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**Analyzing Spatial and Temporal Trends in the
Community Structure of the Peconic Bay Estuary**

A Thesis Presented

by

Tyler Rose Abruzzo

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Abstract of the Thesis

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Understanding the temporal and spatial trends in community structure of a bay is critical to elucidating drivers of ecosystem change and developing management policies. In order to analyze the spatial and temporal trends in the fish and mobile invertebrate assemblage of Peconic Bay, New York, we utilized data from the NYDEC bottom trawl survey. Beginning in 1987, the survey has been conducted monthly from May through October and averaged 381 stations annually. Twenty two taxa were analyzed using multivariate semivariance on Hellinger transformed abundance data. Temporal trends in community structure revealed strong seasonal patterns typical of a temperate estuarine system. However, a long-term pattern was observed where assemblage became gradually more dissimilar as the time interval between surveys was increased. Using multivariate regression tress and redundancy analysis, an abrupt shift in the dominant species abundances was observed in the year 2000 and was linked to long-term

climatic indices, especially the Atlantic Multi-Decadal Oscillation. The latter was in a cold period since 1968, but switched to a warm period in 1995. This dramatic shift in abundances might have been caused by warming temperatures in the bay through either bottom-up (e.g., a change in plankton biomass) or top-down controls, such as predation.

Since recruitment can play a large role in the status of a species population, four species of young-of-the-year fish were studied to identify spatial utilization within the bay, as well as any habitat preferences. GIS mapping was used to visualize patterns of abundance throughout the bay from 2006 to 2012, while generalized additive models were used to detect habitat preferences. Clear spatial patterns and habitat preferences were observed in northern puffer, scup, weakfish, and winter flounder young-of-the-year. The Shannon index of diversity and species richness was also calculated for each tow to discern areas of the Bay that species might disproportionately utilize as habitat. Certain areas within the Peconic Bay were observed to contain greater species diversity, and these areas should be considered in future management and restoration decisions by environmental groups and fishery managers.

Dedication Page

To my Mom and Dad

Who first introduced me to the beautiful marine world
and never let me give up on my dreams.

I cannot thank you enough.

To Jesse

My amazing brother who can always make me laugh
Yet strengthens me for the challenges that life holds

Table of Contents

LIST OF FIGURES ix

 Chapter 1 ix

 Chapter 2 ix

LIST OF TABLES xiii

 Chapter 1 xiii

 Chapter 2 xiii

ABBREVIATIONS xiv

ACKNOWLEDGEMENTS xv

BACKGROUND 1

CHAPTER 1 – Assessing changes in the Peconic Bay finfish and macro-invertebrate
community structure from 1987-2012 using multivariate statistics 5

INTRODUCTION 5

MATERIALS AND METHODS 8

 Survey and Environmental Data Collection 8

 Characterization and Transformation 10

 Environmental Correlates 11

 Statistical Methods..... 12

 Principal Components Analysis 12

 Multivariate regression Tree Analysis 13

 Variograms 14

 Redundancy Analysis 15

RESULTS 16

Principal Components Analysis	17
Multivariate regression Tree Analysis	18
Variograms	19
Redundancy Analysis	20
DISCUSSION	21
LITERATURE CITED	33
CHAPTER 2 – Modeling and Mapping Habitat Preferences and Spatial Utilization of Four	
Young-of-the-Year Species in the Peconic Bay Estuary.....	66
INTRODUCTION	66
MATERIALS AND METHODS	72
Fisheries Survey	72
Generalized Additive Models	73
Mapping	76
RESULTS	77
Northern Puffer	77
Scup	79
Weakfish	81
Winter Flounder	83
Diversity Mapping	85
DISCUSSION	86
Northern Puffer	86
Scup	90
Weakfish	93

Winter Flounder	96
Diversity	100
LITERATURE CITED	103

List of Figures

Chapter 1

Figure 1- Map of Peconic Bay Estuary with survey stations used in the NYSDEC trawl survey	43
Figure 2- Map of the Peconic Bay Estuary and stations where chlorophyll sampling was performed by the SCDHS.	44
Figure 3- Annual Atlantic Multi-Decadal Oscillation (AMO) Index	45
Figure 4- Annual Winter North Atlantic Oscillation (NAO) Index	46
Figure 5- Species that occurred more than 10% of the time in all tows	47
Figure 6- Hellinger transformed relative species abundance	48
Figure 7- Spearman's rank correlation	50
Figure 8- Scree plot from the principal components analysis	51
Figure 9- Biplot of the principal components analysis	52
Figure 10- Biplot of the principal components analysis centered around the origin	53
Figure 11- Validation results of the multivariate regression tree	54
Figure 12- Results of the multivariate regression tree	55
Figure 13a- Monthly variogram	56
Figure 13b- Yearly variogram	56
Figure 14- Triplot of the redundancy analysis	57
Figure 15- Triplot of the redundancy analysis centered around the origin	58
Figure 16- Predicted relative abundance from the redundancy analysis	59
Figure 17- Annual seasonal bottom water temperatures of the Peconic Bay	61

Chapter 2

Figure 1- Map of bottom sediments	111
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Figure 2- Generalized additive model graphs for Northern Puffer YOY	112
Figure 3- Plot of independent and predicted values for Northern Puffer YOY Summer Presence/Absence Model	113
Figure 4- Receiving operating curve for Northern Puffer YOY Summer Presence/Absence Model	114
Figure 5- Plot of independent and predicted values for Northern Puffer YOY Summer Abundance Model	115
Figure 6- Plot of independent and predicted values for Northern Puffer YOY Fall Presence/Absence Model	116
Figure 7- Receiving operating curve for Northern Puffer YOY Fall Presence/Absence Model	117
Figure 8- Plot of independent and predicted values for Northern Puffer YOY Fall Abundance Model .	118
Figure 9- Map of Northern Puffer YOY abundance and contours for all seasons from 2006-2012	119
Figure 10- Map of Northern Puffer YOY abundance and contours for summer months 2006-2012	120
Figure 11- Map of Northern Puffer YOY abundance and contours for fall months 2006-2012	121
Figure 12- Generalized additive model graphs for Scup YOY	122
Figure 13- Plot of independent and predicted values for Scup YOY Summer Presence/Absence Model	123
Figure 14- Receiving operating curve for Scup YOY Summer Presence/Absence Model	124
Figure 15- Plot of independent and predicted values for Scup YOY Summer Abundance Model	125
Figure 16- Plot of independent and predicted values for Scup YOY Fall Presence/Absence Model	126
Figure 17- Receiving operating curve for Scup YOY Fall Presence/Absence Model	127
Figure 18- Plot of independent and predicted values for Scup YOY Fall Abundance Model	128
Figure 19- Map of Scup YOY abundance and contours for all seasons from 2006-2012	129
Figure 20- Map of Scup YOY abundance and contours for summer months 2006-2012	130
Figure 21- Map of Scup YOY abundance and contours for fall months 2006-2012	131
Figure 22- Generalized additive model graphs for Weakfish YOY	132
Figure 23- Plot of independent and predicted values for Weakfish YOY Summer Presence/Absence Model	133
Figure 24- Receiving operating curve for Weakfish YOY Summer Presence/Absence Model	134

Figure 25- Plot of independent and predicted values for Weakfish YOY Summer Abundance Model ..	135
Figure 26- Plot of independent and predicted values for Weakfish YOY Fall Presence/Absence Model	136
Figure 27- Receiving operating curve for Weakfish YOY Fall Presence/Absence Model	137
Figure 28- Plot of independent and predicted values for Weakfish YOY Fall Abundance Model	138
Figure 29- Map of Weakfish YOY abundance and contours for all seasons from 2006-2012	139
Figure 30- Map of Weakfish YOY abundance and contours for summer months 2006-2012	140
Figure 31- Map of Weakfish YOY abundance and contours for fall months 2006-2012	141
Figure 32- Generalized additive model graphs for Winter Flounder YOY	142
Figure 33- Plot of independent and predicted values for Winter Flounder YOY Spring Presence/Absence Model	143
Figure 34- Receiving operating curve Winter Flounder YOY Spring Presence/Absence Model	144
Figure 35- Plot of independent and predicted values for Winter Flounder YOY Spring Abun. Model ..	145
Figure 36- Plot of independent and predicted values for Winter Flounder YOY Summer Presence/Absence Model	146
Figure 37- Receiving operating curve for Winter Flounder YOY Summer Presence/Absence Model ...	147
Figure 38- Plot of independent and predicted values for Winter Flounder YOY Summer Abundance Model	148
Figure 39- Map of Winter Flounder YOY abundance and contours for all seasons from 2006-2012	149
Figure 40- Map of Winter Flounder YOY abundance and contours for spring months 2006-2012	150
Figure 41- Map of Winter Flounder YOY abundance and contours for fall months 2006-2012	151
Figure 42- Map of species richness contours for all seasons 2006-2012	152
Figure 43- Map of species richness contours for spring months 2006-2012	153
Figure 44- Map of species richness contours for summer months 2006-2012	154
Figure 45- Map of species richness contours for fall months 2006-2012	155
Figure 46- Map of Shannon diversity index contours for all seasons 2006-2012	156
Figure 47- Map of Shannon diversity index for spring months 2006-2012	157
Figure 48- Map of Shannon diversity index for summer months 2006-2012	158

Figure 49- Map of Shannon diversity index for fall months 2006-2012 159

List of Tables

Chapter 1

Table 1- List of species that occurred more than 10% of the time in all tows	62
Table 2- Species loadings from the first two principal components	63
Table 3- Redundancy analysis results	64
Table 4- Comparison of species across the Peconic Bay, Long Island Sound, and Narragansett Bay	65

Chapter 2

Table 1- Generalized additive model results for Northern Puffer YOY	160
Table 2- Generalized additive model results for Scup YOY	161
Table 3- Generalized additive model results for Weakfish YOY	162
Table 4- Generalized additive model results for Winter Flounder YOY	163
Table 5a- Model validation for presence/absence generalized additive models	164
Table 5b- Model validation for abundance generalized additive models	165

Abbreviations:

AMO: Atlantic Multi-Decadal Oscillation

ASMFC: Atlantic States Marine Fisheries Commission

FB: Flanders Bay

GPB: Great Peconic Bay

LPB: Little Peconic Bay

NAO: North Atlantic Oscillation

NYSDEC: New York State Department of Environmental Conservation

PB: Peconic Bay (consisting of FB, GPB, LPB and SIS)

PEP: Peconic Estuary Program

SCDHS: Suffolk County Department of Health Services

SIS: Shelter Island Sound

USEPA: United States Environmental Protection Agency

YOY: Young-of-the-year

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Background

Historically, the Peconic Bay Estuary (PB) has played a large role in the economy and the development of the East End of Long Island. The PB has provided resources since the European settlers arrived as far back as 1640. The area was fished by farmers as a way to supplement their pay and to satisfy the resource demand of a growing New York City (Hardy 1976, Weber & Grahn 1995). A well-established fishing center however, was not described until 1750 and it was not until 1798 that the PB were accounted for as a “growing fishery” (Weber & Grahn 1995). At the same time, a lucrative whaling industry was being developed with whaling vessels leaving from the ports of Sag Harbor, Greenport, Jamesport and New Suffolk, and this industry continued into the mid 1850’s (Hardy 1976). The first commercial fishery in the Peconics was created in the 1830’s, catching and processing menhaden which was used as cheap source of fertilizer (Hardy 1976). The fisheries in the PB further expanded with the completion of the Long Island Railroad connecting Long Island City and Greenport in 1844 (Hardy 1976). One hundred years later, by 1938, the Peconics and Gardiner Bay area accounted for about 23% of the total landings for New York (Weber & Grahn 1995). Today, the Peconics still support a large commercial as well as a recreational fishery (Grigalunas & Diamantides 1996, Opaluch et al. 1999).

The PB system is a relatively large (218 km²) estuary that lies between the North and South forks of Long Island, New York (Hardy 1976) (Figure 1). Starting from west to east, the estuary is comprised of the Peconic River, Flanders Bay (FB), Great Peconic Bay (GPB), Little Peconic Bay (LPB), Shelter Island Sound (SIS), Gardiners Bay and the land area that drains into these embayments (Hardy 1976). For the purpose of this thesis, I will refer to the Peconic Bay Estuary (PB) as a compilation of FB, GPB, LPB, and SIS. The PB was formed between 50,000

and 10,000 years ago from receding glaciers and is relatively shallow with an average depth of 4.7 meters (Hardy 1976).

The Peconic River is the major river that flows into the PB and begins just west of the Town of Riverhead (Hardy 1976, Wilke & Dayal 1982); however, groundwater discharge (although varying temporally) accounts for most the freshwater that enters the PB (Hardy 1976, LaRoche et al. 1997). The water flux of the PB is primarily driven by the tide and can be characterized as being a well-mixed, vertically homogenous bay (Hardy 1976), since surface and bottom water are similar in physical characteristics.

The PB is regulated by the federal Environmental Protection Agency (EPA), New York State Department of Environmental Conservation (NYSDEC), Suffolk County, and various towns (Burger & Gochfield 2005, USEPA 2007). There are a number of programs that monitor the Bay because it is highly important to many people in the immediate area and the economy of Long Island. Suffolk County started measuring water quality in 1976 (USEPA 2007), and the NYSDEC's trawl survey began in 1987. The Peconic Bay Estuary Program (PEP) is a "partnership of local, state, and federal governments, citizen and environmental groups, businesses and industries, and academic institutions charged with developing and implementing a watershed-based comprehensive management plan" and was created in 1993 when the PB was named an Estuary of National Significance by the EPA (PEP 2014). The east end of Long Island is highly popular in the summer months where the population nearly doubles in size and towns profit from tourism (Opaluch et al. 1999). Local restaurants are recognized for their selection of seafood and rely on the PB to supply fresh shellfish and finfish. At one point, the harvest of scallops from the PB was valued around \$2 million dollars annually.

Weber & Grahn (1995) report that numerous fisheries in the PB were operating by the mid 1800's, which included species such as bluefish, spanish mackerel, eels, weakfish, flatfish, scup, butterfish and striped bass. From 1950 to 1995, the PB saw annual average landings of 2.1 million pounds of finfish and crustaceans with peaks of 4 and 4.6 million pounds reported in 1963 and 1973. From 1980 to 1992, the top five fisheries, by weight, in the PB were scup, Atlantic menhaden, bluefish, longfin squid and weakfish, which are still important fisheries today. The PB supports a large recreational and commercial fishery for the east end of Long Island.

Although the PB is an important asset to Long Island, there are only a few studies that have characterized its faunal assemblages. Most of the current studies document phytoplankton dynamics (Bruno et al. 1980, Turner 1982, Gobler & Boneillo 2003) and harmful algae blooms (LaRoche et al. 1997, Gobler et al. 2008). Some studies use the PB to compare limited ecological aspects of the system to other suites, like natal homing in fish (Thorrold 2001), food web structure (Lonsdale et al. 2006), and meroplankton grazing (McNamara et al. 2010). Several studies that have been done under the PEP are based on habitat characterization and restoration (PEPNRS. 2010). For example, studies have mapped the PB seafloor using high resolution multibeam and side-scan sonar (Flood 2004), as well as sediment grain size classifications and sessile invertebrate communities (Cerrato and Maher 2007, Cerrato et al 2009, 2010). There are no studies analyzing the fish and mobile invertebrate community structure of the PB, even though the Bay is an important breeding ground for many fish species (Hardy 1976, Ferraro 1980). Although the NYSDEC has been performing annual trawls in the PB since 1987, and Weber et al. 1998 report annual and monthly catch per unit effort (CPUE) for a number of species from 1987-1995, the data have never been analyzed in a comprehensive, quantitative

way. This accumulation of data on fish, water quality, and bottom type is a perfect opportunity to study the fish community of the PB.

Chapter 1

Assessing changes in the Peconic Bay finfish and macro-invertebrate community structure from 1987-2012 using multivariate statistics

Introduction

The biodiversity of ecosystems have been linked to outputs, in terms of ecological services and stability (Worm et al. 2006, Mace et al. 2012), and more diverse systems are considered more resilient and predictable (Elmqvist et al. 2003, Ives & Carpenter 2007, Dovčiak & Halpern 2010). For example, Downing et al. (2012) found that a diverse and species rich community is more resilient to invasive species. The loss of biodiversity can have long-term, negative impacts and affect the performance of an ecosystem, such as decreased productivity, less buffering against natural perturbations, and less stability (Naeem 1994, Worm et al. 2006). Even though these associations have been linked with biodiversity, the exact mechanisms between diversity and its benefits have been unclear and are a topic of much debate (Gross & Cardinale 2007); therefore, the frequent monitoring of ecological communities is one of the many important steps in understanding how or why ecosystem changes occur and is a tool for assessing the overall status of the ecosystem. In turn, better management and policies regarding species can arise due to the enhanced knowledge of the system (Jordaan et al. 2012, Pikitch et al. 2012).

While changes in the structure of communities and ecosystems are common, it is often difficult to identify mechanisms underlying system shifts (Frisk et al. 2008). Cyclic patterns of

abundances of species are widespread and the strength of a year class relies on many different variables, such as recruitment strength, mortality rates or spawning stock biomass (Fogarty 1993). Environmental factors also play a large role. Habitat quality affects the success of a species, as most species are suited for a particular habitat type, and are limited by their tolerance for certain physical aspects, such as temperature (Beitinger et al. 2000). However, environmental factors are variable across different time-scales. Long-term physical trends in the environment are often linked to large-scale climatic conditions (Enfield et al. 2001, Hurrell et al. 2003). For example, the natural weather phenomenon El Niño, induces bottom-up effects that favors either a sardine or anchovy dominated system off the South American coast (Chavez et al. 2003).

The phenomenon of alternating stable states (Beisner et al. 2003, Angeler et al. 2013) has been coined a regime shift (Scheffer et al. 2001), and has been identified in lakes, coral reefs, oceans and coastal systems (Hare & Mantua 2000, Jackson et al. 2001, deYoung et al. 2004). A regime shift can be characterized as a sudden or abrupt shift in species abundance or community composition that usually occurs as a low-frequency, high amplitude event, and can affect the function of the ecosystem. It is usually correlated with climatic indices (McKinnell et al. 2001, Lees et al. 2006).

In the Atlantic Ocean, important drivers of water temperature and the position of the Gulf Stream include the North Atlantic Oscillation (NAO) and the Atlantic Multi decadal Oscillation (AMO). The NAO is driven by changes of sea surface pressure in the North Atlantic caused by the redistribution of atmospheric mass (Hurrell et al. 2003), whereas the AMO is described as anomalies of the sea surface temperature in the North Atlantic (Enfield et al. 2001). These indices are commonly used to explain patterns of circulation throughout the Northern Atlantic Ocean (Dijkstra et al. 2006, Knight et al. 2006). Links between the NAO/AMO and ecosystem

patterns have just started to be studied in the past several years, and have been correlated to large-scale distribution changes in finfish (Nye et al. 2014). Estuary studies conducted in Narragansett Bay, Rhode Island (Collie et al. 2008), and the Long Island Sound (Howell & Auster 2012), report ecosystem shifts associated with the fluctuation of the AMO/NAO and more specifically temperature.

The Peconic Estuary, located between the North and South forks of Long Island, New York, was recognized as an Estuary of National Significance in 1993 (PEP 2014). The estuary is temperate in nature and displays a high degree of seasonality. Some species of finfish permanently reside in the PB while most species undertake, sometimes long, migrations to use the estuary as a spawning, nursery or feeding ground (Perlmutter et al. 1956, Buckel et al. 1999, Thorrold et al. 2001). Important species in the Bay include: winter flounder (*Pseudopleuronectes americanus*), summer flounder or fluke (*Paralichthys dentatus*), windowpane flounder (*Scophthalmus aquosus*), scup or porgy (*Stenotomus chrysops*), bluefish (*Pomatomus saltatrix*), weakfish (*Cynoscion regalis*), striped bass (*Morone saxatilis*), tautog (*Tautoga onitis*), bay anchovy (*Anchoa mitchilli*), Atlantic silversides (*Menidia menidia*), hard clams (*Mercenaria mercenaria*), bay scallops (*Aequipecten irradians*), and blue crabs (*Callinectes sapidus*) (Bortman & Niedowski 1998). Many of these fish and invertebrates drive the productive economy during the summer months (Opaluch et al. 1999).

Although the PB supports a robust commercial and recreational fishery, it has not been well studied in terms of finfish community structure or ecosystem properties. The majority of research has focused on phytoplankton ecology (Bruno et al. 1980, Turner 1982, Gobler & Boneillo 2003), meroplankton grazing (McNamara et al. 2010), and harmful algae blooms (LaRoche et al. 1997, Gobler et al. 2008). A few studies have explored various aspects of the

system ranging from finfish natal homing (Thorrold 2001), lower trophic food-web structure (Lonsdale et al. 2006), sediment grain size classifications, sessile invertebrate communities (Cerrato and Maher 2007, Cerrato et al 2009, 2010) and habitat characterization and restoration (Flood 2004, PEPNRS 2010). While all these studies are important to understanding the PB ecosystem as a whole, a comprehensive study of the finfish and macro-invertebrate community has not been conducted.

Here we present an analysis of the temporal changes that have occurred in the PB's community of finfish and macro-invertebrates using a suite of multivariate statistical techniques. This study uses data generated by the New York State Department of Environmental Conservation's (NYSDEC) annual juvenile trawl survey, conducted in the PB since 1987. Principal components analysis was used to examine species abundance changes through time. To determine if there was a significant shift in the species composition, a multivariate regression tree analysis was performed by using year as a quantitative explanatory variable. In addition, a temporal multivariate variogram analysis was used to examine community structure across multiple time-scales, essentially comparing annual community assemblages to examine the long-term and short-term variation. Finally, to analyze potential community drivers, a redundancy analysis was performed with various environmental variables to investigate if species abundances are responding to abiotic drivers.

Materials and Methods

Survey and Environmental Data Collection

The New York State Department of Environmental Conservation (NYSDEC) has conducted a fishery-independent trawl survey since 1987 in accordance with the Atlantic States

Marine Fisheries Commission's (ASMFC) Fishery Management Plan for weakfish. The survey included not only weakfish but all finfish and shellfish captured and has been used to evaluate commercially important species (Weber et al. 1998). The survey area consisted of Flanders Bay, Great Peconic Bay, Little Peconic Bay, and several smaller bays (Southold Bay, Noyack Bay, and Shelter Island Sound) bordering Shelter Island not including the North and South channels around Shelter Island. The allocation of stations is based on 77 1' latitude and 1' longitude sampling blocks (Figure 1). Each week from May through October, the survey samples 16 randomly chosen stations, with some annual start dates beginning in the end of April and some end dates spilling over into November. Exceptions to this design plan included no trawls in 2005, and none until mid-July in 2006, the beginning of August in 2008, and the beginning of June in 2010. From 1987-2012, a 10.7 meter lobster-style workboat named the David H. Wallace collected samples using a 4.9 meter semi-balloon otter trawl with a 3.2cm mesh codend and a small mesh liner (1.3 cm). Tows were set for 10 minutes at an approximate speed of 2.5 knots. For more information on gear and survey design see Weber et al. (1998).

The general start locations of each trawl usually occurred at the center of each trawl sampling block. From 1987 to 1991, starting and ending locations were recorded using Loran C navigation. In 1992, SatNav which also recorded Loran coordinates was added and was used as the primary navigation system. Therefore, Loran coordinates were recorded for the start and stop locations of each trawl from 1987-2000. Loran coordinates from 1987-2000 were converted to latitude and longitude by using the software Andren SeaMarks 8.2 (Andren Software, Indianalantic FL). After 2000, a GPS navigation system was used which recorded the start and stop locations of each trawl in latitude and longitude.

At the start of each tow, surface and bottom temperature, depth, salinity, dissolved oxygen and secchi disc depth were recorded. Depth was also recorded at the end of a tow. Chlorophyll measurements from 1987-2012 were obtained from the Suffolk County Department of Health Services (SCDHS). Stations 60113, 60114, 60130 and 60170 were sampled continuously from 1987-2012; therefore only chlorophyll measurements from these stations were used (Figure 2). Typically, the SCDHS measured fluorescence using a YSI 6600 Probe 6025. For more information, chlorophyll calibration and QA/QC, see SCDHS (2010).

Two climatic indices were also used in the analysis: the Atlantic Multi-Decadal Oscillation Index (AMO) (Figure 3) and the North Atlantic Oscillation Index (NAO) (Figure 4). These indices were obtained from the National Oceanic & Atmospheric Administration (ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/nao_index.tim, <http://www.esrl.noaa.gov/psd/data/correlation/amon.us.data> [NOAA 2014]). For more information on data collection see www.esrl.noaa.gov and www.cpc.noaa.gov.

Characterization and Transformation

As with many community studies, some species heavily dominate the samples and others are rare. Deciding whether or not to include or exclude rare species in multivariate analyses is an ongoing debate (Poos & Jackson 2012). In the present study, rare species were deleted to study changes in the dominant species within the PB. A species was considered rare if its occurrence was in less than 10% of all tows performed from 1987-2012 (Figure 5, Table 1). After rare species were removed, the relative abundance of each species was calculated for each tow and Hellinger transformed (Legendre & Gallaher 2001). Annual transformed relative abundance was then calculated by summing tow values for each year and dividing by the number of tows for that

year (Figure 6). The Hellinger transformation is useful for datasets with many 0 counts, it down weights the importance of highly abundant species, and combined with Euclidean distance, produces good multivariate representations of ecological data (Legendre & Gallaher 2001).

Several taxa were combined into larger functional groups because of their similar ecological roles: (1) anchovy (bay anchovy (*Anchoa mitchilli*) and striped anchovy (*Anchoa hepsetus*)), (2) spider crab (six spine spider crab (*Libinia dubia*) and nine spine spider crab (*Libinia emarginata*)) and (3) searobin (northern searobin (*Prionotus carolinus*) and striped searobin (*Prionotus evolans*)). The six spine spider crab (*Libinia dubia*) and the nine spine spider crab (*Libinia emarginata*) were not counted in the survey until 1992, but were kept in the analyses since they were missing from the data for only 5 years, and occurred in over 10% of all tows. Twenty-two taxa were included in the analysis (Table 1). The combination of these taxa were performed before the Hellinger transformation was applied to relative abundances calculations.

Environmental Correlates

Monthly averages were calculated for bottom temperature, bottom salinity, bottom DO, and secchi depth. Unlike the biological data, a survey year average was calculated from monthly averages so that months weighted equally, due to monthly and annual fluctuations in the number of tows. For months that the survey did not collect data (May-June of 2006, May-July of 2008 and May of 2010), missing environmental data for each month was estimated by averaging monthly values from the previous and following corresponding month. Annual average chlorophyll was calculated from the Suffolk data using only the four stations previously mentioned that were continuously sampled from 1987-2012. Again, the same averaging

procedure was applied to the chlorophyll data; however, chlorophyll data were not always available for every month of every year. Some years had several consecutive months where chlorophyll were not collected therefore, if monthly values were missing, no interpolation was made and averages were calculated for available months. No chlorophyll data was available for the year 1987. As a result, a yearly average for 1987 was calculated by averaging 1988 and 1989. Since start and end depths were recorded, the average of the two was calculated and used for the location of each tow. The average annual winter (January, February, March) NAO index was used since atmospheric variability over the North Atlantic is the most prominent during this time period (Figure 4) (Hurrell et al. 2003). The average annual AMO index was calculated using all months (Figure 3).

Statistical Methods

In order to capture the structure and temporal patterns in the finfish and shellfish community, we utilized a variety of statistical techniques including: Principal Components Analysis (PCA), Multivariate Regression Tree Analysis (MRT), Multivariate Variograms, and Redundancy Analysis (RDA). Each technique provided a contribution to understanding the dynamics of the PB ecosystem.

Principal Components Analysis

Principal Components Analysis is a well-established statistical technique that originated in the 1930's (Hotelling 1933). The general goal of PCA is to create a new set of uncorrelated variables that reduce the complexity of the data, yet still retain the variation seen in the original data (Jolliffe 2002). PCA is an ordination technique and is used to organize the variability

inherent in the data (McGarigal et al. 2000, Dray et al. 2012). The principal utilization of ordination in ecology is to identify the major gradients in the community that can then be related to ecological factors (McGarigal et al. 2000). The principal components are the eigenvectors of the covariance or correlation matrix derived from the original data. These principal components are characterized by a linear combination of the original number of variables (McGarigal et al. 2000).

PCA was utilized to analyze the broad-scale patterns in the PB finfish and shellfish community to identify important biological and temporal associations. Because the Hellinger transformed relative abundance of each taxa had the same unit of measurement, a covariance matrix was used to analyze the data. All PCA routines were conducted in the statistical software R (R Core Development Team 2010) utilizing the package “vegan”, as well the software Canoco 4.5 (Microcomputer Power, Ithaca NY), which was mainly used for creating biplots.

Multivariate Regression Tree Analysis

Multivariate regression tree analysis (MRT) classifies samples into groups by repeatedly splitting the data based on criteria obtained from explanatory variables (De’ath, 2002). The end result of the MRT is a tree with a top node representing all data and subsequent branches representing subgroups of the data. Branching out from the top, MRT creates a split in the data using explanatory variables, in the present study year, which forms two separate groups chosen to minimize the within group and maximize the between group the sum of squares (De’ath 2002). Many splits may be considered based on different explanatory variables but only splits that reduce model deviance will be selected (Larsen & Speckman 2004). In order to maintain parsimony the number of “splits” are “pruned” based on cross-validation which calculates the

predicted mean square error for each number of splits. The simplest tree whose predicted mean square root error is within one standard error of the minimum error is selected (De'ath 2002).

To investigate whether large-scale, temporal community shifts occurred in the PB, MRT was utilized to analyze temporal variation in community structure using “Year” as an explanatory variable. The analysis was carried out with the ‘mvpart’ package in R. Community temporal trends were analyzed using year as a quantitative (as opposed to categorical) explanatory variable.

Variograms

A multivariate variogram is an approach that can describe the pattern of temporal or spatial variability in a community (Collins et al 2000, Noy-Meir & Anderson 1971, Ver Hoef & Glen-Lewin 1989, Wagner 2003). The approach calculates the semivariance between pairs of samples

$$\gamma = \sum_{i=1}^S (x_{ij} - x_{ik})^2$$

where x_{ij} and x_{ik} in the present study were the Hellinger transformed abundances of species i in samples j and k , respectively, and S is the number of species. The semivariances are then binned by differences in the date of collection or location distance, and the values in each bin averaged:

$$\hat{\gamma}(h) = \frac{1}{n_h} \sum_{jk|h_{jk} \in h} \sum_{i=1}^S (x_{ij} - x_{ik})^2$$

where h represents each collection interval or distance class and n_h is the number of pairs of samples within h . A variogram can then be produced by plotting $\hat{\gamma}(h)$ vs. h .

One drawback of variogram analysis is that only $1/2$ the largest time or distance interval in the data set should be compared (Wagner 2003). Since our time series extended over 25 years (1987-2012), only a maximum time interval of 13 years can be analyzed. This limitation is imposed because larger time intervals exclude data within the middle of the series, potentially biasing the semivariance estimate. For example, if the time interval is $h=15$ years, then data from 1987&2002, 1988&2003, ..., 1997&2012 can be paired and included in the estimate, but data from the years 1998-2011 are excluded since these years have no pairing with data collected 15 years before or after them.

Semivariances and variogram plots were created using the “mso” function in the R library ‘vegan’. This function required input of an ordination object of the biological data, and this input object was created by performing a principal components analysis of the Hellinger transformed data using the “rda” function in “vegan”. The grain parameter in “mso” was adjusted to create time interval bins of 1 month and 1 year to examine different temporal patterns.

Redundancy Analysis

Redundancy Analysis (RDA) is a direct gradient analysis that combines ordination of samples with regression analysis. In doing so, it uses the explanatory variables to describe variation in the response variables, i.e., transformed species abundances (Muller 1981, Dray et al. 2012). RDA is closely related to canonical correlation analysis (CA), however the main goal of RDA is to explain the maximum proportion of residual variance of the explanatory variables whereas CA tries to maximize the within-pair correlations of canonical variates (Lambert et al. 1988).

RDA is useful for identifying environmental drivers that might impact the structure of species assemblages (O'Connor et al. 2012, Perry & Masson 2013) and explain PCA patterns (Dray et al. 2012). Thus, RDA was applied to the Peconics data using annual average Hellinger transformed taxa abundances as the response variables and the following environmental variables as the explanatory variables: annual chlorophyll, annual and seasonal (spring, summer, fall) temperatures, annual salinity, annual dissolved oxygen, annual secchi depth, the North Atlantic Oscillation Index (NAO), the Atlantic Multi-Decadal Oscillation Index (AMO), and the NAO index and the AMO index lagged by 1 and 2 years. RDA was performed in the software package Canoco 4.5 (Microcomputer Power, Ithaca, NY, USA) using a forward selection method for choosing which environmental variables to include in the model. To avoid overfitting the data, explanatory variables identified by forward selection were then trimmed using a second-order Akaike Information Criterion (AICc) (Burnham and Anderson, 1998) to create a final parsimonious set. The final RDA model was rerun in the R package “vegan” to make use of the “predict” function to view the accuracy of the model.

Results

From 1987-2012, there were 9,524 trawls performed capturing 101 species. Of these, 42 species occurred over 1% of the time in the trawls, while only 22 taxa occurred over 10% of the time (Figure 5, Table 1). The five most common taxa, each occurring in >50% of the tows, were calico crabs (*Ovalipes ocellatus*), winter flounder (*Pseudopleuronectes americanus*), scup (*Stenotomus chrysops*), spider crabs (*Libinia spp.*), and bay anchovy (*Anchoa mitchilli*). The annual average Hellinger transformed abundance of these taxa can be seen in Figure 6. Spearman rank correlation with year revealed that there were 8 taxa that had significantly ($p < 0.001$)

increased or decreased during the 26 year time series (Figure 7). Summer flounder ($r_s=0.79$, $p=4.92e-6$), scup ($r_s=0.75$, $p=2.93e-5$), and smallmouth flounder ($r_s=0.74$, $p=4.03e-5$) significantly increased during the time period, while windowpane flounder ($r_s=-0.79$, $p=4.38e-6$), horseshoe crab ($r_s=-0.74$, $p=4.51e-5$), winter flounder ($r_s=-0.73$, $p=5.18e-5$), oyster toadfish ($r_s=-0.66$, $p=4.74e-4$), and calico crab ($r_s=-0.65$, $p=6.61e-4$) all significantly declined.

Principal Components Analysis

The PCA of the annual average Hellinger transformed relative abundance of the 22 most frequently occurring taxa showed that the first two PCs captured 84.6% (PC1:61.2%, PC2:23.4%) of the variation in community composition (Figures 8-10, Table 2). The first PC axis reflected clear annual changes in relative abundance of the different taxa (Figure 9 & 10, Table 2). Species with the highest positive loadings (Table 2) were species that had increased across the time series or were the most dominant in the community. Scup had the highest loading (0.663), indicating that scup captured a dominant trend of increase in the post 2000 time period. Species with negative loadings were seen to have the most decline in abundance throughout from 1987-2012. The second principal component is clearly dominated by anchovy. Out of the four species that had the highest positive loadings on the second PC (anchovy, squid, winter flounder, silverside), three of these species are r-selected life history strategists: characterized by boom and bust cycles of abundance, high fecundity and short life spans. These species had higher periods of abundance during the beginning and end of the time series, with lower abundance in the middle (Figure 6).

Negative scores on the first axis were associated with the years 1987-1999 while positive scores on the axis were associated with the years 2000-2012. Not only does this pattern emerge,

but the years are arranged in a counterclockwise direction on the PCA plot. Quadrant II of the graph contains the late 1980's, while Quadrant III contains the 1990's. Quadrant IV is comprised of the early 2000's and Quadrant I encompasses the late 2000's and early 2010's (Figure 9).

