Abstract

Analysis of a 41-year data set: Environmental influences on the fish assemblages of Albemarle Sound, North Carolina

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North Carolina both historically and currently maintains one of the most productive fishery resource basins in the nation. However, fish stocks are spatially and temporally variable in abundance and distribution in estuarine ecosystems and the influence of changing environmental factors on the inhabiting fish community of Albemarle Sound, North Carolina has not been studied. Sites within Albemarle Sound were sampled (trawls and seines) monthly by the North Carolina Division of Marine Fisheries from 1972 to 2012. A total of 56 families representing 132 fish species including freshwater, estuarine, and marine species were represented in sampling *Anchoa mitchilli, Menidia beryllina, Micropogonias undulates, Leiostomus xanthurus, Alosa aestivalis* and *Morone Americana* were the most abundant species in sampling. Two gear types were utilized during sampling, and the composition of fish assemblages collected between the two gears were significantly different (ANOSIM R=0.759, p=0.001). 1) Spatial analysis: Salinity and wind direction were significantly correlated with for the seine samples spatially (R=0.754, p=0.01), cumulatively describing 51.9% of the total variation in species assemblage. For trawl samples, salinity and dissolved oxygen were significantly correlated with differences in species assemblages (R=0.683, p=0.001), which cumulatively described 38.3% of the variation in the biological patterns. 2) Temporal analysis: Temporal correlations were weaker than spatial correlations, with depth, temperature, salinity,

dissolved oxygen and wind speed only weakly correlated with species assemblage (R=0.28, p=0.01) for the seine samples, and cumulatively described 14.5% of the variation. For the trawl samples, depth and salinity were weakly correlated with biological patterns (R=0.299, p=0.01), cumulatively describing 15.5% of the variation in the biological patterns. These results suggest that spatial variability in fish assemblage and biological patterns in Albemarle Sound are best described by salinity, with northeast and southwest winds indirectly influencing these patterns through wind driven tides. Temporally, correlations were weak and the amount of variability described was moderate, indicating there are other major factors influencing these patterns and fish assemblages through time.

ANALYSIS OF A 41-YEAR DATA SET: ENVIRONMENTAL INFLUENCES ON THE FISH ASSEMBLAGES OF ALBEMARLE SOUND, NORTH CAROLINA

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Introduction

Estuaries are coastal ecosystems with at least one direct inlet connection to the ocean where the draining freshwater mixes with the incoming saltwater. They provide important biological and economic functions including transport, tourism, industry, and functioning as nursery areas (Heip and Herman 1995; Raz-Guzman and Huidobro 2002). Estuaries are important for a wide range of marine taxa (Cowley and Whitfield 2002; McLusky and Elliott 2004; Weinstein and Yáñez-Arancibia 1985; Weisberg et al. 1996) and serve as nursery grounds for many juvenile fish species (Jung and Houde 2003; Ross 2003). Juvenile fish will congregate in these areas because of the excellent habitat, great food availability, and increased protection from predators (McErlean et al. 1973; Shenker and Dean 1979). The associated estuarine taxa often provide high fisheries yields and important economic opportunities (Houde and Rutherford 1993).

Aquatic communities are often studied to determine ecosystem changes as a result of or in conjunction with environmental change (Onorato 2000). Exploited fish populations can fluctuate because of environmental forcing and fishing mortality (Jacobson et al. 2001; McFarlane et al. 2002); and both of these factors are reflected in fisheries catch data. Currently, ecosystem based fisheries management has become a standard part of fisheries management, incorporating not only the status of a fish population but the ecosystem as well (Browman and Stergiou 2004; Garcia 2003). Achieving management and conservation of marine resources on an ecosystem level requires understanding the effects of fishing on fish populations and communities within the context of a changing environment and ecosystem (Browman and

Stergiou 2004; Garcia 2003; NOAA 1999; Pikitch et al. 2004). Naturally the issue arises, how to separate the effects of fishing from the effects of environmental change on fish populations (Hsieh et al. 2005). The use of long-term data sets on the abundance of species taken independently of their fisheries provides a chance to achieve this goal (Hsieh et al. 2005).

Estuaries experience high abiotic variability, and changing environmental factors can influence the inhabiting fish assemblage and distribution. Several studies have characterized the effects of changing environmental factors on fish assemblages and distribution including, the effect of temperature (Carassou et al. 2011; Desmond et al. 2002; Harrison and Whitfield 2006; Jaureguizar et al. 2004; Powles et al. 1984; Selleslagh and Amara 2008), salinity (Harrison and Whitfield 2006; Jaureguizar et al. 2004; Selleslagh and Amara 2008), fresh water flow (Carassou et al. 2011; Jung and Houde 2003; Whitfield 1994), and wind speed (Carassou et al. 2011).

Fish stocks are spatially and temporally variable in abundance and distribution in estuarine ecosystems (Jung and Houde 2003). This is a function of the heterogeneity in the environment (Jung and Houde 2003) and the coastline is not uniform with variable salinity, dissolved oxygen, nutrient levels, and many other changing biotic and abiotic variables. Therefore, fish assemblages are likely to vary through time and space. Serving as a boundary system between freshwater and saltwater, estuaries support characteristic environmental gradients that favor the recruitment for many species with varying physical and trophic structures (Harris et al. 2001; Kimmerer et al. 2001; Sánchez and Raz-Guzman 1997). Fish are an important part of estuaries, comprised of both estuarine resident and migrant species, with marine species visiting the estuarine areas to feed, reproduce, and grow (Raz-Guzman and Huidobro 2002). The high productivity(Day et al. 1987; Nixon et al. 1986) of estuarine systems and their function as nursery areas for multiple fish life history stages in temperate areas is well

documented (Blaber 2008; Drake and Arias 1991; Elliott and Hemingway 2008; Elliott et al. 1990; Kennish 1990; Powles et al. 1984; Shackell and Frank 2000; Szedlmayer and Able 1996; Whitfield 1999). Predator-prey relationships and competition can also indirectly influence fish abundance, distribution, and species composition in estuarine fish communities (Jung and Houde 2003).

Early fish life history is a time of extreme growth (Miller 1997) and mortality. The likelihood of an individual fish surviving from the egg stage and growing into a mature adult is low because of size selective mortality at young ages (Sogard 1997). Mortality rates generally decline as a function of body size with mortality rates decreasing as body size increases (Houde and Hoyt 1987; Miller 1997; Peterson and Wroblewski 1984). These early life stages are extremely vulnerable and it is hypothesized that larval and juvenile fishes migrate into estuaries to utilize the abundant food and refuge from predators to maximize survival (Frank and Leggett 1983; Kennish 1990; van der Veer et al. 2001). The influence of different variables impacting estuarine fish communities combined with the commercial and recreational importance of these fisheries in North Carolina; present the need for long-term studies to understand the impacts these various factors have on estuarine fish assemblages.

The economic value of estuarine fish species is well documented in the United States (Chambers 1992; Houde and Rutherford 1993) resulting in large economic yields. Commercial and recreational fisheries are economically important and North Carolina both historically and currently still maintains one of the most productive fishery resource bases in the United States (Mallin et al. 2000). Considerable effort towards the management and enhancement of the fishery has proceeded to help maintain this resource (Mallin et al. 2000). The high productivity

of these areas provide many species for exploitation, resulting in large economic values (Allen 1982; Deegan and Thompson 1985).

Effective management and conservation efforts must be developed to maintain the productivity and biodiversity of these areas and sustain the fisheries. Information on the ecosystem and inhabiting fish assemblages must be understood for these efforts to be developed and properly implemented. Several studies have characterized the fish assemblages of estuarine areas (Desmond et al. 2002; Harris et al. 1999; Hernández-Miranda et al. 2003; Jackson and Jones 1999; Jung and Houde 2003; McErlean et al. 1973; Powles et al. 1984; Rakocinski et al. 1996; Ramos et al. 2006; Ross 2003; Shenker and Dean 1979; Whitfield 1999), however, no study characterized the fish assemblages of Albemarle Sound, North Carolina. North Carolina maintains an extremely diverse fishery resource base because of the overlap of northern and southern species in the Cape Hatteras area and the extensive, dissected coast line containing large areas of habitat and the Albemarle-Pamlico Estuarine System (Mallin et al. 2000). There is an extensive number of fish species relative to other aquatic environments listed as commercially valuable in North Carolina waters including 28 individual species, and five other species groupings including reef fish, sharks, shrimp, catfish and river herrings (NCDMF 1999).

Biodiversity must be maintained to provide insurance against a changing environment and maintain the high productivity and ecosystem function of an estuary. This allows for ecosystem functions and the goods and services supporting humans and inhabiting species to continue (Hiddink et al. 2008). Biodiversity should also be maintained to protect species that may become important in the future as well as protecting species whose environmental rolls are not yet fully understood (Munasinghe 1993). Juvenile fish stages provide fish biologists insight about certain characteristics the adult fish and overall fish populations contain, providing fish

assemblage information about the biodiversity of Albemarle Sound. Estuaries also provide migratory routes for diadromous fish species as well serving as nursery areas for many fish species (McLusky and Elliott 2004). Understanding the response of estuarine fish species to highly variable and changing environmental conditions will not only expand our biological understanding of estuarine fishes, but may also provide insight on the impact of anthropogenic activities (Selleslagh and Amara 2008). Knowledge of this nature will help increase our overall understanding of estuarine fish communities leading to more successful management and conservation practices.

Understanding the fish assemblages of Albemarle Sound will help to provide future information on the fish stocks of those species found within the sound. Juvenile abundance indices allow for the estimation of spawning stock biomass, year class strength, and a long term data set on juveniles reflects trends in the adult fish populations. Although other studies have investigated fish assemblages in temperate estuaries, the duration of many studies has been only 1 - 2 years, limiting the overall temporal analysis to a short term, seasonal description in species composition and abundance (Akin et al. 2005; Clarke 1993; Dye 1998; Ramos et al. 2006). Long term variation in estuarine fish assemblage structure is less well studied (Desmond et al. 2002; Houde and Rutherford 1993) and important in ecological assessments of how fish utilize these environments. Desmond et al. (2002) conducted an 11 year study in southern California, assessing spatial and temporal estuarine fish and invertebrate assemblages. They found that fish assemblages varied with seasonality as a result of water temperature changes, with species richness and diversity peaking during the summer months. The 5 year study conducted by Jung and Houde (2003) assessed spatial and temporal variation of the pelagic fish community in Chesapeake Bay, USA, revealing that physical forcing primarily driven by freshwater, shaping

the structure of fish communities both annually and regionally. Low diversity and high abundance were also characteristic of the Chesapeake Bay with seasonal succession revealing more adults in the spring and juveniles in the fall. A long term data set provides more options and opportunities to characterize both seasonal and annual variation through several years of data (Vance et al. 1996). These types of data have been collected in Albemarle Sound since 1972 providing a unique opportunity to investigate the fish assemblages. Analyzing the spatial and temporal patterns of fishes in this area are important in understanding the fish assemblages of Albemarle Sound providing additional information for understanding to role and function of the sound. It will also allow for future correlations with weather anomalies and climate change to be incorporated with this data to further our understanding of the additional factors influencing fish assemblages.

The purpose of this study is to characterize the fish assemblages of Albemarle Sound using a long term data set.

The objectives of this study are to:

1. Characterize spatial and temporal trends of the fish assemblages in Albemarle Sound, North Carolina
2. Determine the influence of and identify influential environmental parameters driving trends in the fish assemblages of Albemarle Sound, North Carolina.

The data set used in this study is an excellent vehicle for characterizing the fish assemblages of Albemarle Sound. I focused on spatial and temporal variation within the data set, investigating fish distribution and diversity variation by year and between stations in Albemarle Sound. I also assessed the influence of environmental factors on the Albemarle Sound fish assemblages both

spatially and temporally identifying some of the driving factors and the amount of variation in the fish assemblages those environmental parameters describe.

Methods

Study Site

The Albemarle-Pamlico Sound estuarine system is located in eastern North Carolina and is the second largest estuarine system in the United States. The watershed for the region is approximately 77,700 km^2 and the estuarine system encompasses over 14,485 km of freshwater rivers and streams and over 6,000 km^2 of brackish waters. The five major river basins that flow into the sounds include the Chowan, Roanoke, Pasquotank, Tar-Pamlico, and Neuse Rivers. The seven sounds that are part of the Albemarle-Pamlico Sound estuarine system are Albemarle, Currituck, Croatan, Pamlico, Bogue, Core, and Roanoke Sounds. Albemarle Sound (Figure 1-1) is located in northeastern North Carolina. It is a large estuary covering 1,300 km^2 with over 800 km of shoreline (Copeland et al. 1983). The main estuary extends from the mouth of the Chowan River to the Outer Banks, which separates the sound from the ocean. Albemarle Sound has no direct connection with the Atlantic Ocean, with minimal seawater intrusion from both Roanoke and Croatan Sounds (Riggs 1996). The main estuary has a west to east orientation, widening from less than 5 km to over 20 km respectively (Copeland et al. 1983). The indirect oceanic influence and west to east orientation coupled with topographically flat adjacent lands and generally shallow water (<9.0 m) (Giese et al. 1985), tides and water flow are wind dominated and have a strong freshwater influence from the Chowan and Roanoke Rivers (Copeland et al. 1983). Annual freshwater flow into Albemarle Sound averages 480 cubic meters per second with 250 cms from the Roanoke River (Copeland et al. 1983). The flow of the Roanoke is variable between dry years (150 cms) to approximately 340 cms during wet years (Copeland et al. 1983). The freshwater outflow is strong enough to effectively block saline waters from entering

Albemarle Sound, which is typically oligohaline with the salinity not normally exceeding 5 ppt, with lower salinities in the spring and higher salinities in the fall (Copeland et al. 1983).

Sampling and Sample Collection

Fish abundance data were provided by a fisheries-independent survey, Program 100, conducted by the North Carolina Department of Environmental and Natural Resources (NCDENR), Division of Marine Fisheries (DMF). Preliminary open water trawl sampling began in November 1971, using two trawl types. A 7.9 meter head rope shrimp trawls with 1.9 centimeter bar mesh and a 3.1 meter by 3.1 meter modified cob trawls with 1.9 centimeter bar mesh in the body and 6.4 millimeter bar mesh in the bag. All stations were sampled for 5 minutes. Preliminary shallow water sampling was also conducted with multiple gears including a 1.8 meter by 1.8 meter modified cob trawl with 6.4 millimeter bar mesh, a 18.3 meter bag seine (6.4 millimeter mesh), and 6.1 meter bag seine (6.4 millimeter mesh). Shallow water trawls were pulled for 10 minutes in depths of 4 meters or less. In deeper areas, the trawls were pulled for 5 minutes on the bottom and 5 minutes on the top. Seines were pulled at maximum depths between 0.9 – 1.5 meters for 46 meters.

The Cobb trawls was the best performing gear and was adapted as standard sampling gear for the open water trawls. Sampling began in January of 1972 and was conducted monthly at 96 stations in the Albemarle Sound area. Shallow water sampling began in October 1972 and adapted the 1.8 meter by 1.8 meter Cobb trawl and 18.2 meter bag seine as standard sampling gear. The bag seine was modified with the addition of 3.1 millimeter bar mesh bags to prevent fish from escaping. The gear types and effort used for the open water trawling and shallow water sampling changed 3 times throughout the study from 1972-Present. The number of sample stations in Albemarle Sound (Figure 1-1) remained the same throughout the study. Captured

fishes were identified, counted, and measured (FL). Up to 30 randomly chosen individual fish for each species were measured and all other individuals counted. Samples collected through open water sampling with the trawls and shallow water sampling with the trawls and seines all recorded information in this manner. Environmental conditions including surface and bottom water temperature, salinity, and dissolved oxygen were collected. Depth, pH, wind speed and direction were also recorded for each sample. Dissolved oxygen was only collected in 1981-1987, 1989, and 1991-2012. Sampling was conducted in the same manner from 1972 to present with minor gear changes and some missing values for the environmental conditions. Mean daily discharge from the Roanoke River (Gauge # 02080500) from January 1, 1972 – December 31, 2012 was provided by the United States Geological Survey (USGS) National Water Information System and was added to the data as an environmental parameter.

Data Preparations

Multivariate analysis of assemblage structure for common species and correlations with the environmental parameters were undertaken using the PRIMER-E software (version 6) (Clarke and Warwick 1994). CPUE (Catch per unit of effort) was calculated as number of individuals per minute sampled, and used as abundance data for all trawl calculations to allow for direct comparison. I initially analyzed all data together using multi-dimensional scaling (MDS), and revealed the communities of fish sampled by the gears represented two distinct groups (ANOSIM R=0.759, p=0.001), seines and trawls (Figure 1-2). Therefore, the different gear types were analyzed separately to avoid the influence of gear bias. The similarity percentage (SIMPER) results identify the contribution of each taxa to the dissimilarity between groups, and identified *A. mitchilli*, *M. beryllina*, *M. undulates*, *L. xanthurus*, and *Mugil cephalus* as top species contributing to the dissimilarity between the two gear types (Figure 1-3).

Fish Assemblage Analysis

A multispecies approach was used to characterize the relationships between fish abundance and environmental conditions. For all descriptive statistics including species abundance tables and diversity indices, all species captured in the study were retained. I removed rare species since their highly variable abundance and occurrence may confound multispecies patterns of interest (Wood and Austin 2009) for further analysis. Only the species captured in at least 5% of the samples that caught fish (referred to here on as common species) over the 41 year period were retained for analysis with environmental variables. Most samples were collected during the summer and early fall months therefore, June through October was retained for analysis.

Annual, spatial and temporal group fish diversity indices were quantified using the Shannon-Wiener index (H'), total number of species (S) and equitability was measured by Pielou's evenness index (J') (Pielou 1966). Spatial and temporal differences in diversity indices were compared with an analysis of variance (ANOVA) between the identified spatial and temporal groups for each gear. A linear regression was conducted to identify overall changes in diversity through time. Mean annual abundances (pooled across all stations) for the five most common species and all species combined for each gear type were calculated to identify any trends in abundance through time.

Spatial and Temporal Analysis

All abundance data was log (X+1) transformed and standardized before analysis. Abundance data were converted to triangular matrices of similarity between every pair of samples using the Bray-Curtis similarity coefficient. Similarities between the stations for spatial

arrays and months and years for temporal arrays were graphically represented by clusters using the CLUSTER option and in ordination plots using multidimensional scaling (MDS) options.

The CLUSTER and MDS options in PRIMER were used to identify stations and years based on 70-80% similarity in fish assemblages by looking at each station or year and identifying how similar each was in terms of fish assemblage to the other stations or years. One-way analysis of similarity (ANOSIM) identified significant differences in assemblages, station groups, and year groups. Similarity percentages (SIMPER) (Clarke 1993) characterized the contribution of individual species to the different sample groupings. Mean annual abundance (pooled across all sites) was regressed against time, for the top five most abundant species to identify trends in abundance and changes in dominant species (PROC REG).

