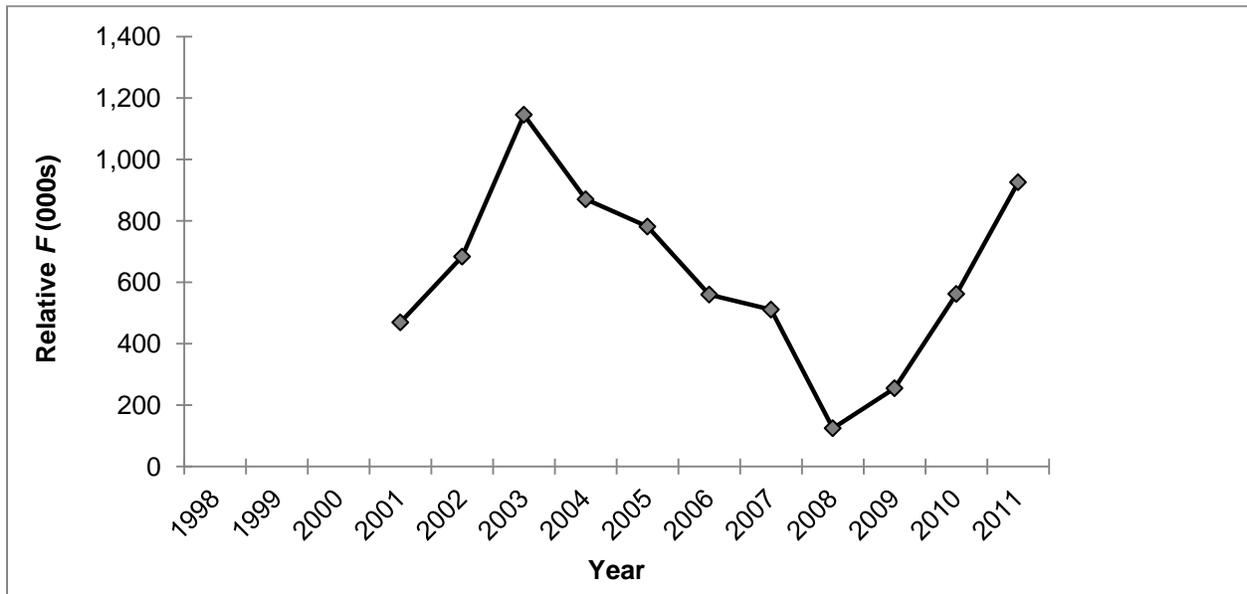
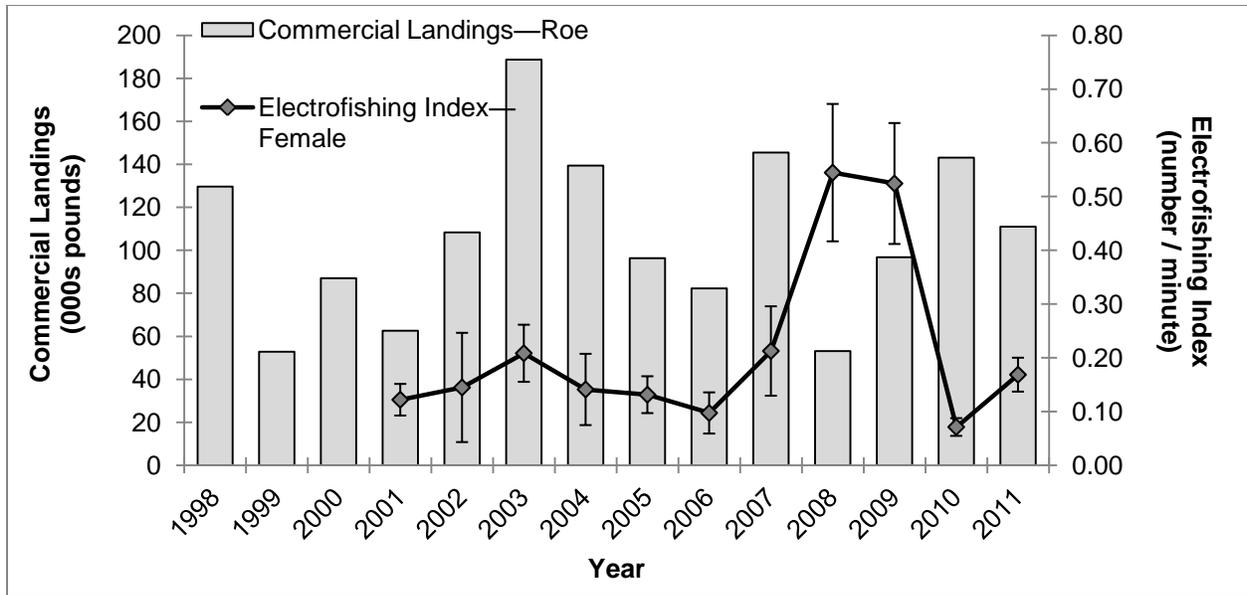
**Figure 2.** Commercial landings of American shad in North Carolina by water body, 1994–2011.



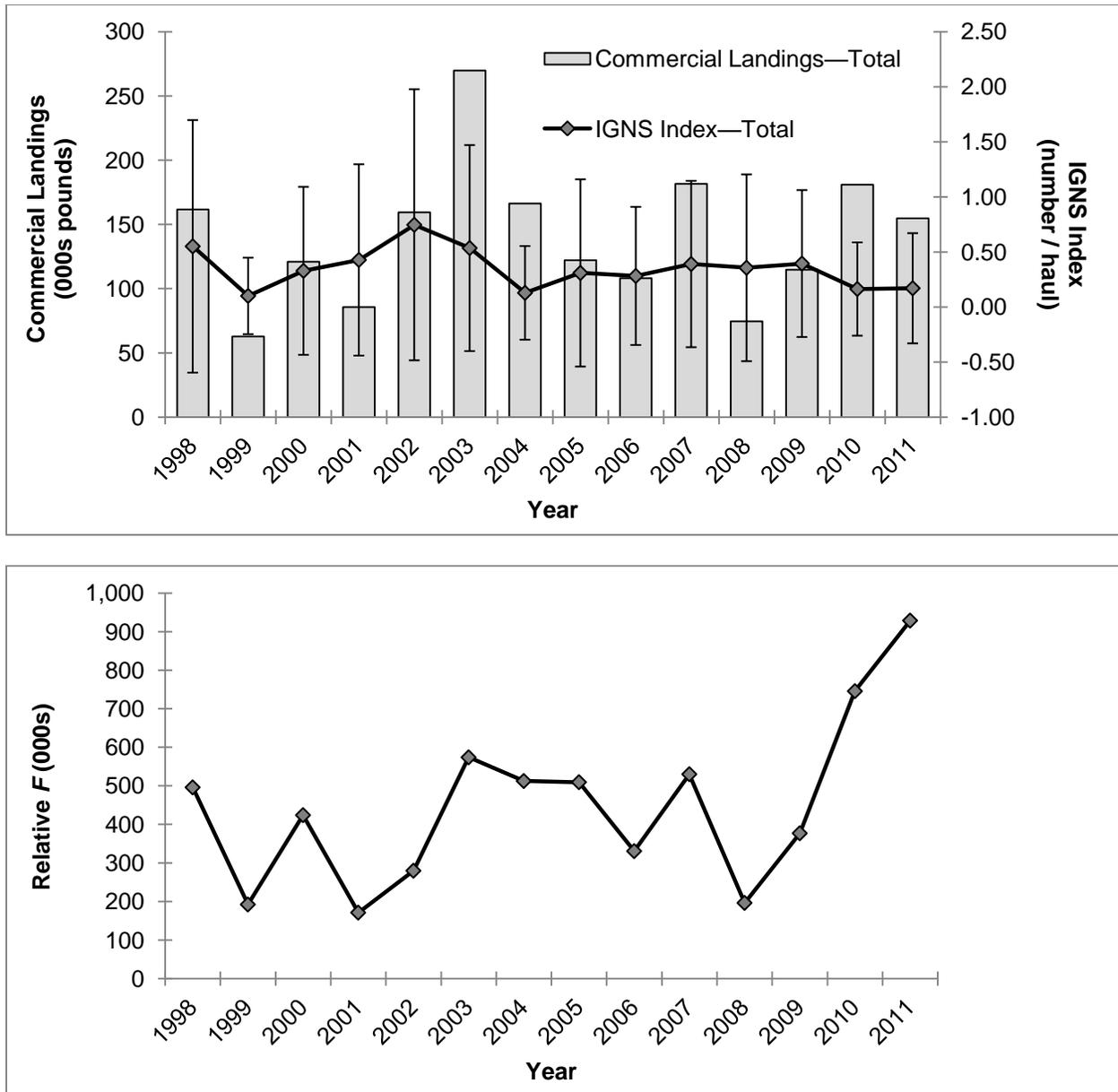
**Figure 3.** Female index from electrofishing survey (March–May; top graph) and female index from IGNS (January–May; bottom graph) for Albemarle Sound, 2000–2011. The error bars represent  $\pm 1$  standard deviation. Threshold represents 25<sup>th</sup> percentile (where 75% of all values are greater).



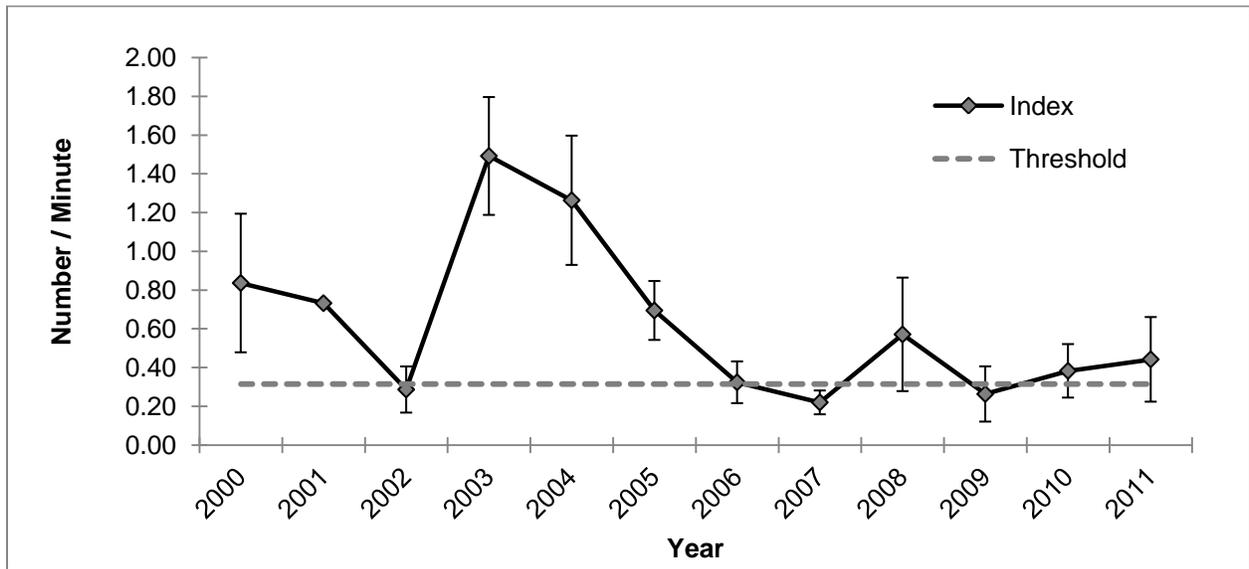
**Figure 4.** Commercial gill net landings of roes (February–April) compared to the female IGNS index (5.0, 5.5 and 6.0-inch mesh sizes, February–April; top graph) and annual estimates of female relative  $F$  based on these data (bottom graph) for Albemarle Sound, 2000–2011. The error bars in the top graph represent  $\pm 1$  standard deviation. The threshold represents the 75<sup>th</sup> percentile (where 25% of all values are greater).



