# Abstract

**Effects of Land Use Change on Juvenile Fishes, Blue Crab, and Brown Shrimp Abundance in the Estuarine Nursery Habitats of North Carolina**

**By Gregory F. R. Meyer**

**December, 2011**

**Director: Yong Wang, PhD**

**Co-Director: Joseph J. Luczkovich, PhD**

**Coastal Resources Management PhD Program**

The U.S. coastal region is home to more than half of the American population. Also, the coastal counties' population is growing much faster than that of inland counties. With a high density and an increasing population, there are rapid changes in land-use and land-cover (LULC) types, characterized mostly by the increase in areal coverage of anthropogenic land uses (agriculture and developed), while "natural/unaltered" land uses (forest and wetland) are in decline. The human population growth and land-use and land-cover changes caused by humans generate nutrients and pollutants to coastal waters, which can affect water quality and aquatic life. Trends in the land-use and land-cover changes that might impact fish and invertebrate species abundance at 71 selected estuarine stations sampled by the North Carolina Division of Marine Fisheries (NCDMF) juvenile sampling program (Program 120) were analyzed. Land use categories of interest were forest, wetland, agriculture, and developed areas. The selected fish and invertebrate species were: Atlantic croaker (*Micropogonias undulatus)*, Atlantic menhaden (*Brevoortia tyrannus)*, pinfish (*Lagodon rhomboides)*, southern flounder (*Paralichthys* *lethostigma)*, spot (*Leiostomus xanthurus*), blue crab *(Callinectes sapidus)*, and brown shrimp (*Farfantepenaeus aztectus)*. Geographic information system (GIS) data, remotely sensed data and statistical techniques were used to quantify the LULC type changes between 1980 and 2000 within the immediate coastal watersheds of North Carolina. Forest has been the most affected, losing about 30.1% of its total area to the increase (~24.1%) of agriculture area. The wetland and developed land use varied depending on location, but their overall changes were small when the whole study area was considered. The long-term trends in abundance of juveniles of selected fish and invertebrate species indicated declines at certain sampling stations, and increases at others. In order to determine whether land use changes were correlated with changes in the selected species, and also to find which other factors might influence changes in their abundance, I analyzed seven predictor variables [(1) percent land use change within local catchments centered on the NCDMF sampling sites, (2) number of pollution point sources in large USDA Natural Resources Soil Conservation watersheds, (3) number of people in US Census tracts within watersheds, (4) water temperature, (5) water salinity, (6) station depth, and (7) distance to inlet (minimum distance by water to an ocean inlet) for each NCDMF juvenile fish and invertebrate trawl sampling program station] in a classification and regression tree statistical analysis to predict normalized change in trawl catch for the selected species in NCDMF Program 120 data between 1980 and 2004. Land use changes were found to be influential to the number of blue crab, southern founder and Atlantic croaker, and declines were observed at 47 stations when land use changes were greater than 13% (blue crab), at 30 stations when land use changes were greater than 21% (southern flounder), and 6 stations when land use changes were greater than 53% (Atlantic croaker). Water salinity was found to be more important than land use change for southern flounder catch, and increased catch was observed at stations with salinity < 14 ppt. No

significant changes due to land use could be associated with changes in Program 120 trawl catch of brown shrimp, Atlantic menhaden, pinfish or spot. There was a long-term increase in pinfish in the Program 120 data. Pinfish increased most at stations where bottom temperature was < 25 C. Atlantic menhaden declined at stations where bottom temperature was < 24 °C. Brown shrimp abundance was increased at stations where the distance to inlet was > 21 km and highest when salinity was > 14 ppt. Spot showed an increase in abundance when distance to inlet was greater than 42 km and the human population was > 883 people/census tract in the year 2000.

Land use change impacts were observed in the classification and regression tree analysis for blue crab at 66% of the NCDMF stations, 42% of stations for southern flounder, and 8% of stations for Atlantic croaker. These three species were ranked first, second, and fourth in commercial value in North Carolina fisheries, and were the only species of those selected for this study that were considered to be overfished in 2000 by the NCDMF. Thus, land use change had the greatest impact on species that were targets of intensive commercial fishing and had low adult spawning stock. This result suggests an interaction between commercial fisheries harvest and land development for agriculture along the coast. Recruitment of these species may have been low because of reduced spawning stock due to commercial harvests, and this reduced recruitment was most noticeable where land use changes were high. Species that were not intensively harvested (pinfish) or had stable adult stock sizes as determined by the NCDMF (brown shrimp, Atlantic menhaden, and spot) were able to produce many recruits, and this high recruitment may have allowed colonization of areas with marginal habitat due to land use changes. Few stations showed declines in abundance of the juvenile stages of these latter species, suggesting that land use change was not a significant factor between 1980 and 2004. However, post-recruitment mortality (survivorship after June throughout the summer and fall) was not monitored by NCDMF and should be studied in the future. The results of this study serve as an early warning to coastal managers regarding the potential impact of coastal land use changes. The abundance and growth of these valuable fishes and invertebrates in North Carolina estuarine nursery habitats could be reduced in the future, given the national trends in coastal development and fishery harvests.

Effects of Land Use Change on Juvenile Fishes, Blue Crab, and Brown Shrimp Abundance in the Estuarine Nursery Habitats in North Carolina

A dissertation

Presented to the Faculty of the Coastal Resources Management PhD program

East Carolina University

In Partial Fulfillment of the Requirement for the Degree

Doctor of Philosophy

By

Gregory F. R. Meyer

December 2011

Coastal Resources Management Program

East Carolina University

2011

Effects of Land Use Change on Juvenile Fishes, Blue Crab, and Brown Shrimp

Abundance in the Estuarine Nursery Habitats in North Carolina

By

Gregory F.R. Meyer

APPROVED BY:

DIRECTOR OF DISSERTATION: ____________________________________________
Yong Wang, PhD

CO-DIRECTOR OF DISSERTATION: ________________________________________
Joseph L. Luczkovich, PhD

COMMITTEE MEMBER: ________________________________________________
Thomas Crawford, PhD

COMMITTEE MEMBER: ________________________________________________
Bin Okmyung, PhD

COMMITTEE MEMBER: ________________________________________________
Tracy Van Holt, PhD

CHAIR OF THE DEPARTMENT ___________________________________________
Hans Vogelsong, PhD

DEAN OF THE GRADUATE SCHOOL_________________________________________
Paul J. Gemperline, PhD

Dedication

This dissertation is dedicated to my family
Gabrielle, Emery, Derrick & Claudine.
Thanks for your patience.

## Acknowledgements

I would like to thank my major advisor, Dr. Yong Wang who believed in me and in this study from the beginning. His advice was always practical, and his gentle but firm nudge kept me going. I appreciated the time he dedicated to seeing this work come to completion. Thanks to Dr. Joseph Luczkovich for all the lessons I learned from him. We spend a lot of time data mining, communicating with NCDMF biologists, and running SYSTAT. Dr. Hans Vogelsong and Dr. Lauriston King were very supportive of my PhD quest. Their understanding and support helped me immensely. Dr. Mark Brinson gave me a job and flexibility to pursue my miscellaneous academic curiosities. Whether I needed funding, to analyze data or produce reports, he was always there, patient, and supportive. He, Dr. Luczkovich and Dr. Terry West were instrumental in getting this research off the ground and running. They helped secure funding and were always there to answer the many data questions I encountered along the way. Dr. West volunteered countless hours helping me make sense of study results for our sponsored grants. Dr. Thomas Crawford not only taught me advanced GIS, showed some tricks, and most importantly cheered me on from the beginning. His making time to answer questions, sometimes after the hours, on weekends or twice the same questions helped tremendously. Because of his patient and selfless mentorship, this study is coming to completion. Writing a paper with Dr. Paul Bin and Dr. Craig Landry brought me to quickly love their hard work and good work ethics. Dr. Tracy Van Holt's always positive, optimistic attitude kept me thinking that I can do it. I thank the many individuals who contributed their time and effort in the field or office, collecting or analyzing data, or sharing the knowledge of juvenile fish recruitment to North Carolina's estuarine waters. I thank especially Katy West and Sean McKenna, biologists at the North Carolina Division of Marine Fisheries (NCDMF), Pamlico District Office for their insight into program 120 as well as their efforts in data quality control. NCDMF’s field technicians, especially Lele and Greg Judy as well as Mike Pulley were helpful in demonstrating field procedures used in program 120’s field data collection. Jason Hassell and Leland Tetterton were helpful in sharing their observations and knowledge about juvenile fish in the Pamlico Sound. Kevin Hart, biologist at the NCDMF and former biology graduate student, Chris Mascio, former East Carolina University student, provided valuable office and field assistance.

I thank my colleagues, current and former graduate students: Kevin Miller, Becky Deehr, Cecilia Krahforst, Jennifer Cudney, John Haywood, Emma Hardison, Ken Riley, Joyce Steinmetz, Meredith Stewart, and many others. Talking to you, discussing your project or mine helped make long days seem like only a few hours.

Thanks to the North Carolina Seagrant for funding two grants that made this study possible: project #: 05-POP-01(Analysis of Potential Effects on Land Cover Change on Blue Crab (*Callinectes sapidus*) Populations in Primary Nursery Areas) and project #: 06-EP-08 (Effects of Land Use Change on Juvenile Fishes and Brown Shrimp Abundance in North Carolina's Estuarine Nursery Habitats

I thank my parents, Agnes and Sylvere Ntawugashira for instilling in me very early in life, the value of a good education and thank to my brother Pierre Tegera for being a great role model. I thank my wife Claudine for working so hard to support me and the whole family while I was in school, as well as care for our children.

# Biography

Gregory received a Bachelor Degree in Biology from the National University of Rwanda at Butare, where he developed interest in environmental conservation. After three years of work with the Ministry of Environment and Natural Resources of Rwanda, he was awarded a Thomas Jefferson Fellowship to study Forestry at the North Carolina State University in Raleigh, North Carolina, U.S.A. After graduation with a Master's degree in Forestry and Ecology, he worked seven years with the Department of Environment and Natural Resources, Division of Coastal Management (DCM) of North Carolina. At DCM, he was member of a team charged with mapping North Carolina's coastal wetlands. In 2001, he moved to Greenville, North Carolina and worked for East Carolina University, Biology Department before joining the Coastal Resources Management PhD program in 2003.

## Contents

## List of Tables

## List of Figures

## List of appendices

**List of Symbols/Abbreviations**

| | |
|---|---|
| AOI | Area of Interest |
| BASINPRO | A group of tools and layers for watershed visualization and analysis, developed by the North Carolina Center for Geographic Information Analysis. |
| BSQ | Band Sequential. |
| CART | Classification and Regression Tree |
| C-CAP | Coastal Change Analysis Program |
| DCM | Division of Coastal Management |
| DOQQ | Digital Ortho Quarter Quad |
| EROS | Earth Resources Observation Systems |
| ESRI | Environmental Systems Research Institute |
| ETM+ | Enhanced Thematic Mapper Plus |
| GCLF | Global Land Cover Facility |
| GIS | Geographic Information Analysis |
| GLCF | Global Land Cover Facility |
| GPS | Global Positioning System |
| HU | Hydrologic Unit |
| LULC | Land Use Land Cover |
| ISODATA | Iterative Self-Organizing Data Analysis |

| | |
|---|---|
| LOWESS | Locally Weighted Smooth Surface |
| MLC | Maximum Likelihood Classification |
| MRLC | Multi Resolution Land Characteristics |
| MSS | Multi Spectral Scanner |
| NCCGIA | North Carolina Center for Geographic Information Analysis |
| NC CHPP | North Carolina Coastal Habitat Protection Plan |
| NCDMF | North Carolina Division of Marine Fisheries |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollution Discharge Elimination System |
| NRCS | Natural Resources Conservation Service |
| POM | Princeton Ocean Model |
| PPT | Parts per Thousand |
| PRE | Proportional Reduction in Error |
| SD | Standard deviation |
| TM | Thematic Mapper |
| UMD | University of Maryland, College Park |
| USDA | US Department of Agriculture |
| USGS | United States Geological Survey |
| WAAS | Wide Area Augmentation System |
| WBD | Watershed Boundary Dataset |

# Preface

This dissertation was concerned with the relationship between land use land cover changes in North Carolina's estuarine catchments and changes in juvenile fish, blue crab and brown shrimp abundances as shown in a long-term juvenile sampling program by the North Carolina Division of Marine Fisheries, juvenile sampling program (Program 120).

The dissertation is organized in three independent chapters and the overall approach is shown in Figure 1. In chapter 1, land use and cover changes observed between years 1980 and 2000 by analyzing satellite imagery taken in the study area at the said time periods were studied using GIS and remote sensing. Chapter 1 will be supplemented with other land use and land cover changes in North Carolina, to highlight statewide trends in land use changes at different spatial scales before submission to the "Journal of Environmental Management". A preliminary analysis of land use changes statewide suggested that while the coastal region is faced mostly with deforestation in favor of agriculture, land use changes statewide were dominated by urbanization.

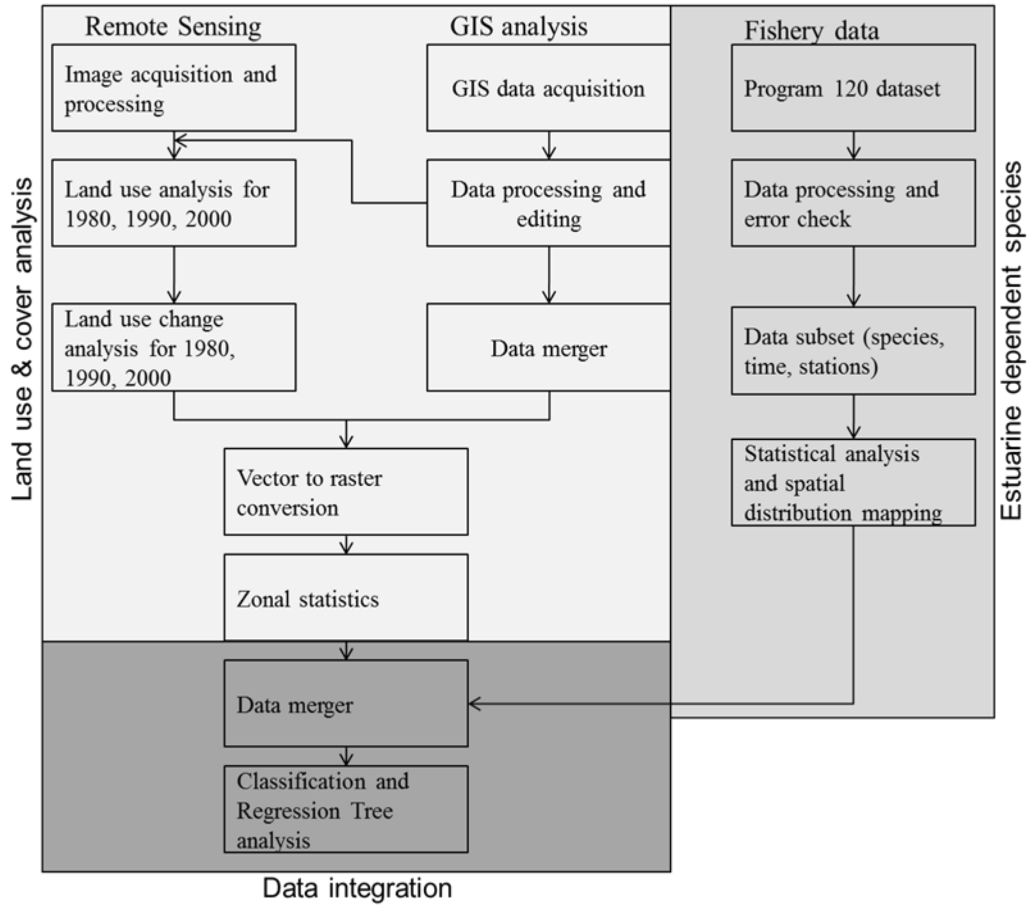



Figure 1. The overall scheme to study land use and catch statistics.

Chapter 2 consists of the analysis of long-term catch of juvenile fish and invertebrates of selected estuarine dependent species in North Carolina estuarine waters. The selected species are: are Atlantic croaker *(Micropogonias undulatus)*, Atlantic menhaden *(Brevoortia tyrannus)*, pinfish *(Lagodon rhomboides),* southern flounder *(Paralichthys lethostigma),* spot *(Leiostomus xanthurus),* blue crab (*Callinectes sapidus*), and brown shrimp (*Farfantepenaeus aztecus).* Using statistical analyses, GIS and remote sensing, I attempted to paint a picture of the long-term trends in juvenile catch, and also answered the question of whether the catch is declining or increasing. With maps of coastal counties and the coastal catchments of interest, chapter 2 showed where changes in catch occurred. Chapter 2 will be submitted to “Marine and Coastal Fisheries” and will have an emphasis on the long-term trends in juveniles of the seven selected species.

Chapter 3 integrated chapters 1 and 2 through land cover data and juvenile catch statistics, and showed whether large percentage area of catchment land use transformed from forest and wetland to agriculture or developed corresponded to areas of juvenile declines. Zonal statistics were used to extract catchment information on land use change dynamics, and classification and regression tree statistical procedure was used to link this to fish data and show trends.

# Chapter I: Land Use and Land Cover Type Changes in Immediate Coastal Watersheds of North Carolina

## 1.1. Introduction

The most important human alteration of the Earth's ecosystems is the use of land to yield goods and services for the benefit of society. The land use change alters the structure and function of the ecosystems, and it can affect how ecosystems interact with surrounding land, water, and the atmosphere (Vitousek et al., 1997, Chapin et al., 2000). In the U.S., its coastal watersheds are subjected to high development pressures given the fast-increasing human population (Culliton et al., 1990; Cairns and Pratt, 1992; Beach, 2002). It is estimated that in the southeastern coastal watersheds the human population will increase by about 60% over the 1960's levels (Culliton et al., 1990). In North Carolina, coastal counties have exceeded the statewide average growth rate by 3.6% in the 1980s (Steel, 1991). The population growth leads to conversion of many thousands of hectares of land into altered LULC types. Thus, one needs to create multi-temporal maps of LULC types to quantify the changes and model the possible consequences.

LULC type mapping and change assessments in North Carolina have been traditionally done as ad-hoc projects, and often at very coarse resolution for a large spatial extent. The U.S. Department of Agriculture (USDA) Natural Resource Conservation publishes the National Resource Inventory (NRI) reports at a state and national level. The reports include soil erosion, land use, and drought information. Until the year 2000, the reports were produced on a five-year cycle (NRCS, 2007), but now the agency can update its reports yearly due to the extensive use of remote sensing technology and datasets, and a significant reduction in the number of field based sample sites. Between 1982 and 2003, forest land reportedly declined by about 15.0%, while developed land increased by 22.5% across the state of North Carolina (Table 1). This reflects the overall trend in the state and this is accentuated in the coastal region (Beach, 2002, Crossett et al., 2004).

Table 1. The National Resources Inventory for the statewide land use and land cover types of North Carolina between 1982 and 2002 in thousands of hectares (USDA, NRCS, 2007).

| **Land Use Type** | **1982** | **1987** | **1992** | **1997*** | **2002** | **% Change 1982-2002** |
|---|---|---|---|---|---|---|
| Forest | 6922.2 | 6782.7 | 6627.0 | 6523.6 | 6365.1 | –8.1 |
| Agriculture | 2703.6 | 2592.2 | 2421.8 | 2292.4 | 2208.5 | –18.4 |
| Pasture | 783.4 | 779.9 | 799.9 | 826.0 | 767.8 | –2.0 |
| Developed | 937.9 | 1105.3 | 1291.5 | 1486.4 | 1782.6 | 47.4 |
| Other | 310.7 | 314.4 | 318.7 | 333.6 | 353.4 | 1.1 |

*There was no wetland data in 1982, 1987, 1992, and 1997.

North Carolina LULC type studies are done every five years by the Coastal Change Analysis Program (C-CAP) of the National Oceanic Atmospheric Administration (NOAA) at the Coastal Services Center, Charleston, South Carolina (http://www.csc.noaa.gov). The primary objective of the C-CAP is to improve the scientific understanding of the linkages among coastal wetland habitats, adjacent uplands, and living marine resources. This is done by documenting changes taking place in the coastal regions due to natural causes and human activities along the coast such as changes in water quality, agricultural and forest management practices, and coastal urban development (Dobson et al., 1995). In 1998, C-CAP used 1991 and 1997 Landsat satellite imagery to assess LULC type change in southern and eastern North Carolina coasts. One of the C-CAP findings suggests that the completion of interstate highway I-40, a concentrated growth of high and low intensity developed areas is taking place around Wilmington, a coastal city in New Hanover County, NC. This implies that infrastructure improvement can bring some unintended ecological consequences. For example, Hawbaker et al. (2006) demonstrated that over time, improved road networks can have secondary impacts on landscape patterns and other land use types. They stated that road construction can remove habitat, alter adjacent areas, interrupt and redirect ecological flows, fragment wildlife corridors, foster invasive species spread, change hydrologic networks, and increase human use of adjacent areas. It is implicitly understood that this is happening in parts of coastal North Carolina, especially Jacksonville City, Onslow County, and Wilmington City, New Hanover County, as well as the Outer Banks. From 1991 to 1997 of the C-CAP analysis, ~9,300 hectares of combined forest, scrub/shrub, and grasslands were lost to low and high intensity development within New Hanover County.

In 1998, the North Carolina Center for Geographic Information Analysis (NC CGIA) published statewide land use and cover maps of North Carolina using Landsat TM, acquired between 1993 and 1996. However, land use change over time was not analyzed. While these maps provide valuable information on what land uses are and where changes occur; they do not document land use changes occurring in the state.

The Multi Resolution Land Characteristics (MRLC) Consortium is a group of federal agencies that joined efforts in 1993 to purchase imagery and develop a consistent LULC type dataset for the nation (Homer et al., 2004). The MRLC has since produced nationwide LULC type information for years 1992 and 2001 with 29 classes. According to Homer et al. (2004), this database provides consistent land cover for federal agencies, all 50 states, and meets their land cover information needs. It can also be used for a wide variety of geographical analysis and applications as it allows flexibility in developing and applying each independent data component to a wide variety of other applications.

Using satellite imagery, hydrography, and hydric soil maps, the North Carolina Division of Coastal Management (DCM) has developed wetland maps for coastal counties of North Carolina. The effort also included coastal wetland functional assessments as well as wetland potential restoration and enhancement mapping. While the results of this effort are often used by local governments in their land use planning and hazard mitigation, it does not deal with land use change over time and how that can affect aquatic life. In particular, the anthropogenic land use types contribute additional and excessive sediments, nutrients, and pollutants through storm water and groundwater flows into watersheds. In North Carolina, this has led to an increased number of shellfish closures, which resulted in the loss of harvest throughout the Pamlico Sound region (Deaton et al., 2010). One of the recommendations by the North Carolina Coastal Habitat Protection Plan, NCCHPP (Deaton et al., 2010) is that studies be carried out to assess the effects of land use and human activities to strategic fish habitat areas. Therefore, this study is one of the many possible ways to answer this question, asked by management and regulatory agencies. This dissertation focused on coastal and estuarine catchments that are areas covered by the NOAA C-CAP, USDA NRI, MRLC, and NC CGIA studies. Furthermore, in this dissertation, guidelines similar to those outlined in the NOAA C-CAP study (Dobson et al., 1995) were followed. This study is unique and different from the programs listed above because it assesses the LULC type changes in estuarine catchments covered by a long-term sampling effort by the NCDMF for the abundance and distribution of fish and invertebrate species along the North Carolina coast. The outcome will contribute to an effort that will link land use change and species abundance.

## 1.2. Methods

Steps were taken in order to assess changes in LULC types between 1980 and 1990, 1990 and 2000 and 1980 and 2000. First, various GIS data layers and satellite images deemed necessary to the study were acquired. Then, the datasets were made to match in one single projection system, the NAD 1983 State Plane of North Carolina 3200. Catchment boundaries were delineated; GIS data layers were clipped within catchments, and 1980, 1990, and 2000 satellite images were classified and interpreted independently before being analyzed for LULC type changes. Final field accuracy assessment was carried out in the summer of 2007.

### 1.2.1. Landsat Satellite Imagery

Land use information was derived by classification of the satellite imagery of the North Carolina coast using the 1980 Landsat 2 Multispectral Scanner (MSS), 1990 Landsat 5 Thematic Mapper (TM), and 2000 Landsat 7 Enhanced Thematic Mapper Plus (ETM+). The MSS data are the oldest and thus the best in terms of the time series that matches the start of the NCDMF study. The MSS data have lower spectral resolution, with only 4 spectral bands and lower ground pixel resolution (57m x 79m pixels) than the Landsat TM or ETM+ data. Band 4 in MSS (green) is similar to Band 2 in TM or ETM+, Band 5 in MSS (red) is similar to Band 3 in TM or ETM+, Band 6 (near infrared) in MSS is similar to Band 4 in TM or ETM+, Band 7 (also near infrared) in MSS is similar to Bands 4 and 5 in TM or ETM+. These differences in spectral and ground pixel resolution presented problems in comparison of the early MSS and later TM and ETM+ data directly, so the following protocol was developed. The MSS, TM, and ETM+ images were re-projected to the same geo-referenced data frame in ERDAS IMAGINE 9.2 software (remote sensing software from ERDAS, Inc.), using the smaller ground pixel resolution of the later Landsat TM and ETM+ satellite data by re-sampling the earlier MSS data at 30×30 m resolution to obtain a co-registered earlier imagery. The path and row information of the imageries used are tabulated in Table 2.

Table 2. Satellite imagery used in the study, specific dates, and data sources

| Dataset | Path/Row | Date (mm/dd/yyyy) | Source |
|---|---|---|---|
| Landsat MSS | P14/R035 | 8/2/1980 | USGS/EROS Center |
| 1980 | P14/R036 | 8/2/1980 | USGS/EROS Center |
| | P15/R036 | 8/3/1980 | USGS/EROS Center |
| Landsat TM | P14/R035 | 6/12/1988 | UMD/GCLF |
| 1990 | P14/R036 | 9/6/1990 | UMD/GCLF |
| | P15/R036 | 5/8/1990 | UMD/GCLF |
| Landsat ETM+ | P14/R035 | 9/23/1999 | USGS/EROS center |
| 2000 | P14/R036 | 9/23/1999 | USGS/EROS center |
| | P15/R036 | 5/11/2000 | USGS/EROS center |

### 1.2.2. GIS Data Layers

Physiographic and topographic features of landscapes associated with primary nursery areas were derived from the BASINPRO 8.0, a compilation of North Carolina statewide data layers, produced by various local or state agencies and centralized at the NCGIA. The layers of interest are hydrography, watershed boundaries, confined animal operations, and water bodies. Data layers available to the public at the North Carolina Department of Transportation were also utilized. These include detailed county roads and 1998 color infrared Digital Orthographic Quarter Quadrangle (DOQQ) air photos, both of which were used as reference to validate satellite imagery features that are not easily identifiable on a 30 x 30 m resolution of Landsat data. After the basic datasets were acquired and archived, the first task was to build a multilayer GIS database in ArcGIS 9.2 (ESRI Inc.) that brought together multiple watershed descriptive layers. The layers assembled included hydrography, watershed boundaries, confined animal operations, National Pollution Discharge Elimination System (NPDES), water bodies, detailed county road layers, NCDMF sampling stations, shorelines, parks and preserves, and ocean inlets.

### 1.2.3. Catchment Boundary Delineation

Because the NRCS watersheds were much larger than the extent of the drainage area impacting tidal creeks where the NCDMF personnel took samples, catchment boundaries were delineated for the analysis. The boundaries were determined using the Federal standards for delineation of hydrologic unit boundaries (USGS, USDA, and NRCS, 2009) that establishes standards and guidelines for creating and delineating hydrologic unit (HU) boundaries, modifying existing HU's, and establishing a national Watershed Boundary Dataset (WBD). The catchments are sub-watershed, each of which encompasses all the streams and ditches draining to a nursery area as denoted by the location of the specific NCDMF sampling stations. Additional guidelines for coastal watersheds (Ferguson and Mew, 2000) were also followed in the catchment delineation. The objectives of these federal guidelines are to establish standards for creating and delineating HU boundaries, modifying existing HU's, and establishing a national WBD. Special attention was made to incorporate the North Carolina guidelines as proposed by Ferguson and Mew (2000).

Catchments were delineated in 3 steps using ArcGIS 9.2 onscreen digitizing capabilities: 1) Overview of the NRCS 14-digit hydrologic unit boundaries. Major stream networks and NCDMF sampling stations were then displayed over the NRCS 14-digit watershed boundaries to generate a general view of the watersheds. Figure 2 is an example showing the NCDMF stations, major stream networks, and 14-digit HU near the lower part of the Pamlico River. Within each watershed, one can distinguish major and minor streams to gain a general idea of the extent of sub-watersheds or catchments.

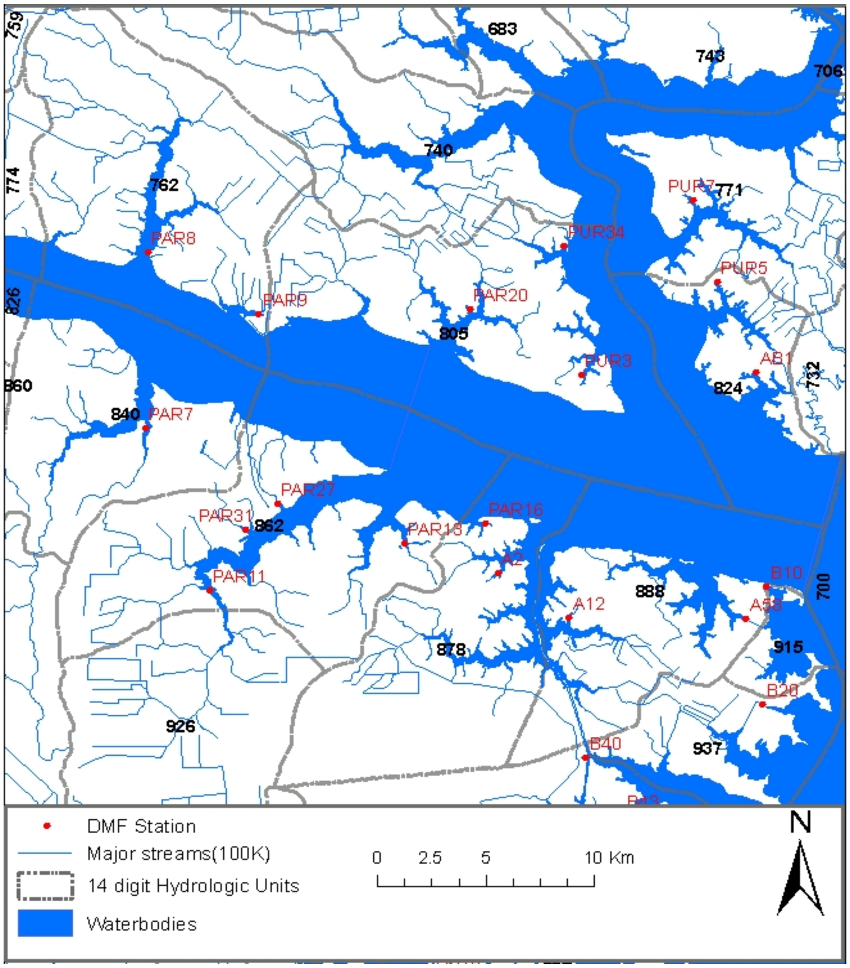



Figure 2. The NCDMF stations, major stream networks, and last 3 digits of the 14-digit HU near lower Pamlico River.

2) Topographic overlays: 14-digit HU's and streams are displayed over the USGS topographic quadrangles to identify the topographic setting of the watershed with respect to sampling station (Figure 3). Topographic data add a new layer of information about landform properties, such as elevation and aspect. The blue lines represent the streams, gray lines represent watershed boundaries, and the red dots are NCDMF sampling stations.

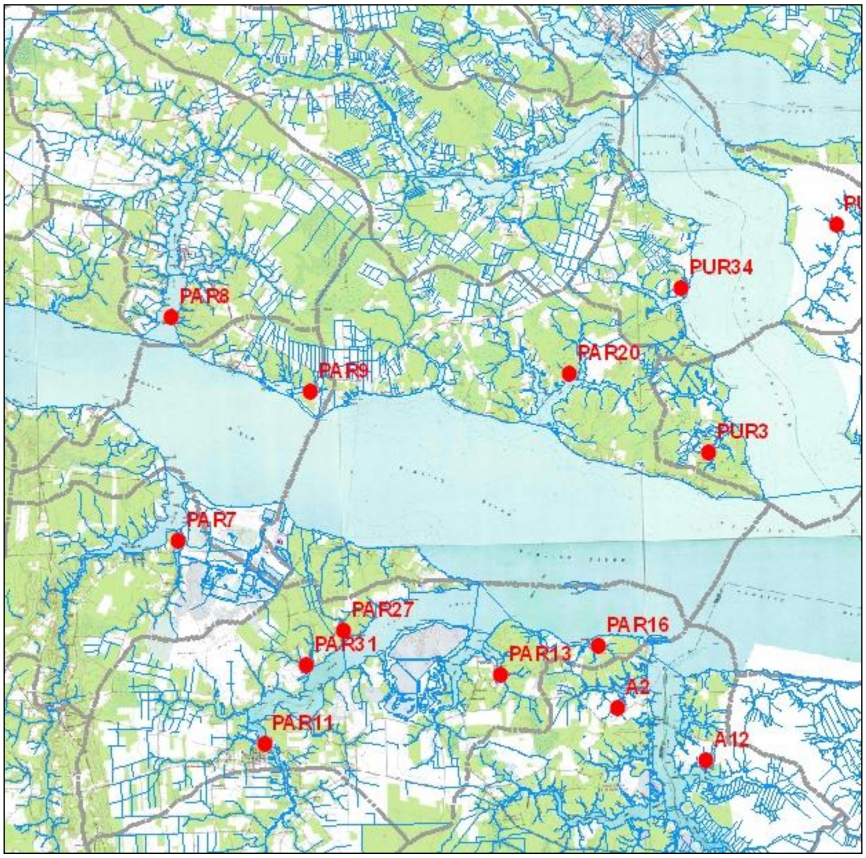


Figure 3. Streams, 14-digit watershed boundaries and NCDMF stations displayed over USGS topographic quadrangle of the lower Pamlico River, NC.

3) Taking into account the stream network and topographic setting in steps 1 and 2, on-screen digitizing was performed to delineate catchments draining to each of the NCDMF sampling stations. Figure 4 shows sample catchments in the lower Pamlico. Catchments boundaries are displayed in yellow, while the USGS watershed lines are in grey. The resulting catchment layer was then used to calculate land use parameters related to each NCDMF sampling station.

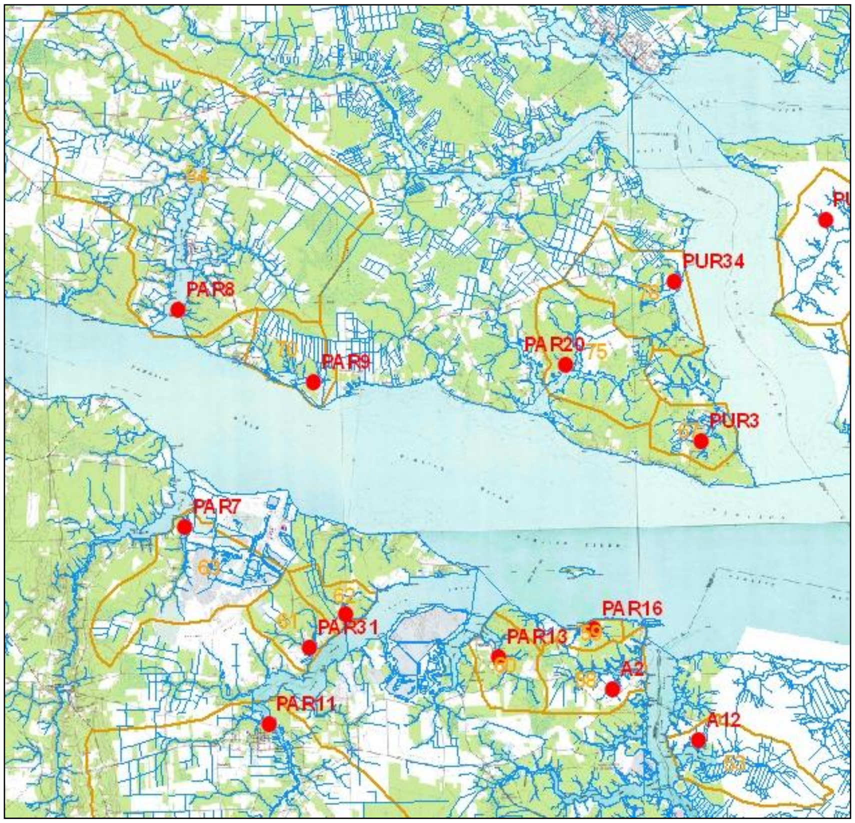


Figure 4. Catchment map and NCDMF stations. Yellow lines are on-screen digitized catchment boundaries. The area shown is the lower Pamlico River, NC.

Images were then clipped to cover the catchment area with a 100 meter surrounding buffer. The buffer zone was added to the catchment boundary to account for possible spatial inaccuracies in the geo-referencing of layer boundaries. Each clipped image was visually inspected and classified using the ERDAS Imagine 9.2 to delineate LULC types. Depending on the location of a given NCDMF sampling station, catchment size can be smaller than or equal to the original watershed. Furthermore, 71 stations out of a total of 105 NCDMF located in 68 catchments were retained for this study (Figure 5) because they had been sampled consistently every May and June from 1980 to 2004. The remaining 34 stations were established more recently (after 1980) or have not been sampled regularly throughout the study period (1980 – 2004).

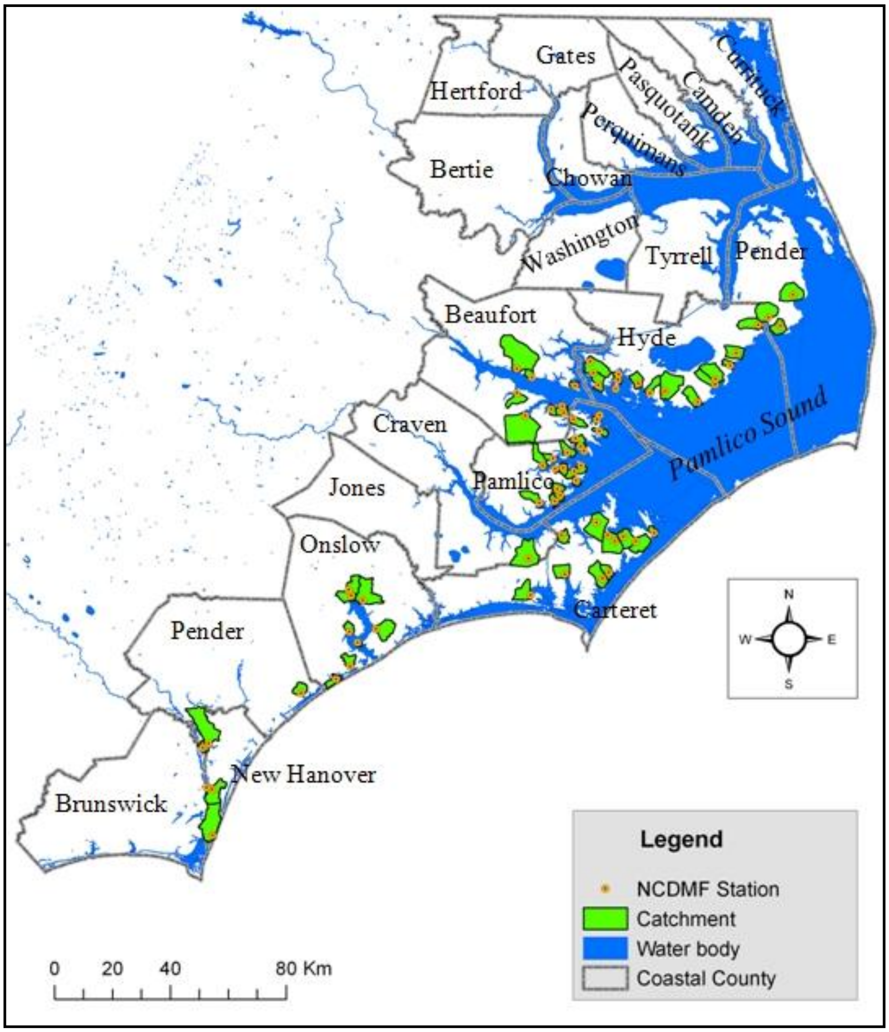



Figure 5. Location of NCDMF sample stations and delineated catchments for the entire study area.

### 1.2.4. Land Use Classification

Numerous techniques can be used for LULC type classification in remote sensing. The most common techniques include supervised classification, unsupervised classification, or a combination of both. The supervised classification is done interactively while the analyst is looking at a display of an image delimiting areas of similar land use by having visited the areas on the ground or using other imagery of higher spatial resolution to determine land use. These examined areas are then used to train a classification algorithm. Among supervised classification methods, the maximum likelihood classifier (MLC) is the most extensively studied and utilized for land cover classification based on multi-spectral remote sensing imagery because of its simplicity and efficiency (Richards and Jia, 2005). Therefore, it has been used in this research. The MLC assumes multivariate normal distribution of pixels within classes and considers both the variances and co-variances of the class signatures when assigning each cell to one of the classes represented in the signature file. Each pixel is assigned to the class for which it has the highest probability of membership. After the training, the MLC algorithm is applied to classify the entire image. Great care must be exercised when selecting training samples because the performance or output of the algorithm is driven by the training sites and processes (Foody and Arora, 1996; Dobson et al., 1995, and Lu et al., 2004). In contrast, the unsupervised classification is carried out by using a computer algorithm that simply recodes each pixel in the image into classes of land use based on the spectral signatures in the data (Lillesand et al., 2008). Among the many possible algorithms of unsupervised classification, the Iterative Self Organizing Data Analysis (ISODATA) clustering algorithm is chosen. Given the differences in spectral and spatial resolution of the images used, as well as the lack of familiarity with the study sites, a combination of both supervised and unsupervised classification methods was utilized to improve the quality of the resulting thematic map.

The datasets obtained from USGS in generic binary format (BSQ) were imported into .img format, which is the main format for ERDAS IMAGINE software. This procedure imports each image, one band at a time. After the bands were imported for each image, they were stacked and placed together as a mosaic in a geo-referenced grid (Figure 6). The geo-referenced imagery was then exported to ArcGIS 9.2. An area of interest was extracted from a mosaic using an ArcGIS layer of the catchment areas.

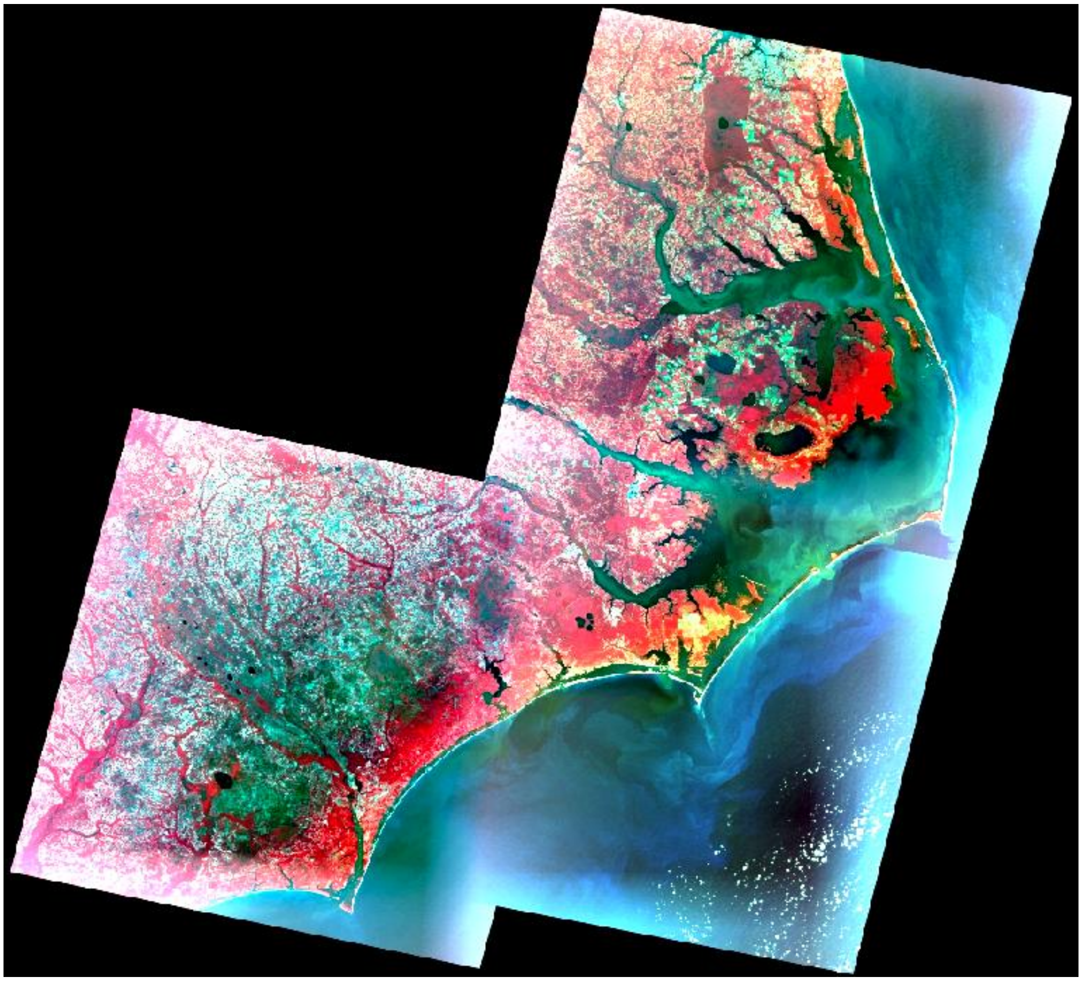


Figure 6. Mosaiced Landsat image for North Carolina's coastal region.

Unsupervised classification was first used because its unbiased mathematical algorithm can help generate any desired number of land use categories simply by analyzing images' spectral signatures. Methods outlined in the guidelines from the NOAA Coastal Services Center (Dobson et al., 1995) were utilized because they have been used and adapted by many coastal communities in the U.S. The supervised classification was used to refine unsupervised classification output using ancillary and ground-truth data to reduce possible classification errors. The ERDAS "RECLASS" algorithm was then trained to identify the pixels in all the imagery with similar characteristics based on the ground-truth data. By setting class identifier values for these pixels and using the trained reclassification algorithm to assign the same class value to each similar pixel in the original data set, each resulting class corresponds to a land use pattern that was originally identified in the ground-truth (Lillesand et al., 2008). This process helped cluster the 21 land use classes (Anderson Level 2) into 5 coarse categories (Anderson Level 1, Anderson et al., 1976) to easily compare maps with a large spatial extent. For instance, all wetlands subcategories (Anderson classes 10 through 15) were collapsed into one class, "wetland", all forested subcategories (Anderson classes 6 through 9) to "forest", all developed subcategories (Anderson classes 2 and 3) to "developed area", and all agricultural subcategories (Anderson classes 4 and 5) to "agriculture"; while the "water" class remained the same. Thus, the LULC type classes are water, forest, wetland, agriculture, and developed area (Figure 7).

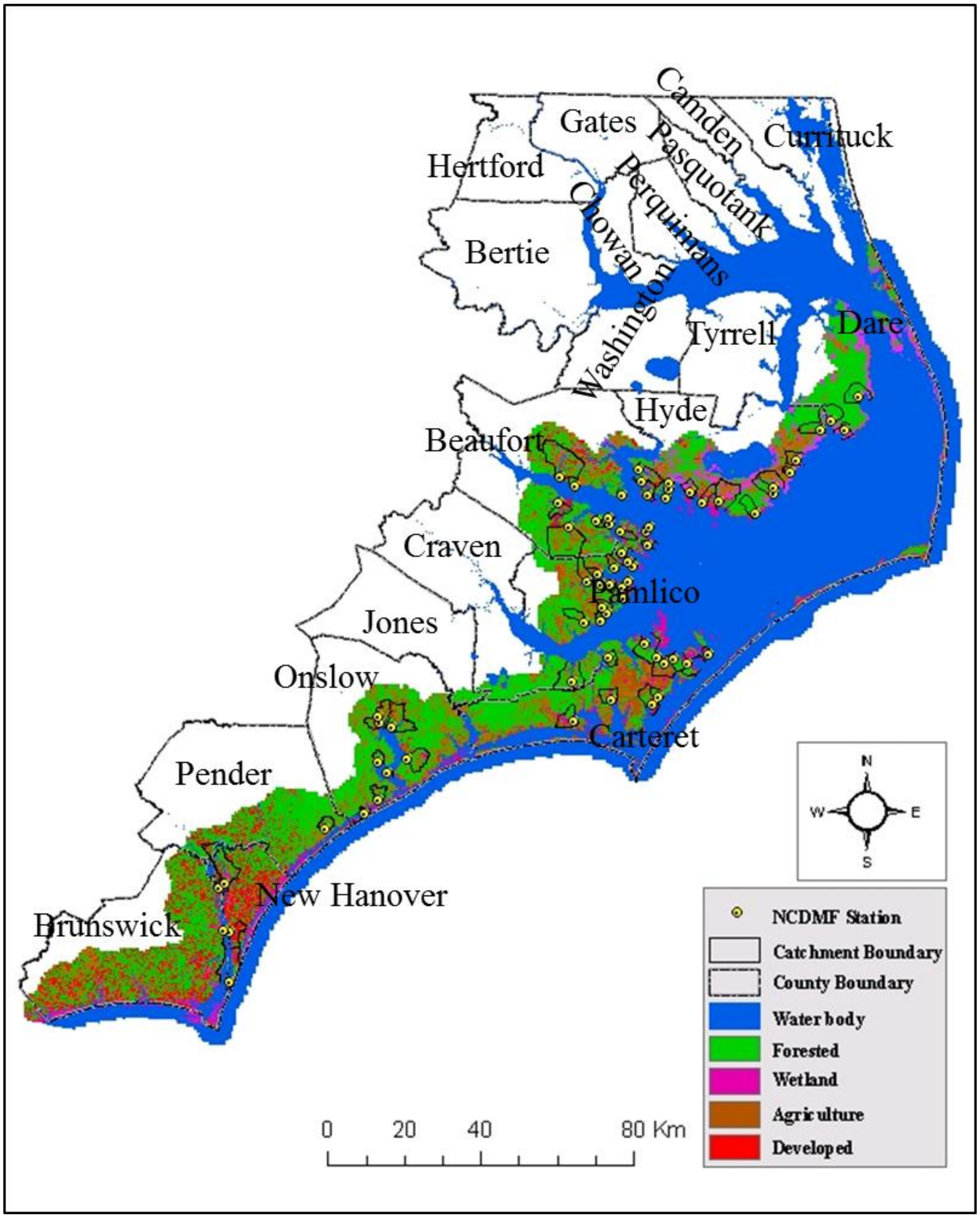



Figure 7. Classified land use from May 2000 Landsat imagery showing 71 NCDMF stations and catchment boundaries.

### 1.2.5. Classification Accuracy Assessment

After multiple temporal Landsat images were classified, an accuracy assessment protocol was developed. The assessment consisted of field verifications on a set of sample points randomly distributed over the study area and determination of the frequency of congruence with the corresponding satellite imagery classified. Site visits were conducted in the summer of 2006 with the assistance of available aerial photographs and DOQQ's. Accuracy assessment also requires that an adequate number of points be sampled for each classified category in order to yield valid statistical analyses. To determine how many sample points are required for a given size area of interest, researchers have used equations based on the binomial distribution or normal approximation, which performs well in determining the overall mapping accuracy (Pontius and Schneider, 2001, Stehman et al., 2003). Congalton and Green (1999) suggested that a multinomial approximation tends to provide a good balance between statistical validity and field practicality. Also, the number of samples for each category can be adjusted based on the relative importance of that category within the objectives of the mapping project or by the inherent variability within one of the categories. Categories with less variability such as water or even-aged forest plantations can be sampled at a lower density, while more variable categories such as uneven-aged forests and agriculture fields should be sampled at higher densities to capture the wide range of variations.

The procedure for generating the appropriate sample size using a multinomial distribution, originally presented by Tortora (1978) and described by Congalton and Green (1999) can be summarized as:

$$n = \frac{B\pi_i(1-\pi_i)}{b_i^2} \tag{1}$$

where $n$ = sample size, $i = 1,\ldots k$ are the number of classes, $\pi_i$ is the proportion of the population in the $i$-th category, $B$ is a constant determined from a Chi square ($\chi^2$) table with 1 degree of freedom, and $b_i$ is the desired precision (for example, if 95% confidence level is desired, $b_i$= 0.05). For instance, at least 184 points were needed to achieve a 95% confidence interval, based on the proportion of the “wetland” category ($\pi$ = 0.14 for wetlands, $b_i$ = 0.05, $B\ (1,\ 0.05) = 3.841$) in this study. Similar calculations on sample sizes or points were made for the other classes. Using the same technique, it was found that a total of about 988 sample sites were desired. The distribution of sample sites by LULC is given in Table 3.

Table 3. Number of desired sample sites by LULC in order to achieve a 95% confidence level. The number of samples are based on the fraction of each land use type in the 2000 year land use categories.

| LULC Types | Number of samples |
|---|---|
| Wetland | 184 |
| Forest | 383 |
| Agriculture | 334 |
| Developed | 87 |
| **Total** | **988** |

In the choosing of ground-truth points, both a simple random sampling method and a stratified random sampling were used. In the random sampling, points are randomly chosen and each pixel in the study area has an equal chance of being selected. One problem with this sampling method is that it tends to under-sample categories with small spatial extents. However, one can increase the number of sample points to compensate for that within each LULC type strata. For instance, the “wetland” and “developed area” categories are very small in size and had been initially under-sampled. Thus, stratified random sampling was used to generate additional points within the “wetland” and “developed area” categories their accuracy was verified in later field trips.

To generate a random distribution of sampling points, the random point generator function of Microsoft Excel was utilized. At first, $10^4$ points spanning between (xmin, ymin) and (xmax, ymax) coordinates, which are respectively the lower left and upper right coordinates of our study area (Figure 8a). This is a relatively high number of points and many landed outside the study area, but it is done in this manner knowing that many of the points would be eliminated for being outside the study area or would be inaccessible because they are located on a water body or private property.

Table 4. Sample field datasheet showing site number, Easting, Northing, and 1980, 1990, 2000 land use and comments.

| Site # | GIS ID | EASTING | NORTHING | Land use 1980 | Land use 1990 | Landuse 2000 | COMMENT |
|---|---|---|---|---|---|---|---|
| 1 | 46 | 335835 | 3931190 | | | | |
| 2 | 131 | 347702 | 3894787 | | F | F | pine forest dying off, near DMF station |
| 3 | 290 | 361023 | 3868910 | | | | |
| 4 | 292 | 337602 | 3926415 | | | | |
| 5 | 323 | 231927 | 3781800 | | | | |
| 6 | 366 | 339385 | 3901330 | | | | |
| 7 | 509 | 409064 | 3926463 | | | | No access |
| 8 | 511 | 337485 | 3861975 | | | | |
| 9 | 528 | 284808 | 3844072 | | | | |
| 10 | 603 | 390878 | 3921448 | | | | No access same as 51/A40 |
| 11 | 632 | 365832 | 3855203 | | | | |
| 12 | 663 | 278146 | 3846343 | | W | W | water body west of Croatan Sound |
| 13 | 667 | 417821 | 3944121 | F | F | F | spoke to owner, forest about 50 years old |
| 14 | 683 | 426151 | 3941618 | | | | |
| 15 | 685 | 347407 | 3880977 | | Ag | Ag | O.G.F cotton fields |
| 16 | 686 | 330086 | 3932700 | | | | |
| 17 | 741 | 290618 | 3836513 | | | F | young mixed forest, possible transition from pine to hardwood, unknown age |
| 18 | 750 | 382527 | 3920965 | | | Ag | off Jackson Swamp Rd/Jackson Hungting club across |
| 19 | 757 | 189615 | 3768903 | | | | |
| 20 | 845 | 225759 | 3800104 | | | | Site unaccessible |
| 21 | 871 | 361594 | 3869576 | | | | Site unaccessible |
| 22 | 879 | 351025 | 3922017 | | | | |
| 23 | 943 | 352472 | 3919829 | | | Ag | Agriculture - currently soy field, behind a small church |
| 24 | 958 | 184467 | 3763836 | | | Ag | Agriculture |
| 25 | 1009 | 446714 | 3969988 | | | F | was forested-recently cut about 2 years old |
| 26 | 1073 | 348465 | 3895600 | | | F | Forested close to Pamlico beach, between Waders and Dave Moore pt. |
| 27 | 1096 | 340044 | 3924262 | | | | |
| 28 | 1169 | 363832 | 3863034 | | Ag | Ag | South of Lake Mattamuskeet |
| 29 | 1187 | 445719 | 3900300 | | | | |
| 30 | 1194 | 275346 | 3825469 | | | Ag | Young forest,less than 5 years old, 2000 clear cut? |
| 31 | 1277 | 443823 | 3966758 | | | | No access at Beaufort/Pamlico county line |

Figure 8a shows the overlay of the points within the given rectangle. After elimination of unusable points, only 256 points were retained as the final number of sample sites to visit (Figure 8b).