Environmental Data Analysis

The influences of environmental parameters (depth, temperature, salinity, dissolved oxygen, wind direction, wind speed, and river discharge) were analyzed with the abundance data using arrays in PRIMER. The draftsman plot option in PRIMER was used to exclude additional water quality parameters that contained strong correlations with other parameters including bottom salinity (correlation with surface salinity), bottom temperature (correlation with surface temperature), and bottom dissolved oxygen (correlation with surface dissolved oxygen) resulting in the parameters listed above. These correlations were identified using the draftsman plot option witch simply plotted each variable along the x and y axis and identified those with strong correlations. Water quality tables were log (X+1) transformed, and normalized for all further analysis.

The BEST analysis (BIOENV option in PRIMER) was used to identify patterns between the fish abundance and environmental data. Biotic and abiotic similarity matrices (the latter

constructed comparing all possible combinations of environmental samples using Euclidian distance coefficients) were compared using the BIOENV option which assesses similarities in patterns between the biological and environmental data using weighted Spearman rank coefficients (Clarke and Warwick 1994). This analysis provided correlations between the data and which environmental variables identified these correlations. The Distance based linear model (DistLM) option in PRIMER analyzed biological community patterns in response to environmental variables, identifying the percent variation in the biological data characterized by the environmental data and which environmental variable(s) (depth, temperature, salinity, dissolved oxygen, wind direction, wind speed, and river discharge) was dominant. The model was run in a step-wise manner using Akaike information criterion (AICc) as selection criteria for selecting variables. Mean environmental variable tables were constructed for depth, temperature, salinity, dissolved oxygen, wind direction, wind speed, and river discharge by year group, station group, month, and overall. ANOVAs were conducted on the identified dominant environmental variables from the BEST and DistLM analyses to determine if these variables were significantly different by group. This will reinforce the separation found in the fish community, used to initially identify the groups. SAS 9.3 was used for all general statistics and data manipulation

Results

Fish Assemblage Characterization

A total of 3,205,341 individuals from 56 families and 132 fish species (freshwater, estuarine and marine) were represented in sampling for the entire study (Appendix I). The most abundant and frequently occurring species was *Anchoa mitchilli* found in 51% of the samples and comprising 56% of the catch, common species by abundance was strongly dominated by *A. mitchilli*, decreasing to *Micropogonias undulatus* comprising 10.2% of the catch but still found in 40% of the samples to *Menidia beryllina* constituting 8.5% of the catch, but occurring in 35% of the samples (Appendix I). For the seine samples *M. beryllina* (79%), *Morone americana* (45%), *Leiostomus xanthurus* (35%), *Strongylura marina* (33%), and *A. mitchilli* (32%) were the top five most frequently occurring species (Table 1-1), and *A. mitchilli* (66%), *M. undulates* (56%), *L. xanthurus* (54%), *M. Americana* (50%), and *M. saxatilis* (29%) were the top five for the trawl samples (Table 1-2).

Diversity

Shannon-Weiner diversity index (H') was variable by year and overall increased through time for both gears (Figure 1-4). However, the increase in H' for the trawl samples was not significant while diversity did significantly increase for the seine samples ($F_{1, 39}$=17.07, $p<0.001$) There was a decrease in H' for both gears from 1988 to 1992. Diversity spatially was significantly different for the two major groups of stations (groups 1 and 2) for seine samples and (groups 1, 2 and 3) for trawl samples (Table 1-3). Temporally, there were significant differences between the major year groups for the seine samples (groups 1 and 2) and group 3 was significantly different than groups 1 and 2 for the trawls samples (Table 1-3).

Top Species Abundance

Species abundances for the top species in both gear types varied through time. For the seine samples, overall abundance significantly decreased through time ($F_{1, 39}$=9.11, p=0.004) along with decreases in abundance for some of the dominant seine species in sampling including *A. mitchilli* and *S. marina* (Figure 1-5). *M. beryllina* had slightly positive trends in abundance but again were not statistically significant, while other species show no change in average abundance thought time including *L. xanthurus* and *M. americana* (Figure 1-5). For the trawl samples, there was a significant increase in overall species abundance ($F_{1, 39}$=26.46, p<0.001) as well as increases in several of the dominant trawl species including *A. mitchilli* ($F_{1, 39}$=43.92, p<0.001), *L. xanthurus* ($F_{1, 39}$=4.67, p=0.037), and *M. undulatus* ($F_{1, 39}$=8.68, p=0.0054) (Figure 1-6). *M. saxatilis* had a positive trend in abundance but did not significantly increase. *M. americana* had a decrease in abundance over time but was not statistically significant (Figure 1-6).

Environmental Factors

The average environmental parameters (mean ± SD) for Albemarle Sound during the study period was depth 2.2m (±1), water temperature 26.4°C (±3.5) , salinity 1.6ppt (±1.9) , dissolved oxygen 7.4mg/L (±1.6), wind speed 9.1knotts (±4.9), and river discharge 173 cms (±143), predominate winds were southwest and northeast for the Albemarle Sound area (Table 1-4). Water temperature and salinity increased from June to October and discharge decreased (Table 1-5). Salinity, water temperature and dissolved oxygen did not change significantly from the beginning to the end of the study period (Figure 1-7).

Spatial Analysis (Seine and Trawl)

Seine. Four groups were identified from the cluster analysis (70% similarity) (Figure 1-8), 28 of the 34 stations were classified as group 1, four stations in group 2, and one station in groups 3 and 4 (Figure 1-9). There were significant differences in species assemblage among the groups (ANOSIM: R=0.972, p=0.001), with different species abundances and compositions between these groups (Figure 1-10). SIMPER results for the groups with more than one sample in each group (ie. groups 1 and 2) had an average dissimilarity of 39.56 with *A. mitchilli, M. beryllina, M. undulates, Hybognathus regius,* and *Notropis hudsonius* identified as the top five species contributing to the dissimilarity between groups (Figure 1-11).

BEST correlation results were significant (R=0.754, p=0.01) with biological patterns best described by salinity and wind direction. DistLM options identified salinity and wind direction cumulatively explain 51.9% of the total variation 47.8% and 4.1% respectively. Therefore, the observed patterns in species assemblage initially identified by spatial groups could be the result of changes in salinity and wind direction. The mean and mode respectively were group 1 (1.3 ppt, SW), group 2 (7.7ppt, NE), group 3 (3.8, SW), and group 4 (0.1, SW) (Table 1-6). The ANOVA results indicate there are significant differences in salinity between the groups (Table 1-6).

Trawl. Five groups were identified from the cluster analysis (70% similarity) (Figure 1-12), group 1 consisted of 40 stations, 16 stations in group 2, three stations in group 3, two stations in group 4, and one station in group 5 (Figure 1-13). Groups 1-3 are considered major groups (containing most of the stations) to clarify result tables and figures. There were significant differences in species assemblage among the trawl station groups (ANOSIM: R=0.67, p=0.001) and differing proportions of species or variations in species between these groups

(Figure 1-14). SIMPER results for the groups 1 and 2, with more the majority of the stations, had an average dissimilarity of 32.7 with the top five contributing species including *Alosa aestivalis, A. mitchilli, M. undulates, L. xanthurus,* and *M. americana* (Figure 1-12). The average dissimilarity between groups 1 and 4 and 2 and 4 was 35.3 and 37.9 respectively with more freshwater species (*Lepomis macrochirus* and *Pomoxis nigromaculatus*) driving the dissimilarity. Group 3 was different than groups 1 and 2 with *M. undulates* leading the average dissimilarity (Figure 1-15).

BEST analysis, correlation results were significant (R=0.683, p=0.01) with biological patterns best described by salinity and dissolved oxygen. Salinity and dissolved oxygen cumulatively explained 38.3% of the total variation 34.7% and 3.5% respectively. The DistLM analysis also included temperature, depth, and wind direction in sequential analysis describing a total of 50.9% of the total variation.

ANOVA results indicated significant differences in salinity and dissolved oxygen between the trawl station groups with groups 1, 2 and 3 all having significantly different salinities and group 1 having higher dissolved oxygen values than any of the other groups, and significantly lower dissolved oxygen values for groups 4 and 5 than the other groups (Table 1-7). The values for other parameters included in the DistLM analysis are listed in (Table 1-7).

Temporal Analysis (Seine and Trawl)

Seine. Seven year groups were identified from the CLUSTER analysis (80% similarity) (Figure 1-16), group 1 contained 20 of the 41 years, group 2 (10), group 3 (5), group 4 (3) and one year in groups 5, 6, and 7. Groups 1-4 are major groups (containing most of the years) to simplify and clarify result tables and figures. There were significant difference in species

assemblage between the year groups (ANOSIM: R=0.74, p=0.001). The groups varied in species composition and abundance between the year groups (Figure 1-17). Seine year groups were similar with moderate differences; SIMPER analysis (average similarity value) for group 1 of 82.9, group 2 (83.4), group 3 (82.1) and group 4 (84.9). The average dissimilarity between major year groups included 1 and 2 of 21.93, 1 and 3 of 20.80 and, 2 and 3 of 23.26, with varying species driving the dissimilarity (Figure 1-18).

BEST correlation results were weak but significant (R=0.28, p=0.01) with biological patterns described by depth, temperature, salinity, dissolved oxygen, and wind speed. DistLM analysis identified salinity, temperature, and wind direction cumulatively explaining 14.5% of the total variation 6.7%, 6.0% and 1.8% respectively. There were no significant differences in salinity, temperature, and wind direction between our major year groups for the seine samples (Table 1-8).

Trawl. The CLUSTER analysis identified 7 different groups (Figure 1-19), group 1 consisted of 19 years, eight years in group 2, seven in group 3, three in group 4, two in group 5 and one year in groups 6 and 7. Groups 1-4 are major groups (containing most of the years) to simplify and clarify result tables and figures. There were significant differences in species assemblages between the groups (ANOSIM: R=0.77, p=0.001) with different species composition and abundances between the groups (Figure 1-20). SIMPER results included average similarities for the years groups of group 1 (73.9), group 2 (74.5), group 3 (75.8), group 4 (76.2), and group 5 (75.7), for the year groups with only 1 year in each year group (ie. groups 6 and 7) similarities were not generated. The average dissimilarities for the major groups containing most of the years included groups 1 and 2 (36.7), groups 1 and 3 (33.7), and group 2 and 3 (44.4) with varying species contributing to the dissimilarity (Figure 1-21).

BEST analysis, correlations were weak but significant (R=0.299, p=0.01) with biological patterns best described by depth and salinity. DistLM results included salinity, depth and temperature which cumulatively explained 15.5% of the total variation 8.2%, 5.2%, and 2.0% respectively.

Patterns in the large scale analysis of environmental parameters help define the observed patterns in species abundance. The three variables defined by the BEST and DistLM analyses, salinity, depth, and water temperature was assessed by group (Table 1-9). ANOVA results concluded there was a significant difference in salinity and depth between year groups 1 and 2, with mean salinity higher for group one and depth higher for group 2. Differences in water temperature were identified for group 4 with a significantly lower average temperature than the groups 1-3 (Table 1-9).

Discussion

Only a few environmental parameters in this study described the majority of the spatio-temporal variability observed in the fish abundance of Albemarle Sound. Salinity, wind direction, and dissolved oxygen were strongly correlated with the abundance data for the spatial analysis, and salinity, depth, water temperature and wind direction were weakly correlated with the abundance data temporally. In both analyses for both gears, salinity (14.5% - 47.8%) always explained more variability in the abundance data than any of the other included variables. Two of the most influential physico-chemical factors impacting the distribution and abundance of estuarine fish assemblages are water temperature and salinity (Headrich 1983; Kennish 1990) and the results of this study support the strong influence of salinity on estuarine fish assemblages.

Overall Fish Assemblage Structure

The catch was overall dominated *A. mitchilli*, with a few other dominant species including *M. beryllina, B. tyrannus, M. undulatus, L. xanthurus, M. americana* and *A. aestivalis*. In a study focusing on spatial and temporal variability of the pelagic fish community in Chesapeake Bay, USA , *A. mitchilli* was the most abundant species, with the catch overall characterized by a few dominant species (*M. americana, A. pseudoharengus, M. undulatus, C. regalis,* and *L. xanthurus*) and several less commonly occurring species(Jung and Houde 2003). Both of these studies utilized temperate estuaries on the east coast of the USA and identified some similarities between species assemblages with *A. mitchilli* as the most abundant species. The presence of numerically dominant species were identified in the Chesapeake Bay and Albemarle Sound estuarine systems along with the presence of numerous less commonly occurring species, concurring this common theme among estuaries. Mean salinity in Albemarle

Sound was different than mean salinity in Chesapeake Bay but *A. mitchilli* was the dominant species in both studies.

Haedrich (1983) surveyed estuaries around the world and estimated that 10 species of fish in a given estuary would encompass approximately 90% of the individuals found in that estuarine system. This holds true for the present study where the seven most dominant species comprised 86% of the individuals found in Albemarle Sound (Appendix I). The total number of species reported for estuaries around the world varied from 23 in the small Mystic River estuary in Massachusetts to 149 in the large tropical Rokan estuary in Sumatra (Headrich 1983) with a moderate number of species typically found in temperate estuaries. The coastal waters of North Carolina tend to be species rich because of the overlap of species from the northern and southern fish stocks located in the waters of North Carolina. There were 139 identified species in sampling, a lot of species for a temperate estuary, closer to the species richness of a tropical estuary. Therefore, the fish assemblage of Albemarle Sound is diverse and complex, utilized by a plethora of species (27% freshwater, 54% estuarine, 19% marine), and numerically dominated by just a few.

Dominant Species Through Time

Changes is species abundances for numerically dominant species were identified in both gears, with a significant increase in overall abundance of all species in the trawl samples, driven by significantly increasing abundances of *A, mitchilli, L. xanthurus*, and *M. undulatus*. Increases in *M. undulatus* have been tied to the North Atlantic Ossilation and warmer winters allowing for the formation of larger year classes or ‘outburst’ due to high juvenile survival rates in mid-Atlantic estuaries (Hare and Able 2007). Then, depending on the duration and frequency of these warm winters, *M. undulatus* range could extend farther north opening up new habitat to the

population (Hare and Able 2007). For the seine samples, the average abundance of all species significantly decreased through time, with the top five numerically dominant species decreasing in abundance, but not significantly changing in time. Variability in species abundances through time is likely the result of a combination of density dependent and density independent processes that impact fish populations through recruitment, growth, and natural mortality (Sissenwine 1984). Sources of natural mortality include predation, starvation, lethal environmental conditions, and disease, with all of these forces impacting recruitment (Sissenwine 1984). In general, disease outbreaks are infrequent (Sissenwine 1984), and during the study period, lethal environmental conditions were not identified on a large scale and are likely not influencing the overall abundance trends in the observed species. Predation occurs constantly on fish assemblages, and early life history stages are prone to the influence of predation during these small life stages. Hunter (1982) identifies the importance of predation on fish egg and larval mortality. Hunter (1982) cites work indicating the starvation rate based on detection of starving larvae were much lower than the high mortality rates of fish larvae and concluded starvation could not account for the mortality and predation must be a major cause.

The influences of environmental variables and abiotic factors on fish assemblages are important and these environmental variables are possibly associated with starvation of early life stage larvae and the availability of food. The influence of environmental variability on predation, especially at the post-larvae stage, is less well understood. It is thought that early life history stages of fish seek protection from predators in nursery areas, limiting vulnerability to predation. Also, growth rate can be influenced by temperature, influencing fish metabolism and in turn, impacting predation vulnerability (Sissenwine 1984; Sogard 1997). These combined influences

shed light on the complexity of recruitment of fish stocks, and mechanisms that could influence species abundance.

Influence of Gear Type on Fish Community

Trawls and seines were used to collect fish in Albemarle Sound. Using MDS, I plotted each station based on fish assemblage by gear and clearly identified two groups one group sampled with the seines and the other group sampled with the trawl. The SIMPER results present *A. mitchilli*, *M. beryllina*, *M. undulates*, *L. xanthurus*, and *Mugil cephalus* are the top species contributing to the dissimilarity between the two gear types. This could be the result of gear selectivity varying between species because of habitat preferences, escape behavior or other gear biases like depth. All of the seine samples were collected from shallow shore areas (<1.5 m) while the trawl samples were collected in deeper areas (>1.5 m). For studies comparing the species composition among assemblages or where results are going to be directly compared, it is important to understand gear biases and the affect that has on the sample collected (Guest et al. 2003). A good example is Pollard's (1984) study where seagrass fish communities sampled using rotenone were more similar to other estuaries that used rotenone, than in the same estuary using a beam trawl (Pollard 1984). In this example, any observed differences in fish community abundance or assemblage may be explained by the gear bias, and disguise any true ecological difference (Guest et al. 2003). The preference for active gears like seines and trawls for sampling is likely due to the ease of use to sample large areas, allowing for broad-scaled surveys.

Temporal Patterns in Diversity

There were significant differences in diversity for the established groups, but biologically these differences are minor with significant overlap in the ranges for Shannon-Weiner diversity

indices and averages differing by one or two tenths. The average number of species caught per sample in each group were not different. The observed patterns in diversity may include spatially, habitat structure, foraging behavior, or development along the sound (ie. drainage canals, docks, bulkheads) and the influence this habitat modification has on the species assemblage. Temporally, changes in diversity might be related to sea level rise and the influence of estuarine species moving into what used to be fresh water areas increasing. This would be the result of habitat migration as salt marshes transgress landward replacing freshwater and brackish marshes (Park et al. 1991) and tidal marshes consequently submerge (Moorhead and Brinson 1995) as habitat conversion unfolds. Church and White (2006) analyzed the rate of sea level rise and estimated a 195mm increase in sea level from 1870 to 2004 with a 20^{th} century rate of sea level rise of 1.7 (0.3) mm per year. This increase in sea level could allow increased intrusion of saltwater into freshwater dominated estuarine systems. This supports the finding that diversity for the seine samples increase over time, proposing the idea that more species now have the ability to utilize these estuarine areas due to the influence of sea level rise and new ranges within species tolerances.

Climate change is also thought to have an influence on the ranges of many species (Nye et al. 2009). Increasing water temperatures are allowing the species assemblages in the Northeast US continental shelf to shift. In a study conducted by Lucey and Nye (2010), species assemblages were shifting to the north, with northern areas now inhabited by species that historically had a more southern distribution. Global water temperatures have increased in recent times (Knutson et al. 2006; Levitus et al. 2000; Lozier et al. 2008) and climate models indicate the likely continuation of this warming trend (IPCC 2007; Solomon et al. 2009). Despite the difficulty identifying the ecological influences of climate change, several studies have detected

an influence (Parmesan and Yohe 2003; Rosenzweig et al. 2008; Walther et al. 2002). Combine the influence of climate change and sea level rise together over the last 4 decades, a resulting increase in diversity through time as a response to a combination of influences could be expected.

Spatial and Temporal influence of Identified Environmental Parameters on Fish Assemblages

Salinity. The main environmental parameter influencing the spatial distribution of fish species in this study was salinity for both gears. The influence of salinity on estuarine fish communities is well documented (Harrison and Whitfield 2006; Jaureguizar et al. 2004; Selleslagh and Amara 2008) and confirmed by other east coast estuarine studies (Able et al. 2001; Jung and Houde 2003). This is likely related to differences in salinity tolerances among fish species (Able et al. 2001; Marshall and Elliott 1998). For spatial groups, the major differences seem to be drive by abundance of common estuarine species; along with the inclusion of marine and freshwater species. Analyzing station groups (east to west) seine station group 2 was dominated by *A. mitchilli* with other euryhaline species. Inland (west) there are more estuarine species that utilize brackish waters (group 1) (ie. *M. americana,* and *A. aestivalis* juvenile stage) to freshwater species (ie. *Ameiurus catus, L. gibbosus*, and *N. hudsonius*) in group 4. This same pattern is observed in the trawl station groups with salinity tolerances influencing the fish assemblage distributions, responding to the ambient salinity.