The PCA supports the general abundance trends that were seen in each individual taxa (Figure 6, 9 & 10, Table 2). Calico crabs were abundant in the 1990's until their decline into the 2000's. Anchovies were abundant the earliest (1987-1990) and latest (2009-2012) survey years. Although, not as abundant as anchovy, squid displayed a similar trend in abundance. Scup and weakfish were not abundant in the 1990's but became abundant in the Bay during the 2000's. The decline of winter flounder, windowpane flounder and horseshoe crab are also noted in the PCA.

Multivariate Regression Tree Analysis

The multivariate regression tree analysis revealed a split in the time series which was also suggested in the PCA. Based on pruning using the minimum cross validated standard error, the most appropriate MRT was one that that included 4 separate groups with a total of 3 splits (Figure 11). According to the MRT (and the PCA), a significant split in community composition occurred in the time-series in the year 2000 (Figure 12). The 1987-1999 group was split at the year 1990 to create two more groups. The 2000-2012 group was split in year 2009. Therefore, this analysis yielded a total of 4 different groupings of contiguous years that shared similar species composition: 1987-1989, 1990-1999, 2000-2008 and 2009-2012.

Although not reported in detail here, MRT analysis of monthly average data revealed a great deal of seasonality in the PB community. The first split occurred between June and July, grouping April, May and June together and July, August, September, October and November

together; this represented a clear split between the spring and summer communities. A further split was then introduced to the grouping of July-November by splitting off the month of July, then the month of August, and leaving September-November. This suggested four breaks in months. Group 1 being April-June, group 2 being July, group 3 August, and group 4 being September-November.

Variograms

The variograms of monthly and annual time intervals showed a gradual increasing trend in semi-variance as the time interval increased (Figure 13). The x-axis (distance) in the variogram is the time interval between compared years. For example, the point on the graph with an x-value of 5, represents the average semivariance of all data in the time-series that are 5 years apart (e.g., in Figure 13b, 1987 and 1992, 1988 and 1993, 1989 and 1994, etc.). The variogram exhibits a monotonically increasing trend, with an exception of samples separated at a distance of 5 and 6 years apart, when the semivariance decreased. This pattern indicated that community differences generally increased as the time interval between surveys increased, at least up to the maximum separation of 13 years used in the analysis.

The variogram with monthly time intervals used to bin the data indicated strong signs of cyclic seasonality, and the results showed that the same months in different years were more similar in community structure compared to within year comparisons separated by several months. For example, the semivariances for data separated by 0, 12, 24, 36, etc. months (the troughs in the plot) were more similar than data separated by 6, 18, 30, etc. months (the peaks in the plot). The latter represent the maximum seasonal separation, and 3 and 9 month offsets are intermediate. This pattern is expected for a temperate estuary. Even though cyclic patterns are

present in the variogram, the overall trend is one of increasing semi-variance, which is consistent with the yearly variogram. Another noteworthy result of the monthly variogram is that the amplitude of the cyclic pattern is smaller at increasing timescales, suggesting that the short term seasonal variability is greater than long term seasonal variability.

Redundancy Analysis

The results of the redundancy analysis after trimming with AICc produced a model with four explanatory variables: the annual AMO lagged by 2 years, the average winter NAO lagged by 1 year, the annual AMO, and average annual chlorophyll (Figures 14 & 15). These four variables explained 53.1% of the Hellinger transformed community variance, and the first two axes of the redundancy analysis displayed 52.0% of the total community variance and 98.0% of the species-environmental relationship (Table 3).

The annual AMO Index only influences community variation along the 1st RDA axis, but there are also contributions of the AMO Index lagged by 2 years and NAO lagged by 1 year to this axis. Annual chlorophyll *a* primarily influences community variation along the 2nd RDA axis, along with AMO Index lagged by 2 years and NAO lagged by 1 year. Interestingly, winter flounder and windowpane flounder are projected in the opposite direction as the AMO index, indicating that these two species are negatively related to the AMO index. Anchovy varied strongly with chlorophyll *a*, scup with the AMO Index lagged by 2 years, and lady crab with NAO lagged by 1 year. The fact that three out of the four selected explanatory variables are climatic indices suggests that interannual community composition changes in the PB were being driven by an external climate driver rather than local environmental conditions.

Predicted Hellinger transformed abundances fit the observed data very well (Figure 16). The fit suggests that the model created from the four significant variables was reasonable in describing the trends seen in individual species abundances.

Discussion

Trends in community composition indicated the dominate finfish species in the PB abruptly changed between the years 1998-2002; whether this change reflects an altered community dynamic under an alternate stable state remains to be seen, but this change within the context of the dataset qualifies as a regime shift. Although, there have been different definitions as to what constitutes as a regime shift, it is agreed upon that regime shifts are sudden, non-linear changes of abundance at multiple trophic levels, where communities shift into a different stable state and often occur on large spatial scales (McKinnell et al. 2001, Lees et al. 2006). The exact mechanisms as to why these changes occur are not clearly identified, but most studies have linked regime shifts to climatic indices or changes in temperatures (Hare & Mantua 2000, Hunt Jr. et al. 2002, Polovina 2005), which is generally the case in the PB. However, changes in abundances of fish species are due to a number of biotic processes such as prey availability or recruitment success. Therefore, climatic shifts that involve temperature or wind patterns may induce physical changes within the ocean or coastal areas that in turn affect productivity, and trophic and population dynamics (Hunt Jr. et al. 2002, Möllmann et al. 2008). The predictive capacity between lagged climatic indices instead of measurements at the survey level suggest patterns in species abundances, and hence interactions, within the PB are not occurring over short time scales, but rather are better described by accumulations of direct and indirect factors operating at greater than annual scales.

In the PB, of the 22 taxa that we studied, significant declines in relative abundance were observed from 1987-2012 in windowpane flounder, winter flounder, horseshoe crab, oyster toadfish and calico crab. Although, not statistically significant, Atlantic silversides saw a decline in abundance as well. On the other hand, increased relative abundance was observed for butterfish, scup, smallmouth flounder, summer flounder, tautog and weakfish. Of these, smallmouth flounder, scup, and summer flounder were found to have significantly increased. While the above species general trends were captured by the analysis, other species relative abundances remained relatively stable with fluctuations likely due to variable annual recruitment.

Most changes in species abundances were not gradual, rather a quick change was centered on the year 2000. Calico crabs were observed to have a precipitous decline in relative abundance around the year 2000 as did windowpane and winter flounder, although winter flounder exhibited some strong recruitment years in 2001 and 2004. Oyster toadfish, although caught much less frequently, experienced a decline in their abundance in the mid-1990's. Butterfish, summer flounder, scup, smallmouth flounder, tautog, and weakfish all increased over the time period 1987-2012, but started to increase in abundance around the same time in the late 1990's. This was a dominant trend in the system, and while fluctuations in species annual abundance occur naturally, a sudden shift that involved 10 species is characteristic of a regime shift.

Atlantic silversides, while having an overall decreasing trend throughout the survey period, are a forage fish like bay anchovy and are characterized by large abundance fluctuations driven by recruitment variability. In addition, Atlantic silversides were commonly caught at stations located near shore in shallower areas where the survey effort would be limited, therefore silverside abundance might not have been accurately accounted for based on their habitat

preference. Anchovy, which have a similar life history to Atlantic silversides, had large fluctuations in abundance. It is interesting to note that longfin squid exhibited an abundance patterns analogous to anchovy, with peaks in abundance during 1988 and 2010. Atlantic silversides displayed a peak abundance during 1988, but not in 2010, and were heavily aligned with chlorophyll as an environmental driver. These species are short lived (1-2 years) with abundance tied to recruitment and local scaled phenomena appear to affect their dynamics more than longer lived species.

Although temperature plays a critical role in the growth and survival of species (Beitinger et al. 2000), other indirect consequences of changes in temperature can be hard to establish. In temperate systems, temperature is important in dictating migratory movements, as fish tend to stay in waters that are suitable to their thermal tolerance, therefore temporal models of fish abundance and distribution will routinely find temperature as a significant environmental variable (Sagarese et al. 2014). The PB has experienced a small annual (May-October) increase in temperature from 1987 of about 0.04°C per year, but broader impacts of ocean changes are likely playing a role in the local community dynamics. The use of an annual average temperature reveals little about when the Bay became warm enough for species to enter or dropped below a certain threshold temperature when species decide to leave. Further research should evaluate the finer scaled effects of temperature on the duration and timing of migratory species in PB.

Along with temperature, secchi depth (turbidity) and salinity were not included in the best RDA model. The PB is mainly driven by tidal forcing, with relatively little freshwater input. Therefore, the Bay is well-mixed and does not have a large salinity gradient throughout the estuary; salinity on average varies from 25 ppt in Flanders Bay to 29 ppt in Shelter Island Sound.

Thus, salinity might structure species within the Bay throughout the season on a fine-scale, but not a long-term basis, since the Bay has remained relatively stable for the survey period.

In the past researchers often relied on local environmental factors to explain patterns in species abundances and distributions (Marshall & Elliott 1998, Selleslagh & Amara 2008), but recently many studies have correlated climatic driving forces such as Pacific Decadal Oscillation (PDO), El Nino or North Atlantic Oscillation (NAO) to species long-term recruitment, landings, etc. (Beamish et al. 1999, Hare et al. 1999, Overland et al. 2010). The Narragansett study (Collie et al. 2008) linked species abundance changes to climatic indices and rising temperatures, while the Long Island Sound study (Howell & Auster 2012) attributed these changes to rising water temperatures, but did not examine climatic indices. Climatic forces can have far reaching effects where one region, for example, can have increased precipitation while another region, hundreds miles away, can have increased periods of droughts (Enfield et al. 2001). Although, abundances and distributions of fish might be affected on a fine-scale, a larger, more long-term picture is important as well.

During the period of regime change in the PB, the Atlantic Multi-Decadal Oscillation (AMO) shifted phases from cold to warm. The AMO has been gaining much attention in the past 10 years as a large scale climate process (Enfield et al. 2001, Dijkstra et al. 2006, Knight et al. 2006, Knudsen et al. 2011) that can affect biological systems (Edwards et al. 2013, Friedland et al. 2014, Nye et al. 2014). The AMO is normally characterized by the sea surface temperature (SST) anomaly in the North Atlantic Ocean (0-60°N). The AMO index is calculated by the SST anomaly after being linearly detrended to account for anthropogenic climate change (Dijkstra et al. 2006, Alheit et al. 2014, Nye et al. 2014). This multi-scale variability in temperature across the North Atlantic has been linked to Atlantic hurricane formation, African drought frequency,

winter temperatures in Europe, north east Brazilian rainfall, Mississippi River outflow and Arctic sea-ice concentrations (Dijkstra et al. 2006, Knight et al. 2006, Edwards et al. 2013, Alheit et al. 2014). Although the mechanisms linking the AMO index and these climatic events are not fully understood, it is theorized that the heat flux is an essential component driving fluctuations of strength of the Atlantic Meridional Overturning Circulation (AMOC) producing internal variability (Dijkstra et al. 2006, Knight et al. 2006, Nye et al. 2014).

Although climatic indices have been linked to many physical and biological processes (Hare & Mantua 2000, Hunt Jr. et al. 2002, Polovina 2005, Nye et al. 2014), the mechanism driving these processes is poorly understood. Biological systems are affected by a suite of biotic and abiotic factors, that most likely act in concert with one another with many feedbacks. Since the AMO index began shifting into a warm phase around the year 1995, changes within the North Atlantic Ocean could be affecting certain species, driving changes in their relative abundance, especially species that do not constantly reside in the PB. For example, the Gulf Stream has been known to shift its latitude which has been correlated to the NAO index (Taylor & Stephens 1998, Nye et al. 2014). As the NAO is related to the AMO, the position of the Gulf Stream could affect the amount of nutrients brought up the Northeast coast or the mixed layer depth, affecting the community of plankton.

Other areas along the Atlantic Coast have linked changes in plankton abundance to climatic drivers. In the Gulf of Maine, *Calanus finmarchicus* abundances were correlated with the NAO (Greene & Pershing 2000). Green & Pershing (2000) hypothesized that *Calanus finmarchicus* abundances might be affected by the presence of a particular water mass with certain water properties that intrudes into the Gulf of Maine in negative NAO years. In turn, Pershing et al. (2005) found that the recruitment of some fish species in the Gulf of Maine were

correlated with the leading zooplankton mode. The amount of primary production in a system can cause fishery yields to vary (Ware & Thomas 2005), and structure herbivorous fish populations (Cury et al. 2000, Ayón et al. 2008). In essence, changes in large-scale ocean processes could potentially induce bottom-up effects that will affect the survival and growth of certain fish and macro-invertebrate species, especially during the winter months when most species reside along the shelf. In conclusion, these climatic shifts that involve temperature or wind patterns induce physical changes within the ocean or coastal areas that in turn affect productivity (Hunt Jr. et al. 2002, Möllmann et al. 2008). Essentially, fluctuations in climate can induce bottom-up effects that drive changes in species populations.

Studies have correlated climatic indices to changes in community structure of phytoplankton and zooplankton (Fromentin & Planque 1996, Greene & Pershing 2000, Beaugrand & Kirby 2010, David et al. 2012), and overall productivity (Belgrano et al. 1999, Palter et al. 2005). The PB plankton biomass was one factor in determining the finfish and macro-invertebrate community. Average total chlorophyll a values across the time series have declined since 1987, with peaks occurring in 1987-1989, 1995-1997 and 2009-2010. A further Pearson (0.53; $p=0.007$) and Spearman rank (0.44; $p=0.027$) correlation between annual anchovy relative abundance and chlorophyll reveals a significant ($p<0.05$) association, indicating that productivity of the PB system and anchovy abundance are linked. Anchovies small size, planktivorous feeding, and short life history expose these species to high mortality, which in turn make them important prey for many species in the Bay. Thus, climatic changes could ultimately affect the composition of phytoplankton and zooplankton which resonates throughout the upper trophic levels causing alterations of food webs or ecosystems (Francis et al. 1998, Frederiksen et al. 2006). Thus, climatic changes could ultimately affect the composition of phytoplankton and

zooplankton which resonates throughout the upper trophic levels causing alterations of food webs or ecosystems (Francis et al. 1998, Frederiksen et al. 2006).

Interestingly, two other large estuaries that neighbor the PB showed similar shifts during the same time period suggesting broad-scale factors may be driving regional system dynamics in otherwise disparate ecosystems. Howell & Auster (2012) describe a phase shift in finfish abundance that occurred in the Long Island Sound (LIS). In their study, they grouped the most numerous species collected in their spring and fall tows into two categories: cold-adapted and warm-adapted species. Overall, they found that the cold-adapted species declined over the time series (1976-2008) in both the spring and fall, and that warm-adapted species increased in both seasons. They correlated this change to rising spring and fall water temperatures in the LIS. Along with this observation, they used a non-metric multidimensional scaling technique to determine years that had similar community composition during 1976-2008. They found that the spring community structure had shifted in the late 1990's and that the years 1984-1998 and 1999-2008 had a different composition of species. The fall community structure did not have as clear a split as the spring did, but after 2000, fall community structure was noticeably different than the 80's and 90's.

Using a trawl survey in Naragansett Bay, Collie et al. (2008) examined the changes in community structure from 1959-2005, as well as studying possible variables that could be contributing to those changes. They correlated sea surface temperature, spring-summer temperature, chlorophyll a concentrations, the winter NAO index, the AMO index, and fishing pressure to changing species abundances. Like the current study performed in the PB, Collie et al. (2008) also lagged the environmental variables by 1 and 2 years as well to account for recruitment. Through non-metric multidimensional scaling, they found a major shift in

community composition occurred in the early 1980's, which they considered to be a regime shift. Collie et al. (2008) mention that the early 2000's community might have been shifting toward a structure similar to the 1970's. Correlations between species abundance and environmental variables revealed that SST and chlorophyll a concentrations were most strongly to the time series. SST and spring-summer SST were significant, as well as, when it was lagged by 1 and 2 years similar to Howell & Auster's (2012) findings. Chlorophyll a concentrations were not lagged. The winter NAO index was also correlated, but not as strongly as SST and chlorophyll a. The AMO index was not significantly similar to the change in community structure, however it was correlated with the decline in demersal fish at one of the stations.

There appears to be coherence in the regime changes that occurred in the PB, Long Island Sound and Narragansett Bay with both individual species and systems exhibiting similar changes. Of the 22 taxa that were found to be dominant in the PB, 15 of those species were also found to be locally important in either the Long Island Sound or Narragansett Bay (Collie et al. 2008, Howell & Auster 2012). Eleven species (butterfish, horseshoe crab, squid, scup, smooth dogfish, spider crab, striped searobin, summer flounder, weakfish, windowpane flounder and winter flounder) had similar trends in abundance while only 4 (calico crab, northern pipefish, northern searobin, tautog) had opposite trends in abundance (Table 4). Calico crabs did significantly decline in the PB, but significantly increased in the Narragansett Bay. The species that displayed similar trends in comparison had strong ($p < 0.001$) signals of change such as the significant increase in scup and butterfish in all three systems as well as the strong decline of windowpane and winter flounder. The fact that these three systems exhibited coherent trends suggests that they might be linked by regional processes or that stocks are connected across systems.

It is important to note that the Peconic survey was designed primarily for targeting young of the year species to examine annual recruitment. Therefore, the codend of the net used has a mesh size of 3.2cm with a 1.3cm mesh liner (Weber et al. 1998). In both the Long Island Sound and Narragansett Bay studies, Howell & Auster (2012) and Collie et al. (2008) report using nets with a 5.1cm cod end. Therefore, the distribution of size ranges of fish and invertebrates caught are most likely different between the LIS and NB studies compared to the PB. While the PB survey focuses more on young of the year fish, the NB and LIS surveys most likely catch some young of the year, but comparatively more juveniles and adults. Also, the LIS survey tows at a speed of 3.5 knots, while the NB study tows at 2 knots, but both tow for a 30 minute duration. The PB survey only tows for 10 min at a speed of 2.5 knots (Weber et al. 1998). Although, there are some differences to the gear and methods of collection for each survey, all three still exhibit similar patterns.

Collie et al. (2008) and Howell & Auster (2012) both discuss how rising sea surface temperatures in the LIS and NB have affected fish communities. They note that species that prefer colder temperatures such as winter and windowpane flounder have seen drastic declines in abundance, while species that prefer warmer waters such as butterfish and scup have seen significant increased abundance. Collie et al. (2008) report a 1.6°C increase in winter temperatures across the time period, which is about a 0.03°C increase per year. Howell & Auster (2012) only had temperature data available from 1991-present and used a regression to extend the data backward to 1984-2008. Although, no rate of change was mentioned, they found annual deviations from mean bottom water temperature shifted to positive values in 1998, which is just 3 years after the AMO changed into a positive state. The PB has exhibited a small increase in seasonal bottom temperatures at an annual rate of about 0.04°C (Figure 17), similar to the value

seen in Narragansett Bay. Not only can temperature affect the distribution of a species directly, but it can impact the success of spawning and recruitment.

Changes in temperature can induce early or late migratory and spawning behavior in different species (Sims et al. 2004, Fincham et al. 2013). Since the PB is a temperate system and mainly used by migratory species, changes in timing of different species migrations could have top down or bottom up effects, resulting in shifting temporal overlaps of predator-prey species. For example, the PB is utilized by at least 6 different species of flatfish (winter flounder, windowpane flounder, summer flounder, smallmouth flounder, hogchoker and four-spot flounder) and they utilize the Bay for different aspects of their species life history. Winter and windowpane flounder enter the Bay in March-May to spawn (Able & Fahay 1998, Collette & Klein-MacPhee 2002), and their YOY settle early in the season (May-June) when other species are rarely present. Late juveniles and adult summer flounder are present in the Bay starting in the beginning of June and persist in the system until the end of September. Summer flounder are common predators of winter flounder YOY and their occurrence overlaps with YOY winter flounder and windowpane flounder. Smallmouth flounder reportedly spawn from spring-fall depending on the latitude (Able & Fahay 1998), but an abundance of juvenile/adult fish aren't seen in the PB until mid-August. From 2006-2012, only 22 YOY smallmouth flounder (<50mm) were caught, and most were caught after September. These species of flatfish exhibit different life histories, especially in terms of spawning; winter flounder spawn in estuaries and bays in the late winter, summer flounder spawn offshore and adults move inshore most likely to feed in the summer months, while smallmouth flounder arrive in estuaries and bay in the late summer/early fall.

In the Peconics, there was an increase in abundance of summer flounder (4.4%/year) and smallmouth flounder (6.3%/year) and severe declines in winter (-9.2%/year) and windowpane flounder (-10.1%/year). A linear regression of average May temperatures and the week when 15% of the total individuals entered the system revealed that summer flounder enter the PB earlier when early spring temperatures are warmer. On average, from 1987-1999, 15% of all individuals for the year entered the PB around week 24, but from 2000-2012 they entered the PB around week 22.5 (two tailed t-test; $p=0.013$). Therefore summer flounder migrate into the system about 12 days earlier since about 2000. Since they enter the estuary earlier, their temporal overlap with winter flounder YOY is more synchronous, allowing summer flounder to prey upon winter flounder YOY for a longer period of time. Thus, since the AMO is in a warm phase and when years exhibit warmer spring temperatures, winter flounder have a longer window time where they are preyed upon by summer flounder.

In contrast, the late summer/fall spawning smallmouth flounder has increased in abundance, while winter flounder that feeds on smallmouth flounder (Collette & Klein-MacPhee 2002) has decreased. Thus, a shift in the timing of migration could create cascading ecosystem effects not directly related to the effect of temperature on a species productivity. In essence, temperature can shift migration patterns, which in turn can influence the spatio-temporal overlaps of predator-prey species, inducing shifts in the trophic dynamics. Trophic dynamic interactions with long-term climate trends are likely present across the region. Winter flounder is currently at historical lows in the Long Island region and high post-settlement mortality of juveniles has been suggested as a mechanism (Yencho et al. in press). The results for the PB are consistent with regional trends and suggest long-term changes of the abundance and occurrence for seasonal predators may be affecting the productivity of local stocks of winter flounder.

Although, abundances and distributions of fish might be affected on a fine-scale, a larger, more long-term picture is important as well, especially for fishery managers in understanding the overall dynamics of an ecosystem. If ecosystem shifts are predictable, then managers can apply a regime-specific harvest rate essentially altering catch limits to match potential yields of different species. Another approach would be to adopt a two-level management strategy which accounts for short-term fluctuations (for example, changes in abundance of forage fish or prey species) and long-term fluctuations (deYoung et al. 2008).

The PB system appears to have transitioned through 4 community configurations in the past 25 years. The most significant shift occurred around 2000 as a result of long-term climate signals. These climate effects can have varying impacts on species' physical environments causing changes in their abundance from either top-down and/or bottom-up controls, such as prey availability or spatio-temporal migratory overlaps in predator-prey species. What is not clear is how biodiversity and ecosystem functioning are linked directly to the climate indices, and whether these shifts represent alternate stable states. Additionally, there is a lack of understanding on whether these shifts are part of a resilient system dynamic and are predictable, or have been caused from some other factor. However, what is clear is that the PB system, as others in the region, is experiencing shifts in communities that are linked to broad climatic drivers. Continued monitoring of the PB ecological community will continue to improve the understanding of how and why ecosystem changes occur, which in turn will improve management decisions.

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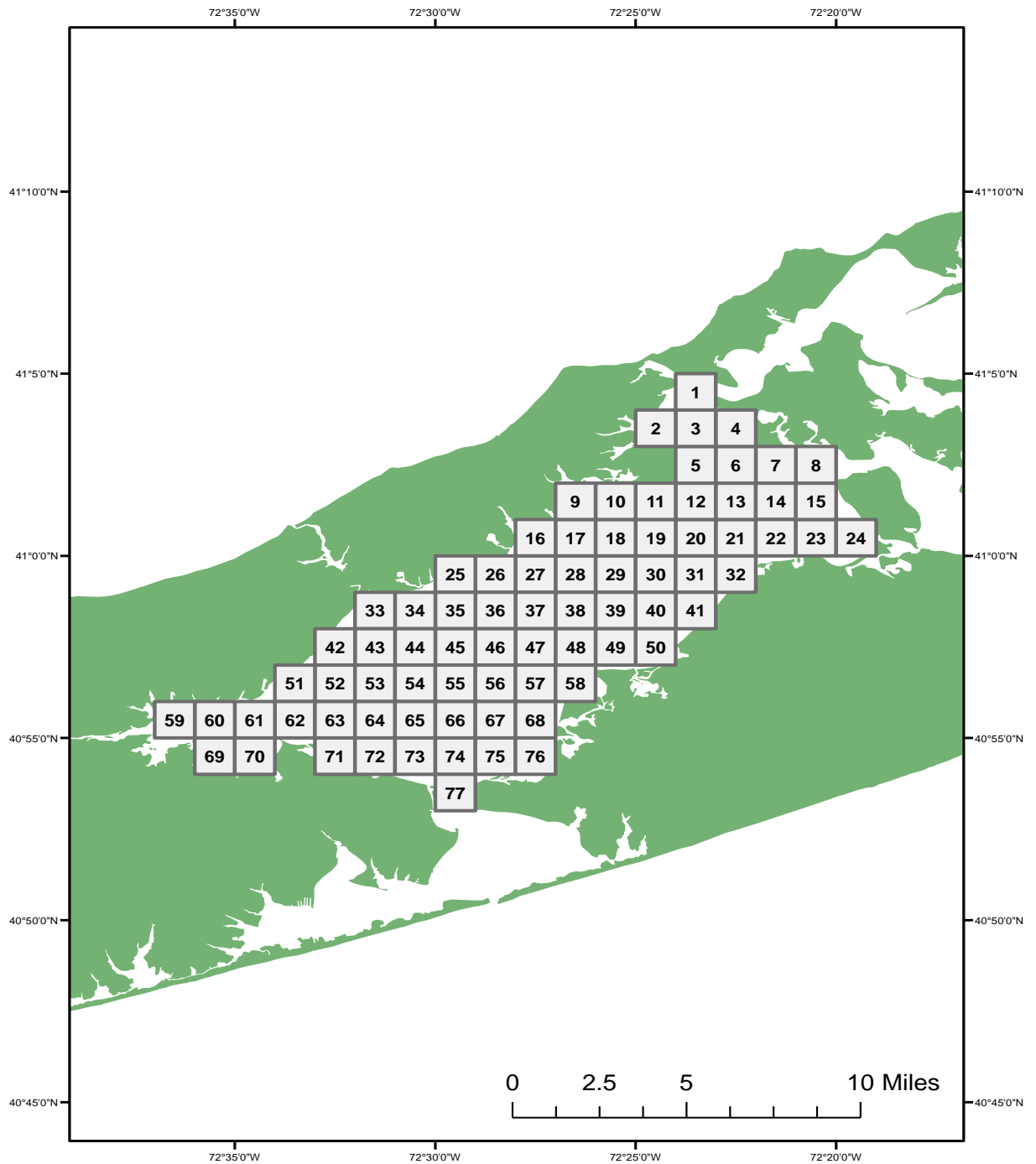


Figure 1. Survey stations used in the Peconic Trawl Survey. Stations were based off of a 1' latitude and 1' longitude grid. Recreated from Weber et al. (1998).

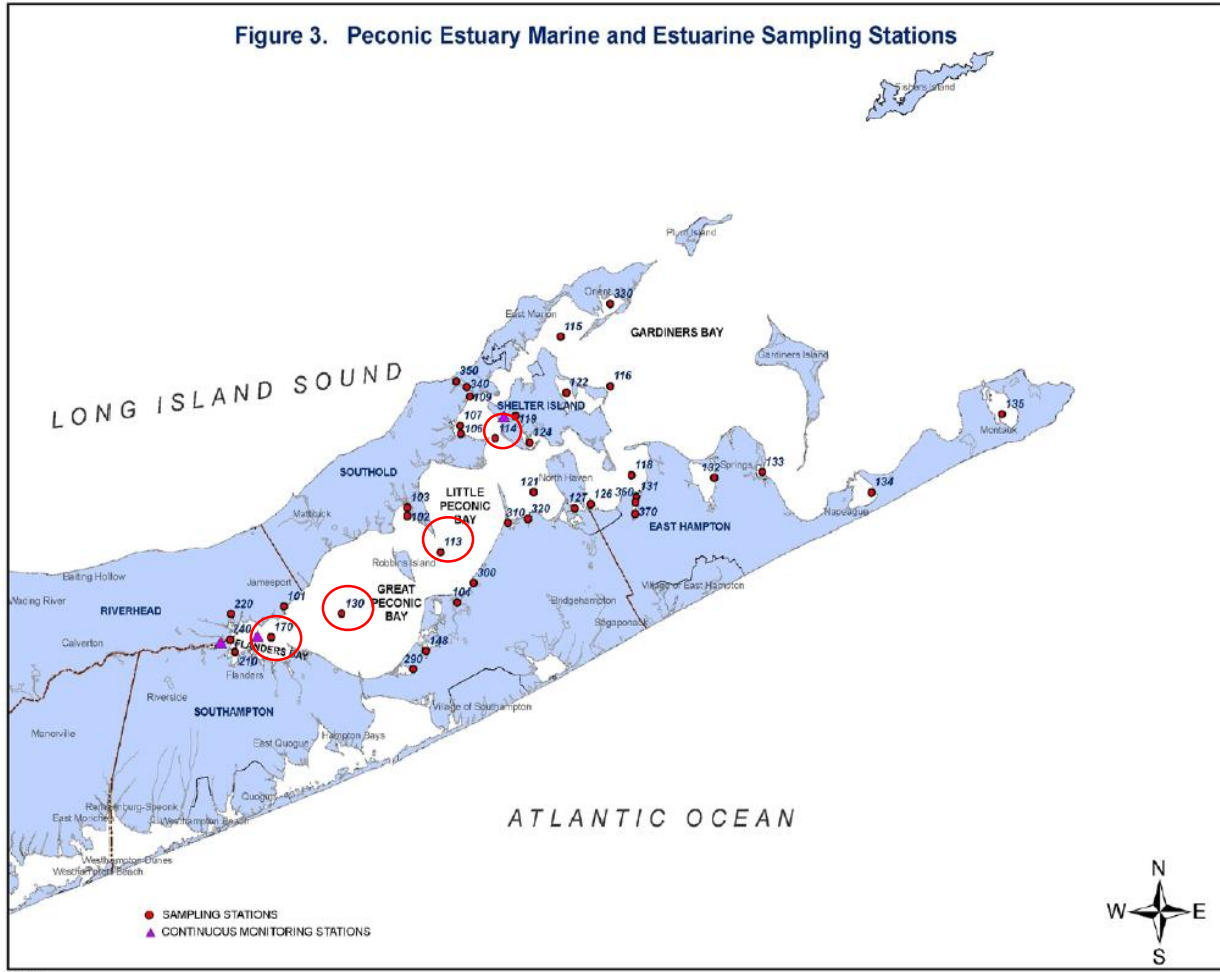


Figure 2. Map of sites where water quality sampling is performed on a monthly basis from Suffolk County Department of Health Services. Chlorophyll values from stations circled in red were used in the current study (St. 133, 114, 130 and 170). Map taken from SCDHS (2010).

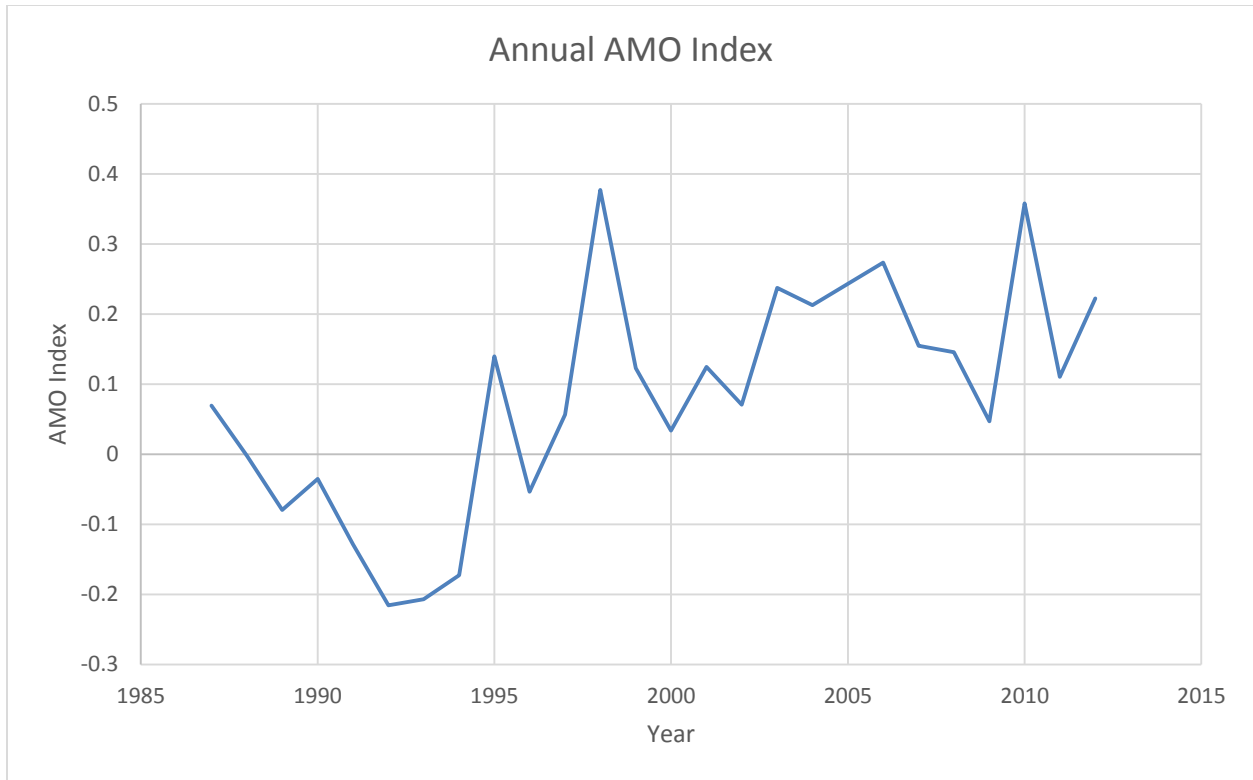


Figure 3. Annual AMO Index. Averaged from monthly values taken from the National Oceanic & Atmospheric Association (NOAA).