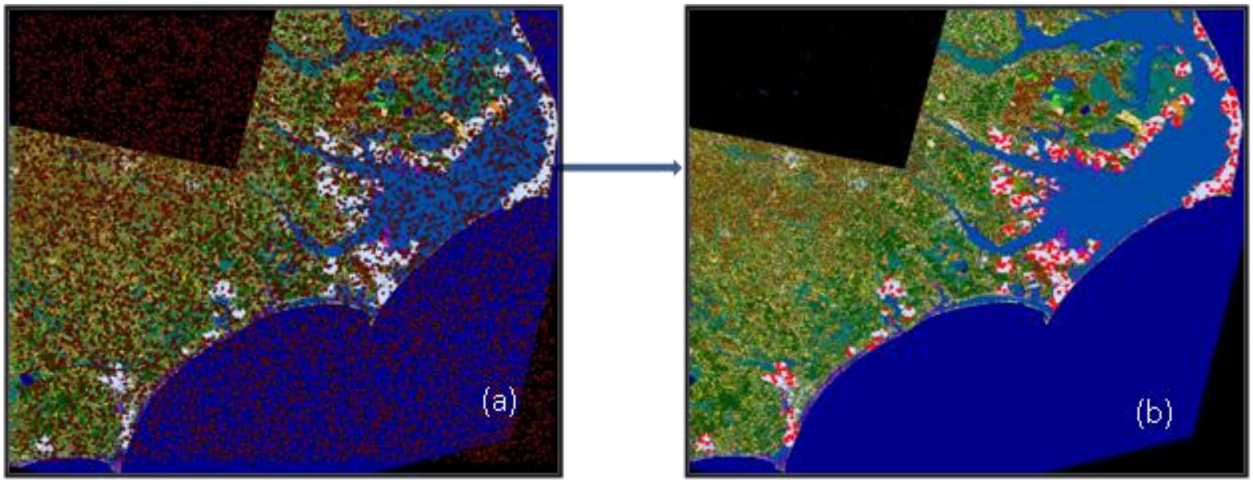



Figure 8. Random point assignment, (a) $10^4$ random points overlaid on the image, and 256 random points that intersected with catchment areas and were accessible are highlighted in red.

The ExpertGPS software (TopoGrafix Inc.) was used to transfer the coordinates of the 256 random sample sites to and from a Global Positioning System (GPS) unit-GARMIN GPSmap 76S (Garmin International Inc., 2005). The GPS receiver has an accuracy of ± 3 meters using the Wide Area Augmentation System (WAAS) capability. A sheet including site number, easting and northing for all random points, and land use types for 1980, 1990, and 2000 are taken to the field (Table 4). The easting is the projected distance of the position from the central meridian, while the northing is the projected distance of the point from the Equator.

Land categories recorded in ground-truthing data were compared to those generated in the office. A confusion matrix consisting of information about actual and predicted land use categories was constructed. Thus, one can compute standard statistical measures of mapping accuracy (e.g., the producer and user errors, overall accuracy, and kappa, κ statistics). In particular, the producer's accuracy tells how often the output correctly predicts known features. It is calculated by dividing the number of correct pixels for a class by the actual number of ground truth pixels for that class (Congalton and Green, 1999; Jensen, 2006). The user's accuracy shows how often the output successfully leads the user to unknown features. It is a measure of the reliability of the output generated from a classification scheme and a statistic that can tell the user what percentage of a class corresponds to the ground-truthed class. The user's accuracy is calculated by dividing the number of correct pixels for a class by the total pixels assigned to that class (Congalton and Green, 1999; Jensen, 2006). The overall accuracy is computed by dividing the total correct (i.e., the sum of the major diagonal) by the total number of pixels in the error matrix.

A Kappa analysis was carried out to assess how the observed accuracy relates to the expected accuracy, using the following formula:

$$K = \frac{Pr(a) - \mathrm{Pr}(e)}{1 - \mathrm{Pr}(e)} \quad (2)$$

where $Pr(a)$ is the observed accuracy and Pr(e) is the hypothetical probability of chance agreement or expected accuracy. The overall accuracy is derived from the percentage of field observations that coincided with the office maps.

### 1.2.6. Land Use Land Cover Change Detection

Change analysis was performed on the classified LULC types from 1980, 1990 to 2000 satellite imagery. Change detection usually involves two steps: 1) pixel-to-pixel comparison of two land cover datasets which are independently produced, and using selected statistical algorithms 2) change enhancement by editing the resulting layer into readily interpretable "from and to” classes. Change detection was performed using the ERDAS post-classification image differencing algorithm.

If two pixels have the same class of wetland (class 1) in 1980 and 2000, the “from to” class is 11 “no change” in the final image (Figure 9). If the pixel changed from forest (class 2) in 1980 to developed (class 4) land use in 2000, a change was detected and a class value of 24 was assigned to that pixel. By examining all pixels in this way, changes of all classes were detected and mapped as the change image of the study area. Between the four land use types considered in this study, there exist twelve possible changes. However, five changes are of interest. They are wetland to agriculture (13), wetland to developed (14), forest to agriculture (23), forest to developed (24), and agriculture to developed (34), marked with dotted lines (Figure 9). Information on the number of hectares that switched use type between 1980 and 2000 was incorporated in the analysis of possible relationship between land use change and changes in juvenile fish and invertebrate catch. It should be noted that the five types of change were previously studied in documenting the water quality and estuarine life decline (Holland et al., 2004; King et al. 2005).

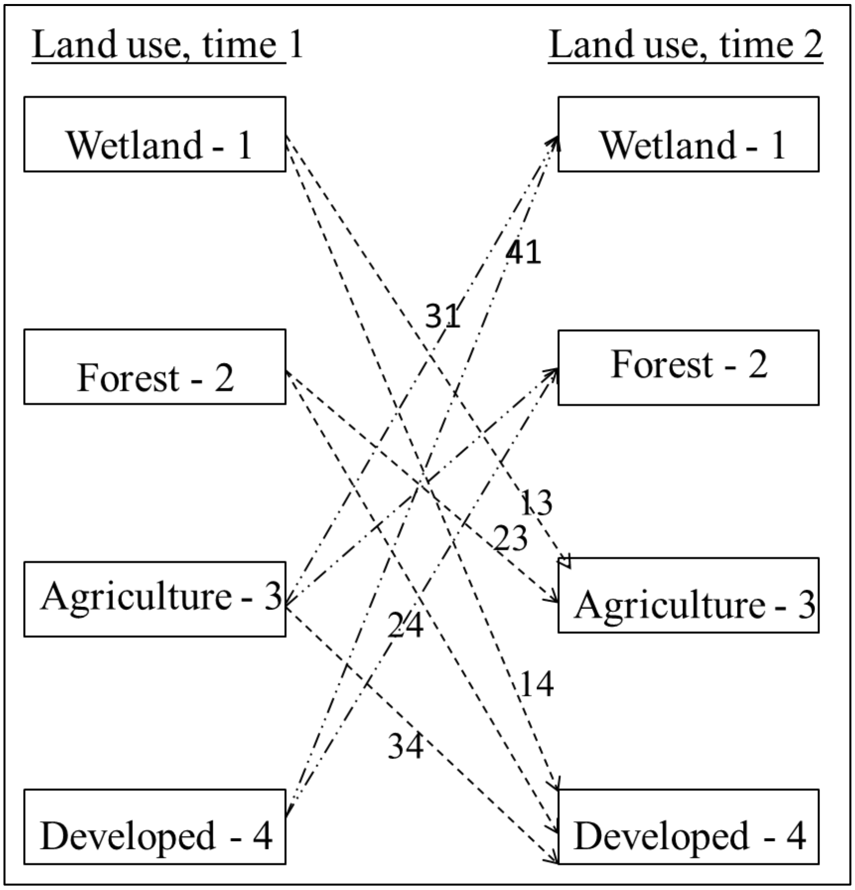



Figure 9. Possible changes of land use types from time1 to time 2

The catchments layer was overlaid on thematic maps and zonal statistics calculated using the spatial analysis module of ARCGIS 9.2 to generate LULC types within each catchment area. For this study, each catchment was used as a zonal layer to extract LULC type changes from the changed map of the whole study area. The zonal statistics function was used to compute statistics on values of a raster image within the zones defined in another vector dataset defining the catchments. "Tabulate Area," an ArcGIS algorithm that cross-tabulates areas between two datasets was utilized to extract land use change information within each individual catchment.

### 1.3. Results and Discussions

#### 1.3.1. Land Use Classification Results

Some wetlands were converted to agriculture; six catchments showed a conversion of 10-20% of original wetland area to agricultural use. The total amount of wetlands expressed comparatively little net change in size and actually showed a small increase in average percent cover of 4.5% (Table 5).

Forested areas declined between 1980 and 2000, much of them were converted to agriculture. Within 71 catchments, the percentage of forest cover declined from a mean of 76.1% in 1980, to 56.3% in 1990, and to 45.6% in 2000 (Table 5). Loss of forested land was generally spread thought out the study area. Thus, forest as a dominant land cover (defined as a cover of at least 55% within a catchment) decreased by nearly by half.

Agriculture land increased from 7.5% in 1980 to 31.6% in 2000. This dramatic change was observed throughout the study area, and especially in those catchments that were already adjacent to agriculture.

The developed LULC category registered a small increase from 4.5% to 7.3% and is mostly concentrated at stations close to existing high human population densities like the cities of Jacksonville and Wilmington.

Table 5. Summary statistics of changes in land use types between 1980 and 2000. Values were computed by summing total areas of catchments and land use class totals for all watersheds surrounding the NC DMF stations.

| Land use | 1980 | | 1990 | | 2000 | | Percent change | | |
|---|---|---|---|---|---|---|---|---|---|
| types | Total Area (ha) | Percent | Total Area (ha) | Percent | Total Area (ha) | Percent | 1980 to 1990 | 1990 to 2000 | 1980 to 2000 |
| Wetland | 15,146 | 11 | 18,667.7 | 13.7 | 20,913.1 | 15.5 | 2.7 | 1.8 | 4.5 |
| Forest | 104,510 | 76.1 | 76,698.5 | 56.3 | 61,560.5 | 45.6 | –19.8 | –10.7 | –30.5 |
| Agriculture | 10,335 | 7.5 | 31,743.1 | 23.3 | 42,621.2 | 31.6 | 15.8 | 8.3 | 24.1 |
| Developed | 7,371 | 5.4 | 9,122.2 | 6.7 | 9,834.1 | 7.3 | 1.3 | 0.6 | 1.9 |

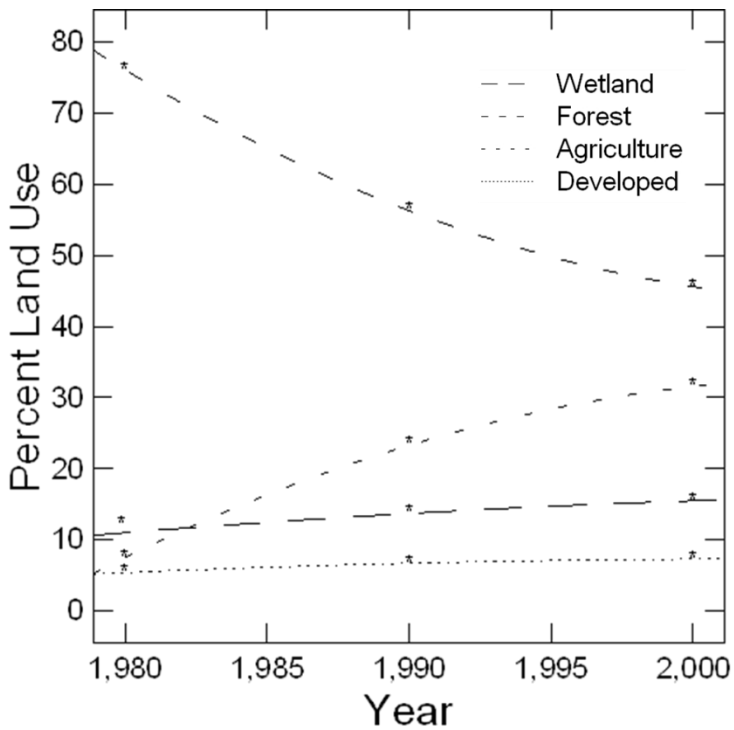



Figure 10. Change in percent forested and wetland area compared to agriculture and developed area.

Agriculture was a minor land category in 1980, but had become a dominant one in 10 of the 67 catchments by year 2000. Nearly all gains in agricultural land were a consequence of conversion or loss of forested land (Table 5, Figure 10). The average increase in agricultural use between 1980 and 2000 was 24.1%. Areal percentage of agriculture land within these catchments increased from 7.5% in 1980 to 23.3% in 1990, and to 31.6% in 2000 (Table 5).

Increases in developed land were localized. Thus, at the level of all of the catchments, developed land cover increased by an average of only 1.6%. Deforestation was also the primary cause of the new developed land. The most extensive accumulation of developed lands (> 20% of land area) was confined to catchments in Jacksonville (within Onslow County) and Wilmington within the county of New Hanover.

The combination of forest and wetland (F+W) areas to serve as a proxy for “unaltered” land and the combination of agriculture and developed (A+D) lands as a proxy for “altered land” revealed that unaltered land declined in percentage within each catchment area, while “altered” land increased (Table 6). In particular, the unaltered category covered 87.1 of the total area of the 67 catchments in 1980; this percentage declined to 70.1 by 1990 and to 61.1 by year 2000. The altered areas increased from 12.9 in 1980 to 30.0 in 1990, and to 38.9 in year 2000. Combined forest and wetland cover dominated 65 of 67 catchments 1980; 53 in 1990 and only 43 in 2000.

Table 6. Proportion of catchments showing altered or unaltered LULC types dominant between 1980 and 2000.

| Year | Percent F+W | Percent A+D | Number of catchments dominated by F+W | Number of catchments dominated by A+D | Total number of catchments |
|---|---|---|---|---|---|
| 1980 | 87.1 | 12.9 | 65 | 2 | 67 |
| 1990 | 70 | 30 | 53 | 14 | 67 |
| 2000 | 61.1 | 38.9 | 43 | 34 | 67 |

### 1.3.2. Classification Accuracy Results

LULC classification accuracy was assessed by using the ground-truthing data. Table 7 shows an error matrix displaying the number of pixels assigned to a particular category after the classification. Table 8 shows the producer's and user's accuracy matrix for the classified image. The overall accuracy was 91.2% and the Kappa coefficient was 0.86. According to Viera and Garrett (2005), a Kappa value of 0.86 meant an almost perfect agreement between producer and user accuracy.

Table 7. Error matrix showing the ground reference data versus the image classification for land use types in coastal watersheds.

| Image classification | | Ground reference | | | | |
|---|---|---|---|---|---|---|
| | | Wetland | Forest | Agriculture | Developed | Total |
| | Wetland | 13 | 1 | 1 | 0 | 15 |
| | Forest | 1 | 63 | 1 | 2 | 67 |
| | Agriculture | 0 | 1 | 48 | 5 | 54 |
| | Developed | 0 | 0 | 1 | 11 | 12 |
| | Total | 14 | 65 | 56 | 18 | 148 |

Table 8. Producer and User's accuracy matrix for the classified image.

| Producer's Accuracy | | Percent | User Accuracy | | Percent |
|---|---|---|---|---|---|
| Developed | 11/18 | 61 | Developed | 11/12 | 92 |
| Agriculture | 48/56 | 86 | Agriculture | 48/54 | 89 |
| Forest | 63/65 | 97 | Forest | 63/67 | 94 |
| Wetland | 13/14 | 93 | Wetland | 13/15 | 87 |

The percent producer accuracy is low (61%) because low intensity developed tend to be confused with sparse forest, and open farms without crops are often interpreted as impervious surfaces. Comparable results were found in the 1991-1997 North Carolina land change analysis by NOAA's CCAP program. Future studies will benefit from using more aerial photos and increasing the sampling intensity in developed land use categories.

### 1.4. Conclusion

LULC type changes of a portion of North Carolina coastal areas between 1980 and 1990, 1990 and 2000, and 1980 and 2000 were studied using Landsat imagery and ancillary datasets. The study area was delineated using USDA's guidelines for watershed delineation (USDA 2007). The delineation of

LULC type through time was performed, using a combination of unsupervised and supervised classifications. The derived types were developed land, agriculture land, forested area, and wetland. Between 1980 and 1990, 1990 and 2000, or 1980 and 2000, deforestation constituted the greatest land use alteration, with an overall loss of 30.5% in the catchments in 20 years. Forested area was largely converted into agricultural land. Agricultural area showed substantial increase, averaging 24.1% in two decades. The loss of forested area to agriculture land was widely spread within coastal counties. There was a small gain locally in developed and wetland areas in some local catchments. This can be explained by finding of a recent shoreline change study that suggested the existence of landward shoreline migration of the East facing shores in the Pamlico Sound (Wang and Allen, 2008). Much greater increases in developed land via deforestation occurred in the catchments located near Jacksonville and Wilmington, where the development of water-front properties in low land areas could be the major cause for the increase. Overall, catchments became dominated by agricultural land in the detriment of forested environment, which can lead to water quality degradation caused by increased sediment load from rapid run-offs, and usage of fertilizers, pesticides, etc. Thus, there is potentially reduction of the abundance of juvenile fish and invertebrates in water bodies located downstream (Meyer and Turner, 1992, Holland et al., 2004; King et al., 2005; Bilkovic et al., 2006). Classification accuracy assessment yielded an overall classification accuracy of 91% and a Kappa statistic value of 0.86. In the realms of land use mapping, these two values are acceptable.

State natural resource managers need to monitor forest loss in eastern North Carolina because of the possible implications to other natural resources management, such as wildlife habitat encroachments and animal corridors, water quality and fisheries.

# Chapter 2. Analysis of Population Changes for Selected Juvenile Fish Species, Blue Crab, and Brown Shrimp in the Estuaries of North Carolina


## Abstract

Long-term trends were evaluated in the North Carolina Division of Marine Fisheries (NCDMF) juvenile fish and invertebrate trawl sampling program (Program 120) at 71 stations in North Carolina Estuaries for selected fish species, blue crab, and brown shrimp between 1980 and 2004. Catches were recorded as the number of individual fish, blue crab or shrimp per trawl during May and June, each year at each station. Time series plots for each species were made using a geometric mean for each year and fitting a locally weighted scatterplot smoothing (LOWESS) curve to the data. In a separate change analysis, I first averaged data for each station and species over two five-year periods: (1) 1980 and 1984, and (2) between 2000 and 2004. Then matched-pair differences of these 5-year averages were calculated for each station and species. Finally, Z-score was computed for each station to normalize data across stations. The Z-score or normalized index allows for the comparison of relative changes over time at stations with very different baseline abundances. The score indicates how many standard deviations an observation is above or below the mean change in catch for all stations. The Z-score for each species was plotted per region to examine the relative variation in catch among stations within various regions in our study area to examine the relative variation in catch among stations with in each region of the study area. Subsequently, yearly time series of catch were plotted to highlight catch fluctuations over a 25-year study period. The plots help to inspect changes in catch using the NCDMF juvenile trawl data visually.

Overall, there was an increase in abundance of juvenile pinfish (*Lagodon rhomboides*), spot (*Leiostomus xanthurus*), southern flounder (*Paralichthys lethostigma*), and blue crab (*Callinectes*

*sapidus*) during the study period. The increase in pinfish were the most striking (increasing from a geometric mean of 1.2 fish/trawl in 1980 to 36.3 fish/trawl in 2001), suggesting that these increases may be associated with shifts in the food web or due to other unknown factors. Atlantic croaker (*Micropogonias undulatus*), Atlantic menhaden (*Brevoortia tyrannus*), and brown shrimp (*Farfantepenaeis aztectus*), did not appear to change when averaged over all stations.

## 2.1. Introduction

Estuaries are partially enclosed bodies of water where freshwater mixes with oceanic saltwater. They extend from the landward edge of saltwater or tidal influence seaward to the boundary between mixed salinity and oceanic saltwater (Day et al. 1989). A wide variety of habitats such as marshes, mud flats, mangrove forests, oyster reefs, and sea grass meadows are found in and around estuaries (Jenkins et al., 1998). Around the world, fish and invertebrates, especially juvenile stages, tend to congregate in these complex habitats because they provide a great protection from predators (often larger fish) and provide more food to grazing fish. Many fish and invertebrates species spawn offshore in large groups. Their larvae and juveniles are carried to shore by ocean currents. They settle in estuaries and tidal creeks, where environmental conditions are gentle, food abundant, and predators mostly absent (Jenkins et al., 2008). Also, by spending time in a habitat separate from adults, juveniles can avoid competing for the same resources while too small to succeed. However, the habitat quality of these fish nurseries areas is being degraded at an alarming rate by in-ward and excessive nutrients, sediments and pollutants from adjacent terrestrial landscapes (Holland et al. 2004, King at al. 2005).

Alteration of the terrestrial landscapes to accommodate the needs of a growing human population has led to extensive timber harvest, agricultural intensification, increased concentration of animal feeding locks, and urban and industrial expansions (Beach, 2002, Defries et al., 2004). Land use changes have been associated to declines of estuarine ecosystem habitat and function, abundance, distribution, and diversity of species (Holland et al., 2004; King et al., 2005, Bilkovic et al., 2006) as well as increased marine eutrophication (Nixon, 1995; Paerl, 2006). Therefore, the purpose of this study was to find out whether there exists any long-term trend in juvenile fish and invertebrates population of seven selected species, using a long-term trawl data collected by NCDMF juvenile trawl program.

The species of interest (Figure 11) are Atlantic croaker *(Micropogonias undulatus)*, Atlantic menhaden *(Brevoortia tyrannus)*, pinfish *(Lagodon rhomboides)*, southern flounder *(Paralichthys lethostigma)*, spot *(Leiostomus xanthurus)*, blue crab (*Callinectes sapidus*), *and* brown shrimp (*Farfantepenaeus aztecus)*.

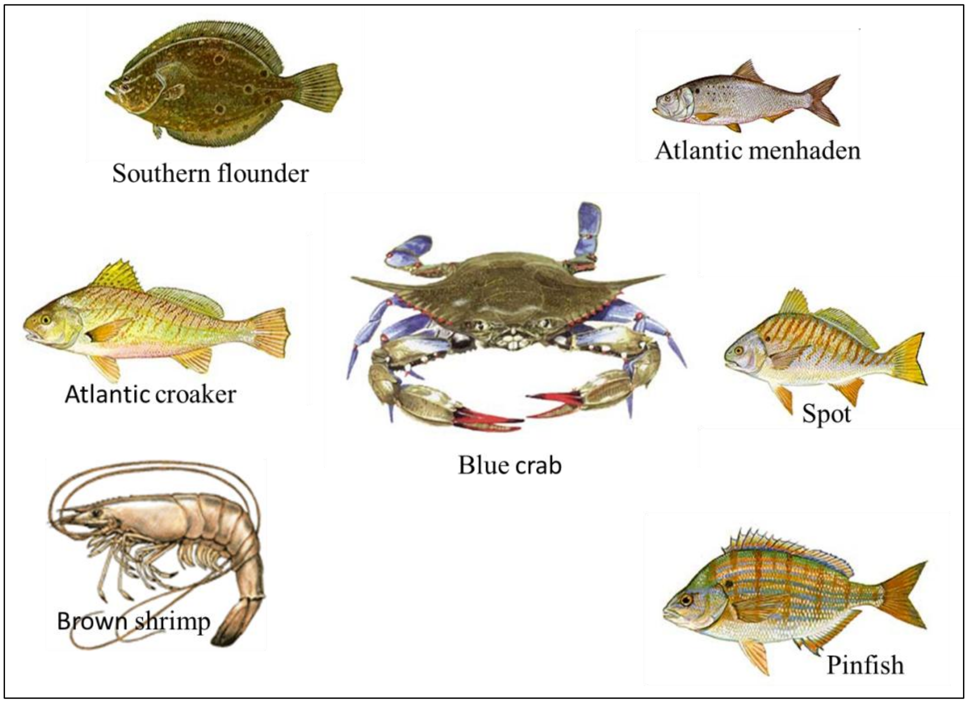



Figure 11. The seven species selected for the Study.

These species were selected because they are consistently collected in large numbers and have a great total weight in yearly NCDMF program 120 catches from 1980 to present time and as adults they are a large part of North Carolina's commercial, recreational, and subsistence fishing catches. Table 9 shows catches in pounds for the species in 2008, yearly dollar value as well as their overall rankings. Four of the seven species top the list of species caught by commercial fishermen on the North Carolina coast in term of value. In addition to the high commercial value, the blue crab is an ecological indicator of habitat quality (Hovel and Lipcius, 2001; Orth and Montfrans, 1987). Thus, NCDMF program 120 collects size and sex information for the blue crab only. Menhaden and pinfish are 35th and 62nd, respectively, but these species are important in the food web and as habitat quality indicators (Jordan et al., 1997). Atlantic menhaden is important ecologically as food for larger fish, such as striped bass, blue fish, and flounder, and is widely used in animal feeds. Pinfish is an ecological indicator species because it is not very heavily fished, so changes in its abundance may suggest effects of land use or environmental changes. Along with catch data, surface and bottom temperature, salinity, and depth were recorded on day of trawl at each station by NCDMF. Dissolved oxygen was not recorded over the entire sequence of sampling, so it will not be used for analysis.

Table 9. North Carolina's commercial fishery catch for seven selected species in 2008 (http://www.ncdmf.net/statistics/comstat/ last accessed 02 October 2011).

| **Species** | **Scientific name** | **Pounds landed** | **Value($)** | **Rank in $** |
|---|---|---|---|---|
| Blue crab | *Callinectes sapidus* | 25,309,539 | $17,065,194 | 1 |
| Brown shrimp | *Farfantepenaeus aztecus* | 5,736,305 | $9,141,172 | 2 |
| Southern flounder | *Paralichthys lethostigma* | 2,297,531 | $4,870,780 | 3 |
| Atlantic croaker | *Micropogonias undulatus* | 10,383,561 | $3,558,280 | 4 |
| Spot | *Leiostomus xanthurus* | 1,364,583 | $997,930 | 13 |
| Atlantic menhaden | *Brevoortia tyrannus* | 963,287 | $148,054 | 35 |
| Pinfish | *Lagodon rhomboides* | 65,456 | $11,950 | 62 |

In a study of the nationwide impact of US commercial and recreational fisheries on marine fish populations, Coleman et al. (2004) examined data from the National Marine Fisheries Service (NMFS) online databases (NMFS, 2010), and from other government agencies, to produce estimates of landings for the continental US. They concluded that lower trophic level fish species like menhaden and walleye pollock (*Theragra chalcogramma*) are targeted by commercial fisheries for producing frozen fish products and fish meal. They are not listed as overfished. However, their continued and increased removals can cause cascading trophic effects that alter the structure, function, and productivity of marine ecosystems. In the Chesapeake Bay, Officer et al. (1984), Jackson et al. (2001) believe that there has been a steady increase in the landings of menhaden since the 1970's, to the point where by the year 2001, menhaden counted for ~90% of the total finfish landings in the Bay.

In addition to these species' economic importance, Warlen and Burke (1990) studied migration of larvae of Fall/Winter spawning marine fishes into the Newport River Estuary in North Carolina. They found that the five most abundant migrating species, accounting for 90% of the individuals, were Atlantic croaker, spot, Atlantic menhaden, pinfish, and speckled worm eel (*Myrophis punctatus*), confirming how numerically important the selected species are in North Carolina estuaries. Joyeux (1999) conducted a passive sampling of larvae migrating to the Pamlico Sound through the Beaufort Inlet via flood and ebb tides. His study confirmed Warlen and Burke's (1990) findings and added that flat fishes were also abundant. The study concluded that species abundance pattern differed according to the pelagic or non-pelagic behavior of the larvae with non-pelagic taxa relying on astronomical tides.

### 2.1.1. Life history for the selected species

Most estuarine-dependent species spawn in the ocean. When and how the larvae or juveniles return to the estuaries vary greatly from species to species. The spatial and temporal patterns of juveniles vary with species, too. Therefore, different species have different life histories, with noted similarities among species of same family (Miller et al., 1991). Able and Fahay (2010) refer to estuarine-dependent species as transient, since they spend only a portion of their lives in estuaries. The small size of recently settled fish may make them experience a high mortality rate due to predation or inhospitable abiotic factors such as extreme temperatures. Based on the amount and completeness of information available for the life of Middle Atlantic Bight fish species, Able and Fahay (2010) synthesized life history information of economically important species.

***Blue crab***

On the western Atlantic Ocean, blue crab range extends from southeastern Canada to South America, but they are most common from New York to Florida and the Gulf of Mexico. Mature blue crabs usually mate in brackish marsh areas of estuaries and spawning takes place in high-salinity waters (Blackmon and Eggleston, 2001). The larvae develop on the continental shelf. Post-larval stage (megalopae) occurs near the surface and is transported shoreward by wind-driven surface currents (Forward et al., 1997, Welsh and Forward, 2001). Megalopae swim to surface waters to ride flood-tide currents, and switch to the bottom during outgoing ebb-tide currents, with movement back to the surface during subsequent flood tides (Forward et al., 1997). The mechanisms used by blue crab megalopae to migrate into the estuary using selective tidal stream transport are increasing salinity and turbulence associated with flood-tide currents (Welch and Forward, 2001).

The abundance of a year-class is initially determined by the number of post larvae that enter the estuary and is greatly influenced by various physical factors such as seasonal wind events, timing and magnitude of tropical cyclones, and current conditions encountered by planktonic crab larvae on the continental shelf. Larval recruitment to North Carolina's estuaries and coastal waters has been positively correlated with proximity to inlets, strength of alongshore northerly winds, and hours of dark flood tide (Eggleston et al., 1998).

Juvenile blue crabs are widely distributed throughout estuaries. Although salinity influences distribution, factors such as bottom type and food availability also play a role in determining distributional patterns of juveniles. Juveniles preferentially use shallow water areas, including structural habitats such as seagrass, salt marsh, detritus, and oyster shell (Orth and Montfrans, 1990; Etherington and Eggleston, 2000).

***Brown shrimp***

Brown shrimp can be found from Massachusetts to Florida and the Gulf of Mexico and extends south to the Yucatan Peninsula, Mexico. They are more abundant in the Gulf of Mexico. Field observations and laboratory experiments indicate that brown shrimp seem to prefer marshes and shallow water habitat with seagrass beds, which provide food, substrate and protection for the young (Zimmerman et al., 1984; Rulifson, 1981). Brown shrimps are omnivorous; they feed on meiofauna associated with sediments, detritus, algae, and benthic organisms. Feeding occurs mostly at night, although some daytime feeding will occurs in turbid water. Growth and production of penaeids in estuaries are related to temperature, salinity, and presence of vegetation (Rulifson 1981; Wenner and Beatty, 1993). Adult brown shrimp spawn in deep ocean waters. Like most estuarine-dependent fish and invertebrates, brown shrimp larvae get transported to estuaries and coastal waters by wind and ocean currents. According to Williams (1965), and Wenner and Beatty (1993), wind driven currents transport larvae to the upper reaches of the estuaries beginning in February, with peaks occurring in mid-March through mid-April. Brown shrimp larvae go through several stages into post larvae and juvenile. Once post larval shrimp enter the estuaries, growth is swift and dependent on salinity and temperature (NCDMF 2006). Sub-adult and adult shrimp seek higher and more stable salinities due to a decrease in the ability for osmoregulation.

***Southern flounder***

Southern flounder has a wide geographical range on the eastern coast of North America from Virginia to Florida and the Gulf of Mexico. The flounder is found in rivers, estuaries, and coastal waters. The southern flounder is part of the Bothidae family (left eye flounders). It appears very similar to summer flounder (*P. dentatus*) and gulf flounder (*P. albigutta*). All three groups are found in North Carolina, and along most of the Atlantic coast including the Gulf of Mexico waters (Able and Fahay, 2010). Southern flounders spend much of their lives on the bottom, where camouflage helps them not be easily detected by prey and predators. Powell and Schwartz (1977) have found that benthic substrate and salinity are two most important factors governing the distribution of southern and summer flounders. Southern flounder are more abundant in areas of low salinity and clayey silt or organic rich mud bottoms, while summer flounder are most abundant in areas of moderate to high salinities and sandy bottom.

According to Watterson and Monaghan (2001), adult southern flounders migrate out of the rivers and estuaries in the late fall to spawn offshore in the warmer waters of the Gulf Stream between November and February. Juvenile and young, sexually immature adult southern flounder are believed to overwinter in the low salinity waters of the rivers and bays for the first two years of their life rather than migrating offshore (Powell and Schwartz, 1977). After the spawning period, adult southern flounders return to the estuaries, coastal waters, and rivers through the inlets (NCDMF, 2001). Newly hatched larvae are transported back to estuaries and coastal waters by oceans currents (Powell and Henley, 1995). It is believed that developing larval southern flounder remain in the offshore waters between 30 to 60 days before getting carried through the inlets into the estuaries during nighttime flood tides (Warlen and Burke, 1990, Burke et al., 1991, Burke et al. 1998). After metamorphosis, the juvenile southern flounder settle on tidal flats towards the head of the estuaries and move upstream to lower salinity habitats (Burke et al., 1991, Guidon and Miller, 1995).

***Atlantic croaker***

The Atlantic croaker is typically distributed from Massachusetts to Florida and the Gulf of Mexico (Able and Fahay, 2010). It is less common north of New Jersey, but abundant farther south where it is a bottom feeding fish of coastal waters and estuaries. During winter, adults move offshore and south towards the South Atlantic. Important habitats for the Atlantic croakers include the continental shelf for larvae and low salinity habitats, such as tidal creeks and tributaries of major bay systems for the earliest settlement stages. Montane and Austin (2005) found that compared to other shelf spawners in the Chesapeake Bay, the Atlantic croaker is more influenced by late summer/fall hurricanes. Spawning takes place in the Middle Atlantic Bight starting in September and peaks in October and ending in December. Pelagic larvae enter the estuaries via ocean inlets and ultimately end up in nursery areas with low salinity.

***Spot***

Spot is distributed between Massachusetts Bay, US to Campeche Bay, Mexico and most abundant between the Chesapeake Bay and North Carolina coast (Able and Fahay, 2010). The spot population is mostly euryhaline. Their larvae and juveniles are more abundant in the Middle Atlantic Bight estuaries, between the Hudson River, New York and Cape Hatteras, North Carolina. Using field observations and laboratory experiments, Rakocinski et al. (2006) found that temperature and salinity are the two most important factors that influence the migration of juvenile spot.

Spawning takes place in the continental shelf from winter to spring and is more intense in warm waters in the outer shelf and south of Cape Hatteras (Able and Fahay, 2010). Larval development takes place on the continental shelf before larvae enter estuaries and then migrate to lower salinity, colder water of the upper estuary.

### *Atlantic menhaden*

According to Able and Fahay (2010) and Murdy et al. (1996), Atlantic menhaden can be found mainly along the Atlantic coast of North America, from Nova Scotia, Canada to Florida, US. They migrate north during spring and return to south during the fall. They spend the winter, mostly south of Cape Hatteras. It has been determined that there is limited spawning during the spring northward migration that extends as far north as Cape Cod, MA and a limited spawning during the summer. Spawning increases remarkably during the fall southward migration. In Delaware estuaries, larvae are typically 10 to 20 mm in length when they ingress (Wang and Kernehan, 1979) from December through May. Larvae are pelagic and ride ocean currents to estuaries where they transform into juveniles at about a length of 30 to 38 mm total length. In New Jersey estuaries, Able and Fahay (2010) state that, periods of low catches are often associated with low water temperatures. However, annual variations have been observed (Warlen, 1994). After arrival in the estuary, juveniles move upstream in low salinity waters and in areas of maximum phytoplankton (Friedland et al., 1996). They stay in the estuarine habitat until temperatures start dropping in September/October.

### *Pinfish*

Pinfish spawn offshore and their larvae are transported shoreward where they migrate into estuaries for continued development (Forward et al., 1998). Adams et al. (2004) state that juvenile pinfish, an abundant and trophically important species depend on seagrass beds because the seagrass and macroalgae associated habitats provide not only shelter from predation, but also a fertile food source. In a larval fish migration study in the Newport River estuary, NC, Warlen and Burke (1990) found that pinfish larvae constituted about 13% of the immigrating larvae. The early season peak is in December, which is followed by a very low recruitment from mid-January to mid-February. The main period of recruitment occurred from late February to early April. Juvenile pinfish consume meiofauna and are most abundant in seagrass habitat (Luczkovich et al. 1999, Gloeckner and Luczkovich 2008).

The life spans of the seven species have been discussed. They spawn offshore and the larvae or juveniles are transported shoreward through inlets. The migration and survival in the estuaries are influenced by the combination of biotic and abiotic factors. The biotic ones include food availability (Burke, 1995), competition with other species (Warlen and Burke, 1990) and the prey/predator dynamics (Burke, 1995). The abiotic factors are ocean currents (Ross and Epperly, 1985), tides, winds, salinity, and water temperature (Pietrafesa et al., 1986). Details of the factors that influence the migration and survival are discussed next.

### 2.1.2. Factors susceptible of influencing juvenile migration and survival in the estuary

There are three major migration patterns by which fish larvae arrive to estuarine and tidal creek systems for reproduction and juvenile feeding (Day et al., 1989): 1) Saltwater spawning followed by migration of the larvae into the estuary. Spawning offshore often takes place during the winter and the larvae are carried inshore through ocean inlets by currents (Ross and Epperly, 1985); 2) Estuarine spawning, where the eggs are hatched and the juveniles reside in estuaries and tidal creeks; 3) Freshwater spawning, where eggs hatch in a river, followed by downstream migration by means of floatation of larvae and juveniles to the estuary. Riverine inputs to estuaries also consist of not only juveniles, larvae, and fresh water, but also of organic and inorganic compounds. They are mostly suspended sediments, detritus, and nutrients, which usually stimulate aquatic primary production in estuaries. River discharge affects the geomorphology, salinity, and turbidity of estuaries, which in turn influences the distribution and abundance of fish and crustaceans (Day et al., 1989; Whitfield, 1996; Lonergan et al., 1999). Ross and Epperly (1985) studied 51 primary nursery areas distributed over a large area of the western Pamlico Sound, North Carolina. Fish and invertebrates species were collected using methods similar to those in the Program 120 trawl survey. They also collected physicochemical attributes such as temperature, salinity, sediments, depth, and percent organics. After grouping stations in clusters using ordination techniques, Ross and Epperly (1985) found that the stations sorted in groups that correspond mostly to geographic areas and habitat types. They also found that deeper areas of the Sound are not the initially preferred habitats of most estuarine-dependent species because high salinity and tidal currents had a pronounced negative effect on certain species. Later, various studies (Pietrafesa et al., 1986; Barnes, 1998; Xie and Eggleston, 1999; Brown et al., 2005; Rodriguez et al., 2006) corroborate Ross and Epperly's (1985) results, confirming that a variety of physical, chemical, and biological factors influence juvenile fish and invertebrate abundance and distribution.

Pietrafesa et al. (1986) investigated the potential influencing of wind direction and speed on the spatial and temporal distribution of juvenile fish in the Pamlico Sound. They used the NCDMF trawl sampling data for selected Western Pamlico stations and water temperature data to test whether juvenile fish ride ocean currents (driven by wind and salinity gradient) passively, as implied by Ross and Epperly (1985) or whether other factors were at play. They found that water temperature, wind direction, and speed influenced distribution of juvenile spot and possibly other species such as Atlantic menhaden.

Xie and Eggleston (1999) carried out a numerical modeling of water circulation in Croatan-Albemarle-Pamlico-Estuarine System (CAPES) of North Carolina. The model incorporates average temperature and salinity of the period of interest as well as wind direction and speed. They found the existence of two distinct water exchange modes between the CAPES (juvenile nursery area) and the ocean, spawning area. The first mode is stratified, where the surface and bottom flows are very different. The second mode is un-stratified and the surface flow goes to the same direction as the bottom flow. This study illustrated the difference in migration pattern of pelagic and demersal species larvae as well as the played by wind, salinity and water temperature.

Joyeux (1999) proposed two hypotheses for larval transport: 1) Tidal stream transport, where organisms migrate vertically within the water column to take advantage of favorable tidal currents, and 2) non tidal flows generated by weather events can provide favorable current conditions. The hypotheses imply that water is moving for an unspecified duration. He applied the hypotheses to study how fish larvae immigrate through the Beaufort Inlet, which is not sensitive to meteorological forcing of water and where semidiurnal tidal regime is relatively regular. He concluded that pelagic and non-pelagic species had different migration strategies: pelagic-Atlantic menhaden ride spring tides and meteological tides, while the founder and croaker rely on the repeatability of astronomical tides (see also Pietrafesa, 1986, Joyeux, 1999).

The effects of astronomical and meteorological factors have been echoed by Taylor et al., (2010) in the study of the effect of winter winds and river discharge on juvenile recruitment and distribution of juvenile winter spawned fish. They found that there was a link between meteorological forcing and coastal currents. They also established that juvenile spot were abundant at south and southeast facing inlets during E and SE winds; coinciding with cyclonic fronts that pass over North Carolina at about 2 weeks interval in the winter. Epifanio and Garvine (2000) reviewed larval fish and crustaceans transport between the continental shelf and estuaries of the Atlantic continental shelf of North America with a focus on three of the most studied species whose temporal reproductive patterns represent the whole year. These are blue crab (summer and early autumn), Atlantic menhaden (winter spawning), and bluefish (affected by physical processes occurring during spring. They found that transport of fish larvae is primarily influenced by the direction of winds and ocean currents, ocean-freshwater density differences (buoyancy driven flow).

In addition to astronomical and meteorological factors, rising water temperature is correlated with the number of larval fish immigrating to the estuary. Warlen and Burke (1990) sampled the Newport River Estuary, North Carolina for larvae of fall/winter spawning fish species to identify and quantify the fall/winter spawned larvae that immigrate into the estuary, and described observed patterns. Five species: Atlantic menhaden, spot, Atlantic croaker, summer flounder, and southern flounder constituted about 72% of their catch. They also found that heavy larval/early juvenile immigration to the estuary coincided with rising winter temperatures between February and April, and that some had an extended immigration period, which was probably a reflection of the length of the spawning season. They suggest that fall/winter immigrants have an advantage because the predation pressure is minimal during the winter.

While field observation based studies have provided a solid foundation to understanding transport mechanisms of fish larvae from offshore spawning areas to estuaries, Brown et al. (2005) stated that it was difficult to interpret larval abundance data and to discern the temporal and spatial variability of dominant physical processes and larval supply dynamics using field observations alone. They remarked that this could justify the large number of recent studies that used larval recruitment simulation models. Amongst these models, Xie and Eggleston (1999) was very relevant to this study because it was carried out locally and focused on one species, blue crab. Xie and Eggleston used the Princeton Ocean Model (POM) to demonstrate how several wind direction scenarios facilitated water exchanges between the Pamlico Sound and the Atlantic Ocean by two distinct modes: (1) the first mode was stratified, whereby the direction of surface flow at inlets was distinctly different from the bottom flow. West and southwest winds usually led to this flow scenario. This was also the case where pelagic fish and crustaceans ride surface currents while demersal species take advantage of bottom water currents (Xie at al., 1999; Pietrafesa et al., 1986). (2) The second mode was unstratified or equivalently barotropic, whereby water transport at the surface is the same as that of near the bottom. This took place during North and NE winds. Since the exchanges occurred in the same directions throughout the water column, this mode produced strong interactions between the sound and ocean. One important finding of this modeling exercise was the fact that Xie and Eggleston (1999) found that inwelling at Oregon inlet was often accompanied by outwelling at Hatteras and Ocracoke inlets and vice versa while during stratified exchanges, inwelling and outwelling could occur in the three main inlets concurrently. In many ways, these exchanges respected the first law of thermodynamics, "energy can be transferred from one system to another in many forms; however, it cannot be *created* nor *destroyed."* Eastern and southeastern winds, which are typical during the fall and winter, bring lots of ocean water to the sound by an un-stratified mode, and are favorable for larval transport of surface and bottom water through Oregon Inlet (Xie and Eggleston, 1999).

The publications reviewed clearly highlight the role of oceanic currents to any successful estuarine recruitment, whether it takes place in winter, spring, summer, or fall. Although different species have different transport strategies, the planktonic journey from spawning sites to estuaries is facilitated by ocean currents (Pietrafesa et al., 1986). Because of changing climatic conditions and increasing greenhouse gases, we have witnessed unpredictable weather events, such as El Niño, La Niña and shoreline change (Scavia et al., 2002). It is unclear how this is going to affect oceanic currents and fish larvae settlement to estuaries.

After juvenile or larvae of fish and invertebrate have arrived in the estuary or tidal creeks, one or several factors are susceptible of affecting their growth and survival. 1) physical factors such as temperature, salinity, depth, sediments, weather, pollution (Ross and Epperly, 1985; Day et al., 1989; Pietrafesa, 1985; Holland et al., 2005; Eggleston, 2003); 2) water quality parameters, dissolved oxygen, and nutrients (Stanley, 1993; Christian et al., 1991; Mallin, 2000); and 3) biological factors including predation, and presence or absence of food (Brown et al., 2005). In order to examine long-term trends in juvenile recruitment to North Carolina's estuarine nurseries areas, researchers at NCDMF collected data of juvenile fish through the Program 120 for seven commercially and ecologically important species.

In 1972, NCDMF initiated survey on juvenile fish and invertebrate to assess population trends in North Carolina estuarine nursery areas. This program, also known as Program 120, has sampled consistently 105 core stations, which are distributed along the North Carolina estuarine shoreline and are considered essential to fish population trends in the estuary statewide (Sean McKenna, personal communication, 2005). NCDMF biologists have chosen these stations because of their unique locations and because they are spaced to represent all of the North Carolina shoreline. Stations were sampled using an otter trawl with a 10.5-foot-headrope and a 3.2 mm mesh cod-end that was towed for 1 minute (~75 m distance) in the middle of a sampling day. Sampling was not done on the same day in each month because of the limitation of the NCDMF manpower. All stations within a region (~10 stations/region) were not sampled on the same day and it takes approximately 1 week to ten days of sampling each month to cover all stations. The NCDMF field crew recorded the total numbers of each of the selected species collected per trawl. For blue crabs, the number of male and female, as well as size (carapace width) for each individual are recorded. In addition, surface and bottom water temperature and salinity were measured at each station using a YSI model 85 multi-parameter water quality meter or equivalent. Depth was measured using a weighted line or measurement stick at the time of trawling. Consequently, a large set of data of multi-site, multi-temporal and multi-species has been collected.

While closely examining the datasets, one notices that not all stations were sampled every year, and especially at the beginning of the program when sampling efforts were not consistent within a year, at certain stations. However, 71 stations were sampled more consistently each year 1980 to 2004. In addition, surveys were carried out March through November of each year until 1987 when data collection was restricted to only May and June due to budget reasons. Therefore, only May and June data of 71 stations that were sampled consistently throughout the entire 25-year period were retained in this study. The average station depth measured over 25 years was also used. Dissolved oxygen was not recorded consistently over the entire sequence of sampling period (only after 1987), and was not considered in this data analysis. Table 10 lists the number of stations sampled in May and June between 1978 and 2004.

Table 10. Sampling effort in the Program 120 dataset

| Year | Stations in May | Stations in June | Total number of sampling trips |
|---|---|---|---|
| 1978 | 32 | 55 | 87 |
| 1979 | 67 | 69 | 136 |
| 1980 | 70 | 71 | 141 |
| 1981 | 73 | 73 | 146 |
| 1982 | 77 | 77 | 154 |
| 1983 | 91 | 92 | 183 |
| 1984 | 94 | 92 | 186 |
| 1985 | 97 | 98 | 195 |
| 1986 | 104 | 100 | 204 |
| 1987 | 105 | 101 | 206 |
| 1988 | 104 | 105 | 209 |
| 1989 | 103 | 103 | 206 |
| 1990 | 102 | 104 | 206 |
| 1991 | 104 | 103 | 207 |
| 1992 | 105 | 103 | 208 |
| 1993 | 101 | 103 | 204 |
| 1994 | 99 | 103 | 202 |
| 1995 | 102 | 102 | 204 |
| 1996 | 103 | 102 | 205 |
| 1997 | 103 | 103 | 206 |
| 1998 | 104 | 104 | 208 |
| 1999 | 103 | 103 | 206 |
| 2000 | 103 | 103 | 206 |
| 2001 | 104 | 104 | 208 |
| 2002 | 104 | 104 | 208 |
| 2003 | 105 | 103 | 208 |
| 2004 | 104 | 104 | 208 |

## 2.2. Methods

The NCDMF trawl survey data were analyzed with the SAS 9.2 software to produce a dataset that is readily available for analysis using most statistical packages. For every station and every year, a geometric mean was computed for the May and June catch. Then, a five-year running average was calculated for the 1980-1984 and 2000-2004 periods. The five-year average was used in order to avoid outliers, in case some trawl surveys caught an uncharacteristically low or high number for anyone the species. A Z-score of change in catch (the difference between the 1980-1984 average and the 2000-2004 average catch) was computed for every species and every station, and can be interpreted as the normalized change in abundance in the trawl catch for each species (in units of standard deviation). The Z-score is a dimensionless quantity derived by subtracting the population mean from an individual raw score and then dividing the difference between 5-year periods by the population standard deviation. For instance, the change of averaged values between 2000-2004 and 1980-1984 can be computed as:

$$\Delta_s = (\bar{x}_{(2000-2004)} - \bar{x}_{(1980-1984)}) \tag{3}$$

for station *s*, and Z-score of change in catch for station

$$Z = \frac{(\Delta_s) - \bar{x}(\Delta_s)}{\sigma_{(\Delta_s)}} \tag{4}$$

where $\Delta_s$ is the change in catch at each station during the interval 1980-2004;

$\bar{x}_{(1980-1984)}$ is the average catch at each station at the start of the period 1980-1984.

$\bar{x}_{(2000-2004)}$ is the average catch at each station for the end of the same period, and

$\sigma_{(\Delta_s)}$ is the standard deviation of the change in catch at each station.

The normalized index allows for the comparison of relative changes (increase, decrease, or no-change) at stations and species with very different baseline abundances. It also allows a comparison of observations of trawl catches with different ranges, i.e., it normalizes the changes in catch for comparison across species and with environmental variables. For instance, a Z-score of +1.5 indicates an increase in catch by 1.5 standard deviations above the mean for a particular species and station between time 1 (1980-1984) and time 2 (2000-2004). A Z-score $\leq$ -1.96 represents a statistically significant decline (i.e. the sample is within the 5% tail of the low-end of a normal distribution) for that station. A Z-score between -1.96 and 1.96 represents no statistically significant change (i.e., the sample is above the 5% tail of the low-end and below the 5% tail of the high-end of the normal distribution). Finally, a Z-score $\geq$ 1.96 represents a statistically significant increase.

## 2.3. Results

Table 11 displays a sample, simplified dataset for blue crab. All the other species data were organized similarly.