Salinity characterized much less variability in the fish assemblage data temporally than spatially, however it was significantly correlated with changes in the fish assemblage through time. This may be the result of large scale and long lasting climatic events such as drought or unusually wet periods, influencing freshwater input. Other parameters that might influence the fish assemblage include biological interactions such as predator prey relationships, year class

strength, and the influence of primary productivity and food web interactions (Sissenwine 1984). Since the environmental parameters included in this study did not characterize a large portion of the variability in the fish assemblages, it is likely other factors have a stronger influence on the fish assemblages of Albemarle Sound.

Wind direction. Wind direction was identified as an influential environmental parameter for the species collected by seine. Albemarle Sound tides are dominantly wind driven (Copeland et al. 1983) and that fact combined with the orientation, size, and geographic features surrounding the sound support the idea that wind direction might influence the fish assemblages of Albemarle Sound. The influence of wind transporting water was revealed in (Hernández-Miranda et al. 2003), when correlations between the distribution and abundance patterns of the entire ichthyoplankton assemblage with wind forcing was revealed. Hernández-Miranda et al. (2003) found wind driven patterns in upwelling and gyre formation correlated with ichthyoplankton assemblages in the near shore coastal waters of central Chile. In the current study, the two most dominant winds were southwest winds, forcing water out of the sound, or northeast, forcing water up into the sound. These irregular tidal flows present in Albemarle Sound may be physically driving the fishes into and out of the estuary. Although weather patterns, while not directly a force have associated winds and precipitation that also influence the dynamics of Albemarle Sound. Hurricanes and Northeasters can force large volumes of water in and out of the Albemarle-Pamlico estuarine system causing large changes in salinity, depositing sediments stirred up during the storm, and bringing numerous larval fishes into the sound systems (Copeland and Gray 1989).

Dissolved oxygen. Dissolved oxygen correlated with the patterns observed in fish abundance for the trawl samples in addition to salinity. This influence was only moderately

identifiable in our spatial groups for the trawl, with some upstream areas having significantly lower dissolved oxygen concentrations then the rest of the sound. This could be due to agricultural runoff indirectly impacting dissolved oxygen levels in these areas and the resulting influence that has on the inhabiting fish assemblage. The Albemarle-Pamlico Estuarine System is generally phosphorous-rich and nitrogen-limited but over the past 40 years, phosphorous loading has increased after declining in the 1950s and 1960s and nitrogen loading has also increased due to population growth (Steel 1991). Despite the increased loading of phosphorous and nitrogen, water column concentrations generally have declined but chlorophyll a concentrations have increased in the upper Albemarle Sound and lower Chowan and Alligator Rivers (Steel 1991). Chlorophyll a is an indicator of algae abundance and uses the nutrients for growth, resulting in lower nutrient levels in the water column. Besides increases in sewage discharge, several other possible causes were identified by Steel (1991) including point sources such as wastewater treatment plants, and nonpoint sources such as sediment, agricultural runoff, and urban runoff, with agricultural and urban runoff identified as the most prevalent environmental concerns (EPA 2007). Combined with the right climate conditions (sunny, warm, low flow conditions), excess nutrients can cause algae blooms, depleting dissolved oxygen levels (Steel 1991).

The effects of dissolved oxygen on the species abundance and distribution may act synergistically with changes in salinity and temperature. Although dissolved oxygen levels are influential in fish distributions and abundances, with many species becoming stressed at levels less than 4.5 mg/L (Poxton and Allouse 1982), the percentage saturation of oxygen in water is determined by temperature (Carter 1988) and salinity (McLusky 1989). During the study period, the average temperature was 25.9 C and the average salinity was 1.7 ppt, and Pomfret et al. (1991) found dissolved oxygen levels less than 7.5 mg/L combined with temperatures greater

than 15 C acted as a barrier for fish movement. However, this is not the case with estuarine species that surface breath or those with wider tolerance ranges. Therefore, dissolved oxygen will impact different species synergistically with salinity and temperature based on the tolerance limits of that species, ultimately affecting species composition.

*Water temperature***.** Water temperature was also an influential environmental parameter influencing the fish assemblage sampled by both gears. Variation in rainfall and temperature regimes within a year and between years can have an impact on ichthyofauna of estuaries (Allen 1982). These impacts would include times of low rainfall resulting in increased salinities and ultimately impacting the fish assemblages, to the seasonal fluctuations in fish assemblages resulting from seasonal changes in water temperature, to major climatological events such as hurricanes. Jung and Houde (2003) identified the influence of environmental factors on the pelagic fish community structure in Chesapeake Bay, USA and concluded seasonal succession of species occurred in the bay as a result of water temperature changes, and year classes of the same species respond differently to environmental variability.

Albemarle Sound, NC would encounter similar conditions as Chesapeake Bay, and likely contains similar patterns in seasonal succession of fishes. As the water starts to cool off from summer to fall, seasonal succession was identifiable from analysis but not directly included. This explains the weak but significant correlation with water temperature found in analysis because only moderate temperature changes were observed on average for the five month study period (June-October), with assemblage responses to this environmental parameter weak, but significant (seasonal succession). Not separating the fish species into year classes, mainly young-of-year and age-1 fishes, may have also disguised patterns in species assemblage and distribution responses to environmental parameters. It is well known that different life stages of the same

species may inhabit areas with completely different ambient conditions and this trend is clearly identified by Jung and Houde (2003). However, there was not a significant change in average annual temperature, only annual variation year to year. The conclusion water temperature has an impact on fish species abundance and distribution is identified, but changes to analysis are needed to determine the extent of the influence, specifically identifying trends on a finer scale over time, and incorporation of additional variables not included in this study.

Harrison and Whitfield (2006) compared estuaries in South Africa and the influence of several environmental parameters on fish assemblages. They concluded that salinity and water temperature were the main factors affecting the distribution and occurrence of estuarine fishes. North Carolina waters embody the southernmost distribution for some northern species (*M. beryllina*, *Fundulus diaphanous*, and *A. pseudoharengus*) and the northern most distribution for some southern species (*Paralichthys lethostigmas*). Variations in annual temperature, or large scale climate patterns influencing the water temperature may influence the timing of certain species entering or leaving the sound. Cooler conditions therefore result in more northern species some years, while warmer conditions are characterized by more southern species. This influence could be the cause for the identification of water temperature as an influential environmental parameter influencing the distribution and occurrence of fishes. In a study assessing the persistence of demersal fish assemblages from Cape Hatteras to Nova Scotia by Gabriel (1992), spatial boundaries of groundfish assemblages were analyzed. This study identified some changes in species abundances on a large spatial scale that were likely linked to changes in temperature, with influxes of spot, croaker, and weakfish occurring mostly during years characterized by unusually warm temperatures in the Southern Mid-Atlantic Bight, extending their ranges northward.

Depth. Depth was identified in the trawl analysis as an influential environmental parameter but the depth range of this study was narrow, averaging 2.1 (±1.2) meters. Depth patterns could be the result of habitat preference by different species in the Pamlico-Albemarle estuarine system (Epperly 1984). In a previous study analyzing fisheries data from the Pamlico-Albemarle Peninsula area by Epperly (1984), spatial and temporal partitioning of the waters corresponded to salinity and depth, with intense utilization of this area as nursery grounds and high recruitment for species throughout the spring (*L. xanthurus, M. undulates, Alosa spp.*) and summer (*M. Americana, A. catus, C. regalis, B. chrysoura*) months. Shallow water species like *F. diaphanous* and *N. hudsonius* would most likely occur in the shallow water seine samples, while schooling pelagic species such as *A. mitchilli* and *B. tyrannus* could be caught in shallow seines or trawls. Benthic species like *L. xanthurus* and *M. undulates* would occur in the deeper trawl sampling areas.

This correlation could also be the indirect result of differences in dissolved oxygen, water flow, and temperature as a result of larger weather events such as regional droughts or extended periods of hot or cold temperatures. In a study focusing on Pamlico Sound, North Carolina (Tolopka et al. In Press) the temporal influence of drought is identified, with temporal station groups in the study corresponding to three periods of drought in North Carolina. The three identified periods of drought were 1985-1988, 1998-2002, and 2007-2012 (NCDWR 2009; Weaver 2005; Zembrzuski et al. 1988). These periods were characterized by reduce precipitation and reduced stream flows for eastern North Carolina attributed to large scale La Nina climate patterns (NCDWR 2007; NCDWR 2009; Weaver 2005). Temporal analysis for the current study presents similar patterns but they are not clearly defined. For the seine temporal groups, the droughts of 1998-2002 and 2007-2012 all fall within group 1 and for the 1985-1988 period of

drought, the years are distributed between several of the temporal groups. Similarly for the trawl temporal groups, the droughts of years 1985-1988 and 2007-2012 are all located in group 1 with years for the drought of 1998-2002 distributed between groups 1 and 3. Additionally, other years not associated with drought conditions are also located within the spatial and temporal groups. There is a possible influence of drought on species assemblages, but other environmental parameters as a result of drought, or in combination with drought are also influencing the fish assemblages but it is likely drought could be driving some of the identified weak correlations between species assemblages and environmental parameters.

Conclusion

Although the multivariate approach used in this study identified influential environmental variables influencing the multispecies patterns of fish abundance and distribution, the total explained variability was very low for our temporal analysis, likely because of the influence of variables not incorporated into analysis or the way the overall analysis was conducted. In order to look at large scale patterns, a lot of data was pooled, and maybe the synthesis of the data at the smaller scale may identify the environmental influence and characterize more variation. Other studies assessing the influence of environmental variables on fish assemblages characterized more temporal variability, greatly exceeding the variability described in this study including Carassou et al. (2011) describing 65.8% of the inter annual variability in juvenile abundances, or seasonal factors alone explaining 22% of the variation in fish assemblages in three Southern California estuaries (Desmond et al. 2002). Temporal analysis overall did not describe a majority of the variation observed in fish distribution and abundance patterns, with spatial analysis characterizing more variability in species assemblages. This is similar to the study conducted by Jung and Houde (2003) where correspondence analysis of species composition by year, season,

and region resulted in the horizontal axis explaining 71.3% of the inertia which was closely related to freshwater input and significantly correlated with salinity. Whereas the vertical axis explained 17.9% of the total inertia, was not correlated with any hydrological variables, and was closely related to seasonal succession of fish communities from April to October.

Variables affecting the biological assemblages in a water body can be divided into three categories: the environment affecting the biology, the interactions between the biological variables, and the means by which biological variables can affect the environmental factors (Marshall and Elliott 1998). This study only addresses the first of these interactions assessing the influence of environmental variability and the response of the fish assemblages to that environmental variability. The inclusion of the additional two interactions and parameters like predation, competition, and population sizes, are required to fully explain addition variation in the fish assemblages. Understanding that not all environmental parameters influencing the fish assemblage are incorporated into this study is important. After those interactions are accounted for, biological interactions simultaneously impact the fish assemblage along with environmental abiotic parameters.

The possibility that other biological interactions rather than environmental interactions have a strong influence on the fish assemblage of Albemarle Sound such as predator-prey interactions, prey availability, competition, spawning stock biomass and primary productivity is probable (Marshall and Elliott 1998; Sissenwine 1984). Since this study was designed and sampled a majority of fishes at the juvenile stage, spawning stock biomass, if incorporated into analysis might help explain more of the variability in the fish assemblage. The relationship between recruitment and spawning stock biomass has been a focus of fisheries scientist because ultimately, population persistence requires recruitment and the replacement of individuals (Pepin

and Myers 1991; Sissenwine 1984). Unexplained variability in recruitment is the result of density independent effects of environmental variation (Martinho et al. 2009; Sissenwine 1984); therefore, coupling recruitment and spawning stock biomass with environmental parameters to characterize the variability in fish assemblages would help describe more variability.

The influence of developed fisheries was briefly addressed in this study but did not help explain further variability and was removed. Commercial fisheries, recreational fisheries or lack of a fishery were identified for the species included in analysis, but with weak temporal correlations and a minor amount of the temporal variation in the fish assemblages characterized in the study, the identification of fish assemblage patterns in response to developed fisheries were not identifiable in this analysis. Additionally, fishing practices indirectly impacting target and non-target species include fishes captured as bycatch, destruction of habitat by fishing gear, or skewing predator-prey relationships would also impact these species (Lucey and Nye 2010) and influence the spatial and temporal distribution of those species and should be incorporated to adequately define fishing pressure.

Also, changes in sampling efficiency throughout the sampling time period could influence the fishes availability to the gears, possibly disguising or influencing trends in the fish assemblages. Changes in sampling protocol for multiple reasons include; variation in the individuals conducting sampling, minor changes to the gear or fishing methodology, and ability to reach the established station location. Interactions between sampling and the environment all influence the recruitment of fish to the gear. With the identification of wind driven tides in Albemarle Sound, sampling locations can be difficult to reach and even moved if areas become inaccessible. The wind can blow large volumes of water in and out of the sound, influencing the area sampled and volume of water sampled, impacting the fishes availability to capture by the

gear. This could have an impact on seine sites in particularly due to the fact they are already located in very shallow areas and with a decreased water level, the volume of water or exact location of sampling could easily change based on tidal condition at that time.

Future Research

This study can serve as a benchmark for future studies attempting to identify influential environmental parameters in Albemarle Sound, North Carolina. I have attempted to document the species assemblages and their distributions in Albemarle Sound, as well as, identify the dominant environmental parameters influencing the fish assemblages. Continued monitoring through Program 100 will continue to provide this type of information to allow for future expansion of this study, and is essential to providing the information required for multispecies fisheries management. Additional environmental parameters utilized in other studies that could be added to this study, helping characterize additional variability include bottom or substrate characteristic of sampling areas, distance from Chowan or Roanoke River mouth or inlet opening, turbidity, barometric pressure, or large scale climatic pattern information from influences such as the North Atlantic Oscillation or additional drought information.

Furthermore, analysis in a different manner could help to identify additional patterns or influences of environmental variables on species distributions and abundances. Analyzing individual species as variables instead of the assemblage groups in this study may allow for the identification of additional patterns. Also, using length ranges to separate individuals of the same species into different year classes, particularly young-of-year and age 1 groups, might characterize more variability since these two year classes of fish could utilize estuarine areas differently. When utilizing species for analysis, the addition of life history strategies such as

spawning seasons and durations and egg types could also help ultimately identify the environmental influence different variables have on fish species and assemblages.

The inclusion of additional biological parameters such as spawning stock biomass, or even fisheries landing data could help identify variability as a result of biological processes. Therefore, characterizing additional variability from other sources, allowing for better characterization of the influence particular environmental variables have on the fish assemblages of Albemarle Sound, North Carolina

Table 1-1The 23 most frequently occurring seine captured species from 1972-2012 for Albemarle Sound, North Carolina included in analysis and the anlysis code used for that species. The number of samples containing that species and their percent contribution to the total abundance followed by their rank based on total abundance.

Scientific Name	Analysis Code	Common Name	Samples Containing Species	Frequency of Occurrence	Percent Total Abundance
Menidia beryllina	Men ber	Silverside, Inland	4755	78.4 (1)	22.5 (1)
Morone americana	Mora me	Perch, White	2726	44.9 (2)	6.75 (5)
Leiostomus xanthurus	Lei xan	Spot	2090	34.4 (3)	2.55 (10)
Strongylura marina	Str mar	Needlefish, Atlantic	1982	32.6 (4)	0.75 (15)
Anchoa mitchilli	Anc mit	Anchovy, Bay	1902	31.3 (5)	16.6 (2)
Notropis hudsonius	Not hud	Shiner, Spottail	1837	30.2 (6)	4.31 (8)
Fundulus diaphanous	Fun dia	Killifish, Banded	1634	26.9 (7)	4.47 (7)
Mugil cephalus	Mug cep	Mullet, Striped	1592	26.2 (8)	1.72 (11)
Morone saxatilis	Mor sax	Bass, Striped	1502	24.7 (9)	1.27 (12)
Perca flavescens	Per fla	Perch, Yellow	1263	20.8 (10)	0.92 (13)
Micropogonias undulates	Mic und	Croaker, Atlantic	1122	18.5 (11)	2.85 (9)
Alosa aestivalis	Alo aes	Herring, Blueback	1055	17.4 (12)	11.0 (4)
Hybognathus regius	Hyb reg	Minnow, Eastern Silvery	904	14.9 (13)	5.09 (6)
Brevoortia tyrannus	Bre tyr	Menhaden, Atlantic	780	12.8 (14)	12.6 (3)
Micropterus salmoides	Mic sal	Bass, Largemouth	753	12.4 (15)	0.20 (24)
Alosa pseudoharengus	Alo pse	Alewife	679	11.1 (16)	0.91 (14)
Lepomis gibbosus	Lep gib	Sunfish, Pumpkinseed	554	9.13 (17)	0.19 (28)
Lepomis macrochirus	Lep mac	Bluegill	550	9.07 (18)	0.39 (17)
Notemigonius crysoleucas	Not cry	Shiner, Golden	399	6.58 (19)	0.37 (18)
Alosa sapidissima	Alo Sap	Shad, American	379	6.25 (20)	0.19 (27)
Ameiurus catus	Ame cat	Catfish, White	374	6.16 (21)	0.50 (16)
Etheostoma olmstedi	Eth olm	Darter, Tesselated	347	5.72 (22)	0.15 (31)
Trinectes maculates	Tri mac	Hogchoker	329	5.42 (23)	0.04 (39)

Table 1-2 The 21 most frequently occurring species in the trawl samples included in analysis and the code used for that species in analysis. The number of samples containing that species as well as the estimated number of individuals caught and their percent contribution to the total abundance followed by their rank based on total abundance.