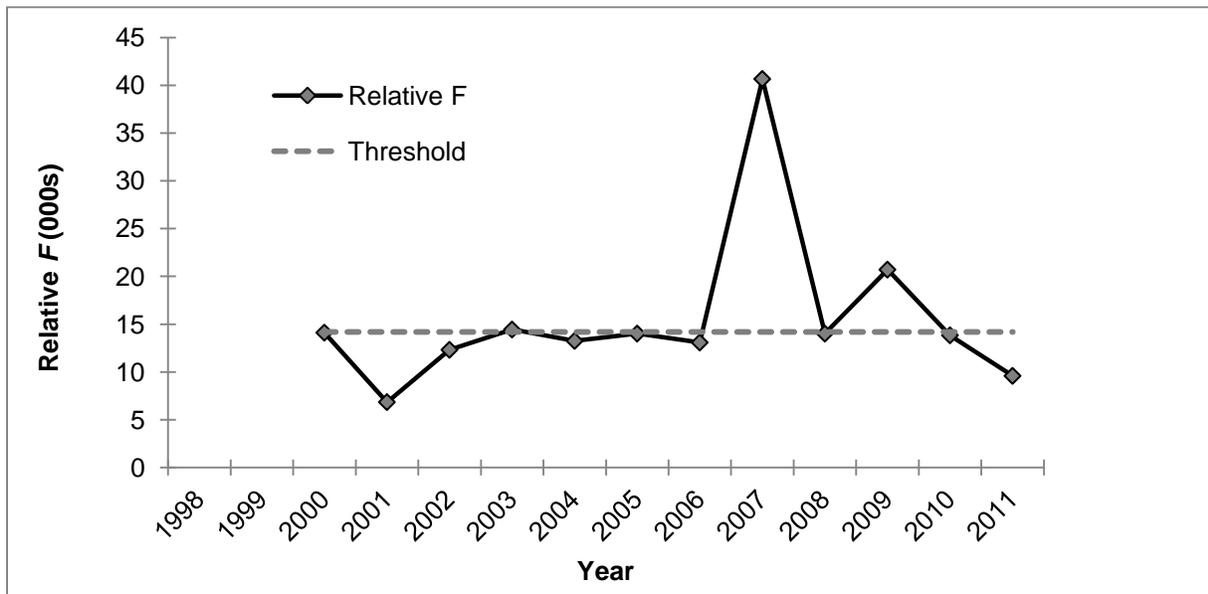
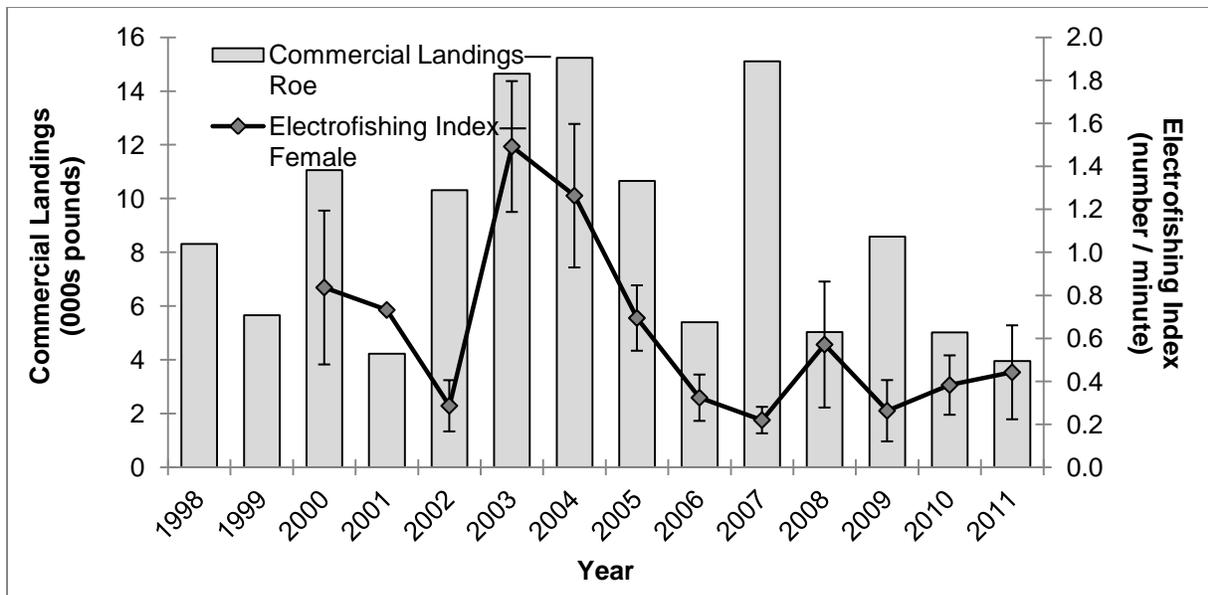
**Figure 5.** Commercial landings of roes by all gear types (March–May) compared to the female electrofishing index (March–May; top graph) and annual estimates of female relative  $F$  based on these data (bottom graph) for Albemarle Sound, 2000–2011. The error bars in the top graph represent  $\pm 1$  standard deviation.