Table 11. Five year average blue crab catch dataset for 1980-84, 1990-94, and 2000-04 and the Z-score of change in catch (latitude and longitude are in North American Datum, 1983)

| STATION | LATITUDE | LONGITUDE | COUNTY | CREEK | CRAB 80-84 | CRAB 90-94 | CRAB 00-04 | DIFF 00-80 | Z-SCORE |
|---|---|---|---|---|---|---|---|---|---|
| CFR11 | 33.982219 | -77.922000 | N.HANOVER | South of Snow’s | 2.4 | 1.0 | 2.0 | -0.4 | -0.12 |
| CFR4 | 34.123889 | -77.929000 | N. HANOVER | North of Snow’s | 2.2 | 1.0 | 0.6 | -1.6 | -0.37 |
| CFR5 | 34.128892 | -77.950000 | BRUNSWICK | North of Snow’s | 1.4 | 0.2 | 0.8 | -0.6 | -0.24 |
| CFR1 | 34.252011 | -77.968000 | BRUNSWICK | Cape Fear River | 1.6 | 1.0 | 3.6 | 2.0 | 0.34 |
| CFR2 | 34.265886 | -77.947000 | N. HANOVER | Smith Creek | 1.2 | 0.4 | 0.4 | -0.8 | -0.18 |
| VC1 | 34.431389 | -77.606000 | PENDER | Virginia Creek | 8.8 | 6.8 | 3.2 | -5.6 | -1.17 |
| SSO1 | 34.477000 | -77.475000 | ONSLOW | Spicer’s Bay | 13.4 | 4.8 | 5.0 | -8.4 | -1.71 |
| SSI1 | 34.517203 | -77.424000 | ONSLOW | Alligator Bay | 7.4 | 2.4 | 4.0 | -3.4 | -0.74 |
| NR10 | 34.593342 | -77.398000 | ONSLOW | Sneads Creek | 1.8 | 0.6 | 1.8 | 0.0 | -0.04 |
| NR13 | 34.625439 | -77.430000 | ONSLOW | Mill Creek | 7.8 | 6.8 | 5.4 | -2.4 | -0.55 |
| NR6 | 34.636392 | -77.331000 | ONSLOW | French’s Creek | 2.2 | 0.6 | 0.4 | -1.8 | -0.37 |
| NR2 | 34.738061 | -77.426000 | ONSLOW | New River | 1.8 | 0.6 | 0.6 | -1.2 | -0.29 |
| NR1 | 34.756111 | -77.436000 | ONSLOW | New River | 1.2 | 0.6 | 0.8 | -0.4 | -0.12 |
| NR4 | 34.724450 | -77.383000 | ONSLOW | N.E. Creek | 1.0 | 0.4 | 0.0 | -1.0 | -0.22 |
| CC3 | 34.751900 | -76.751000 | CARTERET | Mid Newport River | 5.2 | 3.4 | 1.8 | -3.4 | -0.72 |
| CC5 | 34.818111 | -76.623000 | CARTERET | North  River | 2.0 | 1.8 | 2.6 | 0.6 | 0.03 |
| CC7 | 34.825069 | -76.458000 | CARTERET | Oyster creek | 6.6 | 3.0 | 3.6 | -3.0 | -0.64 |
| CC6 | 34.805808 | -76.481000 | CARTERET | Smyrna Creek | 2.0 | 1.4 | 3.2 | 1.2 | 0.23 |
| H2 | 34.864989 | -76.762000 | CRAVEN | Clubfoot Creek | 7.2 | 7.0 | 10.6 | 3.4 | 0.60 |
| CC10 | 34.923061 | -76.359000 | CARTERET | E. Thorofare Creek | 10.2 | 13.0 | 9.8 | -0.4 | -0.08 |
| CC9 | 34.923211 | -76.437000 | CARTERET | Golden Creek | 3.0 | 2.0 | 2.8 | -0.2 | -0.06 |
| J2 | 34.942250 | -76.464000 | CARTERET | Fur Creek | 4.0 | 2.2 | 2.0 | -2.0 | -0.49 |
| G19 | 34.939561 | -76.637000 | CARTERET | Jonaquin Creek | 13.6 | 1.8 | 2.2 | -11.4 | -2.29 |
| J10 | 34.936681 | -76.406000 | CARTERET | Coddugen Creek | 10.0 | 2.6 | 6.2 | -3.8 | -0.78 |
| CC11 | 34.949847 | -76.289000 | CARTERET | SW Prong | 15.8 | 12.8 | 16.2 | 0.4 | 0.00 |

Table 11. (continued). Five year average blue crab catch dataset for 1980-84, 1990-94, and 2000-04 and the Z-score of change in catch (latitude and longitude are in North American Datum, 1983)

| STATION | LATITUDE | LONGITUDE | COUNTY | CREEK | CRAB 80-84 | CRAB 90-94 | CRAB 00-04 | DIFF 00-80 | Z-SCORE |
|---|---|---|---|---|---|---|---|---|---|
| G3 | 34.979000 | -76.507000 | CARTERET | Parson’s Creek | 3.2 | 1.8 | 1.6 | -1.6 | -0.39 |
| F3N | 35.043547 | -76.666000 | PAMLICO | Pierce Creek | 18.0 | 6.4 | 7.0 | -11.0 | -2.12 |
| F12 | 35.037978 | -76.724000 | PAMLICO | Kershaw Creek | 5.8 | 3.2 | 3.0 | -2.8 | -0.62 |
| F1 | 35.063000 | -76.645000 | PAMLICO | Bright Creek | 7.6 | 4.4 | 4.0 | -3.6 | -0.78 |
| E10 | 35.082400 | -76.658000 | PAMLICO | Upper Broad Creek | 7.8 | 4.8 | 2.8 | -5.0 | -1.03 |
| E15 | 35.109261 | -76.586000 | PAMLICO | Green Creek | 6.6 | 7.6 | 14.0 | 7.4 | 1.43 |
| D5 | 35.138369 | -76.594000 | PAMLICO | Bryan Creek | 2.4 | 2.2 | 6.2 | 3.8 | 0.66 |
| CS13 | 35.145419 | -76.667000 | PAMLICO | Moore Creek | 4.6 | 2.2 | 3.8 | -0.8 | -0.24 |
| CS2 | 35.147900 | -76.636000 | PAMLICO | Simpson Creek | 6.0 | 4.4 | 5.0 | -1.0 | -0.20 |
| D8 | 35.156881 | -76.569000 | PAMLICO | Dipping Creek | 3.0 | 7.4 | 10.6 | 7.6 | 1.47 |
| CN1 | 35.176522 | -76.675000 | PAMLICO | Smith Creek | 1.8 | 1.0 | 4.0 | 2.2 | 0.34 |
| CN6 | 35.201272 | -76.558000 | PAMLICO | Dump Creek | 6.2 | 11.8 | 15.4 | 9.2 | 1.68 |
| CN14 | 35.154289 | -76.714000 | PAMLICO | Chapel Creek | 1.2 | 0.6 | 2.0 | 0.8 | 0.07 |
| B43 | 35.214919 | -76.571822 | PAMLICO | Ditch Creek | 8.2 | 16.2 | 10.6 | 2.4 | 0.42 |
| CN3 | 35.195431 | -76.621000 | PAMLICO | Riggs Creek | 3.2 | 7.0 | 7.2 | 4.0 | 0.73 |
| B40 | 35.240089 | -76.591347 | PAMLICO | Upper Jones Bay | 19.0 | 17.8 | 15.6 | -3.4 | 2.90 |
| B20 | 35.264131 | -76.501808 | PAMLICO | Porpoise Creek | 10.6 | 8.4 | 16.2 | 5.6 | 1.04 |
| A12 | 35.300011 | -76.601067 | PAMLICO | Mallard Creek | 4.8 | 1.2 | 0.8 | -4.0 | -0.86 |
| A58 | 35.300492 | -76.510872 | PAMLICO | Clark Creek | 10.4 | 9.4 | 23.6 | 13.2 | 2.50 |
| PAR11 | 35.309089 | -76.783000 | BEAUFORT | South Creek | 1.2 | 0.2 | 0.2 | -1.0 | -0.22 |
| B10 | 35.314639 | -76.500992 | PAMLICO | Long Creek | 10.4 | 9.4 | 21.0 | 10.6 | 1.95 |
| A2 | 35.318681 | -76.636972 | BEAUFORT | Betty Creek | 5.4 | 4.0 | 3.6 | -1.8 | -0.41 |
| PAR16 | 35.340000 | -76.644000 | BEAUFORT | East Prong | 6.4 | 5.8 | 5.4 | -1.0 | -0.33 |
| PAR13 | 35.330700 | -76.685000 | BEAUFORT | Muddy Creek | 4.2 | 1.0 | 2.2 | -2.0 | -0.43 |
| PAR7 | 35.378658 | -76.817000 | BEAUFORT | Porter Creek | 2.2 | 2.6 | 1.8 | -0.4 | -0.14 |
| SB3 | 35.395839 | -76.442000 | HYDE | Striking Bay | 6.4 | 26.0 | 16.4 | 10.0 | 1.91 |

Table 11. (continued). Five year average blue crab catch dataset for 1980-84, 1990-94, and 2000-04 and the Z-score of change in catch (latitude and longitude are in North American Datum, 1983).

| STATION | LATITUDE | LONGITUDE | COUNTY | CREEK | CRAB 80-84 | CRAB 90-94 | CRAB 00-04 | DIFF 00-80 | Z-SCORE |
|---|---|---|---|---|---|---|---|---|---|
| AB1 | 35.406658 | -76.507881 | HYDE | Box Creek | 10.4 | 13.6 | 13.6 | 3.2 | 0.52 |
| OC1 | 35.358589 | -76.130000 | HYDE | Harbor Creek | 14.6 | 31.4 | 27.2 | 12.6 | 2.40 |
| PUR3 | 35.404442 | -76.596000 | BEAUFORT | Bradley Gut | 9.6 | 7.8 | 3.2 | -6.4 | -1.28 |
| RB3 | 35.425092 | -76.434000 | HYDE | Tooley Creek | 11.4 | 6.0 | 10.8 | -0.6 | -0.22 |
| SQB3 | 35.385461 | -76.312000 | HYDE | Oyster Creek | 17.6 | 5.4 | 15.0 | -2.6 | -0.55 |
| PAR9 | 35.428378 | -76.761000 | BEAUFORT | Mixon Creek | 5.2 | 2.2 | 2.0 | -3.2 | -0.70 |
| PUR5 | 35.445439 | -76.528000 | HYDE | Warner Creek | 15.0 | 6.8 | 4.2 | -10.8 | -2.16 |
| RB1 | 35.441739 | -76.431000 | HYDE | Unnamed Western | 4.2 | 13.2 | 8.8 | 4.6 | 0.81 |
| SQB1 | 35.414019 | -76.357000 | HYDE | Shingle Creek | 8.4 | 8.2 | 11.6 | 3.2 | 0.56 |
| JB1 | 35.391011 | -76.255000 | HYDE | NW Creek | 2.6 | 4.0 | 7.0 | 4.4 | 0.77 |
| WB3 | 35.413669 | -76.065000 | HYDE | Douglas Bay | 26.4 | 16.8 | 29.6 | 3.2 | 0.60 |
| WB1 | 35.429561 | -76.064000 | HYDE | Wysocking Bay | 16.0 | 26.4 | 15.4 | -0.6 | -0.20 |
| PUR7 | 35.480511 | -76.541000 | HYDE | Wood Creek | 5.8 | 0.6 | 1.8 | -4.0 | -0.84 |
| FC3 | 35.474042 | -76.008000 | HYDE | Middleton creek | 33.6 | 37.0 | 31.6 | -2.0 | -0.47 |
| FC1 | 35.512181 | -75.986000 | HYDE | Far Creek | 5.2 | 8.4 | 8.8 | 3.6 | 0.62 |
| PAR8 | 35.454497 | -76.818000 | BEAUFORT | Bath Creek | 4.4 | 7.6 | 8.4 | 4.0 | 0.71 |
| LSR3 | 35.601397 | -75.903000 | HYDE | Broad Creek | 3.2 | 2.2 | 4.2 | 1.0 | 0.17 |
| LSR5 | 35.597881 | -75.818000 | DARE | Pains Bay | 7.0 | 9.4 | 9.4 | 2.4 | 0.38 |
| LSR1 | 35.624119 | -75.864000 | DARE | Deep Creek | 8.6 | 10.2 | 7.8 | -0.8 | -0.16 |
| SPB1 | 35.695689 | -75.771000 | DARE | Stumpy Point Bay | 6.2 | 2.4 | 4.6 | -1.6 | -0.39 |

For each species, time series plots are presented using a geometric mean for each year with a LOWESS curve fitted to the data (Figures 11-22). In figures 12, 14, 16, 18, 20, and 22, red circles indicate that catch means declined by a Z-score value greater than 1.96, yellow circles that changes in catch remained within ±1.96 Z-score or “no significant change in catch” occurred, and green circles that mean catch increased by a Z-score greater than 1.96. It should be noted that detailed data plots are attached as appendices 1–42. The appendices are ordered as blue crab: appendices 1–6, brown shrimp: appendices 7 through 12, southern flounder: appendices 13–18, Atlantic croaker: appendices 19 through 24, spot: appendices 25–30, Atlantic menhaden: appendix 31 through 36, and pinfish: appendix 37 through 42.

### 2.3.1. Blue crab

Blue crab catch fluctuated greatly over the 25-year study period with the average catch of 7.1 crabs/trawl. The average catch between 1980 and 1984 was 5.8 crabs/trawl and 11.7 crabs/trawl between 2000 and 2004. A plot of the 25-year time series of blue crab catches, averaged over all 71 stations for May and June collections showed a slight increase in catch (Figure 12). Nineteen ninety six was the peak year for blue crab catch with an overall mean catch of 17.2 crabs/trawl. Overall, the long-term trend in blue crab catch collected at the 71 stations has remained unchanged (Figure 12), as comparisons of means between crab catch in 1980-1984 and 2000-2004 did not show a statistically significant change on the basis of Z-score. Spatially, patterns of overall changes at 71 stations were shown in Figure 13, where boundaries of 5 regions: 1) the lower Cape Fear, 2) New River/Jacksonville, 3) Carteret county, 4) lower Pamlico/Bay River, and 5) Hyde and Dare counties were outlined. Examining data in appendices 2–7, one noticed that three stations, located in Carteret (G19 and F3N, Appendix 3), and Lower Pamlico/Bay River region (PUR5, Appendix 5) registered declines. Three other stations located in Hyde (OC1, Appendix 6), and Pamlico county (A58 and B40, Appendix 5) had increases in crab catches. Figure 14 displays a blue crab catch change in relation to land use changes in adjacent estuarine catchments.

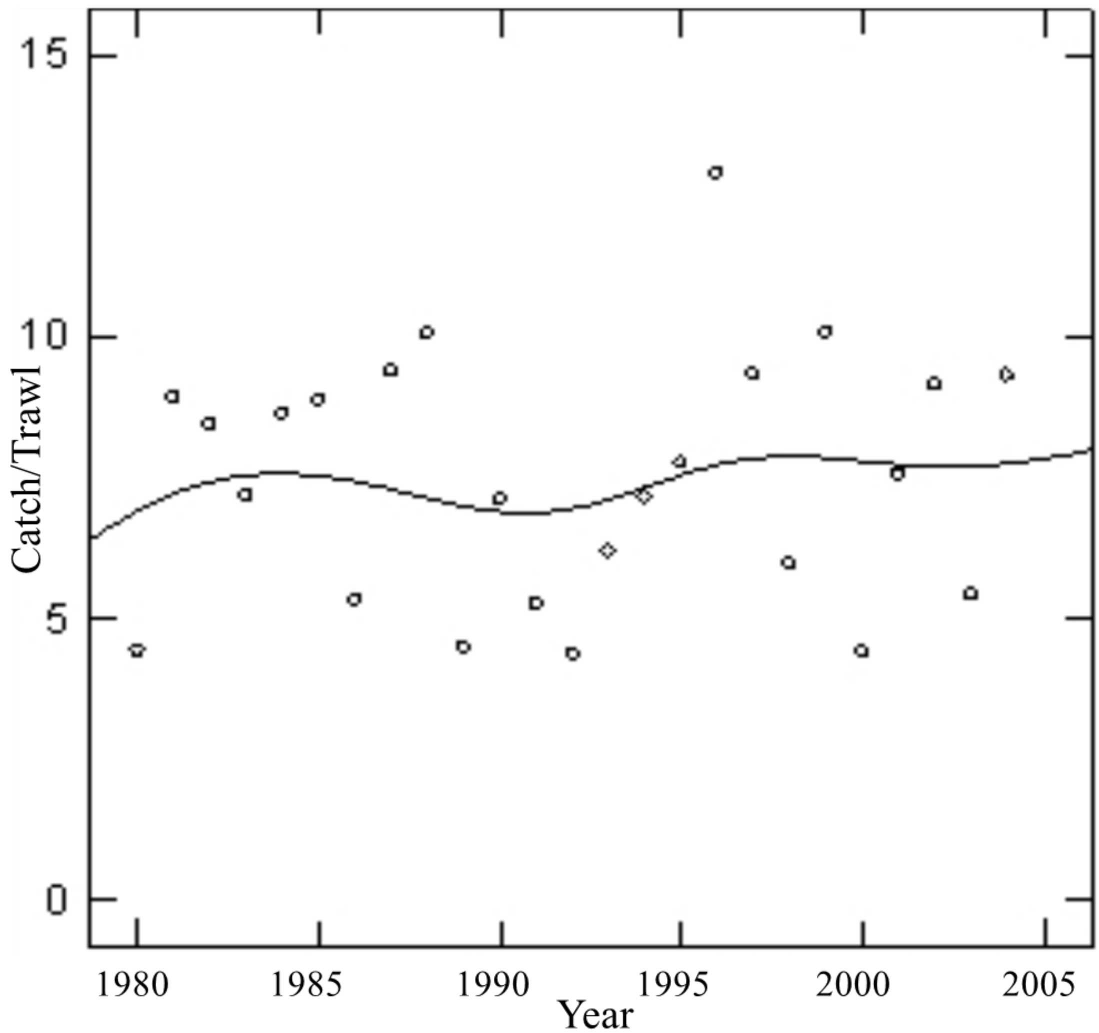



Figure 12. Change in average catch per trawl for blue crab at 71 stations from 1980 through 2004. The curve is a LOWESS fit (f = 0.67).

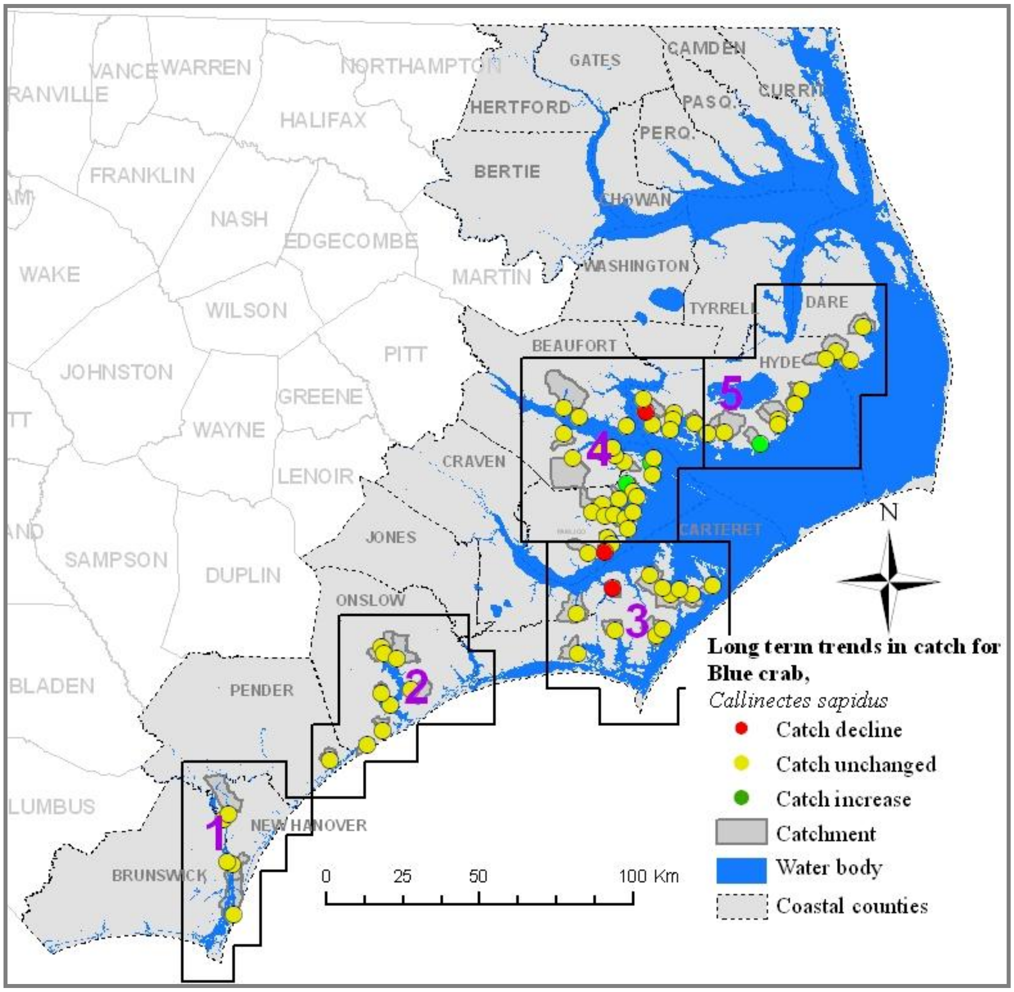



Figure 13. Long term trends in catch for blue crab at 71 stations sampled by the NCDMF. Catch changes are color-coded to show long-term changes: green indicates a significant increase, yellow shows areas of no change, and red shows areas of significant decline in catch.

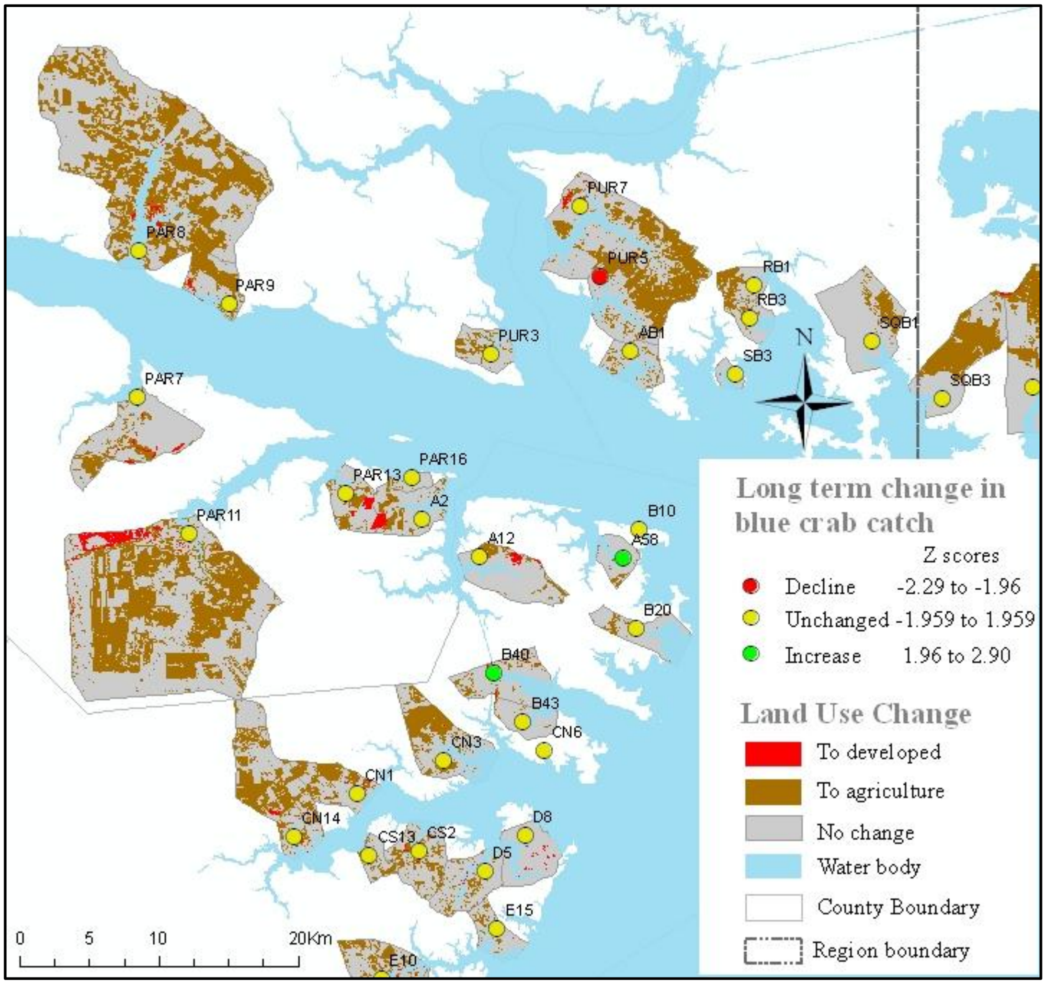



Figure 14. Long-term changes in land use and blue crab catch at 32 stations in Lower Pamlico/Bay River region. (For interpretation of the references to color in the legend, the reader is referred to the electronic version of the chapter on the World Wide Web).

### 2.3.2. Brown shrimp

Brown shrimp catch had an overall mean of 16.7 individuals/trawl during the 25 year study period (Figure 15). There were regular fluctuations, characterized by high peaks, like in 1985 where catch reached 47.8 shrimps/trawl and extremely low catches in 1998 when the mean catch was only 5.1 individuals/trawl (correlation between year and geometric mean catch $r = 0.09$, $p = 0.65$). Considering the spatial extent of the study and the 25 years study period, these differences were not statistically significant as shown in Z-scores (Figure 16). Most of the 71 stations were coded as yellow (no change). A significant increase occurred at four stations (green dots), and a significant decrease at two stations (red dots). The four that increased were FC3 (Middletown Creek), WB1 (Douglas Bay), WB3 (Wysocking Bay), and LSR3 (on Broad creek, tributary of the Long Shoal River), all located in Hyde County and shown on Appendix 12. Brown shrimp catch declined at station NR13 located on Mill Creek, a tributary of Stones Bay in the New River/Jacksonville region (Appendix 8) and station CC7 (Oyster creek, off Core Sound – Appendix 9). The overall trend of brown shrimp catch displayed a slight increase (Figure 15).

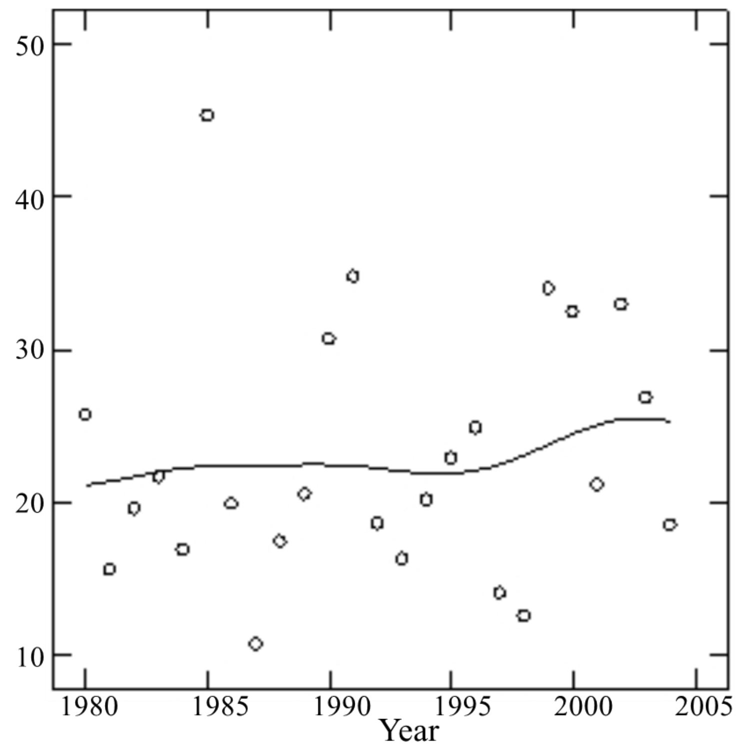



Figure 15. Change in average catch per trawl for brown shrimp at 71 stations from 1980 through 2004. The curve is a LOWESS fit (f = 0.67).

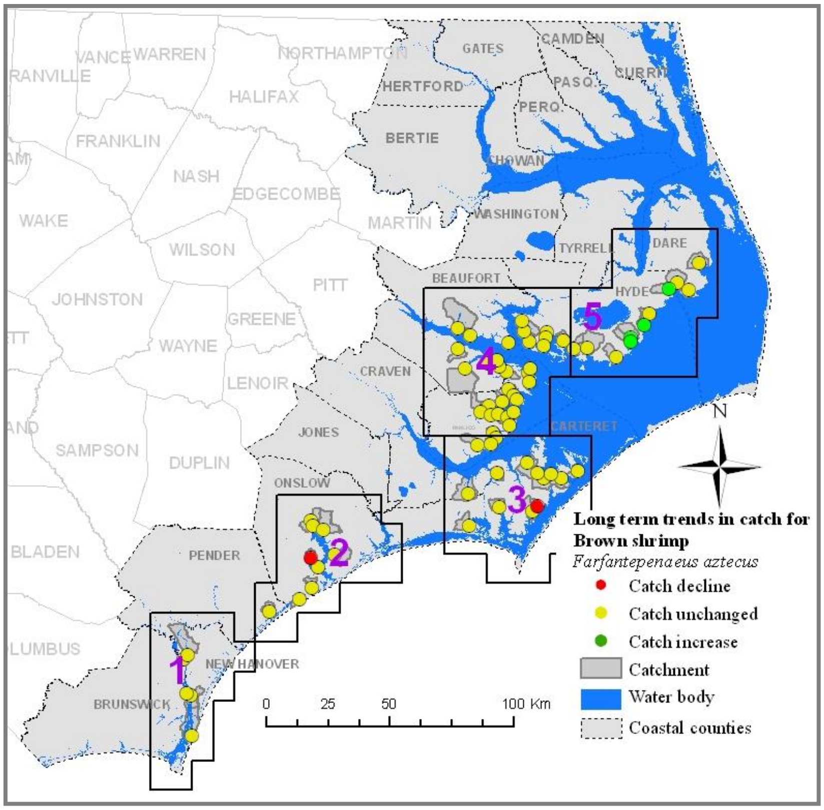



Figure 16. Changes in catch at 71 stations are color-coded to show long-term changes of brown shrimp.

### 2.3.3. Southern flounder

The number of juvenile flounder caught at the 71 NCDMF stations between 1980 and 2004 fluctuated between a geometric mean of 2.8 individuals/trawl in 1980 and 4.2 individuals/trawl in 2004 (correlation between year and geometric mean catch, r = 0.44, p = 0.03). The average catch was 3.7 per trawl, which is among the lowest of the 7 species examined (Figure 17). The overall catch remained unchanged at 68 stations, but increased significantly at three stations. These were CFR1, on the lower Cape Fear River (Figure 18 and Appendix 13), station H2 on Club foot Creek in Craven County (Figure 18), and station D8 located on Dipping creek, a tributary of Long Creek in Pamlico County (Appendix 17). There were no recorded declines in southern flounder catch.

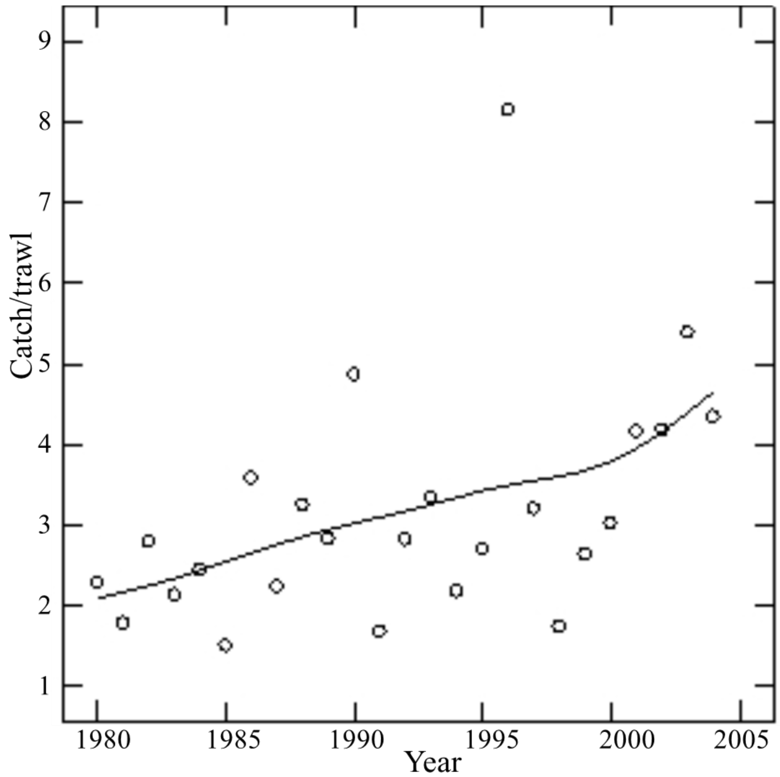



Figure 17. Change in average catch per trawl of southern flounder at 71 stations from 1980 through 2004. The curve is a LOWESS fit (f = 0.67).

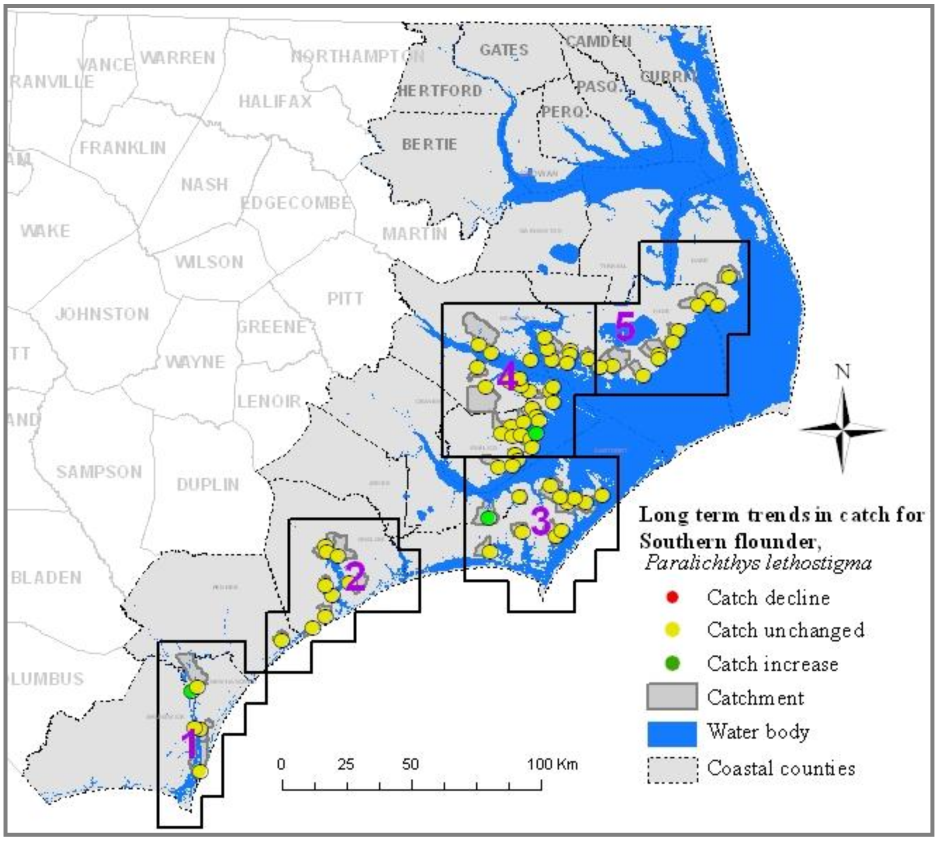



Figure 18. Changes in catch at 71 stations are color-coded to show long-term changes of southern flounder.

### 2.3.4. Atlantic croaker

The overall mean catch for Atlantic croaker was 21.6 fish/trawl (Figure 19). Catches exhibited large fluctuations, with a low of 6.1fish/trawl in 1991, and a high of 58.4 fish/trawl in 1983. Catch declines were observed at three stations, one in Pamlico County (F1, Appendix 21) and two in Beaufort County (PAR11 and PUR5, Appendix 23). Two stations in lower Pamlico River (A2 and PAR16, Appendix 23) showed increases in catch (see also Figure 20).

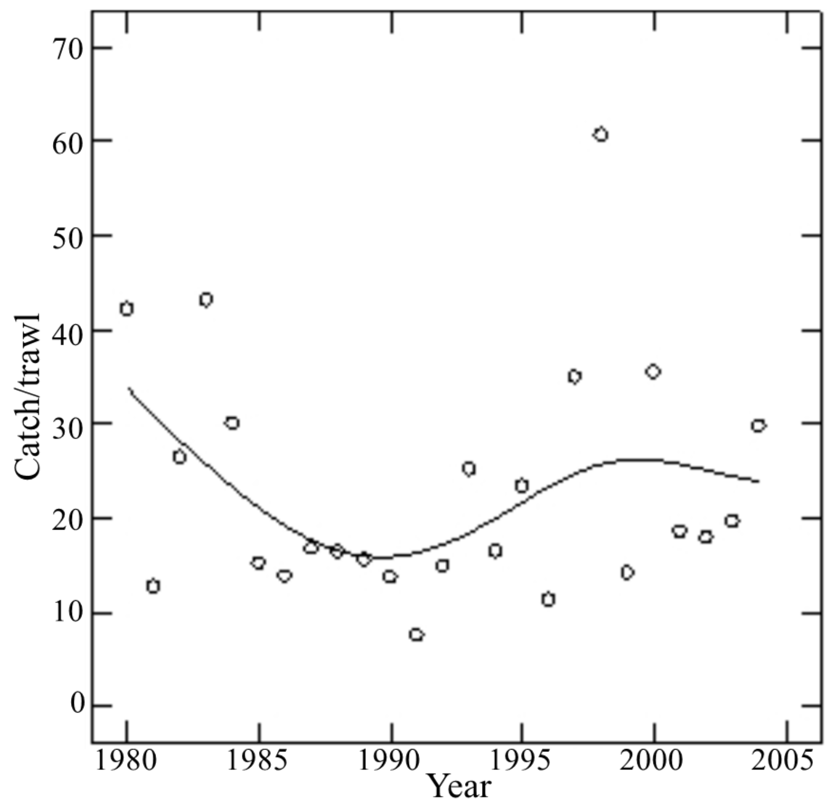



Figure 19. Change in average catch per trawl of Atlantic croaker at 71 stations from 1980 through 2004. The curve is a LOWESS fit (f = 0.67).

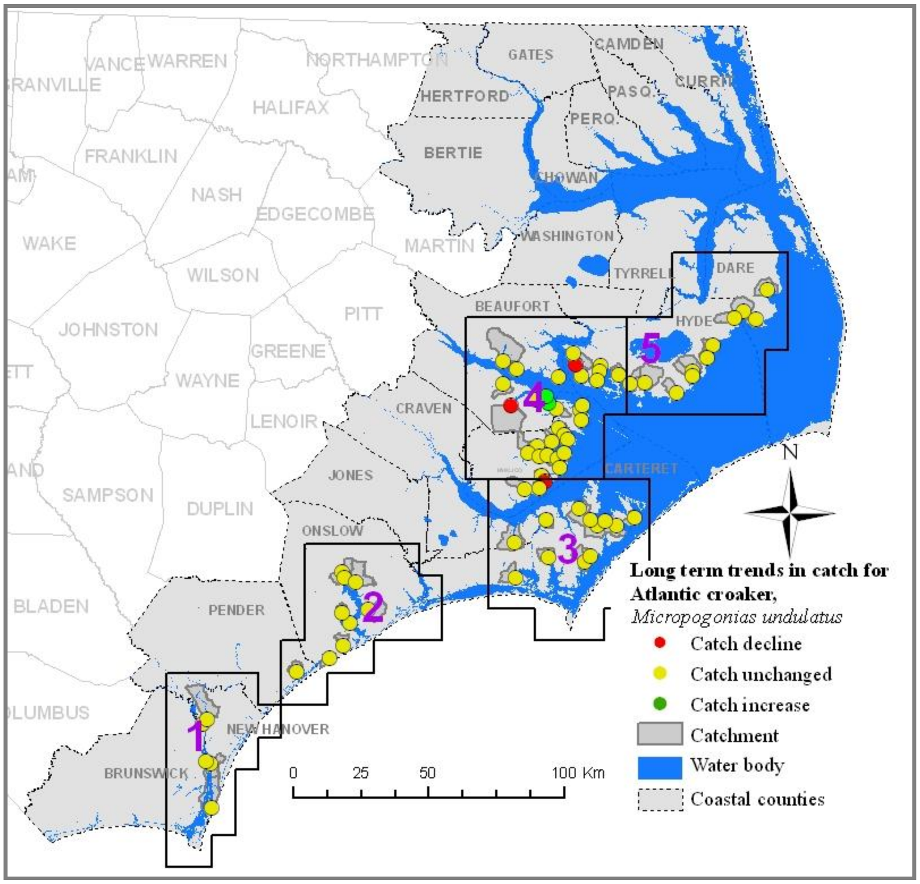


Figure 20. Changes in catch at 71 stations are color-coded to show long-term changes of Atlantic croaker.

### 2.3.5. Spot

The overall mean catch for spot was 114.7 fish/trawl, the highest of all the species considered in this study. Juvenile spot catch increased in mean abundance from an average of 60.7 per trawl in 1980 to178.4 fish per trawl in 2004. However, this trend of increasing abundance was not statistically significant considering the 25 year period (Figure 21, correlation $r = 0.25$, $p = 0.23$). Significant declines of juvenile spot were recorded at two stations, one in Carteret County (Station CC11 located on Lewis creek, a tributary of Core Sound—Appendix 27) and the other in Lower Pamlico/Bay River region (PAR 7, located on Porter Creek – Appendix 29). Increases were observed at three stations in the lower Pamlico/Bay River region (stations A2, A12 and B10 – Appendix 29). Figure 22 is a color coded graphic representation of where the said changes are occurring.

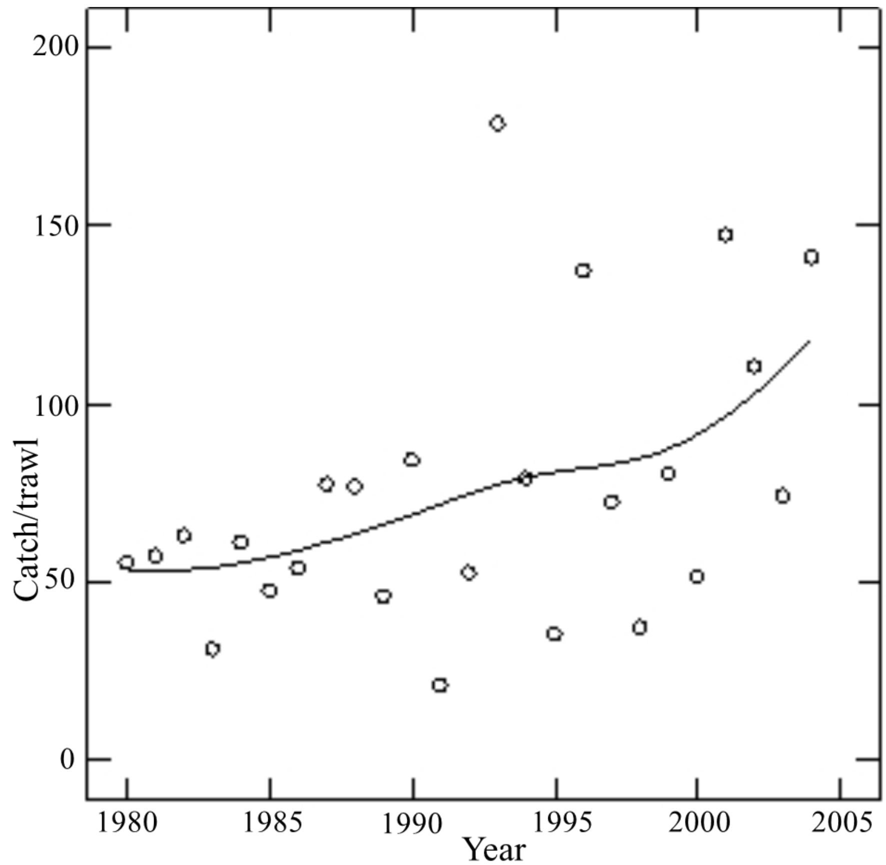



Figure 21. Change in average catch per trawl for spot at 71 stations from 1980 through 2004. The curve is a LOWESS fit (f = 0.67). The correlation between year and geometric mean catch was not significant (r = 0.25, p = 0.23).

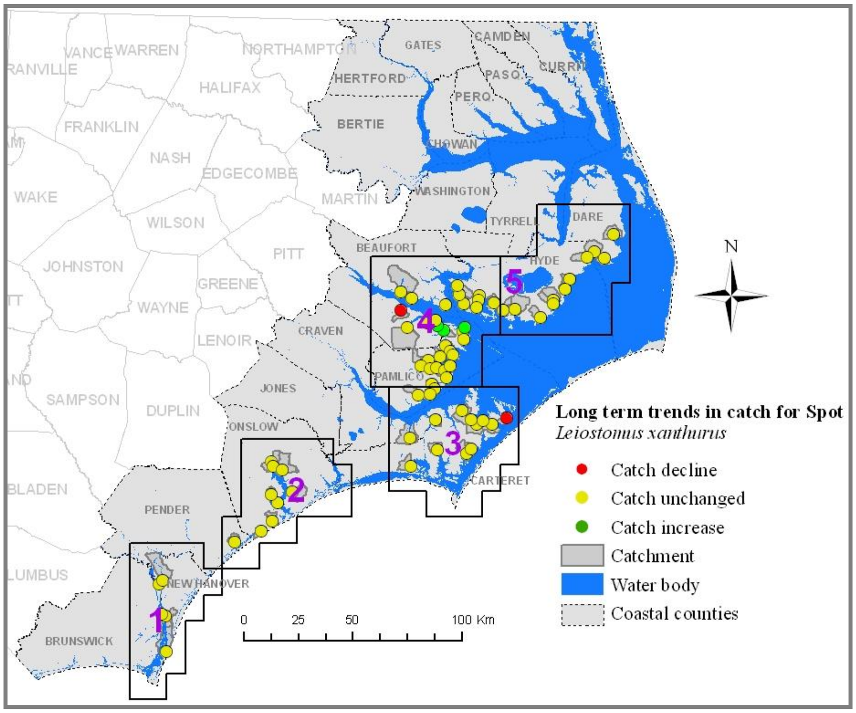



Figure 22. Changes in catch at 71 stations are color-coded to show long-term changes of spot.

### 2.3.6. Atlantic menhaden

Atlantic menhaden exhibited an overall mean catch of 7.2 fish per trawl (Figure 23, correlation between year and geometric mean catch r = – 0.39, p = 0.05). This was the result of a declining trend in mean catch from 8.6 fish/trawl during 1980 to 3.2 fish/trawl in 2000. While station NR4 (Appendix 32) recorded an increase in catch of juvenile Atlantic menhaden, there was a catch decline at three stations. The stations that showed a decline in were F3N, located on Pierce Creek in Oriental, CC9, located on Golden Creek in Carteret County (Appendix 33), and JB1 located on Juniper Bay Creek off Swanquarter Bay (Appendix 36). Figure 23 shows long-term changes in Atlantic menhaden catches at 71 stations on a color-coded map. Sixty-eight stations showed no significant changes, while three registered a decline.

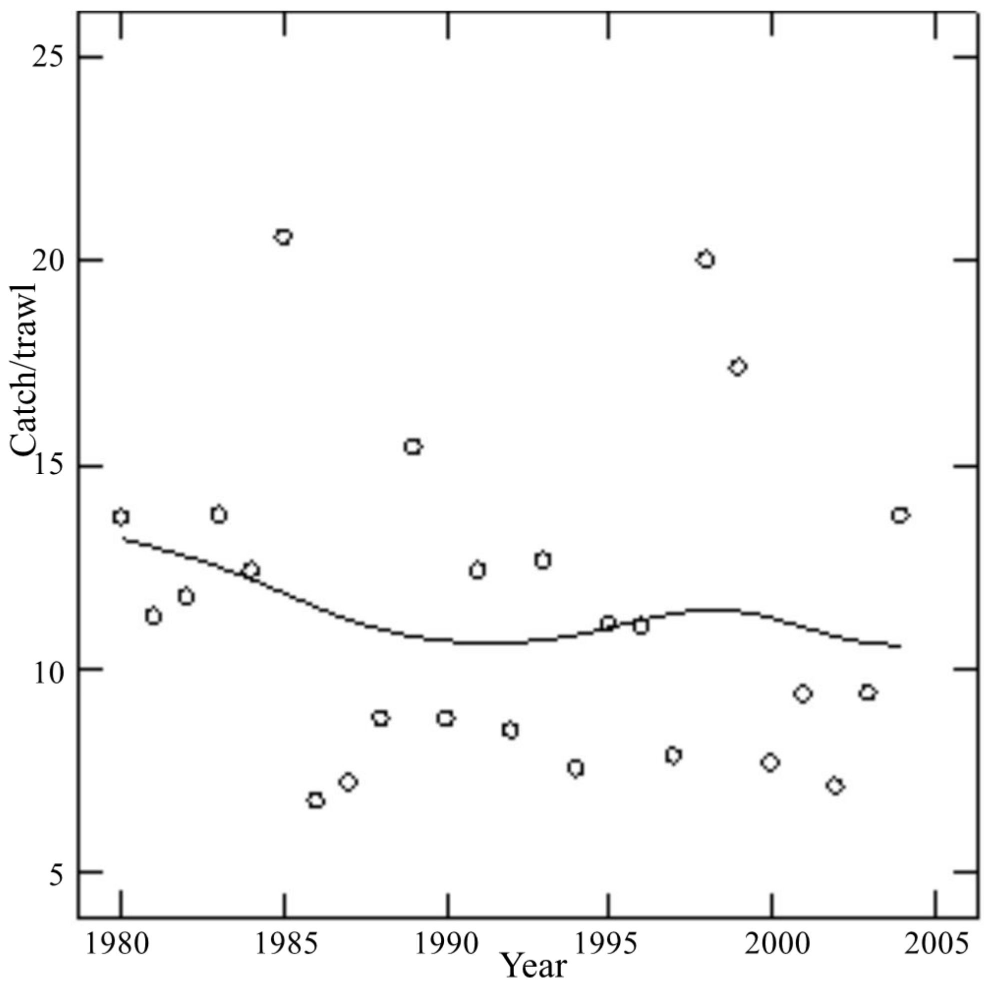



Figure 23. Change in average catch per trawl for Atlantic menhaden at 71 stations from 1980 through 2004. The curve is a LOWESS fit (f = 0.67).

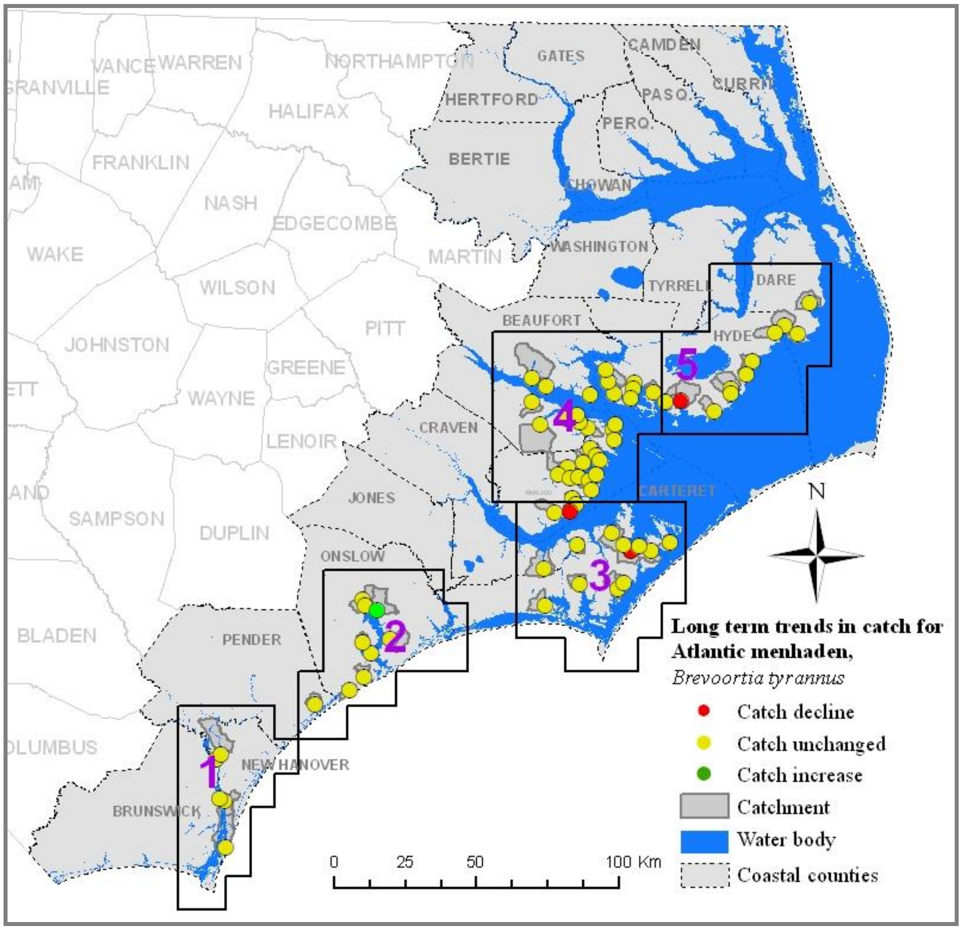



Figure 24.Changes in catch at 71 stations are color-coded to show long-term changes of Atlantic menhaden.

### 2.3.7. Pinfish

The average catch of juvenile pinfish was 15.6 fish/trawl. Catch increased from 1980 through 2004, from a geometric mean of 2.5 individuals/trawl in 1980, to 36.3 fish/trawl in 2001 The correlation between year and geometric mean catch r = 0.65, p = 0.0002 (Figure 25). The differences in mean catch between 2000-2004 and 1980-1984 showed mostly positive values at the 71 stations. Sixty-six stations showed no significant change while five showed a significant increase (Figure 26).The five stations with significant increase in pinfish catch were SS01, located on Everett Bay; NR10 located on Sneads Creek, both on Appendix 38, F1 located on

Pierce Creek, Pamlico County (Appendix 39), E15 (Green Creek, Pamlico County- Appendix 41), and RB3 (Tooley Creek, off Rose Bay- Appendix 41). There was no significant change in pinfish catch in the Hyde/Dare County region. Overall, pinfish catch has shown (Figure 26) an increasing trend.

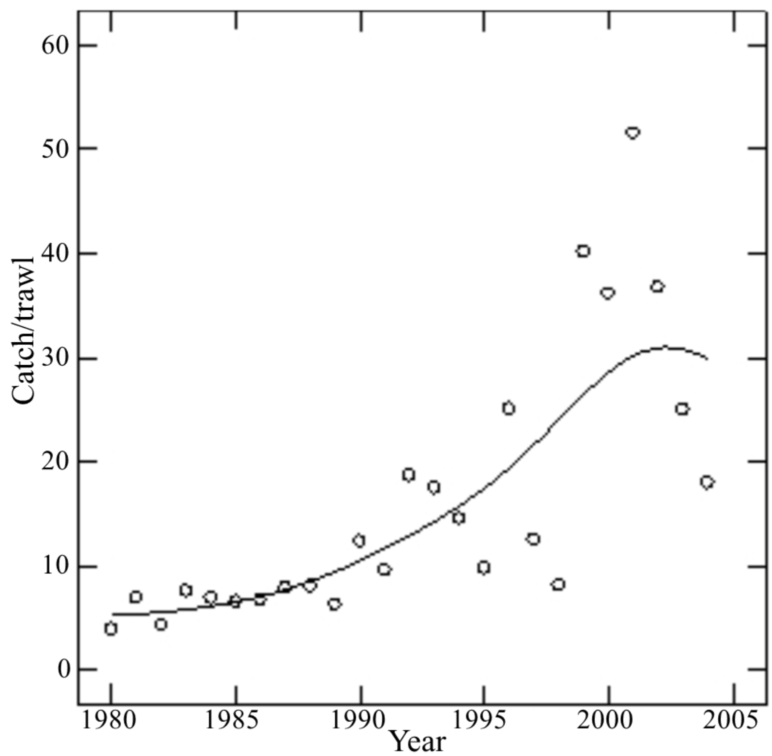



Figure 25. Change in average catch per trawl for pinfish at 71 stations from 1980 through 2004. The curve is a LOWESS fit (f = 0.67).

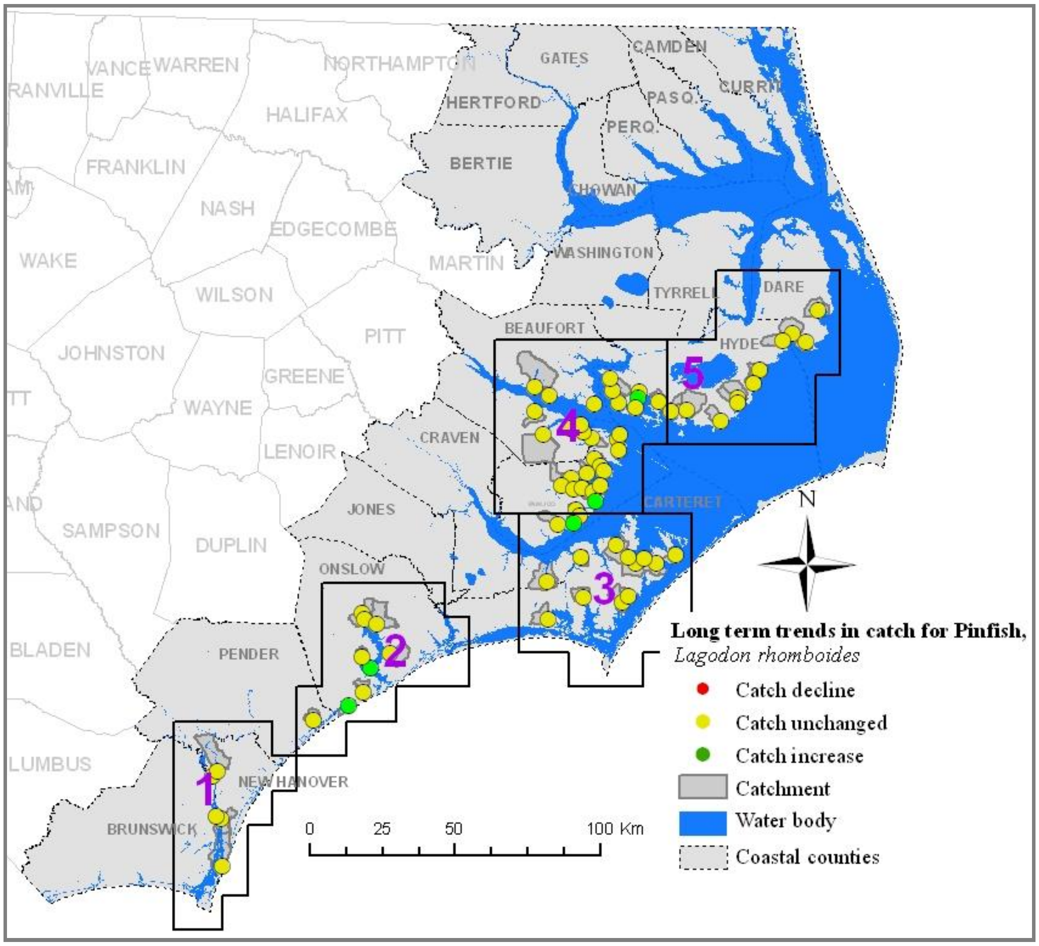



Figure 26. Changes in catch at 71 stations are color-coded to show long-term changes of pinfish.