Scientific Name	Analysis Code	CommonName	Samples Containing Species	Frequency of Occurrence	Percent Total Abundance
Anchoa mitchilli	Anc mit	Anchovy, Bay	5384	65.5 (1)	58.2 (1)
Micropogonias undulates	Mic und	Croaker, Atlantic	4589	55.8 (2)	14.8 (2)
Leiostomus xanthurus	Lei xan	Spot	4399	53.5 (3)	9.11 (3)
Morone americana	Mor ame	Perch, White	4127	50.2 (4)	5.59 (4)
Morone saxatilis	Mor sax	Bass, Striped	2355	28.6 (5)	1.60 (6)
Trinectes maculates	Tri mac	Hogchoker	1968	23.9 (6)	0.61 (11)
Ameiurus catus	Ame cat	Catfish, White	1816	22.1 (7)	0.85 (8)
Bairdiella chrysoura	Bai chr	Perch, Silver	1521	18.5 (8)	0.63 (10)
Brevoortia tyrannus	Bre tyr	Menhaden, Atlantic	1497	18.2 (9)	1.56 (7)
Alosa pseudoharengus	Alo pse	Alewife	1260	15.3 (10)	0.84 (9)
Alosa aestivalis	Alo aes	Herring, Blueback	1173	14.2 (11)	3.17 (5)
Perca flavescens	Per fla	Perch, Yellow	701	8.53 (12)	0.22 (15)
Pomoxis nigromaculatus	Pom nig	Crappie, Black	604	7.35 (13)	0.41 (13)
Lepomis macrochirus	Lep mac	Bluegill	582	7.08 (14)	0.50 (12)
Cynoscion regalis	Cyn reg	Seatrout, Weakfish	541	6.58 (15)	0.11 (20)
Ameiurus nebulosus	Ame neb	Catfish, Bullhead,Brown	530	6.45 (16)	0.14 (17)
Paralichthys lethostigma	Par let	Flounder, Southern	514	6.25 (17)	0.04 (24)
Lepomis gibbosus	Lep gib	Sunfish, Pumpkinseed	507	6.17 (18)	0.12 (19)
Ictalurus punctatus	Ict pun	Catfish, Channel	470	5.71 (19)	0.10 (21)
Notropis hudsonius	Not hud	Shiner, Spottail	448	5.45 (20)	0.28 (14)
Dorosoma cepedianum	Dor cep	Shad, Gizzard	424	5.16 (21)	0.13 (18)

Table 1-3 Totals species (S), Shannon Weiner diversity index (H') and Pelou's evenness index (J) by gear for both the spatial and temporal groups. Numbers presented are average sample diversity for that gear and group with the range of values in parenthesis (Using sample averages allowed for comparisons between groups). ANOVA results are indicated by the superscript letters for Shannon Weiner diversity index values. Groups with the same letter are not significantly different at the p=0.05 cutoff.

Diversity Indices	Groups in Analysis						
			Seine Spatial Groups				
	Group 1	Group 2	Group 3	Group 4			
Total Species (S)	5.6 (1-20)	4.8 (1-15)	6.7 (1-17)	4.5 (1-12)			
Shannon's Diversity Index (H')	0.9 (0-2.4) ^{A}	0.7 (0-2.3) ^{B}	0.9 (0-2.4) ^{A}	0.8 (0-2.0) ^{A}			
Pelou's Evenness Index (J)	0.5 (0.0-1)	0.5 (0.0-1)	0.5 (0.0-1)	0.6 (0.0-1)			
			Trawl Spatial Groups				
	Group 1	Group 2	Group 3	Group 4	Group 5		
Total Species (S)	4.9 (1-14)	4.3 (1-15)	5.2 (1-13)	5.0 (1-13)	6.0 (1-16)		
Shannon's Diversity Index (H')	0.7 (0-2.4) ^{A}	0.6 (0-2.2) ^{B}	0.9 (0-2.0) ^{C}	0.9 (0-2.0) ^{C}	1.0 (0-1.9) ^{C}		
Pelou's Evenness Index (J)	0.5 (0.0-1)	0.5 (0.0-1)	0.6 (0.0-1)	0.7 (0.0-1)	0.6 (0.1-1)		
			Seine Temporal Groups				
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Total Species (S)	5.9 (1-20)	4.9 (1-14)	4.8 (1-14)	5.5 (1-18)	3.6 (1-12)	7.1 (1-17)	5.7 (1-14)
Shannon's Diversity Index (H')	0.9 (0-2.4) ^{B}	0.8 (0-2.2) ^{C}	0.7 (0-2.0) ^{C}	0.8 (0-1.9) ^{C}	0.6 (0-2.0) ^{D}	1.1 (0-2.0) ^{A}	0.9 (0-1.9) ^{B}
Pelou's Evenness Index (J)	0.5 (0.0-1)	0.5 (0.0-1)	0.5 (0.0-1)	0.5 (0.0-1)	0.5 (0.0-1)	0.6 (0.0-0.9)	0.5 (0.0-1)
			Trawl Temporal Groups				
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Total Species (S)	5.0 (1-15)	4.2 (1-16)	4.4 (1-13)	5.0 (1-11)	5.1 (1-14)	3.4 (1-14)	3.0 (1-9)
Shannon's Diversity Index (H')	0.7 (0-2.2) $^{A, B}$	0.7 (0-2.4) $^{A, B}$	0.5 (0-2.0) ^{C}	0.8 (0-1.9) ^{A}	0.8 (0-1.9) ^{A}	0.6 (0-2.0) ^{C}	0.7 (0-1.7) ^{B}
Pelou's Evenness Index (J)	0.5 (0.0-1)	0.5 (0.0-1)	0.4 (0.0-1)	0.5 (0.0-1)	0.5 (0.0-0.9)	0.6 (0.0-1)	0.7 (0.0-1)

Table 1-4 Mean (± Standard Deviation) for Albemarle Sound NC (1972-2012) to get overall averages and standard deviations. Dissolved oxygen was only collected in 1981-1987, 1989, and 1991-2012. Wind direction is recorded as the mode with the direction for that numeric value included in parenthesis. River discharge values are from Roanoke River (USGS Gauge # 02080500).

Environmental Variable	Mean
Depth (meters)	2.1 (1.2)
Temperature (°C)	25.9 (4.0)
Salinity (ppt)	1.7 (2.1)
Dissolved Oxygen (mg/L)	7.4 (1.6)
Wind Speed (Knotts)	9.0 (4.8)
Wind Direction	6 (NE)
Discharge (cubic meters per second)	184 (153)

Table 1-5 Mean (± Standard Deviation) for monthly environmental parameters in Albemarle Sound North Carolina (!972–2012). Wind direction is recorded here as the mode with the direction for that numeric value included in parenthesis. River discharge values are from Roanoke River (USGS Gauge # 02080500).

Month	Depth (M)	Water Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (mg/L)	Wind Speed (Knotts)	Wind Direction	Discharge (cms)
June	1.5 (1.0)	27.0 (2.2)	1.0 (1.4)	7.2 (1.4)	8.7 (4.4)	6 (SW)	220 (152)
July	2.1 (1.1)	28.7 (1.7)	1.4 (1.7)	7.1 (1.5)	8.9 (4.8)	6 (SW)	178 (144)
August	2.3 (1.2)	28.4 (1.9)	1.6 (1.8)	7.2 (1.4)	4.5 (2.1)	6 (SW)	146 (105)
September	2.1 (1.2)	25.2 (2.3)	2.3 (2.7)	7.4 (1.7)	9.4 (5.1)	6 (SW)	151 (144)
October	2.2 (1.2)	19.9 (3.7)	2.1 (2.4)	8.0 (1.7)	9.4 (4.9)	6 (SW)	155 (144)

Table 1-6 Mean (± Standard Deviation) for seine sample environmental parameters influencing the seine station group fish assemblages and indicated ANOVA results between the groups for that environmental parameter (1972-2012). Groups with different superscript letters for a given parameter are significantly different using the 5% cutoff.

Group	Salinity (ppt)	Wind Direction
1	1.3 (1.7)^{A}	6 SW
2	7.7 (4.5)^{B}	2 NE
3	3.8 (2.4)^{C}	6 SW
4	0.1 (0.3)^{D}	6 SW

Table 1-7 Mean (± Standard Deviation) for trawl sample environmental parameters influencing the trawl station group fish assemblages and indicated ANOVA results between the groups for that environmental parameter (1972-2012). Groups with different superscript letters for a given parameter are significantly different using the 5% cutoff.

Group	Salinity (ppt)	Dissolved Oxygen (mg/L)	Water Temperature (°C)
1	2.5 (2.1)^{A}	7.8 (1.5)^{A}	25.6 (3.9)
2	1.1 (1.6)^{B}	7.3 (1.4)^{B}	25.6 (4.1)
3	0.2 (0.4)^{C}	7.0 (1.5)^{B}	25.7 (3.8)

Table 1-8 Mean (± Standard Deviation) for seine sample environmental parameters influencing the seine year group fish assemblages and indicated ANOVA results between the groups for that environmental parameter (1972-2012). Groups with different superscript letters for a given parameter are significantly different using the 5% cutoff. The dominant wind was southwest for all groups,

Group	Salinity (ppt)	Water Temperature (°C)
1	1.6 (2.2)^{A}	26.3 (3.9)
2	2.0 (2.9)$^{A, B}$	25.6 (4.5)
3	1.2 (2.5)$^{B, C}$	26.4 (4.0)
4	1.0 (2.7)$^{C, D}$	26.3 (4.6)

Table 1-9 Mean (± Standard Deviation) for trawl sample environmental parameters influencing the trawl year group fish assemblages and indicated ANOVA results between the groups for that environmental parameter (1972-2012). Groups with different superscript letters for a given parameter are significantly different using the 5% cutoff.

Group	Salinity (ppt)	Water Temperature (°C)	Depth
1	2.2 (2.0)^{A}	25.6 (3.9)$^{A, B, C}$	2.8 (0.7)$^{C, B}$
2	1.0 (1.7)^{C}	25.4 (4.1)$^{B, C}$	3.2 (1.3)^{A}
3	2.4 (2.4)^{A}	25.9 (3.6)$^{B, A}$	2.9 (0.7)^{B}
4	1.0 (1.0)^{B}	24.9 (3.6)^{C}	2.8 (0.7)^{B}

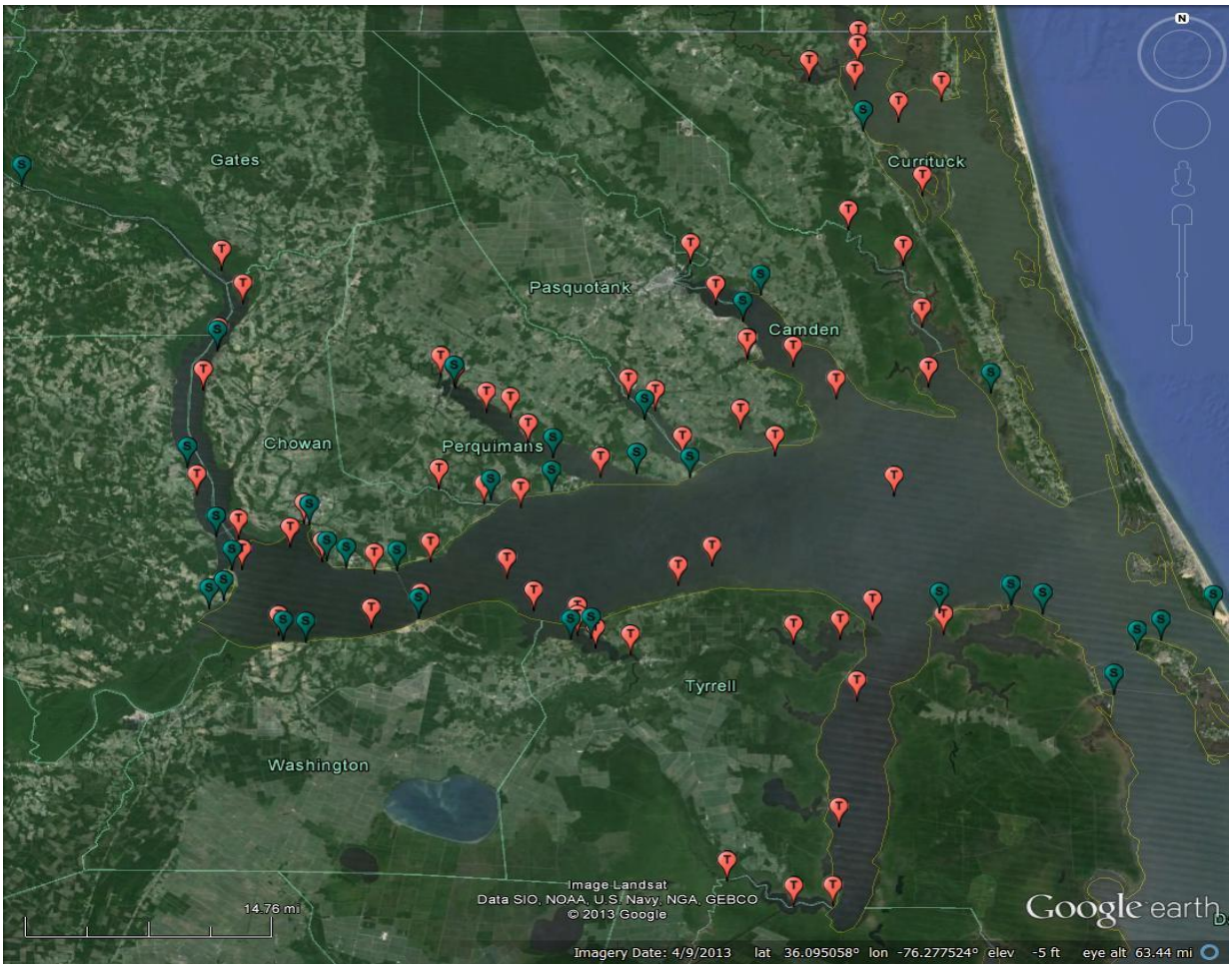

Figure 1-1 A map of Albemarle Sound, North Carolina and field site locations for Program 100 sampling conducted from 1972-2012. The open water trawl (red balloons labeled T) and shallow water seine (teal balloons labeled S) sampling sites (N=96) located throughout the sound.

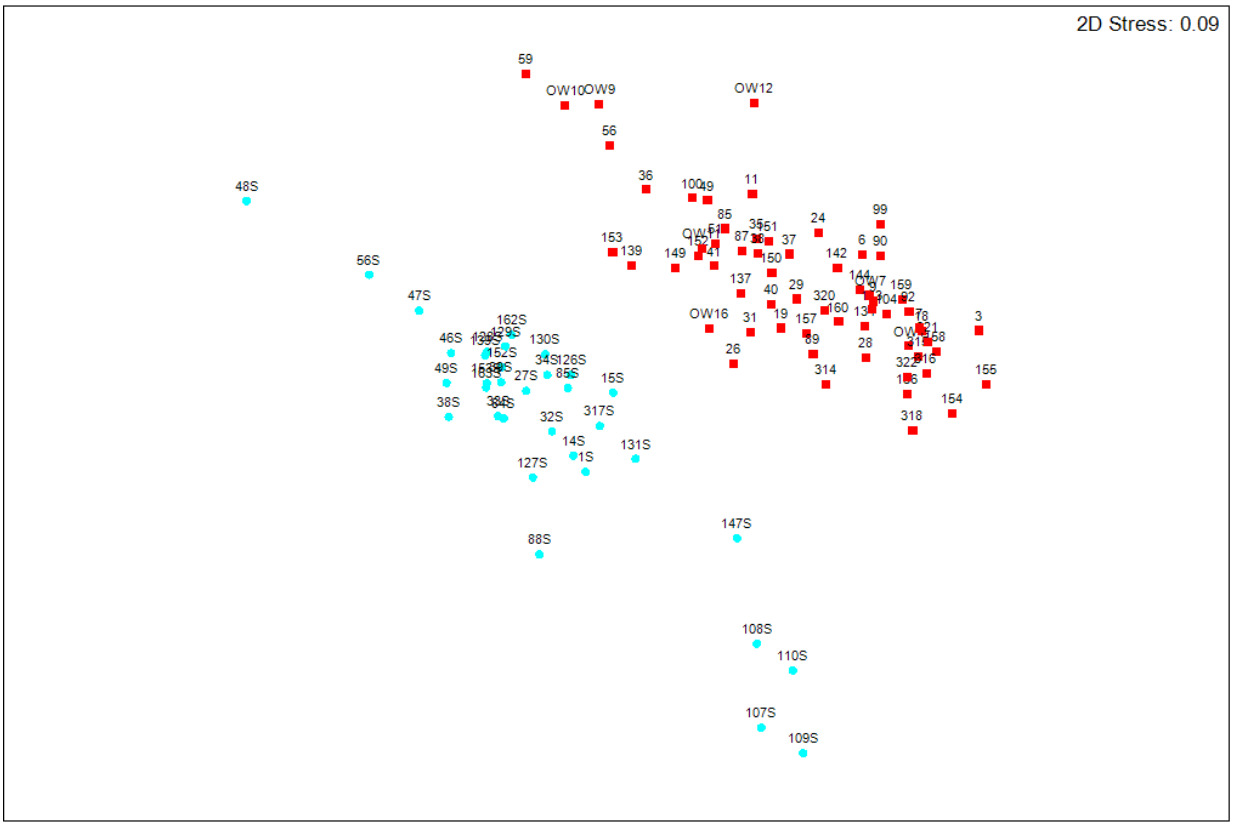

Figure 1-2 Two-dimension ordination using MDS showing each station in sampling (1972-2012) based on species assemblage caught at that station (N=96). Analysis is based on Bray-Curtis similarity matrix. Teal circles are seine sampling stations and red squares are trawl sampling stations.

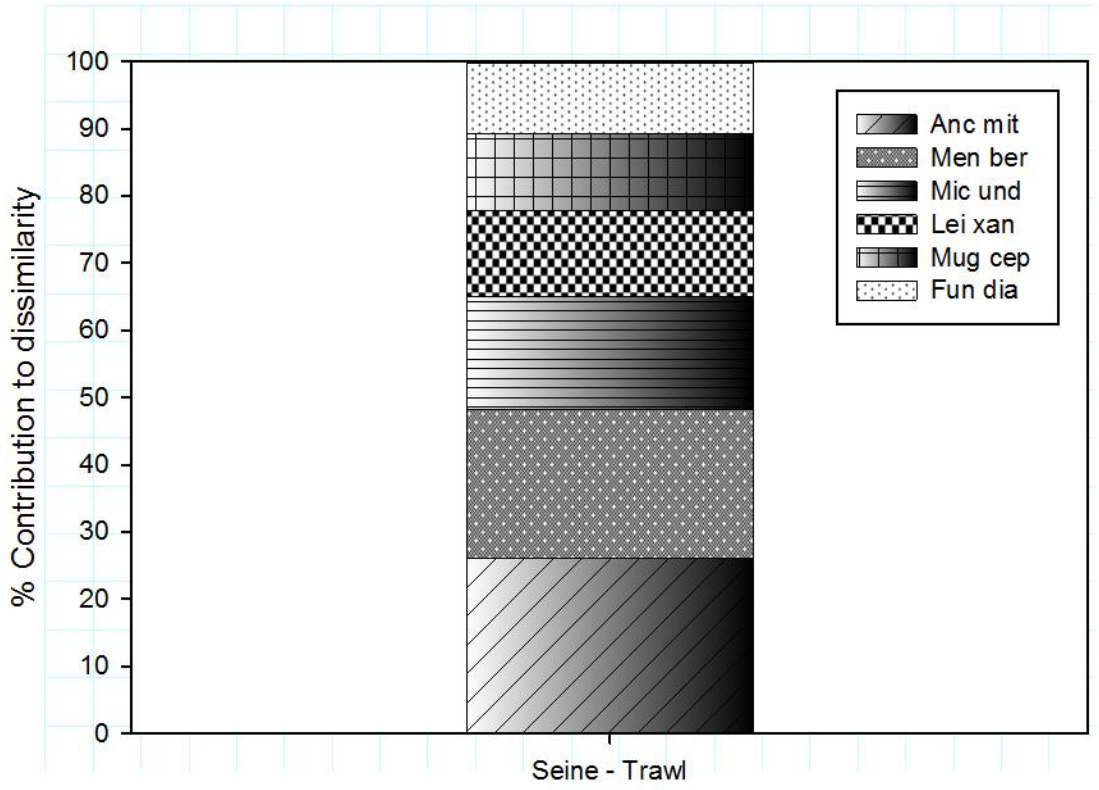

Figure 1-3 SIMPER results presenting the species contributions to the dissimilarity between the fishes sampled by the different gear types (seine or trawl) from 1972-2012. This figure was standardized by the total for all species contributing 5% or more to the dissimilarity. For species code translations please review tables 1-2 and 1-3.