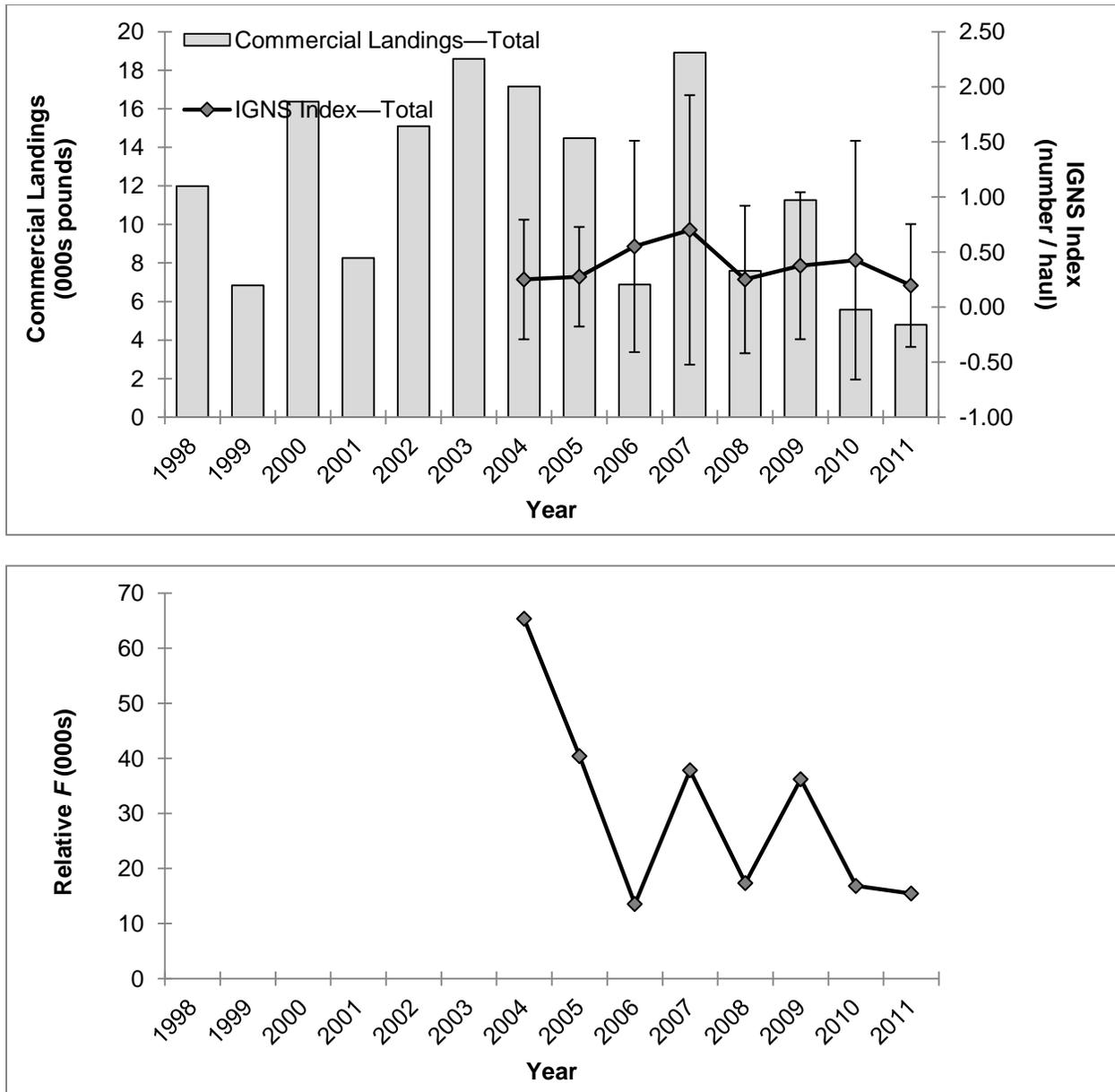
**Figure 6.** Commercial gill net landings (February–April) compared to the total IGNS index (5.0, 5.5 and 6.0-inch mesh sizes, February–April; top graph) and annual estimates of total relative  $F$  based on these data (bottom graph) for Albemarle Sound, 1998–2011. The error bars in the top graph represent  $\pm 1$  standard deviation.



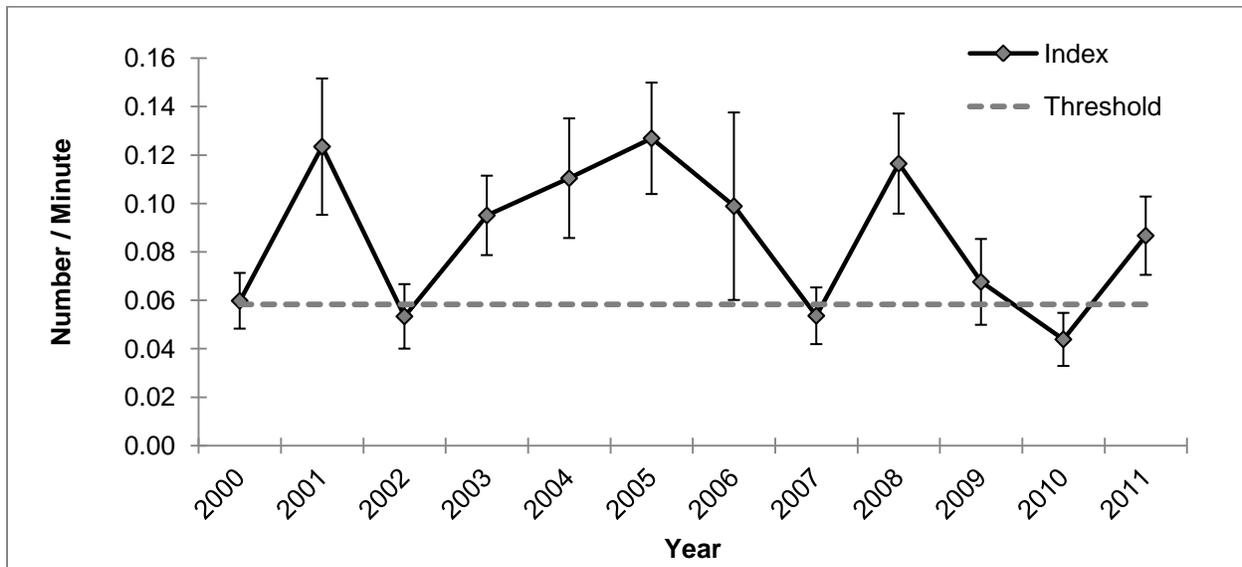
**Figure 7.** Female electrofishing index (March–May) for the Tar-Pamlico River, 2000–2011. The error bars represent  $\pm 1$  standard deviation. The threshold represents the 25<sup>th</sup> percentile (where 75% of all values are greater).