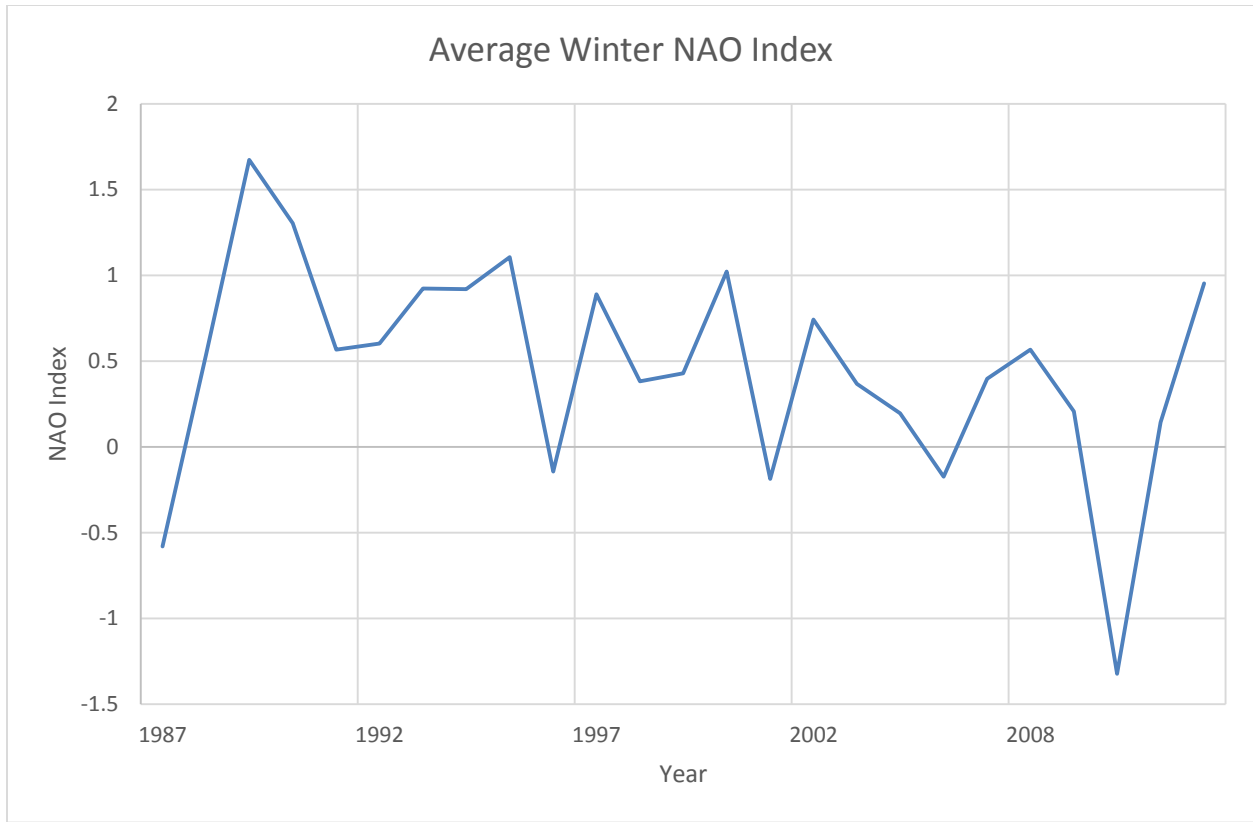


Figure 4. Winter (Jan-Mar) NAO Index. Averaged from monthly values taken from the National Oceanic & Atmospheric Association (NOAA).

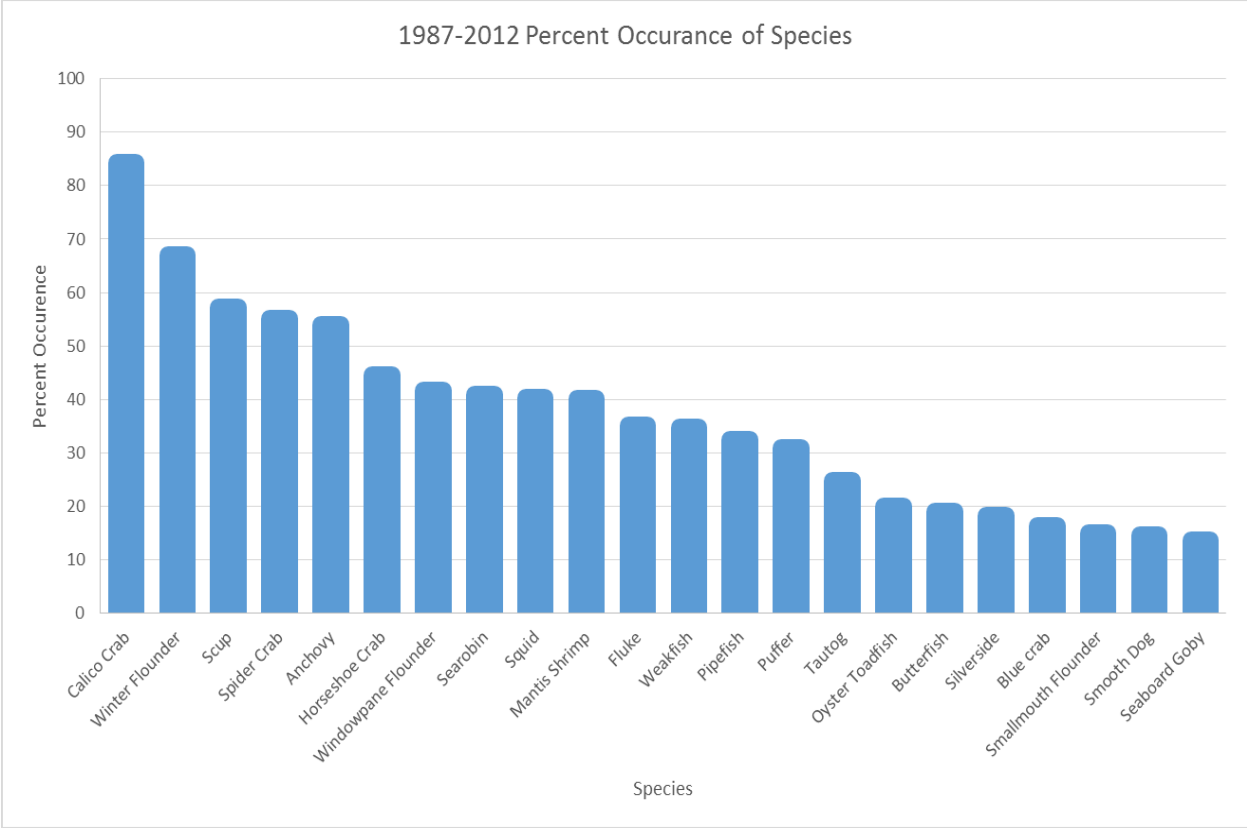
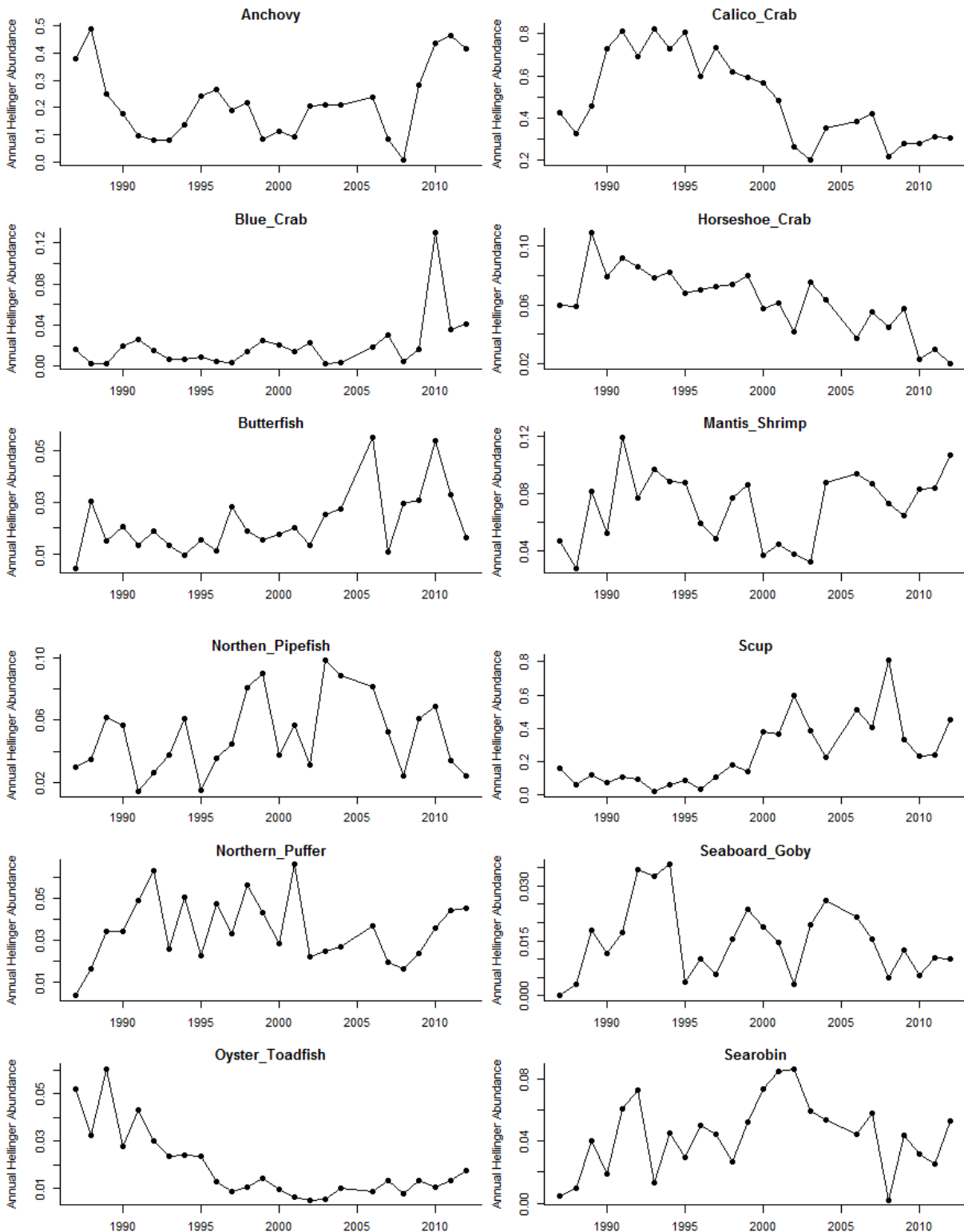


Figure 5. Bar graph of the taxa that occurred more than 10% of the time in all tows from 1987-2012.



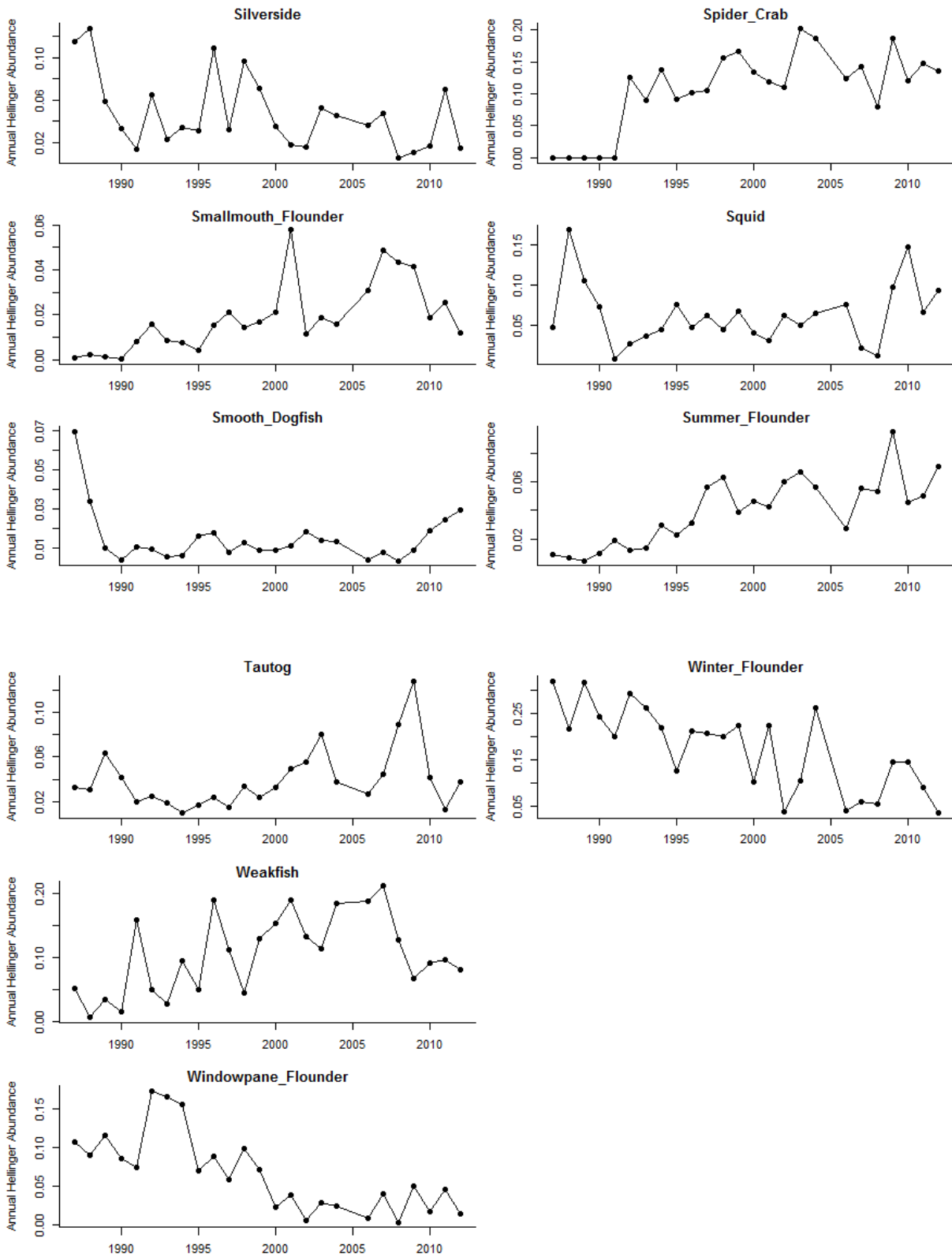


Figure 6. Hellinger transformed survey year relative abundance of the 22 taxa that occurred more than 10% of the time in all tows.

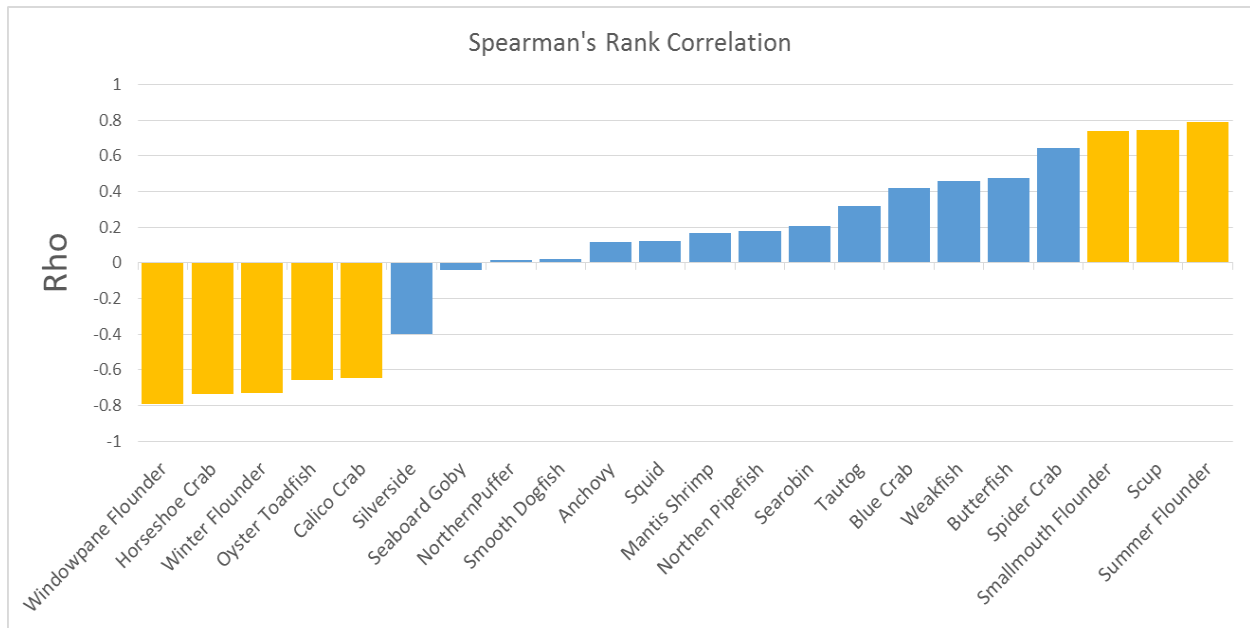


Figure 7. Spearman's Rank Correlation between years and Hellinger transformed abundance. Rho is a measure of the correlation between the year and the species relative abundance based on ranking. Species' bars that appear in yellow are statistically significant at the $p < 0.001$ level.

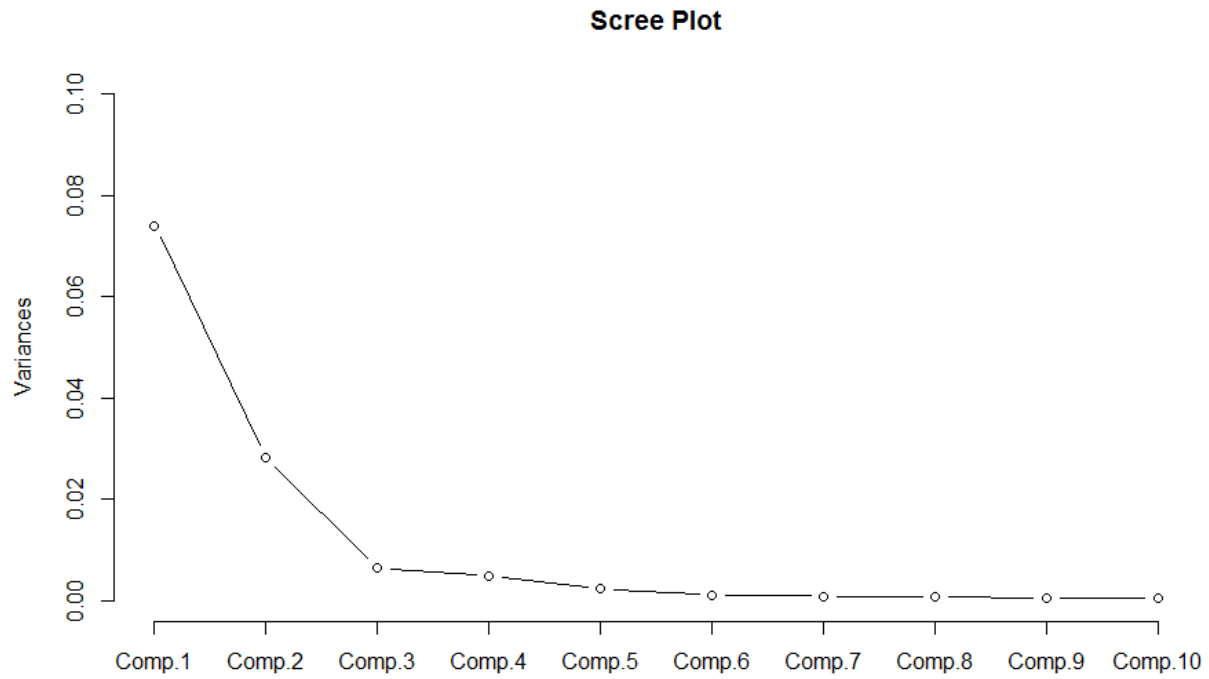


Figure 8. Scree plot of the first 10 components of the Principal Components Analysis. The first two components comprised 84.6% of the variance in community composition.

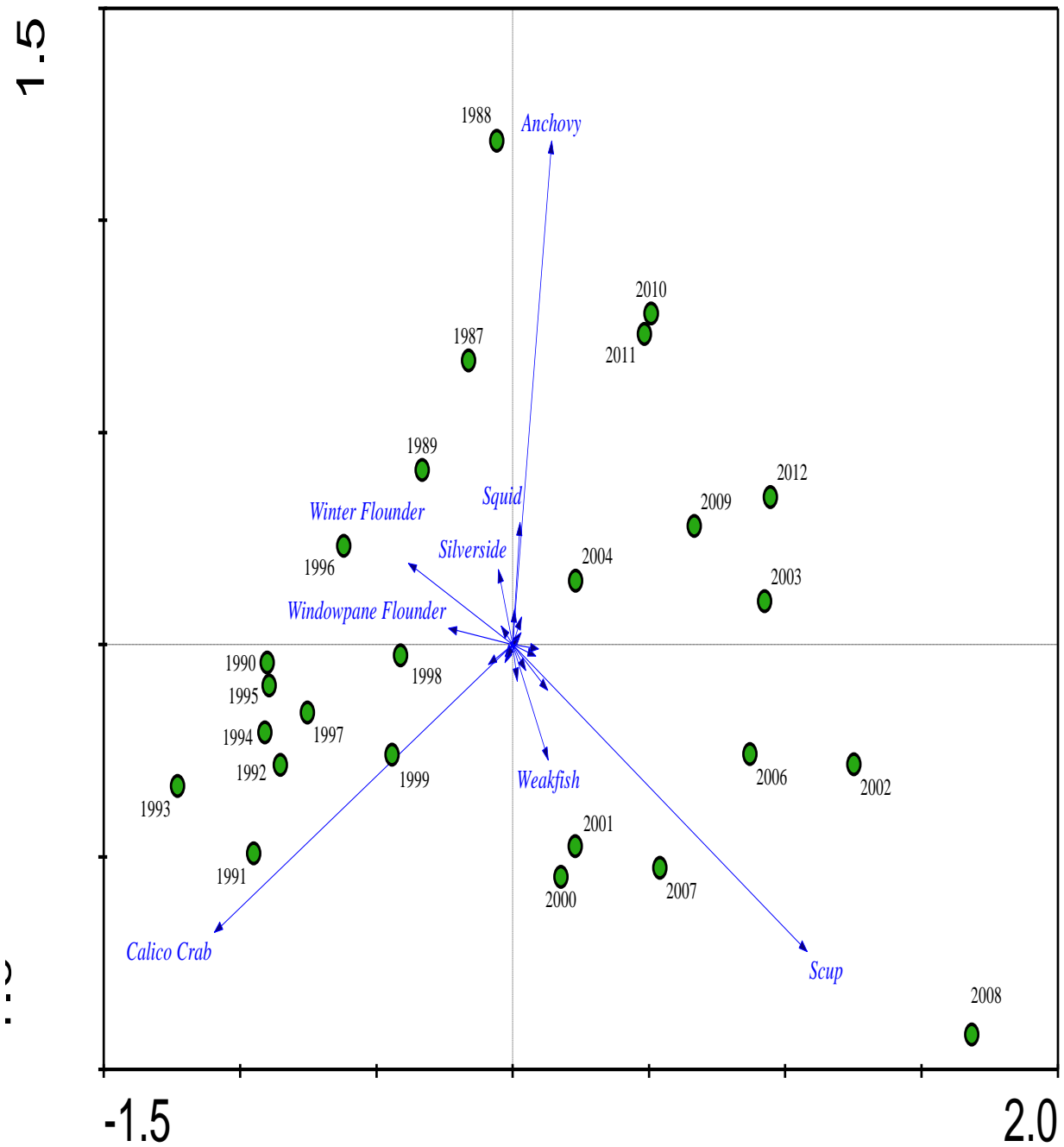


Figure 9. Biplot of the principal components analysis performed. The x-axis is the first principal component, while the y-axis is the second principal component. Blue arrows represent species. Green circles represent years.

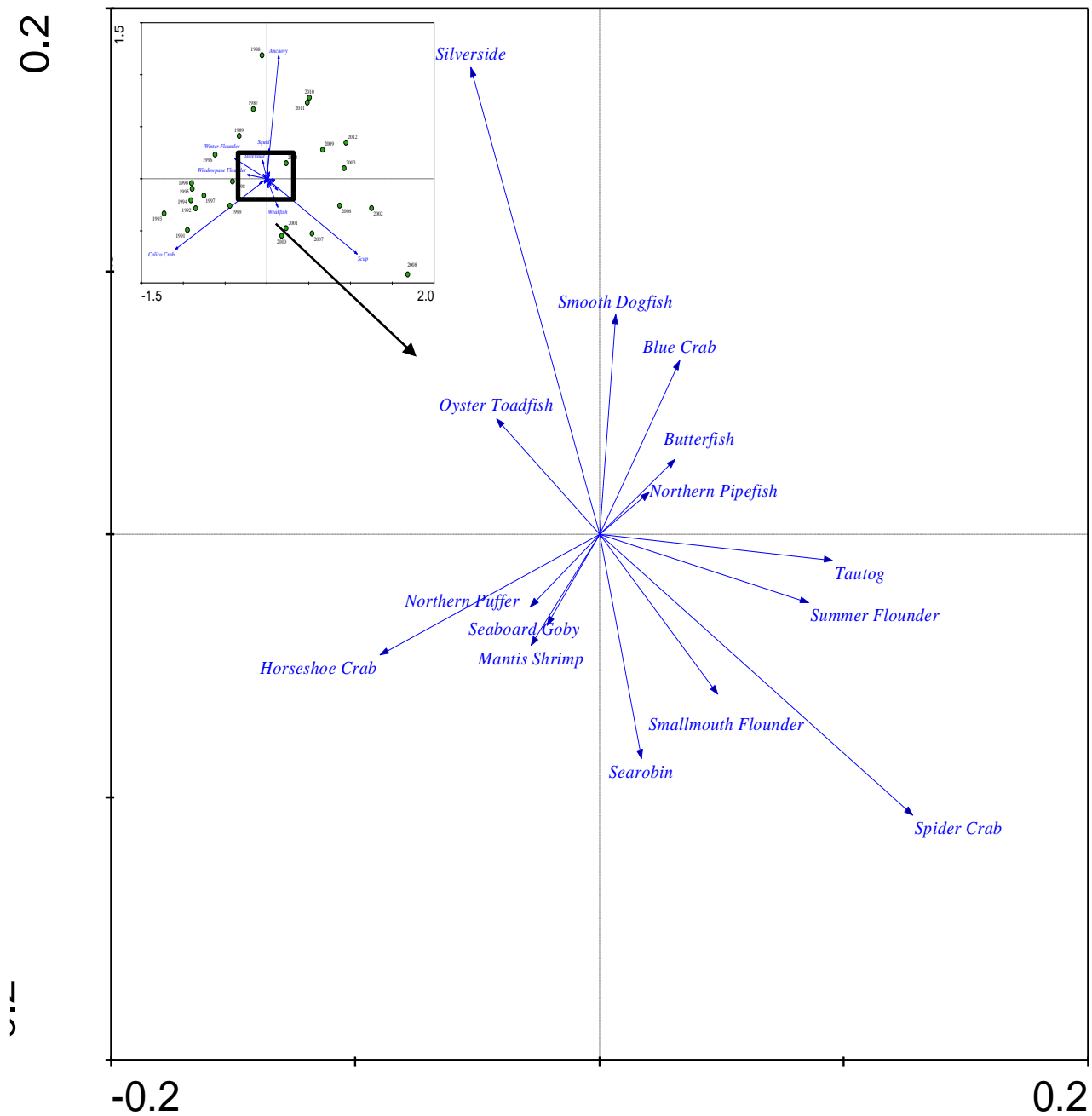


Figure 10. An expanded view of the species that had low loading values from the principal component analysis in Figure 9. The x-axis is the first principal component, while the y-axis is the second principal component. Blue arrows represent species.

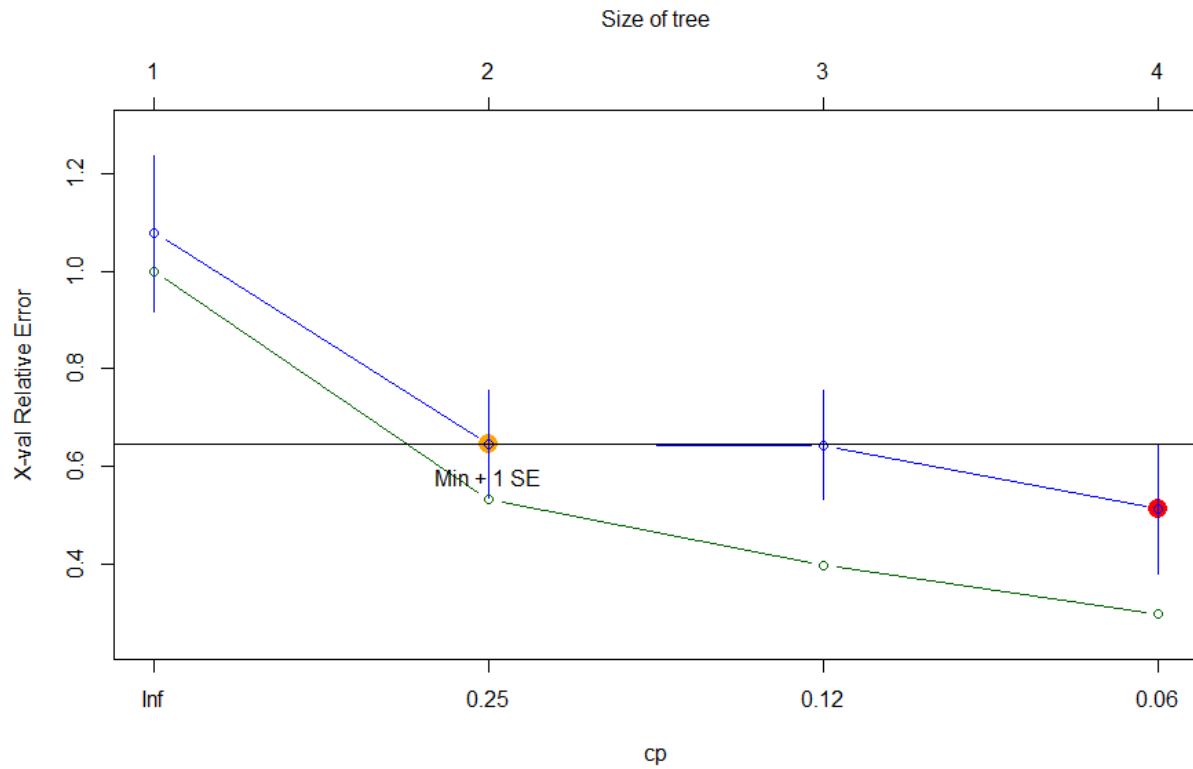


Figure 11. Cross-validation relative error (blue line) with error bars and complexity parameter (cp) based on the size of the tree. The green line is the relative error of the regression tree. The black line is 1 unit of standard error above the minimum of the curve.

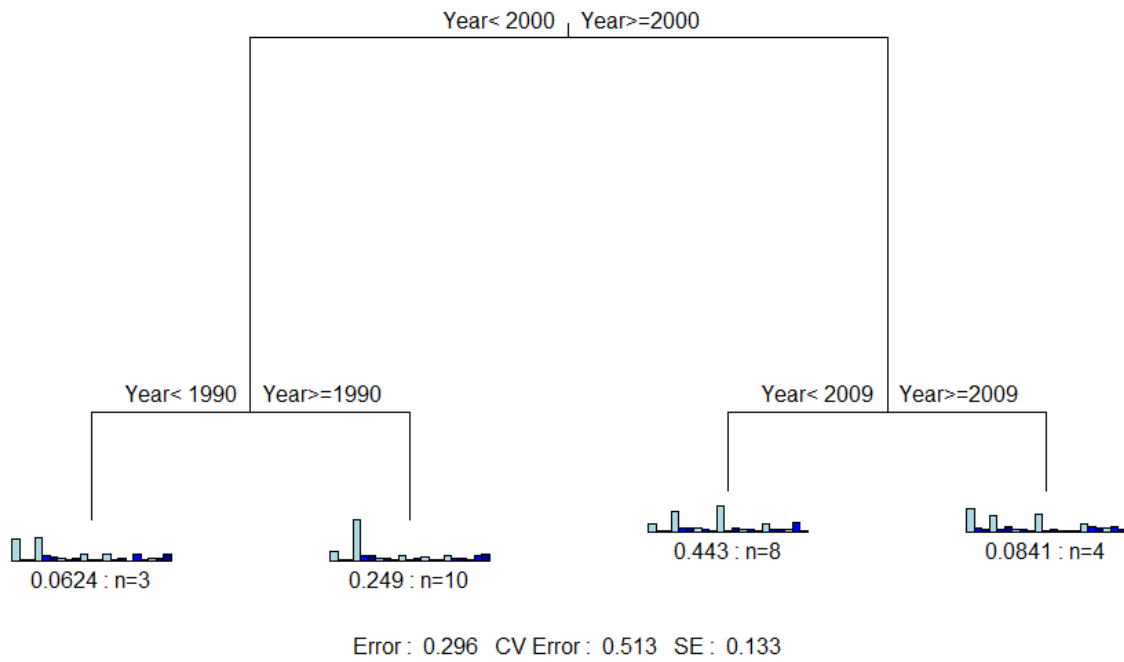


Figure 12. Results of the multivariate regression tree analysis.

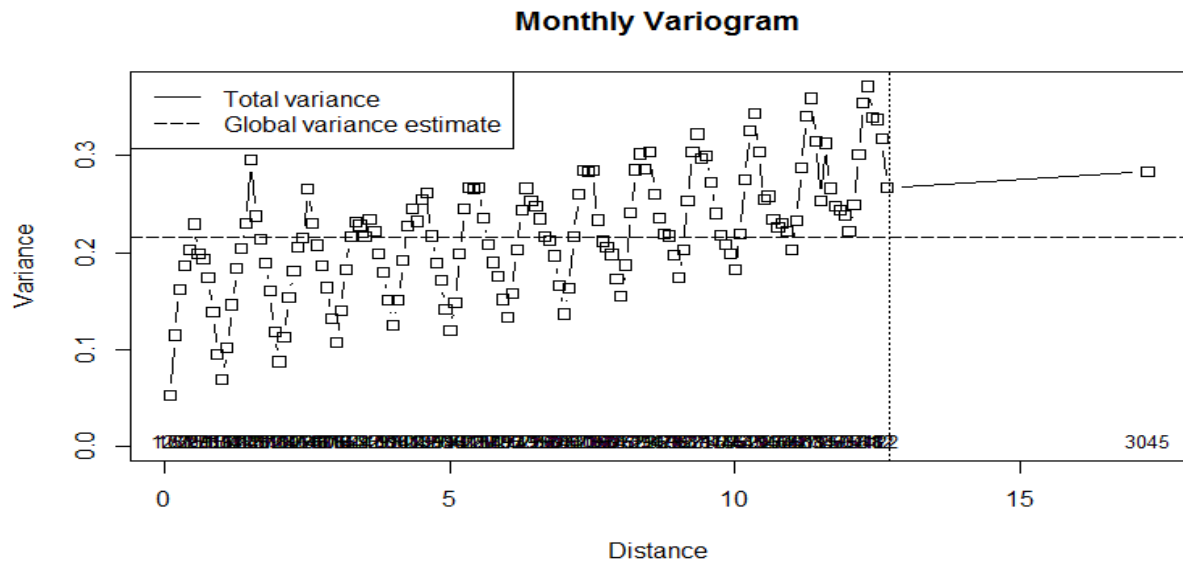


Figure 13a. Monthly variogram of the 22 taxa. The x-axis represents the temporal distance between pairs of samples, while the y-axis is the semi-variance between pairs of samples.

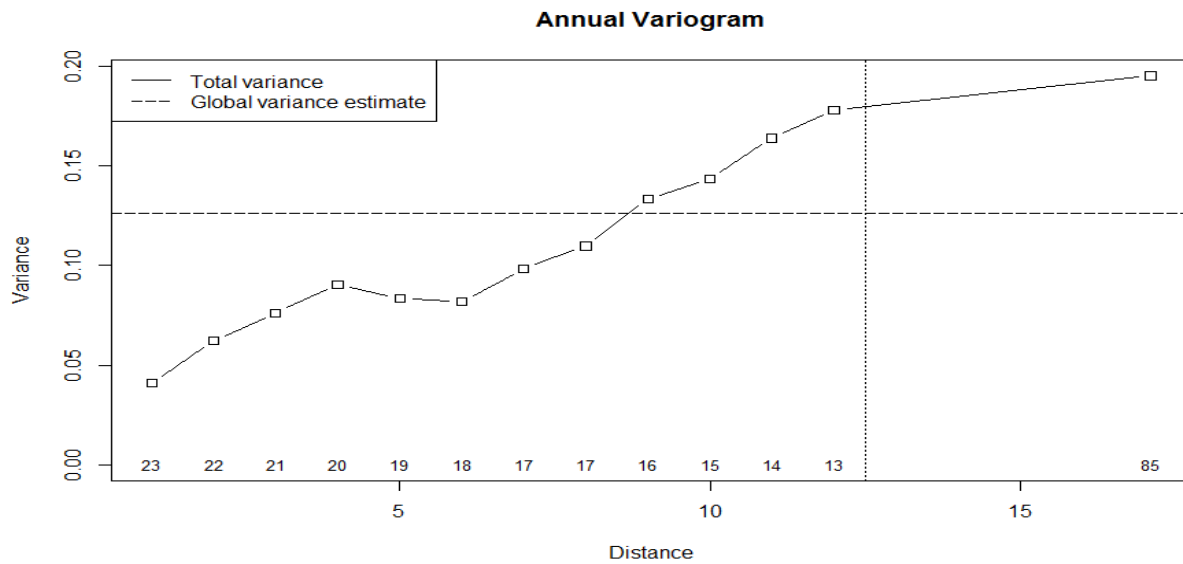


Figure 13b. Yearly variograms of the 22 taxa. The x-axis represents the temporal distance between pairs of samples, while the y-axis is the semi-variance between pairs of samples.