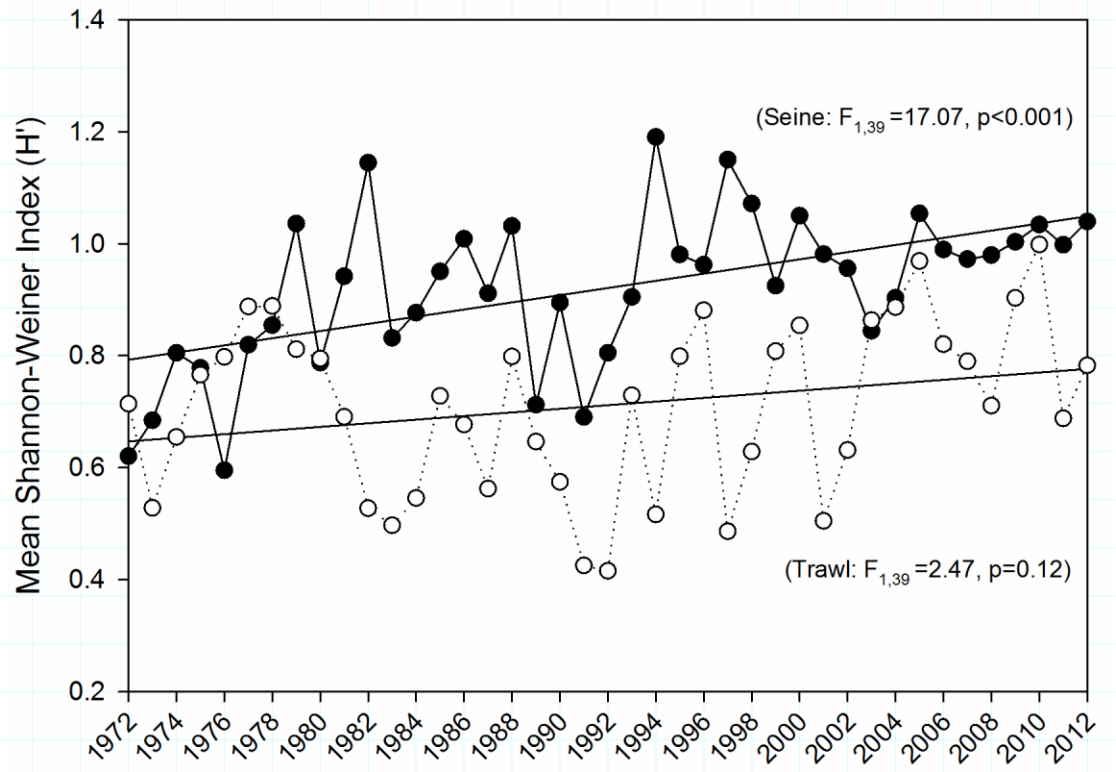

Figure 1-4 Mean Shannon-Weiner index (H') plotted by year for the seine samples (black circles) and trawl samples (white circles) with linear regression lines plotted for each curve.

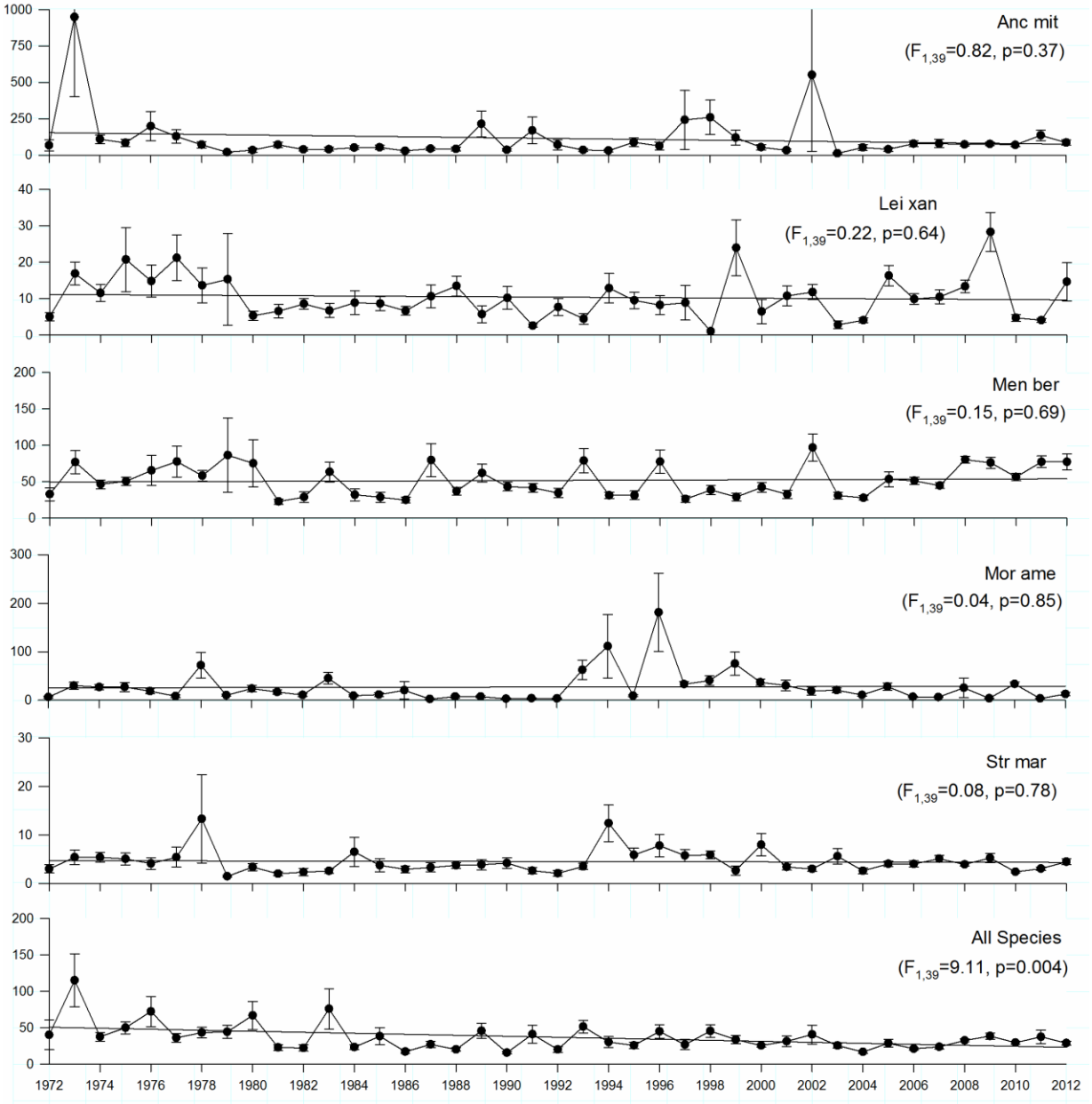

Figure 1-5 Seine top five most abundant species and all seine species annual mean abundance through time, error bars are standard error. For species codes, refer to table 1-2. Note the different scales along the Y-axis. F statistic and p value included under the species code for the linear regression analysis (black line).

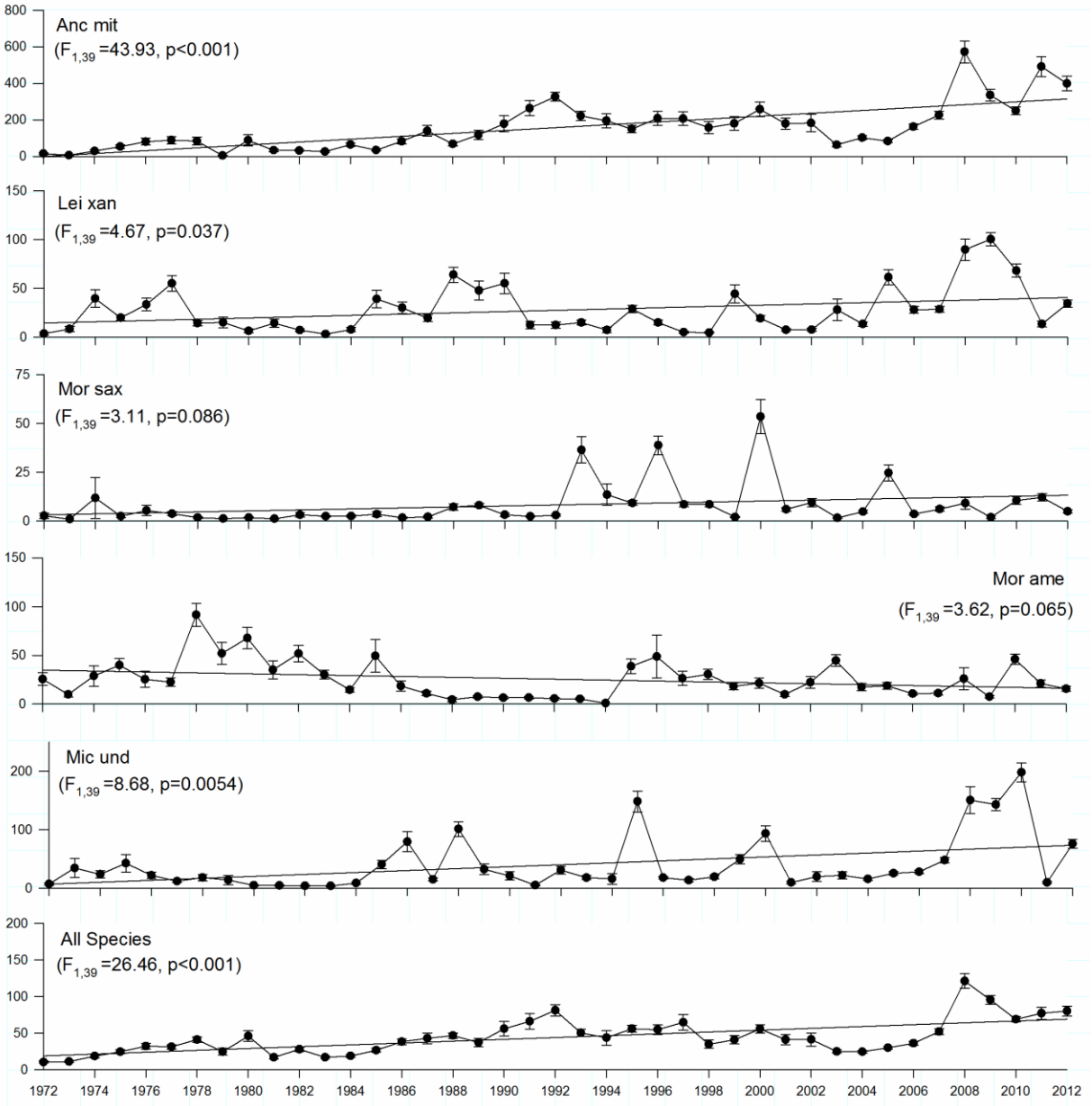

Figure 1-6 Trawl top five most abundant species and all seine species annual mean abundance through time, error bars are standard error. For species codes, refer to table 1-3. Note the different scales along the Y-axis. F statistic and p value included under the species code for the linear regression analysis (black line).

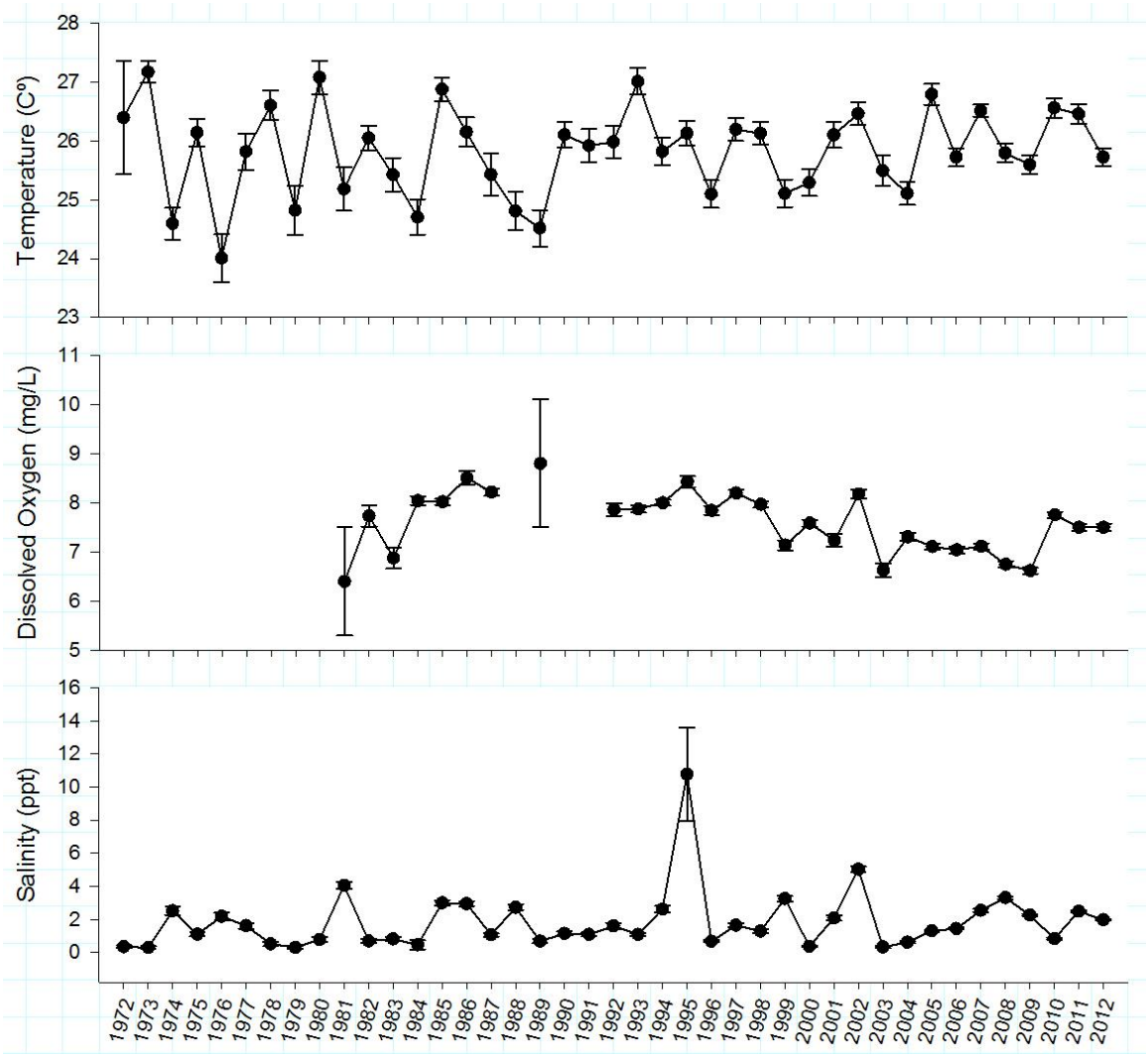

Figure 1-7 Annual averages for salinity, dissolved oxygen and water temperature for all stations from 1972 to 2012 in Albemarle Sound, North Carolina. Dissolved oxygen was only collected in 1981-1987, 1989, and 1991-2012. Error bars are standard error.

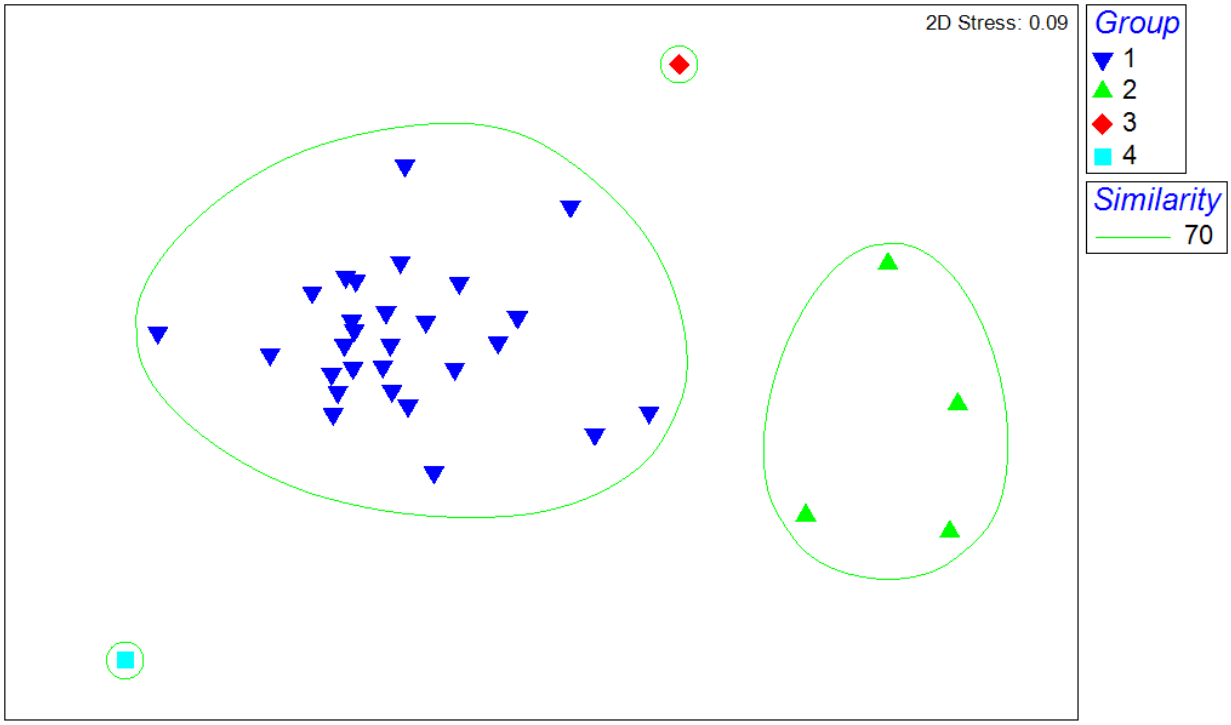

Figure 1-8 Two-dimension ordination using MDS presenting each seine station in sampling (N=34) based on species assemblage caught at that station from 1972-2012 in Albemarle Sound. Analysis is based on Bray-Curtis similarity matrix. Groups were superimposed on the ordination, being represented by the circles, from the CLUSTER analysis at the 70% similarity revealing four seine spatial groups.(group 1 upside-down triangles, group 2 upright triangles, group 3 diamonds, and group 4 squares)