## 2.4. Discussion

The analysis of trends in catch of juveniles of the seven selected species reveals varying trends. While most of the species have remained stable (blue crab, brown shrimp, Atlantic croaker, spot and Atlantic menhaden), and others slightly increasing (southern flounder and pinfish), their annual catches have fluctuated year after year. Overall, when examined in the absence of environmental data (see Chapter 3), none of the species registered a statistically significant decline or increase, based on Z-scores that were lower than -2 or greater than 2 (two standard deviations below or above the long-term mean for a station). For any single species by this criterion (raw changes in abundance), the maximum number of stations with declines is three out of 71 (Table 12). This level of variation suggested that the observed “declines”, without considering land use effects, for example, could be due to chance alone. In Chapter 3, the influence of land use change and other environmental factors that contributed to this variation will be analyzed. Southern flounder and pinfish did not show declines at any station, which could be an indication of a healthy population. With 7.0% of the stations studied there is a long-term increase in juvenile pinfish recruitment. This could be due to the fact that adult stock pinfish are not heavily fished, while some of their predators like blue crab are sought after by commercial and recreation fishing. Brown shrimp shows a strong trend of increase with four stations (5.6 %) showing a significant increase. This trend is especially discernible in the Hyde/Dare region.

Table 12. Summary table of changes in catch for the seven species

| Species | Decline<br>station name – location | Increase<br>station name – location |
|---|---|---|
| Blue crab | G19 - lower Pamlico River,<br>F3N - lower Neuse River<br>PUR5 - Pungo River | OC1-East Bluff Bay |
| Southern flounder | ———— | CFR1 - Lower Caper Fear Rive<br>H2 - Lower Neuse River<br>D8 - Bay River |
| Brown shrimp | NR13 - Mill Creek, New River<br>CC7 - Oyster Creek, off Core Sound | LSR3 - Broad Creek, off Long Shoal River<br>FC3 - Middleton town Creek<br>WB1 - Wysocking Bay<br>WB3 - Douglas Bay, off Wysocking Bay |
| Atlantic croaker | F1 - Orchard Creek, lower Neuse River<br>PAR11 - South Creek<br>PUR5 - Warner Creek, off Pungo River | PAR16 - East Prong Cypress Branch, off lower Pamlico River<br>A2 - Betty Creek, off Pamlico River |
| Spot | CC11 - Lewis Creek, off Core Sound<br>PAR7 - Porter Creek, off Pamlico River | A2 - Betty Creek, lower Pamlico River<br>A12 - Mallard Creek, off Pamlico River<br>B10 - Long Creek, off Pamlico River |
| Menhaden | JB1 - Juniper Bay, Pamlico Sound<br>F3N - Pierce Creek, lower Neuse River<br>CC9 - Golden Creek, West Bay, Pamlico Sound | NR4 - North East Creek, off New River |
| Pinfish | ———— | SS01 - Everett Bay, near Topsail Beach<br>NR10 - Sneads Creek, off New River<br>F3N - Pierce Creek, lower Neuse River<br>E15 - Green Creek, lower Neuse River<br>RB3 - Tolley Creek off Rose Bay |

It has been documented that the adult blue crab population is declining in the Chesapeake Bay (Lipcius and Stockhausen, 2002), and along the North Carolina coast (Eggleston et al., 1998). Lipcius and Stockhausen (2002) document a concurrent reduction in the spawning stock, recruitment, larval abundance and female size in the Chesapeake Bay during the period of 1992 to 2000. Kahn and Helser (2005) report that over fishing in the Delaware Bay has triggered a compensatory spawning in blue crab, so that the fishing pressure is not being felt. Jennings and Kaiser (1998) collaborated the assertion that the compensatory increase in individual fecundity, coupled with an apparent increase in the proportion of females spawning annually but limited the decline in egg production over time. The NCDMF dataset of juvenile fish and invertebrate catch from 1980 to 2004 does not show significant increase or decline in any of the seven selected species. This is likely due to the fact that the five major factors of successful maintenance of populations (Miller 1991) have not been severely altered. These factors are recruitment, adequate food supply, and refuge from predation, abiotic environment, and a successful migration to juvenile nursery areas (Miller et al. 1991). However, the increased removal by commercial and recreational fishing, and predation of adults may translate in the declining number of larvae and juveniles, as is likely the case with menhaden (Uphoff, 2003, Hartman, 2003).

Furthermore, Jackson et al. (2001) examined historical overfishing and were able to link it to recent coastal ecosystems declines. The premise of their study is that, severe overfishing of one particular species can drive it to ecological extinction, because overfished populations can no longer interact significantly with other species in the community. Species with a similar trophic level assume their ecological role, until they too are overfished (or preyed upon) or die of epidemic diseases brought about by overcrowding.

Fisheries management agencies need to remain vigilant, so that no species are brought to extinction by overfishing or by the deterioration of fish habitat, including fish nursery areas.

## 2.5. Concluding Remarks

Long-term trends in the Program 120 data for a selected set of seven commercially and ecologically important species of finfish and crustaceans in North Carolina estuarine nursery areas have been examined. The selected species ranked by the importance of their commercial value ($) were blue crab, brown shrimp, southern flounder, Atlantic croaker, spot, Atlantic menhaden, and pinfish. The study revealed that overall, the juvenile population did not change significantly over the 25 years (1980–2004), while it was well documented that the adult population declined in other studies (Lipcius and Stockhausen, 2002) due to fishing pressures and deteriorated environmental conditions (Sellner et al., 2003). It has been widely believed that overfishing could trigger compensatory fecundity and spawning in certain species including blue crabs (Kahn and Helser 2005). However, the increased removal by fishing and predation of adults might reach a threshold that translates in the declining number of larvae and juveniles, as the likely case of menhaden (Utz et al., 2009; Uphoff, 2003). Resource management agencies need to increase measures to protect fish nursery areas, reinforce existing fishing regulations, and continue to monitor juvenile recruitment to North Carolina's estuaries. Sampling efforts should also be extended to late summer months (July to October) to document juvenile survival during periods of high water temperatures and hypoxia.

# Chapter 3. Relationship between land use land cover change and changes in juvenile fish and invertebrate abundance in the estuarine nursery areas of North Carolina.

**Abstract**

Land use and land cover change analysis was performed for years 1980, 1990, and 2000 of a study area covering 71 estuarine catchments adjacent to tidal creeks along the North Carolina coast. The stations were selected by the North Carolina Division of Marine Fisheries (NCDMF) as assessment locations for fish and invertebrate nursery areas. Abundance of a selected set of juveniles of estuarine-dependent species was estimated using the trawl catch of the species by the NCDMF's Program 120, a long-term sampling program. The selected species were blue crab (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztectus),* southern flounder (*Paralichthys lethostigma),* Atlantic croaker (*Micropogonias undulatus),* spot (*Leiostomus xanthurus*), Atlantic menhaden (*Brevoortia tyrannus),* and pinfish (*Lagodon rhomboides)*.

Changes in land use and land cover and in the abundance of species were statistically studied in a classification and regression tree (CART) analysis. Landscape variables were also considered to find which factors were related the most to the observed changes in juvenile fish and invertebrate abundance. The variables were mean bottom temperature, mean bottom salinity, average station depth, distance from each station to the closest inlet, number of point sources and the human population density in the 14-digit watershed in year 2000. CART analysis indicated that there was a negative correlation between the percentage change in conversion of wetland and forested lands to agriculture and developed areas and change in abundance of juvenile blue crabs between 1980 and 2004. Many of the stations in the southern counties,

New Hanover, Onslow, and Carteret, where rapid development is on-going, showed declines. The less developed counties, Hyde, Beaufort, and Pamlico showed increases in blue crab catches. Between 1980 and 2004, a significant decline in catch of southern flounder occurred at those stations with more than 21% land use change from unaltered (forest and wetland) to altered (agriculture and developed) areas. Atlantic croaker declined in stations with more than 54% land use changes from forest and wetland to agriculture or developed land. Declines in spot and pinfish were associated with high human population density in the larger watershed. Atlantic menhaden, the only planktivorous species analyzed did not show any observable trends in abundance as land use changed in the surrounding watershed. CART analysis also suggested that some abiotic factors influenced change in catch. Catch of brown shrimp and southern flounder increased with increasing bottom salinity (salinity > 14 ppt). Increased bottom temperature was associated with increases in Atlantic menhaden and pinfish, and to a lesser extent, brown shrimp and Atlantic croaker. Distance to inlets influenced the change in catch of spot, brown shrimp, and to a lesser extent, Atlantic menhaden and Atlantic croaker. Station depth significantly influenced the change in catch of southern flounder and brown shrimp. The number of juvenile pinfish increased in overall abundance between 1980 and 2000 in those catchments where human population density was low. Apart from the above impacts, it was found that there was no major land use change that affects the overall juvenile fish and invertebrate population of the seven selected species between 1980 and 2004. Amongst the stations that showed declines, southern flounder and Atlantic croaker declined in those stations with disproportionate land use change.

## 3.1. Introduction

Land use change is recognized by the research community as one of the most important factors of global environmental change at the same level as climate change (Vitousek et al., 1997). It can have significant impacts on biodiversity (Skole et al. 1994) and climate change (Lambin 2001). Land use changes have also been associated to declines of estuarine ecosystem habitat and function, abundance and diversity of estuarine species (Holland et al. 2004, King et al 2005, Bilkovic et al. 2006) as well as increased marine eutrophication (Nixon 1995, Paerl et al. 2006). Land use change can be caused by anthropogenic drivers such as deforestation, farming, urbanization, industrialization, and road construction or by natural environmental drivers such as climate change, drought, global warming, fire, and flooding (Skole et al., 1994; and Thomas et al., 2004). Land use changes from unaltered (wetlands or forests) to altered types (agriculture or urban) has been shown to affect streams and rivers by releasing nutrients (Cuffney et al., 2005; Nixon, 1995, and Paerl et al., 1998), pesticides and pollutants (Holland et al.,2005), and sediments (Howarth, 1991) to water bodies downstream. By altering ecosystems, humans also affect ecosystem services, and therefore the ability of biological systems to support human needs (Vitousek et al., 1997). Since this dissertation is concerned with linking catchment/watershed land use changes to estuarine environment and juvenile fish and invertebrate abundance, I will concentrate on the relationship between watershed land use change and estuaries.

In order to explain the complex relationship between land use change and estuaries, a conceptual model is developed to explain the key elements of changing land use that affect estuaries (Figure 27).

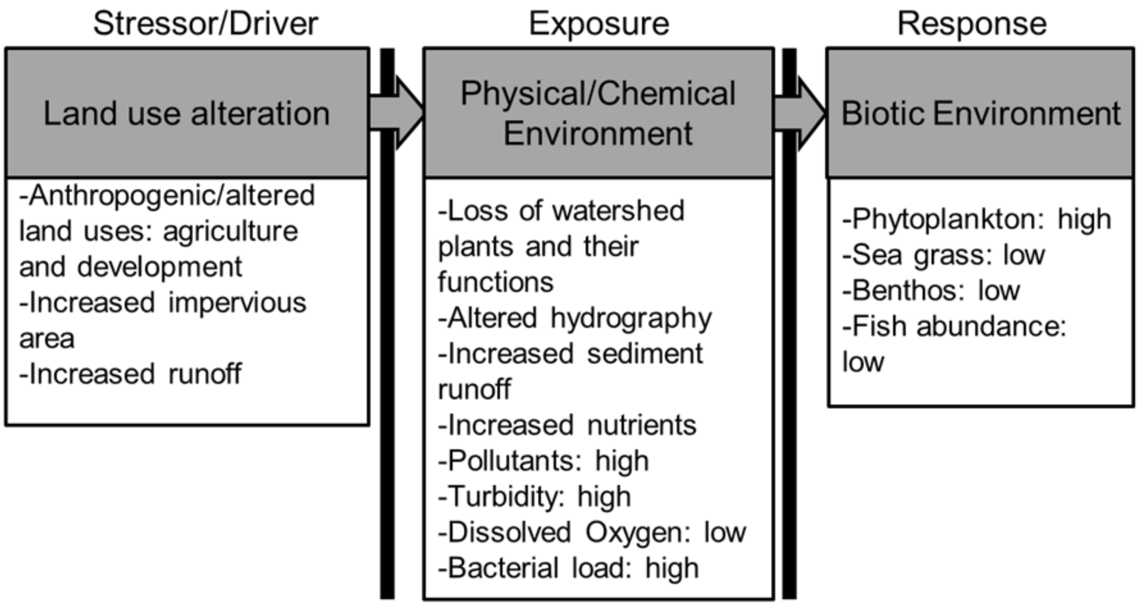



Figure 27. Conceptual model of the relationship between catchment/watershed land use change and estuaries.

Figure 27, which is an adaptation of Holland et al. (2004), illustrates the relationship between coastal catchments and estuaries in Eastern North Carolina. Catchment land use alteration is characterized by the increase of anthropogenic land use types, increase of impervious area, and runoff. According to Arnold and Gibbons (1996), increase in impervious cover is linked to an increase in the amount of nutrients and pollutants washed off watersheds. They also state that as the natural landscape is altered, or paved over, a chain of events is initiated that typically ends in degraded water resources. They characterized streams within watersheds containing <10% of impervious cover as unaltered (or protected), 10-30% as impacted, and greater than 30% as degraded. Holland et al. (2004) take this finding one major step further, stating that when the degree of imperviousness exceeds about 10%, adverse changes in water quality will generally be observed and severe biological degradation may occur when more than about 30% of the watershed is converted to impervious cover. Holland et al. (2004)

studied the relationship between several parameters with the increase in watershed impervious surface and found that water salinity range, the concentration of chemical contaminants, fecal coliform, and abundance of stress tolerant taxa increased with the increase of watershed imperviousness. Also, they observed that the number of stress intolerant species, penaeid shrimps, and concentration of silt/clay declined as the percent impervious increased. King et al. (2004) added to this that the closer to water body the impacted catchments are, the greater impact they will have on estuarine life. In fact, King et al. (2004) were able to link PCB contamination in white perch (*Morone americana*), to the amount and spatial arrangement of the amount of developed land use in the watersheds that discharge in the estuary.

Other specific case studies suggest that the human population increase is associated with land use changes that impact aquatic ecosystems. Cuffney et al. (2005) developed an urban intensity index using a basin-scale human population, infrastructure, land use, land cover, and socio-economic characteristics. The study looked at three different cities: Boston, MA, Birmingham, AL, and Salt Lake, UT. They found that species richness declined with the increasing urban intensity index. In the Neuse River basin (North Carolina), Stow et al. (2001) found that basin scale land use change was the most important variable explaining stream's invertebrate response to urban intensity index. Stow et al. (2001) studied historical nutrient input to the Neuse River basin, North Carolina from 1980 to 1998. They found that nutrient input to the river increased over the years in close concert with the basin's population increases and land use changes, and caused several incidents including algal blooms, low level of dissolved oxygen, fish kills, and outbreak of toxic microorganisms. Stow et al. (2001) also suggests that even if we reduce nutrient input in watersheds, it would take a very long time before the effect of nutrient reduction is felt, especially in those areas with a long history of nutrient accumulation on land.

Mallin et al. (2000) found that growing human population and urbanization are at the base of the increase of point and non-point source of pollution along the North and South Carolina coast. They added that farming, residential and commercial land development, and golf course construction and maintenance are all sources of fertilizers, pesticides, herbicides, sedimentation and turbidity.

There exist many drivers of land use change, some are anthropogenic and others are natural. Aspects of this model will be explained in five concepts: 1) land use change drivers, 2) land use change impact on nutrients cycling, 3) agriculture and nutrients, 4) nutrient transfer mechanisms from landscapes to estuaries, and 5) the effect of landscape change on marine life.

### 3.1.1. Land use change drivers

Land alteration to harvest timber, grow crops, raise animals, build industries or cities is one of the foundations of human civilization. To some extent, land cover change is unavoidable or necessary in order to accommodate the needs of a growing human population. However, land alteration continues to expand in an unorganized fashion (Beach, 2002) and is having impacts on the local and global ecosystems (Vitousek et al., 1997). For example, Allen and Lu (2002) found that between 1973 and 1994, the human population of Charleston, SC increased by 40%, and in the same time, the urban land use category had increased by 250%. Also, in Charleston, South Carolina, Holland et al. (2005) found that the amount of chemical pollutants was substantially higher in urban and industrial watersheds where the impervious cover exceeded 40%. Urban/industrial watersheds contained greater amounts of organic (PAHs, PCBs, and DDT) and trace metal (Cu, Cr, Pb, Zn, Cd, and Hg) contaminants than other creek classes.

### 3.1.2. Land use change impact on nutrient cycling

Land use change is one of the important factors of the global and local environmental change (Vitousek et al., 1997). Forest ecosystems perform nutrient cycling, nutrient uptake, and retention by biota, which retards nutrient movement from the land to streams and rivers (Feller, 2009). Deforestation disrupts this retention and leads to altered nutrient fluxes to fresh waters. Several factors control nutrient loading to streams such as watershed topography, soil erodability, precipitation characteristics, stream channel characteristics, and the extent of roading in a watershed (Feller, 2009). At Hubbard Brook Experimental Forest in New Hampshire, Bormann et al. (1974) reported that deforestation and repression of growth for 3 years increased export of particulate matter from 2.5 MT/km$^2$/year to about 38 MT/km$^2$/year, in the third year after cutting the forest. In temperate watersheds, it is reported that pristine watersheds export about 0.1-0.2 MT nitrogen/km$^2$/year, while agriculture and urbanized watersheds may export more than 10 MT of nitrogen/km$^2$/year (Hessen, 1999). A major fraction of the amount of nitrogen exported from temperate watersheds is in the form of organic nitrogen and is associated with the amount of organic carbon, which may range from 0.9 to 7.3 MT/km$^2$/year. The export of phosphorus will show pronounced variability among watersheds, depending on population and land use alteration. Fluxes of nitrogen and phosphorus tend to increase with watershed disturbance, but there is a strong tendency towards higher nitrogen/phosphorus ratios in more disturbed watersheds, especially agricultural areas.

### 3.1.3. Agriculture and nutrients

Fertilizers with Nitrogen, Phosphorous, and Potassium are essential to agriculture for they help increase crop production, but they also can cause problems in water bodies. Today, about 33% of the land surface of earth is under agriculture use (Vitousek et al. 1997). Agriculture intensification relied upon ample supply of inorganic nitrogen (nitrate and ammonia), which was first produced in 1907 (industrial scale in 1913) using the Haber-Bosch process, originally developed by a German chemist, Haber. Nitrogen is considered to be the most important nutrient for the primary productivity in terrestrial and marine environments (Vitousek and Howarth, 1991; Hessen, 1999). Its application on farmlands has increased agricultural production but also has led to an increase in nutrient discharge in streams (Jordan et al., 1997). In large watersheds, it has been found that the rate of nitrate discharge to streams is highly correlated with anthropogenic input of nitrogen from atmospheric deposition, fertilizer application, cultivation of nitrogen-fixing crops, and net import of agricultural products (Jordan and Weller, 1996). In contrast, discharges of phosphorus may be more strongly influenced the underpinning watershed geology (igneous or sedimentary rock) than anthropogenic inputs (Dillon and Kirchner, 1975). For example, discharges of phosphorus from some watersheds were found to be related to rates of erosion or soil type, but not to rates of application of phosphorus fertilizer (Jordan et al., 1997).

Increase in nutrient application to farms has played a large role in excess nutrient discharge to estuaries, which can lead to marine eutrophication and anoxic conditions (Zimmerman and Canuel, 2000). These conditions were reported in the Gulf of Mexico (Mitch et al., 2001), the Chesapeake Bay (Gallegos and Jordan, 1992; Zimmerman and Canuel, 2000), and the Neuse River Estuary and Pamlico Sound in North Carolina (Stanley, 1993; Mallin and Cahoon, 2003). Mitch et al. (2001) state that the Mississippi River drains a basin of about 3 million $km^2$. It contributes nitrogen to the Gulf of Mexico not only by nitrogen runoff from the large Midwestern farms, but also by the hydrologic alteration of the landscape, and atmospheric depositions of nitrate. Domestic water discharges from cities and suburbs, point sources of discharge such as animal feedlots, and other sites of intensive agriculture activity are also important contributors of nutrients. This phenomenon is replicated across the nation. According to Hessen (1999), a significant correlation has been shown between total nitrogen runoff and crop yield, as well as between nitrogen runoff and soil mineral content of nitrogen. Holland et al. (2004) found a correlation between land use degradation, and nutrient runoff with living resources including reduced abundance of stress-sensitive micro and macrobenthic taxa, reduced abundance of commercially and recreationally important shrimp, and altered food webs. A watershed condition study carried out in 23 sub-watersheds in lower Chesapeake Bay (King et al., 2005) found that watershed development and especially development near a stream influenced the stream's water quality and had an effect on macro-invertebrate assemblages.

### 3.1.4. Nutrient transfer mechanisms from landscapes to estuaries

Nutrients are transferred from landscapes to water bodies, often intermittently. Pulses of nutrients into estuaries are linked to seasonal agricultural activities, irregular events such as heavy precipitation or large construction projects (Carpenter et al., 1998). The nutrients are transported by overland flow delivered via rivers draining urban centers and agricultural watersheds (Paerl, 2006; Howarth et al., 1996; Jaworski et al., 1997). In addition, nutrients arrive by groundwater flow (Peterjohn and Correll, 1984) or through the atmosphere to receiving waters (Carpenter, 1998; Paerl et al., 2002). As they are transported by streams, nutrients are retained, used or transformed by biological activity (autotrophic or heterotrophic production) or chemical cycling (Bernot et al. 2006).

### 3.1.5. The effects of landscape change on marine life

Because of the amount of discharges they receive from coastal rivers and watersheds, estuaries are among the most productive aquatic ecosystems on Earth (Paerl et al., 2006). With the increased coastal urbanization (Beach, 2002, Kemp et al., 2005, Crawford, 2007) and agricultural intensification, more nutrients are loaded to estuaries, which can lead to accelerated estuarine primary production or eutrophication. Eutrophication is characterized by increased algal bloom, including some harmful taxa, such as *Pfiesteria piscicida* (Anderson et al., 2002; Sellner et al., 2003; Mallin et al., 2005), increased accumulation of organic matter, and excessive oxygen consumption (Paerl, 2006). Other factors that influence estuarine primary production include natural processes such as circulation, upwelling relaxation, and/or the chance occurrence of the right combination of environmental factors such as temperature and salinity (Sellner, 2003).The enhanced growth of phytoplankton and algal blooms, if concentrated in one part of the estuary for a long time, can have deleterious consequences to the estuarine habitat. This is often avoided by water mixing and short residence time, which help with flushing of eutrophic water column.

In order to establish whether there exists a relationship between land use change and juvenile fish and invertebrate abundance in North Carolina coastal area, a collection of datasets was analyzed using statistical analyzes, GIS, and remote sensing procedures, which were supplemented by field accuracy assessment surveys.

## 3.2. Methods

To examine the long-term trends in land use and catches of selected species of juvenile estuarine-dependent fish and invertebrates, I combined (a) satellite remote sensing, (b) land use classification of a multi-date satellite imagery, (c) change analysis of the land use classes within defined catchment areas, and (d) analysis of the NCDMF Program 120 trawl catch data. The imagery data sets were analyzed using Anderson level 2 land use classification (Anderson et al. 1976). The resultant land use data was merged with summary statistics of the NCDMF Program

120 catch data to allow a comparison of changes in land use and catches in each of the 71 associated sampling stations. The overall approach is shown in a conceptual framework (Figure 28).

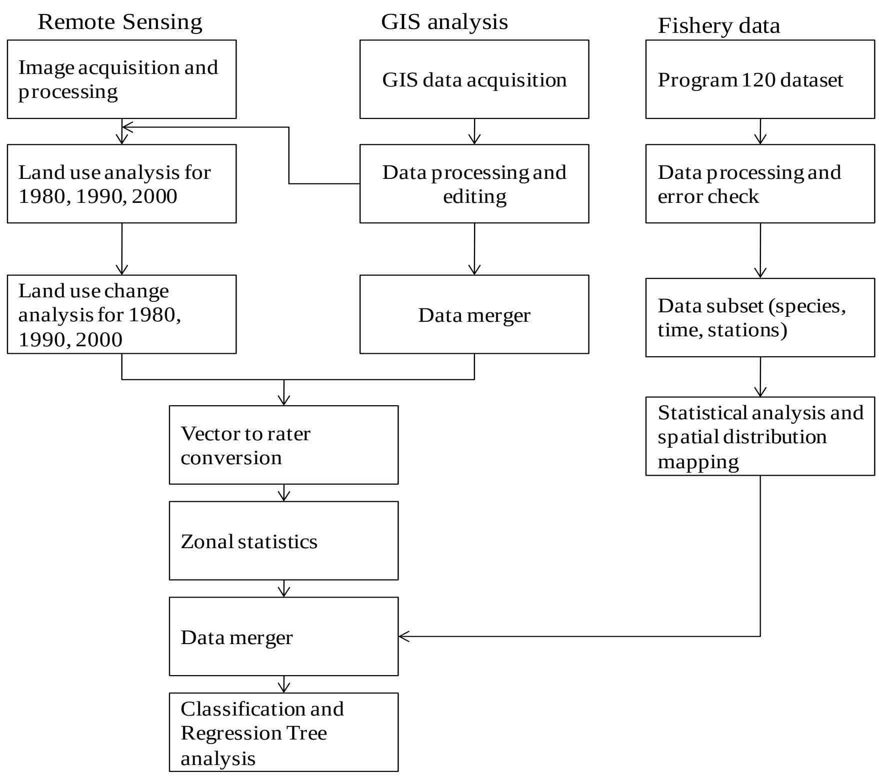



Figure 28. The overall scheme to study land use and catch statistics.

### 3.2.1. GIS and Remote Sensing

Landsat imagery from 1980, 1990, and 2000 were classified using the ISODATA clustering algorithm of the unsupervised classification technique. The unsupervised classification was supplemented by a supervised classification utilizing the MLC algorithm. Change analysis was performed on the classified imagery using the post classification image differencing technique to generate information on areas that have changed This information includes pixel to pixel land use categories from time 1 and time 2 and allow computation of the spatial extent of changes by catchment. The number of hectares that switched use type between 1980 and 2000 was incorporated in the analysis of possible relationship between land use change and changes in juvenile fish and invertebrate catch.

GIS techniques were utilized to delineate individual estuarine catchments or sub-watersheds. Each encompasses all the streams and ditches draining downstream to a nursery area as denoted by the NCDMF sampling stations. Catchment boundaries were determined using the federal and North Carolina standards for delineation of hydrologic unit boundaries (USGS and USDA, 2009; Ferguson and Mew, 2000). Other GIS data layers were acquired to provide additional landscape variables, potential explanatory variables of observed changes in juvenile fish caches. The catchments layer was overlaid on the change map and zonal statistics (land use statistics within each zone - catchment) generated using the spatial analysis extension of ARCGIS 9.3. Zonal statistics function was used to calculate statistics on values of an image (raster) within the zones defined in another dataset that can be either raster or vector. The "Tabulate Area" algorithm that cross-tabulates areas between two datasets (ESRI, ArcGIS 9.3, 2008) was utilized.

### 3.2.2. NCDMF Data Analysis

The NCDMF's program 120 dataset was processed and summarized to extract mean of annual juvenile catch per station from 1980 to 2004. The resulting spreadsheet shows the yearly mean catch of juvenile per station and catchment. Initial station selection was done based on local field knowledge regarding juvenile fish abundance and distribution. Environmental variables such as station depth, salinity, sediment type, and temperature were also taken into account. The variables were also summarized and added to the species dataset (chapter 2). Selected land use/cover changes per catchment were also incorporated in the form of percentage of catchment size. Changes in the number of fish caught over the 25 year study period were assessed by time series plots of the catches of juvenile fishes, crabs, and shrimps averaged over all the stations using a geometric mean. Time series helped examine the overall temporal trends in abundance and assess how physical and environmental factors might have affected catches. Each of the selected species abundances in trawls at each station were correlated with bottom temperature (°C), bottom salinity (parts per thousand), and average station depth (m).

### 3.2.3. Statistical Analysis

To relate the land use environmental variables and their changes to the abundance, one averaged catches from each station within three 5-year periods (1980-1984, 1990-1994, and 2000-2004), which were post- and closely- connected with each of the Landsat images (1980, 1990, and 2000). Intervening years were omitted. This made it possible to use the classified Landsat imagery and catch data together in CART analysis (De'Ath and Fabricius, 2000; King et al., 2005). In this way, the mean trawl catches of selected species, environmental variables, and associated land use changes in each catchment can be visualized and integrated. Figure 29 offers a schematic display of how these variables are integrated.

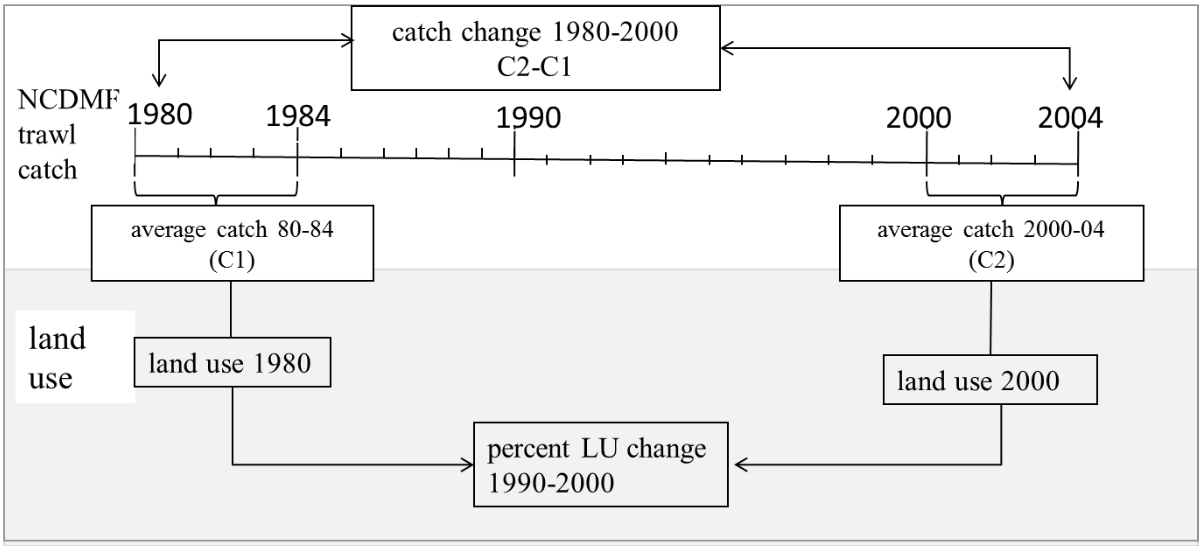



Figure 29. Schematic representation of the process used to relate land use change to changes in species catch between 1980, 1990, and 2000.

For each species and every station, a Z-score of the normalized change in the mean catch during May and June was computed. The Z-score approach provided a normalized index of catches for each station, helping to assess whether or not a station exhibited a significant increase or decrease in abundance of each species over the 25-year period spanning from 1980 to 2004. At each station, a Z-score ≤ -1.96 represents a statistically significant decline (95% confidence). A Z-score between -1.96 and 1.96 represents no statistically significant change. Finally, a Z-score ≥ 1.96 represents a statistically significant increase.

CART analysis was used to determine which environmental or landscape factors most explained the observed changes in juvenile catch over the 25-year spanning from 1980 to 2004. Within the CART analysis, the response variable was the Z-score of the catch change at each station. The land use change predictor variables for the CART analysis was the total percentage of land use change in each catchment; computed as the sum of (1) forested land changed to developed land ($A_{fd}$), (2) forested land that changed to agriculture ($A_{fa}$), (3) agricultural land that changed to development use ($A_{fd}$), (4) wetland that changed to agriculture use ($A_{wa}$), and (5) wetland that changed to developed ($A_{wd}$), all divided by the catchment land areas ($A_t$). Additional landscape parameters considered as predictor variables were (a) the distance of each station to closest inlet, (b) the number of NPDES point sources (including animal feeding operations) within the 14-digit watershed in which the catchment is located, (c) the human population within the watershed area during the 2000 US Census, and (d) the averaged (1980-2004) station depth, and averaged (1980-2004) bottom temperature and average salinity measured at time of trawl.

$$\%\text{land use change} = \frac{A_{fa}+A_{fd}+A_{ad}+A_{wa}+A_{wd}}{A_t} * 100 \qquad (5)$$

## 3.3. Results

### 3.3.1. Land use change and juvenile fish and invertebrate abundance

Throughout the study area, the extent of land use land cover change varied, with catchment close to urban centers witnessing the highest rates of changes. Estuarine catchments located in or close to state or federally protected lands had the lowest rate of change. The percent land use change varied between 0 to 75%, with a geometric mean of land use changed equal to 13.3%. Table 11 showed the overall land use changes in delineated catchments by individual NCDMF stations.

Land use change varied depending on the geographic location of the sampling station, with catchments located in agricultural landscapes witnessing more forest conversion to agriculture, while catchments located around Jacksonville and Wilmington were more affected by urbanization.

Table 11. Areal estimates of land use change from 1980 - 2000 in delineated catchments by individual NCDMF stations.

| Station | County | Total Area (ha) | Water Area (ha) | Land Area (ha) | Forest to Developed (ha) | Forest to Agriculture (ha) | Wetland to Developed (ha) | Wetland to Agriculture (ha) | Agriculture to Developed (ha) | Total Area Change (ha) | % Land change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A12 | PAMLICO | 1316.1 | 66.51 | 1249.59 | 30.22 | 121.27 | 2.84 | 8.61 | 4.87 | 167.81 | 13.43 |
| A2 | BEAUFORT | 1011.13 | 64.35 | 946.78 | 33.79 | 162.61 | 0 | 15.68 | 2.76 | 214.84 | 22.69 |
| A58 | PAMLICO | 475.63 | 235.8 | 239.83 | 0 | 1.46 | 0 | 34.44 | 0 | 35.9 | 14.97 |
| AB1 | HYDE | 739.74 | 130.23 | 609.51 | 0.16 | 33.55 | 0 | 64.66 | 0 | 98.36 | 16.14 |
| B10 | PAMLICO | 103.36 | 38.3 | 65.06 | 0 | 1.46 | 0 | 6.5 | 0 | 7.96 | 12.24 |
| B20 | PAMLICO | 883.68 | 281.16 | 602.52 | 0 | 45.24 | 0 | 14.95 | 0 | 60.19 | 9.99 |
| B40 | PAMLICO | 1165.89 | 197.19 | 968.7 | 10.07 | 122.41 | 2.76 | 9.67 | 1.62 | 146.53 | 15.13 |
| B43 | PAMLICO | 560.04 | 69.3 | 490.74 | 0.49 | 16.33 | 0 | 0.08 | 0 | 16.89 | 3.44 |
| CC10 | CARTERET | 2985.57 | 932.31 | 2053.26 | 157.74 | 50.12 | 13 | 9.26 | 0.81 | 230.92 | 11.25 |
| CC11 | CARTERET | 754.29 | 24.93 | 729.36 | 2.19 | 17.87 | 0.16 | 1.54 | 0 | 21.77 | 2.98 |
| CC3 | CARTERET | 2952.6 | 182.16 | 2770.44 | 101.77 | 299.96 | 2.03 | 45.73 | 81.79 | 531.29 | 19.18 |
| CC5 | CARTERET | 2401.67 | 18.09 | 2383.58 | 29.81 | 986.8 | 2.44 | 64.09 | 5.36 | 1088.5 | 45.67 |
| CC6 | CARTERET | 3275.94 | 343.35 | 2932.59 | 10.15 | 304.68 | 2.03 | 8.53 | 3.09 | 328.47 | 11.2 |
| CC7 | CARTERET | 1456.17 | 101.07 | 1355.1 | 4.71 | 235.55 | 2.68 | 6.82 | 0.57 | 250.34 | 18.47 |
| CFR1 | BRUNSWICK | 738.24 | 9.72 | 728.52 | 6.01 | 33.55 | 1.71 | 5.04 | 5.77 | 52.07 | 7.15 |
| CFR11 | NEW HANOVEI | 6410.41 | 2913.39 | 3497.02 | 254.88 | 270.8 | 36.06 | 51.58 | 29.48 | 642.81 | 18.38 |
| CFR2 | NEW HANOVEI | 7170.9 | 169.65 | 7001.25 | 334.32 | 869.27 | 19.66 | 17.3 | 379.24 | 1619.79 | 23.14 |
| CFR4 | NEW HANOVEI | 3801.6 | 945.99 | 2855.61 | 301.75 | 311.99 | 37.12 | 48 | 30.22 | 729.08 | 25.53 |
| CFR5 | NEW HANOVEI | 3801.6 | 945.99 | 2855.61 | 301.75 | 311.99 | 37.12 | 48 | 30.22 | 729.08 | 25.53 |
| CN1 | PAMLICO | 894.33 | 31.95 | 862.38 | 7.55 | 310.77 | 0 | 12.27 | 6.09 | 336.68 | 39.04 |
| CN14 | PAMLICO | 2315.59 | 47.34 | 2268.25 | 10.64 | 792.92 | 1.95 | 50.36 | 5.69 | 861.55 | 37.98 |
| CN3 | PAMLICO | 1668.33 | 261.81 | 1406.52 | 5.2 | 532.67 | 0 | 3.74 | 0.89 | 542.5 | 38.57 |
| CN6 | PAMLICO | 286.57 | 35.11 | 251.46 | 0 | 6.82 | 0 | 0.08 | 0 | 6.9 | 2.75 |
| CS13 | PAMLICO | 340.75 | 6.21 | 334.54 | 1.87 | 79.03 | 0.08 | 1.3 | 0.57 | 82.85 | 24.77 |
| CS2 | PAMLICO | 1045.15 | 81.9 | 963.25 | 12.51 | 248.14 | 0 | 0.08 | 1.79 | 262.52 | 27.25 |
| D5 | PAMLICO | 1029.51 | 86.31 | 943.2 | 0.16 | 142.63 | 0 | 0.08 | 0 | 142.87 | 15.15 |

Table 11 (continued)

| Station | County | Total Area (ha) | Water Area (ha) | Land Area (ha) | Forest to Developed (ha) | Forest to Agriculture (ha) | Wetland to Developed (ha) | Wetland to Agriculture (ha) | Agriculture to Developed (ha) | Total Area Change (ha) | % Land change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D8 | PAMLICO | 988.44 | 279.45 | 708.99 | 0 | 0.81 | 0 | 0 | 0 | 0.81 | 0.11 |
| E10 | PAMLICO | 1292.01 | 38.61 | 1253.4 | 6.25 | 393.21 | 0.16 | 0.49 | 1.14 | 401.25 | 32.01 |
| E15 | PAMLICO | 582.45 | 100.35 | 482.1 | 0.41 | 60.51 | 0.08 | 0.89 | 0 | 61.89 | 12.84 |
| F1 | PAMLICO | 942.51 | 176.85 | 765.66 | 5.69 | 174.8 | 0 | 0.57 | 0.73 | 181.78 | 23.74 |
| F12 | PAMLICO | 2188.41 | 12.69 | 2175.72 | 8.77 | 283.39 | 0 | 1.06 | 6.09 | 299.31 | 13.76 |
| F3N | PAMLICO | 786.96 | 149.49 | 637.47 | 11.94 | 90.32 | 1.62 | 0.41 | 18.44 | 122.73 | 19.25 |
| FC1 | HYDE | 2462.95 | 287.1 | 2175.85 | 0 | 391.75 | 0 | 6.99 | 0 | 398.73 | 18.33 |
| FC3 | HYDE | 866.19 | 38.61 | 827.58 | 18.93 | 125.31 | 0 | 60.68 | 0.16 | 205.08 | 24.78 |
| G19 | CARTERET | 1461.94 | 72 | 1389.94 | 11.13 | 371.28 | 0.32 | 3.49 | 0.49 | 386.71 | 27.82 |
| G3 | CARTERET | 4823.01 | 809.01 | 4014 | 10.88 | 557.85 | 2.68 | 12.1 | 0 | 583.52 | 14.54 |
| H2 | CRAVEN | 6199.66 | 352.35 | 5847.31 | 225.07 | 760.59 | 8.29 | 28.1 | 80.01 | 1102.06 | 18.85 |
| J10 | CARTERET | 2690.79 | 426.51 | 2264.28 | 64.9 | 64.17 | 0.65 | 5.04 | 0 | 134.75 | 5.95 |
| J2 | CARTERET | 1461.94 | 272.61 | 1189.33 | 16.33 | 864.15 | 0.16 | 14.62 | 0.41 | 895.67 | 75.31 |
| JB1 | HYDE | 5445.91 | 100.44 | 5345.47 | 1.79 | 380.86 | 0 | 27.54 | 0 | 410.19 | 7.67 |
| LSR1 | DARE | 3979.51 | 317.43 | 3662.08 | 0.16 | 3.66 | 0 | 3.82 | 0.1 | 7.74 | 0.21 |
| LSR3 | HYDE | 2605.55 | 22.59 | 2582.96 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LSR5 | DARE | 2082.72 | 471.51 | 1611.21 | 0.16 | 0.08 | 0 | 0.24 | 0.02 | 0.5 | 0.03 |
| NR1 | ONSLOW | 2324.75 | 23.22 | 2301.53 | 306.3 | 249.04 | 11.78 | 3.17 | 209.07 | 779.35 | 33.86 |
| NR10 | ONSLOW | 315.24 | 78.66 | 236.58 | 8.29 | 24.04 | 0.57 | 1.14 | 0.08 | 34.11 | 14.42 |
| NR13 | ONSLOW | 1105.91 | 2.88 | 1103.03 | 48.98 | 378.83 | 0 | 3.09 | 4.47 | 435.37 | 39.47 |
| NR2 | ONSLOW | 1900.74 | 114.03 | 1786.71 | 198.6 | 205.74 | 2.44 | 6.01 | 101.61 | 514.4 | 28.79 |
| NR4 | ONSLOW | 5316.28 | 283.5 | 5032.78 | 748.49 | 502.3 | 7.47 | 6.09 | 493.36 | 1757.71 | 34.93 |
| NR6 | ONSLOW | 3395.14 | 39.24 | 3355.9 | 163.59 | 1211.55 | 2.84 | 15.03 | 3.17 | 1396.18 | 41.6 |
| OC1 | HYDE | 2453.53 | 190.53 | 2263 | 0 | 44.59 | 0.16 | 0 | 0 | 44.76 | 1.98 |
| PAR11 | BEAUFORT | 9988.57 | 37.08 | 9951.49 | 183.41 | 3745.69 | 0.49 | 79.76 | 45.24 | 4054.59 | 40.74 |
| PAR13 | BEAUFORT | 794.09 | 21.42 | 772.67 | 27.7 | 152.05 | 0.97 | 11.78 | 28.67 | 221.18 | 28.62 |

Table 11 (continued)

| Station | County | Total Area (ha) | Water Area (ha) | Land Area (ha) | Forest to Developed (ha) | Forest to Agriculture (ha) | Wetland to Developed (ha) | Wetland to Agriculture (ha) | Agriculture to Developed (ha) | Total Area Change (ha) | % Land change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PAR8 | BEAUFORT | 9897.73 | 348.84 | 9548.89 | 38.26 | 3779.4 | 1.87 | 48.41 | 5.28 | 3873.21 | 40.56 |
| PAR9 | BEAUFORT | 838.03 | 26.37 | 811.66 | 10.97 | 305.41 | 0.57 | 18.03 | 0.16 | 335.13 | 41.29 |
| PUR3 | BEAUFORT | 662.75 | 32.13 | 630.62 | 0.49 | 118.59 | 0.32 | 23.23 | 0 | 142.63 | 22.62 |
| PUR5 | HYDE | 1480.57 | 95.04 | 1385.53 | 0.08 | 450.96 | 0 | 38.26 | 0 | 489.3 | 35.32 |
| RB1 | HYDE | 494.04 | 16.92 | 477.12 | 0 | 164.56 | 0 | 8.2 | 0 | 172.77 | 36.21 |
| RB3 | HYDE | 455.27 | 61.02 | 394.25 | 0 | 64.82 | 0 | 12.91 | 0 | 77.73 | 19.72 |
| SPB1 | DARE | 4119.5 | 812.34 | 3307.16 | 0.16 | 15.43 | 0 | 15.6 | 0.47 | 31.66 | 0.96 |
| SQB1 | HYDE | 1811.78 | 59.76 | 1752.02 | 0.49 | 200.95 | 0 | 20.23 | 0 | 221.66 | 12.65 |
| SQB3 | HYDE | 1805.09 | 34.11 | 1770.98 | 2.92 | 815.5 | 0 | 4.14 | 0 | 822.57 | 46.45 |
| SSI1 | ONSLOW | 1662.44 | 1.98 | 1660.46 | 164.07 | 396.62 | 1.3 | 3.57 | 23.47 | 589.04 | 35.47 |
| SSO1 | ONSLOW | 1300.56 | 438.48 | 862.08 | 48.25 | 50.2 | 33.79 | 27.54 | 10.88 | 170.65 | 19.8 |
| VC1 | PENDER | 1662.99 | 27.72 | 1635.27 | 180.48 | 422.78 | 1.71 | 4.47 | 17.95 | 627.38 | 38.37 |
| WB1 | HYDE | 3331.92 | 205.83 | 3126.09 | 39.96 | 429.76 | 0 | 4.63 | 0.89 | 475.25 | 15.2 |
| WB3 | HYDE | 1996.05 | 77.4 | 1918.65 | 69.93 | 239.9 | 0 | 21.12 | 2.36 | 333.31 | 17.37 |

### 3.3.2. Land use change and species abundance

In the assessment of the relationship between catchment land use change and juvenile abundance, change in trawl catch Z-score between 1980 and 2004 was plotted as a function of the percentage change in land use land cover during the same period and within each catchment. Figure 30 through 37 display the relationship, species by species. Overall, there is a negative relationship between the land use change and abundance for blue crab, southern flounder, Atlantic croaker, spot and pinfish.

***Blue crab***

There is a weak negative correlation between the percentage change in land uses and change in abundance of blue crabs between 1980 and 2004, and there is a downward sloping LOWESS fit (Figure 30). A linear regression of Z-score change in blue crab catch on percentage land use change is significant, but explains a small amount of the variation (Adjusted $R^2 = 0.14$, $P= 0.001$). Three stations showed a significant catch increase (2 standard deviations (SD) above the long-term mean) and had a small percent change in land use, whereas the change in catch at another three stations indicated a significant decline (2 SD below the long-term mean), and these had a large percentage in change in land use.

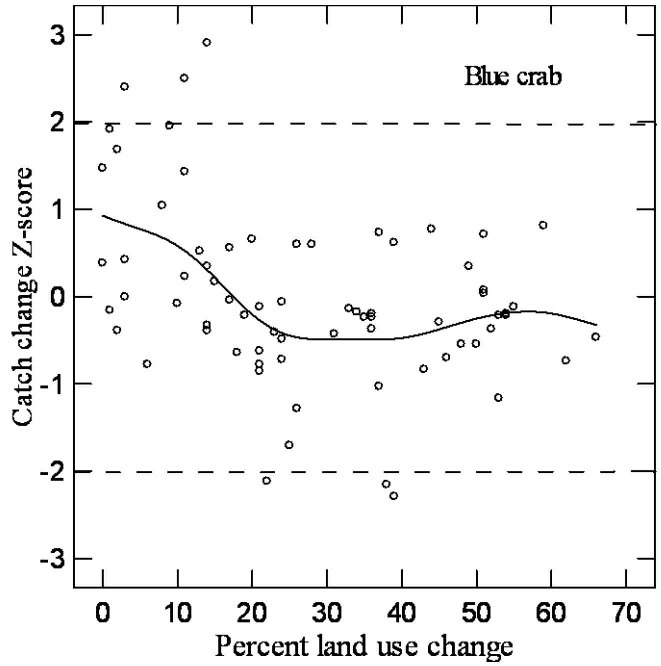



Figure 30. Change in trawl catch Z-score (1980-2004) at each sampling station as a function of percent land use change within catchments for blue crab. The line is a LOWESS (tension =0.5) fit to the data.

***Brown shrimp***

The overall long-term trends of brown shrimp catch have been reasonably stable. However, there was no significant association between Z-score of change in catch and percent land use change (linear regression, P = 0.77 (Figure 31). Four stations, all located in the Hyde/Dare County area, show a slight increase. In this area, urbanization is very slow; especially that most of the land is state or federally owned, and therefore sheltered from anthropogenic land developments. In other parts of the coast, brown shrimp catch has been stable.

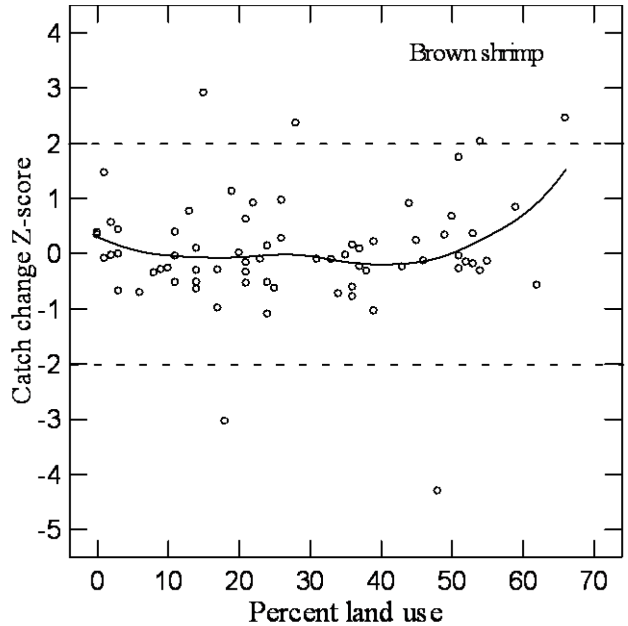



Figure 31. Change in trawl catch Z-score (1980-2004) at each sampling station as a function of percent land use change within catchments for brown shrimp. The line is a LOWESS (tension =0.5) fit to the data.

***Southern flounder***

The majority of stations (68 stations) show no relationship between changes in catch and the changes in land use land cover (Figure 32). The z-score declined as percentage of land use change increased (Figure 31), which is a significant linear decrease (linear regression: southern flounder z-score in catch change = -1.47 * (% land use change) + 0.41, p=0.03). Three stations located respectively in lower Cape Fear, lower Neuse and Bay River area have registered small catch increases. Due to their differences in land use trends, it is believed that this is due to chance alone or other factors are at play.

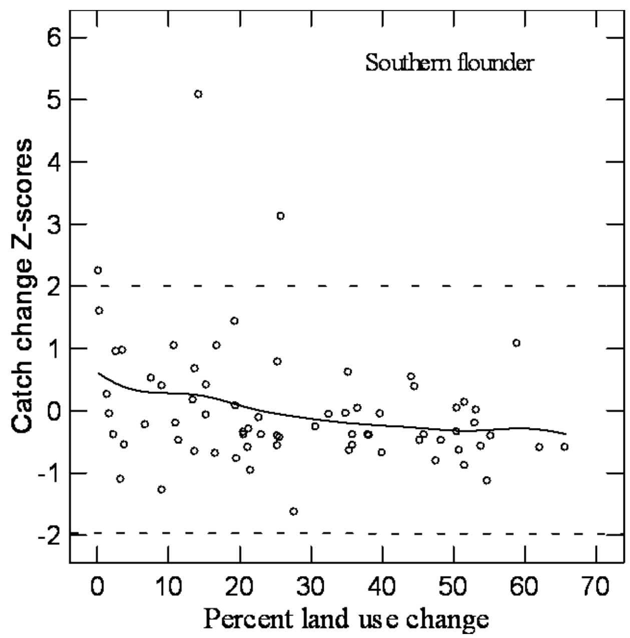



Figure 32. Change in trawl catch Z-score (1980-2004) at each sampling station as a function of percent land use change within catchments for Southern flounder. The line is a LOWESS (tension =0.5) fit to the data.

### *Atlantic croaker*

The relationship between change in catch of Atlantic croaker and changes in land use did not show any significant trend (Figure 33). At sixty-six stations, there was no change. Five stations where changes occur were all located in the eastern part of the Pamlico Sound

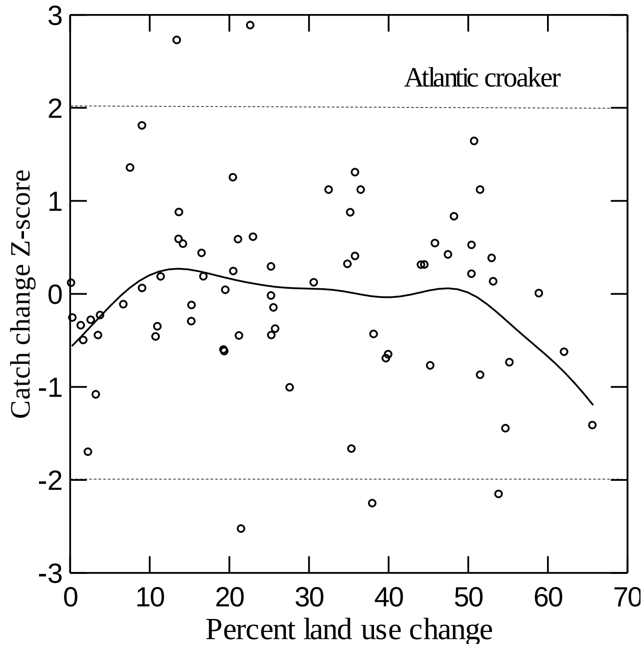



Figure 33. Change in trawl catch Z-score (1980-2004) at each sampling station as a function of percent land use change within catchments for Atlantic croaker. The line is a LOWESS (tension =0.5) fit to the data.

***Spot***

Like Atlantic croaker, spot did not show a significant correlation between change in catch and land use land cover change ($r = -0.08$, $p = 0.51$) (Figure 34). All the 5 stations that show increase (3) or decline (2) in catch, are located in the western part of the Pamlico Sound.

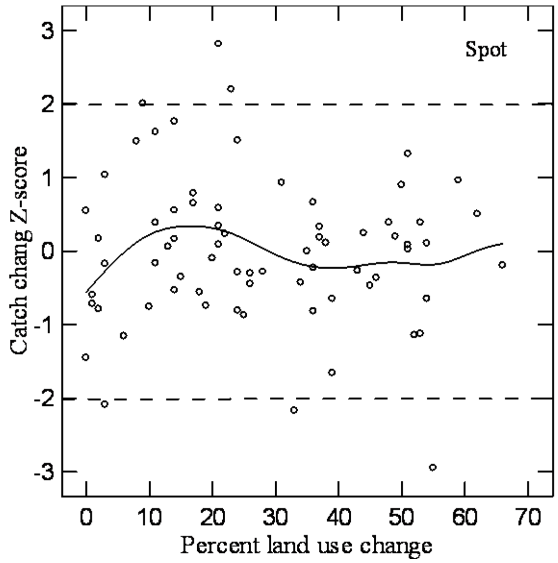



Figure 34. Change in trawl catch Z-score (1980-2004) at each sampling station as a function of percent land use change within catchments for spot. The line is a LOWESS (tension =0.5) fit to the data.

***Atlantic menhaden***

The change in catch of Atlantic menhaden did not show correlation with land use change (Figure 35). The number of stations with an overall decline in catch is counter-balanced by those stations with catch increase.