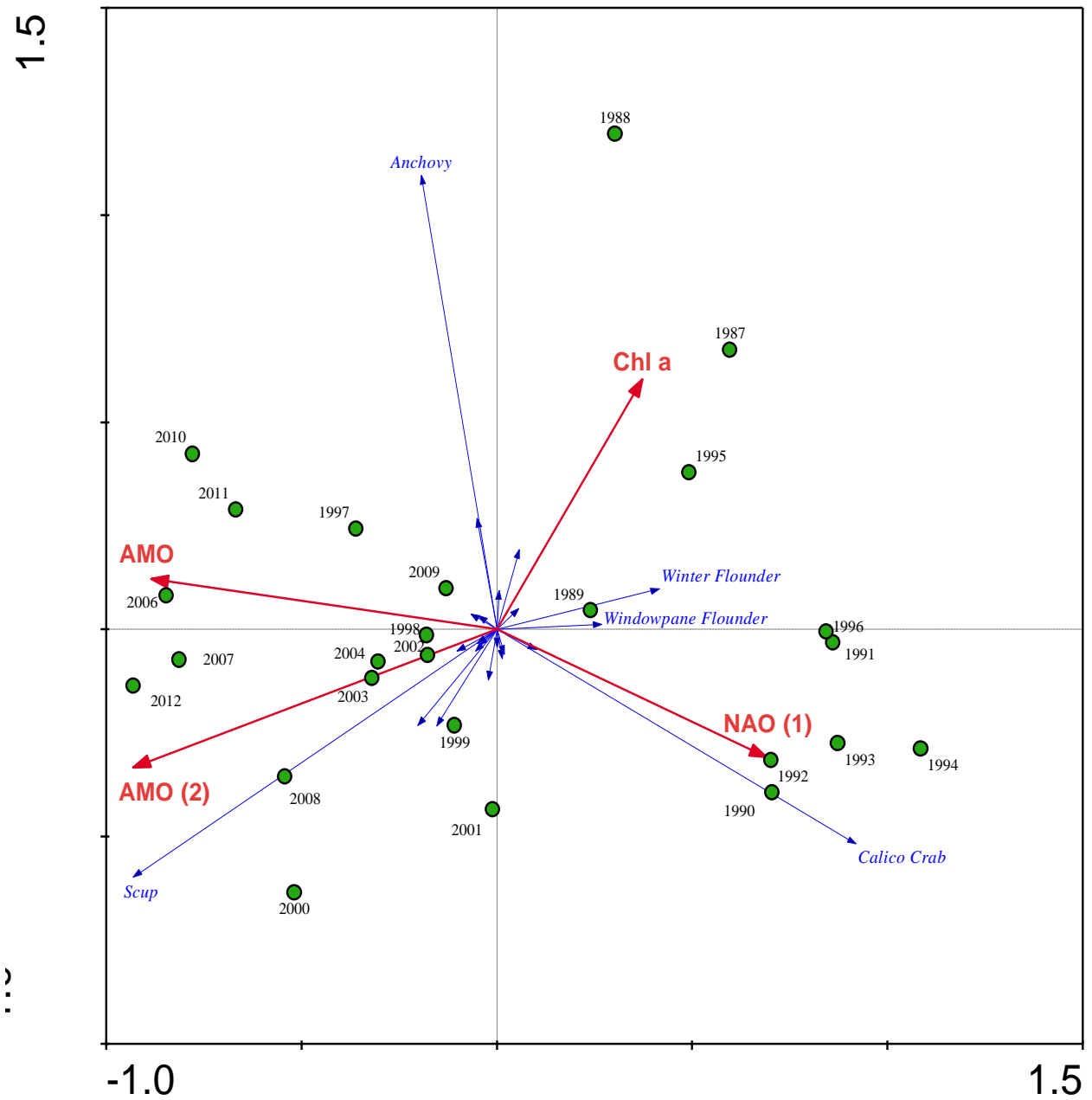


Figure 14. Redundancy Analysis results. The first two RDA axes are plotted. The green circles represent samples (annual transformed abundances) The blue lines represent species and the red lines represent environmental variables. Only the environmental variables that were included in the minimum AICc model are plotted.

0.3

0.3

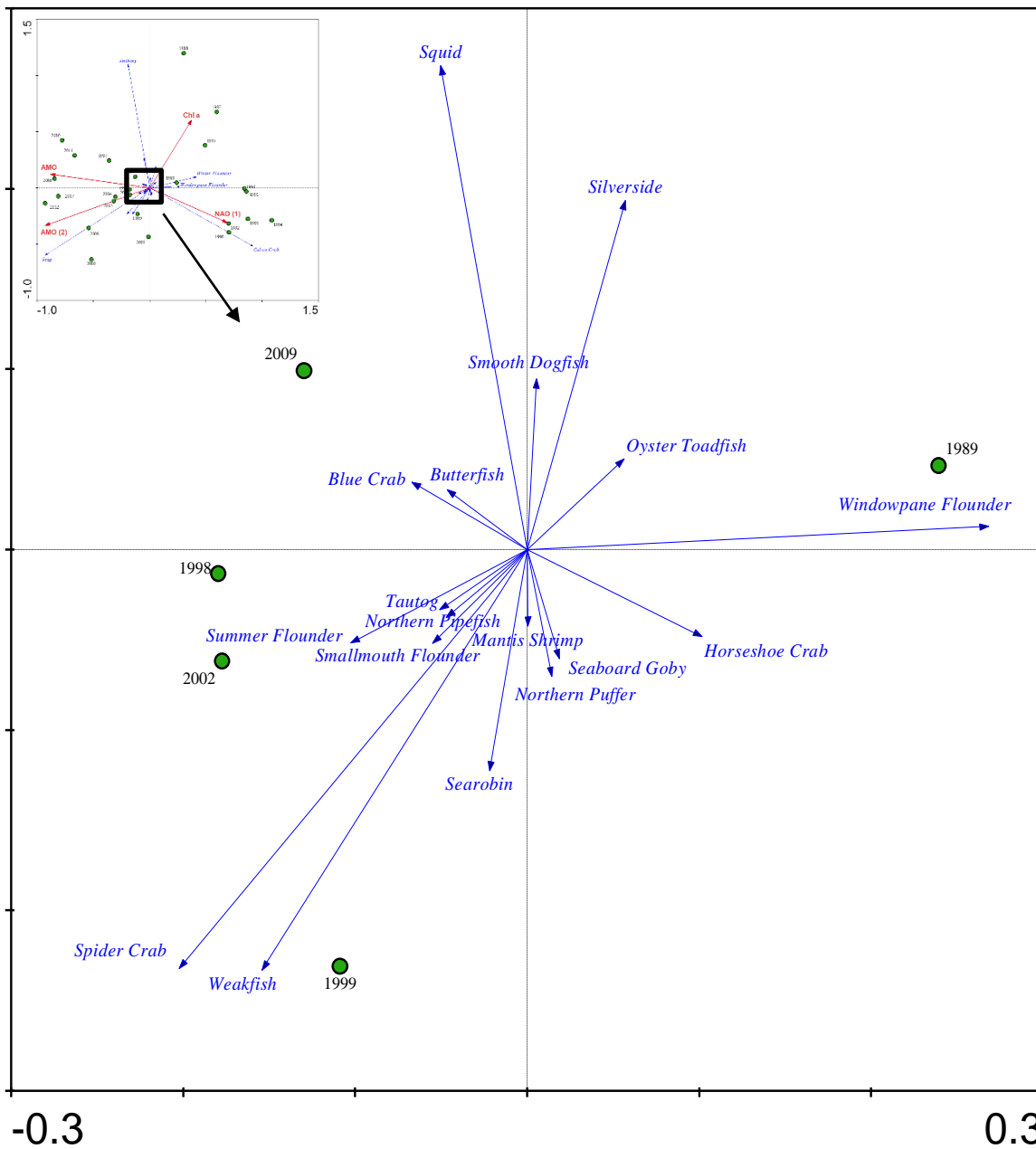
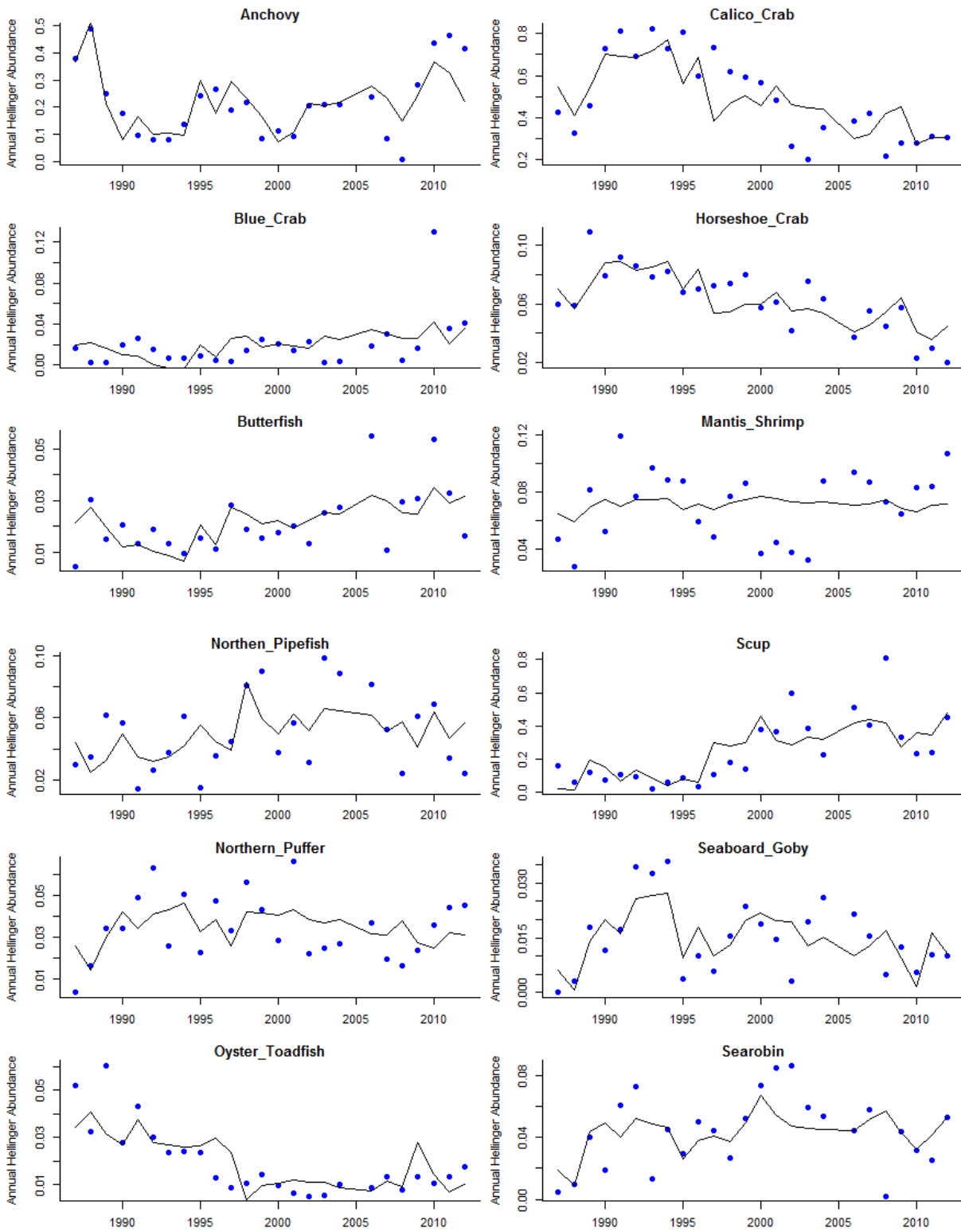


Figure 15. An expanded view of the species that had low loading values from the Redundancy Analysis in Figure 14.



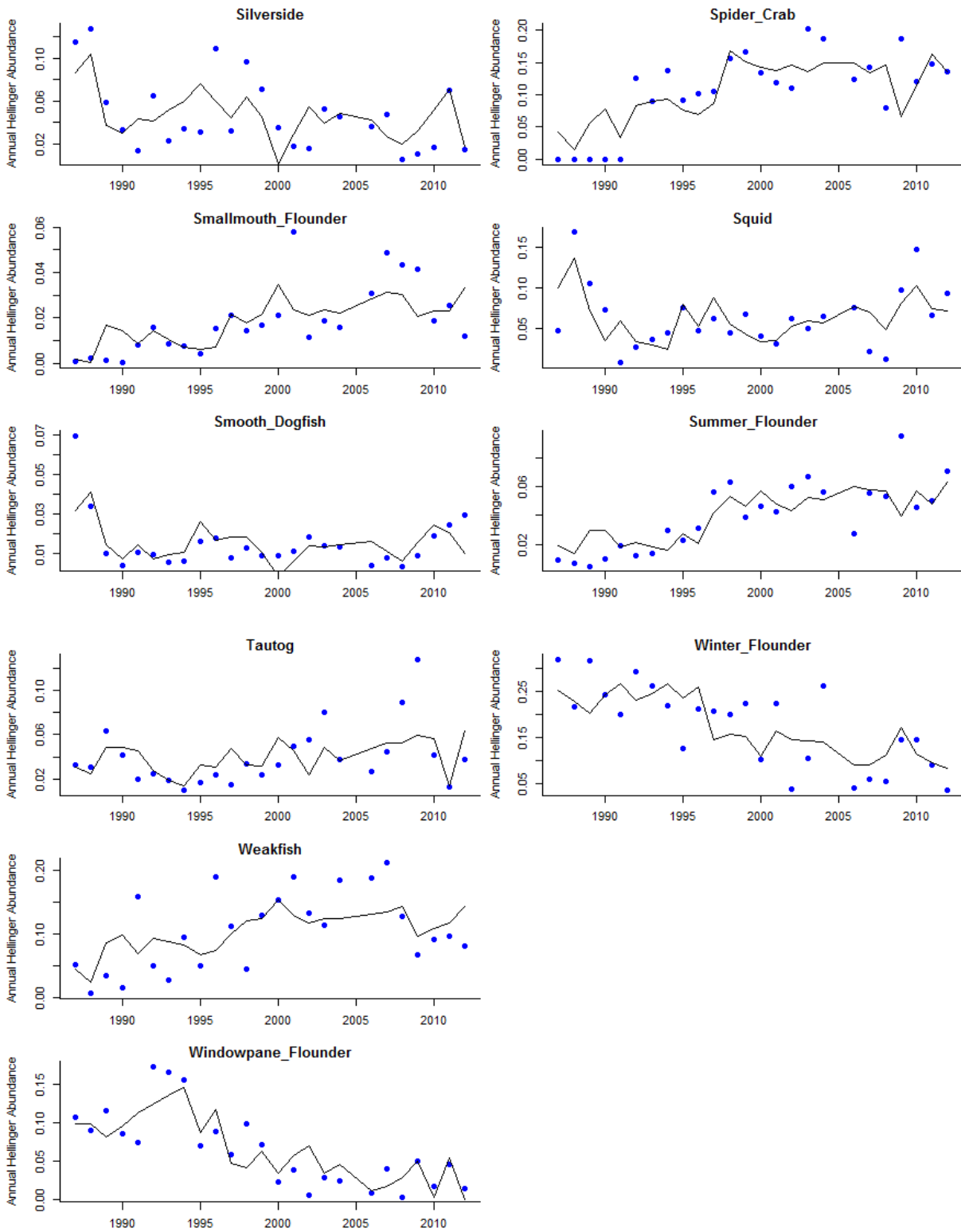


Figure 16. Plots of species annual Hellinger transformed abundance (points) and the predicted abundance (lines) based on the results of the RDA model.

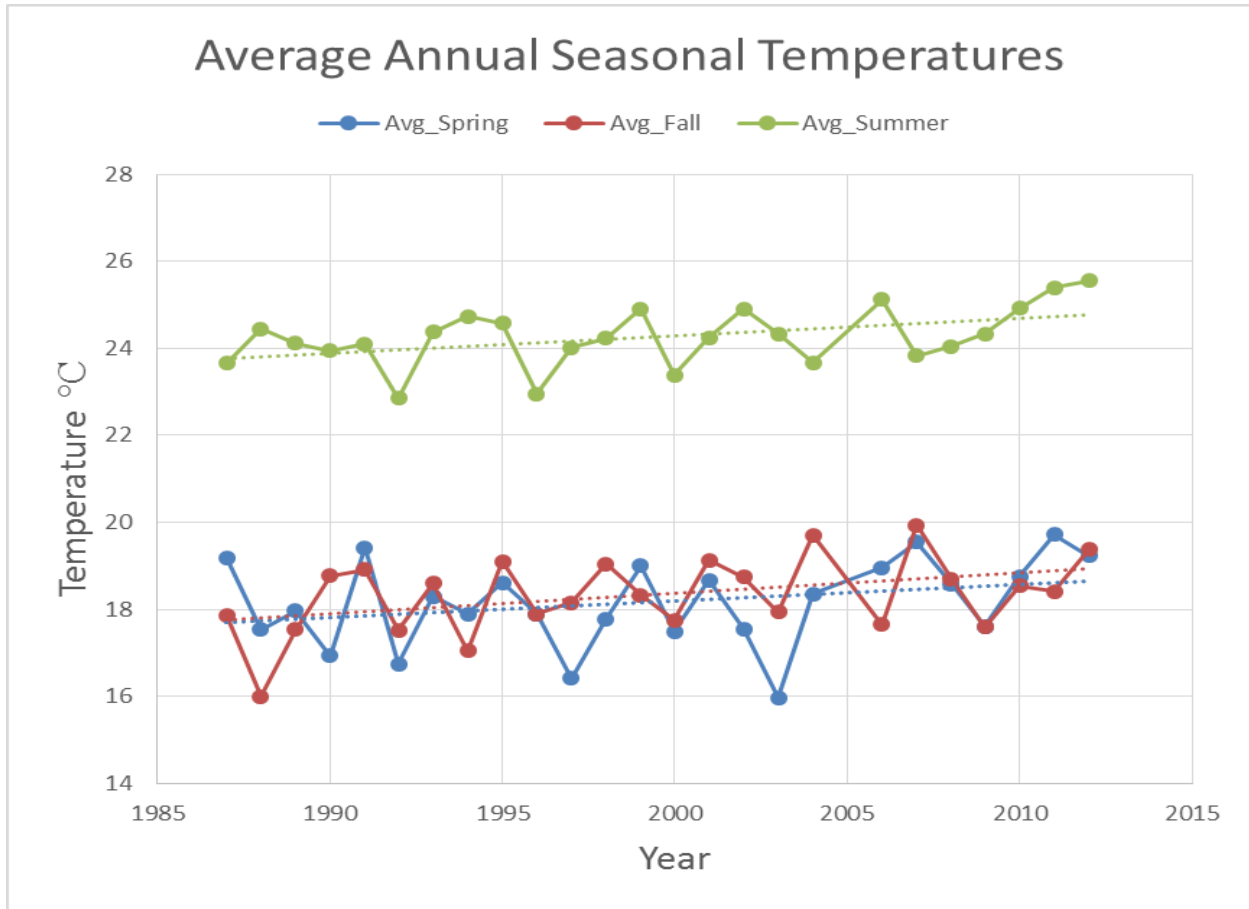


Figure 17. Observed seasonal bottom water temperatures of the Peconic Bay. Green lines are annual temperatures of the summer (July-August). Blue lines are annual temperatures of the spring (May-June) and red lines are annual temperatures of the fall (September-October). Dotted colored lines are the linear regression for the plotted temperatures (Summer: slope=0.040, $R^2=0.212$, Spring: slope=0.039, $R^2=0.091$, Fall: slope=0.047, $R^2=0.17$)

Scientific Name	Common Name	Percent Occurrence (%)
<i>Ovalipes ocellatus</i>	Calico Crab	84.3
<i>Pseudopleuronectes americanus</i>	Winter Flounder	67.0
<i>Stenotomus chrysops</i>	Scup	57.2
<i>Libinia dubia</i> + <i>Libinia emarginata</i>	Spider Crab spp.	55.2
<i>Anchoa mitchilli</i> + <i>Anchoa hepsetus</i>	Anchovy spp.	53.9
<i>Limulus polyphemus</i>	Horseshoe Crab	44.6
<i>Scophthalmus aquosus</i>	Windowpane Flounder	41.7
<i>Prionotus evolans</i> + <i>Prionotus carolinus</i>	Searobin spp.	40.9
<i>Loligo pealei</i>	Long-Finned Squid	40.4
<i>Squilla empusa</i>	Mantis Shrimp	40.2
<i>Paralichthys dentatus</i>	Summer Flounder	35.1
<i>Cynoscion regalis</i>	Weakfish	34.7
<i>Syngnathus fuscus</i>	Pipefish	32.5
<i>Sphoeroides maculatus</i>	Puffer	30.9
<i>Tautoga onitis</i>	Tautog	24.7
<i>Opsanus tau</i>	Oyster Toadfish	20.0
<i>Peprilus triacanthus</i>	Butterfish	19.0
<i>Menidia spp.</i>	Silverside spp.	18.2
<i>Callinectes sapidus</i>	Blue Crab	16.3
<i>Etropus microstomus</i>	Smallmouth Flounder	14.9
<i>Mustelus canis</i>	Smooth Dogfish	14.6
<i>Gobiosoma ginsburgi</i>	Seaboard Goby	13.6

Table 1. List of species, along with their scientific name and common name, that occurred in more than 10% of all tows performed from 1987-2012.

Species	PC1	PC2
Scup	0.663	-0.443
Anchovy	0.088	0.728
Weakfish	0.080	-0.167
Spider Crab	0.079	-0.065
Tautog	0.058	-0.006
Summer Flounder	0.052	-0.016
Smallmouth Flounder	0.030	-0.037
Blue Crab	0.020	0.041
Butterfish	0.019	0.017
Squid	0.016	0.177
Northern Pipefish	0.012	0.010
Searobin	0.010	-0.052
Smooth Dogfish	0.004	0.051
Seaboard Goby	-0.013	-0.021
Mantis Shrimp	-0.017	-0.026
Northern Puffer	-0.017	-0.017
Oyster Toadfish	-0.026	0.027
Silverside	-0.032	0.109
Horseshoe Crab	-0.055	-0.028
Windowpane Flounder	-0.145	0.024
Winter Flounder	-0.235	0.118
Calico Crab	-0.671	-0.415

Table 2. Species loadings from the first two principal components. Species are arranged from highest to lowest loadings from PC1

Axes	1	2	3	4	Total variance
Eigenvalues	0.376	0.144	0.008	0.002	1
Species-environment correlations	0.79	0.793	0.517	0.529	
Cumulative percentage variance:					
of species data	37.6	52	52.8	53.1	
of species-environment relation	70.9	98	99.6	100	
Sum of all eigenvalues					1
Sum of all canonical eigenvalues					0.531

Table 3. RDA results for the minimum AICc model.

Species	Peconic Bay	Long Island Sound	Narragansett Bay
Butterfish	+	+	+
Horseshoe Crab	-	N/A	-
Lady Crab	-	N/A	+
Longfin Squid	+	N/A	+
Northern Pipefish	+	N/A	-
Northern Seabrook	+	-	N/A
Scup	+	+	+
Smooth Dogfish	+	+	N/A
Spider Crab	+	N/A	+
Striped Seabrook	+	+	+
Summer Flounder	+	+	+
Tautog	+	-	-
Weakfish	+	+	+
Windowpane Flounder	-	-	-
Winter Flounder	-	-	-

Table 4. Species of finfish and macro-invertebrates that occurred in at least 2 of the 3 comparable systems (Peconic Bay, Long Island Sound, Narragansett Bay). Positive trends in abundance are represented by +, while negative trends are represented by -. Species that were not mentioned or included in a survey are represented by N/A. Species highlighted in green have similar trends in abundance in each of the systems, while species highlighted in black have opposite trends in abundance in at least two of systems.

Chapter 2

Modeling and Mapping Habitat Preferences and Spatial Utilization of Four Young-of-the-Year Species in the Peconic Bay Estuary

Introduction

Animal populations exhibit distributions that are heterogeneous throughout space and time. Spatially, the area that a population occupies should, theoretically, be the most suitable habitat in terms of survival and fitness (Morris 1987). The non-randomness of species habitat and the tendency of species to choose optimal habitat led to the “ideal free distribution” theory (Fretwell & Lucas 1970), which postulates that a species will distribute themselves in the best habitat assuming that they have full knowledge of all available habitat and are free to move. However, the habitat that a population chooses is based on a multitude of factors and can be categorized as density-independent (e.g. temperature) or density-dependent (e.g. competition) (Morris 2003, Camp et al. 2011, Huijbers et al. 2012). Understanding the relationship between species and habitat is a fundamental component of properly employing conservation and management decisions with a place-based component, such as conservation or marine protected areas.

Marine and estuarine fish species are expected to choose habitat based on physical environmental preferences (temperature, salinity, oxygen) that would maximize growth and reproduction (Morris 1987, Froeschke & Stunz 2012). These optimal conditions, however, might be confounded by density-dependent effects. An individual will be exposed to inter- and intra-specific competition as well as predation, and will therefore select areas where predation risks and competition rates are lower (Rahel & Stein 1988, Hobbs & Munday 2004, Bentley et al.

2014). Species abundance, however, is not static, and theory suggests that as the abundance of a population increases, the distribution of the population will be expected to shift and expand into new, possibly less suitable habitats (Fretwell & Lucas 1970). This has been observed in striped bass (*Morone saxatilis*; Callihan et al. 2014), anchovy (*Engraulis encrasicolus*) and sardine (*Sardinops sagax*; Barange et al. 2009), and juvenile cod (*Gadus morhua*; Laurel et al. 2004). Thus, many factors can result in individual choice of suitable habitat towards maximizing their probability of survival.

To further complicate the potential efforts to model a species' preferred habitat, most species undergo an ontogenetic shift in habitat selection (Dahlgren & Eggleston 2000, Gratwicke et al. 2006, Elliott et al. 2007). This is known to occur in many marine species as the habitat needed to survive after hatching through early life history critical periods are different than juvenile growth and adult spawning and foraging habitat preferences. These ontogenic changes in a species habitat requirements result in the structuring of a population, most likely separating breeding/nursery grounds from adult habitats (Beck et al. 2001). This can result in the migration of a species from its spawned location to a different habitat location, as the needs of a species changes throughout its life and with different seasons.

Estuaries are one of the most productive habitats in the world (Allen 1982), and many fish migrate long distances (Kendall & Walford 1979, Thorrold et al. 2001) to take advantage of these areas either as spawning grounds, nursery areas, or foraging habitat (Beck et al. 2001, Elliott et al. 2007). Studies have shown that species benefit from nursery areas most likely because of the availability of prey items, refuge from predators, and optimal growing conditions (Sheaves et al. 2014). While estuaries are potentially important for juvenile nursery areas, they are also places where predators can aggregate to take advantage of the accumulation of prey

(Buckel et al. 1999). Because estuaries provide important habitat to developing fish, and are potentially subjected to high predation pressure, it is important to understand what type of habitats certain species utilize and where these areas are in an estuary (França et al. 2012), especially when considering areas for conservation efforts (Barberá et al. 2012).

The Peconic Bay has a diverse community of finfish that occupy the area, especially in during the summer months, as is the case with temperate estuary and coastal habitats (Jordaan et al. 2011). Northern puffer (*Sphoeroides maculatus*), scup (*Stenotomus chrysops*), weakfish (*Cynoscion regalis*) and winter flounder (*Pseudopleuronectes americanus*) are important ecologically and economically in the PB community, and all display periods of high and low abundance through the year. In addition to seasonal patterns, species have demonstrated differing trends in abundance over time. For example, northern puffer abundance in the Bay has remained relatively constant since 1987, while winter flounder's abundance has seen dramatic declines. On the other hand, scup and weakfish abundances have increased in the Bay. Thus density independent and dependent related effects are expected to differentially impact individual species in relation to abundance trends, thus these four species will form specific examples of habitat use in a temperate estuary complex.

Northern puffer (*Sphoeroides maculatus*) are found in abundance along the East Coast from Massachusetts to northern Florida where their distribution slightly overlaps with their confamilial species the southern puffer (*Sphoeroides nephelus*). The northern puffer (puffer) are inshore migratory fish that inhabit bays and estuaries in the summer and migrate offshore in the winter. Spawning occurs from mid-May into the fall, where the female deposits eggs with an adhesive surface in the sediment to be fertilized (Sibunka & Pacheco 1981, Able & Fahay 1998, Collette & Klein-MacPhee 2002). Puffers use their powerful jaws to opportunistically feed on

invertebrates such as small crabs, shrimp, amphipods, barnacles, small mollusks and sea urchins (Shipp & Yerger 1969, Sibunka & Pacheco 1981, Collette & Klein-MacPhee 2002). They are well known for their ability to inflate their stomach with air or water in distress. This defense mechanism is to scare or deter possible predators, therefore only a few species are known to prey on puffers, those being large pelagic fish such as tuna, bluefish, and some sharks (Collette & Klein-MacPhee 2002). Puffers were an important food fish during World War II, but catches have since declined. Currently, there is little to no commercial market for these fish, although they are sometimes sold as “sea squab” (Collette & Klein-MacPhee 2002). Little is known about the population structure of this species, and besides being accounted for in community surveys (Wilk et al. 1996, Howell & Auster 2012), little information exists on abundance estimates. However, they are an important species in the estuaries of the Northeast U.S (Weber & Grahn 1995).

Scup (*Stenotomus chrysops*) are demersal, schooling (often by age), temperate fish found in abundance between Massachusetts and North Carolina, and are an important migrant species in Long Island Sound and Narragansett Bay (Steimle et al. 1999, Collette & Klein-MacPhee 2002). Scup overwinter in southerly offshore locations between New Jersey and North Carolina and return inshore to bays and estuaries in the spring as far north as Massachusetts. Spawning does not seem to occur on the continental shelf but rather in estuaries or large bodies of water in more saline areas beginning in April (Able & Fahay 1998). No reports of spawning activity have been reported south of New Jersey (Steimle et al. 1999). Frequent predators of scup are sharks, dogfish, bluefish, summer flounder, weakfish, black sea bass, and striped bass (Steimle et al. 1999, Collette & Klein-MacPhee 2002). Smaller scup (<250mm) are reported to prey upon cnidarians, polychaetes, amphipods, and mysids as well as small crustaceans, mollusks, and fish

eggs and larvae (Steimle et al. 1999, Collette & Klein-MacPhee 2002). There is a large commercial and recreational fishery for scup south of Cape Cod, which brings many fisherman to the coast in the summer season (Opaluch et al. 1999, Collette & Klein-MacPhee 2002). Commercial landings peaked around 1960 reaching about 22,000 metric tons. In 2011, landings in the commercial fishery were about 6,800 metric tons, while recreational rod-and-reel landings were estimated at about 1,600 metric tons.

Weakfish (*Cynoscion regalis*) are a highly migratory, schooling fish (Thorrold et al. 2001) ranging from Florida to Massachusetts, being most abundant between North Carolina and New York (Able & Fahay 1998, Collette & Klein-MacPhee 2002). Multiple spawning events take place in bays and estuaries between March through August depending on location, with the peak production between May and July (Mercer et al. 1989, Able & Fahay 1998, ASMFC Weakfish T.C. 2009). Estuaries are known to be important nursery areas for juvenile weakfish, where juveniles mostly feed on crustaceans, mysid shrimp, and anchovies. Estuaries also provide foraging areas for adults which prey predominately on clupeids and anchovies, but also feed on crustaceans, mysid shrimp, squid, mollusks, annelids, scup, butterfish, and flounders (Mercer et al. 1989, Greco & Targett 1996, Collette & Klein-MacPhee 2002). Weakfish diet has been reported to vary based on location (Greco & Targett 1996, ASMFC Weakfish T.C. 2009). Predators of young weakfish include blue fish, striped bass and adult weakfish, while adults are preyed upon by sharks, dogfish, and summer flounder (Collette & Klein-MacPhee 2002, Sagarese et al. 2011). A fishery has existed for weakfish since the eighteenth century, but have seen wide fluctuations in commercial landings (Collette & Klein-MacPhee 2002). Since 1950, commercial harvest of weakfish on the Atlantic coast has ranged from 400-16,000 metric tons.

Peak catches were between 1975-1985, but dropped precipitously after 1989 with one the lowest catches seen in 2007 (~388 metric tons) (ASMFC Weakfish T.C. 2009).

Winter flounder are a species of flatfish which, historically and currently, maintain an important commercial and recreational fishery, as one of the meatiest and thus sought after flatfishes (Collette & Klein-MacPhee 2002). They are unique in the sense that they spawn in the winter usually between January and April (Able & Fahay 1998, Pereira et al. 1999), and contain an anti-freeze protein in their blood that allows them to tolerate water temperatures as low as -1.4°C (Collette & Klein-MacPhee 2002). Currently, a debate exists over whether there are two subpopulations of winter flounder, those being resident fish that stay in estuaries and bays throughout the year and a migratory population that moves offshore after spawning (Sagarese & Frisk 2011, Fairchild et al. 2013, Gibson 2013). Young of the year utilize inshore nursery areas such as shallow bays and estuaries and do not seem to move far from their settlement areas (Saucerman & Deegan 1991, Collette & Klein-MacPhee 2002). Low recruitment to the fishery is thought to be one of the reasons why the population has been at its lowest abundance (O'Leary et al. 2013, Wilber et al. 2013). In New York, as of 2009, commercial catch levels of winter flounder are at 9%, and the recreational fishery has reported catch at less than 2%, of the levels that were observed at the peak of the fishery in the 1980's.

The focus of this study was to create spatial habitat models for four species of YOY fish that are important to the Peconic Bay community, identify areas of specific use, and determine the key abiotic features that describe the spatial pattern of species. This study used data generated by the New York State Department of Environmental Conservation's (NYSDEC) annual juvenile trawl survey. To identify and visualize essential areas within the PB that might disproportionately contribute to the success of YOY, GIS maps of abundance were created and

abundances interpolated to identify core areas of use. Then generalized additive models were implemented to describe abiotic habitat preferences of the four YOY species. In addition, general areas of high species richness and diversity were also mapped.

Materials and Methods

Fisheries Survey

The NYSDEC has conducted a fishery-independent trawl survey since 1987. The survey area consisted of Flanders Bay, Great Peconic Bay, Little Peconic Bay, and several smaller bays (Southold Bay, Noyack Bay, and Shelter Island Sound) bordering Shelter Island not including the North and South channels around Shelter Island. The allocation of stations is based on 77 1' latitude and 1' longitude sampling blocks (Figure 1). Each week from May through October, the survey samples 16 randomly chosen stations, with some annual start dates beginning in the end of April and some end dates spilling over into November. Exceptions to this design plan included no trawls in 2005, and none until mid-July in 2006, the beginning of August in 2008, and the beginning of June in 2010. Throughout the survey, 10.7 meter lobster-style workboat named the David H. Wallace collected samples using a 4.9 meter semi-balloon otter trawl with a 3.2cm mesh codend and a small mesh liner (1.3 cm). Tows were set for 10 minutes at an approximate speed of 2.5 knots (Weber et al. 1998). For more information on gear and survey design see Weber et al. (1998).