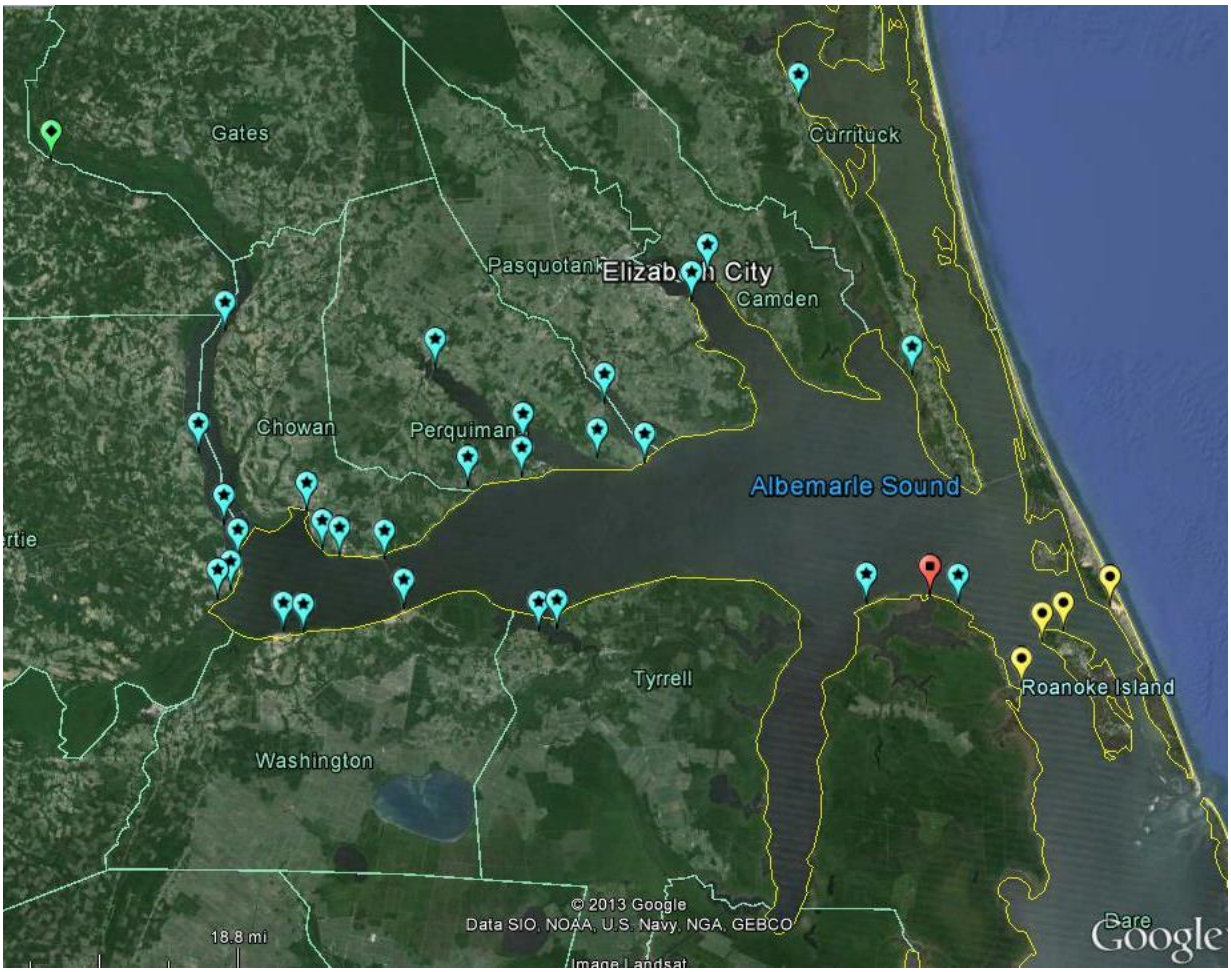

Figure 1-9 A map of Albemarle Sound North Carolina and field site locations for the seine stations (N=34) by spatial group. Station symbols indicate the seine spatial group identified from the CLUSTER analysis that station is in (group 1 stars, group 2 circles, group 3 squares, and group 4 diamonds)

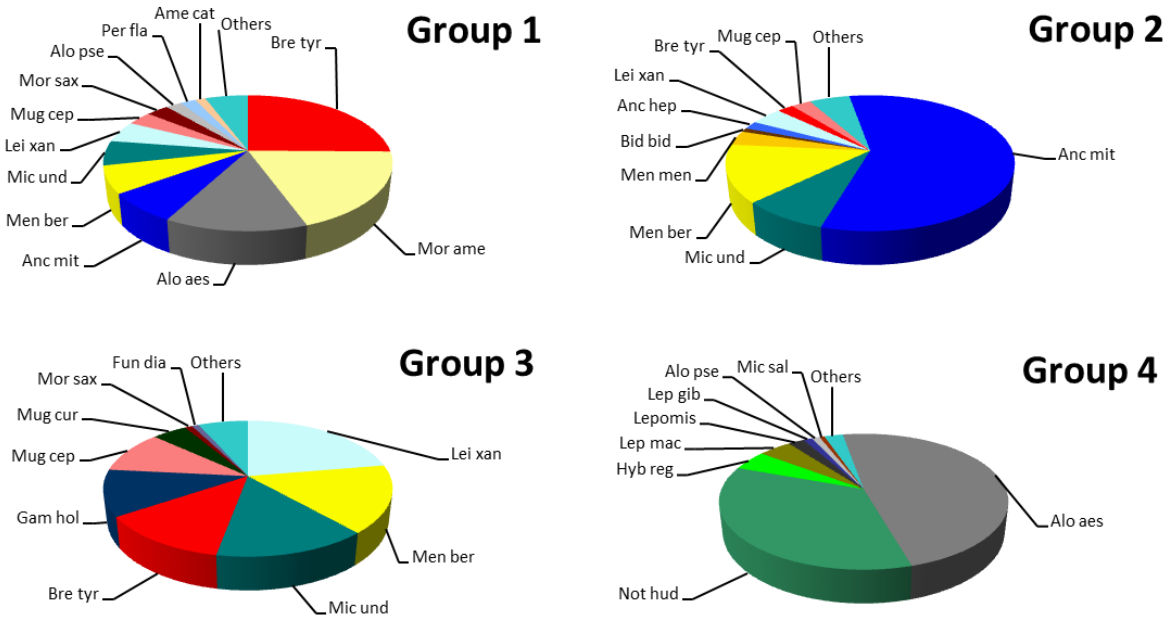

Figure 1-10 Species composition pie charts (% total abundance for the study 1972-2012) for each of the seine spatial groups identified from the CLUSTER analysis. For species code translations please review table 1-2.

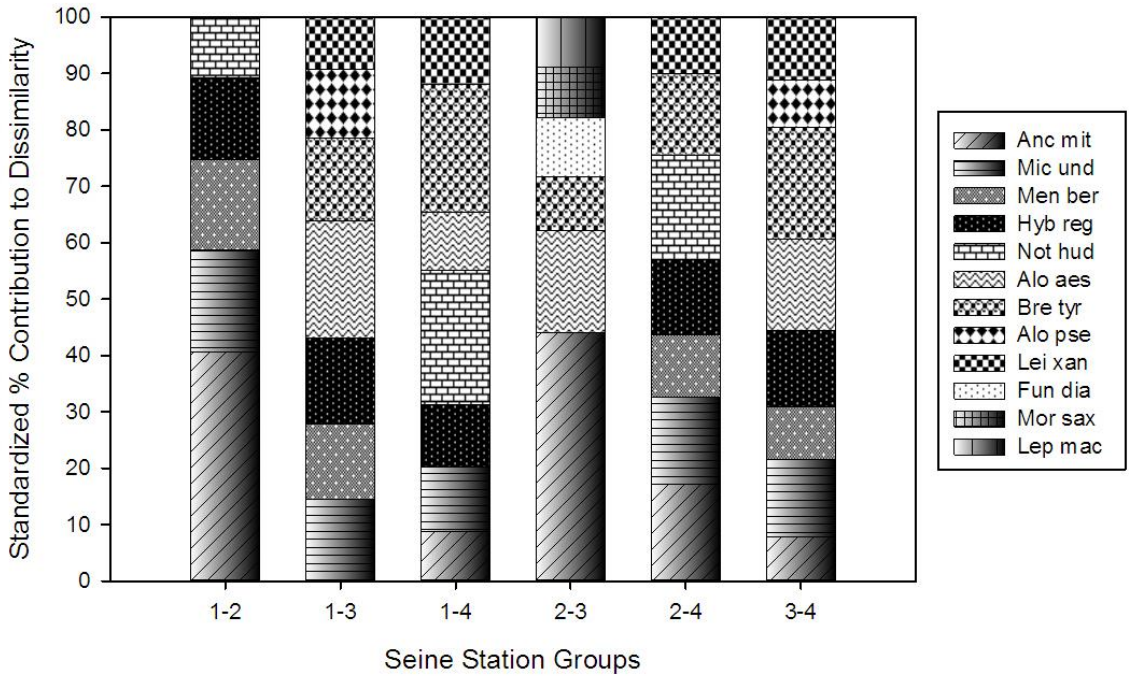

Figure 1-11 SIMPER results presenting percent contributions of fish species to dissimilarity between the different seine spatial groups during the study (1972-2012). This figure was standardized by the total for all species contributing 5% or more to the dissimilarity. For species code translations please review table 1-2.

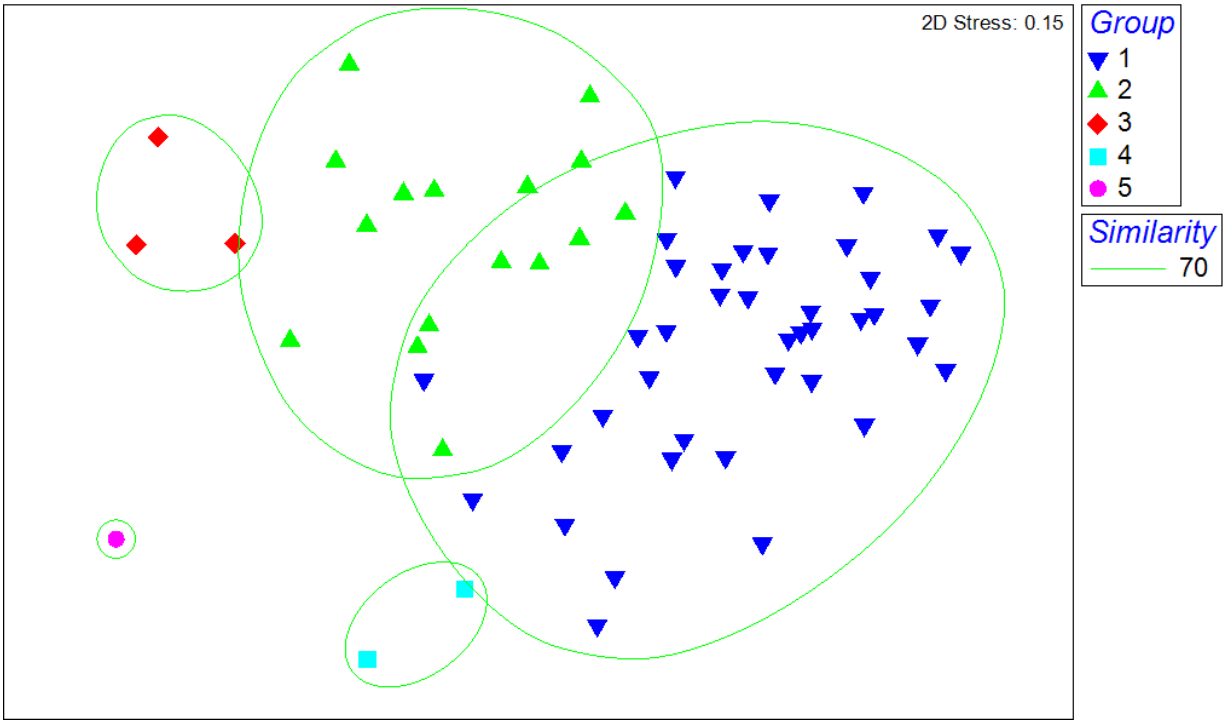

Figure 1-12 Two-dimension ordination using MDS presenting each trawl station in sampling (N=62) based on species assemblage caught at that station from 1972-2012 in Albemarle Sound. Analysis is based on Bray-Curtis similarity matrix. Groups were superimposed on the ordination, being represented by the circles, from the CLUSTER analysis at the 70% similarity revealing five trawl spatial groups.(group 1 upside-down triangles, group 2 upright triangles, group 3 diamonds, group 4 squares, and group 5 circles) and three major groups (those including a majority of the stations) groups 1-3.

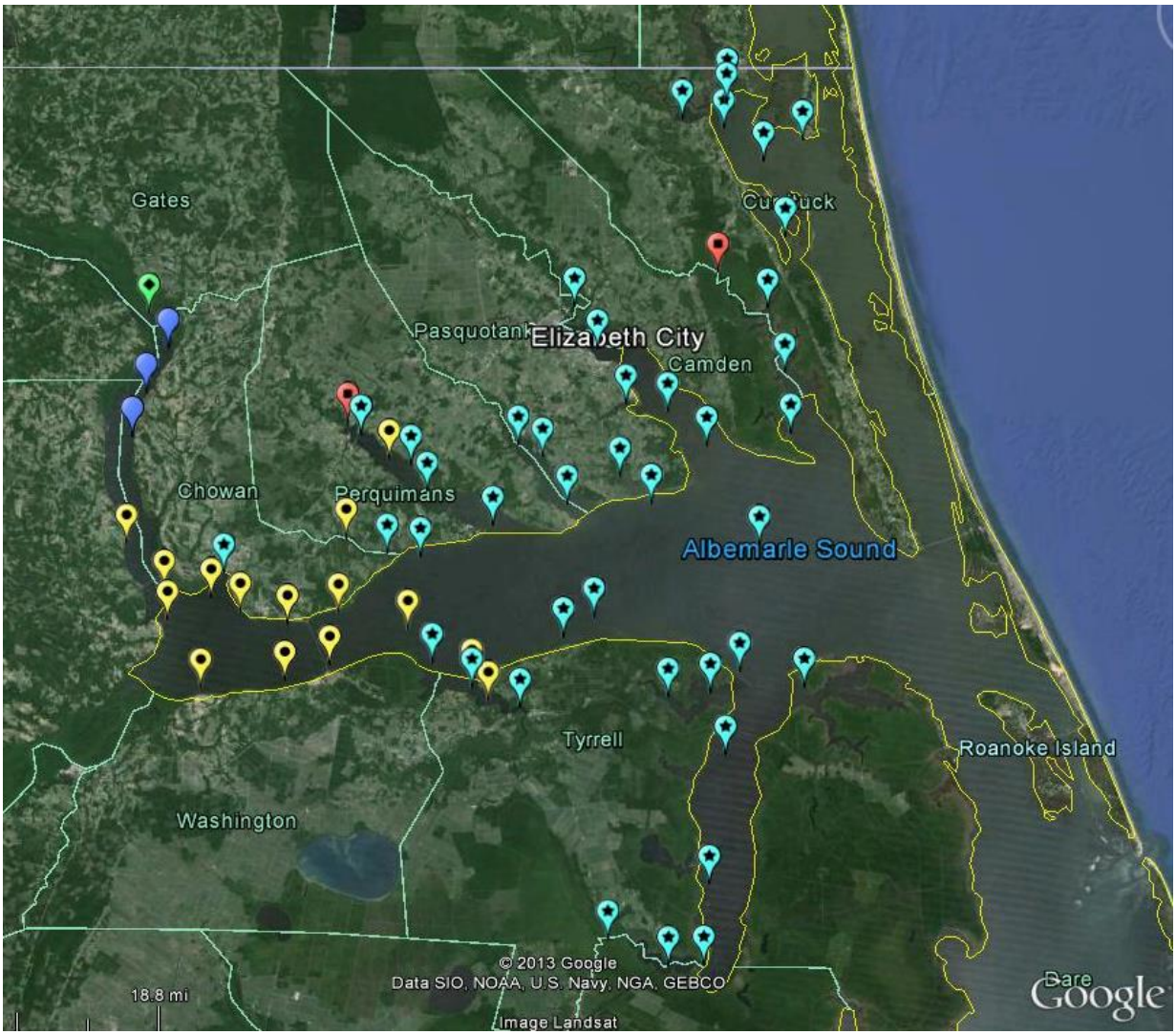

Figure 1-13 A map of Albemarle Sound North Carolina and field site locations for the trawl stations (N=62) by group. Station symbols indicate the trawl station group identified from the CLUSTER analysis that station is in (group 1 stars, group 2 circles, group 3 empty points, group 4 squares, and group 5 diamonds)

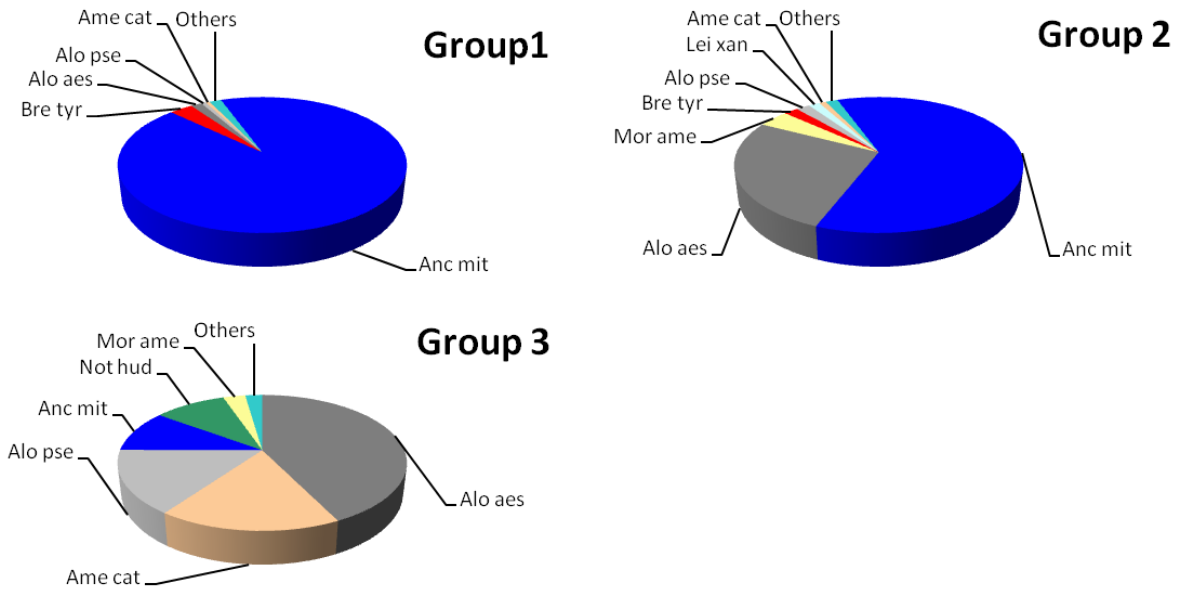

Figure 1-14 Species composition pie charts (% total abundance for the study 1972-2012) for the major trawl spatial groups identified from the CLUSTER analysis. For species code translations please review table 1-3.