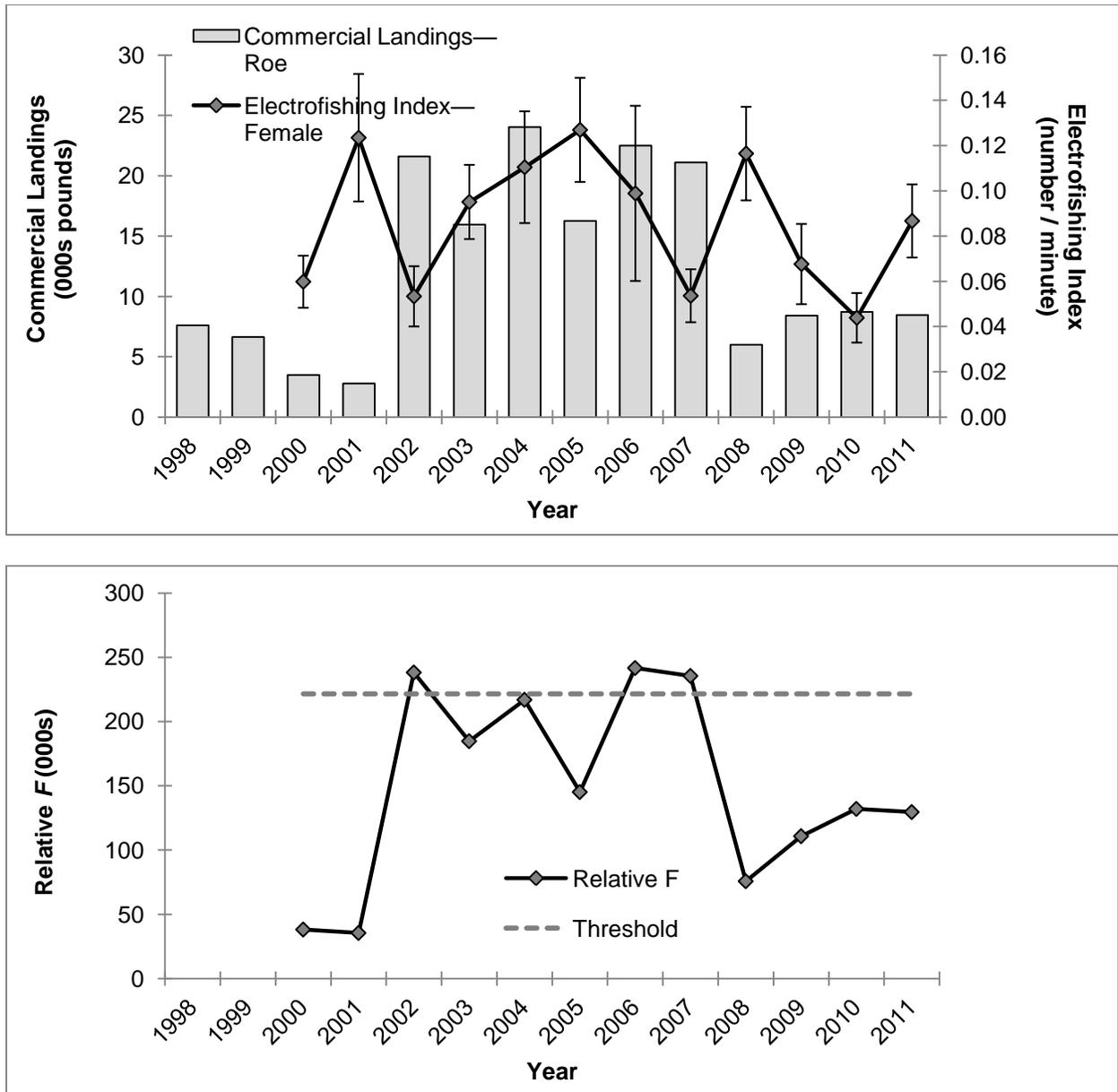
**Figure 8.** Commercial landings of roes by all gear types (March–April) compared to the female electrofishing index (March–May; top graph) and annual estimates of female relative  $F$  based on these data (bottom graph) for the Tar-Pamlico River, 2000–2011. The error bars in the top graph represent  $\pm 1$  standard deviation. The threshold represents the 75<sup>th</sup> percentile (where 25% of all values are greater).