The general start locations of each trawl usually occurred at the center of each trawl sampling block. After 2000, a GPS navigation system was used to record the start and stop locations of each trawl. At the start of each tow, surface and bottom temperature, depth, salinity, dissolved oxygen and secchi disc depth were recorded. Depth was also recorded at the end of a tow.

Four species of young of the year fish were selected to study their seasonal habitat preferences (northern puffer [*Sphoeroides maculatus*], scup [*Stenotomus chrysops*], weakfish [*Cynoscion regalis*] and winter flounder [*Pseudopleuronectes americanus*]). Length data were extracted from the trawl survey from 2006-2012, and analyses were performed on YOY (northern puffer [$<101\text{mm}$], scup [$<84\text{mm}$], weakfish [$<153\text{mm}$], and winter flounder [$<91\text{mm}$]) (Able & Fahay 1998, Collette & Klein-MacPhee 2002). The data for each species was categorized into the season in which they were caught (Spring=April-June, Summer=July-August, Fall=September-October) and analyzed separately.

Generalized Additive Models

A two-stage GAM was created for each species and for each season, due to the large number of zero counts in the data (Welsh et al. 1996, Jensen et al. 2005, Sagarese et al. 2014). The first stage model (PA) was based on occurrence (presence-absence) and utilized a logit link function and binomial errors. The second stage model (ABUN) included only those tows that contained ≥ 1 individual of that particular species and was based on abundance expressed as the number individuals caught per tow (CPUE). This model utilized a log link function and negative binomial errors. Winter flounder YOY were rarely caught in the fall months, and therefore a GAM could not be created for this season due to the lack of data. Northern puffer, scup, and weakfish did not enter the PB system until late June, so spring season GAMs were not created for these species. In total, each species had PA and ABUND GAMs created for two seasons.

Explanatory variables taken from the trawl survey data included bottom temperature, bottom salinity, bottom dissolved oxygen, depth and secchi depth. Additionally, grain size data estimated during acoustic benthic mapping research was included in the analyses (Flood 2004;

Cerrato & Maher, 2007; and Cerrato et al. 2009, 2010). The sonar mapping study used side scan and multibeam sonar data to delineate bottom types of the PB. Each bottom type was subsequently sampled to estimate percent gravel, percent sand, percent mud, and organic content. Average sediment characteristics of each bottom type region were estimated utilizing the ArcMap data from the surveys and carrying out a spatial join of the bottom type polygons with the grain size point feature data. A second spatial join was then applied to assign the average grain size characteristics attributed to each bottom type to each trawl whose midpoint occurred within the bottom type polygon. Tows whose midpoint did not fall into bottom type areas were not used in the creation of the GAMs. Additionally, tows were only used in the GAM if they contained information for each explanatory variable (temperature, salinity, dissolved oxygen, depth and secchi depth, and grain size).

All GAMs were created using the rationale in Sagarese et al. (2014) and the packages “mgcv” (Wood 2011) and “MuMIn” (Bartoń 2014) in R (R Core Development Team 2010). Cubic regression splines were used in each model, along with 5 pre-specified knots or 5 degrees of freedom ($k=5$). To validate how well the GAM was able to predict the occurrence or abundance of a particular species, tows were randomized and divided into a training set that contained 70% of the data to create the models. The other 30% was used later as “test” data to estimate how well the model predicted a species’ occurrence or abundance (Fielding & Bell 1997, Brotons et al. 2004, Sagarese et al. 2014). All GAMs were first built using all of the variables. PA and CPUE models took the form of:

$$p = s(Temp) + s(Sal) + s(Depth) + s(DO) + s(Sec) + s(Sand) + s(Mud) + s(OM)$$

where p is the estimated probability of a species occurrence or abundance, s is the cubic regression spline, $Temp$ is the bottom temperature ($^{\circ}C$), Sal is the bottom salinity (ppt), $Depth$ is

the depth (meters), *DO* is the bottom dissolved oxygen (mg/L), *Sec* is the secchi depth (meters), *Sand* is the percentage of sand that constitutes the sediment, *Mud* is the percent mud found in the sediment, and *OM* is the organic matter contained in the sediment (percent loss on ignition). Percent gravel was not used in the GAMs to prevent co-linearity problems. The “dredge” function in the R package “MuMIn” was then applied to model every potential combination of explanatory variables. The model with the lowest Akaike Information Criterion (AIC) was selected as the best model.

To further test the validity of the PA GAMs (Swets 1988, Pearce & Ferrier 2000), Receiving Operating Curves (ROCs) were created in R using the package “pROC” (Robin et al. 2014). ROCs provided a graphical approach to evaluate the sensitivity (true positives) and specificity (false positives) of the presence-absence models (Zweig & Campbell 1993, Fielding & Bell 1997). This is done by plotting the individual sensitivity (true positive fraction) values on the y-axis and their specificity (false positive fraction) values on the x-axis based on the independent “test” data (in this case the withheld 30% of data). A model that predicts the “test” data perfectly will have a true positive fraction of 1.0 and a false positive fraction of 0 and will therefore create a curve (or a right angle) in the upper left hand corner of a plot. Incorrect predictions of the “test” data create a 45° angle or positive linear line. The area under the curve (AUC) will therefore range from 0.5-1.0, and is an indicator of the probability that a random sample can be classified correctly (Hanley & McNeil 1982, Fielding & Bell 1997). AUC values ranging from 0.7-0.9 were considered to be acceptable, while values >0.9 were considered to be exceptional (Sargarese et al. 2014). Confidence intervals of the sensitivity at increments of 5% were computed with 2000 stratified bootstrap replicates (Leathwick et al. 2006, Sargarese et al. 2014).

Mapping

Along with creating GAMs to study environmental preferences, maps of young of the year fish abundance were produced using ArcGIS 10.1. Data were mapped seasonally. Multiple years had to be pooled to obtain a clear picture of spatial distribution due to a lack of evenly distributed tows across the Bay during some years. All tows that did not fall within the PB region or were projected on land areas were considered to have inaccurate location data and were taken out of the analysis. Abundance maps were generated with six graduated symbols that included zero and five nonzero classes.

Contour maps of seasonal species abundance of the four selected species were created using the Geostatistical Wizard tool in ArcMap. Because the PB is broken up by spits and islands, a continuous interpolation method was deemed inaccurate to be used in this situation; therefore the kernel smoothing method was selected under the interpolation with barriers. An outline of the study area was used as the “barrier” in the contouring process. This outline also bounded the edge of the contours as 304.8m (1,000ft) from land since trawl survey does not represent nearshore fish populations. Contour plots were clipped to fit the outline. All seasonal species abundance contour plots were split into 12 classes with one class representing a prediction of 0. For each species, class intervals were based on the abundance range. Class intervals were repeated for each season of a particular species so that seasonal contours could be compared.

In addition, Shannon diversity and species richness were calculated for each tow and plotted to distinguish areas of the Bay that were high diversity areas for YOY fish. Diversity and species richness calculations included YOY Northern puffer (*Sphoeroides maculatus*; <101mm), scup (*Stenotomus chrysops*; <84mm), weakfish (*Cynoscion regalis*; <153mm), winter flounder (*Pseudopleuronectes americanus*; <91mm), silversides (*Menidia menidia*; <61mm), bay

anchovy (*Anchoa mitchilli*; <43mm), smooth dogfish (*Mustelus canis*; <391mm), tautog (*Tautoga onitis*; <51mm), butterfish (*Peprilus triacanthus*; <91mm), northern searobin (*Prionotus carolinus*; <51mm), striped searobin (*Prionotus evolans*; <71mm), smallmouth flounder (*Etropus microstomus*; <51mm), summer flounder (*Paralichthys dentatus*; <327mm), and windowpane flounder (*Scophthalmus aquosus*; <201mm).

Results

In most cases, the seasonal PA models for all four species outperformed their equivalent abundance models, in terms of percent deviance explained and adjusted R^2 values. PA models for all species had a range of explained deviance of 9.03%-30.7%, while abundance models ranged from 4.56%-41.8% (Tables 1-4).

Northern Puffer

There was a total of 1,993 northern puffers measured from 2006-2012 ranging from 8-280 mm. Young of the year (<101mm) northern puffers represented 77.5% of the individuals caught. The model with the lowest AIC created for Northern puffer summer PA only explained 9% of the deviance (Table 1, Figure 2). Bottom temperature was highly significant ($p<0.001$) in the model, whereas bottom salinity ($p<0.05$), secchi depth ($p<0.01$), bottom DO ($p<0.05$), and depth ($p<0.05$) were also significant. Percent mud ($p<0.1$) was also included in the minimum AIC model. Northern puffer probability of being present increased with temperature, salinity, and depth and decreased with DO and secchi depth. The probability of occurrence was also higher in sediments that contained a lower percentage of mud (Figure 2). The slope of an observed vs predicted linear regression revealed that it was not significantly different from a 1:1

line, indicating that the model was not biased in predicting Northern Puffer PA (Figure 3). When summer PA “test” data was plotted in a ROC plot the AUC was 77.8% with a standard deviation of 7.0% (Figure 4, Table 5a).

The best summer abundance GAM explained only 4.6% of the deviance and only included sediment organic matter ($p < 0.05$) and percent mud ($p < 0.1$). Therefore, when Northern puffers were caught, they were typically more abundant in muddy areas with low sediment organic matter (Figure 2, Table 1). Cross-validation “test” data had a Pearson correlation of 0.26 and a Spearman Rank correlation of 0.23 (Table 5b). The slope of the observed vs predicted regression line was not significantly different from a 1:1 line (Figure 5).

In the fall, from September through October, the best PA model explained 28% of deviance. Variables that were included in the model were bottom temperature ($p < 0.001$), percent sand ($p < 0.01$), percent mud ($p < 0.05$) and sediment organic matter ($p < 0.01$) (Table 1). Following the trends seen in the model (Figure 2), Northern puffers had a higher probability of being caught in areas of low mud, high sand, and moderate sediment organic matter content. Northern puffers probably leave the system when temperatures fall below 18°C, as they are less likely to be caught at low temperature (Figure 2). The slope of the observed vs predicted regression was not significantly different than 1 (Figure 6). The AUC from the ROC plot for the fall PA data was higher than it was for the AUC from the summer PA data, with an AUC of 87.6% and a standard deviation of 5.9% (Figure 7, Table 5a)

The fall abundance model explained the most deviance of the northern puffer models (42%) and included bottom salinity ($p < 0.1$), depth ($p < 0.05$) and percent sand ($p < 0.01$) (Table 1). Northern puffers seem to be found in higher abundance in areas of moderate depths (7-11 meters), low salinity (< 28.5 ppt) and areas with a higher percentage of sand (Figure 2). The

Pearson correlation between the observed and predicted “test” data was 0.29 and the Spearman Rank correlation was 0.24 (Table 5b). The slope of observed vs predicted regression line was not significantly different from 1 (Figure 8).

Maps of the distribution of northern puffer illustrate that Northern Puffers are dispersed throughout the PB (Figure 9-11). Although being ubiquitous through the PB in the summer, they were caught in higher abundances in Cutchogue Harbor, and the southern regions of the GPB and LPB. They were even found in Flanders Bay. YOY were found in Noyack Bay and Southold Bay, but in relatively less abundance compared to other areas. Later in the year, in the fall, the amount of YOY caught per tow was less than what was observed in the summer. Again, northern puffer YOY were spread throughout the Peconics, but found in higher abundance in Noyack Bay and just west of Jessup’s Neck, as well as in the LPB as a whole.

Scup

There were 34,252 scup measured from 2006-2012, ranging 5-664 mm. Young of the year (<84mm) scup represented 40.7% of the total number of individuals caught. Summer and fall PA models for scup explained 27.6% and 21.3% of the deviance (Table 2). Variables included in the summer model were bottom temperature ($p<0.001$), bottom salinity ($p<0.001$), bottom DO ($p<0.1$), secchi depth ($p<0.05$), percent sand ($p<0.01$) and percent mud ($p<0.05$) (Figure 12, Table 2). The fall model included bottom temperature ($p<0.01$), bottom salinity ($p<0.001$), depth ($p<0.05$), bottom DO (not significant), and sediment organic matter ($p<0.01$) (Figure 12, Table 2). For both the summer and fall models, salinity trends revealed bimodal peaks or troughs. The summer model had a “W” shaped relationship with salinity, with a peak around 28.5 ppt, and local minimums at about 26 and 29.0 ppt. The fall model had an “M”

shaped curve with a minimum around 29.0 ppt and local maxima at 27 and 31 ppt. Summer scup probability of occurrence increased with temperature, had a single maximum for DO and secchi depth, and had a curved shape with intermediate minimum or maximum for sand and mud. The fall model indicated that scup probability of occurrence increased with temperature and depth. There was no apparent trend with bottom DO, which was expected since DO was not a significant descriptor (Figure 12). Although percent sand and mud were found in the summer model, the best fall model left these variables out and instead included sediment organic matter. These three variables (percent sand, percent mud, and sediment organic matter) tend to be correlated with each other, so it would be expected that one variable might be substituted in the model for another. The fall model had two maximum peaks in the sediment organic matter curve, with a maximum values occurring around 1% LOI and 4% LOI (Figure 12).

Abundance models for scup explained 8% of the deviance in the summer and 21% of the deviance in the fall (Table 2). The summer model included bottom salinity (not significant), bottom DO (not significant) and sediment organic matter ($p < 0.1$), while the fall model included bottom temperature ($p < 0.001$), bottom salinity ($p < 0.05$), depth ($p < 0.1$), bottom DO (not significant), secchi depth ($p < 0.01$) and percent sand (not significant) (Figure 12, Table 2). Summer scup abundance increased with salinity, reached a maximum at bottom DO values of 4.5-7 mg/L, and at areas with low to moderate values of sediment organic matter. In the fall, abundances of scup increased with temperature, depth, and secchi depth, and decreased with salinity. Maximum abundances were found at intermediate DO and minimum at an intermediate % sand (Figure 12).

ROC plots that were produced for the summer PA model revealed an AUC of 85.1% and a standard deviation of 6.0%, inferring that the model did an acceptable job accounting for false

positives (Figure 14, Table 5a). Although the fall model explained more deviance than the summer model, the ROC plot of the fall model had an AUC of 73.1% with a standard deviation of 9.2%, meaning that this model had a tendency to incur more false positives, and caution must be used when interpreting the results (Figure 17, Table 5a). As for all 4 scup models, each observed vs predicted slopes were not significantly different from the 1:1 line (Figures 13, 15, 16, and 18).

Juvenile scup were rarely found before the beginning of July. In the summer, juveniles can be found throughout the PB, from Shelter Island up to Flanders Bay (Figure 20). However, a greater abundance (~15-20) of juveniles were found in the eastern portion of the Bay, east of Robins Island. The largest abundance of juveniles appear to be caught in Southold Bay based on of the interpolation. In the Great Peconic Bay, more juveniles were caught in the southern portion and around the edges, than in the northern and inner areas. In the fall, juveniles were still in high abundance in the Peconics, and were found throughout the PB (Figure 21). Although, a greater number (~10-15) were found in the eastern portion of the PB rather than Great Peconic Bay and Flanders Bay (~6-8).

Weakfish

There were 11,231 weakfish measured from 2006-2012, ranging from 9-510mm. Young of the year (<153mm) weakfish represented 79.5% of the total amount of individuals caught. The summer PA model of weakfish explained 22.3% of the deviance, while the abundance model explained 15.9% of the deviance (Table 3). The summer PA model included the variables depth (<0.001), bottom DO (not significant), percent sand (<0.1) and sediment organic matter (<0.05), whereas the summer abundance model included the variables

salinity (<0.001), depth (not significant), secchi depth (<0.1) and sediment organic matter (<0.01) (Figure 22, Table 3). According to the models, weakfish were more frequently found at depths greater than 7 meters over sediment that is composed of less than 60% of sand. In areas where weakfish were caught, abundances increased with depth and sediment organic matter and decreased with secchi depth. Higher abundances were found where salinity was between 25 and 29 ppt (Figure 22).

The fall PA model explained 30.7% of the deviance and included temperature (<0.001), salinity (<0.01), depth (<0.01), secchi depth (not significant), percent sand (not significant) and percent mud (<0.05) (Figure 22, Table 3). From the model, weakfish were more likely to be caught in warm, deeper water of low salinity with low amounts of sand and intermediate amounts of mud (Figure 22). The fall abundance model explained more deviance (38.0%) than the fall PA model (30.7%) and included temperature (<0.01), salinity (<0.001), depth (<0.05), percent sand (<0.01) and percent mud (<0.01), inferring that weakfish increased in abundance with temperature, depth, sand and mud contents and decreased with salinity (Figure 22, Table 3). In this model, abundance increased with percent sand and percent mud; intuitively, this cannot be possible as percent mud and sand are negatively correlated to each other. This might be due to the disproportionate amount of data points that contained $>50\%$ mud, which can also be seen in the rugs in Figures (22). Of the total amount of tows used in the GAMs, each season (spring, summer, fall) only contained 29.8%, 29.4%, and 38.1% of data points that represented areas where mud was $>50\%$. Due to the low amount of data, the models might have become unstable when accounting for bottom type preferences.

Summer and fall PA models displayed an AUC of 73.6% and 89.0% according to their ROC plots (Figures 24, 27, Table 5a). For each model, when the independent data was plotted

against the predicted test data, the slopes were not significantly different than 1, indicating that the created models could be used in an unbiased way to predict the PA or abundance of weakfish (Figures 23, 25, 26, 28). The summer abundance model was not as accurate as the fall model, although the fall model did display confounding trends of sediment types.

Mapping of weakfish distribution showed distinct areas of occurrence (Figure 29). In the summer and the fall weakfish YOY were caught in almost every tow from the middle of the Great Peconic Bay (Figures 30, 31). Along with being found in the Great Peconic Bay, weakfish were also caught around Nassau Point and the LPB. Other areas of occurrence were found in Noyack Bay and Southold Harbor. Weakfish were found in higher abundances in the summer compared to the fall.

Winter Flounder

There were 2,822 winter flounder measured from 2006-2012, ranging from 17-451mm. Young of the year (<91mm) winter flounder represented 42.7% of the total of all individuals caught. The best spring GAM for winter flounder PA included the variables temperature (<0.001), salinity (<0.001), depth (not significant) and sediment organic matter (<0.05), and explained 26.8% of the deviance (Figure 32, Table 4). Overall, winter flounder had a higher probability of being caught at intermediate temperatures between 20-24°C, at low salinity, deeper water depths, and high sediment organic matter (Figure 32). Validation of the model, in terms of a ROC plot, revealed an AUC of 80.4% \pm 8.8% which is within an acceptable range (Figure 34, Table 5a), and the slopes of the 1:1 line and the observed vs. predicted data were not significantly different (Figure 33).

The spring abundance model of winter flounder incorporated salinity (<0.1), depth (<0.01), secchi depth (not significant) and percent sand (not significant), while explaining 32.6% of the deviance (Figure 32, Table 4). Trends in abundance were apparent from the GAM, with higher abundances in moderate salinity (26-27 ppt), moderate depths (5-8 meters), moderate percent sand (50-79%) and shallower secchi depths (Figure 32). Slopes of the 1:1 line and the observed vs. predicted data were not significantly different (Figure 35).

The summer PA model explained 24.7% of the deviance and included salinity (<0.001), depth (<0.1), DO (not significant), percent sand (not significant) and percent mud (<0.1) (Figure 32, Table 4). Trends seen in the GAM predict that winter flounder occurrence declined with salinity and DO, and increased with depth. Occurrences were also higher where the sediment had a moderate percentage of mud (0%-50%) and low sand ($< 20\%$) (Figure 32). Validation analysis of the model indicated that it was reasonable, achieving an AUC of $85.3\% \pm 7.1\%$ according to the ROC plot (Figure 37), and the slopes of the 1:1 lines and the observed vs. the predicted data were not significantly different (Figure 36).

The summer abundance model for winter flounder explained the most deviance (37.5%) out of the 4 PA and abundance winter flounder models (Table 4). It included the variables, temperature (<0.1), percent sand (<0.05) and percent mud (<0.05). Abundance declined with increasing temperature, sand, and mud content (Figure 32). As can also be seen in the fall weakfish abundance model, trends in sediment preference contradict each other, with higher abundance in areas with a low percentage of mud and a low percentage of sand. The model had a Pearson correlation of 0.38 and a Spearman rank correlation of 0.40 between the observed and predicted data (Table 5b), while the slope was not significantly different from a 1:1 line (Figure 38).

Contour maps indicated that winter flounder were more abundant in the spring months and inhabited the western portions of the PB system (Figures 40-42). In the spring months, winter flounder occurred in the central portion of the Great Peconic Bay. They were also found in Cutchogue Harbor and along the southern portion of the Little Peconic Bay, although they were also caught in some parts of the northern Little Peconic Bay as well. They were generally not found in the areas east of Jessup's neck, although some YOY were caught in Noyack Bay (Figure 41). In the summer, fewer winter flounder were found, but they were primarily caught in the northwest region of the Great Peconic Bay and Flanders Bay. As in the spring, they were also found in the northern and southern areas of the Little Peconic Bay east of Robins Island (Figure 42).

Diversity Mapping

There were 1,888 tows (443 spring tows, 741 summer tows, and 704 fall tows) used in the creation of the species abundance and diversity maps. Across all seasons, the spring months were the least diverse in terms of species richness and the Shannon diversity index (Figures 43, 47). Areas that contained the highest species richness (1-2 species) include the middle and western parts of the Great Peconic Bay, as well as the western portion of the Little Peconic Bay up to Robin's Island. Only two regions, Flanders Bay and Cutchogue harbor had non-zero diversity areas in the spring.

The summer months contained the highest species richness and diversity values relative to the spring and fall (Figures 44, 48). Areas with the highest species richness (4-5) occurred around Nassau Point. The same can be said for diversity, along with other peaks in Little Peconic Bay, the center portion of the Great Peconic Bay, and Noyack Bay.

Species richness and diversity in the fall were intermediate between spring and summer values (Figures 45,49). The highest species richness values (3-4) were observed in the middle portion of the Great Peconic Bay, in the center portion of the Little Peconic Bay, and areas in Noyack Bay. Diversity contours revealed the same general pattern found in the species richness results.

Discussion

The 4 species and diversity indices showed clear spatial segregation throughout the PB system. The structuring and diversity appeared to increase in the summer months, where the overlap between the various YOY fish and invertebrates were the highest. Because each species had distinct patterns, each will be treated separately.

Northern Puffer

Northern puffers are found along the Atlantic coast from Newfoundland to northern Florida, although are more commonly found in cooler waters from the Middle Atlantic Bight and northward during annual coastal migrations (Able & Fahay 1998). Northern Puffers overwinter offshore, and return to coastal waters, bays, estuaries to spawn (Sibunka & Pacheco 1981, Able & Fahay 1998). Data from the Peconics supports these observations with Northern Puffer YOY first appearing in the Bay around mid to late July between 30-55 mm, indicating YOY are either the result of spawning in PB or are advected into the system. Since eggs have an adhesive covering and are reported as being laid and adhering to the substrate until hatching (Able & Fahay 1998), advection would occur post-hatch. Although, Monteleone (1992) reported Puffer larvae in the Great South Bay of Long Island while collecting plankton samples at the surface.

Other areas in the Northeast do not report juvenile puffers, only adults or juveniles (Able & Fahay 1998), indicating that puffers might have selective breeding sites, which need to be taken into consideration in understanding northern puffer population.

Results from the GAMs reveal that temperature in both the summer and fall PA models were the most significant. In the summer, northern puffer YOY were not commonly caught until the water reached about 25 °C, which is consistent with the fact that YOY were not caught in trawls until mid to late July and is typically when waters reach 25 °C in the PB. Only four YOY were caught in the spring, but were captured during the last few days of June. Northern puffers begin leaving the Peconic system around 18 °C according to the GAM (Figure 2), validated by the fact that YOY abundance substantially decreased in abundance in the beginning of October which are typically when waters reach about 18 °C. According to the model, temperature seems to be the most important driving factor when it comes to the spatial distribution of northern puffer. However, it only describes the appearance and departure of YOY in the system, as they were typically caught in all areas of PB throughout the summer and fall months.

Models of northern puffer revealed no clear pattern of sediment preference. The summer PA model indicated a preference for less muddy areas, yet the abundance model suggested a higher use of muddy areas. The same situation occurs in the fall model except with sand (Figure 2). Other studies have found no clear indication of sediment preference as well (Able & Fahay 1998, Collette & Klein-MacPhee 2002). Szedlmayer & Able (1996) reported occurrences over a range of depths (0.6-3.7m) and sediments (3.8%-54.4% silt). Our models showed no clear preference for depth, as it was only included in two (Summer PA and Fall ABUN) of the four models. Of those two, a positive association was found with northern puffer presence and depth.

The same is seen in the Fall ABUN model, but the strength of the association becomes weaker after about 10m, which could be due to the smaller amount of data at those depths.

While no clear indication of environmental preferences was detected from the models, mapping of the northern puffer YOY abundance revealed a slight pattern in area utilization in the PB (Figures 9,10,11). Capture of northern puffer YOY was found across the whole PB in the summer throughout the years 2006-2012, yet some areas were found to have a higher abundance of YOY. Few YOY were captured in the Southold Bay area. Considerable catches were made in Noyack Bay, but the majority of YOY were caught in the Little Peconic Bay especially the southern portion, as well as the southern region of the Great Peconic Bay (Figure 10). Fall captures typically followed the same distribution patterns as the summer, however the kernel smoothing method indicated a large utilization area of the eastern portion of Noyack Bay (Figure 11). This may be an artifact, due to the fact that 2 of the tows performed in that area contained 29 and 39 individual YOY. Both of these tows occurred at the end of September in 2011 possibly indicating a group of YOY leaving the Peconics through the southern channel. The same event occurred just south of Robins Island where a tow contained 15 YOY. However, the area just west of Jessup Neck does not seem to be an artifact, but rather a region where YOY might congregate due to some biological opportunity (protection, prey, etc.), or perhaps were caught as they were making their migration out of the estuary. That area has been noted as having a possible old oyster reef therefore it most likely provides structured habitat. Juveniles have been found in large schools, unlike the adults which tend to be more solitary (Able & Fahay 1998). Thus, while it is important to note that no variables appeared in all four models, indicating that northern puffer YOY are not structured by a particular environmental variable, they might prefer structured habitat, such as around piers, algae cover or rocky structures (Collette & Klein-MacPhee 2002),

which were not possible to observe during the trawl survey. On the other hand, they may be well adapted to occupy different habitats within the PB and biotic factors, such as predation and competition, could be affecting the distribution of YOY more so than the physical environment.

Despite being known as the “charismatic” blowfish (because of its ability to expand when in peril [Collette & Klein-MacPhee 2002]), there is little literature on the northern puffer, especially regarding abundance and population structure. Most literature is not directly studying the species, but rather based on recording catches of trawl samples or community studies (Szedlmayer & Able 1996, Wilk et al. 1996, Martino & Able 2003). Although, some papers have been published on its’ taxonomy, physical characteristics, and reproduction (Shipp & Yerger 1969, Sibunka & Pacheco 1981), there are few direct studies done in the past 20 years. The paucity of data on this species might be due to the fact that there is little to no recreational or commercial fishery for them anymore, although Weber & Grahn (1995) report that northern puffer (swellfishes) were the second most landed fish by weight taken from the PB during the 1950’s and 1960’s. Little information is found on current landings for this species.

Northern puffers should be recognized and considered when studying the PB ecosystem, especially since their diet consists of mollusks and crustaceans (Sibunka & Pacheco 1981, Collette & Klein-MacPhee 2002). This is important to take into consideration when trying to implement clam or oyster recovery efforts. Although, northern puffer YOY typically are found throughout the whole region of the Peconics, one area where they do not seem to inhabit is the northern edge of the Great Peconic Bay, more specifically they were never captured at station 33. Sediment mapping designates this area as mostly sand (78%) but there are no other noteworthy environmental factors that might make this area uninhabitable for northern puffer YOY. To

improve the management of anthropogenic stress in PB, and the greater region, a better understanding of the role of puffer is needed.

Scup

In the Peconics, based on the trawl survey from 1987-2012, scup were sometimes caught as early as the beginning of the May and even as late as the end of October. However, scup were most commonly seen in the system at the end of June and early July up until the middle of October. From 2006-2012, where length data was available, young of the year (<83mm) were first seen in the system around mid-late June, while juveniles or adults (>83mm) could be found in the system earlier. These observations are validated by the GAM models, where YOY scup were usually found in waters warmer than 23.5°C, which typically occurs by late June, and in the fall leave when waters reach about 20°C, which usually occurs by late September (Figure 12). These findings are in line with the published work on scup, commonly found from Massachusetts to South Carolina, and occasionally as far north as Nova Scotia (Able & Fahay 1998, Steimle et al. 1999). Scup is a mostly demersal fish that undergoes seasonal migrations to spawn inshore and overwinter offshore. Inshore migration and spawning usually occur from May through August and peaks during June (Able & Fahay 1998) between southern New England and the New York Bight (Steimle et al. 1999). There is probably only one spawning event per area, as there is only one peak of abundance in eggs and larvae (Able & Fahay 1998). Young of the year, juveniles, and adults will feed in estuaries and coastal habitats during the summer months and are seen migrating offshore around November. The Peconic Bay has long been identified as a spawning ground for scup (Perlmutter 1939), and from 1972-1974, Ferraro (1980) supported this observation by collecting and identifying scup eggs in the PB. Young of the year fish were

not seen below 40mm by late October, but averaged about 74mm, indicating slow growth during their first year (Able & Fahay 1998).

The GAMs indicated that salinity had a strong effect on scup's habitat preferences, as they were included in every model and were significant ($p < 0.001$) in the two PA models (Figure 12, Table 2). Scup seem to have an affinity for higher salinities, as they are always present in areas of 28 ppt or more (except for the fall PA model). This has also been observed in the Hudson River-Raritan Bay estuary as well as the Long Island Sound (Stone et al. 1994, Able & Fahay 1998), where scup were more commonly seen in more saline (>25.0 ppt) waters. The interpolation maps of the Peconics corroborate these observations. Based on these maps, scup can be seen across the whole area of the Peconics but are found in greater abundances in the eastern portion on the Bay, east of Robins Island (Figures 19,20,21). Since the Peconic Bay has little water input from the Peconic River, or any other rivers, it is well-mixed and bottom salinities through the Bay are quite high ranging from 24 ppt in Flanders Bay up to 32.5 ppt near Shelter Island. A gradient does exist from Flanders Bay to Shelter Island, but it is gradual. Depending on the season, the Great Peconic Bay usually averages about 28 ppt or less and could allude to why YOY scup can be found in higher abundance east of Robins Island.

YOY scup do not seem to associate with a particular bottom type. Out of the four models, only percent sand and percent mud were included in the one model (summer PA) (Table 2). Sediment organic matter was included in two of the models (summer abundance and fall PA). The summer PA model indicates that scup are more likely to be found on bottoms that have a higher percentage of sand and a low percentage of mud (Figure 12). When SOM was included in the models, there was a slight indication that scup preferred areas with little SOM, which is generally associated with areas of sand. However, no clear pattern arises. Other studies have

reported that juvenile scup were found over bottoms with no structure such as in Great Bay-Little Egg Harbor (Stone et al. 1994), but scup have also been found in structured habitats such as mussel beds, rock rubble or reefs where trawls are unlikely to sample (Steimle et al. 1999). Thus it does not seem that scup prefer a certain bottom type but rather are opportunistic.

The high scup abundance could have confounded findings that scup have no preference for bottom type.. Theory suggests that when a species abundance is high, individuals will likely expand into new areas because of higher rates of intra-specific competition (Fretwell & Lucas 1970). Although scup are sometimes known to form schools (Collette & Klein-MacPhee 2002), they will nonetheless need to find other areas to forage if prey become scarce in their preferred habitat. Therefore, habitats that are utilized by species at high abundances might not be their preferred habitat. This would suggest that a “true” preference for habitat can only be seen when a population is at a low.

Diets of scup vary with ontogeny. Juveniles feed on polychaetes, epibenthic amphipods, copepods small crustaceans and mollusks, and fish eggs and larvae (Steimle et al. 1999). Adult scup are known to prey on larger crustaceans and bivalve mollusks and have also been found to prey on polychaetes, small squid, vegetable detritus, insect larvae, hydroids, sand dollars and small fish but can vary based on location (Steimle et al. 1999). A diet study done by Sagarese et al. (2011) on adult scup (175-370mm) from Port Jefferson Harbor, Great South Bay and Shinnecock Bay revealed that their gut contained about 62% of clam by weight. Although the Peconic Bay may contain a different assortment of prey species for scup, it is clear that scup seem to prefer bivalves. This can have implications for shellfish aquaculture sites located in the Peconics. Areas for aquaculture sites have already been established within the Peconic Bay with many sites already being utilized (Davies et al. 2011). Based on scup utilization of the Peconic

Bay, it would appear that shellfish aquaculture sites would benefit from use of locations where scup have a lower probability of being found, mainly in the western portion of the PB. However, if this measure was to be implemented and scup predation became an issue to industry, then continued monitoring of scup occurrence would be needed.

Weakfish

Weakfish YOY are sometimes seen in the Peconic Bay as early as mid-June, but they are commonly seen in the beginning of July based on the year, and generally leave the estuary around the beginning of October. This is most likely why temperature was not included in the two summer GAMs for weakfish, because they are present throughout the summer months (July-August), regardless of the temperature. The fall models however indicated that weakfish are absent once the water temperature drops to about 16°C (Figure 22), which seems to be typical as they are reported to follow the 16°C-24°C isotherm (Collette & Klein-MacPhee 2002).

As with the other species, the observation in PB match patterns seen along the eastern U.S coast from Massachusetts to Florida, and particularly in the more common range between New York and North Carolina (Able & Fahay 1998, ASMFC Weakfish T.C. 2009). A migratory fish, weakfish commonly enter estuaries and bays to spawn in the spring and traveling offshore or to southern, warmer regions in the fall (Mercer 1989, Thorrold et al. 2001, Collette & Klein-MacPhee 2002). Weakfish spawn multiple times during a season between March and August peaking from May through July (Able & Fahay 1998, Collette & Klein-MacPhee 2002). It is hypothesized that larvae tend to stay near where they were spawned, inside estuaries or bays, through selective tidal stream transport, where they move up and down in the water column during flood and ebbs tides (Rowe & Epifanio 1994)

Some studies have shown that dissolved oxygen can impact how fish structure themselves in an estuary (Wannamaker & Rice 2000, Brady & Targett 2013). Hypoxic and anoxic conditions in estuaries is of the utmost concern because it can cause fish kills and decrease available habitat for many species (Rabalais et al. 2010). Hypoxic and anoxic conditions are usually caused by the autotrophic respiration often in conjecture with stratification (Kenney et al. 1988, Rabalais et al. 2010). Brady & Targett (2013) found that movement of juvenile weakfish was affected by dissolved oxygen gradients in an estuarine tributary in Delaware. Juvenile weakfish avoided hypoxic (<2.0 mg/l) areas by making daily migrations up and down the tributary. Throughout the current study of the PB, of the 9,183 trawls that recorded a bottom DO value, only 0.13% (12) were observed to be under 2 mg/L. Additionally, these values were recorded in July-September, when DO levels are expected to fall due to increased autotrophic activity. Therefore, the PB does not lose most of its suitable habitat to hypoxia. Conversely, the lower Peconic River and some tributaries in the PB estuary itself do record major hypoxic events, but steps have been taken to mitigate these occurrences (PEP 2007). Overall, the survey area rarely sees hypoxic conditions, therefore weakfish in the PB do not seem to be experiencing a loss in habitat, which was supported by GAMs where DO was only included in one of the weakfish models and even then it was a not a significant variable.