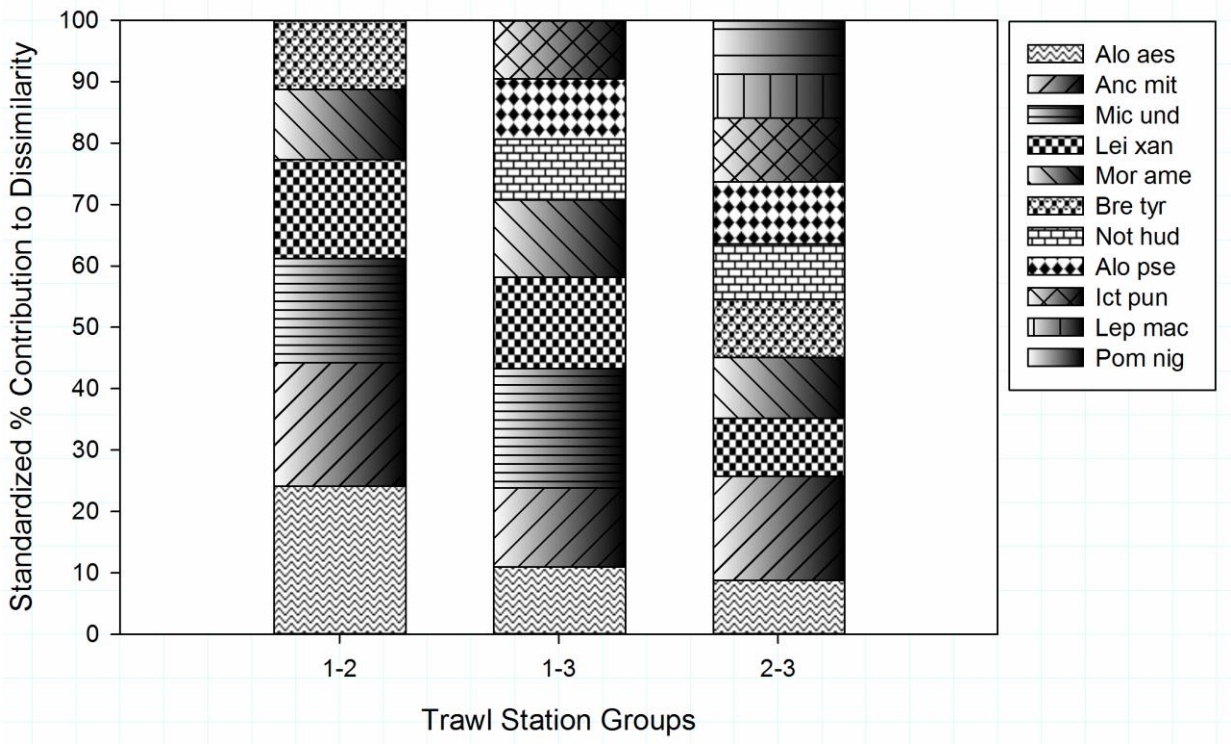

Figure 1-15 SIMPER results presenting percent contributions of fish species to dissimilarity between the major trawl spatial groups (Groups 1-3) during the study (1972-2012). This figure was standardized by the total for all species contributing 5% or more to the dissimilarity. For species code translations please review table 1-3.

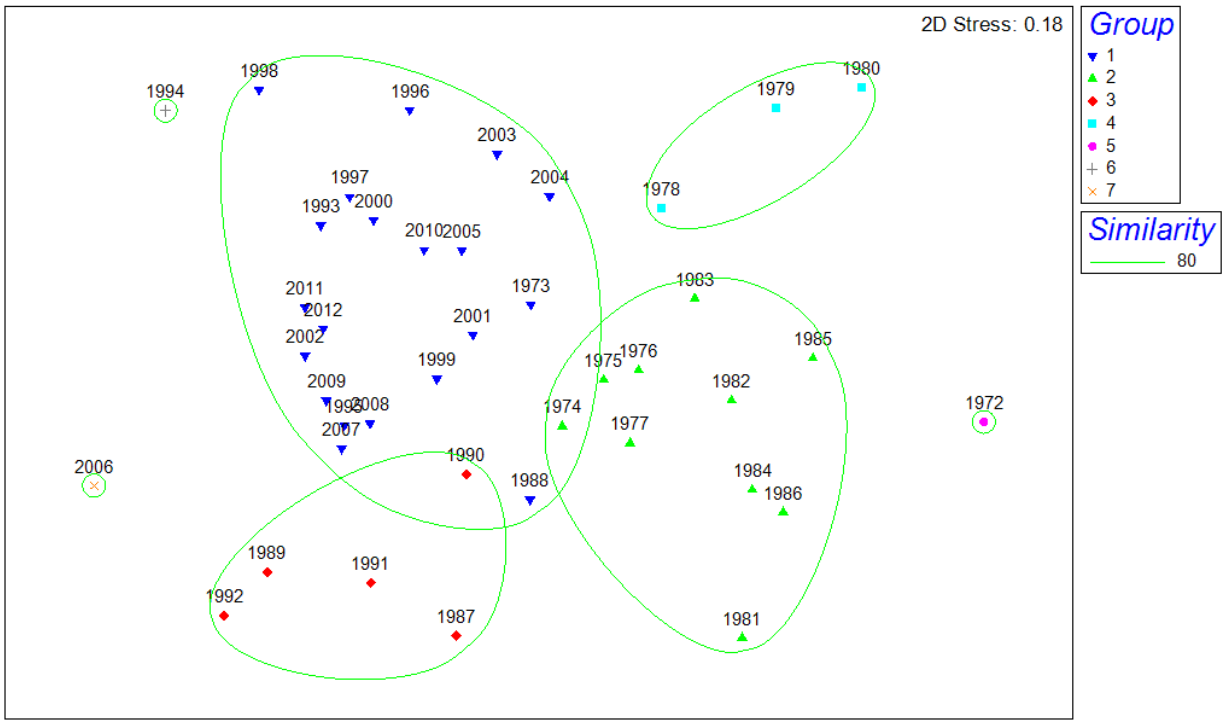

Figure 1-16Two-dimension ordination using MDS plotting each year in sampling based on species assemblages caught during that year for the seine samples. Analysis is based on Bray-Curtis similarity matrix. Groups were superimposed on the ordination, being represented by the circles, from the CLUSTER analysis at 80% similarity, identifying seven temporal year groups. (group 1 upside-down triangles, group 2 upright triangles, group 3 diamonds, group 4 squares, group 5 circles, group 6 crosses, and group 7 Xs) and four major groups (those including a majority of the years) groups 1-4.

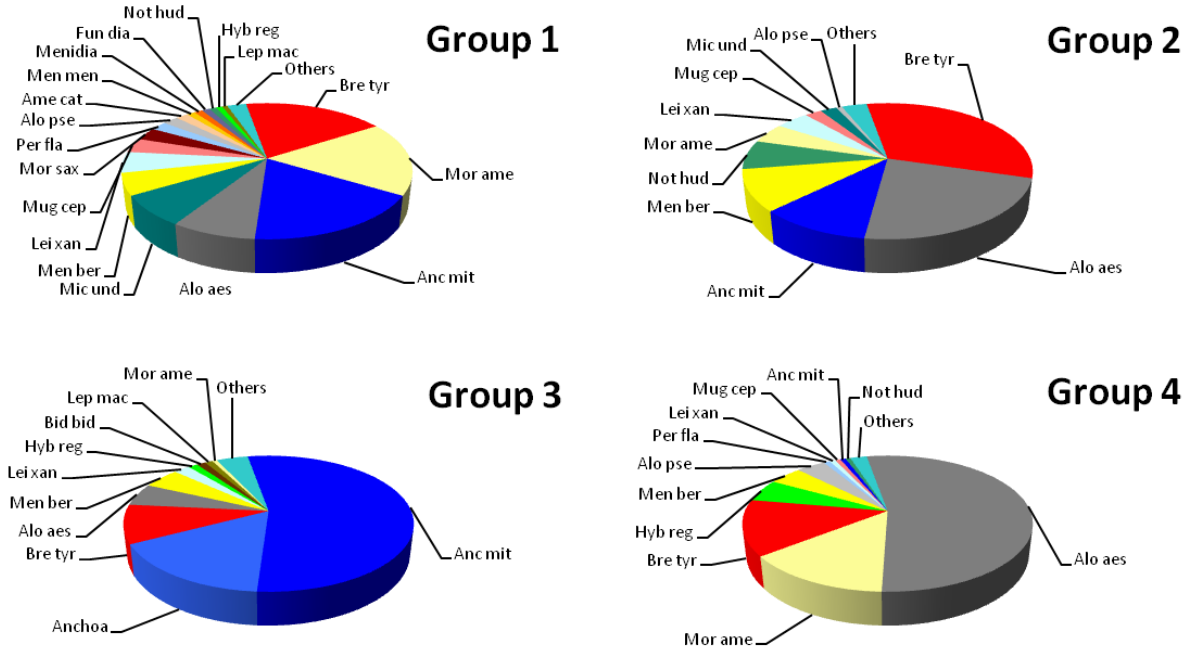

Figure 1-17 Species composition pie charts (% total abundance for the study 1972-2012) for the major seine temporal year groups identified from the CLUSTER analysis. For species code translations please review table 1-2.

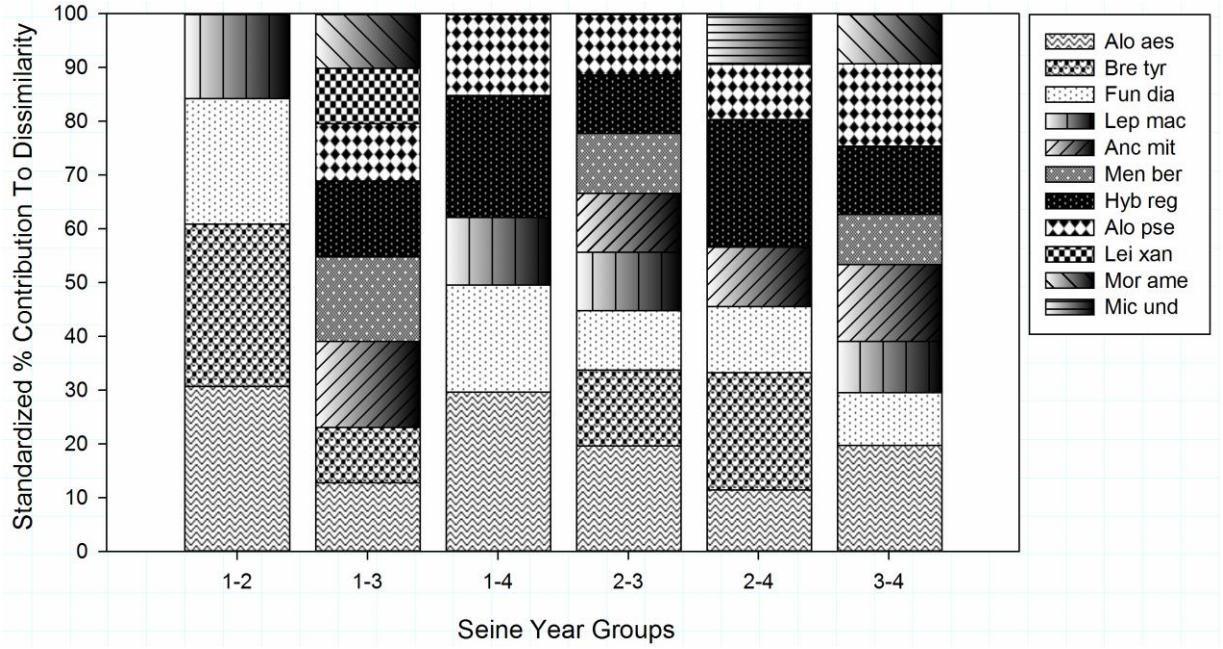

Figure 1-18 SIMPER results presenting percent contributions of fish species to dissimilarity between the major seine temporal year groups (Groups 1-4) during the study (1972-2012). This figure was standardized by the total for all species contributing 5% or more to the dissimilarity. For species code translations please review table 1-2.

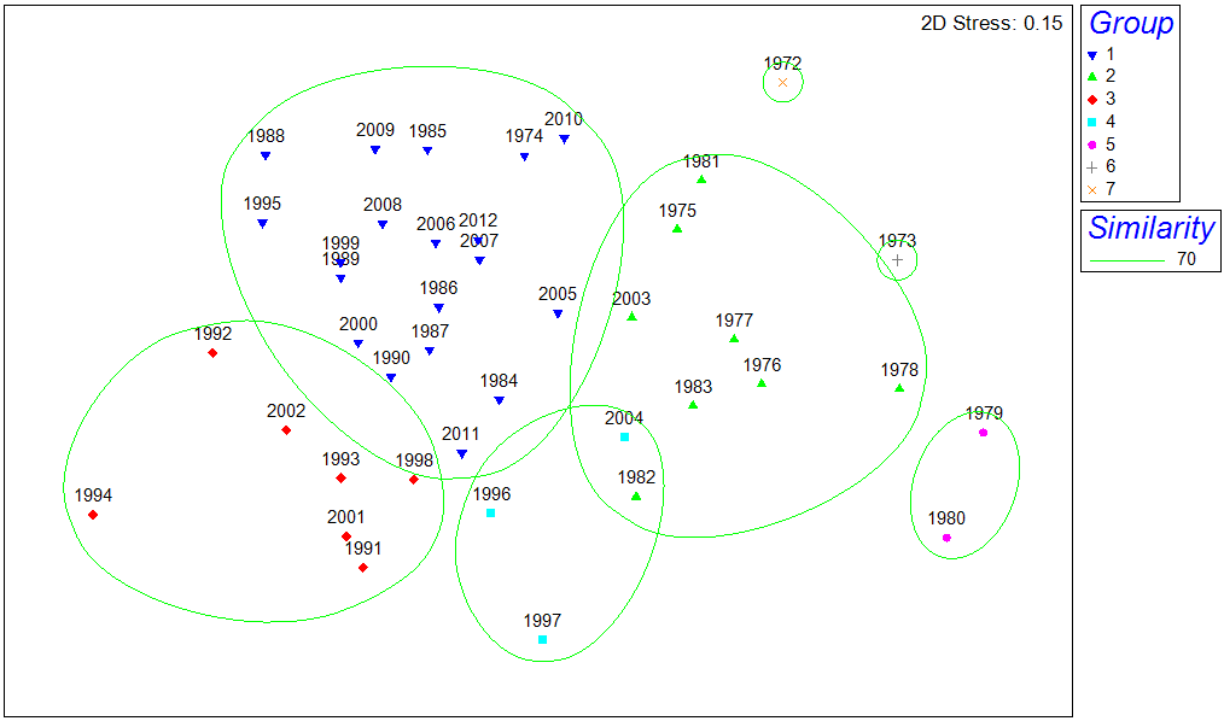

Figure 1-19 Two-dimension ordination using MDS plotting each year in sampling based on species assemblage caught during that year for the trawl samples. Analysis is based on Bray-Curtis similarity matrix. Groups were superimposed on the ordination, being represented by the circles, from the CLUSTER analysis at the 70% similarity, identifying seven temporal year groups. (group 1 upside-down triangles, group 2 upright triangles, group 3 diamonds, group 4 squares, group 5 circles, group 6 crosses, and group 7 Xs) and four major groups (those including a majority of the years) groups 1-4.

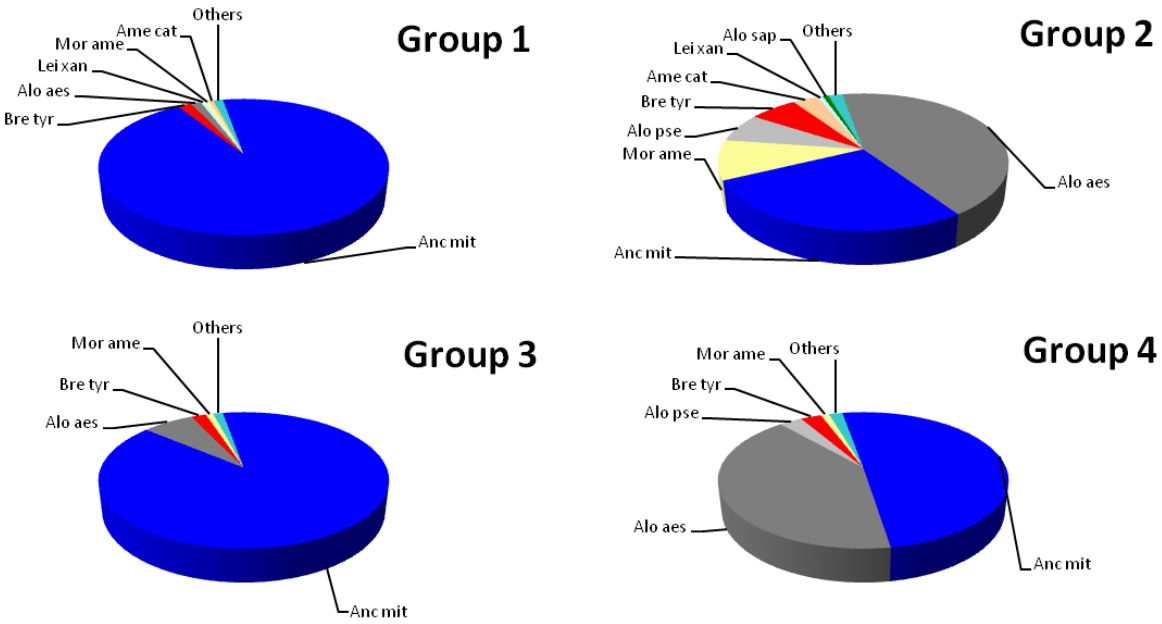

Figure 1-20 Species composition pie charts (% total abundance for the study 1972-2012) for the major trawl temporal year groups identified from the CLUSTER analysis. For species code translations please review table 1-3.