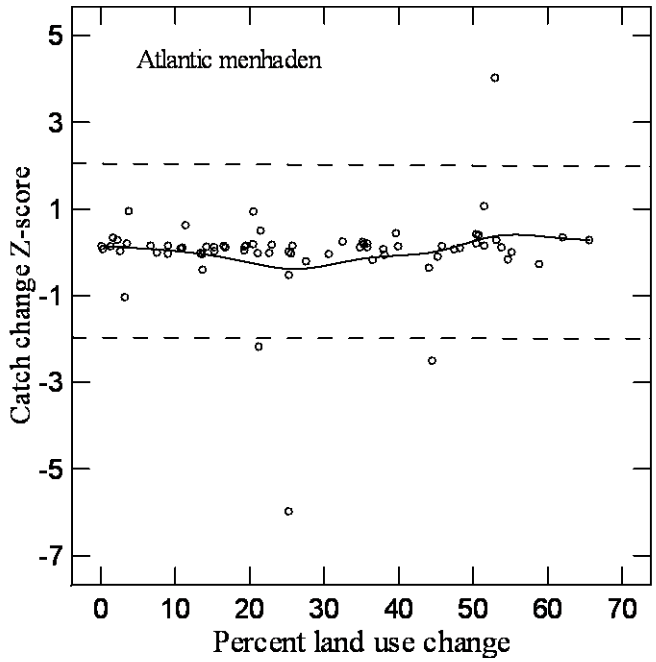



Figure 35. Change in trawl catch Z-score at each sampling station as a function of percent land use change within catchments for Atlantic menhaden. The line is a LOWESS (tension =0.5) fit to the data.

***Pinfish***

The change in pinfish catch was very variable station to station, but did not show a clear correlation with changes in land use land cover (correlation between Z-score and land use change $r = -0.07$, $p = 0.59$, Figure 36). Of the 71 one stations, 68 did not show change in catch of juvenile pinfish, while the three stations that increased catch are found in catchments characterized by low levels of land use change. This means that juvenile pinfish abundance could be influenced by other factors, but that high levels of land use alteration are likely having a negative effect.

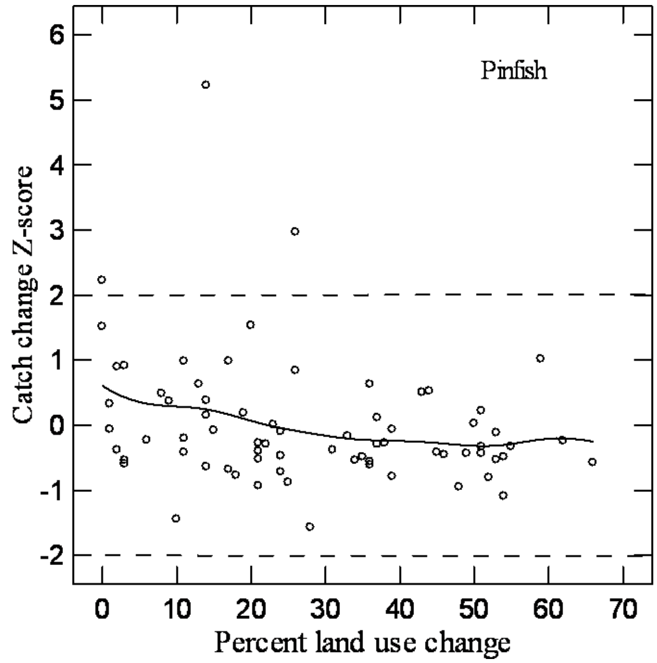



Figure 36. Change in trawl catch Z-score of pinfish (1980-2004) at each sampling station as a function of percent land use change within catchments for pinfish. The line is a LOWESS (tension =0.5) fit to the data.

### 3.3.3. Abiotic factors and species abundance

Water depth, and bottom water temperature and salinity were measured by the NCDMF at the time of trawl. The relationship between these environmental factors and catch was explored, species-by-species. No consistent trends were found between station depth as well as water temperature and catch. However, salinity was found to be potentially important to juvenile fish and invertebrate abundance (Figure 37).

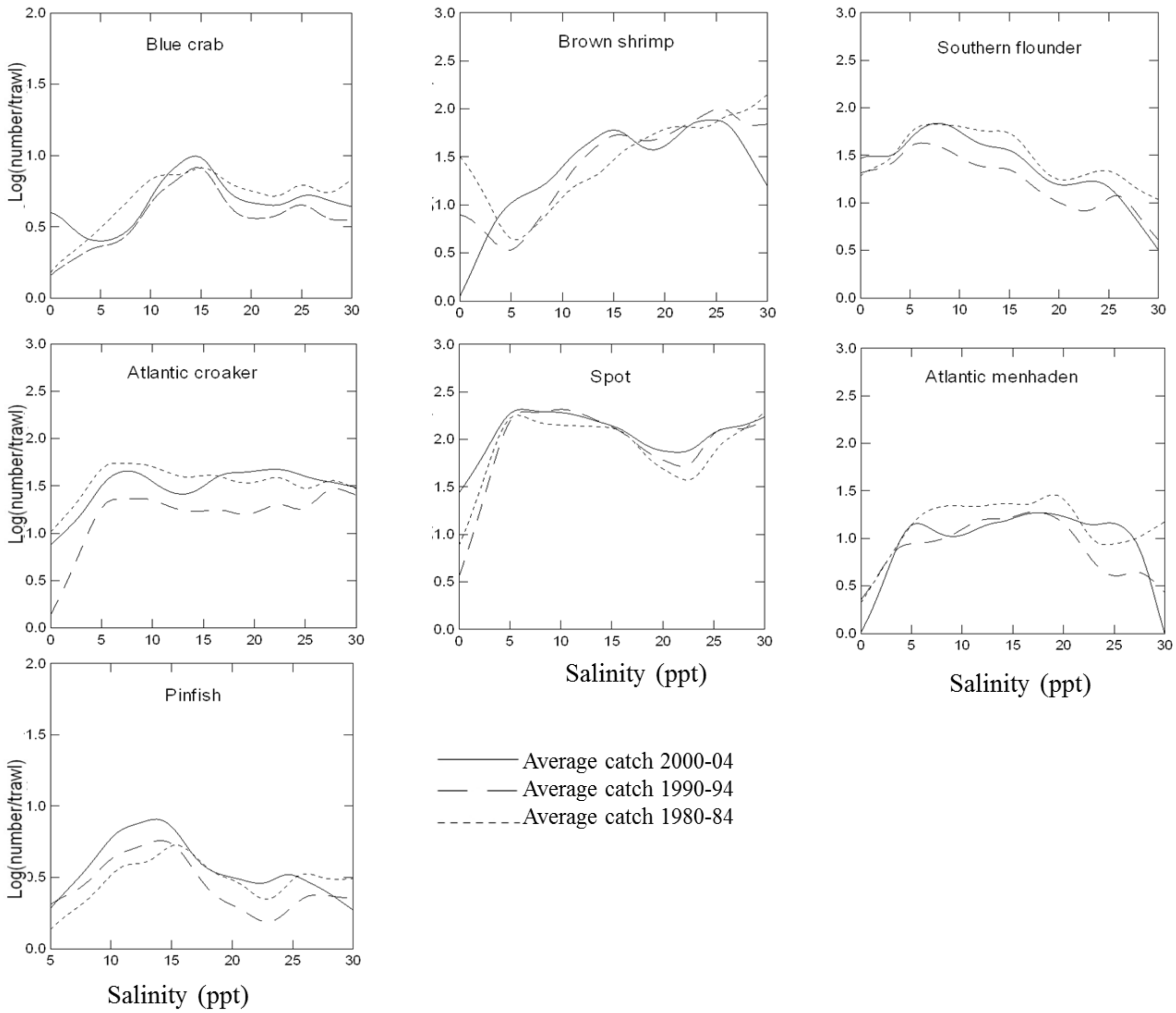



Figure 37. Log transformed average catch per species, plotted against yearly average water salinity in parts per thousands (ppt) at 71 stations.

The number of juvenile blue crab were found to peak at about 15 ppt, which corroborates with published salinity preferences for juvenile blue crabs (Mazzotti et al. 2010). However, juvenile brown shrimp abundance increased with salinity and peaked at 25-26 ppt for all the three time periods considered. Beyond peak salinity, the number of juvenile brown shrimp caught declined. The analysis of southern flounder abundance as a function of salinity shows that juvenile flounder are mostly mesohaline, showing peak abundance at around 10-12 ppt, and declining at higher salinity waters. The abundance of Atlantic croaker as function of salinity shows an increase as water salinity increases till around 10 ppt, then remain relatively constant until higher salinity waters. The abundance of spot shows similar trends in low salinity water, but declines abruptly at around 20 ppt. Moser and Miller (1994) suggested that juvenile spot and croaker‘s salinity preference depend on the fish size, but spot are less stressed by sudden changes in water salinity, which means that other factors must be at play here. Abundance of Atlantic menhaden as function of salinity did not vary much from the average catch when water salinity is 5 and 20 ppt, but declines abruptly at low or high salinity waters. Pinfish abundance shows similar trends in 1980-84, 1990-94 and 2000-04. It increased with salinity and peaks between 12 and 16 ppt.

### 3.3.4. CART Analysis

Classification and regression tree (CART) statistical analysis was performed on change in catch of each species 1980-2004 using station specific environmental predictor variables to find out which parameters explained the greatest variation in change of catch. Variables used were station depth (m), distance to nearest inlet (km), bottom salinity (ppt), bottom temperature ($^{o}$C), number of NPDES sites in the catchment, total human population in year 2000, and overall change in land use as a percentage of catchment area. Results, species-by-species are given next.

***Blue crab***

Overall the CART analysis explained 54% of the variation in charge in catch of the blue crab (Overall Proportional Reduction of Error, PRE= 0.54). The first partition of the CART indicated that land use land cover change is an important factor in blue crab change in abundance (PRE = 0.298 for first classification, Figure 38). As land use changes ≥ 12.8% in the catchment the blue crab catch per trawl declines by about 0.4 in mean values measure with the unit of one standard deviation. Otherwise, the average crab catch increased by 0.8 crab per each trawl. In case the water temperature is greater than 25°C, catch declined even more, by an average of 0.6 crab per trawl. CART also shows that distance to inlet is important to blue crab abundance. More crabs were caught in stations where the distance to closest ocean inlet was < 33.9 km. The chance to catch crabs increases at locations where there is a small change in LULC type, and where there is an ocean inlet within a short distance.

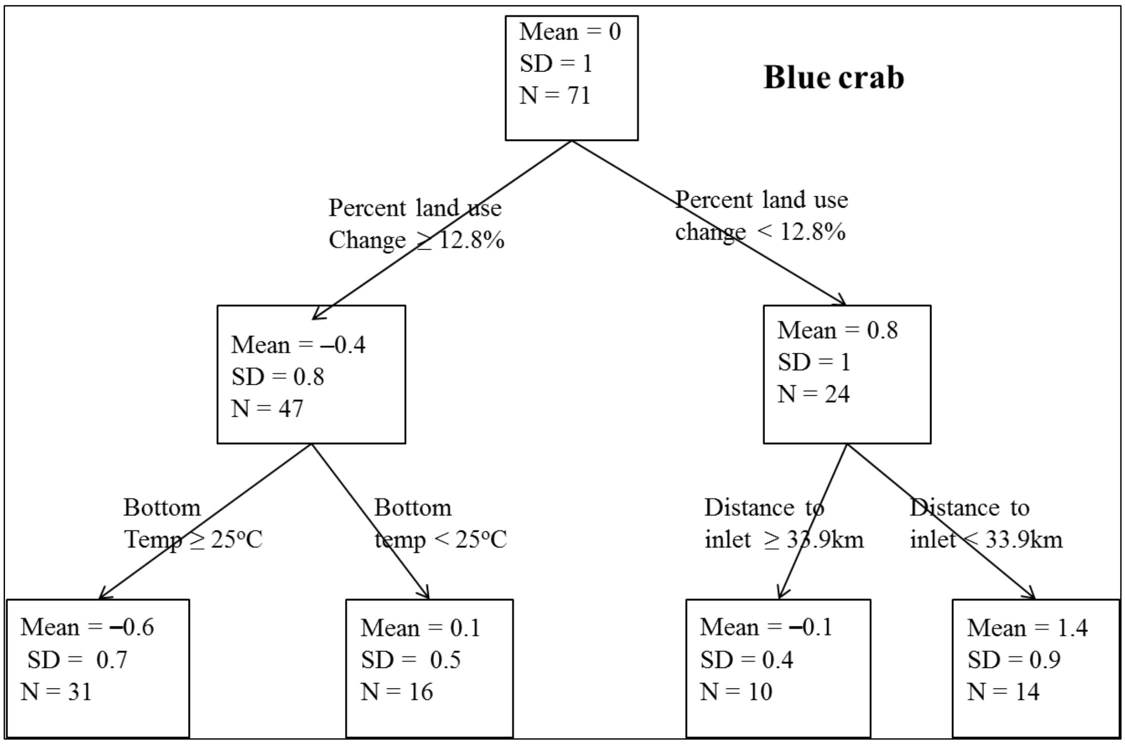



Figure 38. A CART analysis of the standardized Z-score of change in catch of blue crab between 1980 and 2000. Overall model PRE = 0.54.

***Brown Shrimp***

Brown shrimp catches decreased if a station was closer to an inlet than 20.9 km (mean Z-score = –0.7 SD unit) at 21 stations. Otherwise, the catch increased (mean Z-score = 0.3 SD unit) at the 50 stations that were farther than 20.9 km (Figure 39).

Of the 21 stations, there were relatively less shrimps (mean Z-score = –1.2 SD unit) at 11 stations where the water temperature was ≥ 25 °C at the time of trawl. Of the 50 stations that were distant from inlets, if the salinity was lower than 13.6 ppt, catches declined with mean Z-score = –0.1 SD unit at 44 stations. Further analysis of the 44 stations suggested that brown shrimp catch decreased further (mean = –0.1 SD unit) at 28 stations with a depth greater than 0.96 m. The percentage land use change in the surrounding watershed during 1980-2000 was not a significant factor for brown shrimp catches. Thus, the increase of the catch of brown shrimp was associated with great distances from an ocean inlet and high bottom water salinity, as well as shallow water.

Of the 21 stations, there were relatively less shrimps (mean Z-score = –1.2 SD unit) at 11 stations where the water temperature was ≥ 25 °C at the time of trawl. Of the 50 stations that were distant from inlets, if the salinity was lower than 13.6 ppt, catches declined with mean Z-score = –0.1 SD unit at 44 stations. Further analysis of the 44 stations suggested that brown shrimp catch decreased further (mean = –0.1 SD unit) at 28 stations with a depth greater than 0.96 m. The percentage land use change in the surrounding watershed during 1980-2000 was not a significant factor for brown shrimp catches. Thus, the increase of the catch of brown shrimp was associated with great distances from an inlet, high bottom water salinity, and a shallow water depth.

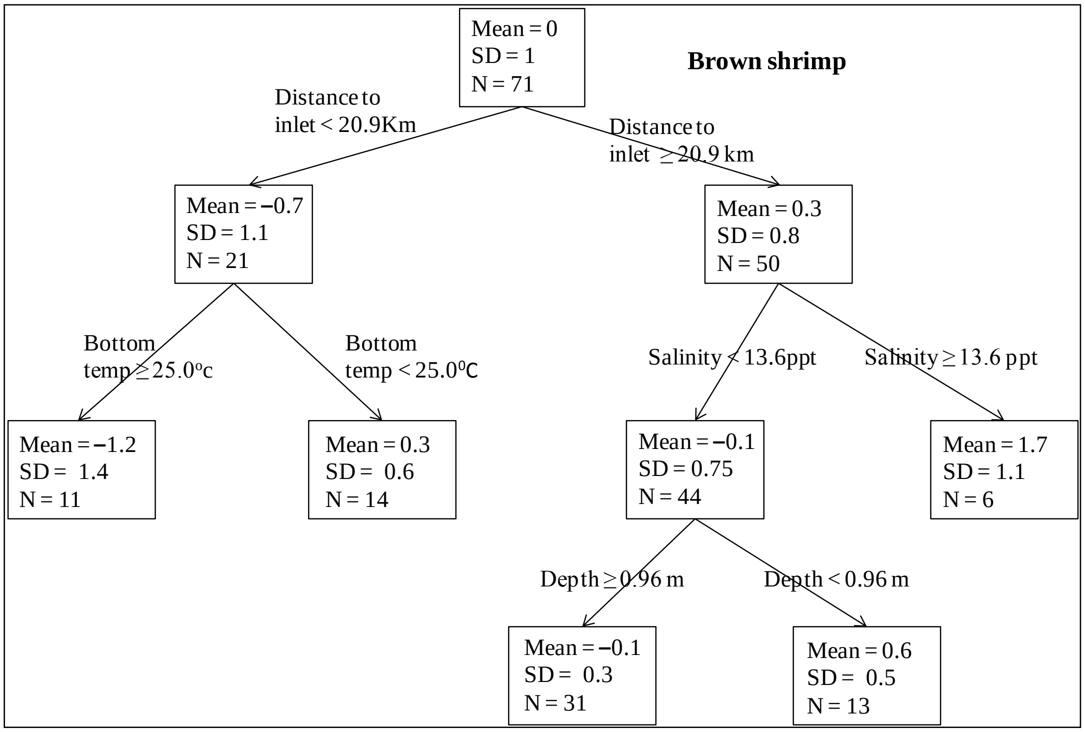



Figure 39. A CART analysis of the standardized Z-score of change in catch of brown shrimp between 1980 and 2000. Overall model PRE = 0.45.

***Southern flounder***

The overall model explained 45% of the variation in change of southern flounder catch (PRE = 0.45). Positive Z-scores of catch change (mean = 0.3 SD units, Figure 40) were recorded at 50 stations where the bottom salinity was < 14.0 ppt. Otherwise, southern flounder catch mean declined by 0.6 SD unit at 21 stations where salinity was higher than 14 ppt. The second partition of these 50 stations  showed that at 20 stations where land use change was less than 21%, mean catch increased by a mean = 0.8 SD unit). If the land use change exceeded that threshold, the Z-scores became negative (mean = –0.1 SD unit) and this happened at 30 stations. Within the 30 stations, there was further catch decline (mean = –0.3 SD unit) if station depths was greater than 0.9 m (N = 24). Therefore, CART shows juvenile southern flounder catch increasing in lower salinity water (< 14 ppt) and in catchments with low percentage of land use change (< 21%).

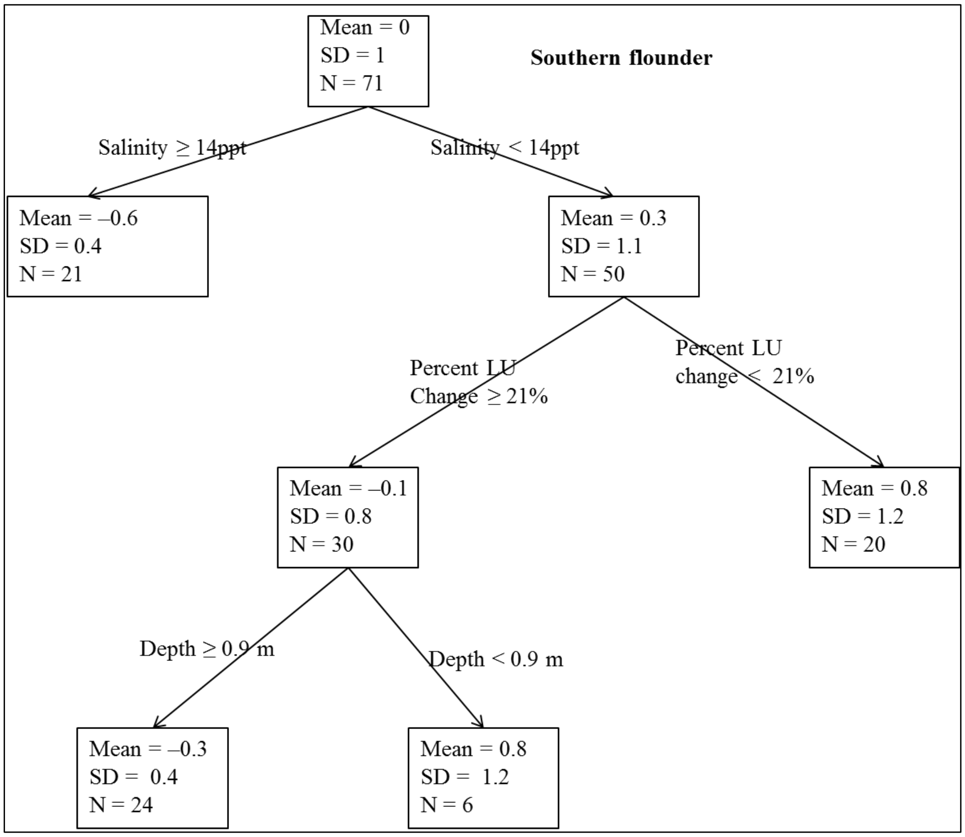



Figure 40. A CART analysis of the standardized Z-score of change in catch of southern flounder between 1980 and 2000. Overall model PRE = 38.

***Atlantic croaker***

Atlantic croaker's catches increased (mean = 0.1 SD unit) at the 65 stations that had percentage land use change less than 54%; if there were greater change in land use, the Z-score of catch change became negative (mean = –1.1 SD units at 6 stations, Figure 40) . Of the 65 stations, 44 that were closer than 46.6 km to an ocean inlet witnessed catch decline (mean = –0.1 SD unit). Of the 44 stations, there was further catch decline at 22 sampling stations that were located at 23.7 km or closer to an ocean inlet (mean= –0.5 SD unit). The second partition of the 65 stations indicated that the Z-score of change in catch increased at 21 stations (mean = 0.6 SD unit) where the distance to an inlet was greater than 47 km. The third partition suggested that croaker increased more (mean = 0.9 SD units) at 14 of the 21 stations that were located less than 62 km from an ocean inlet (Figure 41). Finally, of the 14 stations located between 46.6 and 62 km from an inlet, seven stations that had bottom temperatures greater than 25.2 °C, also had high Z-scores of change in catch (mean = 1.7 SD unit). For Atlantic croaker, the CART analysis suggests that land use changes exceeding 54% are associated with declines in catches (low Z-scores), but stations between 47 and 62 km from inlets with temperatures greater than 25°C had increasing catches (greatest Z-scores) between 1980 and 2004.

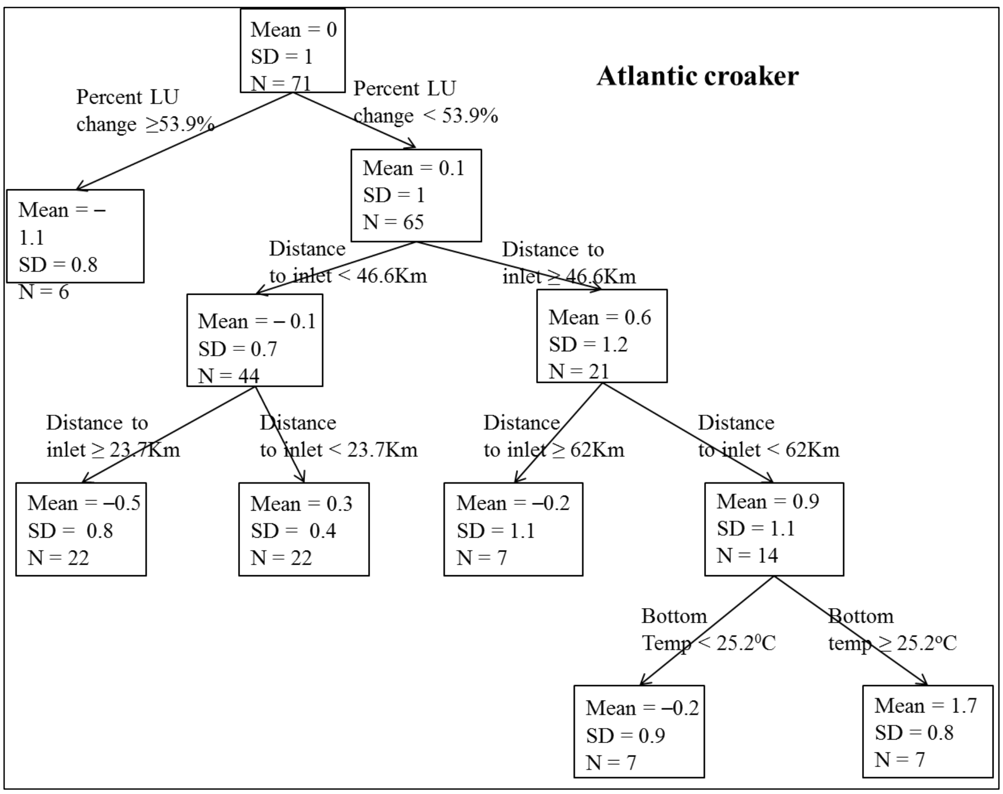



Figure 41. A CART analysis of the standardized Z-score of change in catch of Atlantic croaker between 1980 and 2000. Overall model PRE = 0.50.

***Spot***

Forty two stations showed a catch decline when they were located less than 41.7 km of the closest ocean inlet (mean = –0.4 SD unit) (Figure 42). Further than 41.7 km, mean spot catch increased 0.5 SD unit at 29 stations. Of the 29 stations, spot catch was relatively less at 24 stations where the human population was less than 883/km$^2$ in the greater 14-digit watershed; otherwise catch increased (mean = 0.6 SD unit). Of the 24 stations where the human population did not exceed 883 persons/km$^2$ in the 14-digit watershed, positive catch Z-scores were observed at 18 stations located at less than 64 km from an ocean inlet. Catch of juvenile spot increased away from ocean inlets, and human population density within the greater watershed did not appear to be a detriment to the high number of juvenile spot caught at NCDMF stations.

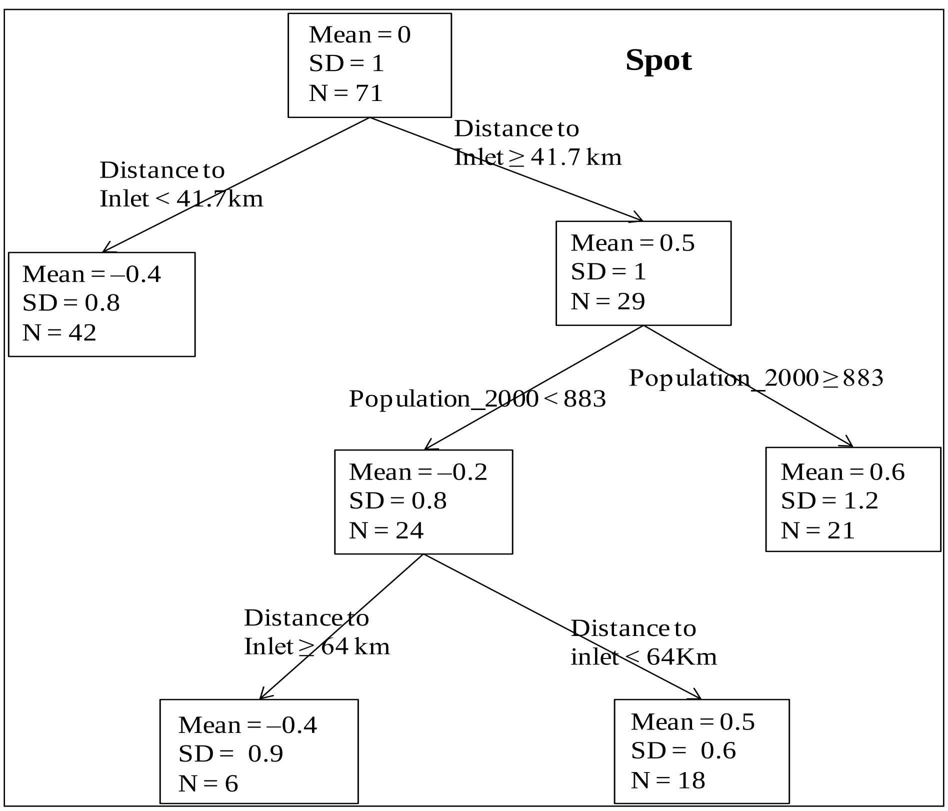



Figure 42. A CART analysis of the standardized Z-score of change in catch of spot between 1980 and 2000. Overall model PRE = 0.45.

***Atlantic menhaden***

Atlantic menhaden's catches decreased at stations where water temperatures were lower than 24°C (mean = –1.2 SD unit) at the 5 stations. The remaining 66 stations recorded a catch mean increase by 0.1 SD. Of the 66 stations, 46 that are located further than 24.5 km away from an inlet showed a catch decline by 0.1 SD unit. Catch increased at 20 stations (mean = 0.4 SD units) where the distance to an inlet was less than 24.5 km. For Atlantic menhaden, percent land use change was not a significant predictor variable in the CART analysis, but warm water temperature and short distance to closest ocean inlet had a positive influence on the mean catch (Figure 43).

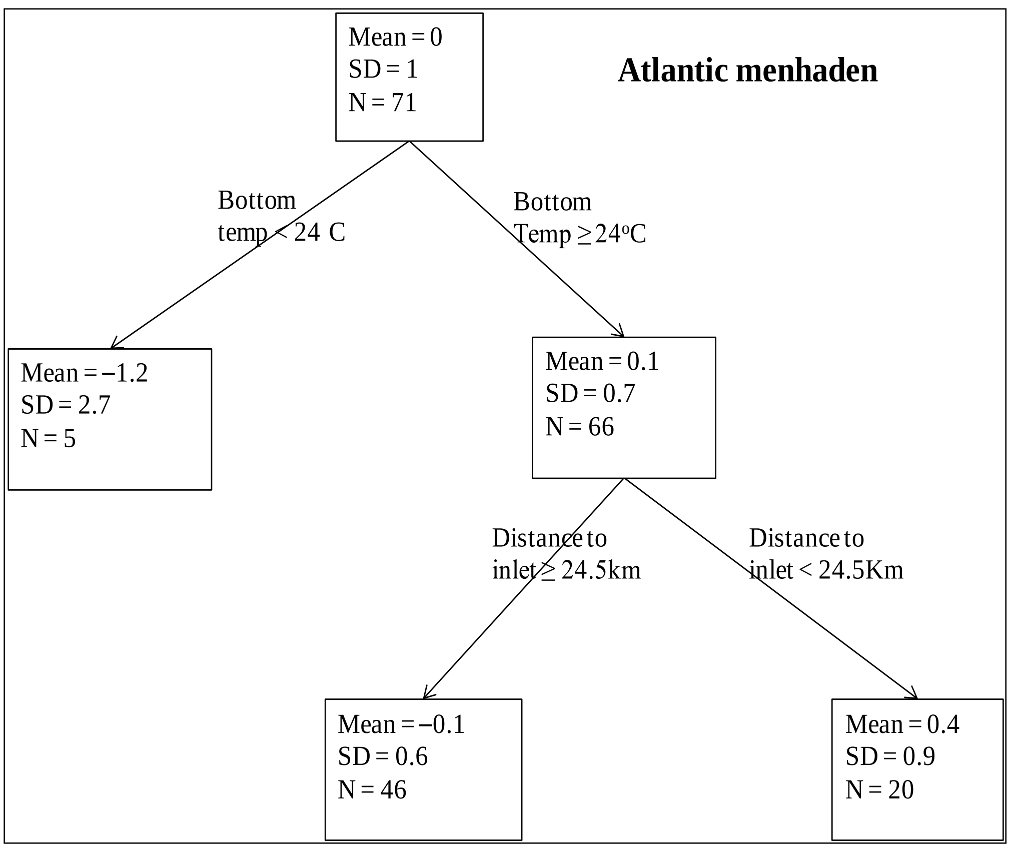



Figure 43. A CART analysis of the standardized Z-score of change in catch of Atlantic menhaden between 1980 and 2000. Overall model PRE = 0.15.

***Pinfish***

If water temperature was greater than 24.8°C, the mean catch of juvenile pinfish declined by 0.3 SD unit, otherwise pinfish catches increased (mean = 0.5 SD unit) at the 27 stations (Figure 44). Of the 27 stations catches were low (Z-score of catch change mean = –0.1 SD units) at 20 stations where human population exceeded 2 persons/km$^2$. Otherwise catch increased at 7 stations (mean = 1.5 SD units), where the human population did not exceed 2 persons/km$^2$. Catch declined (Z-score of catch change mean = –0.1 SD units) at 15 of the 20 stations, where water temperature was less than 24.7°C. Where temperature was greater than 24.8°C, pinfish catch increased (mean = 1.1 SD units) at 5 stations. Thus, the CART analysis shows that changes in pinfish catches between 1980 and 2004 were associated with water temperature and human population density.

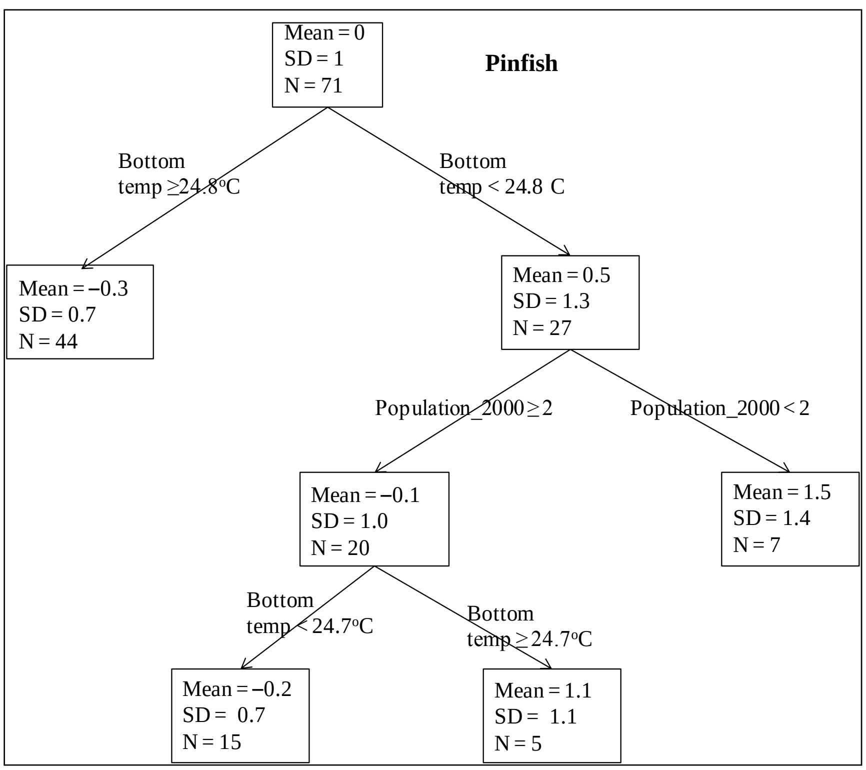



Figure 44. A CART analysis of the standardized Z-score of change in catch of pinfish between 1980 and 2000. Overall model PRE = 0.40.

## 3.4. Discussion

In general, each species responded in different ways to the changes in land use during the study period. Blue crab, southern flounder, and Atlantic croaker may be the species significantly affected by an increased amount of land use change in the catchment surrounding certain stations, which appeared to cause a decline in abundance relative to other stations. The three species are heavily fished in North Carolina's waters, and are respectfully number 1, 3, and 4 in the dollar value of catch. It is possible these results could be also picking up the impact of intensive fishery. Spot, Atlantic menhaden, and brown shrimp did not show any association between declining catches in the DMF program 120 trawls and increased percentage of land use change in the surrounding watershed (Table 13). However, some abiotic factors did impact the abundance on a species by species basis. In particular, salinity was probably the most important abiotic factor for blue crab, brown shrimp, southern flounder, spot, and pinfish (Table 13) since distance to inlet can also be interpreted as a proxy measure of salinity. Overall, brown shrimp catch per trawl increased with station salinity (Figure 38) while peak catches of juvenile southern flounder and spot in all years were associated with low salinity stations (< 15 ppt, Figure 38 and Figure 40). Pinfish peak catches were bimodal in 2000-04 (Figure 42), with peaks both at low salinity (oligohaline: 5-10 ppt) and mesohaline (20-25 ppt) stations. There were no evident associations between catches of juvenile pinfish and salinity in 1980-84 or 1990-94. Bottom temperature was a significant factor associated with change in abundance of blue crab, brown shrimp, Atlantic croaker, Atlantic menhaden, and pinfish. The catch of juveniles of these species increased when the bottom temperature was less than about 24 °C depending on other factors.

Station depth was found to influence the catch of brown shrimp and southern flounder where shallow stations (~0.9m) had a better catch than deeper ones (Figure 38, Figure 39).

Table 12. Mean catches (number per trawl) for the target species and significant factors affecting abundance at all stations as identified in the CART analysis.

| **Species** | **Geometric mean/catch per trawl** | **Land use change** | **Bottom Temp ($^oC$)** | **Bottom Salinity (ppt)** | **Depth (m)** | **Distance to inlet (km)** |
|---|---|---|---|---|---|---|
| Blue crab | 7.1 | X | X | -- | -- | X |
| Brown shrimp | 16.7 | -- | X | X | X | X |
| Southern flounder | 3.7 | X | X | X | X | -- |
| Atlantic croaker | 21.6 | X | -- | -- | -- | X |
| Spot | 114.7 | -- | -- | -- | -- | X |
| Atlantic menhaden | 7.2 | -- | X | -- | -- | X |
| Pinfish | 7.3 | -- | X | -- | -- | -- |

A summary of partitions of the CART analysis is done in table 14. According to the CART results above and Table 14, distance from an inlet, bottom salinity, bottom water temperature, percent land use change within a catchment surrounding the station, and station depth are the factors that most influence these species. The number of NPDES permits in the watershed was not associated with changes in catch for any species.

Table 13. Summary of partitions of the CART tree for change in catch at 71 NCDMF stations for the seven target species (1= first CART tree split, based on the highest amount of variation explained in Z-score of change in catch 1989-2004, 2 = second CART tree split, etc.).

| Species | Salinity (ppt) | Temp (oC) | Distance from Inlet (km) | Depth (m) | Population 2000 | % LU change |
|---|---|---|---|---|---|---|
| Blue crab | -- | 2 | 2 | -- | -- | 1 |
| Brown shrimp | 2 | 2 | 1 | -- | -- | -- |
| Southern flounder | 1 | -- | -- | 3 | -- | 2 |
| Atlantic croaker | -- | 4 | 2,3 | -- | | 1 |
| Spot | -- | -- | 1,3 | -- | 2 | -- |
| Atlantic menhaden | -- | 1 | 2 | --- | --- | -- |
| Pinfish | -- | 1,3 | -- | -- | 2 | -- |

### 3.5. Conclusion and remarks

The analysis of land use change in coastal watersheds and the Program 120 data between 1980 and 2004 resulted the following outputs. The abundance of brown shrimp, Atlantic menhaden did not change significantly between 1980 and 2004. Atlantic croaker exhibited a long-term decline in abundance, especially at stations with large scale land use modifications (> 53.9% area changed, mostly from conversion of forest to agriculture) in the surrounding watersheds. Coast-wide increases in blue crab, southern flounder, spot, and pinfish have been observed. While the overall trend for pinfish is increasing, this species did not increase if the human population was dense in the surrounding watershed. Also, for southern flounder, a catch decline was observed at locations where large scale land use modifications were present.

Before the end, two remarks are provided. First, these findings seem contradictory previous studies in North Carolina (Mallin and Cahoon, 2003; Loucaides et al. 2007), and to those found in estuarine systems such as the Chesapeake Bay (Nixon, 1995, King et al., 2005; Bilkovic et al., 2006), and South Carolina (Holland et al., 2004, Garner and Weinstein, 2007). In particular, the land use changes have been associated with degradation of benthic estuarine conditions (Holland et al., 2004; King et al., 2005; Bilkovic et al., 2006). Runoff from agricultural fields has been demonstrated to increase phytoplankton growth, to depress submerged aquatic vegetation, to degrade benthic habitats, and to lower dissolved oxygen in receiving estuarine waters (Nixon, 1995; Mallin and Cahoon, 2003; Loucaides et al., 2007). Possible arguments of the difference include the levels of land use change. The developed (urban) land use would have to exceed 10% of the total land area observed in the Chesapeake Bay and South Carolina, but North Carolina's estuarine catchments never reached such high levels. Furthermore, our analyses focused on fishes and invertebrates that are mobile, highly variable spatially and temporally, and operating at a higher trophic level than organisms measured in the Chesapeake Bay and South Carolina studies. Also, the data collected in May and June trawls may not show the impact of land use land cover changes. Greater stress to aquatic organisms was usually expected in July through September when hypoxia associated with high water temperatures and benthic respiration was more likely (Christian et al. 2009, Paerl et al. 2006). Finally, there may be factors such as varying substrate type (West et al., 2000), and ocean currents, as well as presence or absence of aquatic vegetation (Ross and Epperly, 1985) at play.

Second, this study may have not captured the full scale of the influence of land use change in estuaries because NCDMF program 120 sampling is done only in May and June, before the high summer temperatures, when estuarine systems are more susceptible to land use change effects. Thus, it is recommended that the NCDMF consider trawling surveys in the late summer (July through September/October) at selected stations. The increased sampling effort would help capture system stress induced by watershed runoff, high summer temperatures, and increased coastal urbanization. Late summer sampling would also help monitor growth and survival of the studied species after the peak recruitment in May and June in watersheds with differing amounts of land use land cover change.

# Chapter 4. General Summary Remarks

Between 1980 and 2000, deforestation constituted the greatest land use land cover change North Carolina's estuarine catchments. There was an overall loss of 30.5% in the catchments during the 20 years. Forested area was largely converted into agricultural land and agricultural area showed substantial increase, gaining 24.1% in two decades. The loss of forested area to agriculture land was widely spread within coastal counties. There was a small gain locally in developed and wetland areas in some localized catchments. Great increases in developed land via deforestation occurred in the catchments located near Jacksonville and Wilmington, where the development of water-front properties in low land areas could be the major cause for the increase. Overall, catchments became dominated by agricultural land in the detriment of forested environment, which can lead to water quality degradation because of the increased sediment load from rapid run-offs, and usage of fertilizers, and pesticides. The changes could be even faster had some watersheds not been protected under the 1972 Coastal Area management Act (CAMA) that seeks to protect all coastal habitats essential to fisheries or water qualities.

The long-term trends were analyzed in the North Carolina Division of Marine Fisheries' Program 120 trawl catch for a selected set of seven commercially and ecologically important species of finfish and crustaceans. The species were blue crab, brown shrimp, southern flounder, Atlantic croaker, spot, Atlantic menhaden, and pinfish. The study revealed that overall, the juvenile population did not change significantly over the 25 years (1980–2004), while it was well documented that the adult population declined in other studies (Lipcius and Stockhausen, 2002). It has been widely believed that overfishing could trigger compensatory fecundity and spawning in certain species including blue crabs (Kahn and Helser 2005).

The increased removal of fish by commercial and recreation fishing and predation of adults could reach a threshold that translates in the declining number of larvae and juveniles, as the likely case of Atlantic menhaden (Utz et al., 2009; Uphoff, 2003). Additional sampling and experimental studies were recommended to integrate species catch and environmental factors such as land use change, human population density, the number of point and nonpoint source of pollution in the watersheds, water salinity and temperature.

When land use change and juvenile fish abundance were analyzed, it was found that there was no clear correlation between the two, mostly because the juvenile population was stable in stations studied, and because most catchments' land use did not witness dramatic changes. These findings seem contradictory previous studies in North Carolina (Mallin and Cahoon, 2003; Loucaides et al. 2007), and to those found in estuarine systems such as the Chesapeake Bay (Nixon, 1995, King et al., 2005; Bilkovic et al., 2006), and South Carolina (Holland et al., 2004, Garner and Weinstein, 2007). Possible arguments of the difference include the levels of land use change. The developed (urban) land use would have to exceed 10% of the total land area observed in the Chesapeake Bay and South Carolina, but North Carolina's estuarine catchments never reached such high levels. Furthermore, our analyses focused on fishes and invertebrates that are mobile, highly variable spatially and temporally, and operating at a higher trophic level than organisms measured in the Chesapeake Bay and South Carolina studies. Also, there may be factors such as varying substrate type (West et al., 2000), ocean currents, as well as presence or absence of aquatic vegetation (Ross and Epperly, 1985) at play.

Therefore, to sort the causes for observed differences, there need to be an increased sampling effort that would cover late summer months (July-October) in order to capture system stress induced by watershed runoff, high summer temperatures, and increased coastal urbanization. Late summer sampling would also help monitor juvenile growth and survival of the studied species after the peak recruitment in May and June, which is period of high water temperatures and hypoxia.

## References


Able, K.W., and M.P. Fahay. 2010. Ecology of estuarine fishes: temperate waters of the western north Atlantic. John Hopkins University Press. 566 p.

Adams, A.J., J.V. Locascio, and B.D. Robbins. 2004. Microhabitat use by a post-settlement stage estuarine fish: evidence from relative abundance and predation among habitats. *Journal of Experimental Marine Biology and Ecology*. 299:17–33.

Allen, J., K.S.Lu. 2003. Modeling and predicting future urban growth in the Charleston region of South Carolina: a GIS-based integrated approach. *Conservation Ecology*. 8:2-22.

Arnold C.L, and C.J. Gibbons. 1996Impervious surface coverage: The emergence of a key environmental indicator. *Journal of the American Planning Association*.62:243-258.

Anderson, J.R., E.E. Hardy, J.R. Roach, and R.E. Witmer. 1976. A land cover and land use classification system for use with remote sensor data. U.S. Geological Survey Professional Paper 964. 36 p.

Anderson, D.M., P.M. Gilbert, and J.M. Burkholder. 2002. Harmful algal blooms and eutrophication: nutrients sources, composition, and consequences. *Estuaries*. 25:704-726.

Barnes, D.K. 1998. Use of benthic macroinvertebrates to assess impacts of agricultural land use in nontidal coastal plain streams. Master’s thesis. The University of Virginia, Charlottesville, VA.

Beach, D. 2002. Coastal sprawl: the effects of urban design on aquatic ecosystems in the United States. Pew Oceans Commission, Arlington, VA, 32 p.

Bernot M.J., J.L. Tank, T.V. Royer, and M.B. David. 2006. Nutrient uptake in streams draining agricultural catchments of the Midwestern United States. *Freshwater Biology*. 51:499-509.

Bilkovic, D.M., M. Roggero, C.H. Hershner, and K.H. Havens. 2006. Influence of land use on macrobenthic communities in near shore estuarine habitats. *Estuaries and Coasts.* 29:1185–1195.

Blackmon, D.C., and D.B. Eggleston 2001. Factors influencing planktonic, post-settlement dispersal of early juvenile blue crabs (*Callinectes sapidus* Rathbun). *Journal of Experimental Marine Biology and Ecology*. 257:183–203.

Bormann, F.H., G.E. Likens, T.G. Siccama, R.S. Pierce, and J.S. Eaton. 1974. The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. *Ecological Monographs*.44:255-277.

Brown, C.A., G.A. Jackson, S.A. Holt, and G.J. Holt. 2005. Spatial and temporal patterns in modeled particle transport to estuarine habitat with comparisons to larval fish settlement patterns. *Estuarine, Coastal and Shelf Science*. 64: 33-46.

Burke, J.S., J.M. Miller, and D.E. Hoss. 1991. Immigration and habitat selection of *Paralichthys dentatus* and *Paralichthys lethostigma* larvae and juveniles in an estuarine nursery ground, North Carolina, USA. *Netherlands Journal of Sea Research* 27:393–405.

Burke, J.S., M. Ueno, Y. Tanaka, H. Walsh, T. Maeda, I. Kinoshita, T. Seikai, D.E. Hoss, and M. Tanaka. 1998. The influence of environmental factors on early life history patterns of flounders. *Journal of Sea Research* 40:19–32.

Cairns, Jr. J., and J.R. Pratt. 1992. Restoring ecosystem health and integrity during a human population increase to ten billion. *Journal of Aquatic Ecosystem Health* 1:59-68.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorous and nitrogen. *Ecological Application*. 8:559–568.

Chapin, F.S., III, E.S. Zavaleta, V.T. Eviner, R.L. Naylor, P.M. Vitousek, H.L. Reynolds, D. U. Hooper, S. Lavorel, O.E. Sala, S.E. Hobbie, M.C. Mack, and S. Diaz. 2000. Consequences of changing biodiversity. *Nature*. 405:234–242.

Christian, R.R. J.N. Boyer, and D.W. Stanley. 1991. Multi-year distribution patterns of nutrients within the Neuse River Estuary, North Carolina. *Marine Ecology Progress Series*. 71:259-274.

Coleman, F.C. W.F. Figueira, J.S. Ueland, and L.B. Crowder. 2004. The impact of United States recreational fisheries on marine fish populations. *Science.* 35:1958–1960.

Congalton, R.G., and K. Green. 1999. Assessing the accuracy of remotely sensed data: Principles and practices. Lewis Publishers, New York, 137 p.

Crawford, W.T. 2007. Where does the coast sprawls the most? Trajectories of residential development and sprawl in coastal North Carolina, 1971-2000. *Landscape and Urban Planning.* 83:294-307.

Crossett, K.M, T.J. Culliton, P.C. Wiley, and T.R. Goodspeed. 2004. Population trends along the coastal United States: 1980-2008. National Oceanic and Atmospheric Administration, Coastal Trends Report Series. 51 p.

Cuffney, T.F., H. Zappia, E.M.P. Giddings, and J. F. Coles. 2005. Effects of urbanization on benthic macroinvertebrate assemblages in contrasting environmental settings: Boston, Massachusetts; Birmingham, Alabama; and Salt Lake City, Utah. *American Fisheries Society Symposium*. 47:361–407.

Culliton, T., M. Warren, T. Goodspeed, D. Remer, C. Blackwell, and J. McDonough, 1990: 50 years of population change along the nation's coasts 1960–2010: The second report of a coastal trends series. Strategic Assessment Branch, Oceans Assessments Division, Office of Oceanography and Marine Assessment, National Ocean Service, NOAA, Rockville, MD, 41 p.

Day, J.W. Jr., C.H.S. Hall, W. Kemp, A. Yanez-Arancibia. 1989. Estuarine Ecology. Wiley, New York.

Deaton A.S, W.S. Chappell, K. Hart, J. O'Neal, and B. Boutin. 2010. North Carolina Coastal Habitat Protection Plan. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City, NC. 659 p.

De'Ath, G., and K.E. Fabricius. 2000. Classification and regression trees: a powerful yet simple technique for ecological data analysis. *Ecology*. 81:3178–3192.

DeFries, R.S, J.A. Foley, and G.P. Asner. 2004. Land use choices: Balancing human needs and ecosystem function. *Frontiers in Ecology and the Environment*, 2:249-257.

Dillon, P.J., and W.B. Kirchner. 1975. The effect of geology and land use on the export of phosphorous from watersheds. *Water Research*. 9: 135-148.

Dobson, J.E., E.A. Bright, R.L. Ferguson, D.W. Field, L.L. Wood, K.D. Haddad, J.R. Jensen, H. Iredale, V.V. Klemas, R.J. Orth, and J.P. Thomas. 1995. NOAA Coastal Change Analysis Program (C-CAP): Guidance for regional implementation. NOAA Technical Report # 123. Washington, DC. 140 p.

Eggleston, D.B., D.A. Armstrong, W.E. Elis, and W.S. Patton. 1998. Estuarine fronts as conduits for larval transport: hydrodynamics and spatial distribution of Dungeness crab post larvae. *Marine Ecology Progress Series* 164:73-82.

Eggleston, D.B. 1998. Population dynamics of Blue crab in North Carolina: Statistical analyses of fisheries survey data. Final report to the North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries. 71 p.

Etherington, L.L., and D.B. Eggleston. 2003. Spatial dynamics of large-scale, multi-stage crab dispersal: determinants and consequences for recruitment. *Canadian Journal of Fisheries and Aquatic Science.* 60:873-887.

Feller M.C. 2009. Deforestation and nutrient loading to fresh waters. *Elsevier Inc*. 29 p.

Ferguson R.L., and H. E. Mew. 2000. Proposal to Change Hydrologic Unit Delineations over the Estuarine Waters of North Carolina. White Paper. Coastal Subcommittee, North Carolina River Basin Coordinating Committee, Natural Resources Conservation Service.13 p.

Foody G.M., M.K. Arora. 1996. Incorporating mixed pixels in the training, allocation and testing stages of supervised classifications. *Pattern Recognition Letters* 17:1389-1398.

Forward, R.B., J. Swanson, R.A. Tankersely, and J.M. Welch. 1997. Endogenous swimming rhythms of blue crab, *Callinectes sapidus*, megalopae: effects of offshore and estuarine cues. *Marine Biology.* 127:621-628.

Forward, R.B., R.A. Tankersely, K.A. Reinsel. 1998. Selective tidal stream transport of spot (*Leistomus xanthurus* Lacepede) and pinfish (*Lagodon rhomboides* Linnaeus) larvae: Contribution of circatidal rhythms in activity. *Journal of Experimental Marine Biology and Ecology*. 226:19–32.

Friedland, K.D.; D.W. Ahrenholz; J.F. Guthrie. 1996. Formation and seasonal evolution of Atlantic menhaden juvenile nurseries in coastal estuaries. *Estuaries*. 19:105-114.

Garner T.R., J.E. Weinstein, and D.M. Sanger. 2007. Polycyclic Aromatic Hydrocarbon contamination in South Carolina salt marsh-tidal creek systems: Relationships among sediments, biota, and watershed land use. *Archives of Environmental contamination and Toxicology*. 57:103-115.

Gloeckner D.R., J.J. Luczkovich.2008. Experimental assessment of trophic impacts from a network model of a seagrass ecosystem: Direct and indirect effects of gulf flounder, spot and pinfish on benthic polychaetes. Journal of Experimental Marine Biology and Ecology 357:109–120.

Guidon, K.Y., and J.M. Miller (1995) Growth potential of juvenile southern flounder *Paralichthys lethostigma*, in low salinity nursery areas of Pamlico Sound, North Carolina, USA

Hartman, K. 2003. Population-level consumption by Atlantic coastal striped bass and the influence of population recovery upon prey communities Fisheries Management and Ecology, 10:281-288.

Hawbaker, T.J., Radeloff, V., Clayton, M., Hammer, and Gonzaklez-Abraham. 2006. Road development, housing growth, and landscape fragmentation in northern Wisconsin: 1937-1999. *Ecological Applications. 16*:1222-1237.

Hessen, D.O. 1999. Catchment properties and the transport of major elements to estuaries. *Advances in Ecological Research*. 29:1-41.

Holland, A.F., D.M. Sanger, C.P. Gawle, S.B. Lerberg, M.S. Santiago, G.H.M. Riekerk, L.E. Zimmerman, and G. I. Scott.2004. Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds. *Journal of Experimental Marine Biology and Ecology*. 298:151–178.

Homer C., C. Huang, L. Yang, B. Wylie, and M. Coan. 2004. Development of a 2001 National Land-Cover Database of the United States. *Photogrammetric Engineering & Remote Sensing*: 70:829–840.

Hovel, K.A., and R.N. Lipcius. 2001. Habitat fragmentation in a seagrass landscape: Patch size and complexity control blue crab survival. *Ecology*. 82:1814-1829.

Howarth, R.W., J.R. Fruci, and D. Sherman.1991. Inputs of sediment and carbon to an estuarine ecosystem: Influence of land use. *Ecological Applications*. 1:27-39.

Jackson, J.B.C., M.X. Kirby, W.H. Berger, K.A. Bjorndal, L.W. Botsford, B.J. Bourque, R.H. Bradbury, R. Cooke, J. Erlandson, J.A. Estes, T.P. Hughes, S. Kidwell, C.B. Lange, H.S. Lenihan, J.M. Pandolfi, C.H. Peterson, R.S. Steneck, M.J. Tegner, R.R. Warner 2001. Overfishing and the recent collapse of coastal ecosystems. *Science*. 2893:629-638.

Jaworski, N.A.,R.W. Howarth, and L.J. Hetling. 1997. Atmospheric deposition of nitrogen oxides onto the landscape contributes to coastal eutrophication in the Northeast United States. *Environmental Science and Technology*. *31:*1995–2004.

Jenkins, G.P, M.J. Keough, and P.A. Hamera. 1998. The contributions of habitat structure and larval supply to broad-scale recruitment variability in a temperate zone, seagrass-associated fish *Journal of Experimental Marine Biology and Ecology*. 226:259–278.

Jennings, S., and M.J. Kaiser. 1998. The effects of fishing on marine ecosystems. *Advances in Marine Biology*. 34:201-212.