Based on the GAMs, depth seemed to be the most important habitat characteristic when it came to the spatial distribution of weakfish in the Peconics. Depth was included in every model and was significant (<0.05) in 3 out of the 4 (Table 3). Deeper area associations by YOY weakfish abundance have also been reported by other authors (Able & Fahay 1998). Mapping indicated that YOY were commonly found in greater abundance in the middle of the Great Peconic Bay and the central portion of the Little Peconic Bay, as well as Noyack Bay. These are

the deepest parts of the Bays and are most likely caused by internal currents and water velocity associated with the water circulation (Tetra Tech, Inc. 1997).

Most of the GAMs indicated that YOY weakfish preferred areas of higher sediment organic content and mud, which is consistent with findings in Great Bay-Little Egg Harbor, New Jersey (Able & Fahay 1998). This habitat is associated with the middle of the GPB, where mapping indicated large abundances of YOY. Studies done in the Chesapeake and Delaware Bay area revealed that mysid shrimp was an important prey item for juvenile weakfish, along with bay anchovy (Greca & Targett 1996, ASMFC Weakfish T.C. 2009). Other crustaceans are probably important as well (Collette & Klein-MacPhee 2002). Although, a diet analysis of weakfish in the PB has not been performed, YOY and adult weakfish might be preying upon the shrimp species along with bay anchovy which were all found to be present in the middle of the GPB. Collette & Klein-MacPhee (2002) also report that butterfish is a prey item of weakfish, which was commonly caught in the middle of the GPB as well as in the deeper parts of the PB, implying that a spatial overlap occurs between weakfish and butterfish. Weakfish appear to forage in the deeper, muddier parts of the PB for prey.

Weakfish are known to be a schooling fish (Collette & Klein-MacPhee 2002), which might explain why we see such clear congregations of weakfish YOY abundance in the mapping of their spatial distribution. Other than the GPB, areas of high weakfish YOY abundance were observed in Cutchogue Harbor, around Nassau Point (the western and southern portions of LPB), and Noyack Bay, areas that tend to be relatively deep with mud bottoms.

In conclusion, weakfish YOY school in the deeper areas of the PB with muddy sediments. Although these patterns in weakfish spatial structure arise around abiotic factors, it is most likely that they choose these habitats due to biotic “reasons”. Weakfish can swim in the

water column and are not necessarily always demersal (Collette & Klein-MacPhee 2002), but deeper areas of the PB could provide habitat with low light levels so that they are not detected by predators. Therefore, choice of deeper waters may be due to either predator avoidance or prey selection, or a balance of both.

Winter Flounder

Winter flounder are more commonly found from the Gulf of the St. Lawrence to the Chesapeake Bay, as they prefer cooler temperatures (Able & Fahay 1998, Collette & Klein-MacPhee 2002). Wuenschel et al. (2009) found few adult winter flounder south of the Northern New Jersey coast, indicating that their range is contracting from historical observations. Unlike the other species that have been observed in this study, winter flounder spawn in the winter to early spring (January-March) with timing varying by latitude. Earlier studies have reported that spawning takes place inshore usually in bays and estuaries, where YOY swim upstream to areas of lower salinity (Able & Fahay 1998, Collette & Klein-MacPhee 2002). However, this view has been recently challenged and it is suggested that there may be an offshore and inshore spawning contingents (Gibson 2013). Wuenschel et al. (2009) found ripe and spent adult male and female winter flounder in the coastal waters of Northern New Jersey, suggesting that spawning could be taking place outside of bays and estuaries. Fairchild et al. (2013) also reported that adult winter flounder in the Gulf of Maine were hardly seen moving into estuaries, although migratory behavior of winter flounder seem to be different north and south of Cape Cod, which is attributed to differences in thermal regimes.

Regardless of these views, the Peconic Bay is an important breeding and nursery ground for winter flounder due to the high occurrence of YOY found in the system. Due to its extremely

low population level, categorizing habitat areas for young of the year winter flounder is critical for the protection of the species. Theoretically, since the population is at the lowest recorded level, habitat preferences should be more recognizable (Fretwell & Lucas 1970), unlike scup. Temperature seemed to be a key factor affecting the occurrence of winter flounder. Throughout the survey, YOY were typically caught up until week 30 (the end of July). The bottom water temperatures in the Peconic Bay from 2006-2012 in week 30 averaged about 25°C with a range of 23°C -28°C. Winter flounder are especially susceptible to warm waters with most studies reporting lethal temperatures between 19.3°C-23°C and that they never recover from heat shock (Collette & Klein-MacPhee 2002). However, in 2009, young of the year were caught up until the beginning of October. Goldberg et al. (2002) reported similar patterns of winter flounder YOY occurrence in two New Jersey estuaries. Sagarese & Frisk (2011) found that some adult winter flounder were present in Shinnecock Bay, Long Island during the summer as well, and Yencho et al. (in press) found larval settlement occurring dates into July and August in Shinnecock Bay, indicating this phenomenon might not be as rare as was once thought, and that a resident or estuary spawning contingents are plausible.

To escape the cold, winter flounder can bury themselves in the sediment which had been recorded as being 2-3°C warmer (Grothues et al. 2012). This behavior has also been documented during the summer, where the sediment was cooler (Olla et al. 1969), and could be an explanation of why and how we were able to find winter flounder in the Peconics during the summer months when temperatures are lethal to their survival. This could confound our efforts to determine if YOY leave the estuary or if they continue to inhabit the area throughout the summer, as is it thought that YOY stay in estuaries and bays for about 2 years, but if summer temperatures are detrimental to the survival of an individual then it is not clear what the benefit

of residence would be. Likewise, studies have reported mortality of winter flounder at water temperatures above 26.5°C, yet the current study and others (Sagarese & Frisk 2011) report winter flounder occurring in Long Island waters in the summer where bottom temperatures can reach 28°C. Further studies should be implemented to delineate if YOY leave the PB and enter the Atlantic Ocean or Long Island Sound into deeper waters to avoid warm summer temperatures, if there are two contingent populations in the PB, and whether previously reported temperature thresholds are not applicable to inshore resident populations.

According to our models, winter flounder were more likely to found in less saline (<28 ppt) waters. This trend can also be observed in the interpolation maps with most YOY caught west of Robins Island in the GPB, where salinity in the spring is usually less than 27 ppt. This trend is consistent with other studies which found the YOY migrate up the estuary into less saline waters (Able & Fahay 1998). Besides being captured in the GPB, other noteworthy areas of interest include Cutchogue Harbor, the southern portion of the LPB and the southern parts of Noyack Bay. Cutchogue Harbor saw a high abundance of YOY, and is probably an important nursery ground, as it is a sheltered cove with a relatively low current velocity (Tetra Tech 1997). This could be an important settlement area, where larvae are dispersed. This phenomenon has also been found in Great Bay- Little Egg Harbor, New Jersey by Curran & Able (2002), where large abundances of YOY were found in two small coves.

The GAMs were not able to deduce a clear trend in winter flounder bottom habitat use. This is consistent in what has been reported in other studies (Stoner et al. 2001), and that winter flounder have been called opportunistic when it comes to bottom habitat choice. However, Stoner et al. (2001) did report that their GAM, which modeled habitats for YOY <25mm, included sediment organic content in the model and concluded that these small fish preferred

areas with muddy to fine sand bottoms, which is easier substrate for YOY to bury themselves in. Our GAMs for winter flounder only included SOM for the spring PA model which showed a positive association, but mud was included in the two summer models, exhibiting negative effects on presence and abundance (Figure 32, Table 4). Our findings included all winter flounder YOY that were less than 91mm in length in comparison to Stoner et al. 2001, who divided YOY into two separate groups (<25mm and 25-55mm). Therefore, winter flounder YOY could potentially display an ontogenetic shift in preferred bottom type as early as their first year, or that shift in relation to unique attributes of habitats. Some evidence of this shift could be observed in the Peconics, based on the interpolations maps, where in the spring, YOY were commonly caught in the middle of the GPB where the sediment is quite muddy. In contrast, the summer map displays a shift in the center of abundance towards the northwest area of the GPB where sediment there is more sandy and shallower. Results from this study do not emphasize that winter flounder YOY have a strong selection for bottom type, yet it is possible that winter flounder undergo an ontogenetic shift early in their life history that we were not able to pick up in this study.

Interpolation maps indicate that winter flounder YOY aggregated in 4 areas in the spring: Noyack Bay, Cutchogue Harbor, the southern portion of Little Peconic Bay, and the southern and western portion of the Great Peconic Bay. These aggregations suggest that subpopulations of winter flounder could exist in the Peconics since winter flounder are observed to return to their natal spawning grounds and display a high degree of genetic structuring (Buckley et al. 2008). More research should be conducted on these specific areas of PB, especially genetic testing, to determine if these are subpopulations. If subpopulations were found to exist in the PB then it

could potentially impact how the species is managed in this localized region of Long Island and the leasing program for aquaculture sites that has been developed in the Bay.

Winter flounder populations in the PB, or Long Island for that matter, have not seen any inclination of recovery. YOY recruitment is critical for sustaining healthy populations, yet populations of winter flounder in the PB seem to be exhibiting weak recruitment success. For example, high abundances of winter flounder YOY were seen in Cutchogue Harbor and Noyack Bay during the spring, yet little no YOY were caught there in the summer. Since YOY are known to move very little (Saucerman & Deegan 1991), we would expect to see occupancy in the same locations or relatively close by, suggesting that mortality in these areas is high. Species richness and diversity indices illustrate that these two areas have relatively high abundances of other species, which could pose as predators to winter flounder YOY. Blue crabs and sand shrimp have been reported as preying on winter flounder eggs and YOY (Taylor & Danila 2005, Collier et al. 2014), as well as summer flounder, striped bass, bluefish, striped searobin, smooth dogfish, sand lance, comorants and moon jellies (Manderson et al. 2000, Collette & Klein-MacPhee 2002, Sagarese et al. 2011). We suggest that low recruitment of winter flounder YOY into the population, because of high YOY mortality from predation, is part of the underlying issue of the lack of winter flounder population recovery.

Diversity

Diversity and species richness is highly seasonal within the Bay. In the spring, there was relatively little to no diversity of YOY fish within the Bay. This is due to the fact that the only YOY fish species in the Bay at this time is usually winter flounder, windowpane flounder, and occasionally some anchovy depending on the week because of their early spawning times. Other

invertebrate species that were not included in the analysis but occur in the PB during the spring are calico crabs, spider crabs, and horseshoe crabs. Some adult species of fish can be found in the PB during the spring who spawn in the system. This pattern reflects the deconstruction of ecosystems on an annual basis in temperate systems, and the reorganization and increasing structure through the summer growth period that is controlled by physical processes (Moring 1990, Jordaan et al. 2011).

The areas around Nassau Point and the southern portion of Little Peconic Bay contain the most diversity during the summer, along with areas of Southold Bay, Noyack Bay, and south central portion of the Great Peconic Bay. When looking at these areas on the sediment grain size map, they tend to be in muddy areas. This might be because of the higher amounts of sediment organic matter that are usually found in these areas lead to higher prey availability for many demersal fish species. Little diversity is seen between the Jessup's Neck and Cedar Beach, where the Little Peconic Bay runs into Shelter Island Sound. This area has a relatively high spring tidal current reaching up to 1.1 m/s (Hardy 1976). YOY might not be found in these areas because the stronger water currents might lead these smaller fish to expend more energy maintaining their position in the water column. The same situation might be occurring in the south of Robin's Island, where spring tidal current there can reach 1.2 m/s (Hardy 1976). Conversely, these are areas where large adult predators are primarily located, which would not be effectively sampled using the trawl survey. Another area that has a relatively small amount of diversity is the north area of the Great Peconic Bay. While most of this area is considered to be sandy and shallow, there are no other defining features that would suggest that this area is different from other shallow, sandy areas of the Bay. More study is needed to identify why parts of PB are less diverse.

Summer months (July-August) are when most migratory species enter PB and when YOY start to be caught in the trawl. Summer and fall species richness and diversity contouring revealed similar patterns, which indicate that the YOY fish species tend to stay in these high diversity areas from the time they enter to the time they leave. This is particularly encouraging for the aquaculture lease program set up in the Peconic Bay, because managers can distinguish areas of the Bay that YOY utilize more frequently than others and thus mitigate negative effects of aquaculture in important fish habitats. Better management decisions, that have the least impact on important habitat, can be made on the location of these leased aquaculture sites based on the information presented here. In conclusion, economically important aquaculture sites and areas of high YOY fish utilization can coexist within the PB, as to reduce the impact of habitat loss to these YOY fish.

If species conform to “ideal free distribution”, then species would choose habitats based on their ideal growth requirements. The fish populations of the PB exhibit distributions that are heterogeneous throughout space and time, although direct links to survival and fitness are difficult to identify. Non-randomness of species habitat use was detected, and temperatures, salinity, depth, as well as certain sediment characteristics were related to four species of YOY. Species did appear to segregate across the bay, although areas of higher richness did also indicate clumping in certain key regions. Density-independent and density-dependent factors are likely at play. Continued efforts to improve our understanding of the relationship between species and habitat is a fundamental component for properly employing conservation and management decisions within any Marine Spatial Planning exercise in the PB system.

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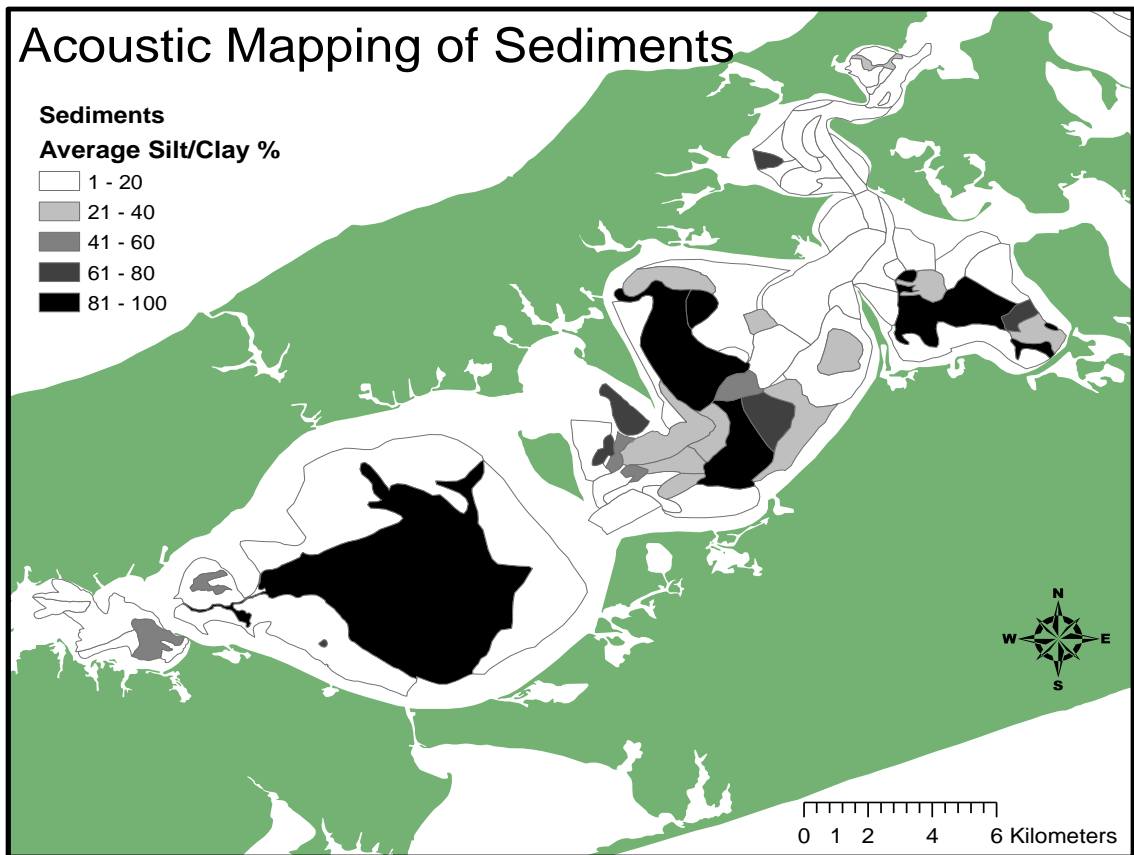


Figure 1- Map of the bottom sediments in the Peconic Bay Estuary. Sonar mapping and sediment sampling were performed to delineate bottom types. Darker areas on the map correspond to areas that have higher percentages of mud (silt+clay). (See legend). (Data taken from Flood 2004, Cerrato & Maher 2007, Cerrato et al. 2009, 2010)

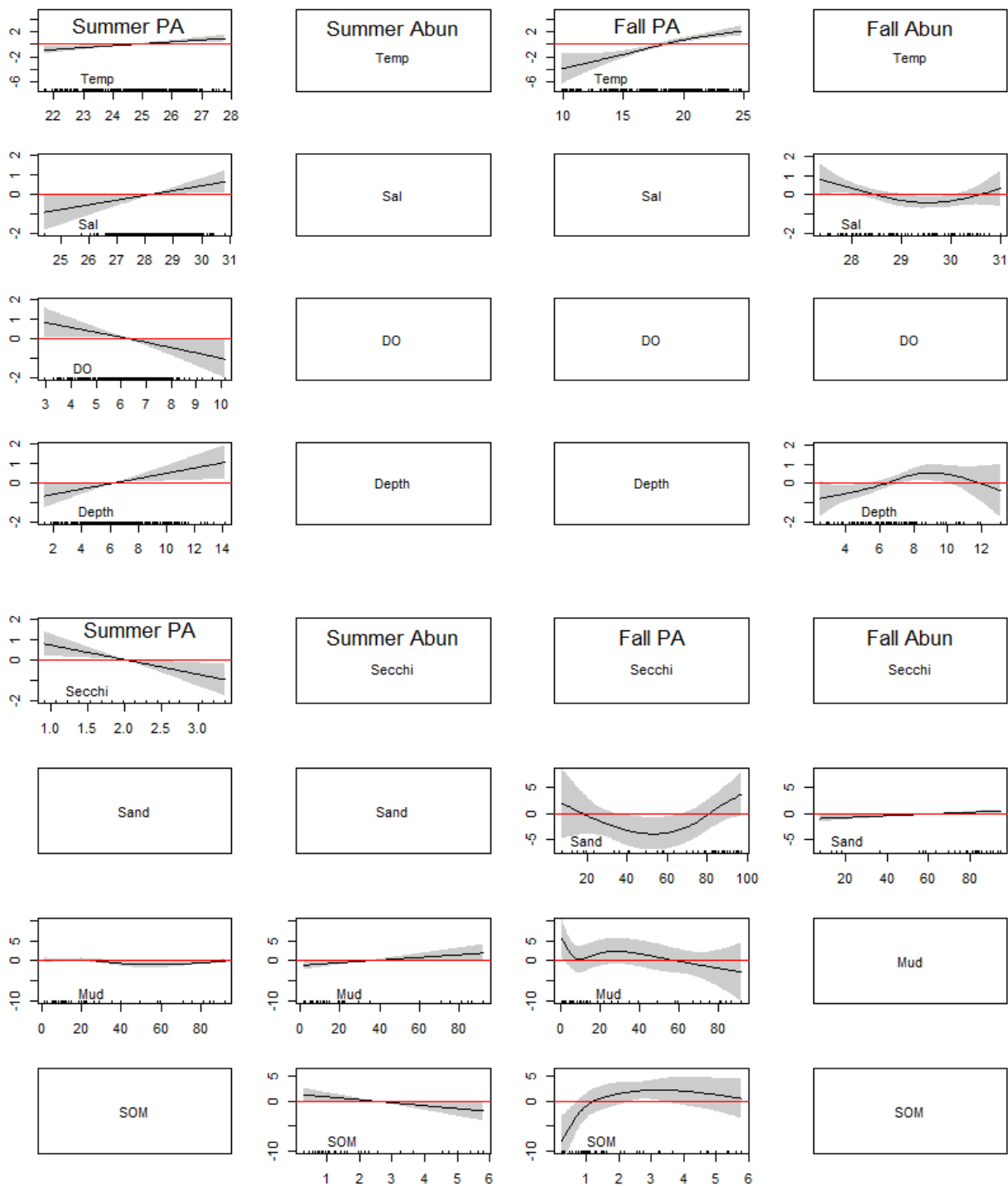


Figure 2. Generalized additive model (GAM) plots for occurrence (PA) and abundance (Abun) models of Northern Puffer YOY during summer and fall. The y axis represents the degree of smoothing or effect of the variable on the model. The x axis reflects the relative density of data points as shown by the “rug”. Shaded regions reflect the 95% confidence intervals around response curves. Empty box indicates the exclusion of that variable from the optimal model. Note that ranges on x and y axes differ among panels.

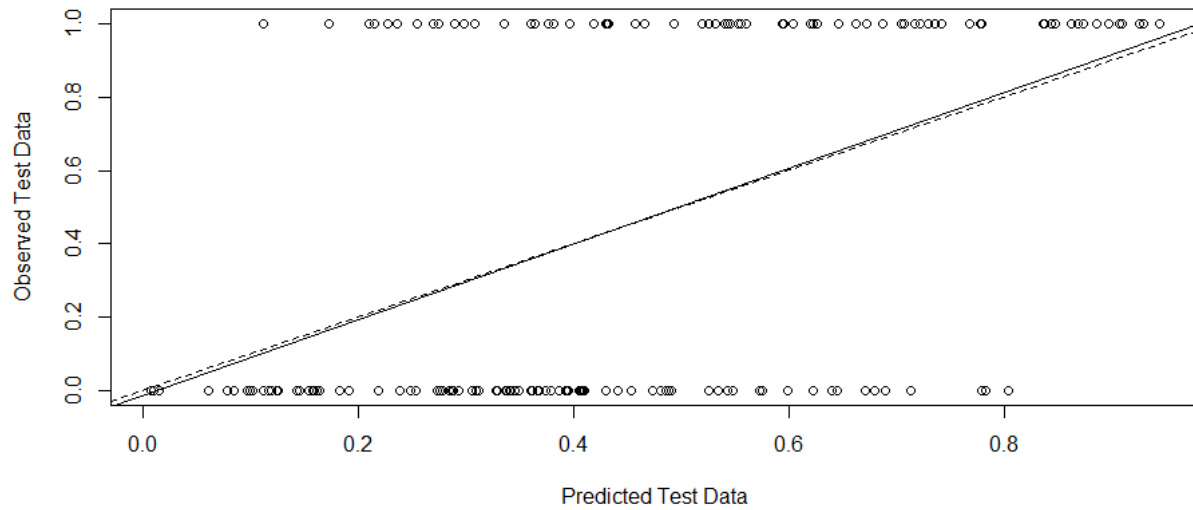


Figure 3. Northern Puffer YOY Summer Presence/Absence Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

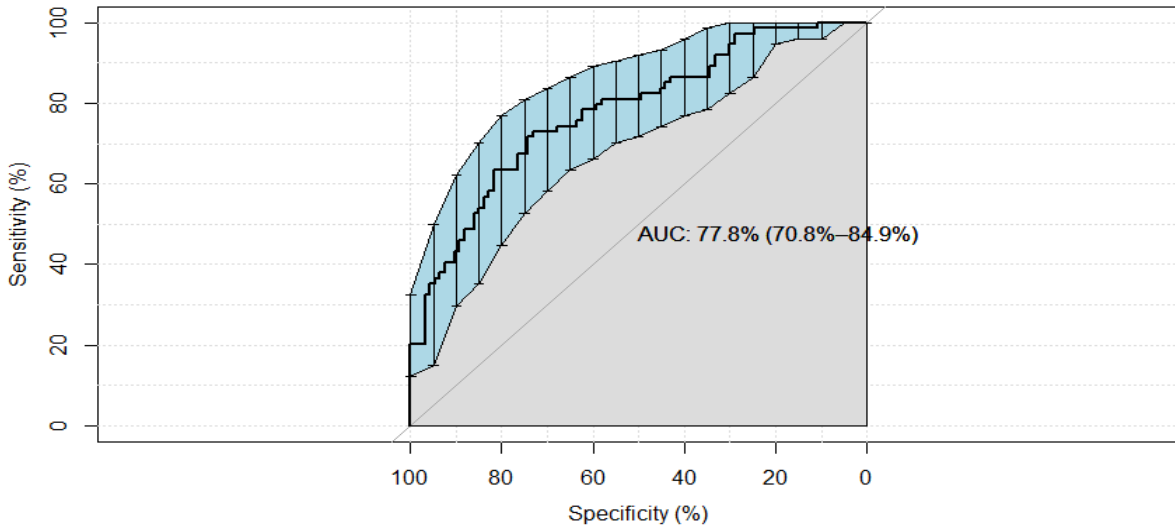


Figure 4. Northern Puffer YOY Summer Presence/Absence Model ROC plot for the validation of the Summer PA Northern Puffer GAM. Solid line is actual values while the blue area indicates the confidence intervals with error bars based on bootstrapping of 5% intervals. The x-axis represents the specificity or the false-positive fraction ($\frac{\text{\# of false-positives}}{\text{\# of true-negative} + \text{\# of false-positives}}$) while the y-axis represents the sensitivity ($\frac{\text{\# of true-positives}}{\text{\# of true-positives} + \text{\# of false-negatives}}$) or the true-positive fraction AUC is area under the curve with the confidence intervals in parentheses.

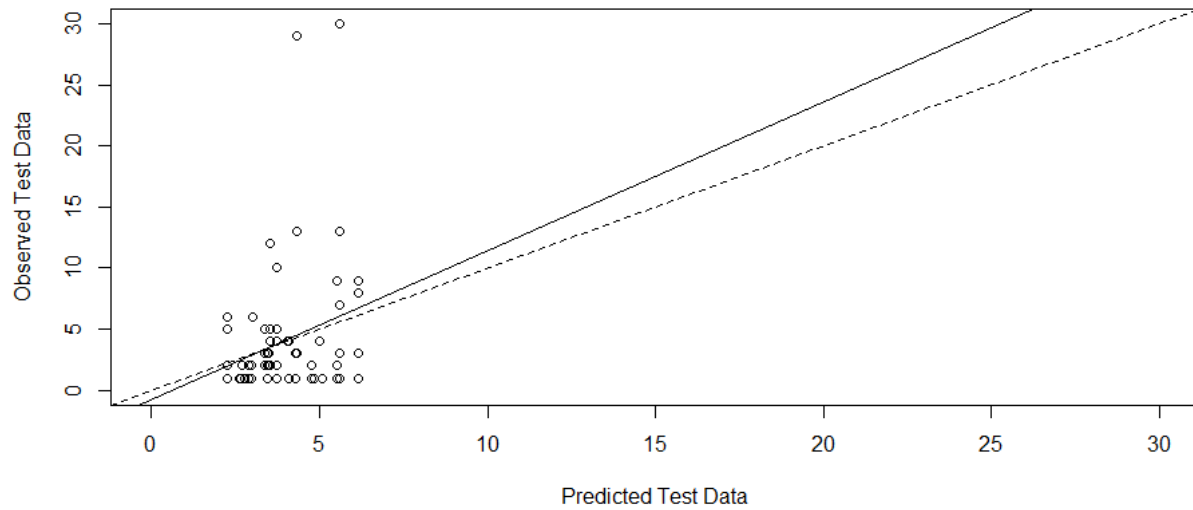


Figure 5. Northern Puffer YOY Summer Abundance Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

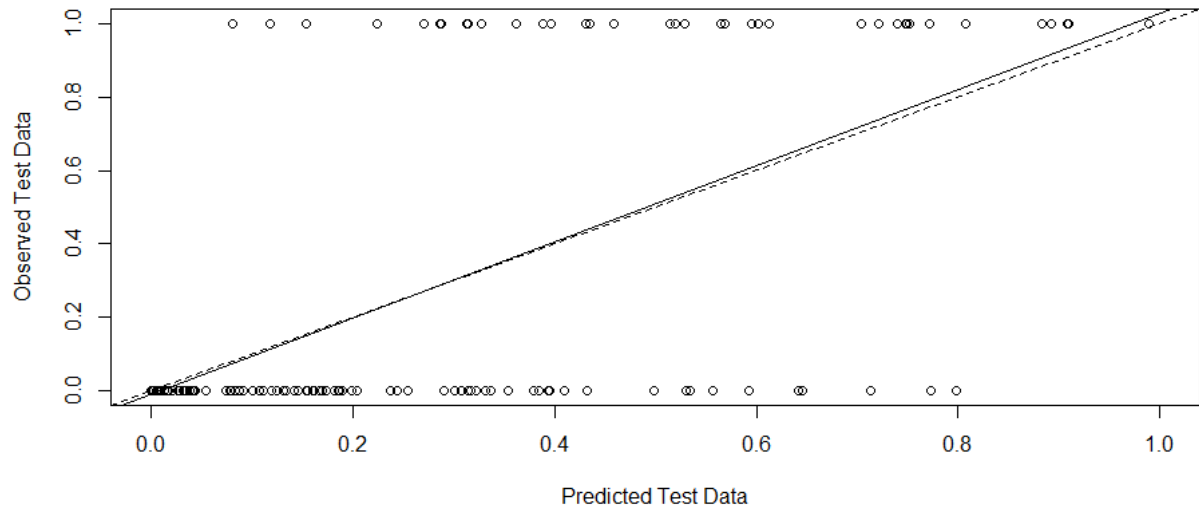


Figure 6. Northern Puffer YOY Fall Presence/Absence Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

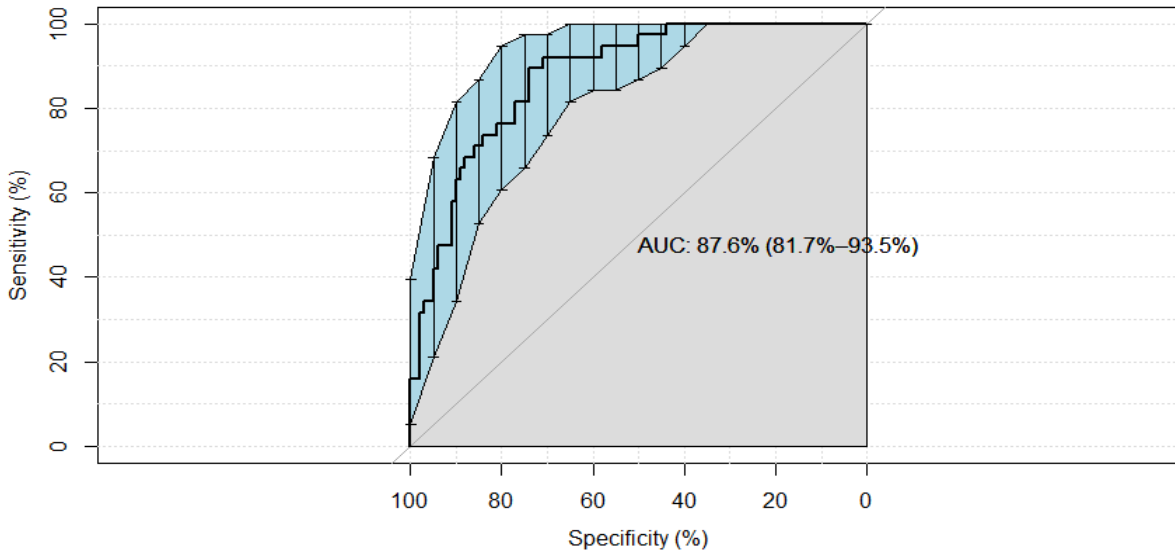


Figure 7. Northern Puffer YOY Fall Presence/Absence Mode ROC plot for the validation of the Fall PA Northern Puffer GAM- Solid line is actual values while the blue area indicates the confidence intervals with error bars based on bootstrapping of 5% intervals. The x-axis represents the specificity or the false-positive fraction ($\frac{\# \text{ of false-positives}}{\# \text{ of true-negative} + \# \text{ of false-positives}}$) while the y-axis represents the sensitivity ($\frac{\# \text{ of true-positives}}{\# \text{ of true positives} + \# \text{ of false-negatives}}$) or the true-positive fraction AUC is area under the curve with the confidence intervals in parentheses.