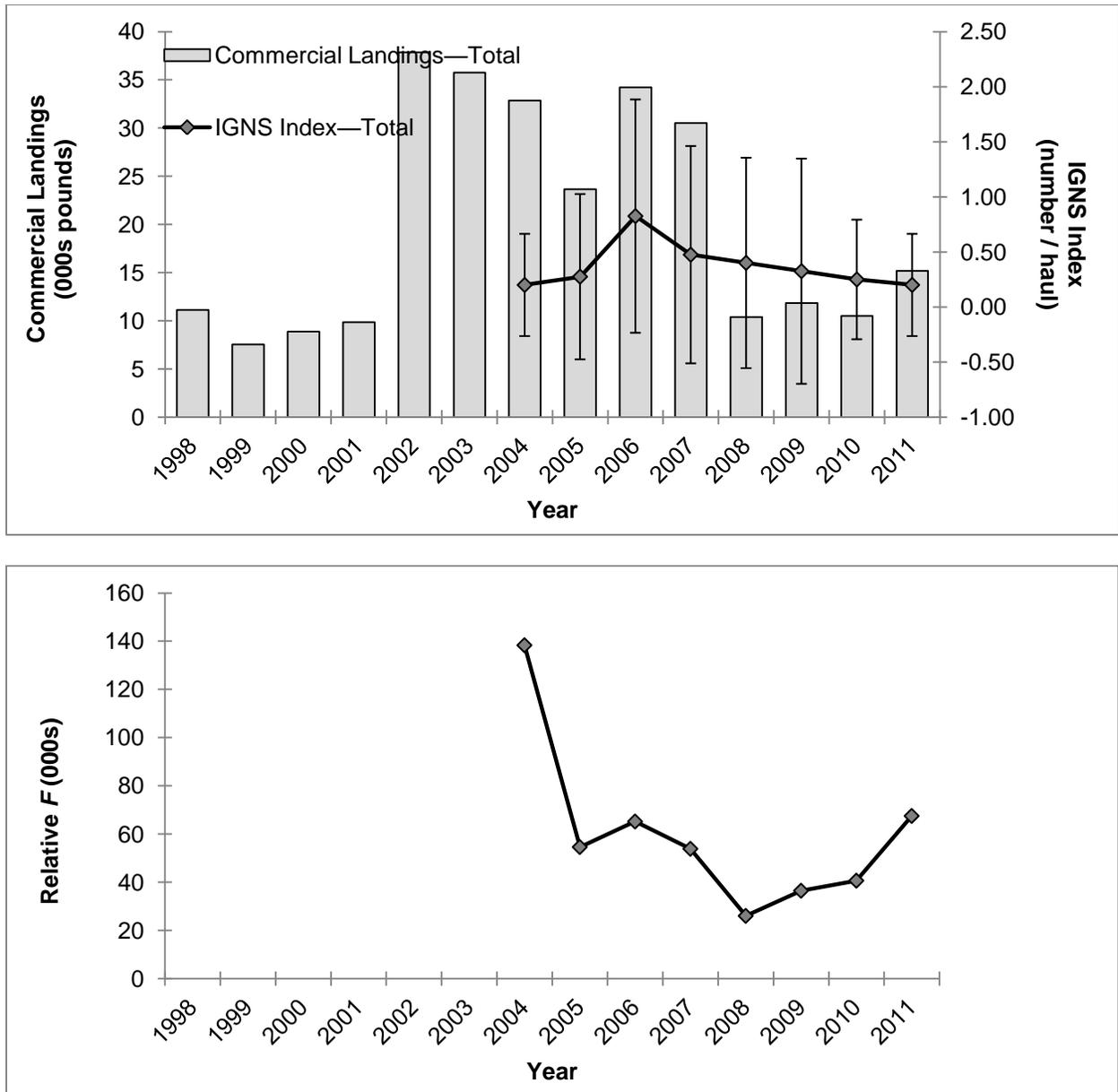
**Figure 9.** Commercial gill net landings (February–April) compared to the total IGNS index (4.5, 5.0, 5.5, 6.0, and 6.5-inch mesh sizes, February–April; top graph) and annual estimates of total relative  $F$  based on these data (bottom graph) for the Tar-Pamlico River, 2004–2011. The error bars in the top graph represent  $\pm 1$  standard deviation.



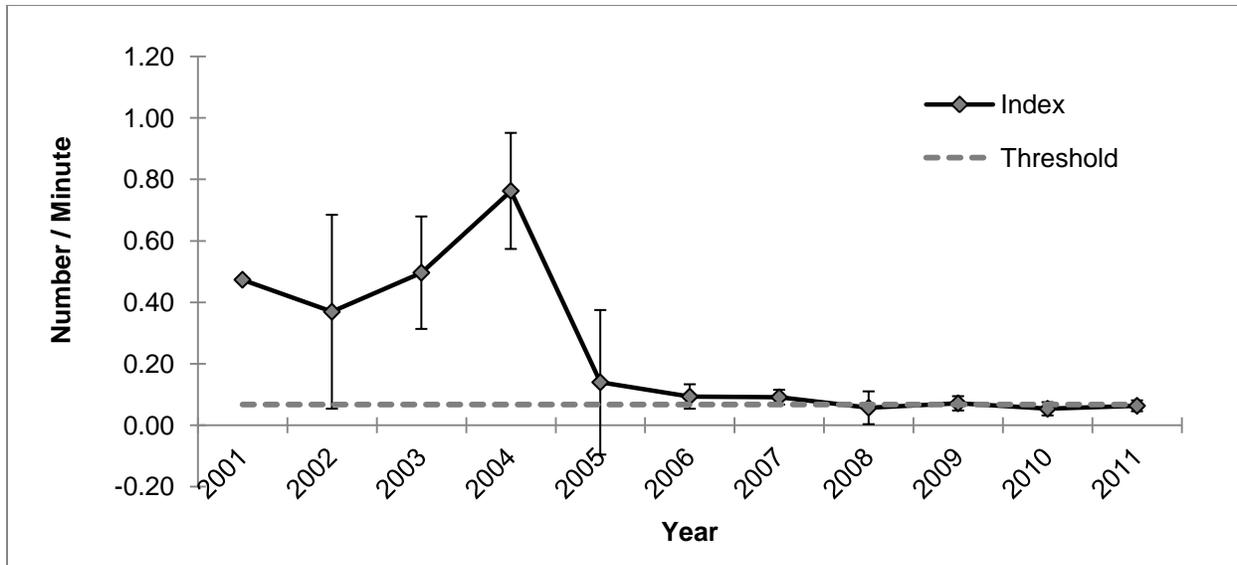
**Figure 10.** Female electrofishing index (March–May) for the Neuse River, 2000–2011. The error bars represent  $\pm 1$  standard deviation. The threshold represents the 25<sup>th</sup> percentile (where 75% of all values are greater).