Jensen, J.R. 2006. Remote sensing of the environment: an earth resource perspective. Second edition. Prentice Hall Series in geographic information science. Upper Saddle River, New Jersey.592 p.

Jordan, T.E., and D.E. Weller. 1996. Human contributions to terrestrial nitrogen flux. *BioScience*. 46:655-664.

Jordan, T.E., D.L. Correll, and D.E. Weller. 1997. Effects of agriculture on discharges of nutrients from Coastal Plain watersheds of Chesapeake Bay. *Journal of Environmental Quality*. 26:836-848.

Joyeux, J.C. 1999. The Abundance of fish larvae in estuaries: Within-tide variability at inlet and immigration. *Science*, 22:12-21.

Kahn, D.M., and T.E. Helser. 2005 Abundance, dynamics and mortality rates of the Delaware Bay stocks of blue crabs, *Callinectes sapidus*. *Journal of Shellfish Research*, 24:269-284.

King R.S., J.R. Beaman, D.F. Whigham, A.S. Hines, M.E. Baker, and D.E. Weller. 2004. Watershed land use is strongly linked to PCB's in white perch in the Chesapeake Bay subestuaries. *Environmental Sciences and Technology*. 38:3546-3552.

King R.S., A.H. Hines, F.D. Craige, S. Grap. 2005. Regional, watershed and local correlates of blue crab and bivalve abundances in sub-estuaries of Chesapeake Bay, USA. *Journal of Experimental Marine Biology and Ecology*. 319:101–116.

Lambin E.F., B.L. Turner, H.J. Gheist, S.B. Agbola, A. Angelsen, J.W. Bruce, O.T. Coomes, R. Dirzo, G. Fisher, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X. Lin, H. Skanes, W. Steffen, G.D. Stones, U. Svedin, T.A. Veldkamp, C. Vogel, and J. Xu. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change*. 11:261–269.

Lambin, E.F, H.J. Geist, and E. Lepers. 2003. Dynamics of land use and land cover change in tropical regions. *Annual Review of Environmental Resources*. 28:205–41.

Lillesand, T.M., R.W. Kiefer, and J.W. Chipman. 2008. Remote sensing and image interpretation. John Wiley & Sons Limited. New York. 763 p.

Lipcius, R.N., W.T. Stockhausen. 2002. Concurrent decline of the spawning stock, recruitment, larval abundance, and size of the blue crab *Callinectes sapidus* in Chesapeake Bay. *Marine Ecology Progress Series*. 226:45-61.

Lonergan, N.R. and S.E. Bunn.1999. River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. *Australian Journal of Ecology.* 24:431–440.

Loucaides S., L.B. Cahoon, and E.J. Henry. 2007. Effects of watershed impervious cover on dissolved silica loading in storm flow. *Journal of the American Water Resources Association*. 43:841–849.

Lu, D., P. Mausel, M. Batistella, and E. Moran. 2004. Comparison of land cover classification methods in the Brazilian amazon basin. ASPRS 2003 Annual Conference Proceedings.

Luczkovich J.J., G.P. Ward, J.C. Johnson, R.R. Christian, D. Baird, H. Neckles, and W. M. Rizzo. 2002. Determining the trophic guilds of fishes and macro-invertebrates in a seagrass food web. *Estuaries*. 25:1143–1163.

Mazzotti, F.J., L.G. Pearlstine, T. Barnes, A. Volety, K. Chartier, A. Weinstein. and D. DeAngleis. 2006. Stressor response models for the Blue Crab, *Callinectes, sapidus*. JEM Technical Report. Final report to the South Florida Water Management District and the U.S..Geological Survey. University of Florida, Fort Lauderdale Research and Education Center, Fort Lauderdale, Florida, 12 p.

Meyer, W.B., and B.L. Turner 1992. Human population growth and global land use/cover change. *Annual Review of Ecology and Systematics*. 23:39-61.

Mallin, M.A., J.M. Burkholder, L.B. Cahoon, and M.H. Posey. 2000. North and South Carolina coasts. *Marine Pollution Bulletin*. 41:56-75.

Mallin, M.A., L.B. Cahoon. 2003. Industrialized animal production: a major source of nutrient and microbial pollution to aquatic ecosystems. *Population and Environment*. 24:369-385.

Mallin, M.A., M.R. McIver, H.A. Wells, D.C. Parsons, and V.L. Johnson. 2005. Reversal of eutrophication following sewage treatment upgrades in the New River Estuary, North Carolina. *Estuaries*. 28:750-760.

Miller, J.M., J.S. Burke, and G.R. Fitzhugh 1991. Early life history patterns of Atlantic North American flatfish: Likely (and unlikely) factors controlling recruitment. *Netherlands Journal of Sea Research*. 27:261-275.

Mitch, W.J, J.W. Day, J.W. Gilliam, P.M. Groffman, D.L. Hey, G. W. Randall, and N. Wang. 2001. Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to counter a persistent ecological problem. *Bioscience*. 51:373-388.

Montane, M.M., and H.M. Austin. 2005. Effects of Hurricanes on Atlantic croaker (*Micropogonias undulatus*) recruitment to Chesapeake Bay. Chesapeake Research Consortium Publication 05-160. Edgewater, MD. 8p.

Moser, M.L. and J.M. Miller 1994. Effects of salinity fluctuation on routine metabolism of juvenile spot, *Leistomus xanthurus*. *Journal of Fish Biology*. 45:335-340.

Murdy, E.O., R.S. Birdsong, and J.A. Musick. 1997. Fishes of Chesapeake Bay. Smithsonian Institution Press. 324p.

North Carolina Division of Marine Fisheries. 2006. Fishery Management Plan for Shrimp. Morehead City, North Carolina. 390p.

Nixon, S.W. 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia*. 41:199-219.

Kemp, W.M., W.R. Boynton, J.E. Adolf, D.F. Boesch, W.C. Boicourt, G. Brush, J.C. Cornwell, T.R. Fisher, P.M. Gilbert, J.D. Hagy, L.W. Harding, E.D. Houde, D.G. Kimmel, W.D. Miller, R.I.E. Newell, M.R. Roman, E.M. Smith, and J.C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. *Marine Ecology Progress Series.* 303:1-29.

Officer, C.B., R.B. Biggs, J.L. Taft, L.E. Cronin, M.A. Tyler, W.R. Boynton. 1984. Chesapeake Bay Anoxia: Origin, Development, and Significance. *Science.* 233:22-27.

Orth, R.J, V.J. Montfrans. 1987. Utilization of marsh and seagrass habitats by early stages of *Callinectes sapidus*: a latitudinal perspective. *Bulletin of Marine Science* 46:126–144.

Paerl, H.W. J.L Pinkney, J.M. Fear, and B.L. Peierls. 1998. Ecosystem responses to internal and watershed organic matter loading: consequences for hypoxia in the eutrophying Neuse River Estuary, North Carolina, USA. *Marine Ecology Progress Series*. 166:17-25.

Paerl, H.W., R.L. Dennis, and D.R. Whithall. 2002. Atmospheric deposition of nitrogen, implications for nutrient over-enrichment of coastal waters. *Estuaries.* 25:677-693.

Paerl, H.W. 2006. Assessing and managing nutrient-enhanced eutrophication in estuarine and coastal waters: Interactive effects of human and climatic perturbations. *Ecological Engineering.* 26:40–54.

Peterjohn, W.T., and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. *Ecology.* 65:1466-1475.

Pontius R.G. and L.C. Schneider. 2001. Land cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystems and Environment*. 85:239-248.

Powell, A.B., and F.J. Schwartz, 1977. Distribution of Paralichthid flounders (Bothidae: *Paralichthys*) in North CarolinaEstuaries. *Chesapeake Science*. 18:334-339.

Powell, A.B., and T. Henley 1995. Egg and larval development of laboratory-reared gulf flounder, Paralichthys albigutta, and southern flounder, P. lethostigma (Pisces, Paralichthyidae). *Fisheries Bulletin*. 93:504-515.

Rabalais, N.N., R.E. Turner, D. Scavia. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. *BioScience*. 52:129-142.

Rakocinski, C.F., M.S. Peterson, B.H. Comyns, G.A. Zapfe, and G.L. Fulling. 2006. Do abiotic factors drive the early growth of juvenile spot (*Leiostomus xanthurus*)? *Fisheries Research.* 82:186–193.

Richards, J.A. and X. Jia. 2005. *Remote Sensing Digital Image Analysis: An Introduction*. Springer-Verlag. New York, Inc., Secaucus, NJ, USA. 449 p.

Rodriguez, W., P.V. August, Y. Wang, J.F. Paul, A. Gold, and N. Rubinstein.2006. Empirical relationships between land use/cover and estuarine condition in the Northeastern United States. *Landscape Ecology*. 22:403–417.

Ross, S.W., and S.P. Epperly.1985. Utilization of shallow estuarine nursery areas by fishes in Pamlico Sound and adjacent tributaries, North Carolina. In: Yanez-Arancibia A. (ed) Fish community ecology in estuaries and coastal lagoons: Towards an ecosystem integration. UNAM Press, Mexico. p 207–232.

Rulifson, R.A. 1981. Substrate preferences of juvenile penaeid shrimps in estuarine habitats. *Contributions to Marine Sciences*. 24:35-52.

Scavia, D., J.C Field, D.F. Boesch, R.W. Buddemeier, V. Burkett, D.R. Cayan, M. Fogarty, M.A. Harwell, R.W. Howarth, C. Mason, D.J. Reed, T.C. Royer, A.H. Sallenger, and J.G. Titus. 2002. Climate Change Impacts on U.S. Coastal and Marine Ecosystems. *Estuaries*. 25:149-164.

Sellner, K.G., G.J. Doucette, G. J. Kirkpatrick. 2003. Harmful algal blooms: causes, impacts and detection. *Journal of Industrial Biotechnology*. 30:383-406.

Skole, D.L., Chomentowski, W.H., Salas, W.A., and A.D. Nobre. 1994. Physical and human dimensions of deforestation in Amazonia. In the Brazilian Amazon, regional trends are influenced by large-scale external forces but mediated by local conditions. *BioScience*. 44:314-322.

Stanley, D.W. 1993. Long-term trends in Pamlico River Estuary Nutrients, chlorophyll, Dissolved Oxygen, and Watershed Nutrient Production. *Water Resources Research*. 29:2651-2662.

Steel, J. 1991. Albemarle-Pamlico Estuarine System, Technical Analysis of Status and Trends. DENR, Raleigh, NC, APES Report No. 901.

Stehman S.V., J.D Wickham, J.H. Smith, and L. Yang. 2003. Thematic accuracy of the 1992 National Land-Cover Data for the eastern United States: Statistical methodology and regional results. *Remote Sensing of Environment*. 86:500–516.

Stow, C.A., M.E. Borsuk., and D.W. Stanley. 2001. Long-term changes in watershed nutrient inputs and riverine exports in the Neuse River, North Carolina. *Water Resources*. 35:1489-1499.

Taylor, J.C., W.A. Mitchell, and J.A. Buckel, H.J. Walsh, K.W. Shertzer, G. Bath, M. Jonathan, and A. Hare. 2010. Relationships between Larval and Juvenile Abundance of Winter-Spawned Fishes in North Carolina, USA. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem. *Science.* 2009:12-21.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F. N. Erasmus, M.F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, S.E. Williams, 2004. Extinction risk from climate change. *Nature*. 427:145–148.

Tortora, R. 1978. A note on sample size estimation for multinomial populations. *The American Statistician.* 32:100-102.

Uphoff, J. 2003. Predator-prey analysis of striped bass and Atlantic menhaden in upper Chesapeake Bay. *Fisheries Management and Ecology*. 10:313-322.

U.S. Department of Agriculture. 2009. Summary Report: 2007 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. 123 p.

U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service. 2009. Federal standards and procedures for the National Watershed Boundary Dataset. U.S. Geological Survey. Techniques and Methods. 11–A3, 55 p.

Utz, R.M., Hilderbrand, R.H., Boward, D.M., 2009. Identifying regional differences in threshold responses of aquatic invertebrates to land cover gradients. *Ecological Indicators.* 9:556–567.

Xie, L., and B.D. Eggleston. 1999. Computer simulations of wind-induced estuarine circulation patterns and estuary-shelf exchange processes: the potential role of wind forcing on larval transport. *Estuarine, Coast and Shelf Science.* 49:221-234.

Verburg P.H., P. Schoa, M. Dijsta, and A. Veldkamp. 2004. Land use change modeling: current practice and research priorities. *Geojournal*. 61: 309-324.

Viera, A.J., J.M. Garrett. 2005. Understanding Inter-observer Agreement: The Kappa Statistic. *Family Medicine Research Series*. 37:360-363.

Vitousek, P.M., and R.W. Howarth.1991. Nitrogen limitation on land and in the sea: How can it occur? *Biogeochemistry.* 13:87-115.

Vitousek, P.M., H.A. Mooney, J. Lubchenco, and J.M. Melillo. 1997. Human domination of earth's ecosystems. *Science.* 277:494–499.

Wang, J.C.S. and R.J. Kernehan. 1979. Fishes of the Delaware estuaries: a guide to the early life histories. E. A. Communications. Towson. MD.

Wang Y., and T.R. Allen. 2008. Estuarine shoreline change detection using Japanese ALOS PALSAR HH and JERS-1 L-HH SAR data in the Albemarle-Pamlico Sounds, North Carolina, USA. *International Journal of Remote Sensing.* 29:4429–4442.

Warlen, S.M., J.S. Burke. 1990. Immigration of larvae of fall/winter spawning marine fishes into a North Carolina Estuary. *Estuaries.* 13:453-462.

Warlen, S.M. 1994. Spawning time and recruitment dynamics of larval Atlantic menhaden, *Brevoortia tyrannus,* into a North Carolina estuary. *Fishery Bulletin.* 92:420-433.

Watterson, J.C., and J.P. Monaghan. 2001. Flounder pound net fishery. In: Assessment of North Carolina commercial fin fisheries, 1997–2000. North Carolina Department of

Environment and Natural Resources, Division of Marine Fisheries, Completion Report NA 76 FI 0286, Morehead City.

Welsh, J.M. and R.B. Forward. 2001. Flood Tide of blue crab, *Callinectes sapidus*, postlarvae: behavioral responses to salinity and turbulence. *Marine Biology*. 139:911-918.

Wenner, E.L. and H.R. Beatty. 1993. Utilization of Shallow Estuarine Habitats in South Carolina, U.S.A., by Postlarval and Juvenile Stages of *Penaeus spp*. (Decapoda: Penaeidae). *Journal of Crustacean Biology. 13:280-295.*

West, T.L., L.M. Clough, and W.G. Jr Ambrose. 2000. Assessment of function in an oligohaline environment: Lessons learned by comparing crested and natural habitats. *Ecological Engineering*. 15:303–321.

Whitfield, A.K. 1996. Fishes and the environmental status of South African estuaries. *Fisheries Management and Ecology*. 3:45–57.

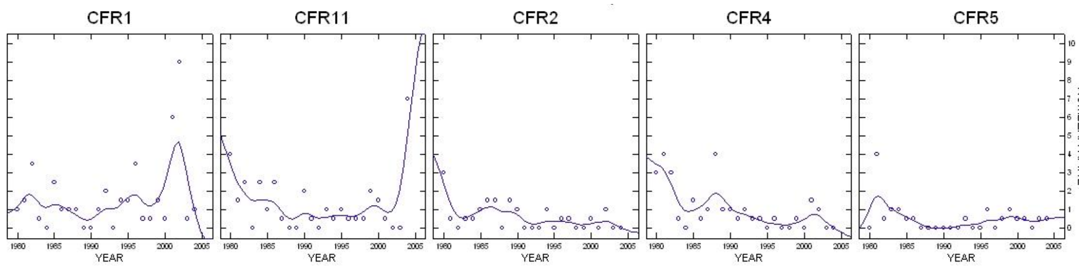
Williams, A.B .1965. Marine decapods crustaceans of the Carolinas. U.S. Fish and Wildlife Service. *Fisheries Bulletin.* 65:1-298.

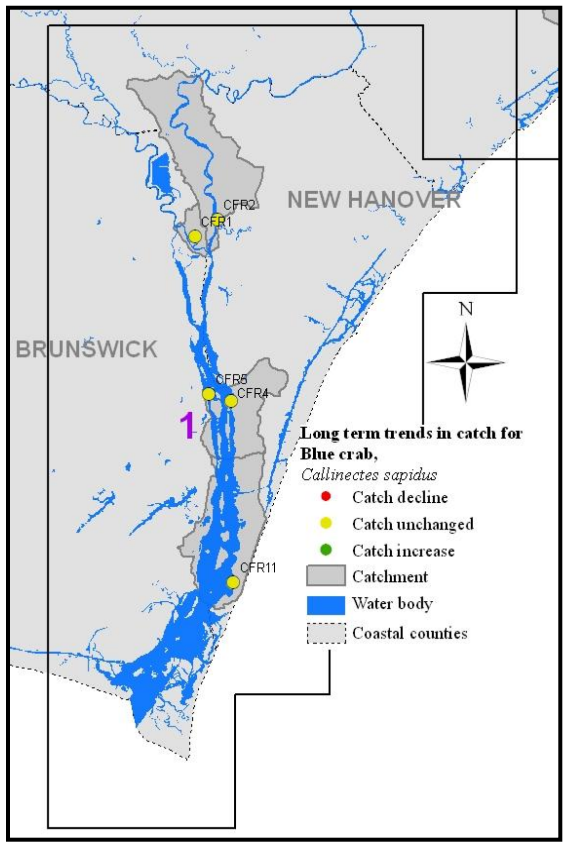
Zimmerman, R.J., T.J. Minello, and G. Zamora. 1984. Selection of vegetated habitat by *Penaeus aztecus* in a Galveston Bay salt marsh. United States National Marine Fisheries Service *Fishery Bulletin.* 82:325-336.

# Appendices

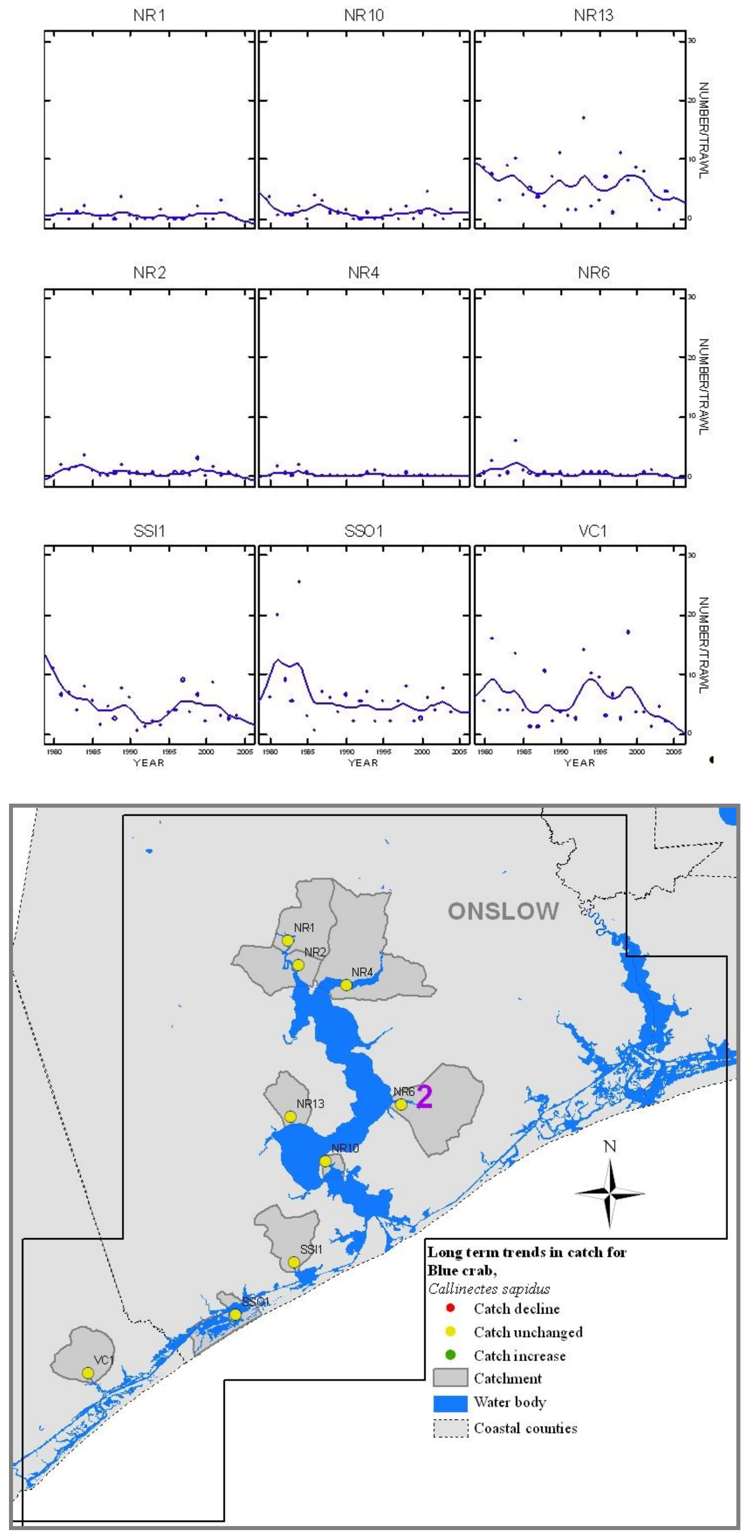
## Catches by species and geographic region

Detailed changes in abundance of the seven species for the 25-year period spanning from 1980 to 2004 are given in Appendices 1–42. Each appendix is made up with two panels: 1) a color coded map displaying areas of changes or lack of changes. A red circle shows a significant decline in catch for an area (two standard deviations below the long-term average for that station, i.e., Z score $< -1.96$), yellow circle no change, and green a significant increase (two standard deviations above the long-term average for that station, i.e., Z score $> 1.96$). 2) The second panel is a group of scatter plots showing yearly abundances of averaged May and June trawls catches for each station and by region. Catch was plotted (y-axis) against Year (x-axis) and the points were grouped by station.

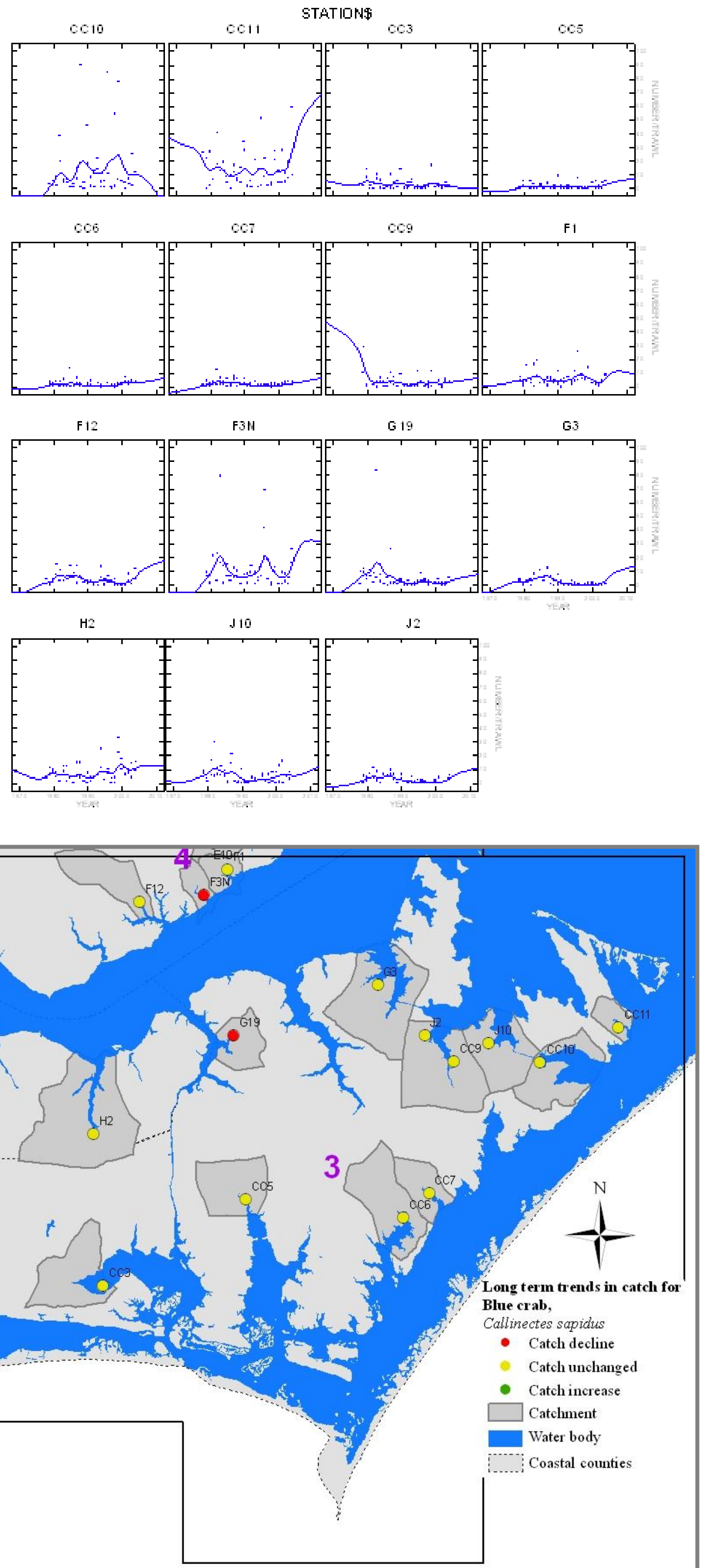


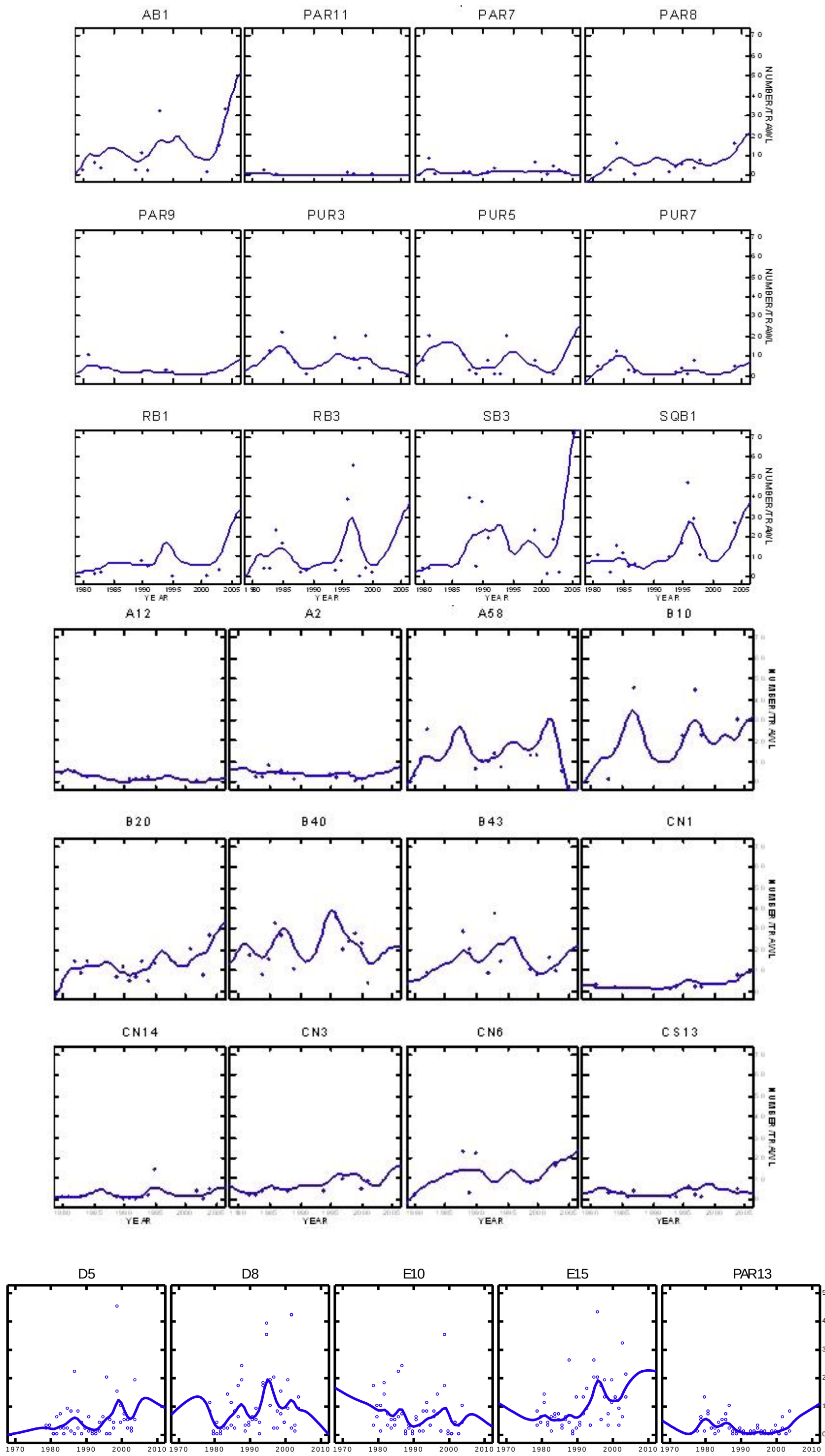

Appendix 1. Change in number of blue crab caught per trawl at five stations in the lower Cape Fear region.



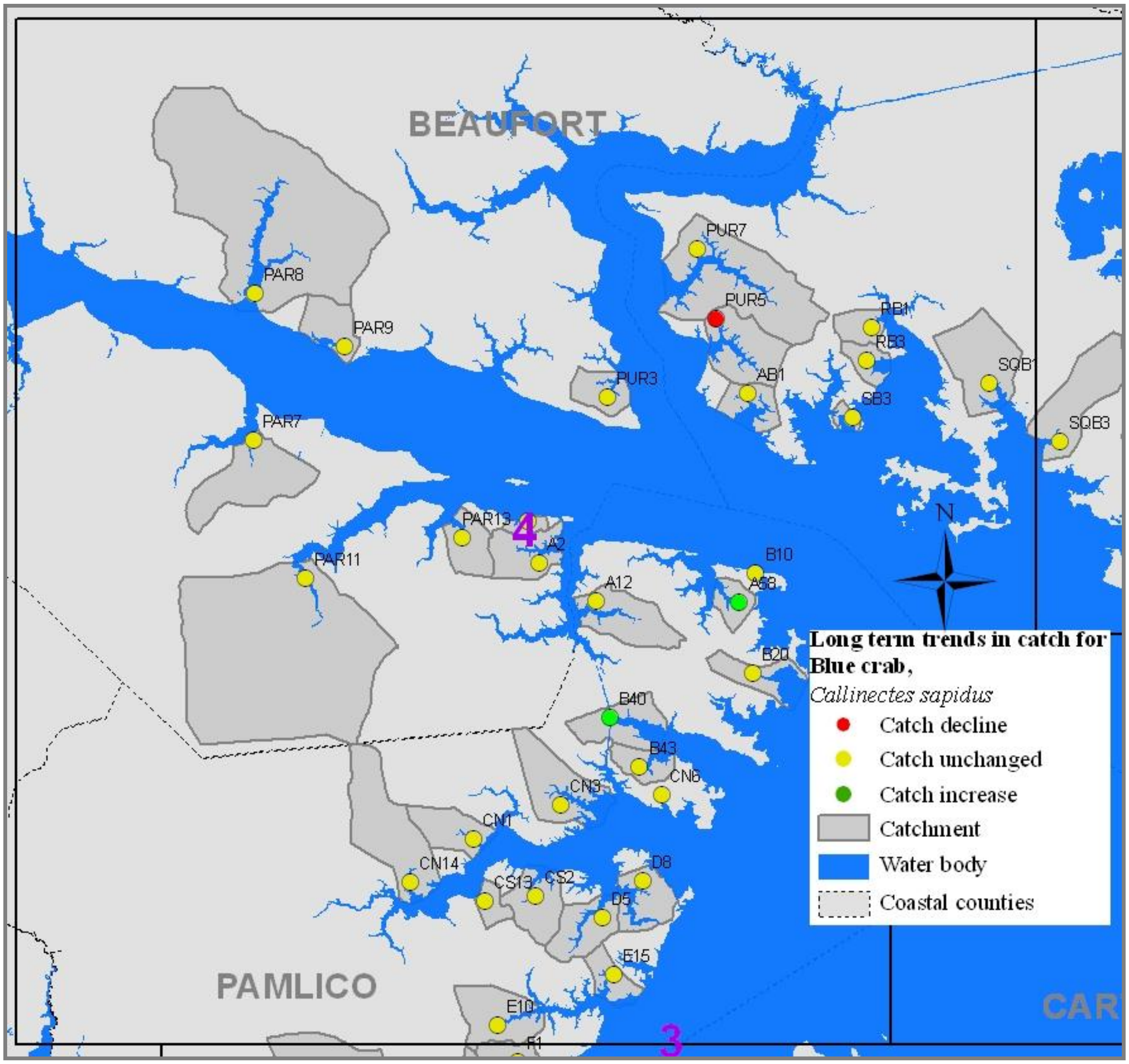

Appendix 2. Change in number of blue crab caught per trawl at nine stations in the New River/Jacksonville region.



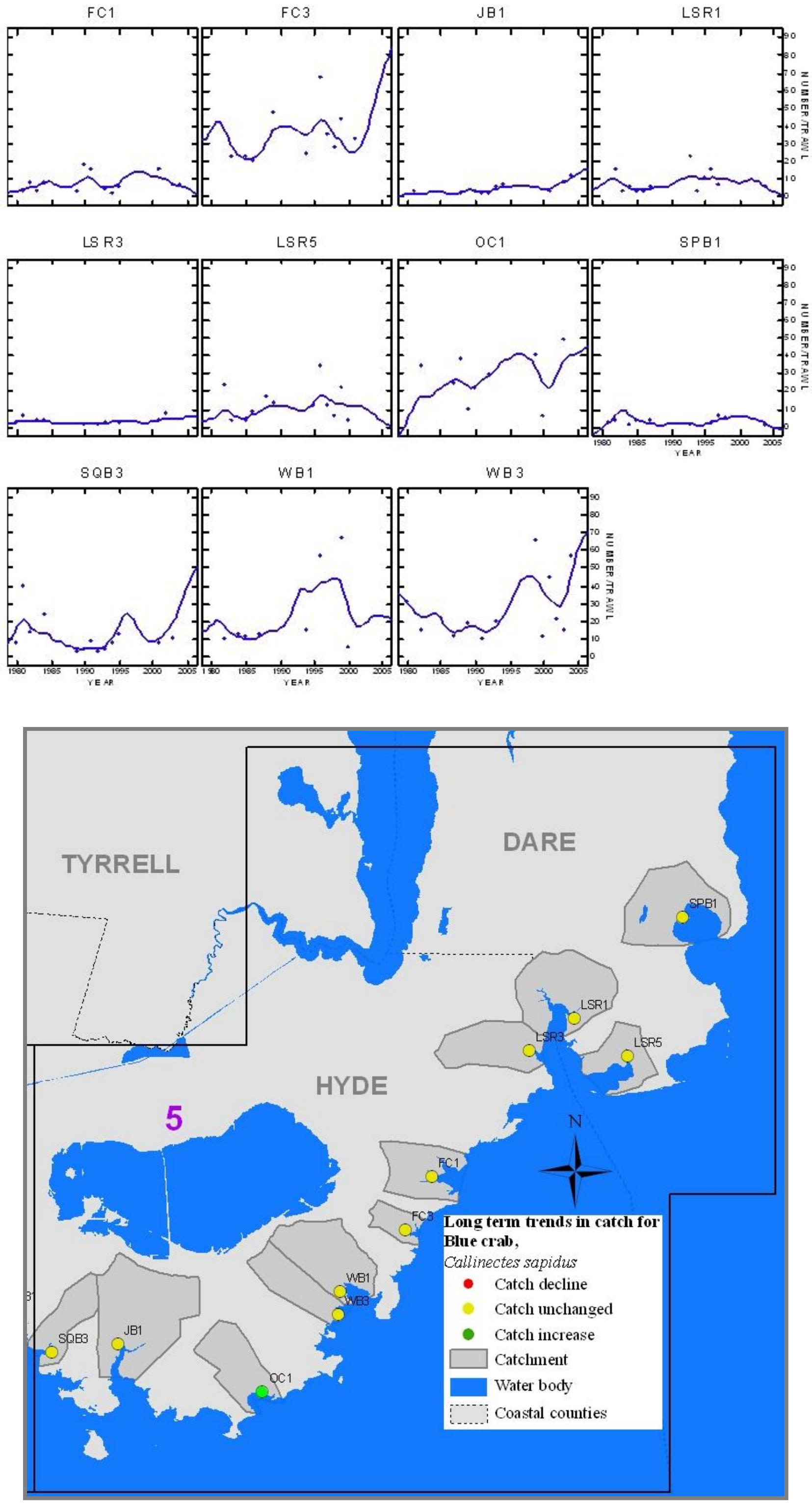

Appendix 3. Change in number of blue crab caught per trawl at 15 stations in the Carteret County region.



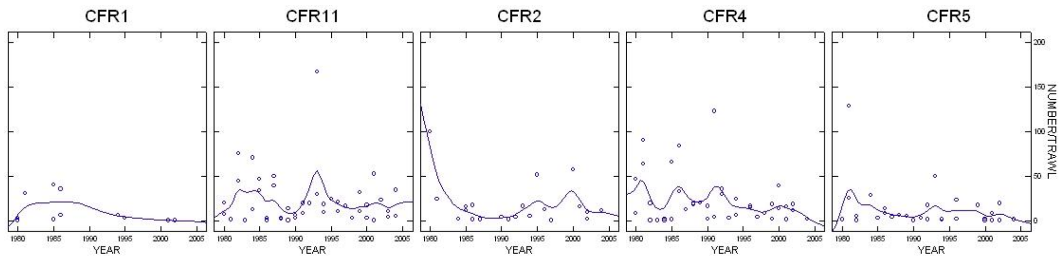

Appendix 4. Change in number of blue crab caught per trawl at 29 stations in the lower Pamlico/Bay River region.

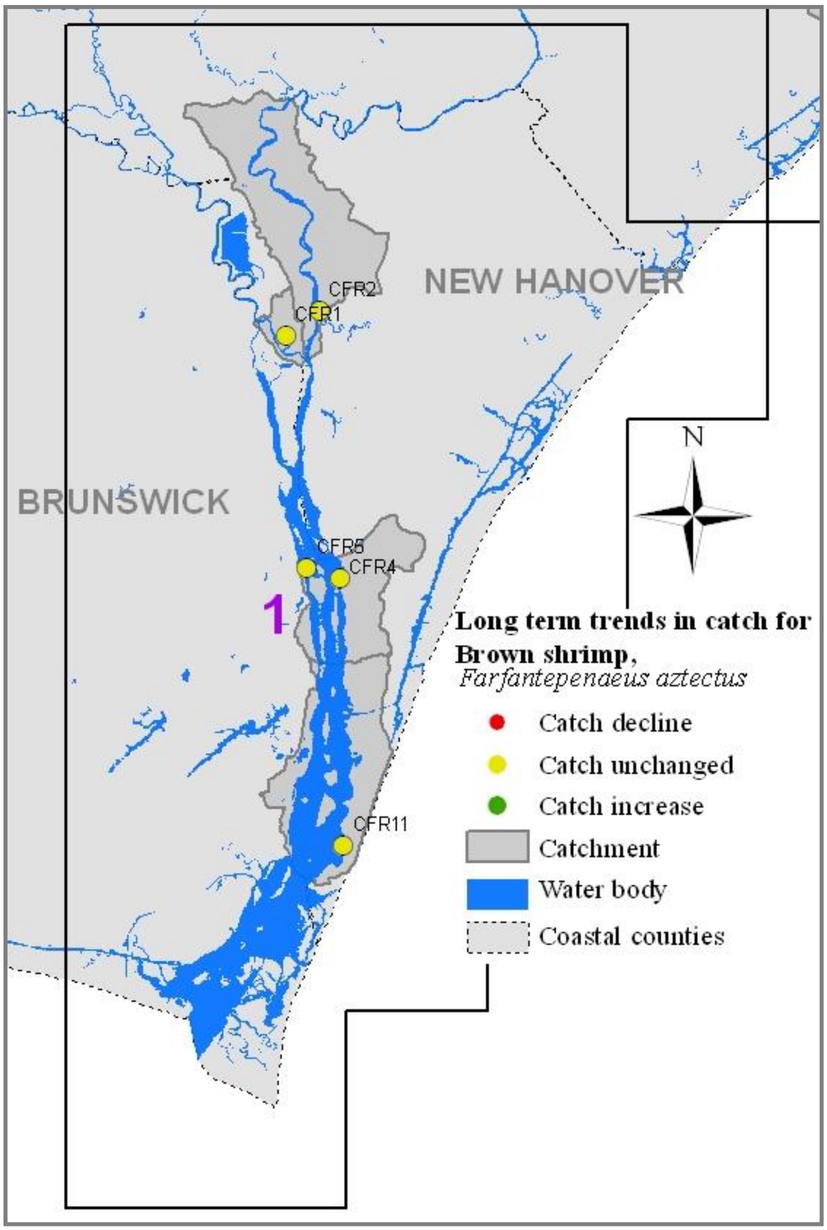



Appendix 5. Map of change in number of blue crab caught per trawl at 29 stations in the lower Pamlico/Bay River region.

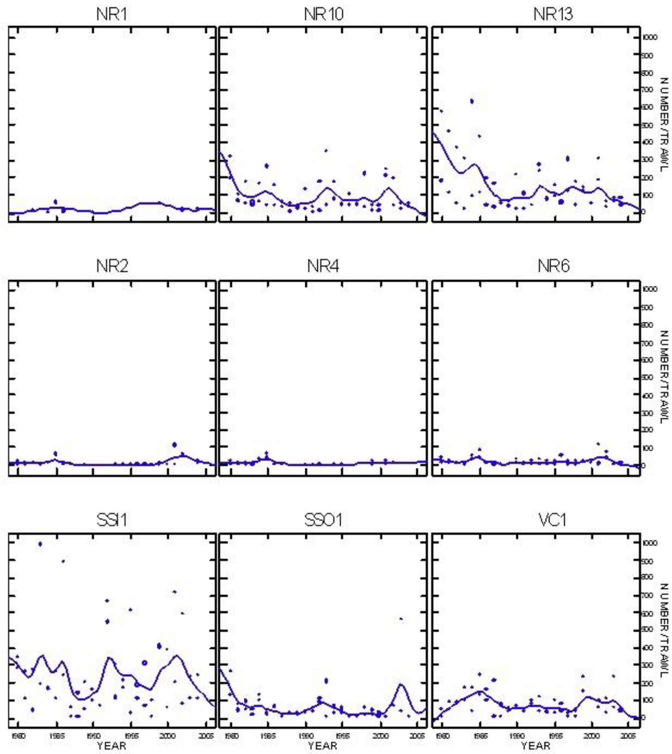


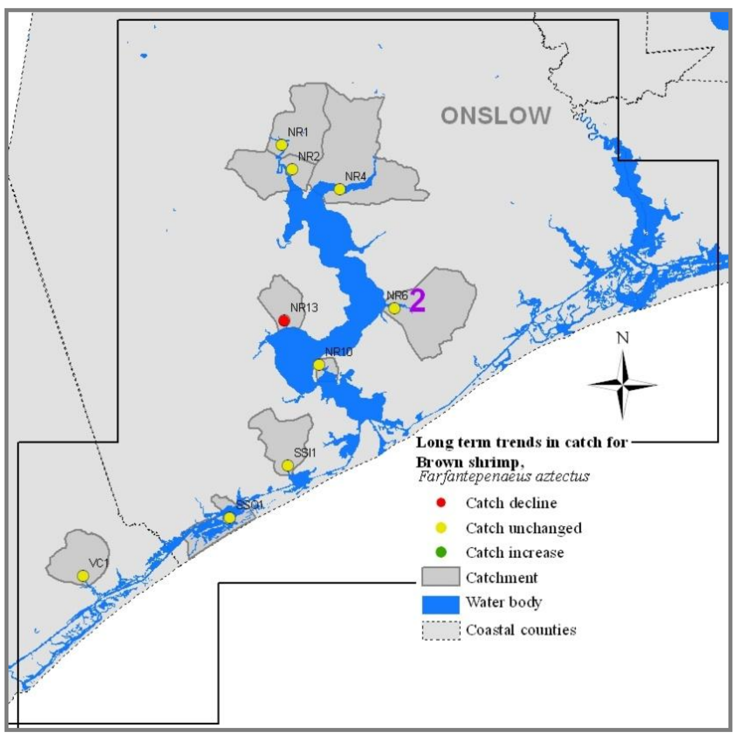

Appendix 6. Change in number of blue crab caught per trawl at 11 stations in the Hyde/Dare County region



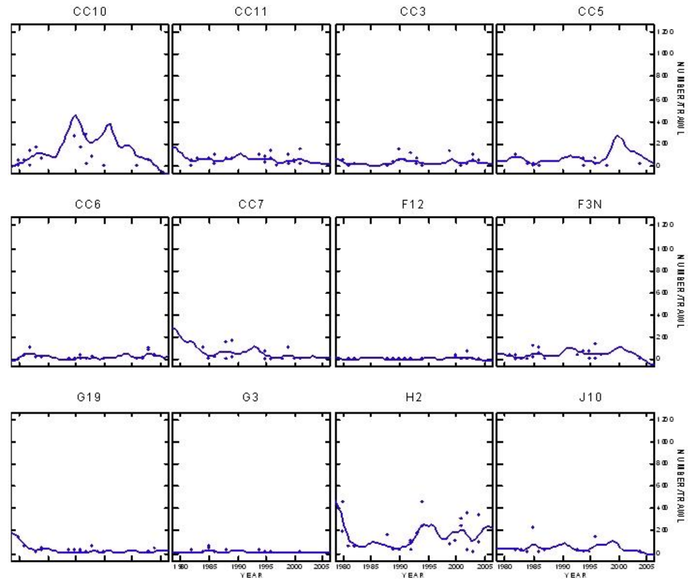



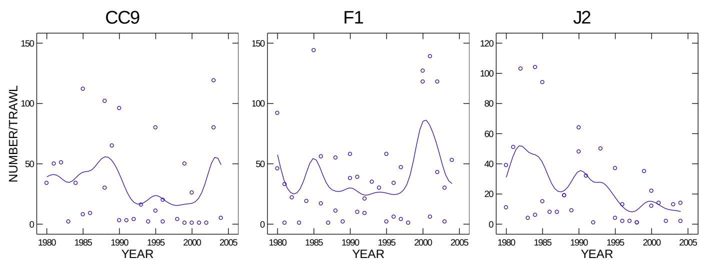

Appendix 7. Change in number of brown shrimp caught per trawl at five stations brown shrimp lower Cape Fear region.

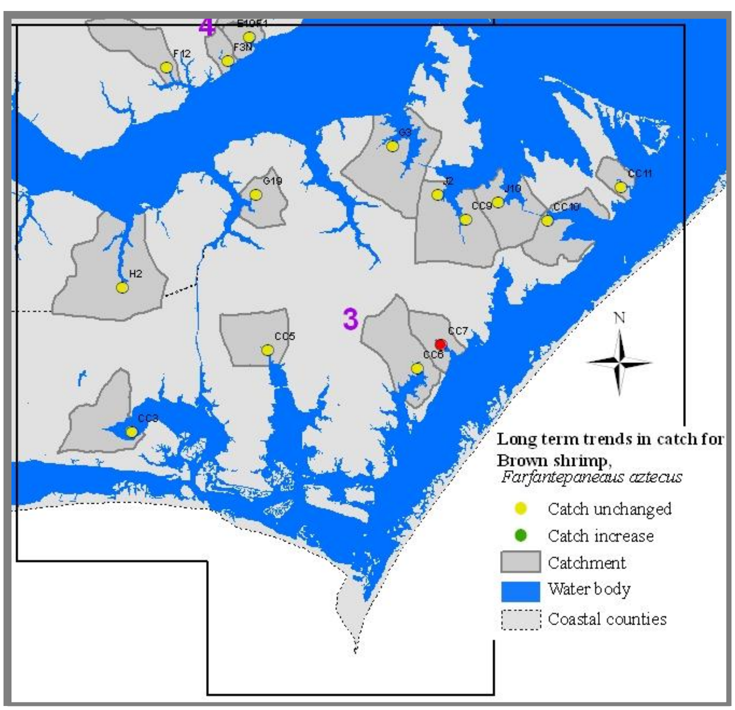


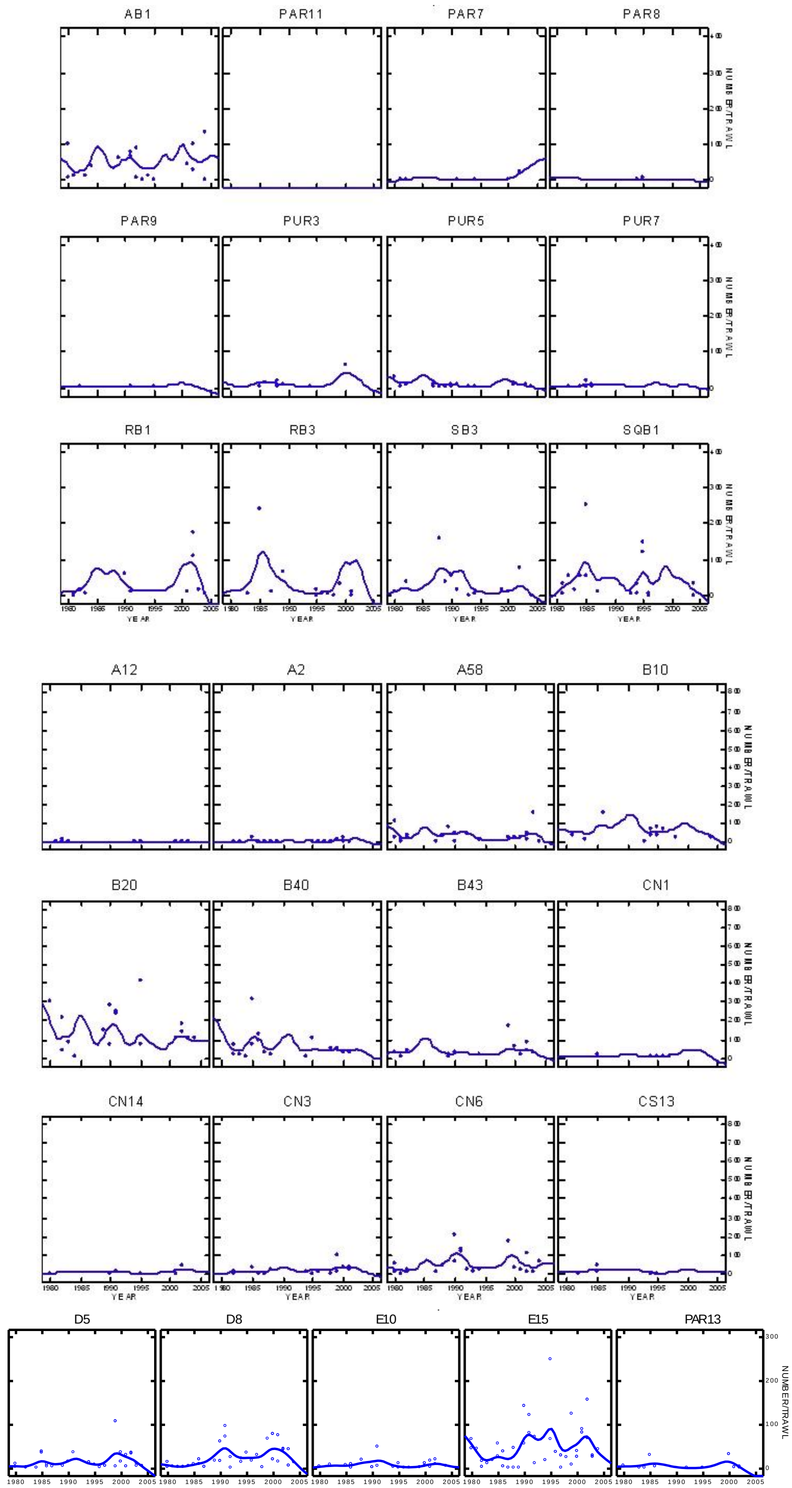

Appendix 8. Change in number of brown shrimp caught per trawl at nine stations in the New River/Jacksonville region.



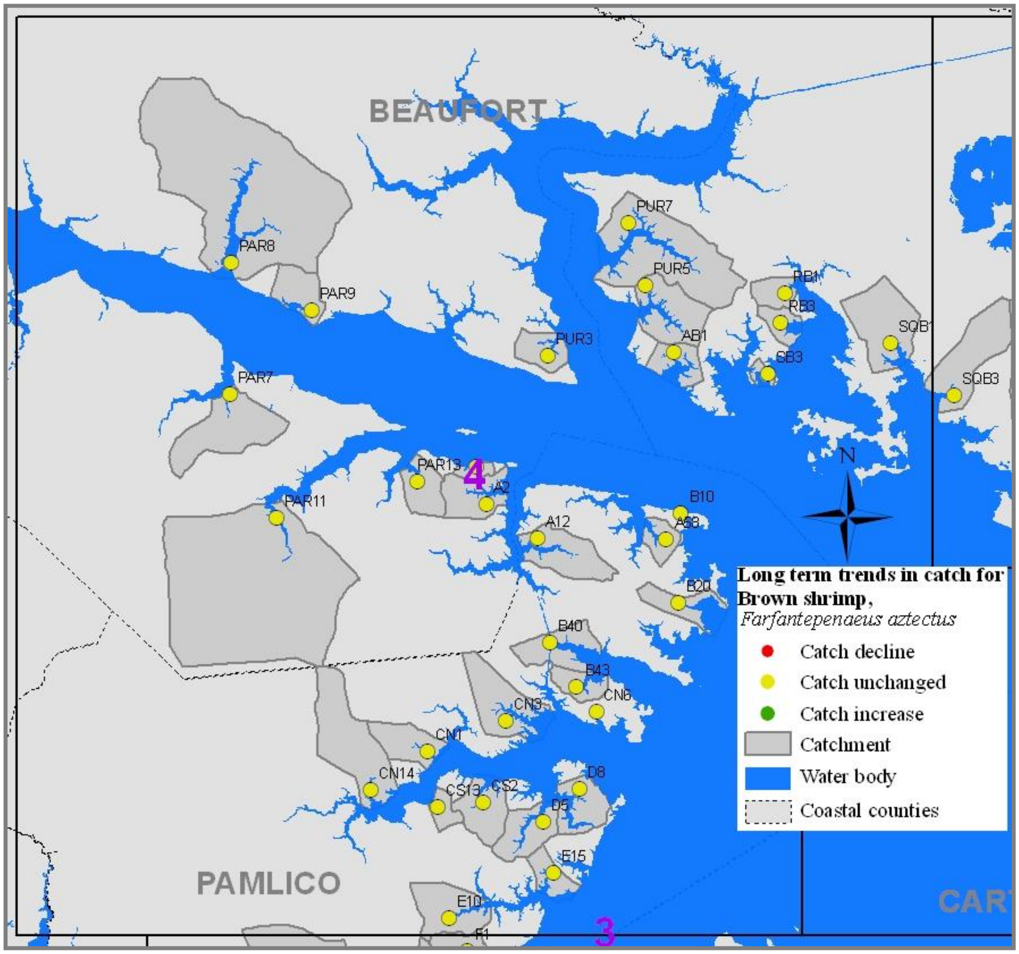



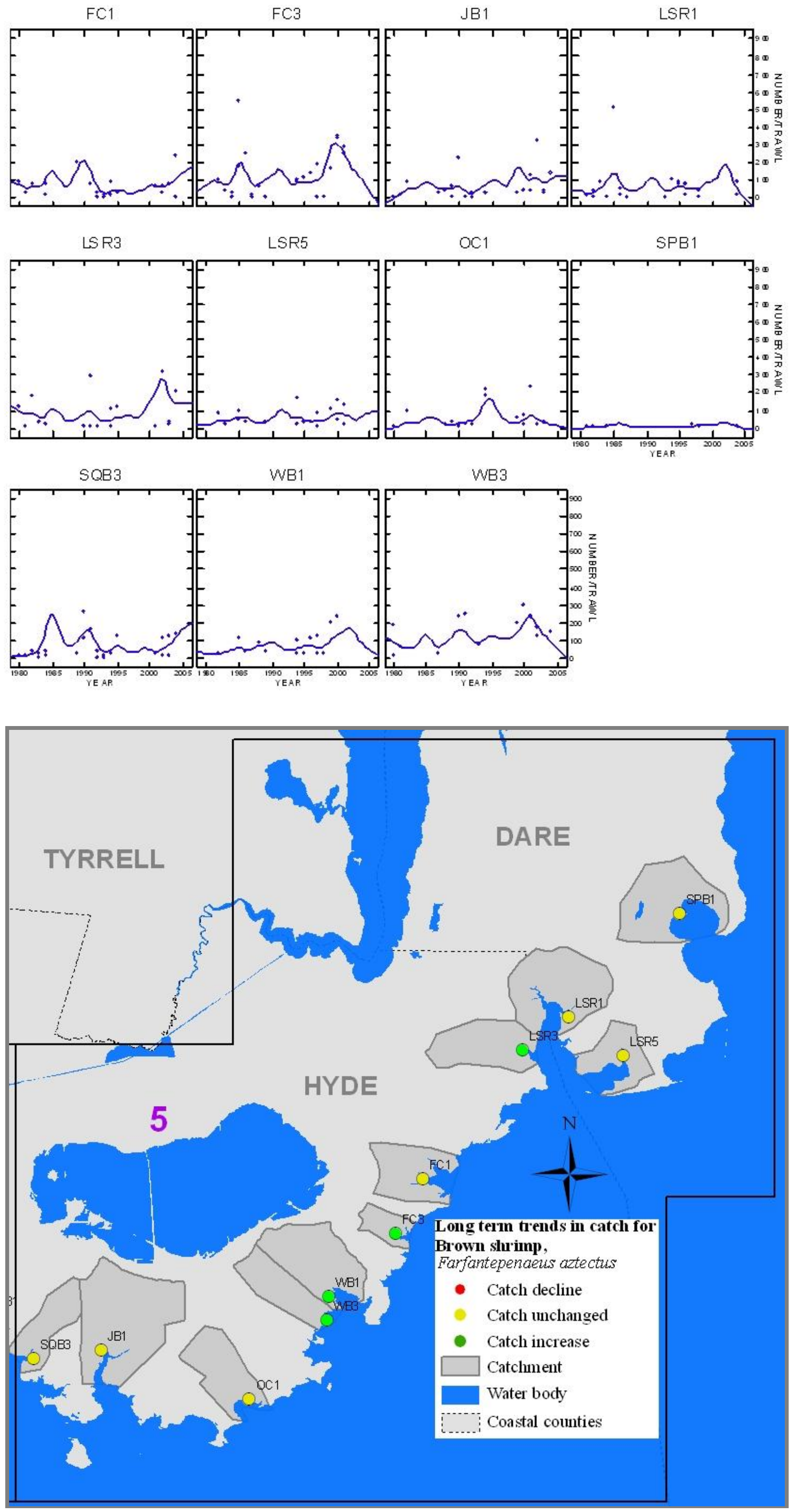

Appendix 9. Change in number of brown shrimp caught per trawl at 15 stations in the Carteret County region.