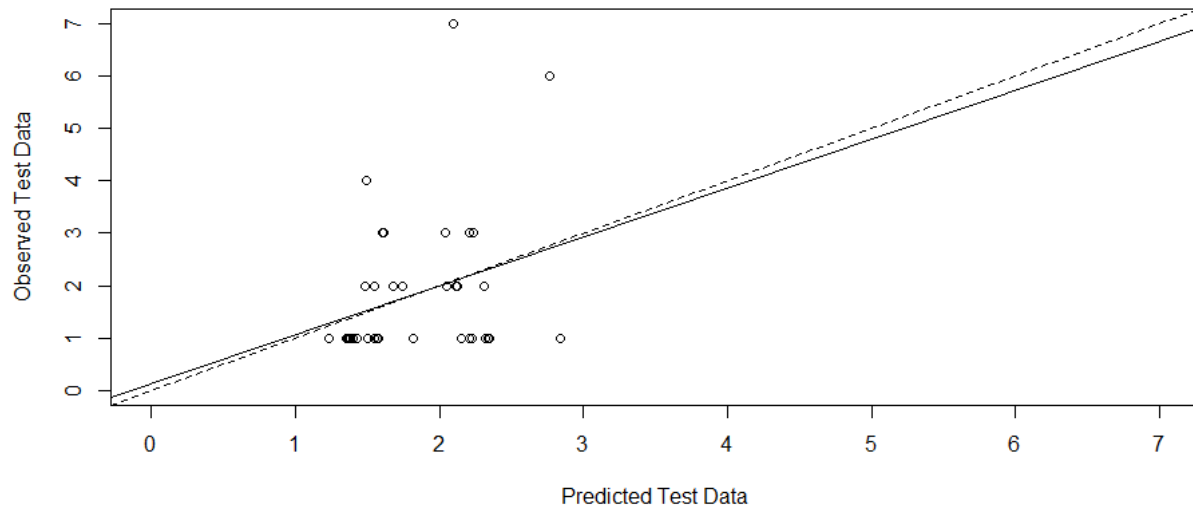


Figure 8. Northern Puffer YOY Fall Abundance Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

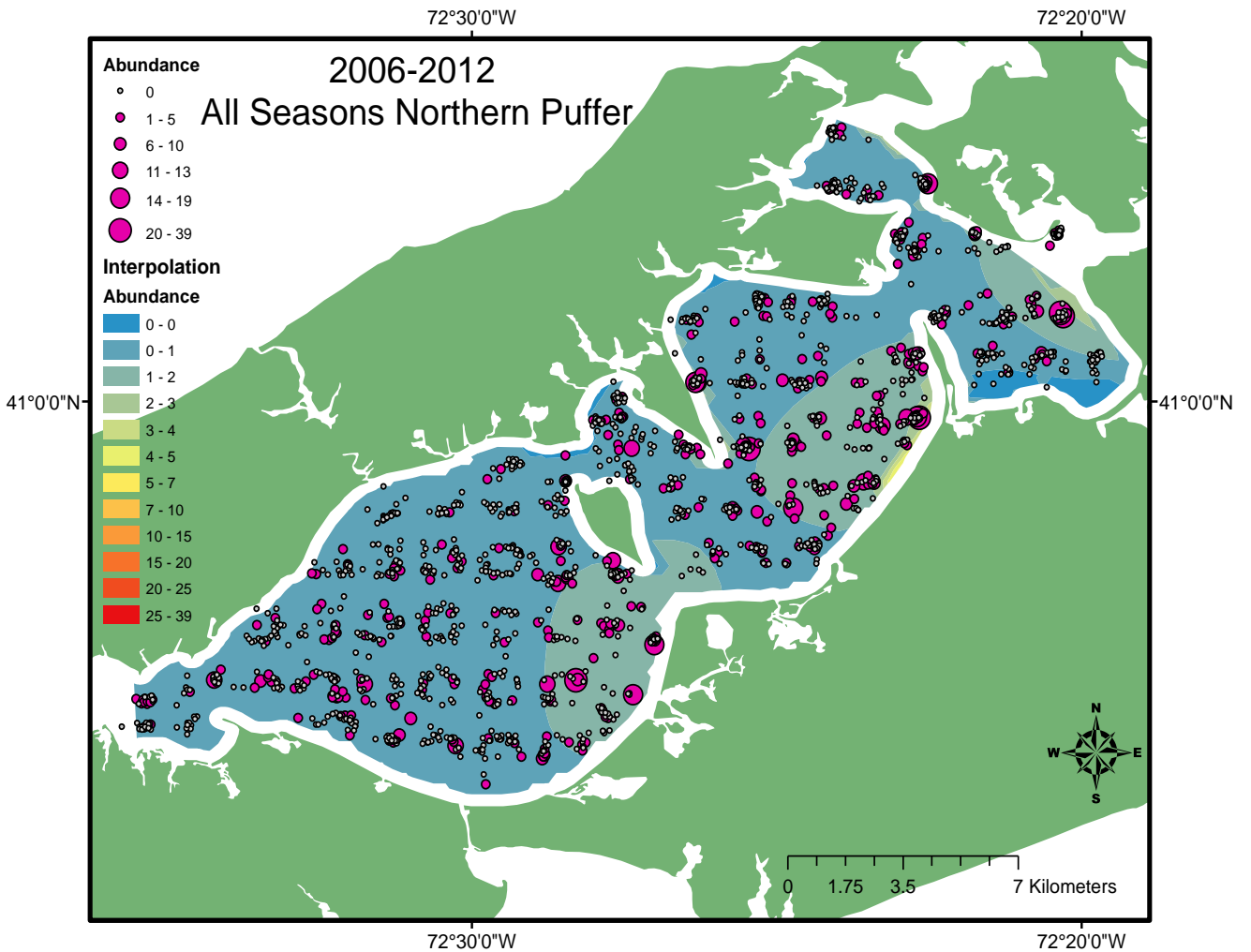


Figure 9. Map of Northern Puffer YOY abundance and interpolations for all seasons from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

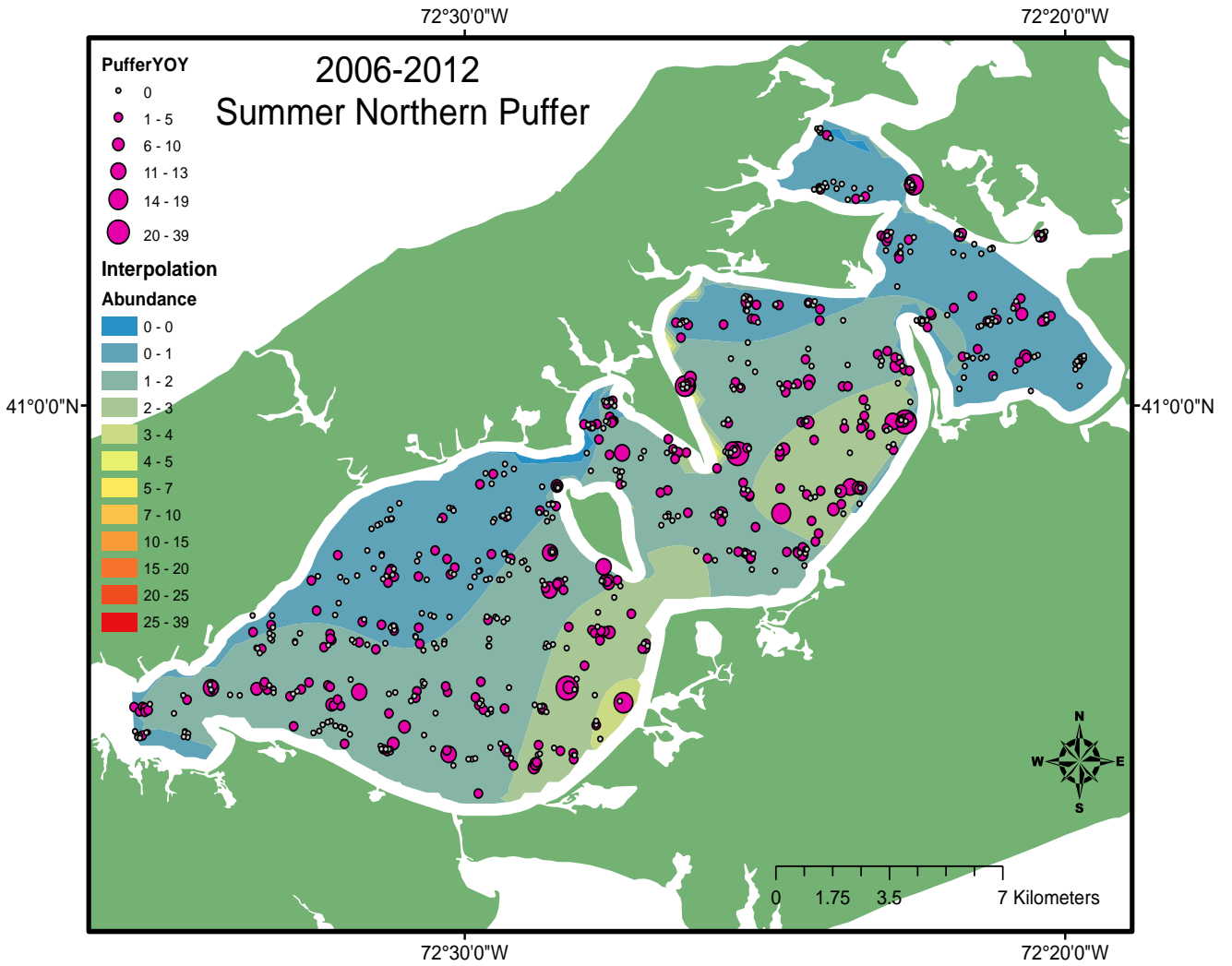


Figure 10. Map of Northern Puffer YOY abundance and interpolations for summer months from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

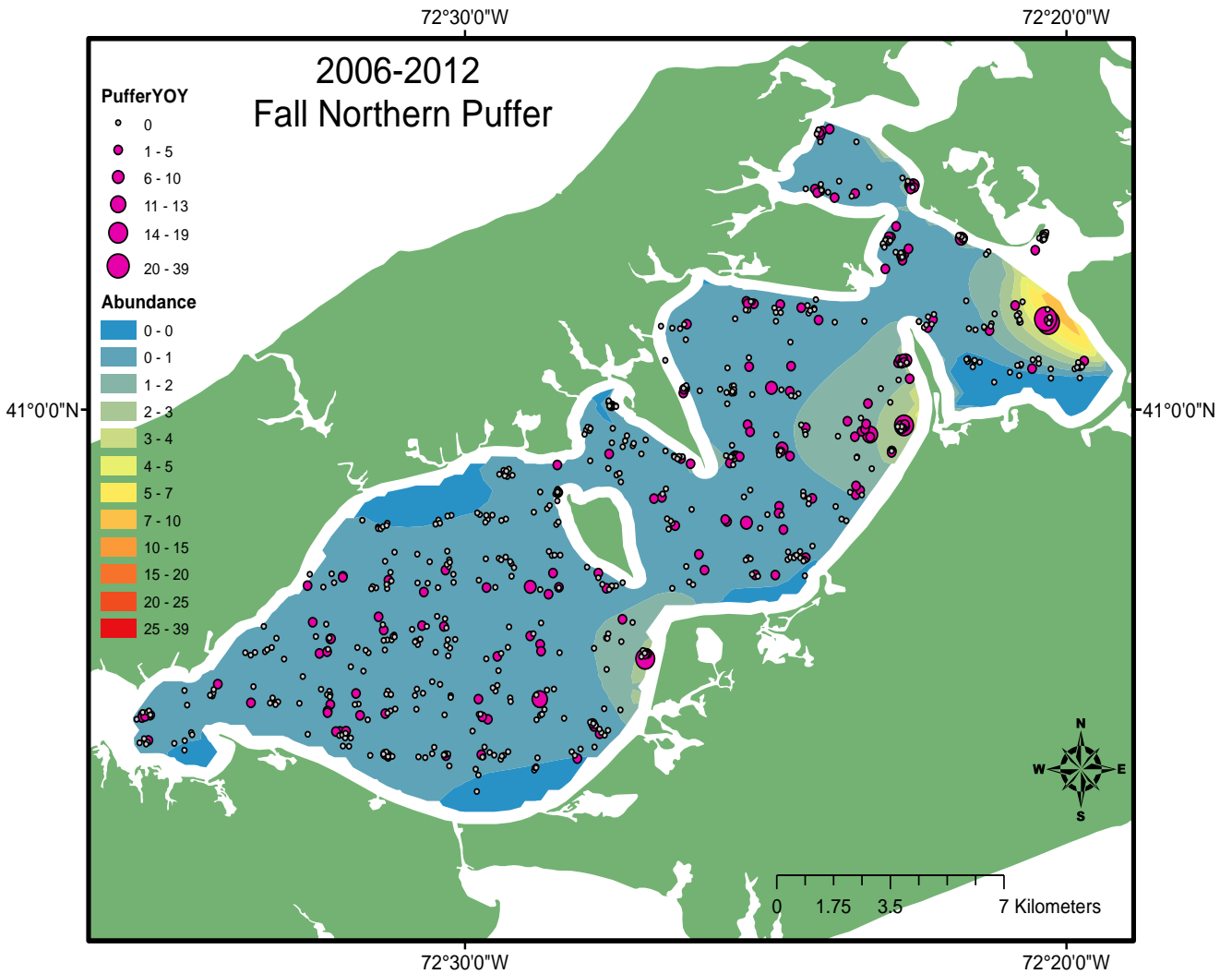


Figure 11. Map of Northern Puffer YOY abundance and interpolations for fall months from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

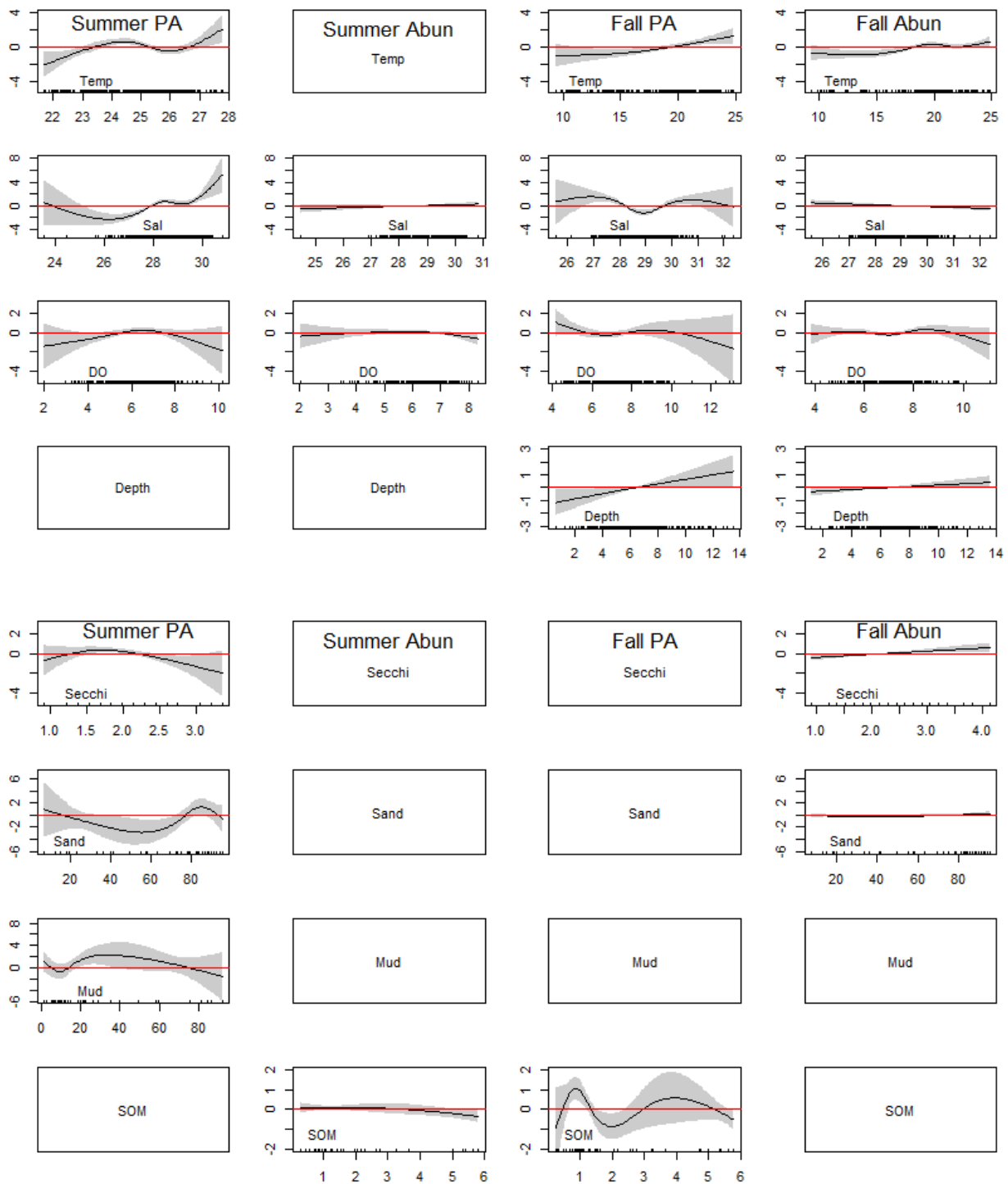


Figure 12. Generalized additive model (GAM) plots for occurrence (PA) and abundance (Abun) models of Scup YOY during summer and fall. The y axis represents the degree of smoothing or effect of the variable on the model. The x axis reflects the relative density of data points as shown by the “rug”. Shaded regions reflect the 95% confidence intervals around response curves. Empty box indicates the exclusion of that variable from the optimal model. Note that ranges on x and y axes differ among panels.

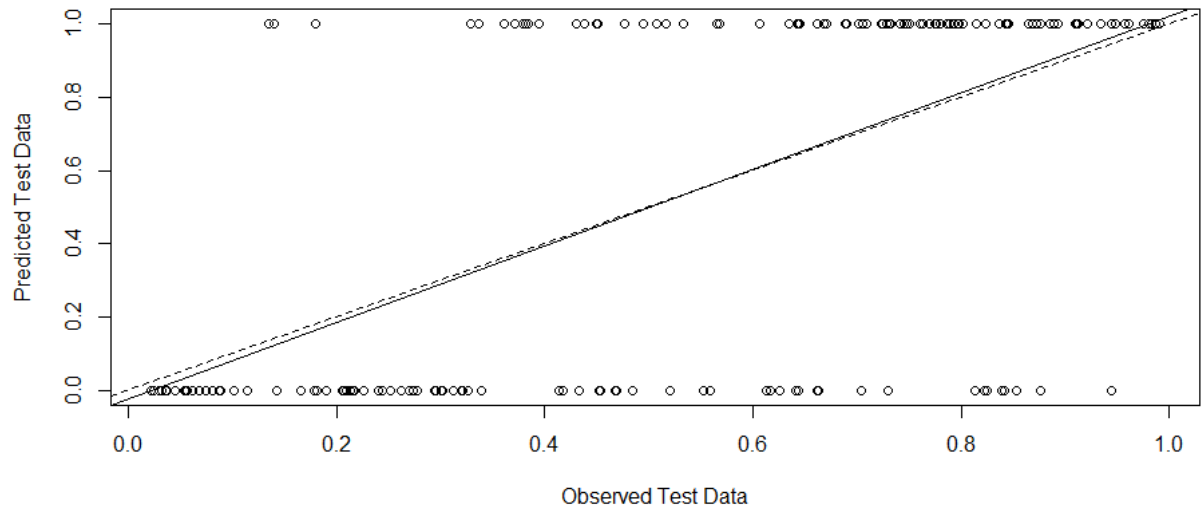


Figure 13. Scup YOY Summer Presence/Absence Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

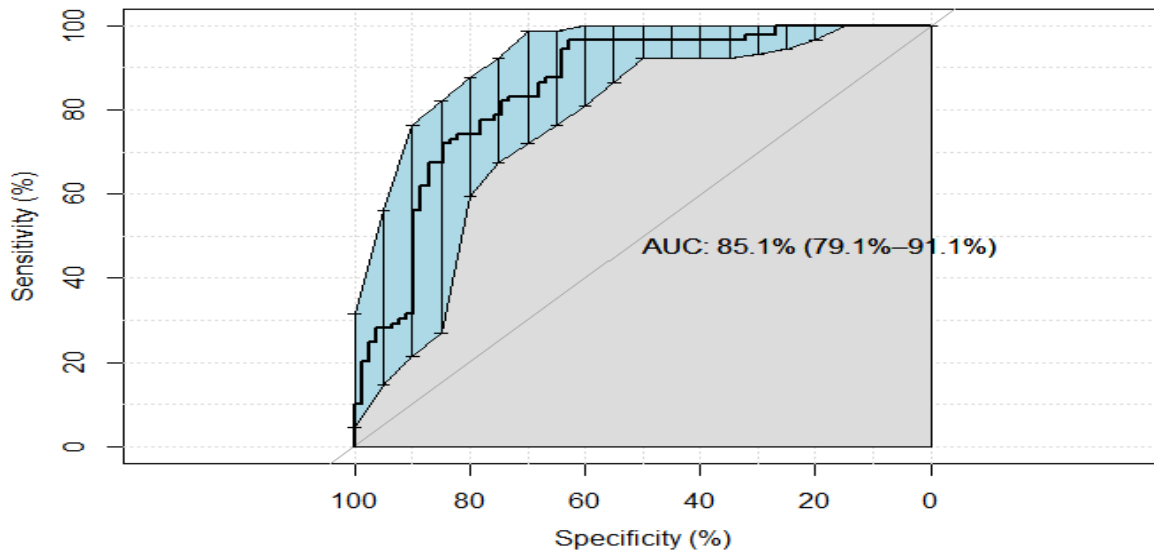


Figure 14. Scup YOY Summer Presence/Absence Model ROC plot for the validation of the Summer PA Scup GAM- Solid line is actual values while the blue area indicates the confidence intervals with error bars based on bootstrapping of 5% intervals. The x-axis represents the specificity or the false-positive fraction ($\#$ of false-positives/ $\#$ of true-negative + $\#$ of false-positives) while the y-axis represents the sensitivity ($\#$ of true-positives/ $\#$ of true positives+ $\#$ of false-negatives) or the true-positive fraction AUC is area under the curve with the confidence intervals in parentheses.

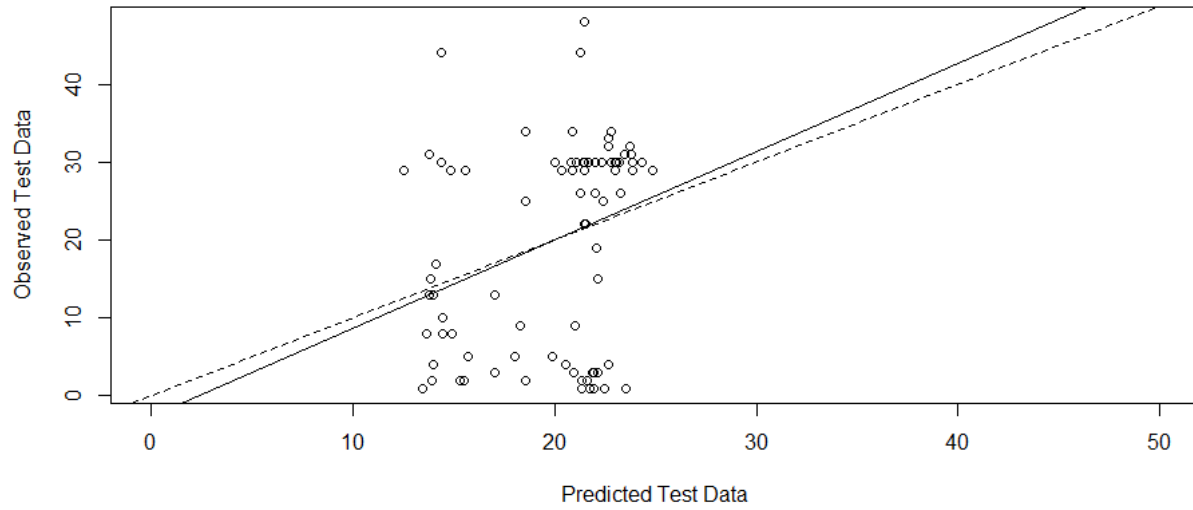


Figure 15. Scup YOY Summer Abundance Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

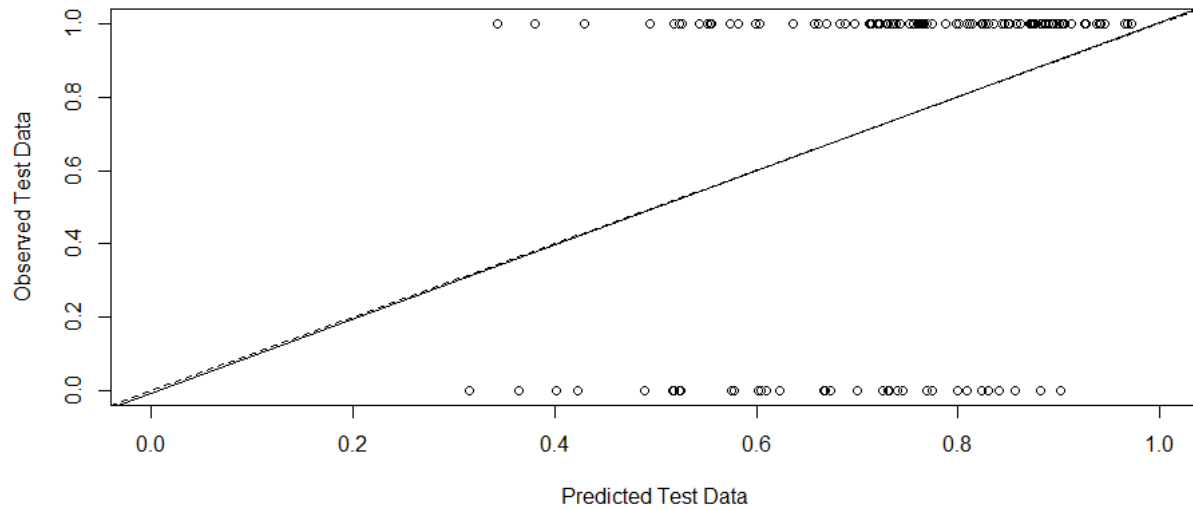


Figure 16. Scup YOY Fall Presence/Absence Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

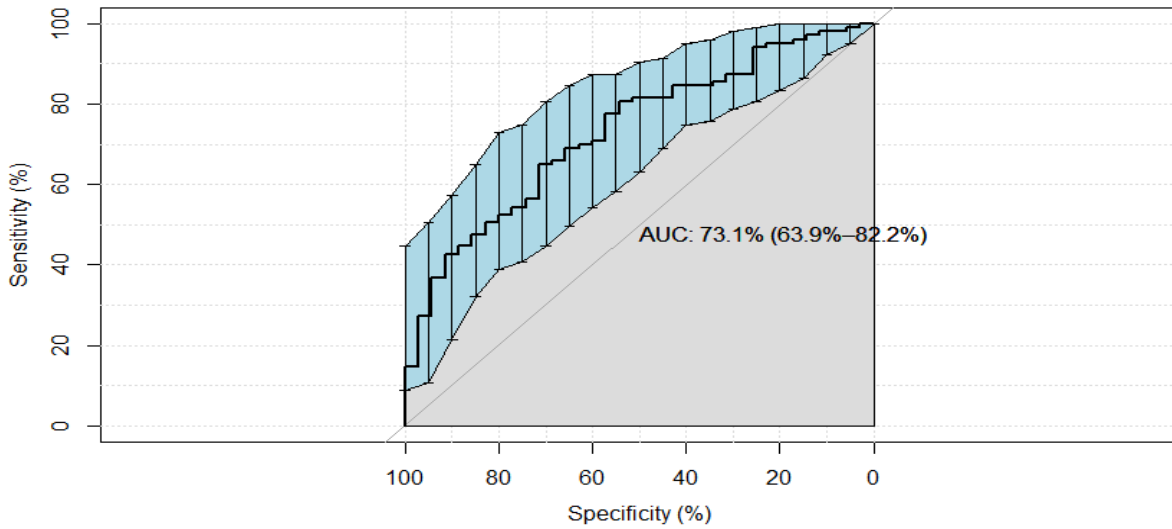


Figure 17. Scup YOY Fall Presence/Absence Model ROC plot for the validation of the Fall PA Scup GAM- Solid line is actual values while the blue area indicates the confidence intervals with error bars based on bootstrapping of 5% intervals. The x-axis represents the specificity or the false-positive fraction ($\#$ of false-positives/ $\#$ of true-negative + $\#$ of false-positives) while the y-axis represents the sensitivity ($\#$ of true-positives/ $\#$ of true positives+ $\#$ of false-negatives) or the true-positive fraction AUC is area under the curve with the confidence intervals in parentheses.

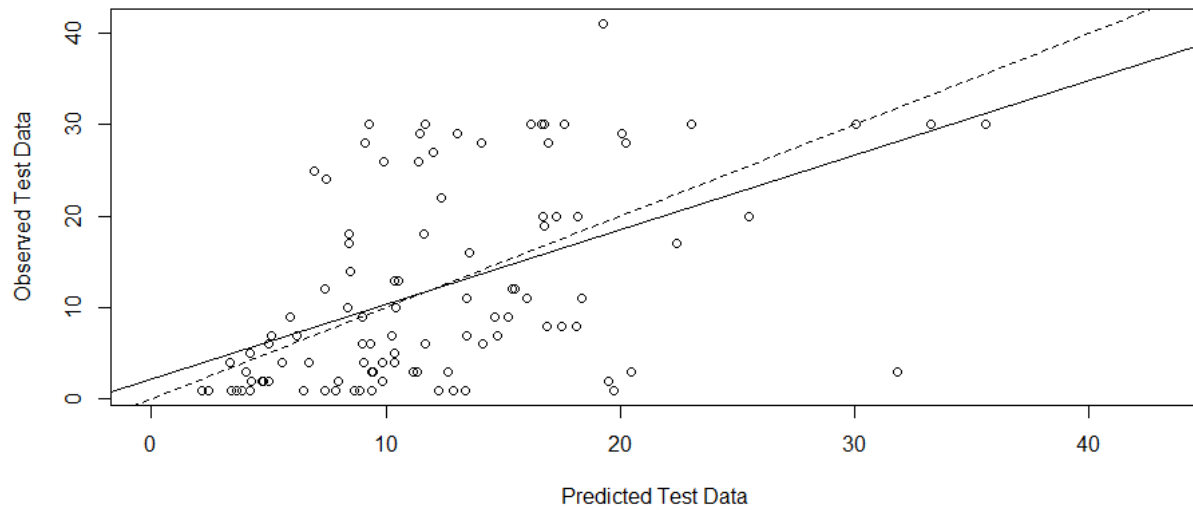


Figure 18. Scup YOY Fall Abundance Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

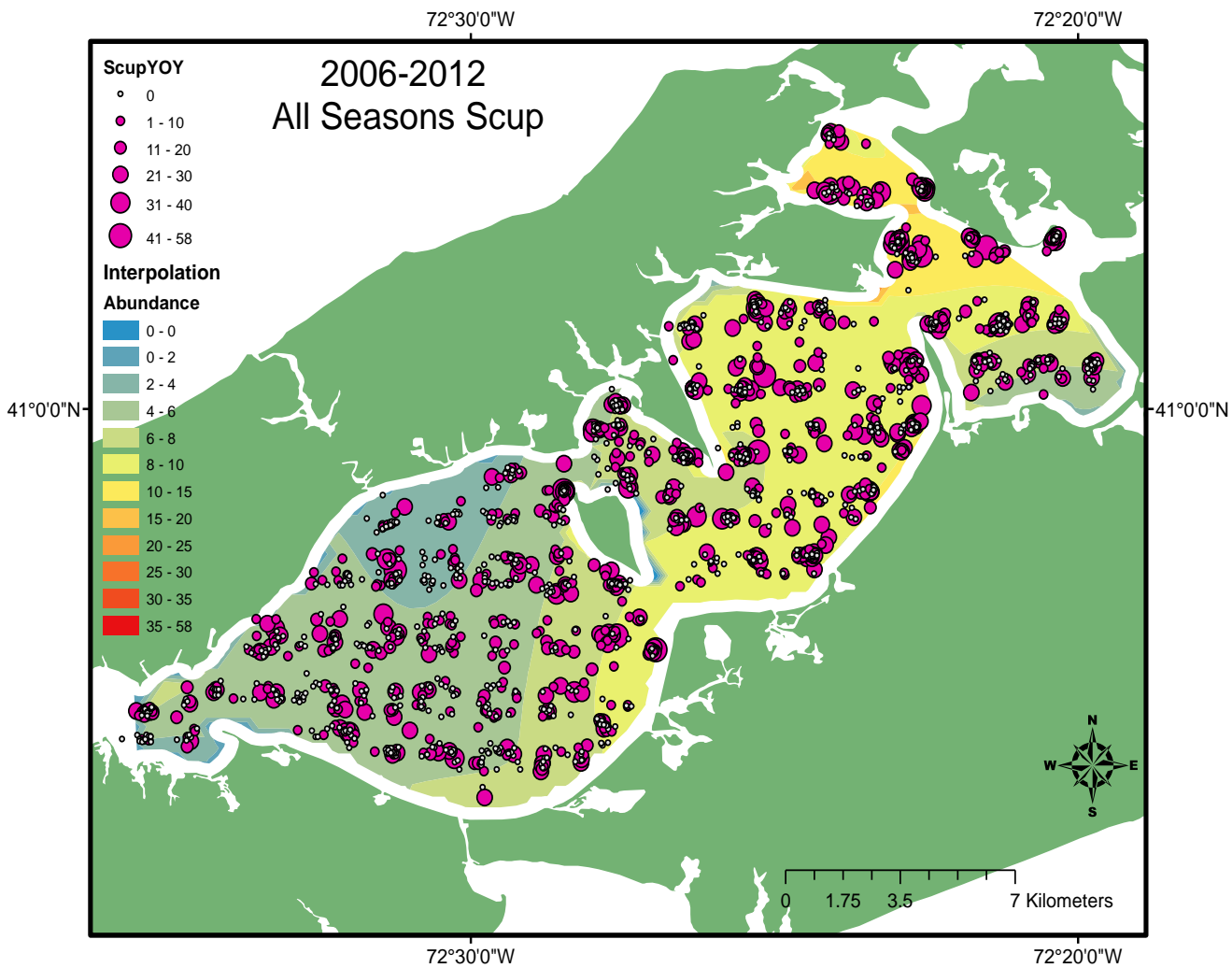


Figure 19. Map of Scup YOY abundance and interpolations for all seasons from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

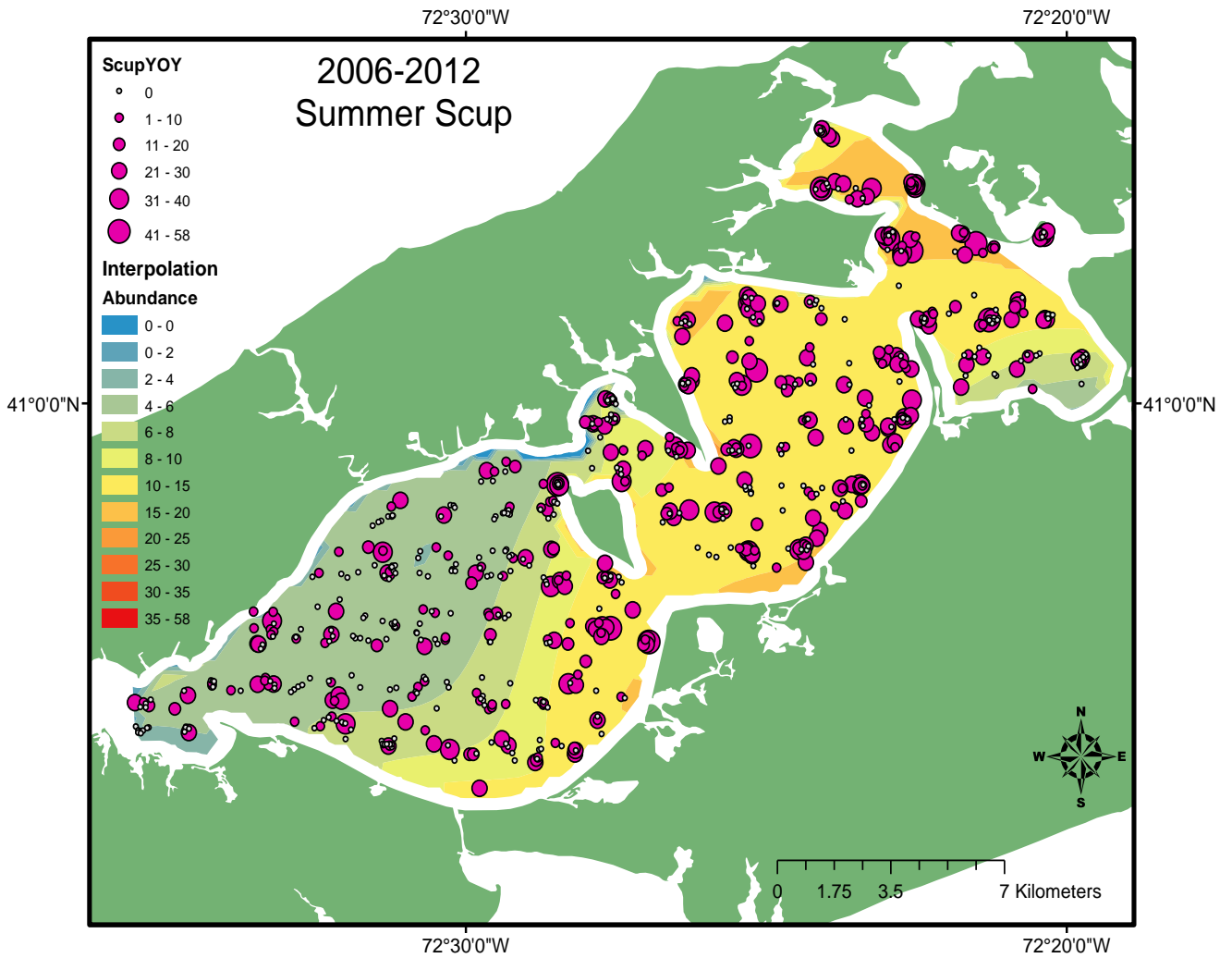


Figure 20. Map of Scup YOY abundance and interpolations for summer months from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