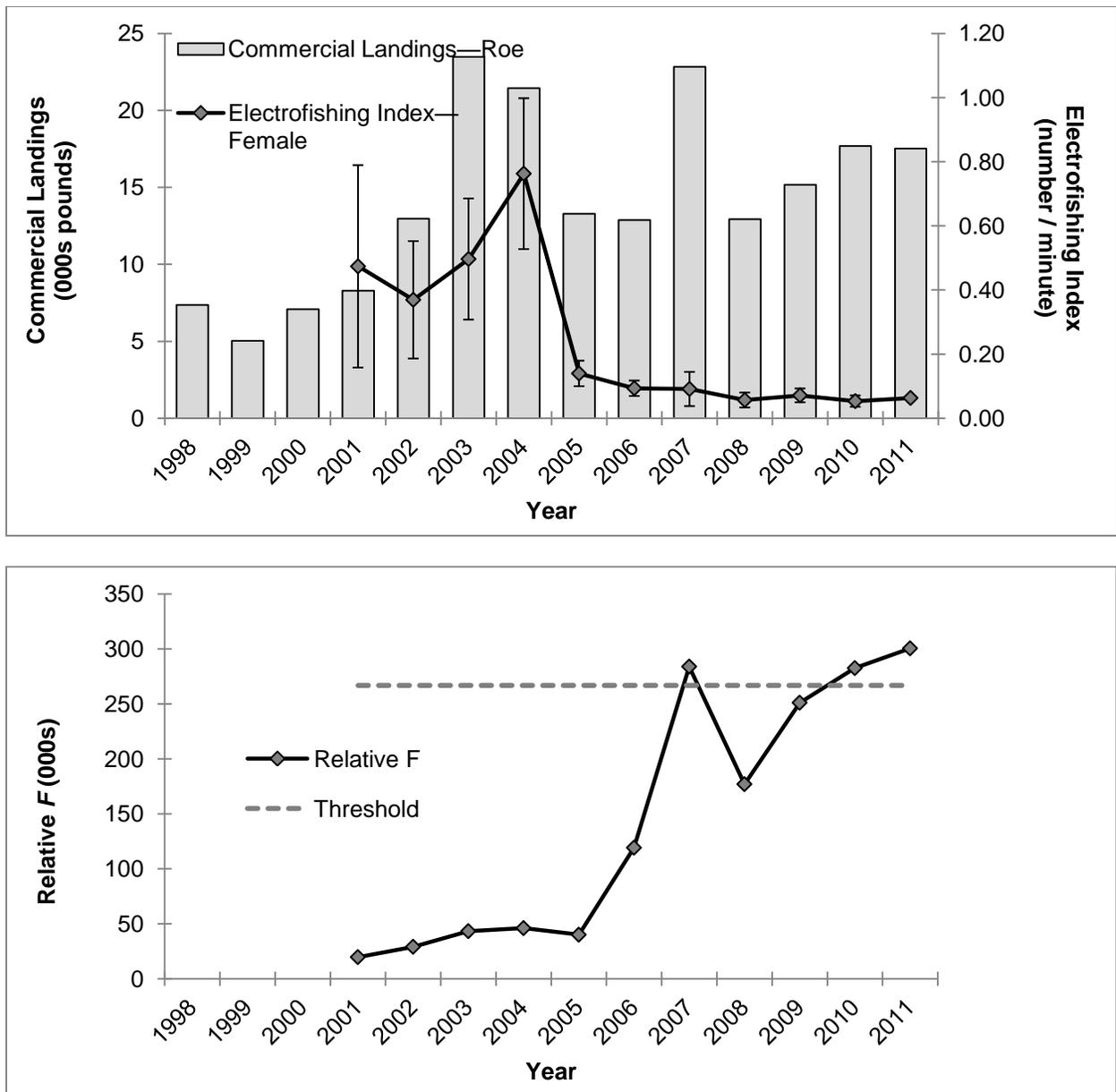
**Figure 11.** Commercial landings of roes by all gear types (March–May) compared to the female electrofishing index (March–May; top graph) and annual estimates of female relative  $F$  based on these data (bottom graph) for the Neuse River, 2000–2011. The error bars in the top graph represent  $\pm 1$  standard deviation. The threshold represents the 75<sup>th</sup> percentile (where 25% of all values are greater).