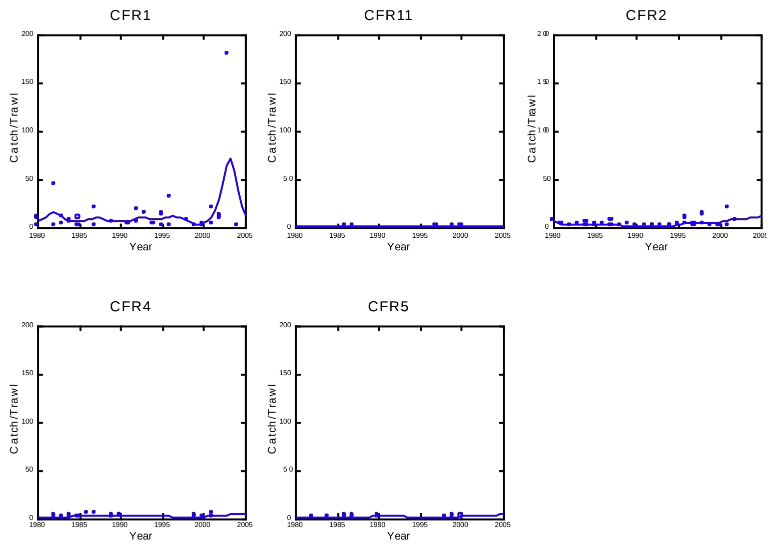

Appendix 10. Change in number of brown shrimp caught per trawl at 29 stations in the lower Pamlico/Bay River region.

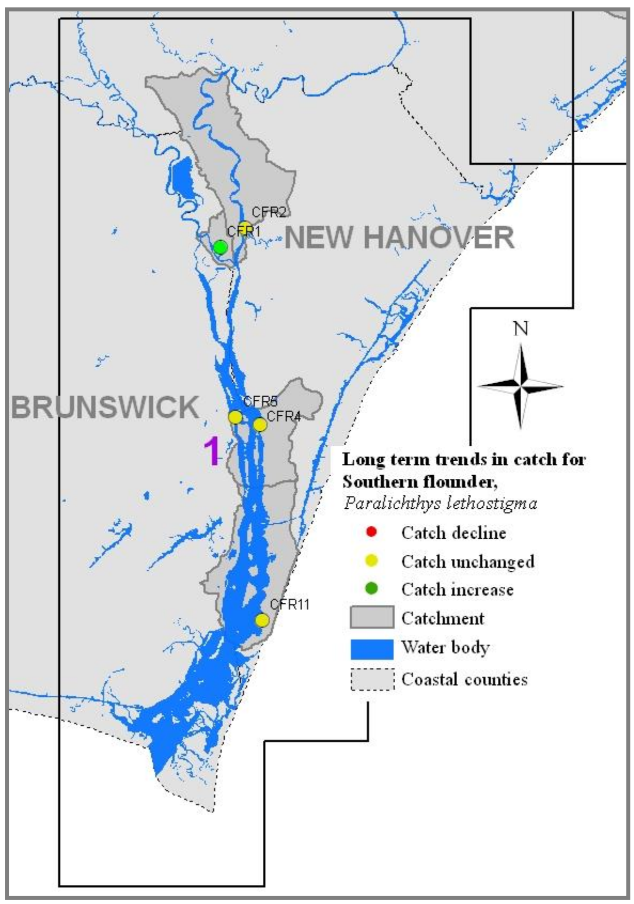



Appendix 11. Map showing change in number of brown shrimp caught per trawl at 29 stations in the lower Pamlico/Bay River region.

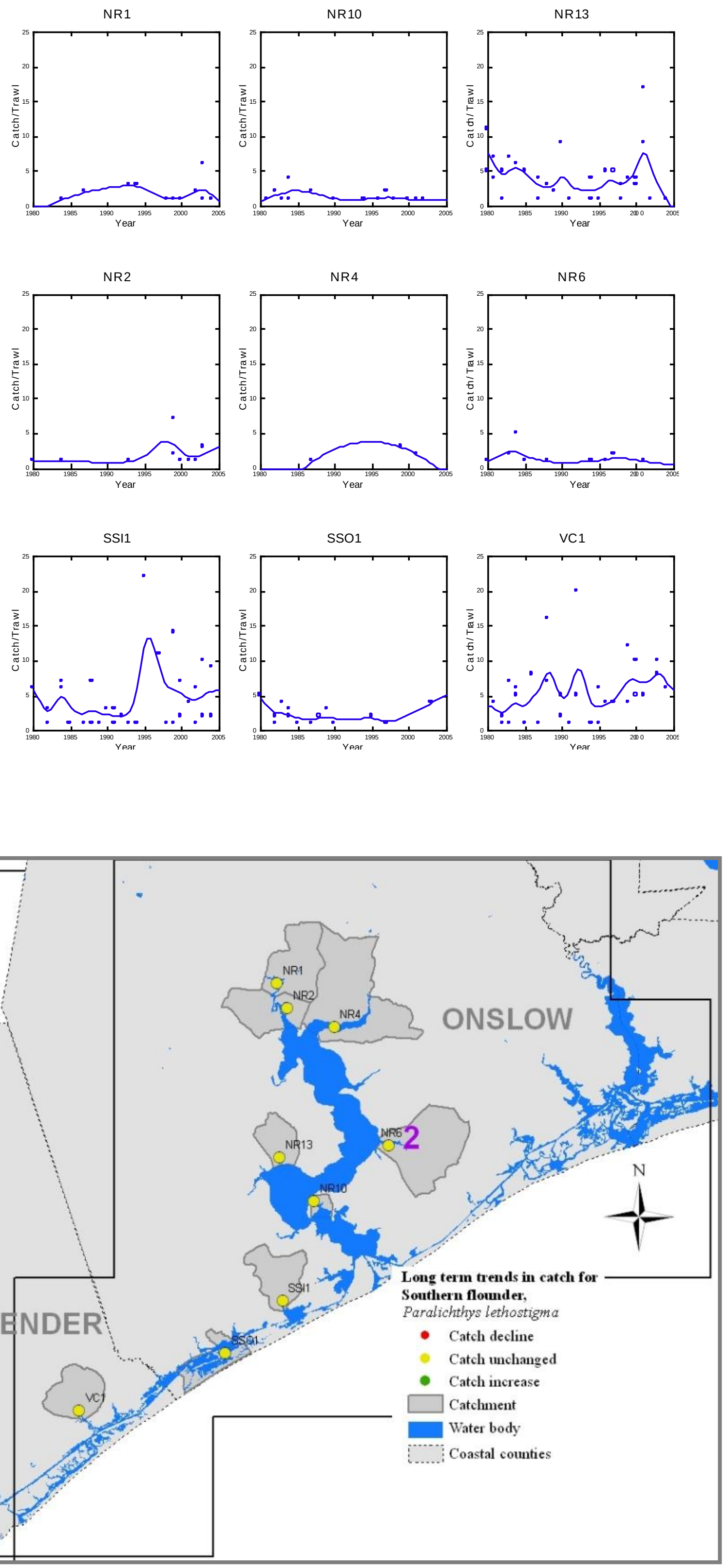



Appendix 12. Change in number of brown shrimp caught per trawl at 11 stations in the Hyde and Dare County region.

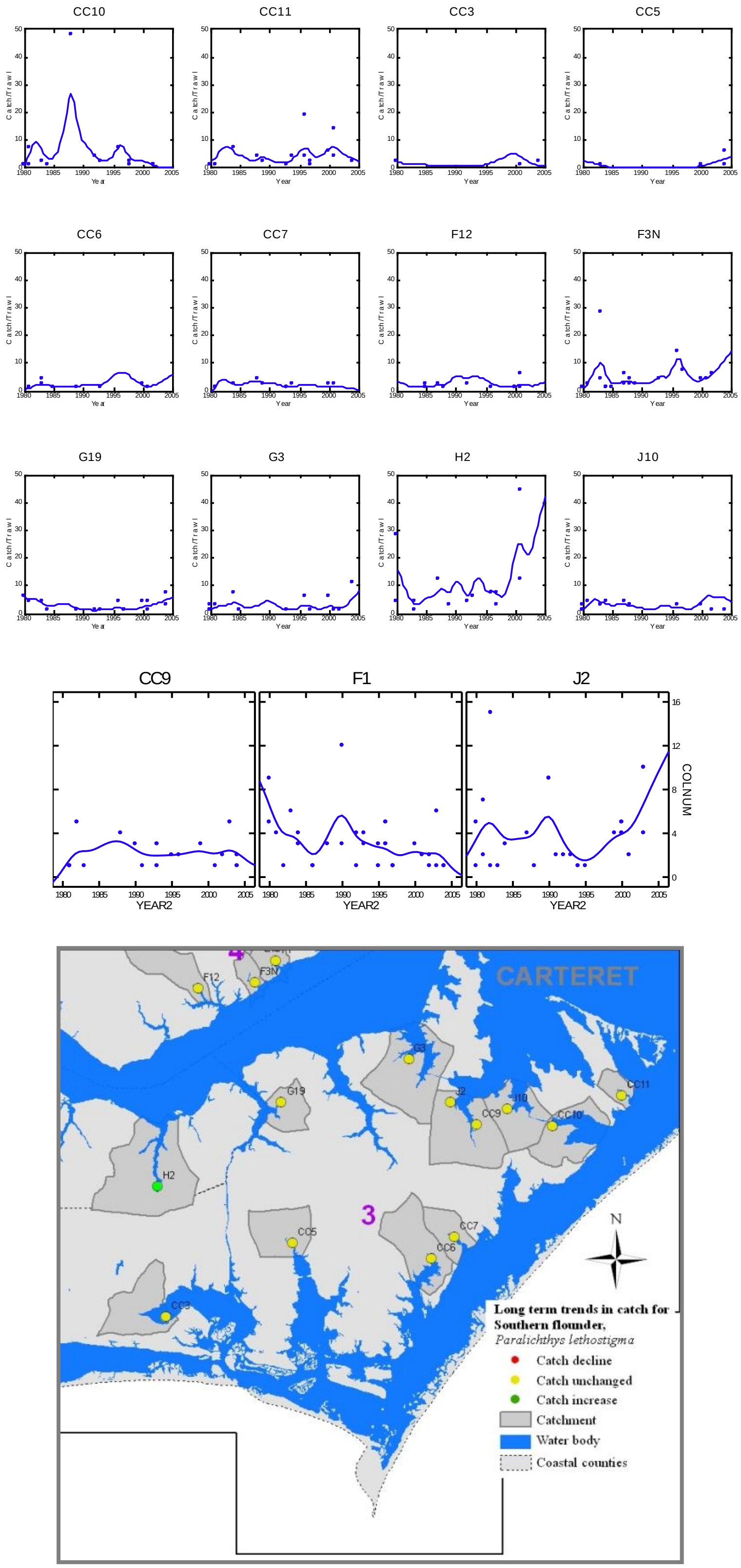


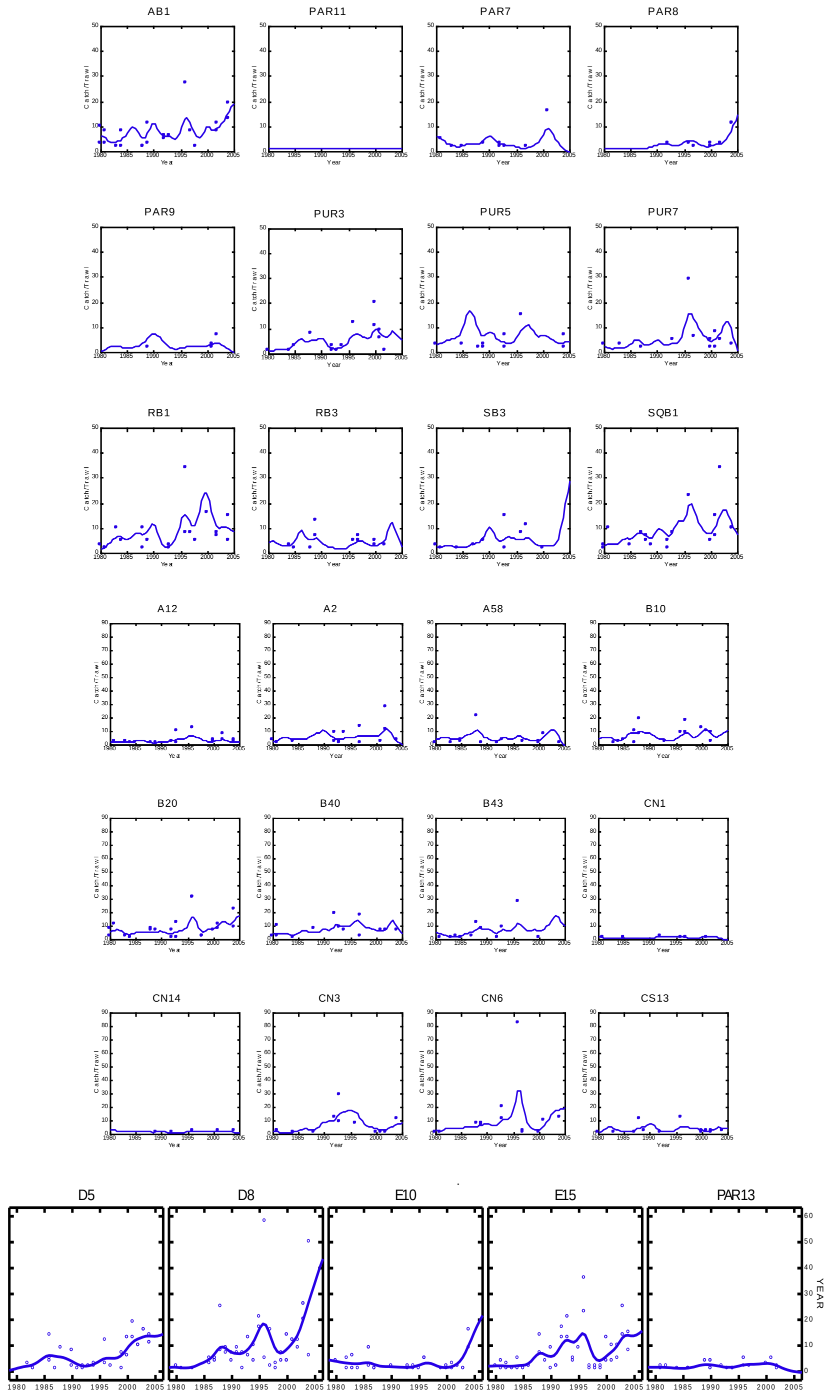

Appendix 13. Change in number of southern flounder caught per trawl at five stations in the lower Cape Fear region.



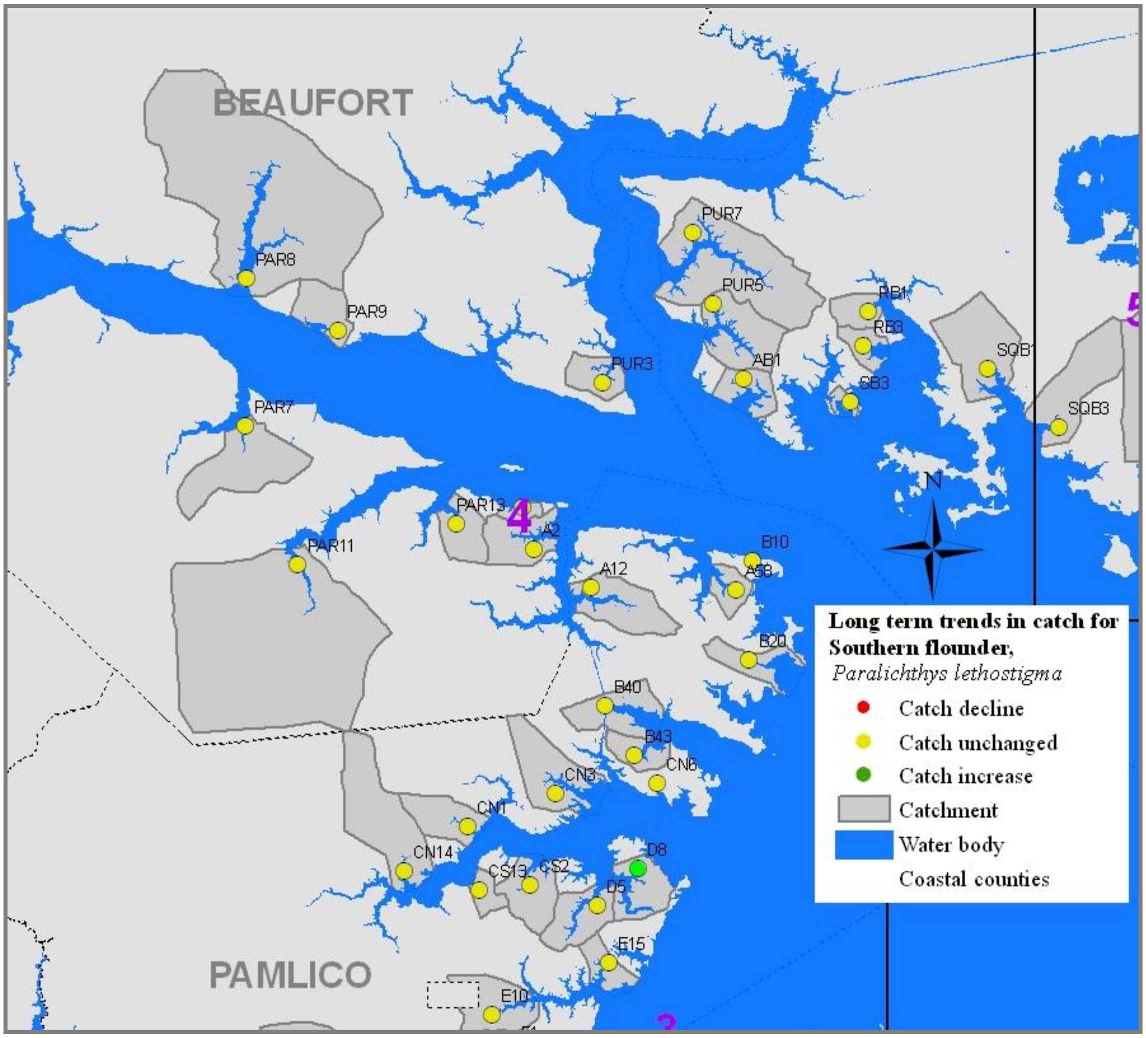

Appendix 14. Change in number of southern flounder caught per trawl at nine stations in the New River/Jacksonville region.



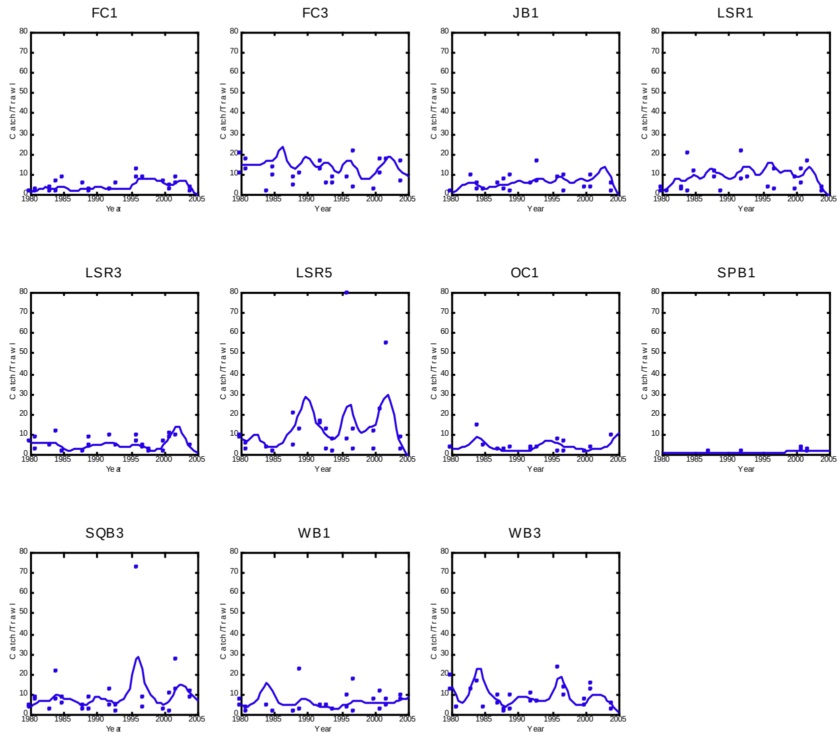

Appendix 15. Change in number of southern flounder caught per trawl at 15 stations in the Carteret County region.

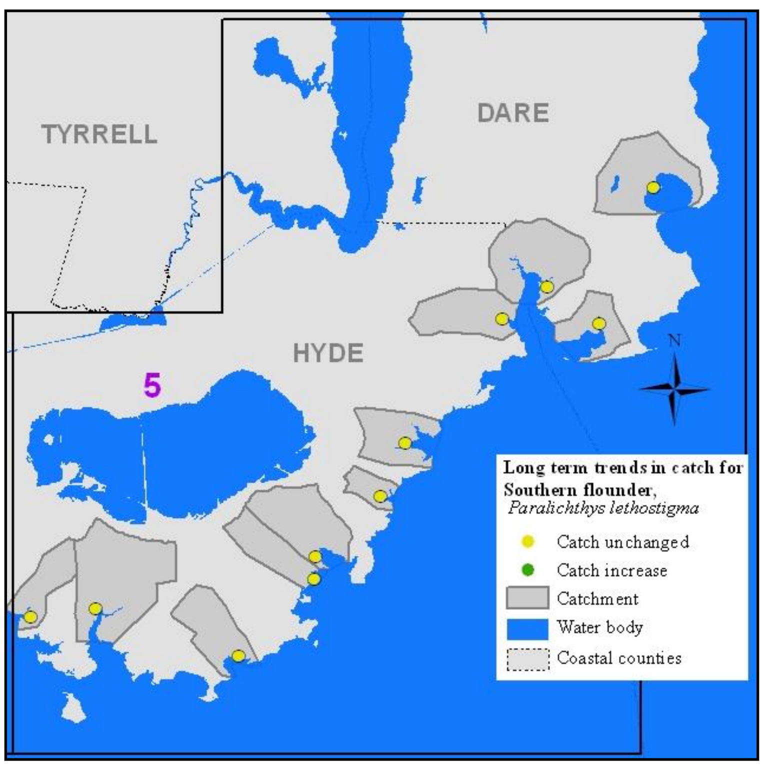



Appendix 16. Change in number of southern flounder caught per trawl at 29 stations in the lower Pamlico/Bay River region.

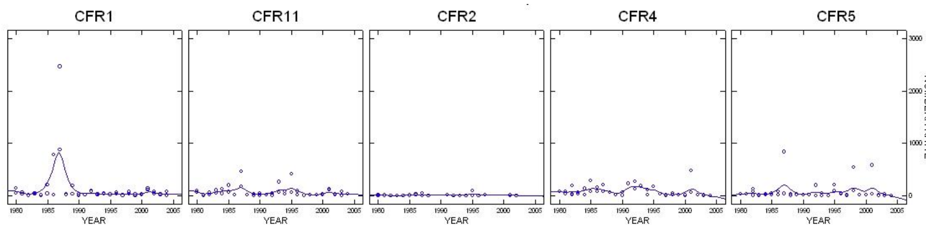



Appendix 17. Map showing change in number of southern flounder caught per trawl at 29 stations in the lower Pamlico/Bay River region and a map of the region

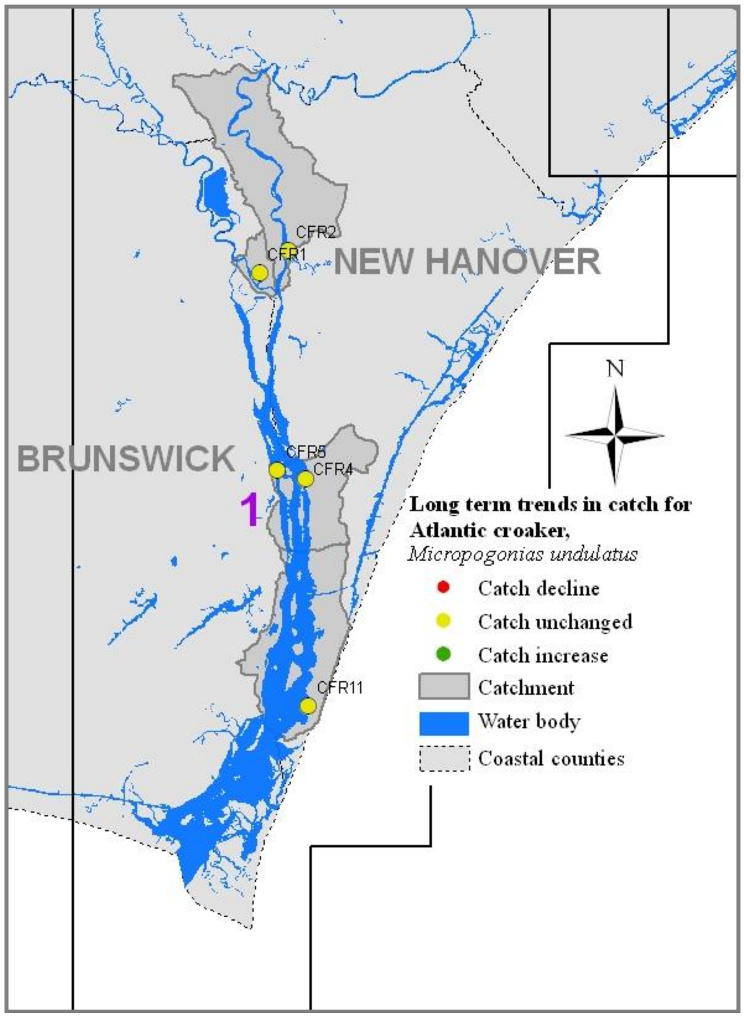



Appendix 18. Change in number of southern flounder caught per trawl at 11 stations in the Hyde/Dare County region.

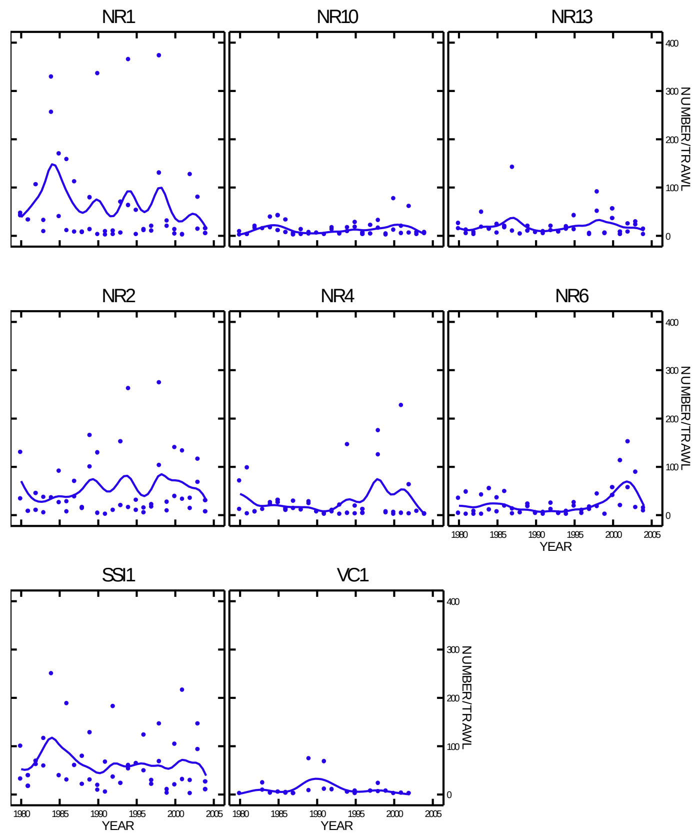


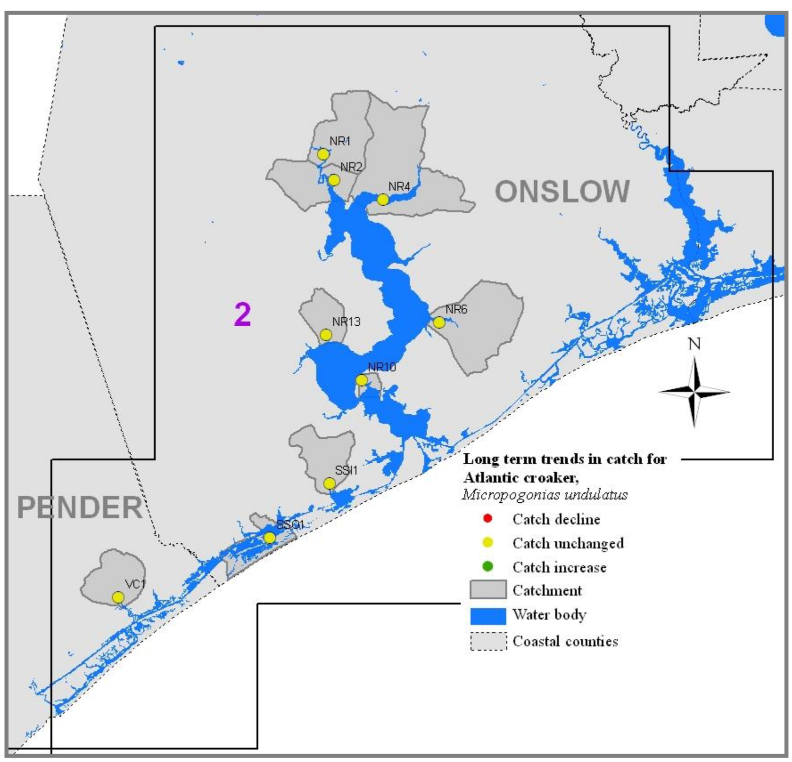




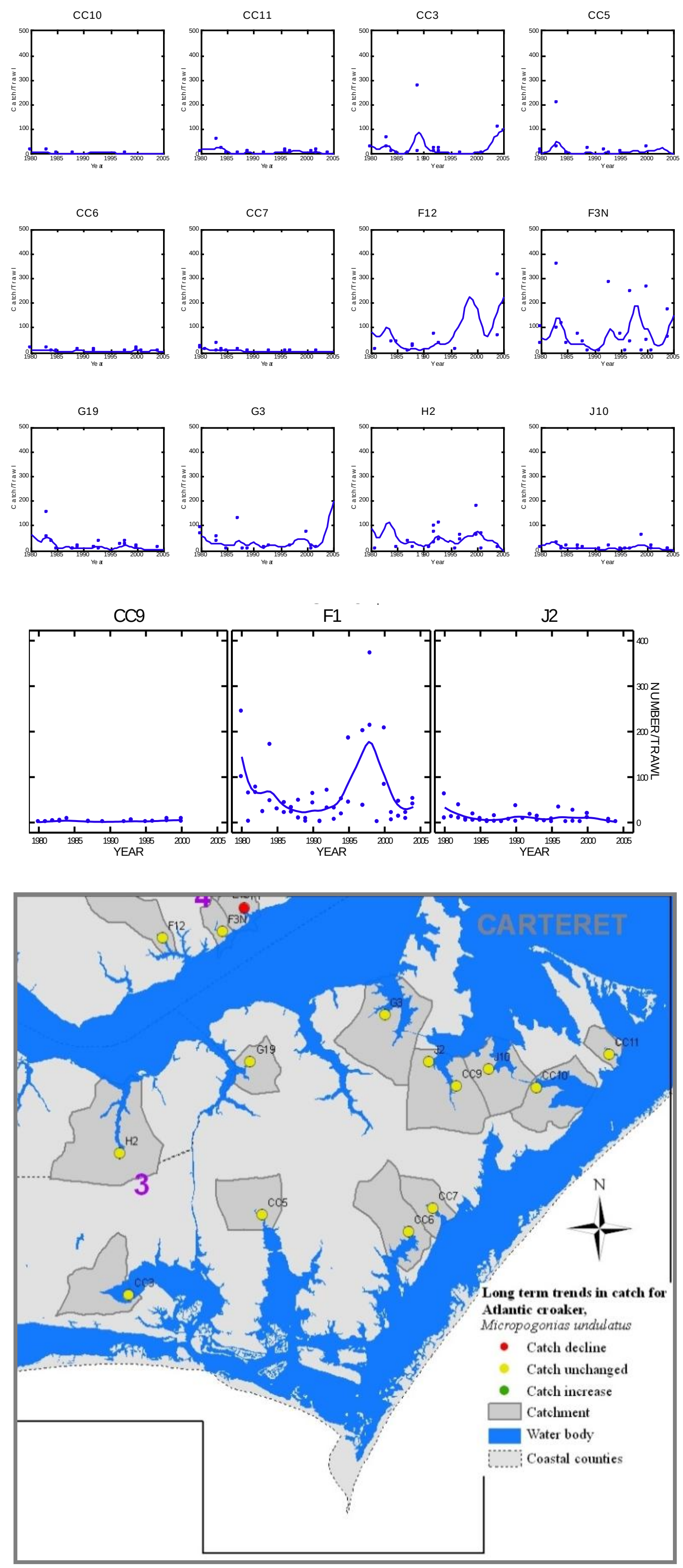


Appendix 19. Change in number of Atlantic croaker caught per trawl at five stations in the lower Cape Fear region.

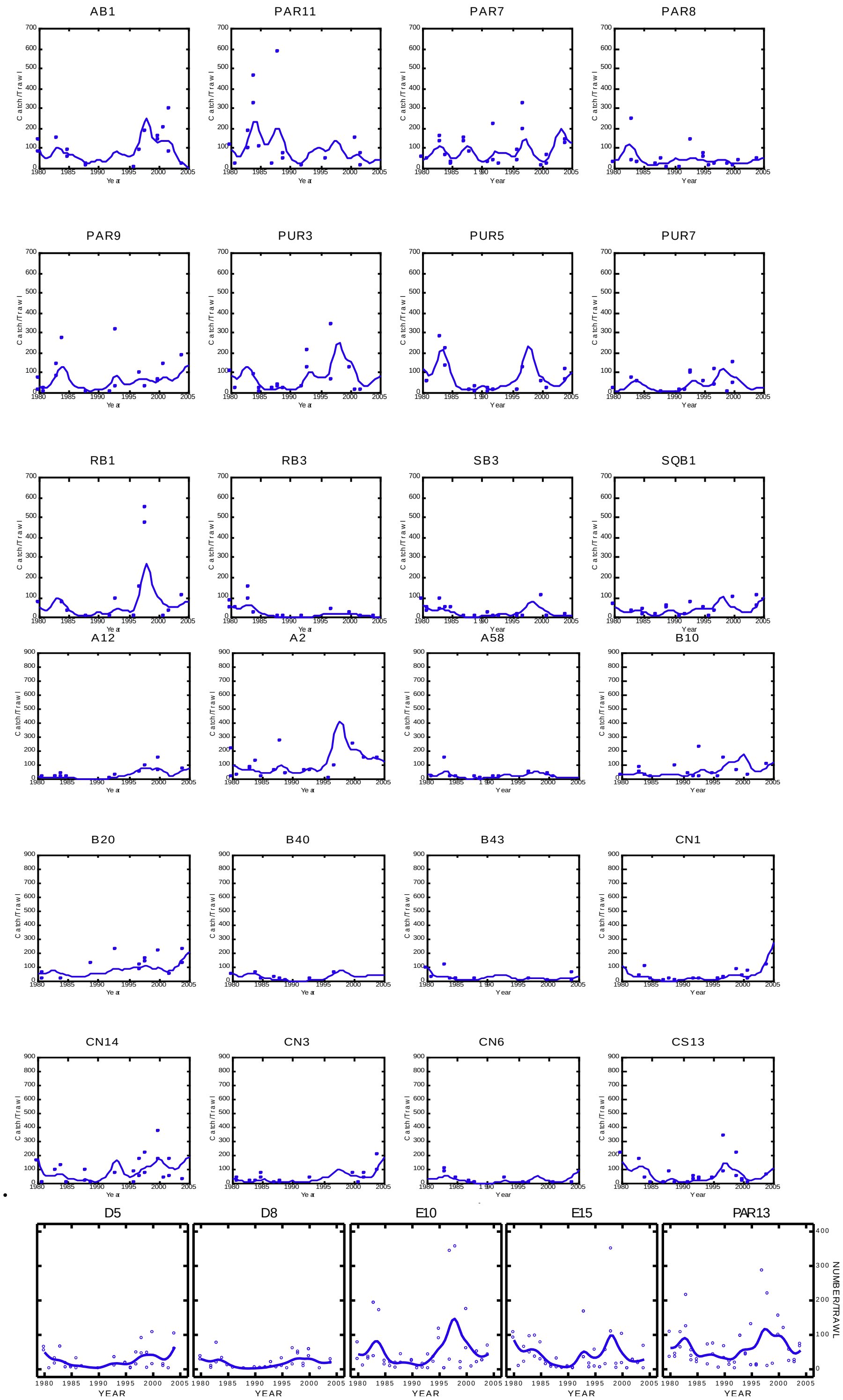


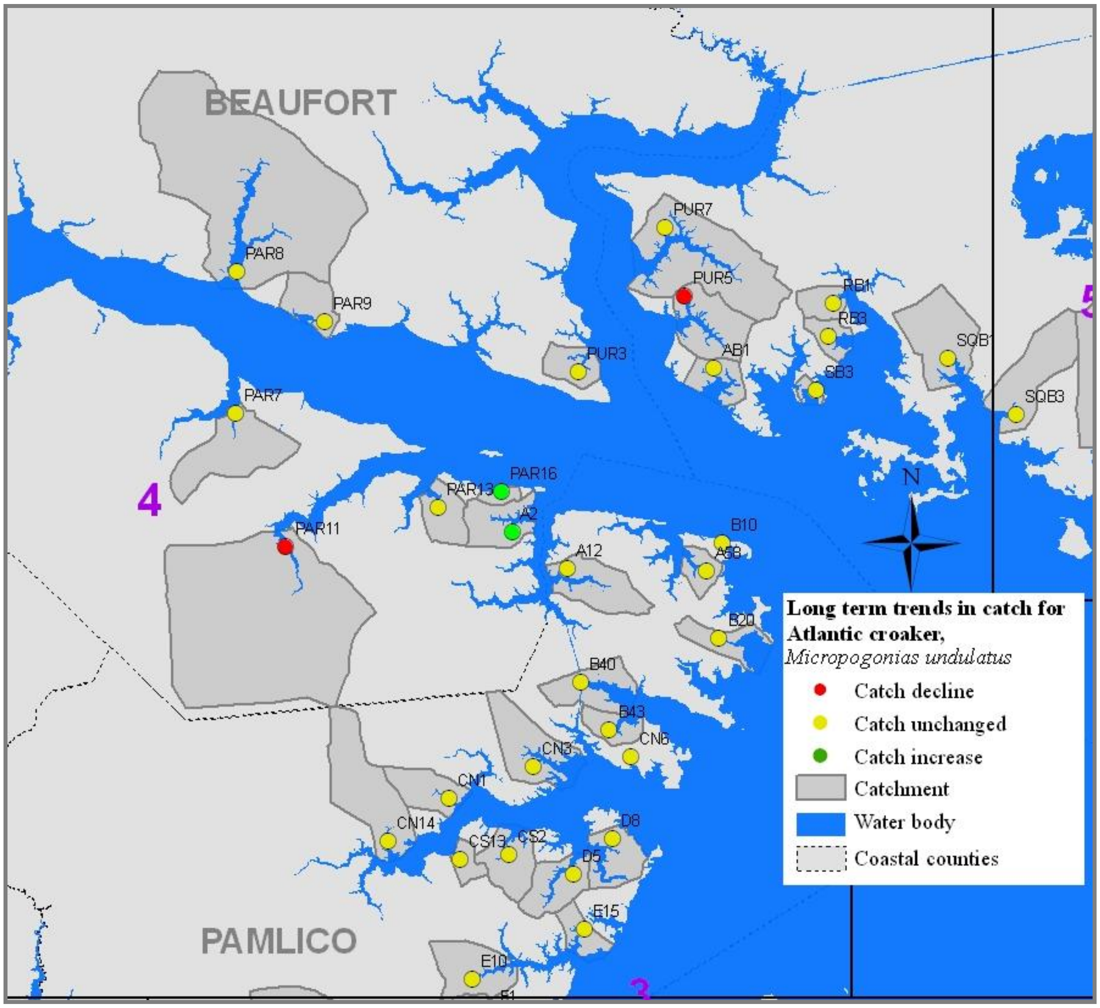

Appendix 20. Change in number of Atlantic croaker caught per trawl at eight stations in the New River/Jacksonville region. No data was available for station SS01.



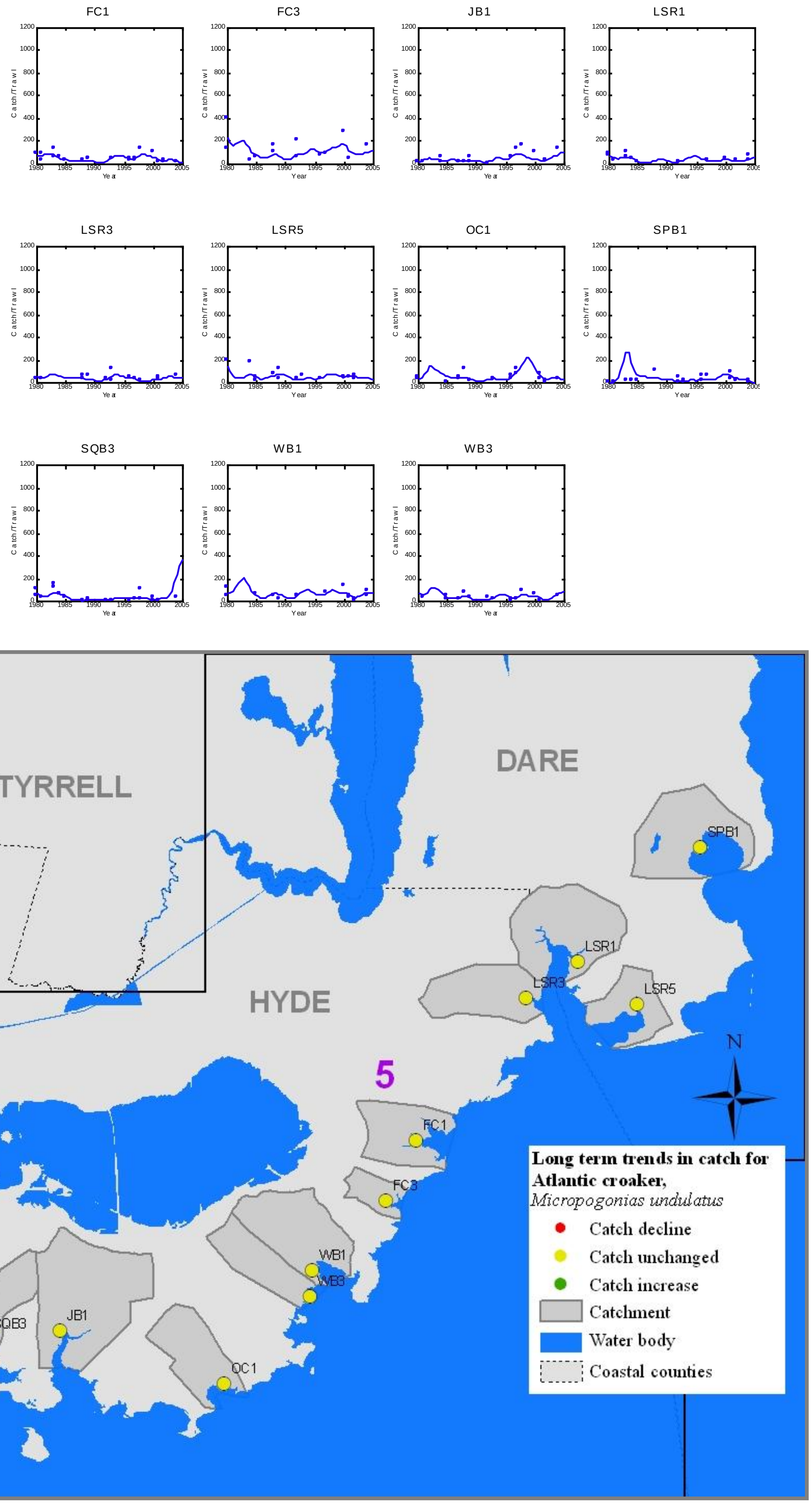

Appendix 21. Change in number of Atlantic croaker caught per trawl at 15 stations in the Carteret County region.



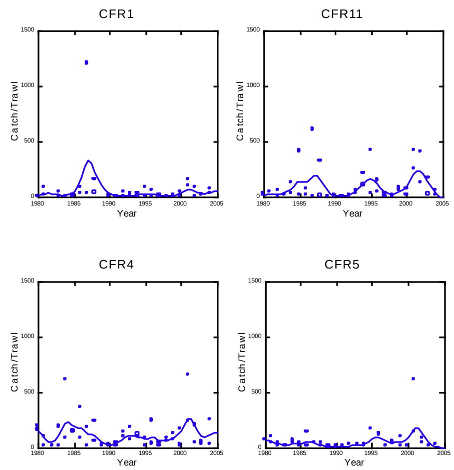

Appendix 22. Change in number of Atlantic croaker caught per trawl at 29 stations in the lower Pamlico/Bay River region.

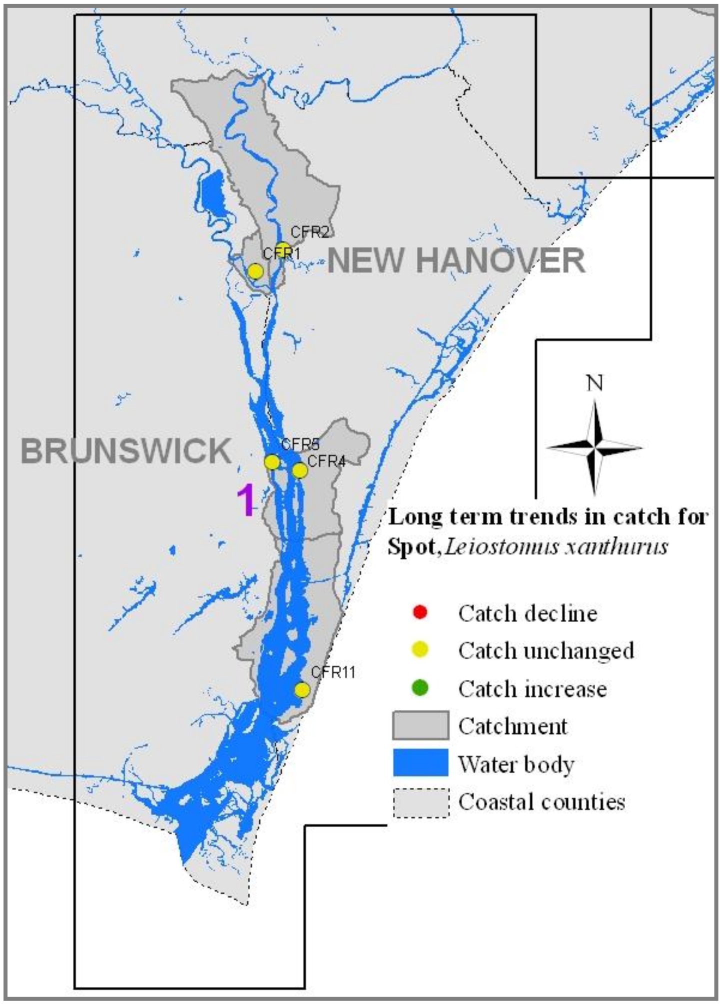


Appendix 23. Map showing change in number of Atlantic croaker caught per trawl at 29 stations in the lower Pamlico/Bay River region.

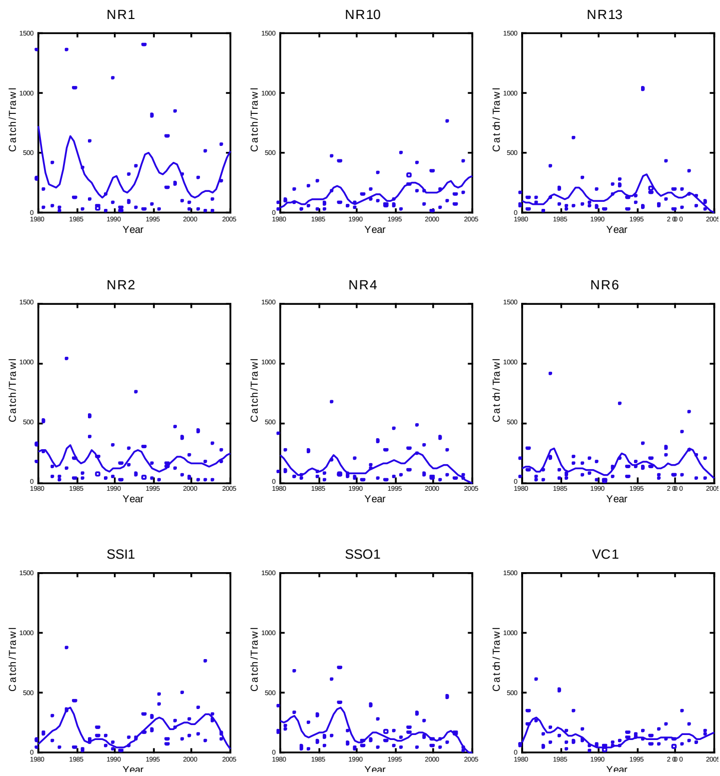


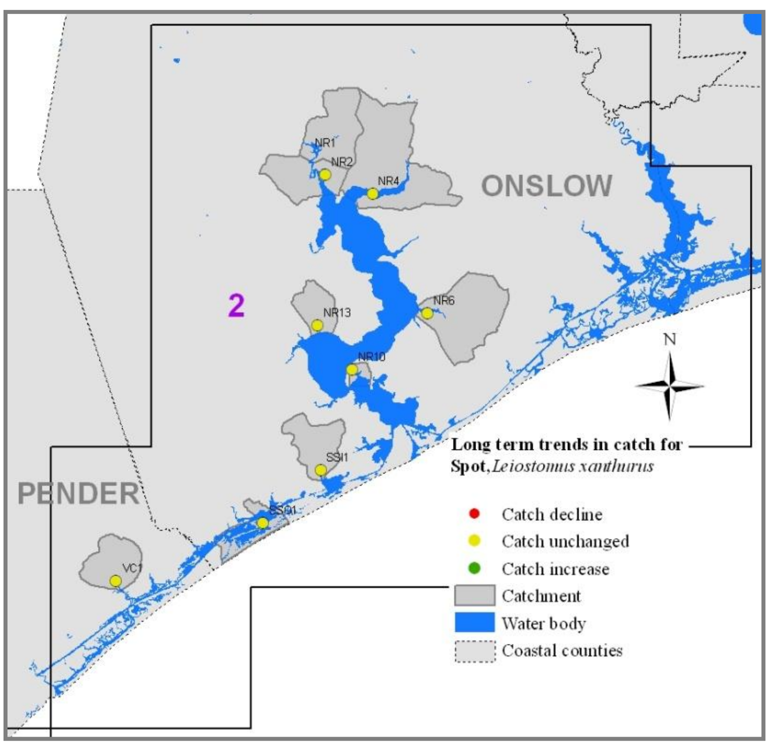

Appendix 24. Change in number of Atlantic croaker caught per trawl at 11 stations in the Hyde/Dare County region.