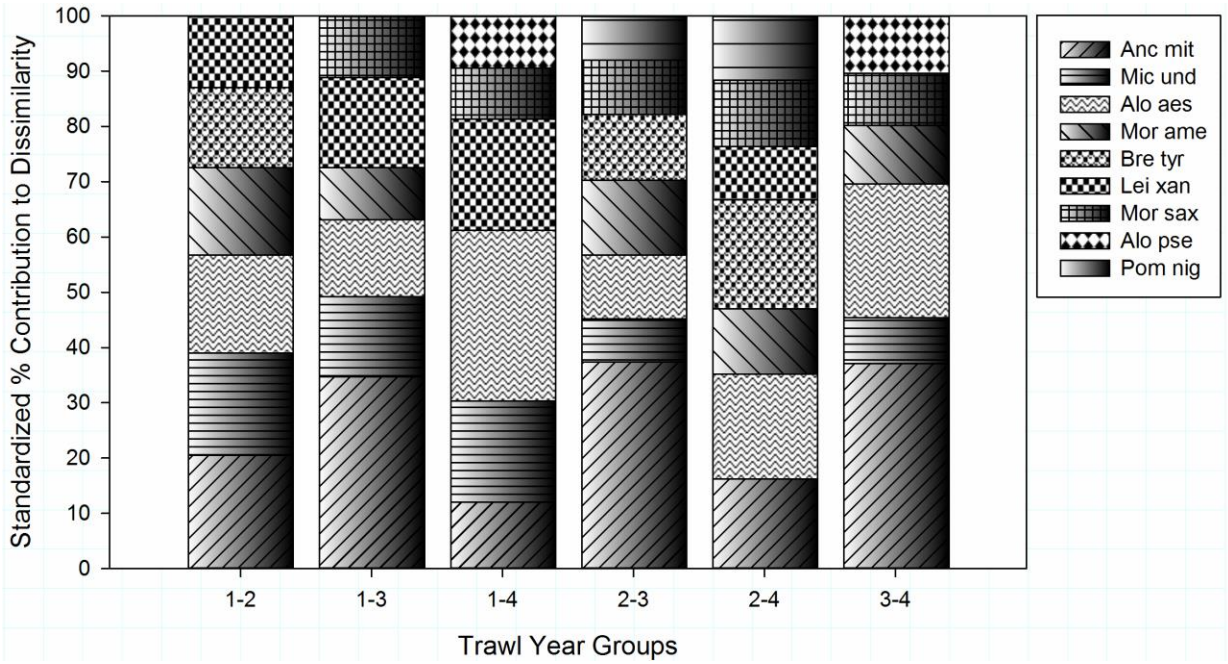

Figure 1-21 SIMPER results presenting percent contributions of fish species to dissimilarity between the major trawl temporal year groups (Groups 1-4) during the study (1972-2012). This figure was standardized by the total for all species contributing 5% or more to the dissimilarity. For species code translations please review table 1-

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Appendix I

Family	Genus	Scientific Name	Common Name	Percent Total Abundance	Percent Frequency of Occurrence	Habitat	Fishery
Achiridae	Trinectes	*Trinectes maculatus*	Hogchoker	0.39	16.09	M, F, E	N
Amiidae	Amia	*Amia calva*	Bowfin	<0.01	0.23	F	R
Antennariidae	Antennarius	*Antennarius ocellatus*	Frogfish, Ocellated	<0.01	0.01	M	N
Aphredoderidae	Aphredoderus	*Aphredoderus sayanus*	Perch, Pirate	0.02	0.60	F	N
Asipenseridae	Acipenser	*Acipenser oxyrhynchus*	Sturgeon, Atlantic	<0.01	0.07	M, F, E	N
Atherinopsidae	Membras	*Membras martinica*	Silverside, Rough	0.07	1.03	M	N
	Menidia	*Menidia beryllina*	Silverside, Inland	8.82	34.47	M, F, E	N
		Menidia menidia	Silverside, Atlantic	0.12	0.76	M, E	N
		Menidia spp.	Silversides, Menidia	0.03	0.22	M, F, E	N
Batrachoididae	Opsanus	*Opsanus tau*	Toadfish, Oyster	<0.01	0.01	M	N
Belonidae	Ablennes	*Ablennes hians*	Needlefish, Flat	<0.01	0.04	M, E	N
	Scomberesox	*Scomberesox saurus*	Saury, Atlantic	<0.01	0.02	M	N
	Strongylura	*Strongylura marina*	Needlefish, Atlantic	0.29	13.94	M, F, E	N
		Strongylura spp.	Needlefishes(Strongylura)	<0.01	0.09	M, F, E	N
	Tylosurus	*Tylosurus acus*	Needlefish, Agujon	0.01	0.01	M	N
		Tylosurus crocodilus	Needlefish, Houndfish	<0.01	0.03	M	N
		Belonidae	Needlefishes	<0.01	0.01	M, F, E	N
Blenniidae	Chasmodes	*Chasmodes bosquianus*	Blenny, Striped	<0.01	0.03	M, E	N
		Blenniidae	Blennies	<0.01	0.01	M, E	N
Carangidae	Caranx	*Caranx hippos*	Jack, Crevalle	0.01	1.01	M, E	R, C
		Caranx latus	Jack, Horse-eye	<0.01	0.01	M, F, E	R
		Caranx ruber	Bar Jack	<0.01	0.01	M	R
		Caranx spp.	Jacks (Caranx)	<0.01	0.01	M, F, E	R, C

	Chloroscombrus	*Chloroscombrus chrysurus*	Bumper, Atlantic	<0.01	0.01	M, E	N
	Diapterus	*Diapterus auratus*	Pompano, Irish	<0.01	0.01	M, E	N
	Oligoplites	*Oligoplites saurus*	Leatherjack	<0.01	0.09	M, E	N
	Selene	*Selene vomer*	Lookdown	<0.01	0.02	M, E	N
	Trachinotus	*Trachinotus carolinus*	Pompano, Florida	<0.01	0.08	M, E	R, C
		Trachinotus falcatus	Permit	<0.01	0.13	M, E	R
		Carangidae	Jacks	<0.01	0.04	M, F, E	R, C
Catostomidae	Moxostoma	Moxostoma	Suckers (Moxostoma)	0.01	0.71	F	N
		Moxostoma anisurum	Redhorse, Silver	<0.01	0.01	F	N
		Moxostoma macrolepidotum	Redhorse, Shorthead	<0.01	0.25	F	N
		Catostomidae	Suckers	<0.01	0.02	F	N
Centrachidae	Centrarchus	*Centrarchus macropterus*	Flier	<0.01	0.09	F	R
	Enneacanthus	*Enneacanthus gloriosus*	Sunfish, Bluespotted	<0.01	0.20	F	R
	Lepomis	*Lepomis auritus*	Sunfish, Redbreast	0.02	1.23	F	R
		Lepomis cyanellus	Sunfish, Green	<0.01	0.04	F	R
		Lepomis gibbosus	Sunfish, Pumpkinseed	0.15	7.43	F	R
		Lepomis gulosus	Sunfish, Warmouth	<0.01	0.26	F	R
		Lepomis macrochirus	Bluegill	0.46	7.93	F	R
		Lepomis microlophus	Sunfish, Redear	0.02	1.02	F	R
		Lepomis spp.	Sunfishes (Lepomis)	0.17	2.32	F	R
	Micropterus	*Micropterus salmoides*	Bass, Largemouth	0.09	6.05	F	R
	Pomoxis	*Pomoxis annularis*	Crappie, White	<0.01	0.04	F	R
		Pomoxis nigromaculatus	Crappie, Black	0.25	4.61	F	R
		Pomoxis spp.	Crappies	0.01	0.30	F	R
		Centrarchidae	Sunfishes	<0.01	0.08	F	R
Clupeidae	Alosa	*Alosa aestivalis*	Herring, Blueback	6.26	15.60	M, F, E	C
		Alosa mediocris	Shad, Hickory	0.02	2.04	M, F, E	R, C
		Alosa pseudoharengus	Alewife	0.88	13.58	M, F, E	C
		Alosa sapidissima	Shad, American	0.10	4.02	M, F, E	R, C
		Alosa spp.	Herrings, River	<0.01	0.03	M, F, E	C
	Brevoortia	*Brevoortia tyrannus*	Menhaden, Atlantic	5.88	15.93	M, E	C
	Dorosoma	*Dorosoma cepedianum*	Shad, Gizzard	0.17	4.99	M, F, E	C
		Dorosoma petenense	Shad, Threadfin	0.04	1.23	M, F, E	N
	Etrumeus	*Etrumeus teres*	Herring, Round	<0.01	0.01	M	N
	Opisthonema	*Opisthonema oglinum*	Herring, Atlantic Thread	0.01	0.55	M	N
Coryphaenidae	Coryphaena	*Coryphaena hippurus*	Dolphin	<0.01	0.01	M, E	R, C

Cynoglossidae	Symphurus	*Symphurus plagiusa*	Tonguefish, Blackcheek	<0.01	0.05	M, E	N
Cyprinidae	Ctenopharyngodon	*Ctenopharyngodon idella*	Carp, Grass	<0.01	0.04	F	R, C
	Cyprinella	*Cyprinella analostana*	Shiner, Satinfin	0.03	0.44	F	N
	Cyprinus	*Cyprinus carpio*	Carp, Common	0.01	0.92	F, E	R, C
	Erimyzon	*Erimyzon oblongus*	Chubsucker, Creek	<0.01	0.04	F	N
	Hybognathus	*Hybognathus regius*	Minnow, Eastern Silvery	2.00	6.97	F	N
	Notemigonius	*Notemigonius crysoleucas*	Shiner, Golden	0.15	3.51	F	N
	Notropis	*Notropis cummingsae*	Shiner, Dusky	<0.01	0.02	F	N
		Notropis hudsonius	Shiner, Spottail	1.84	16.00	F	N
		Notropis petersoni	Shiner, Coastal	<0.01	0.01	F	N
		Notropis procne	Shiner, Swallowtail	0.10	0.64	F	N
		Notropis spp.	Shiners (Notropis)	0.01	0.24	F	N
		Cyprinidae	Minnows	<0.01	0.03	F	N
Cyprinodontidae	Cyprinodon	*Cyprinodon variegatus*	Minnow, Sheepshead	<0.01	0.01	M, F, E	N
		Cyprinodontidae	Killifishes	<0.01	0.01	M, F, E	N
Elopidae	Elops	*Elops saurus*	Ladyfish	0.02	1.49	M, E	N
Engraulidae	Anchoa	*Anchoa hepsetus*	Anchovy, Striped	0.15	2.19	M, E	N
		Anchoa mitchilli	Anchovy, Bay	42.12	51.01	M, F, E	N
		Anchoa spp.	Anchovies	<0.01	0.08	M, F, E	N
	Engraulis	*Engraulis eurystole*	Anchovy, Silver	<0.01	0.01	M	N
Ephippidae	Chaetodipterus	*Chaetodipterus faber*	Spadefish, Atlantic	<0.01	0.05	M, E	R, C
Esocidae	Esox	*Esox niger*	Pickerel, Chain	<0.01	0.36	F	R
Fundulidae	Fundulus	*Fundulus diaphanus*	Killifish, Banded	1.76	12.10	F, E	N
		Fundulus heteroclitus	Killifish, Mummichog	<0.01	0.01	M, F, E	N
		Fundulus lineolatus	Killifish, Lined Topminow	<0.01	0.01	F	N
		Fundulus majalis	Killifish, Striped	0.01	0.12	M, E	N
		Fundulus spp.	Killifishes, Fundulus	0.01	0.07	M, F, E	N
	Lucania	*Lucania parva*	Killifish, Rainwater	<0.01	0.04	M, F, E	N
Gasterosteidae	Apeltes	*Apeltes quadracus*	Stickleback, Fourspine	<0.01	0.02	M, F, E	N

Gerreidae	Eucinostomus	*Eucinostomus argenteus*	Mojarra, Spotfin	0.01	0.47	M, F, E	N
		Eucinostomus gula	Silver Jenny	0.02	0.91	M, F, E	N
		Eucinostomus spp.	Mojarras (Eucinostomus)	<0.01	0.12	M, F, E	N
		Gerreidae	Mojarras	0.01	0.22	M, F, E	N
Gobiesocidae	Gobiesox	*Gobiesox strumosus*	Skilletfish	<0.01	0.06	M, E	N
Gobiidae	Gobionellus	Gobionellus spp.	Gobies (Gobionellus)	<0.01	0.01	M	N
	Gobiosoma	*Gobiosoma bosc*	Goby, Naked	0.04	1.74	M, E	N
	Microgobius	*Microgobius thalassinus*	Goby, Green	0.01	0.23	M	N
		Gobiidae	Gobies	<0.01	0.04	M	N
Hemiramphidae	Hyporhamphus	*Hyporhamphus unifasciatus*	Halfbeak, silverstripe	<0.01	0.04	M, E	N
Ictaluruidae	Ameiurus	*Ameiurus brunneus*	Catfish, Bullhead,Snail	<0.01	0.01	F	R, C
		Ameiurus catus	Catfish, White	0.71	15.34	F	R, C
		Ameiurus melas	Catfish, Bullhead,Black	<0.01	0.04	F	R, C
		Ameiurus natalis	Catfish, Bullhead,Yellow	0.01	0.69	F	R, C
		Ameiurus nebulosus	Catfish, Bullhead,Brown	0.11	4.38	F, E	R, C
	Ictalurus	*Ictalurus furcatus*	Catfish, Blue	0.03	1.25	F, E	R, C
		Ictalurus punctatus	Catfish, Channel	0.08	4.23	F	R, C
		Ictalurus spp.	Catfishes (Ictalurus)	0.01	0.11	F, E	R, C
	Noturus	*Noturus gyrinus*	Catfish, Tadpole Madtom	<0.01	0.13	F	R, C
		Noturus spp.	Catfish, Madtoms	<0.01	0.35	F	R, C
		Ictaluridae	Catfishes	<0.01	0.05	F	R, C
Labridae	Lachnolaimus	*Lachnolaimus maximus*	Hogfish	<0.01	0.01	M	R, C
	Orthopristis	*Orthopristis chrysoptera*	Pigfish	<0.01	0.36	M, E	R, C
Lepisosteidae	Lepisosteus	*Lepisosteus osseus*	Gar, Longnose	0.01	0.89	F, E	N
Lutjanidae	Lutjanus	*Lutjanus griseus*	Snapper, Gray	<0.01	0.20	M, F, E	C
		Lutjanus spp.	Snappers (Lutjanus)	<0.01	0.01	M, F, E	C
	Rhomboplites	*Rhomboplites aurorubens*	Snapper, Vermilion	<0.01	0.01	M	R, C
Malacanthidae	Lopholatilus	*Lopholatilus chamaeleonticeps*	Tilefish	<0.01	0.01	M	R, C
Monacanthidae	Aluterus	*Aluterus schoepfi*	Filefish, Orange	<0.01	<0.01	M	N

Moronidae	Morone	*Morone americana*	Perch, White	6.05	47.99	M, F, E	R, C
		Morone saxatilis	Bass, Striped	1.54	27.01	M, F, E	R, C
Mugilidae	Mugil	*Mugil cephalus*	Mullet, Striped	0.67	11.40	M, F, E	R, C
		Mugil curema	Mullet, White	0.08	1.27	M, F, E	R, C
		Mugil spp.	Mullets	0.01	0.05	M, F, E	R, C
Paralichthyidae	Paralichthys	*Paralichthys dentatus*	Flounder, Summer	0.01	1.27	M	R, C
		Paralichthys lethostigma	Flounder, Southern	0.03	4.08	M, E	R, C
		Paralichthys spp.	Flounders, Paralichthid	<0.01	0.01	M, E	R, C
Percidae	Perca	*Perca flavescens*	Perch, Yellow	0.49	13.75	F, E	R, C
Peridae	Etheostoma	*Etheostoma fusiforme*	Darter, Swamp	<0.01	0.02	F	N
		Etheostoma olmstedi	Darter, Tesselated	0.08	3.54	F	N
		Etheostoma serrifer	Darter, Sawcheek	<0.01	0.01	F	N
		Etheostoma spp.	Darters (Etheostoma)	<0.01	0.04	F	N
Pinguipedidae	Diplectrum	*Diplectrum formosum*	Perch, Sand	<0.01	0.02	M	R
Poeciliidae	Gambusia	*Gambusia holbrooki*	Mosquitofish, Eastern	0.09	0.69	F, E	N
Polyprionidae	Polyprion	*Polyprion americanus*	Wreckfish	<0.01	0.01		
Pomatomidae	Pomatomus	*Pomatomus saltatrix*	Bluefish	0.01	0.92	M, E	R, C
Sciaenidae	Cynoscion	*Cynoscion nebulosus*	Seatrout, Spotted	0.01	1.92	M, E	R, C
		Cynoscion nothus	Seatrout, Silver	<0.01	0.01	M, E	N
		Cynoscion regalis	Seatrout, Weakfish	0.08	3.91	M, E	R, C
	Equetes	*Equetes iwamotoi*	Drum, Blackbar	<0.01	0.01	M	N
	Leiostomus	*Leiostomus xanthurus*	Spot	6.53	45.43	M, E	R, C
	Menticirrhus	*Menticirrhus americanus*	Kingfish, Southern	<0.01	0.25	M, E	R
		Menticirrhus saxatilis	Kingfish, Northern	<0.01	0.04	M, E	R
		Menticirrhus spp.	Kingfishes	<0.01	0.03	M, E	R
	Micropogonias	*Micropogonias undulatus*	Croaker, Atlantic	10.16	39.99	M, E	R, C
	Pogonias	*Pogonias cromis*	Drum, Black	<0.01	0.14	M, E	R, C
	Sciaenops	*Sciaenops ocellatus*	Drum, Red	0.03	1.06	M, E	R, C
	Stellifer	*Stellifer lanceolatus*	Drum, Star	<0.01	0.01	M, E	N
		Sciaenidae	Drums	<0.01	0.01	M, E	R, C

Scombridae	Scomberomorus	*Scomberomorus cavalla*	Mackerel, King	<0.01	0.01	M	R, C
		Scomberomorus maculatus	Mackerel, Spanish	<0.01	0.18	M	R, C
Serranidae	Centropristis	*Centropristis striata*	Sea Bass, Black	<0.01	0.04	M	R, C
	Epinephelus	Epinephelus spp.	Groupers (Epinephelus)	<0.01	0.01	M	R, C
	Schultzea	*Schultzea beta*	Bass, School	<0.01	0.01	M	
Sparidae	Archosargus	*Archosargus probatocephalus*	Sheepshead	<0.01	0.20	M, E	R, C
	Lagodon	*Lagodon rhomboides*	Pinfish	0.03	1.88	M, F, E	R, C
Sphyranidae	Sphyraena	*Sphyraena barracuda*	Barracuda, Great	<0.01	0.01	M, E	R
Stromateidae	Peprilus	*Peprilus alepidotus*	Harvestfish	<0.01	0.08	M, E	N
		Peprilus triacanthus	Butterfish	<0.01	0.01	M, E	C
Syngnathidae	Syngnathus	*Syngnathus floridae*	Pipefish, Dusky	<0.01	0.03	M	N
		Syngnathus fuscus	Pipefish, Northern	0.01	0.11	M, F, E	N
		Syngnathus louisianae	Pipefish, Chain	<0.01	0.12	M	N
		Syngnathus spp.	Pipefishes (Sygnathus)	0.03	2.70	M, F, E	N
Synodontidae	Synodus	*Synodus foetens*	Lizardfish, Inshore	<0.01	0.13	M, E	N
Terapontidae	Bairdiella	*Bairdiella chrysoura*	Perch, Silver	0.47	11.82	M, F, E	R
Trachinoidei	Astroscopus	Astroscopus spp.	Stargazers (Astroscopus)	<0.01	0.01	M	N
Trichiuridae	Trichiurus	*Trichiurus lepturus*	Cutlassfish, Atlantic	<0.01	0.01	M, E	C
Triglidae	Prionotus	*Prionotus tribulus*	Searobin, Bighead	<0.01	0.01	M	N
		Triglidae	Searobins	<0.01	0.01	M	N
Umbridae	Umbra	*Umbra pygmaea*	Mudminnow, Eastern	<0.01	0.01	F	N
Zeidae	Zenopsis	*Zenopsis ocellata*	John Dory, American	<0.01	0.01	M	N
		Acanthopt. Perciformes percoidei	Fishes, Unid. (Percoidei)	<0.01	0.01		
		Osteicthyes teleostei	Fishes, Unidentified	<0.01	0.05		

	Pleuronectiformes	Flounders	<0.01	0.01