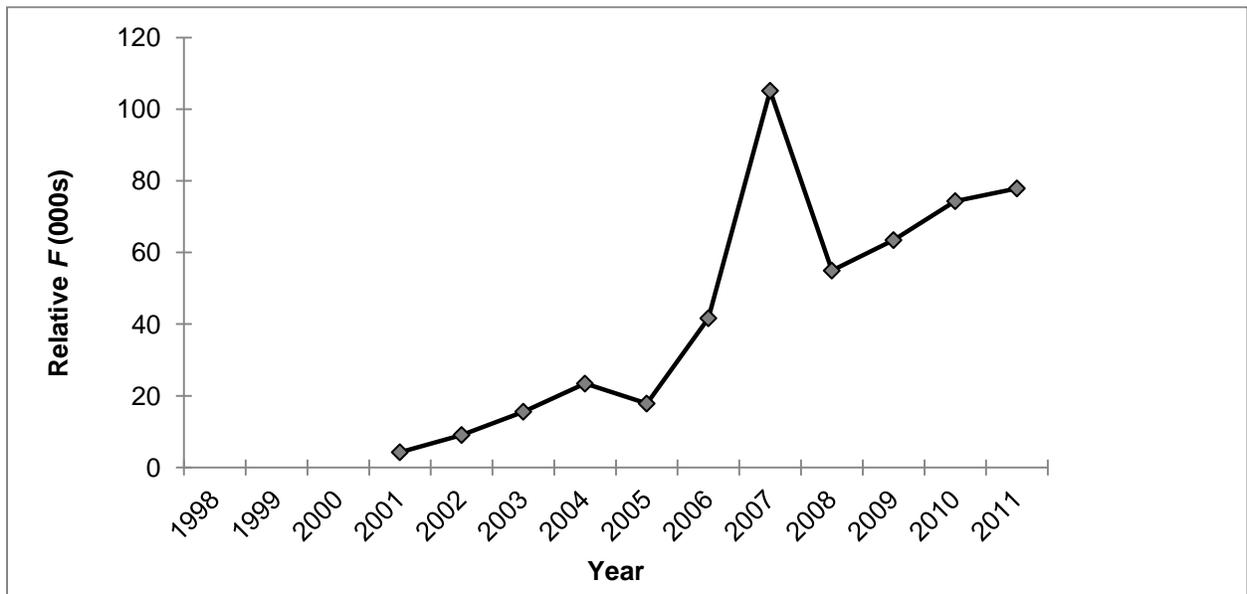
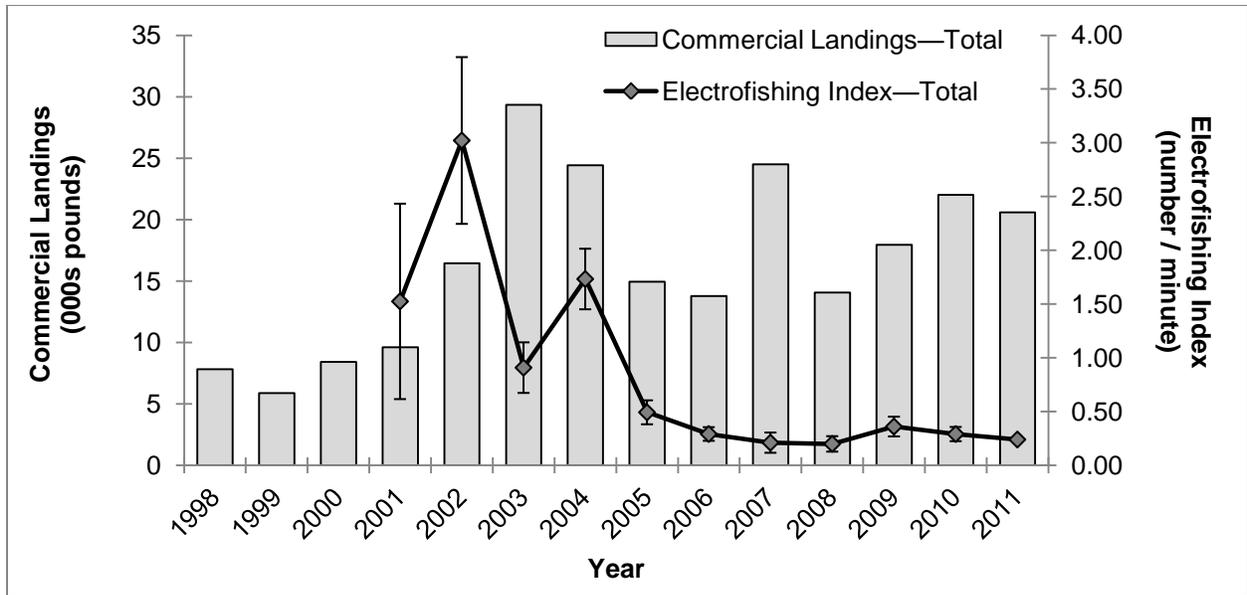
**Figure 12.** Commercial gill net landings (February–April) compared to the total IGNS index (4.5, 5.0, 5.5, 6.0, and 6.5-inch mesh sizes, February–April; top graph) and annual estimates of total relative  $F$  based on these data (bottom graph) for the Neuse River, 2004–2011. The error bars in the top graph represent  $\pm 1$  standard deviation.



**Figure 13.** Female electrofishing index (March–May) for the Cape Fear River, 2001–2011. The error bars represent  $\pm 1$  standard deviation. The threshold represents the 25<sup>th</sup> percentile (where 75% of all values are greater).



**Figure 14.** Commercial landings of roes by all gear types (March–May) compared to the female electrofishing index (March–May; top graph) and annual estimates of female relative  $F$  based on these data (bottom graph) for the Cape Fear River, 2001–2011. The error bars in the top graph represent  $\pm 1$  standard deviation. The threshold represents the 75<sup>th</sup> percentile (where 25<sup>th</sup> of all values are greater).



**Figure 15.** Commercial landings by all gear types (March–May) compared to the total electrofishing index (March–May; top graph) and annual estimates of total relative  $F$  based on these data (bottom graph) for the Cape Fear River, 2001–2011. The error bars in the top graph represent  $\pm 1$  standard deviation.