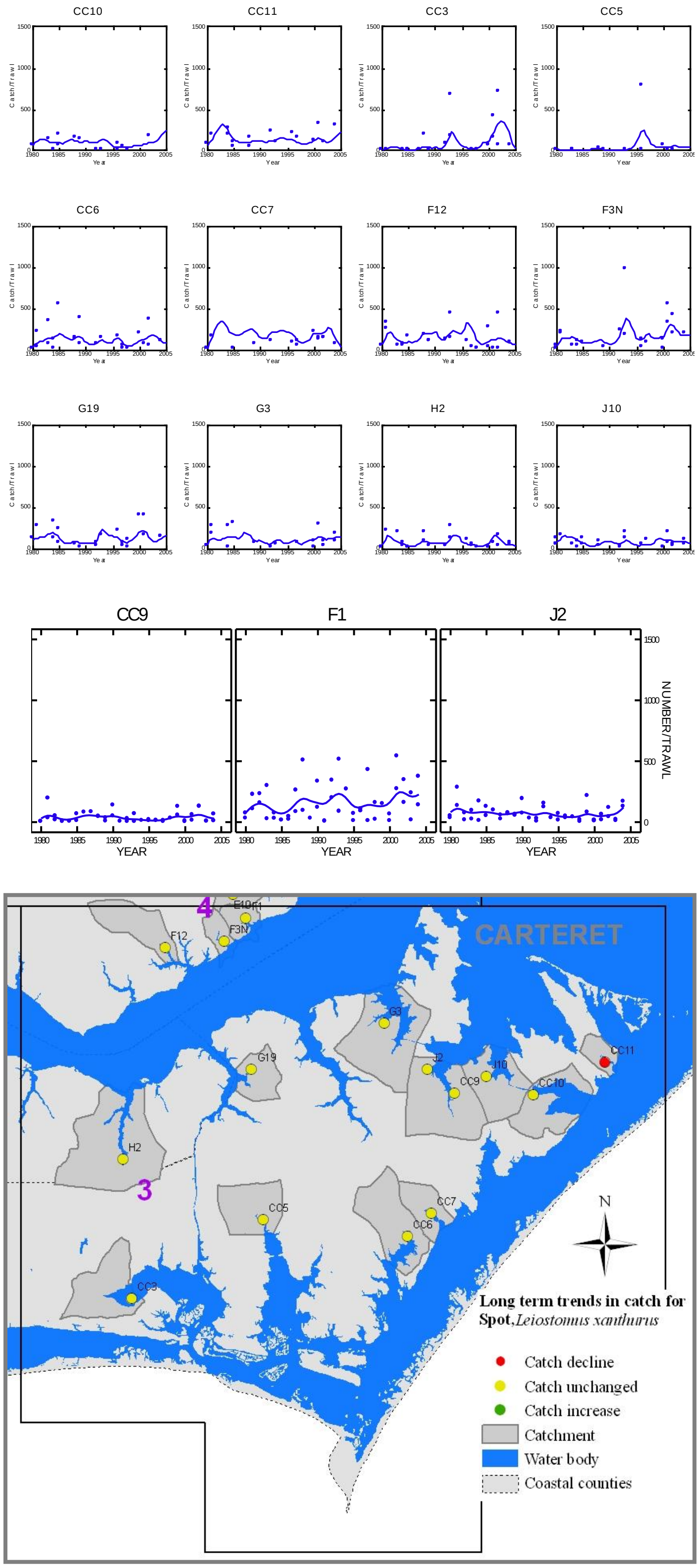




Appendix 25. Change in number of spot caught per trawl at five stations in the lower Cape Fear River.

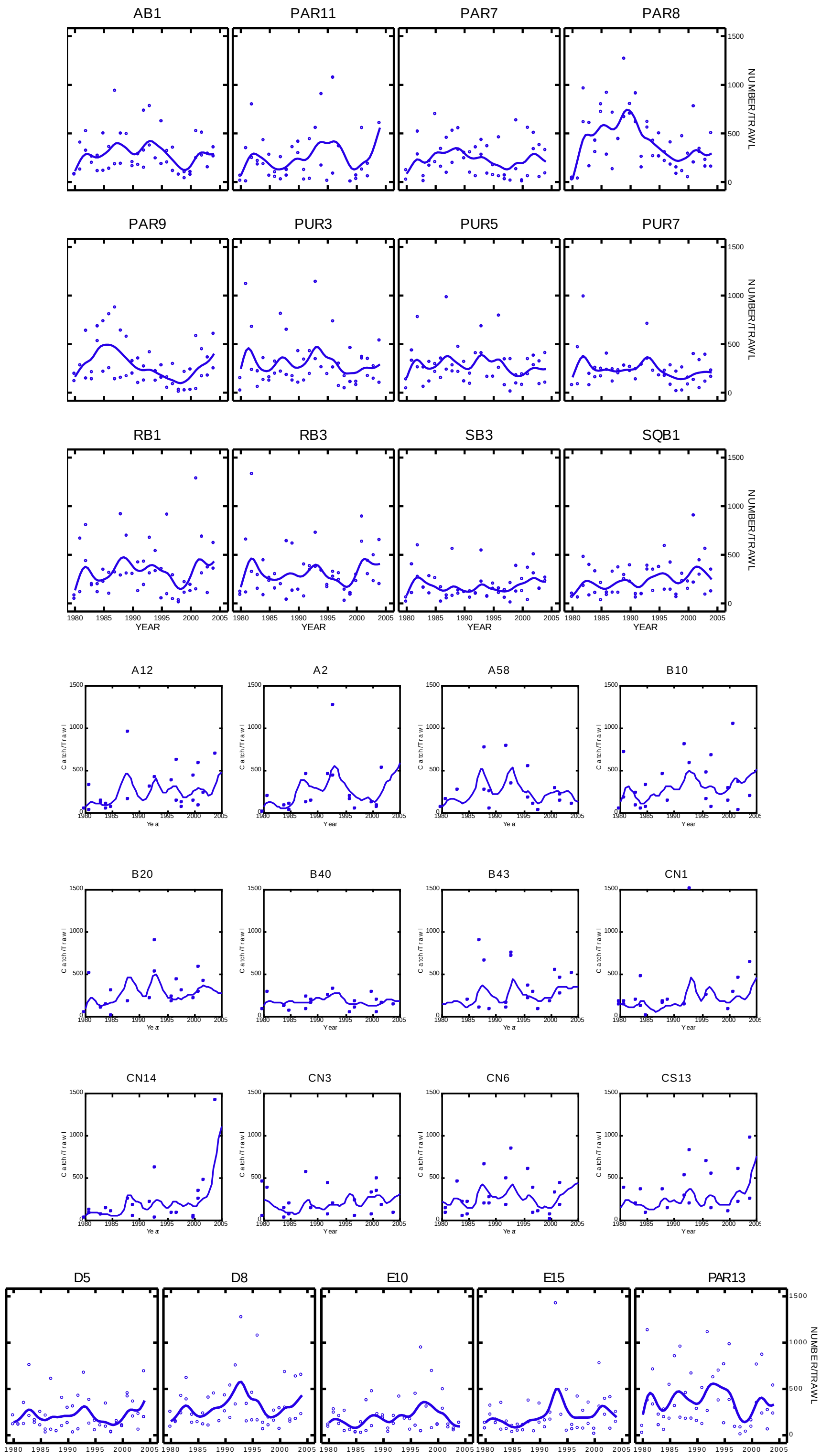


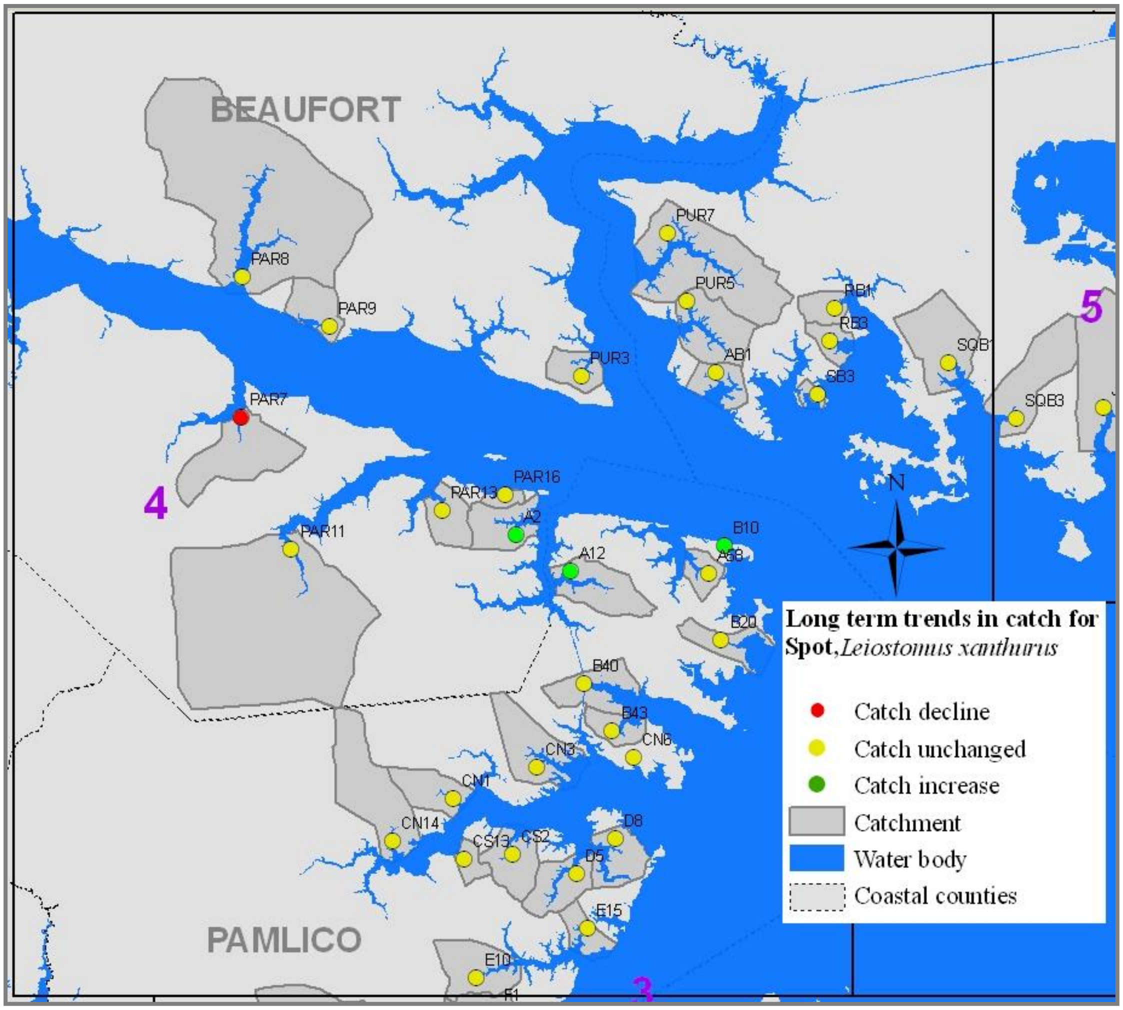

Appendix 26. Change in number of spot caught per trawl at nine stations in the New River/ Jacksonville region.



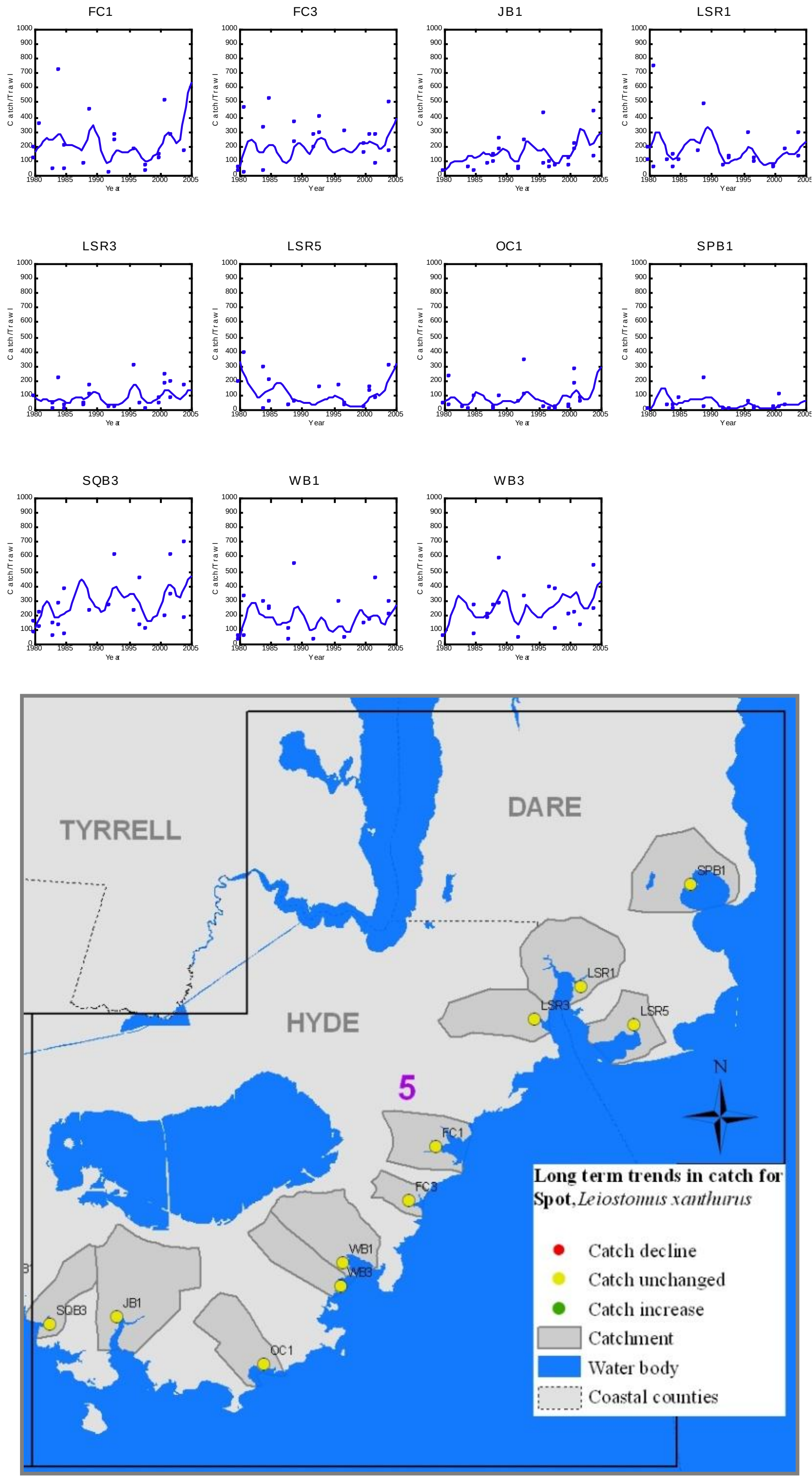

Appendix 27. Change in number of spot caught per trawl at 15 stations in the Carteret County region.



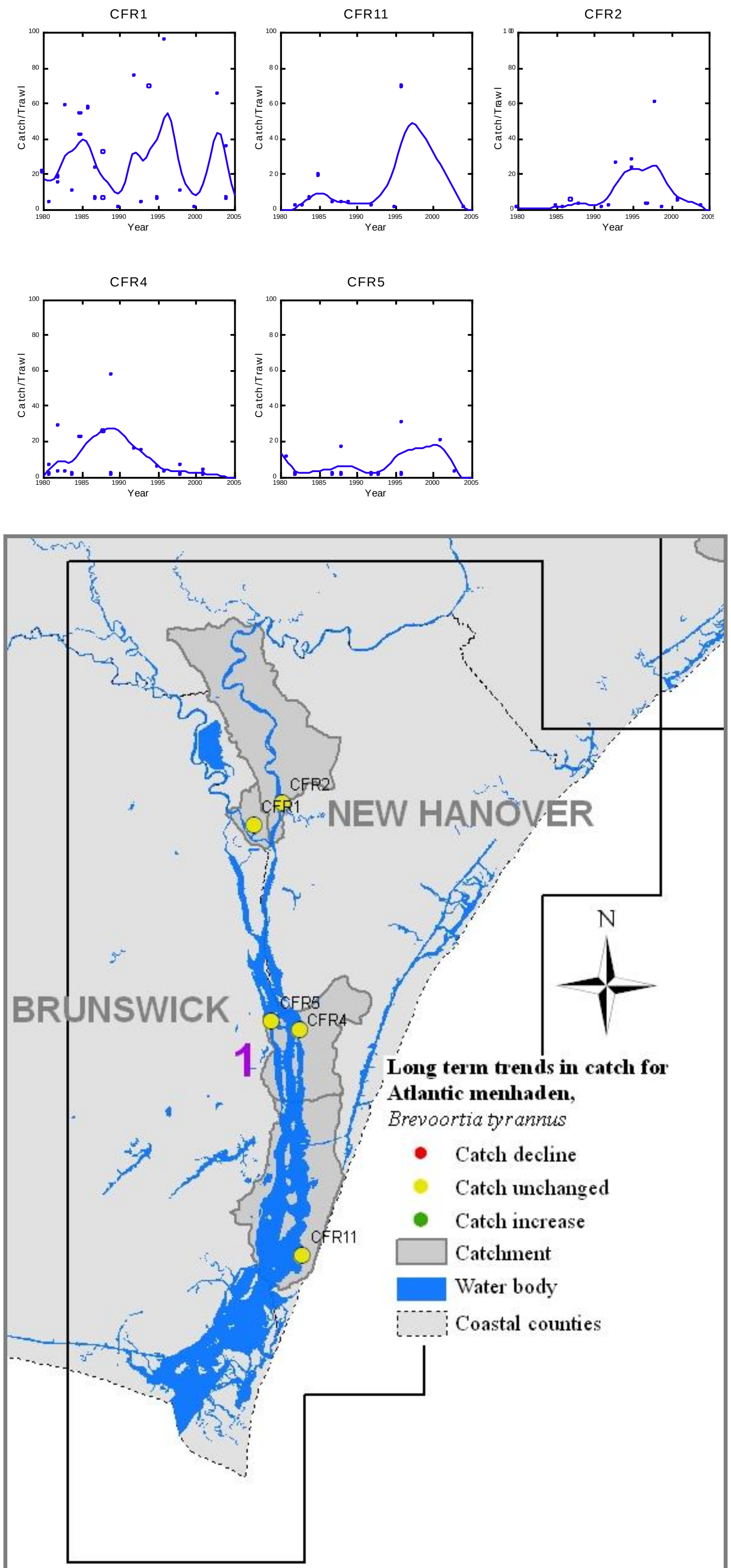

Appendix 28. Change in number of spot caught per trawl at 29 stations in the lower Pamlico/Bay River region.



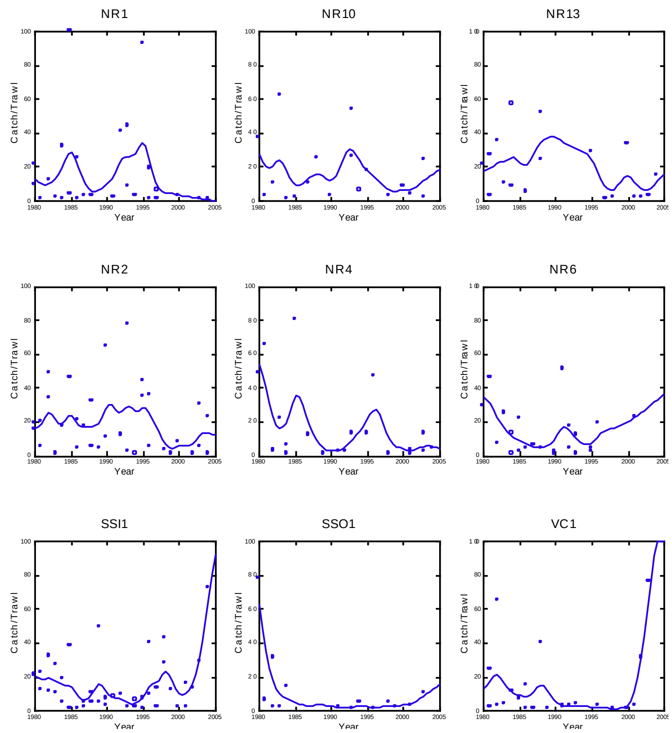

Appendix 29. Map showing change in number of spot caught per trawl at 29 stations in the lower Pamlico/Bay River.

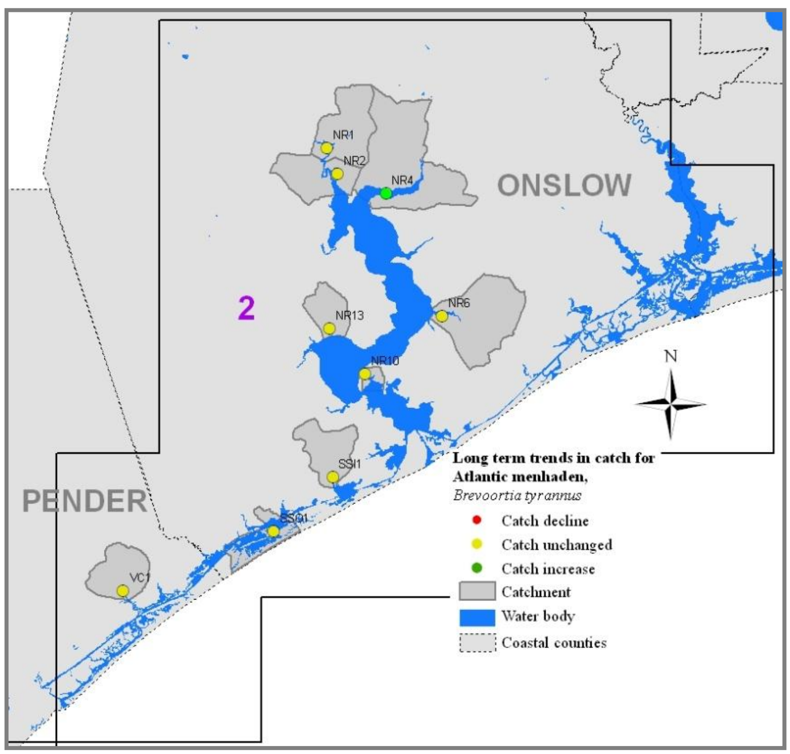



Appendix 30. Change in number of spot caught per trawl at 11 stations in the Hyde/Dare County region.

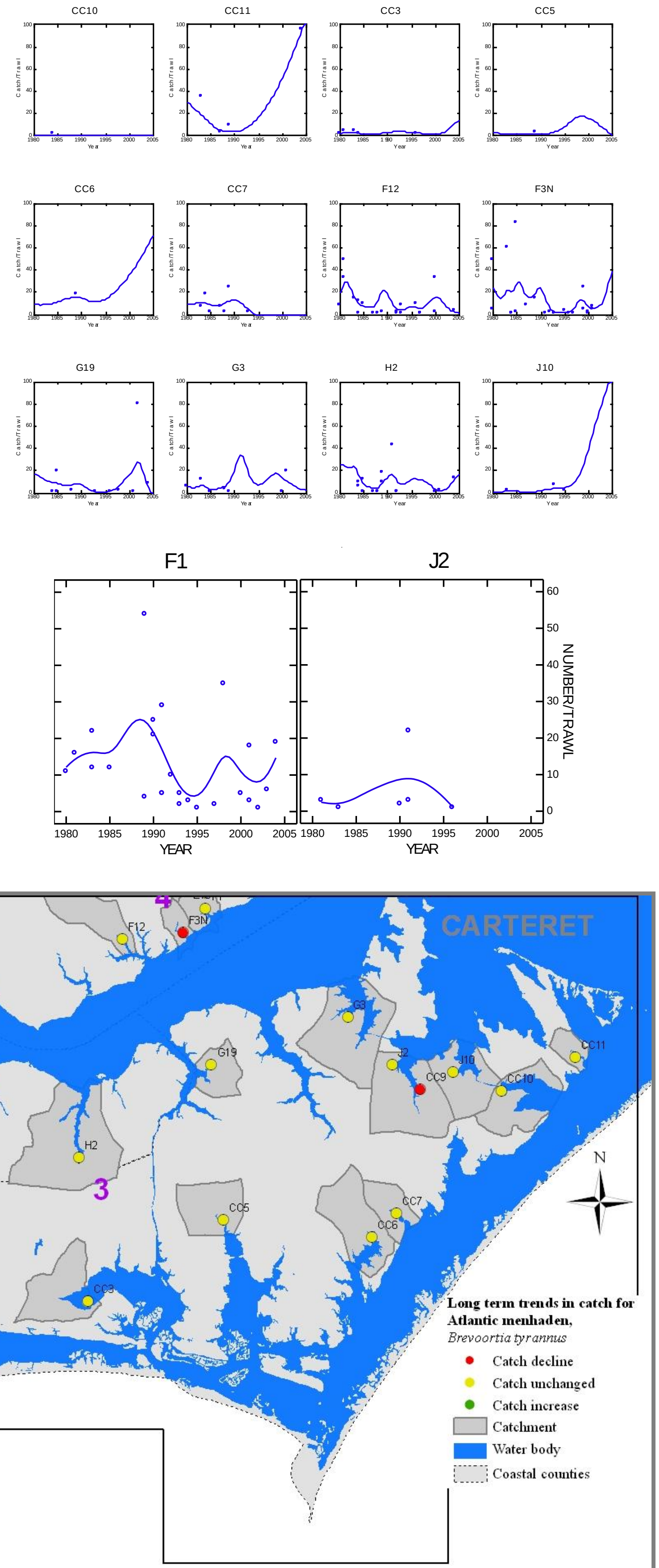



Appendix 31. Change in number of Atlantic menhaden caught per trawl at five stations in the lower Cape Fear region.

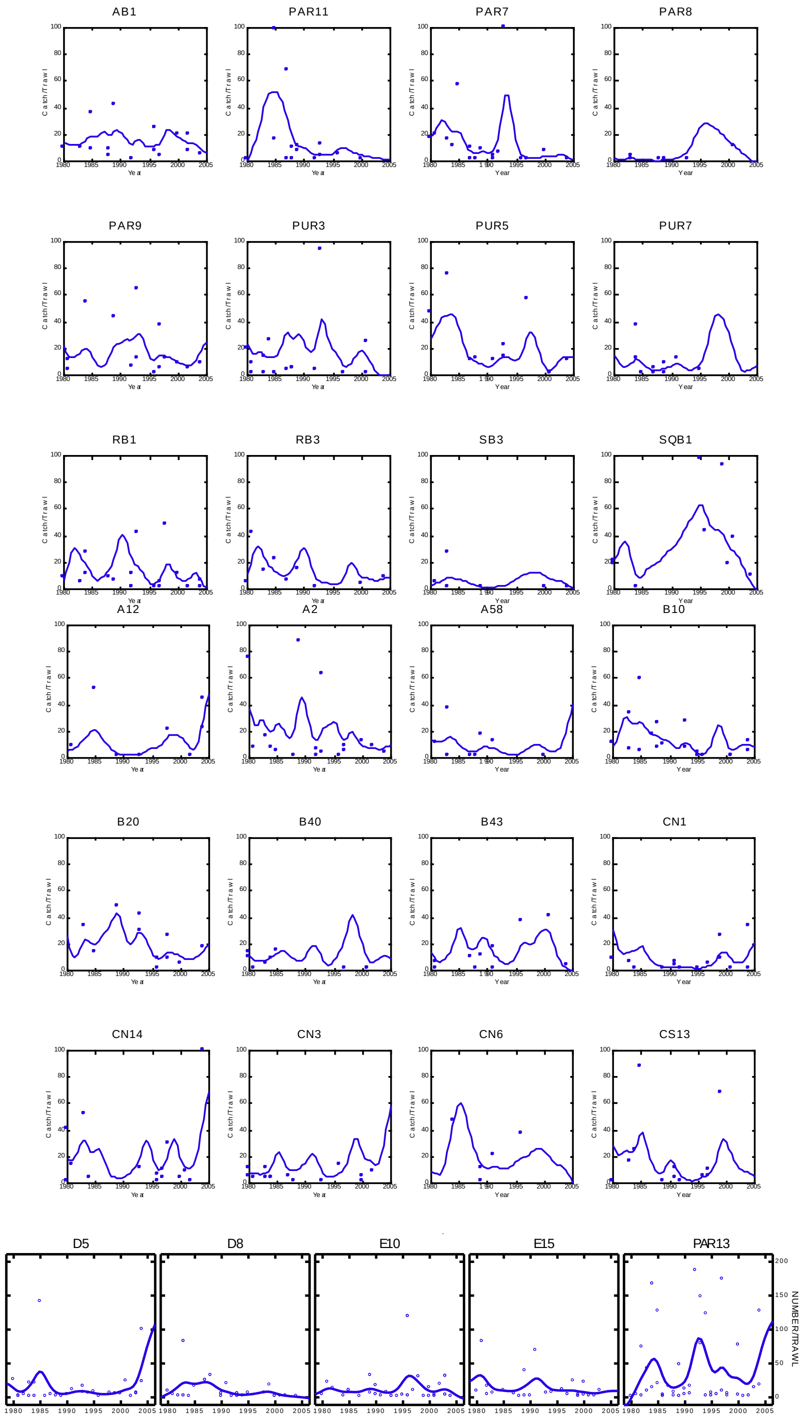


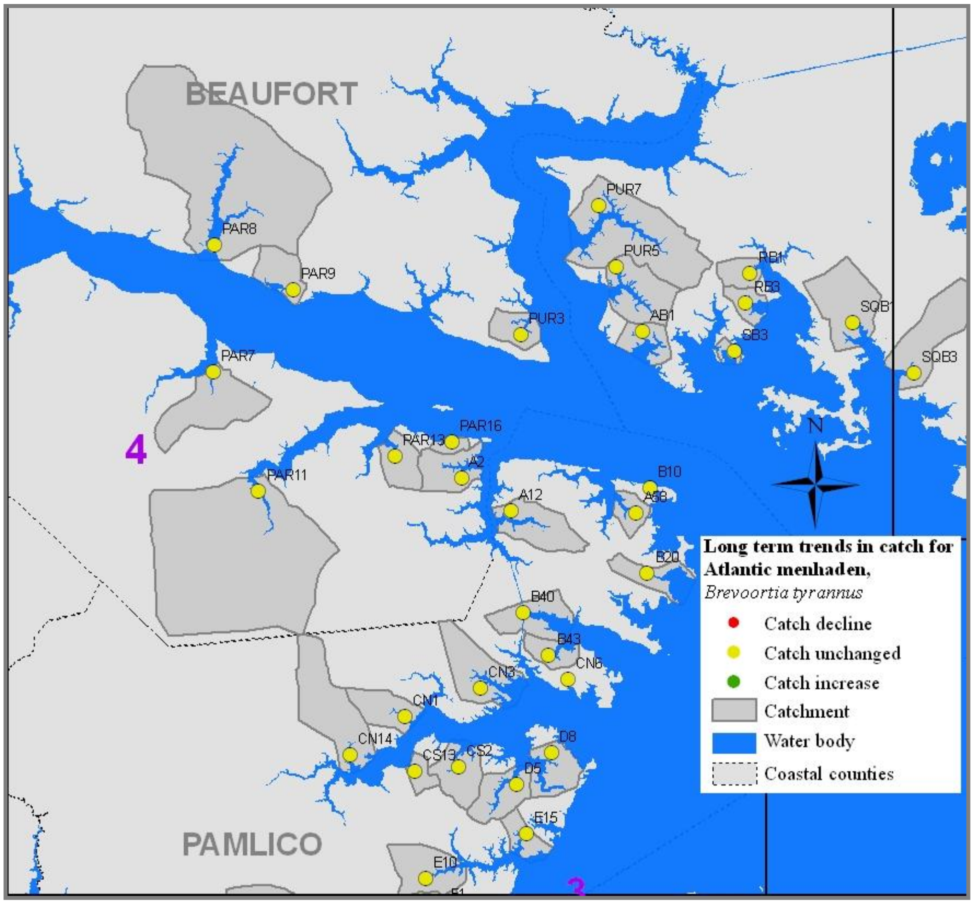

Appendix 32. Change in number of Atlantic menhaden caught per trawl at nine stations in the New River/Jacksonville region.



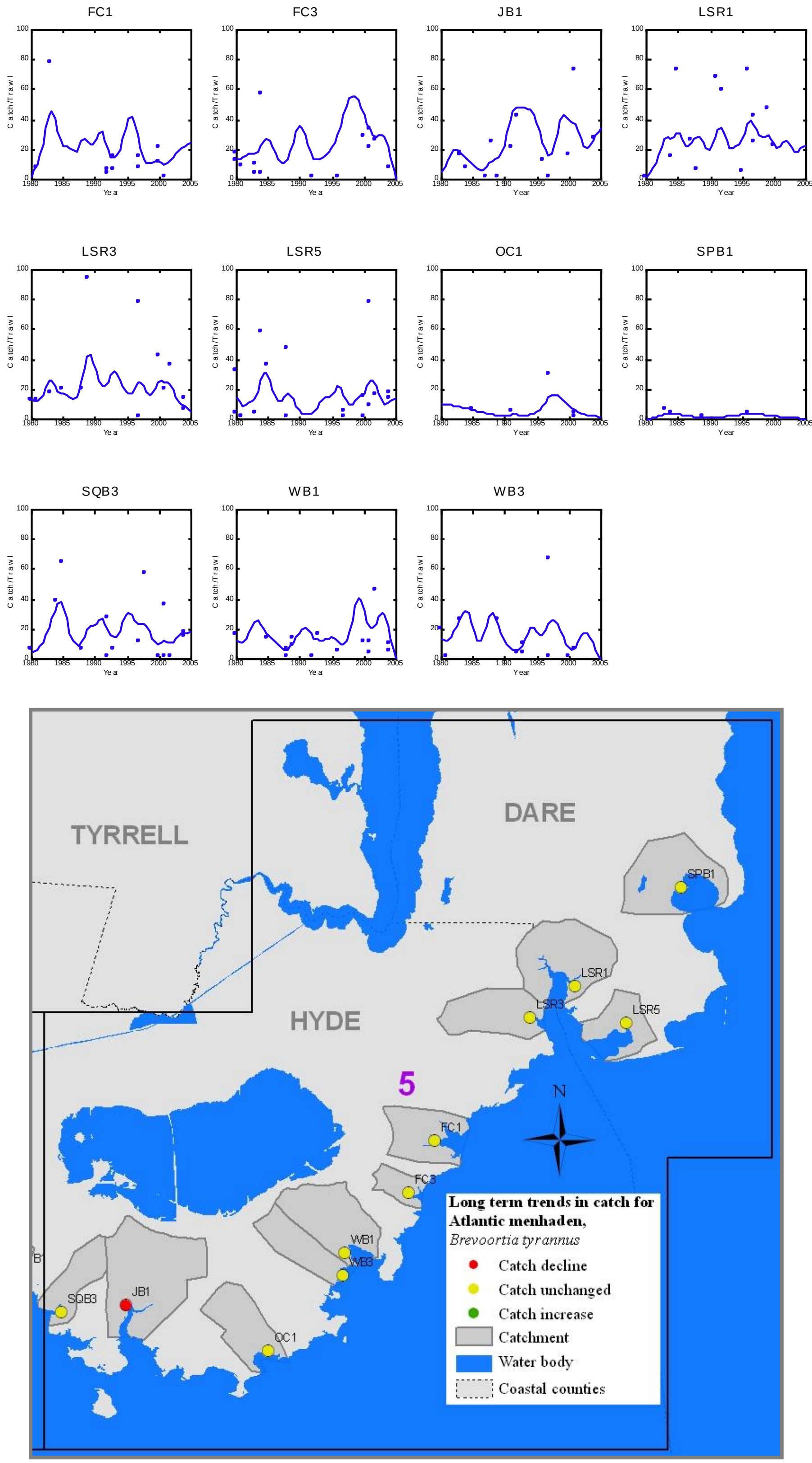

Appendix 33. Change in number of Atlantic menhaden caught per trawl at 14 stations in the Carteret County region



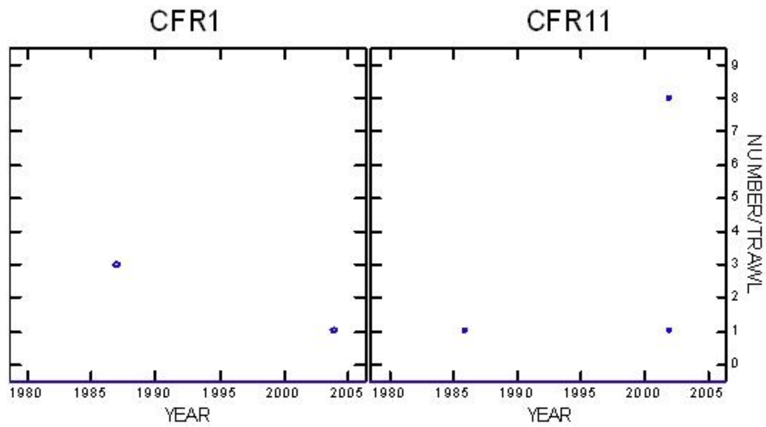

Appendix 34. Change in number of Atlantic menhaden caught per trawl at 29 stations in the lower Pamlico/Bay River region.

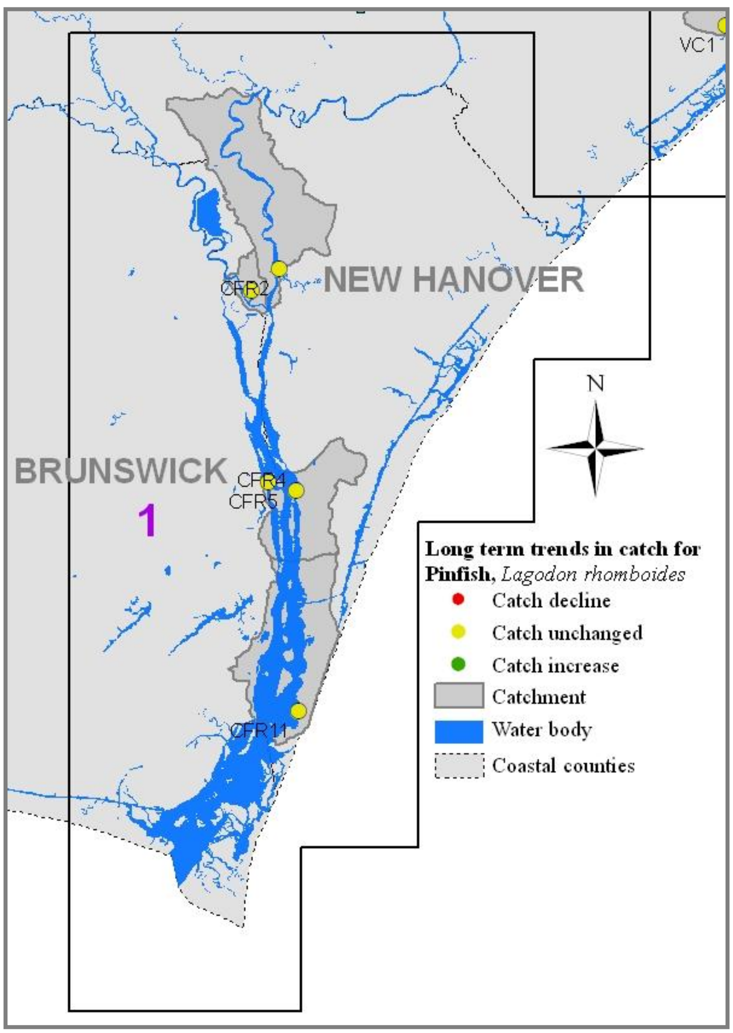



Appendix 35. Change in number of Atlantic menhaden caught per trawl at 29 stations in the lower Pamlico/Bay River region and a map of the region.

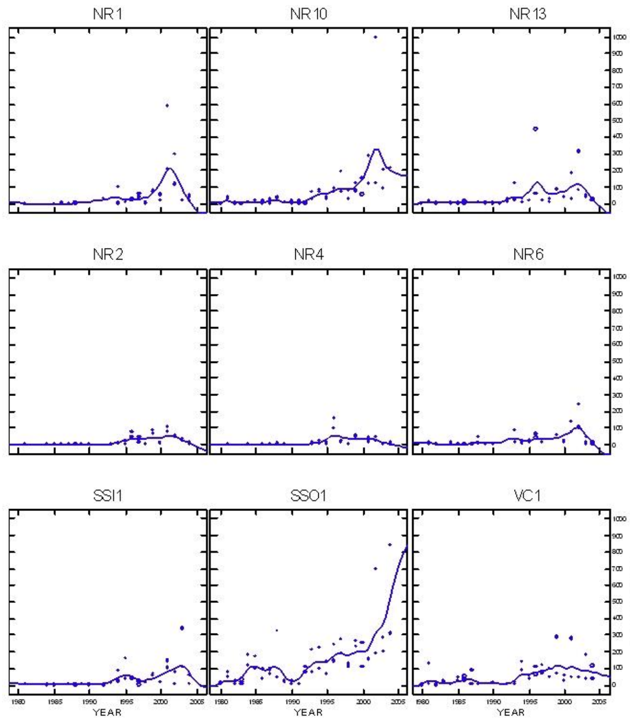


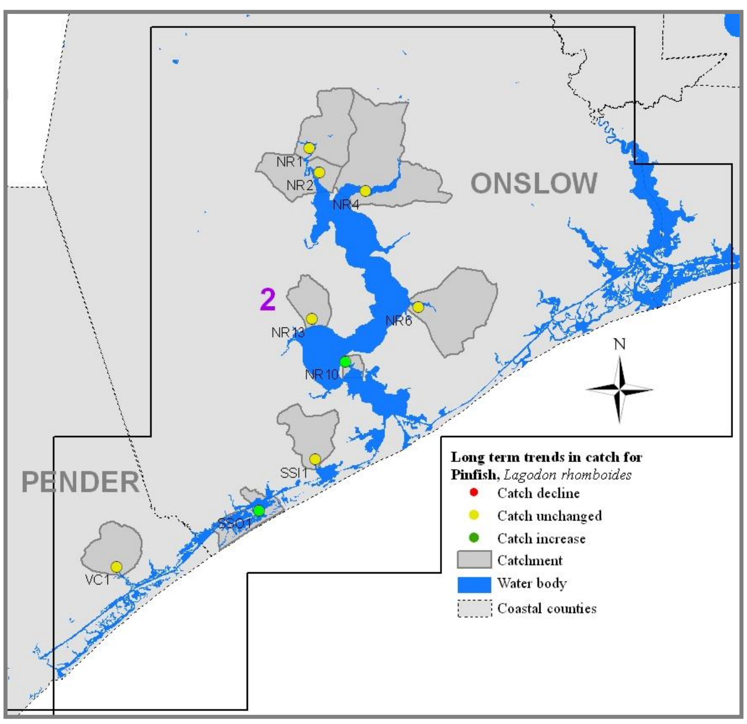

Appendix 36. Change in number of Atlantic menhaden caught per trawl at 11 stations in the Hyde/Dare County.



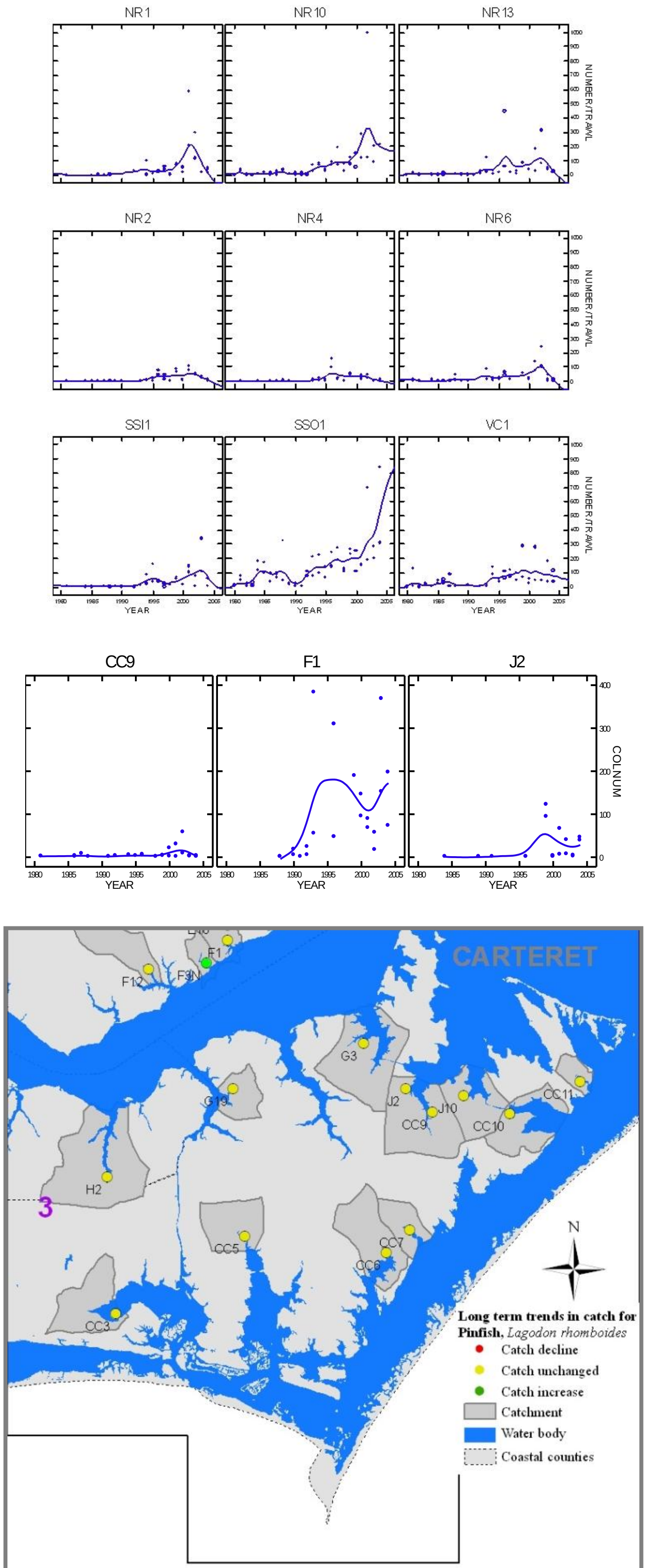




Appendix 37. Change in number of pinfish caught per trawl at two stations in the lower Cape Fear region.

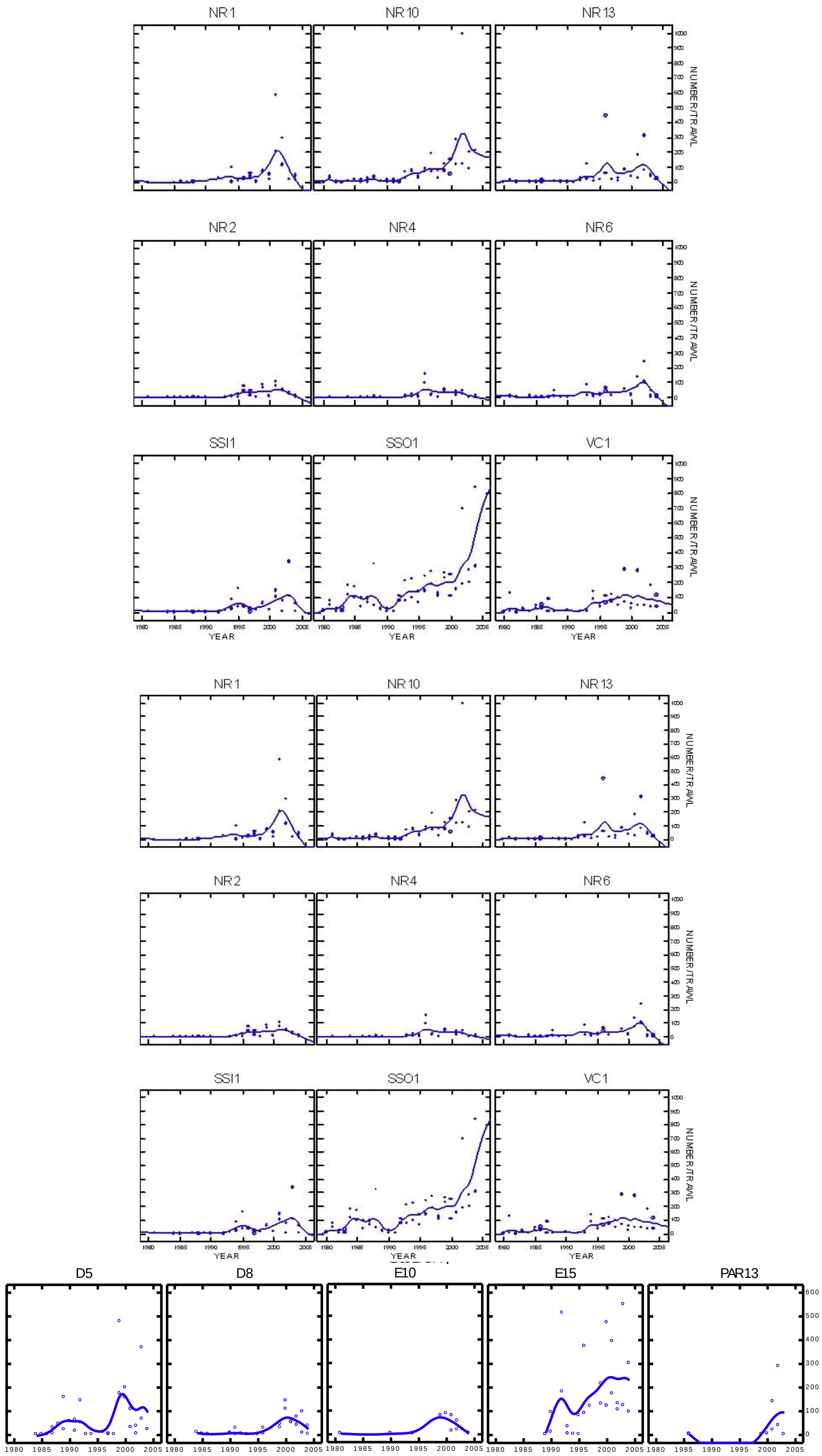


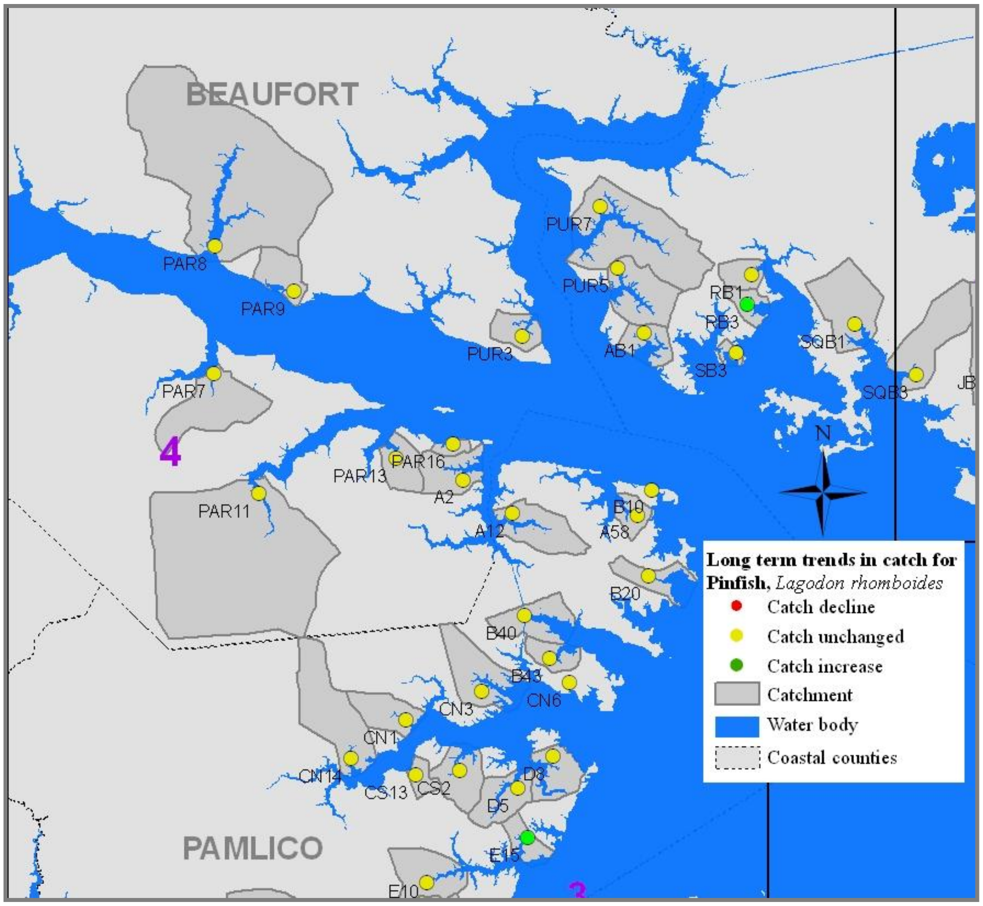

Appendix 38. Change in number of pinfish caught per trawl at nine stations in the New River/Jacksonville region.



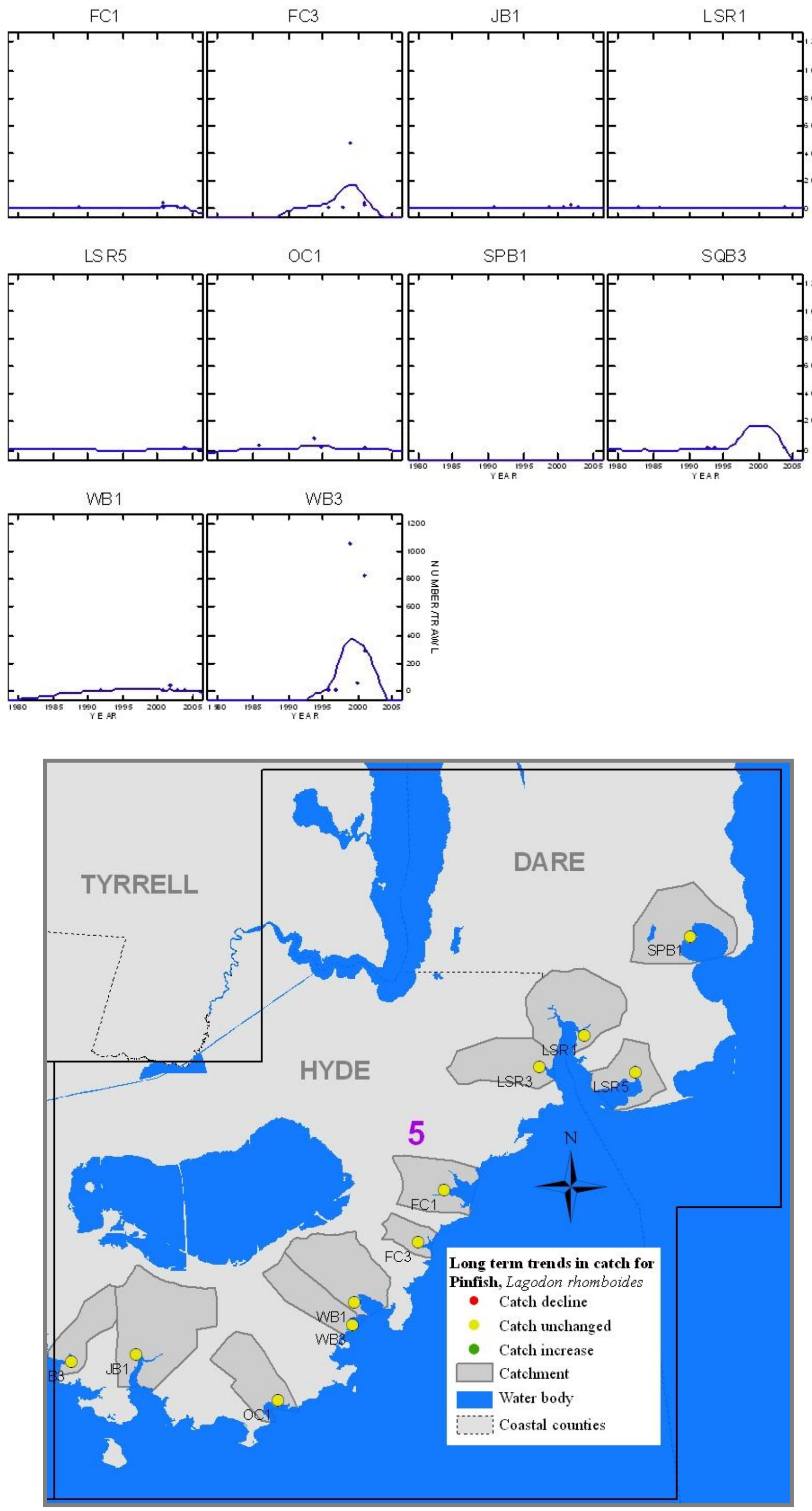

Appendix 39. Change in number of pinfish caught per trawl at 12 stations in the Carteret County region.




Appendix 40. Change in number of pinfish caught per trawl at 23 stations in the lower Pamlico/Bay River region. No data were available for six stations.




Appendix 41. Map showing change in number of pinfish caught per trawl at 29 stations in the lower Pamlico/Bay River region.




Appendix 42. Change in number of pinfish caught per trawl at 10 stations in the Hyde/Dare County region. No data were available for station LSR5.