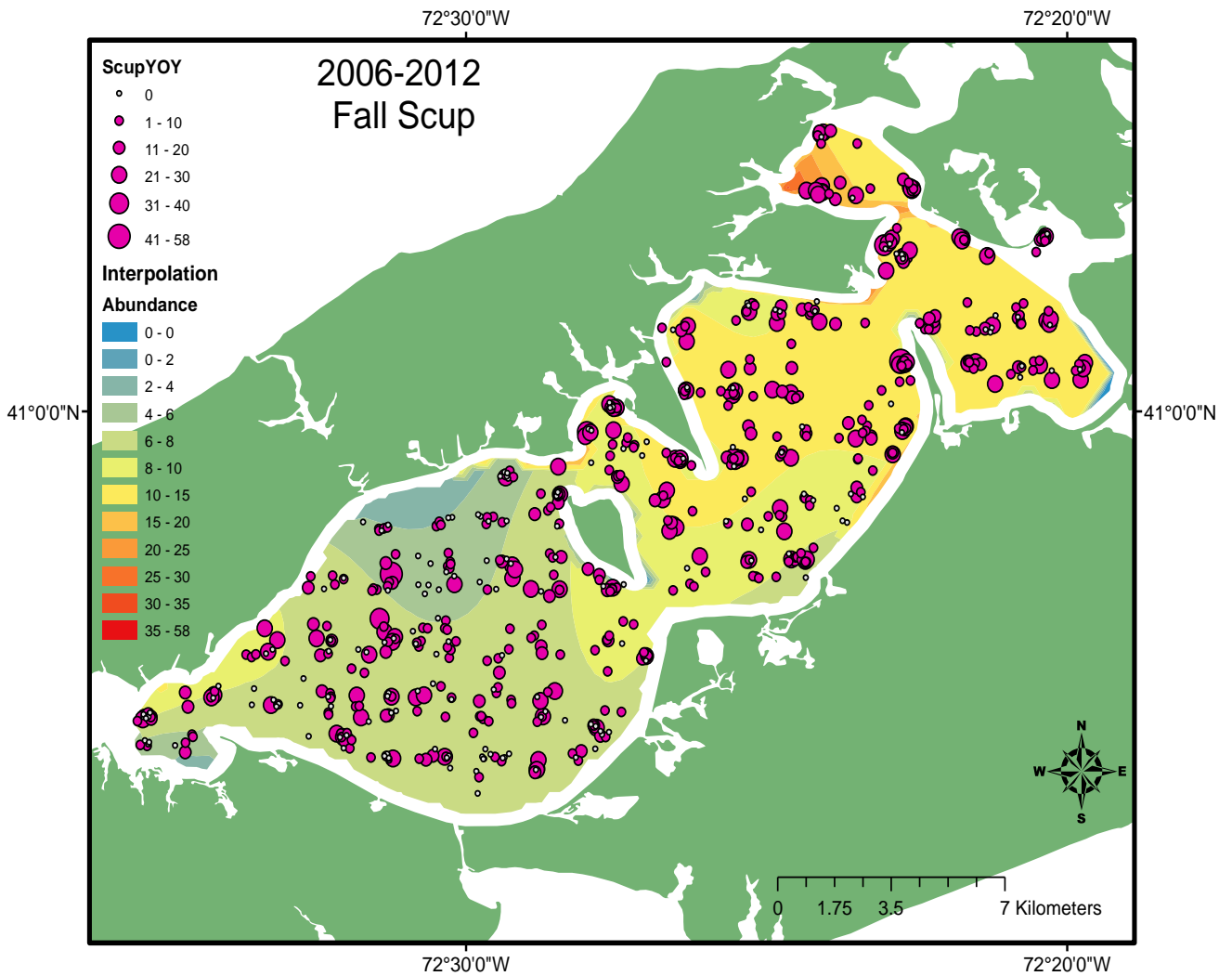


Figure 21. Map of Scup YOY abundance and interpolations for fall months from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

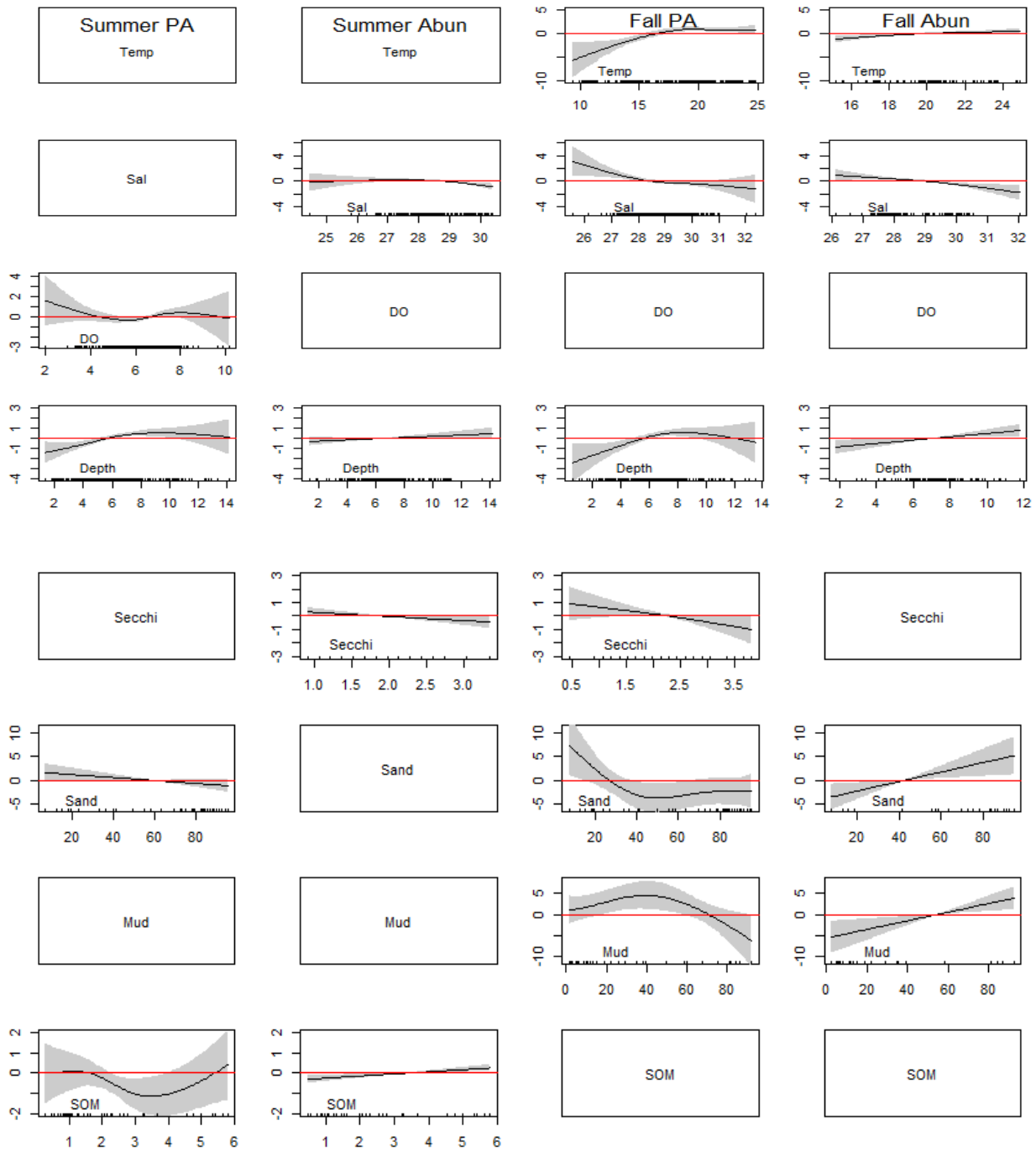


Figure 22. Generalized additive model (GAM) plots for occurrence (PA) and abundance (Abun) models of Weakfish YOY during summer and fall. The y axis represents the degree of smoothing or effect of the variable on the model. The x axis reflects the relative density of data points as shown by the “rug”. Shaded regions reflect the 95% confidence intervals around response curves. Empty box indicates the exclusion of that variable from the optimal model. Note that ranges on x and y axes differ among panels.

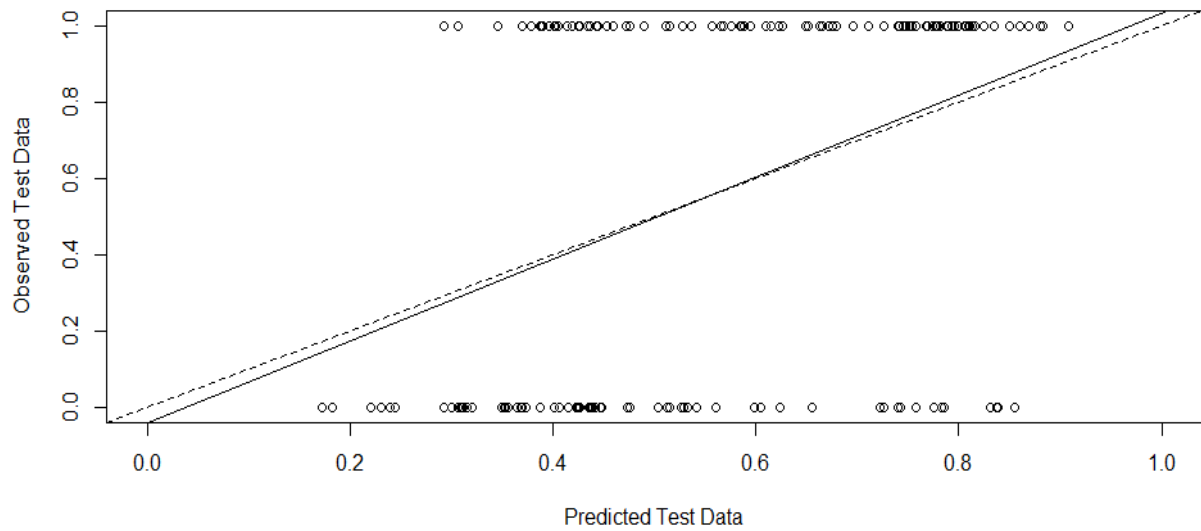


Figure 23. Weakfish YOY Summer Presence/Absence Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

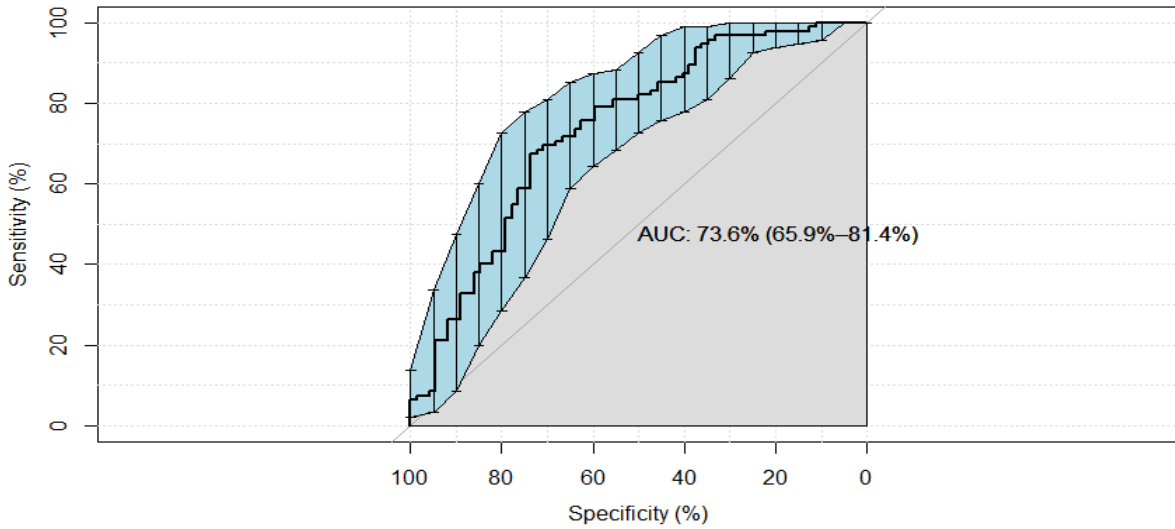


Figure 24. Weakfish YOY Summer Presence/Absence Model ROC plot for the validation of the Summer PA Weakfish GAM- Solid line is actual values while the blue area indicates the confidence intervals with error bars based on bootstrapping of 5% intervals. The x-axis represents the specificity or the false-positive fraction ($\frac{\# \text{ of false-positives}}{\# \text{ of true-negative} + \# \text{ of false-positives}}$) while the y-axis represents the sensitivity ($\frac{\# \text{ of true-positives}}{\# \text{ of true positives} + \# \text{ of false-negatives}}$) or the true-positive fraction AUC is area under the curve with the confidence intervals in parentheses.

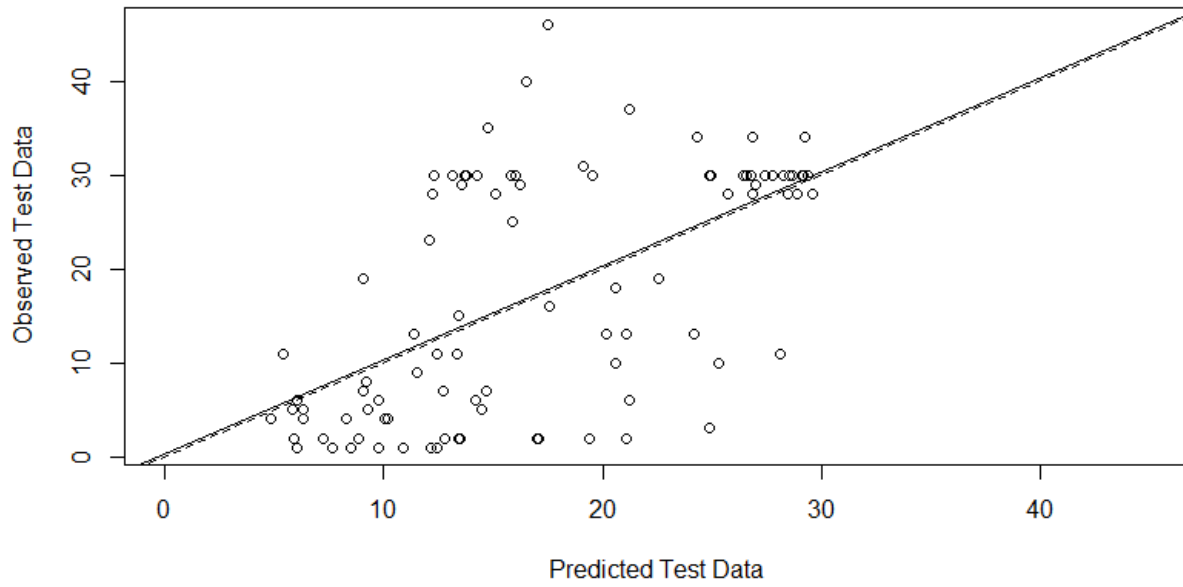


Figure 25. Weakfish YOY Summer Abundance Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

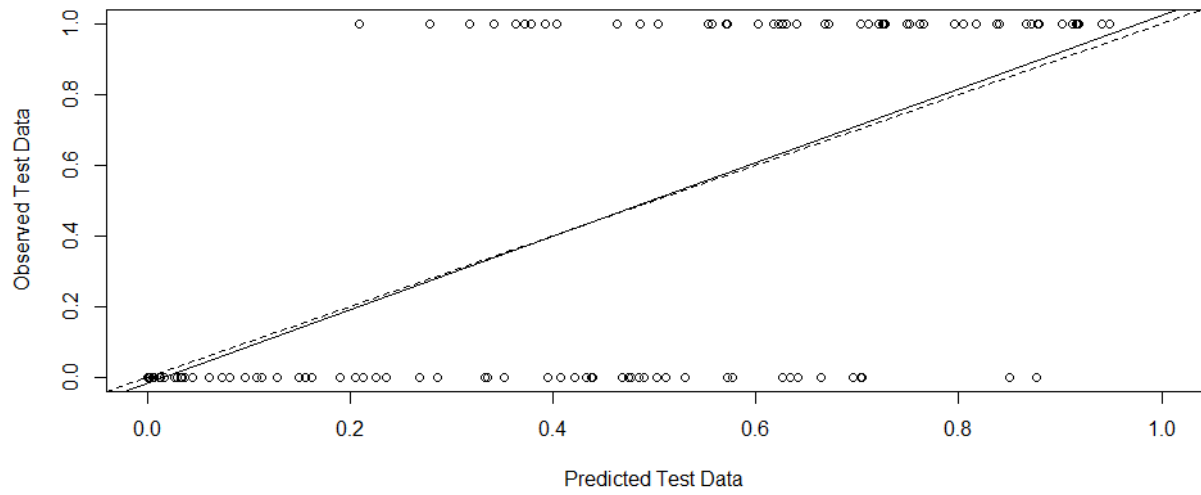


Figure 26. Weakfish YOY Fall Presence/Absence Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

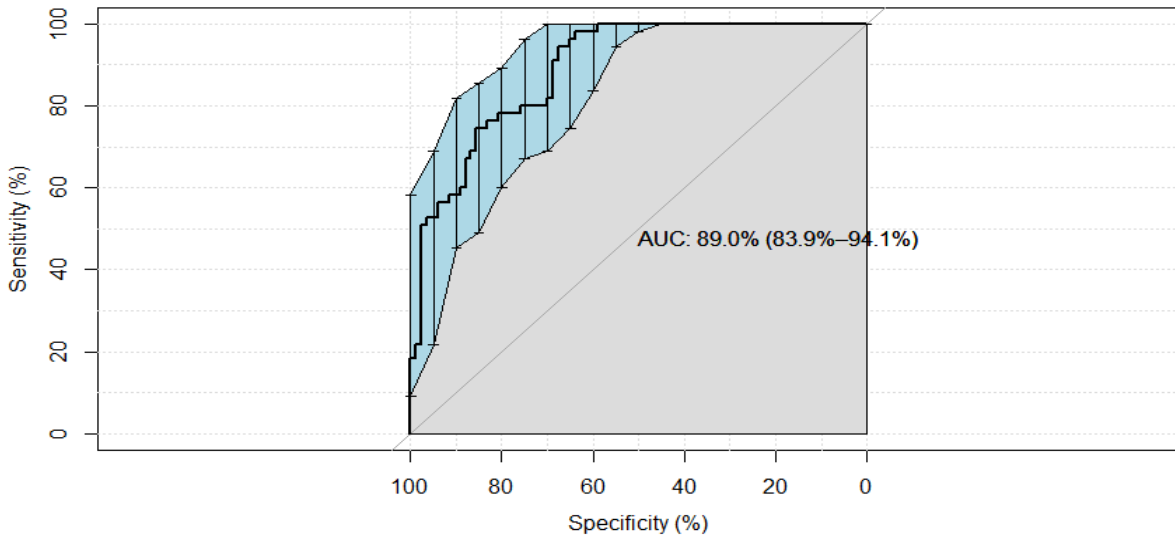


Figure 27. Weakfish YOY Fall Presence/Absence Model ROC plot for the validation of the Fall PA Weakfish GAM- Solid line is actual values while the blue area indicates the confidence intervals with error bars based on bootstrapping of 5% intervals. The x-axis represents the specificity or the false-positive fraction ($\#$ of false-positives/ $\#$ of true-negative + $\#$ of false-positives) while the y-axis represents the sensitivity ($\#$ of true-positives/ $\#$ of true positives+ $\#$ of false-negatives) or the true-positive fraction AUC is area under the curve with the confidence intervals in parentheses.

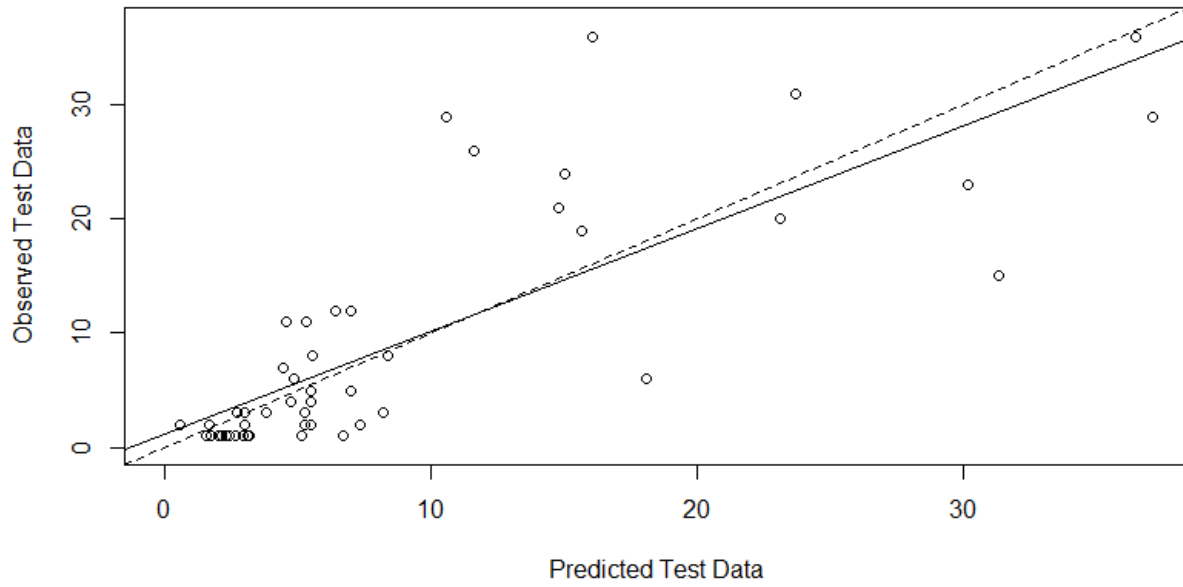


Figure 28. Weakfish YOY Fall Abundance Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

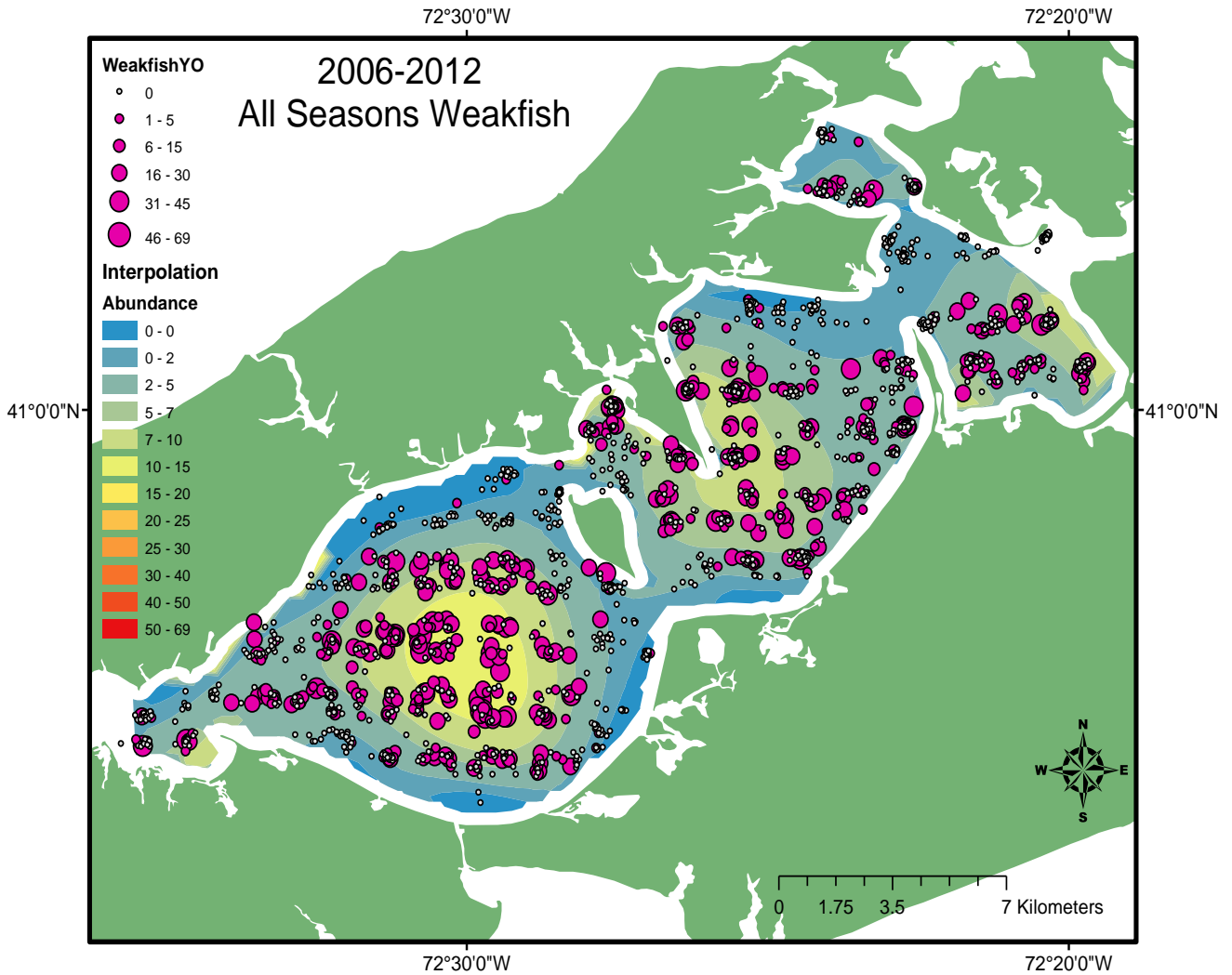


Figure 29. Map of Weakfish YOY abundance and interpolations for all seasons from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

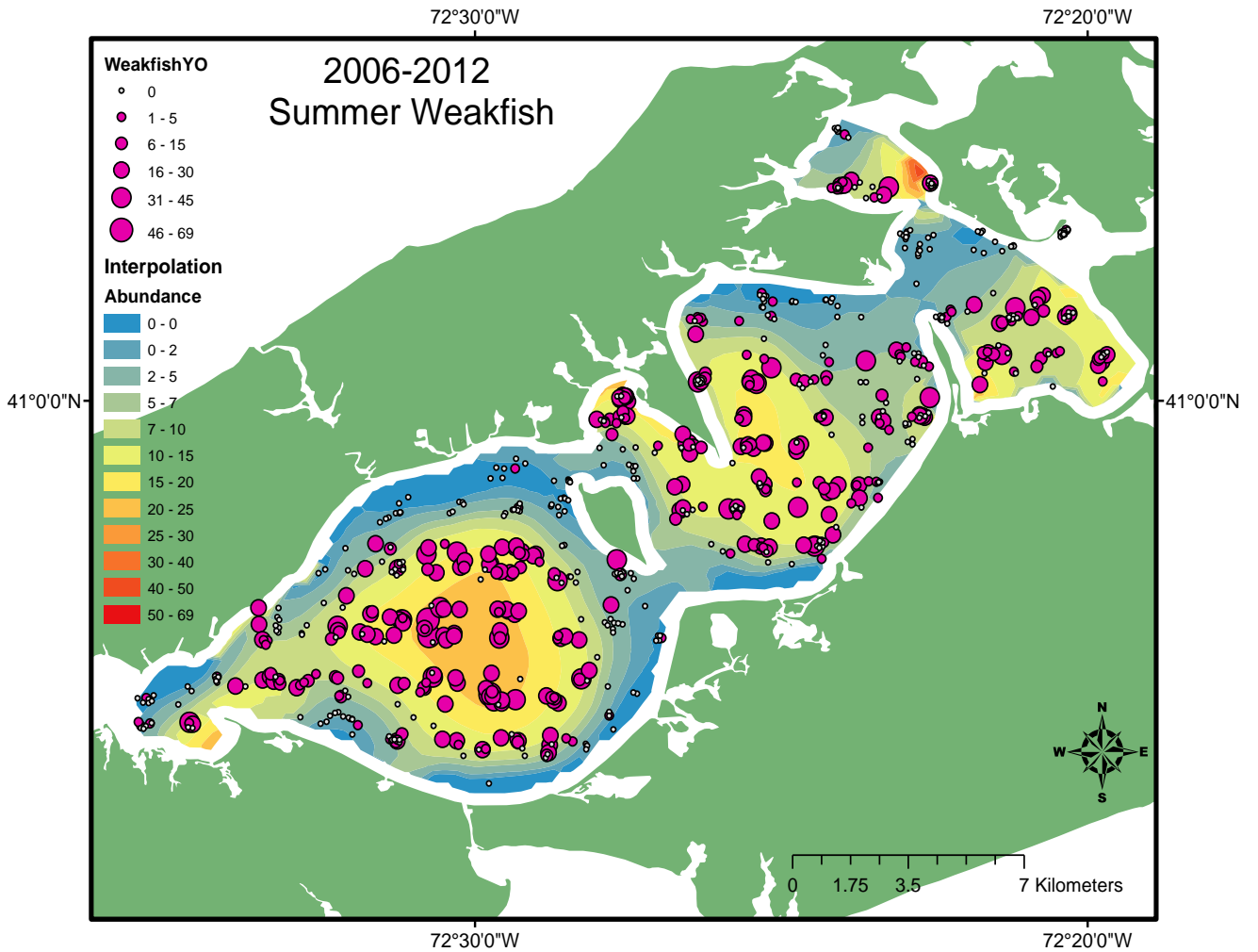


Figure 30. Map of Weakfish abundance and interpolations for summer months from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

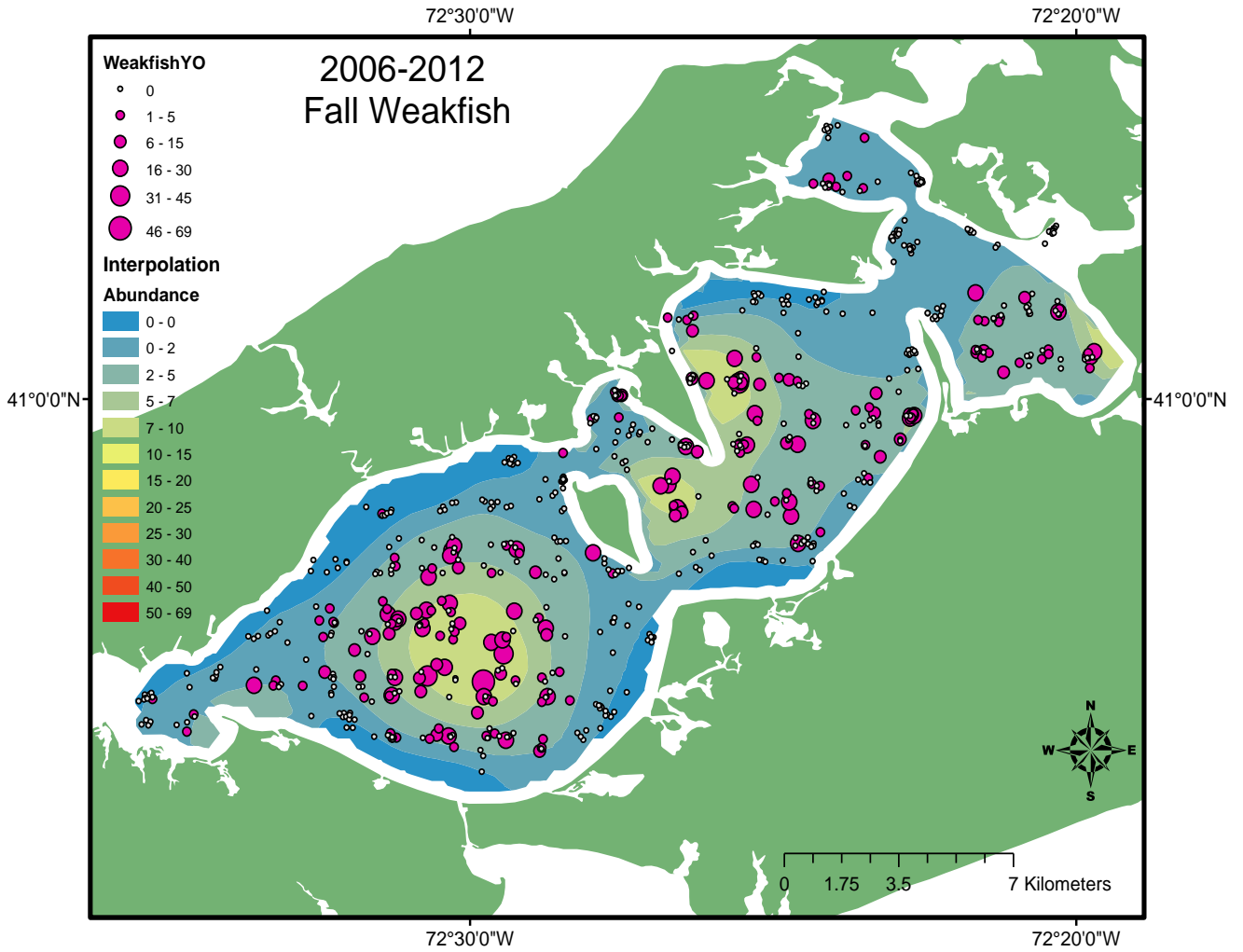


Figure 31. Map of Weakfish YOY abundance and interpolations for fall months from 2000-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

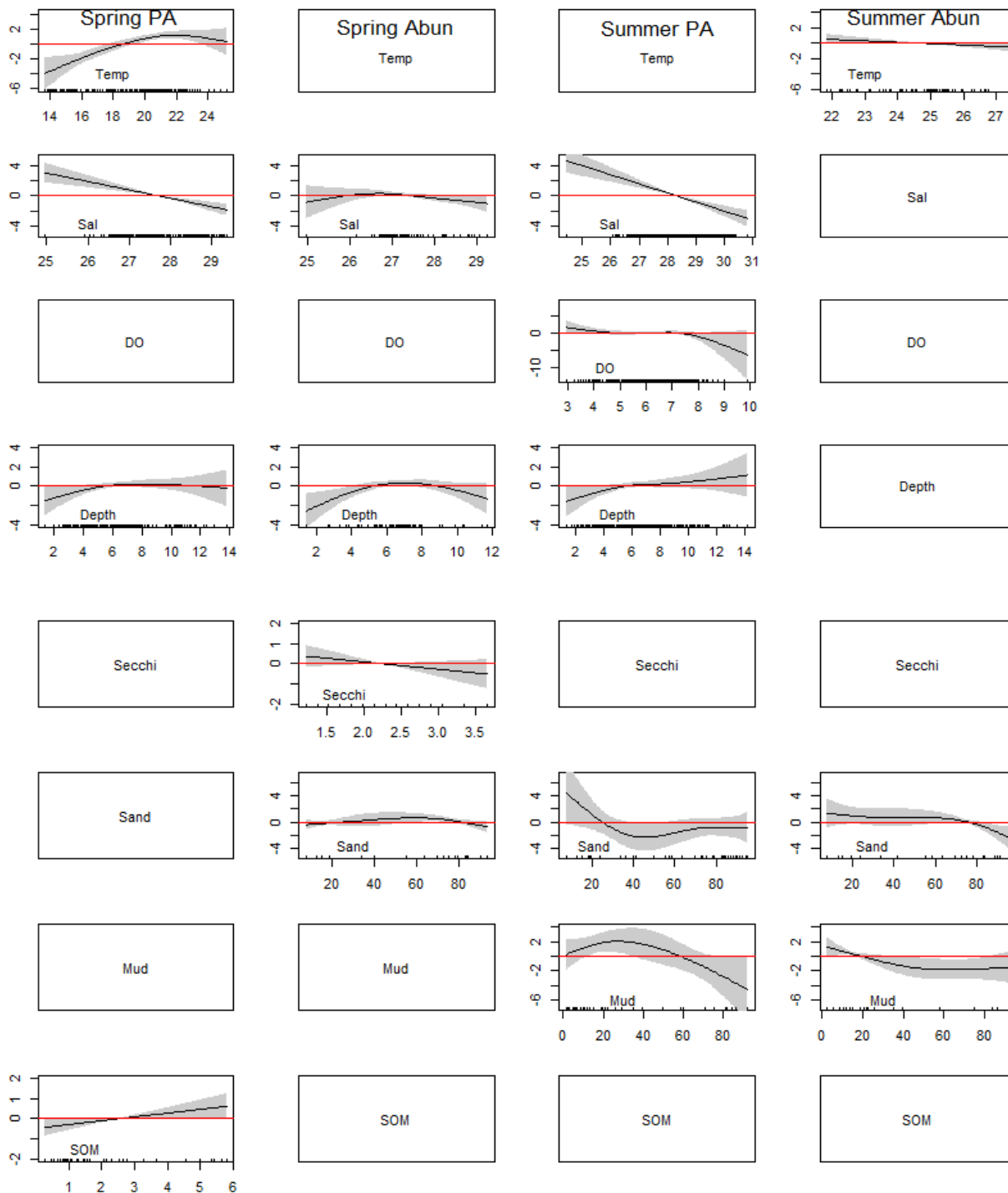


Figure 32. Generalized additive model (GAM) plots for occurrence (PA) and abundance (Abun) models of Winter Flounder YOY during summer and fall. The y axis represents the degree of smoothing or effect of the variable on the model. The x axis reflects the relative density of data points as shown by the “rug”. Shaded regions reflect the 95% confidence intervals around response curves. Empty box indicates the exclusion of that variable from the optimal model. Note that ranges on x and y axes differ among panels.

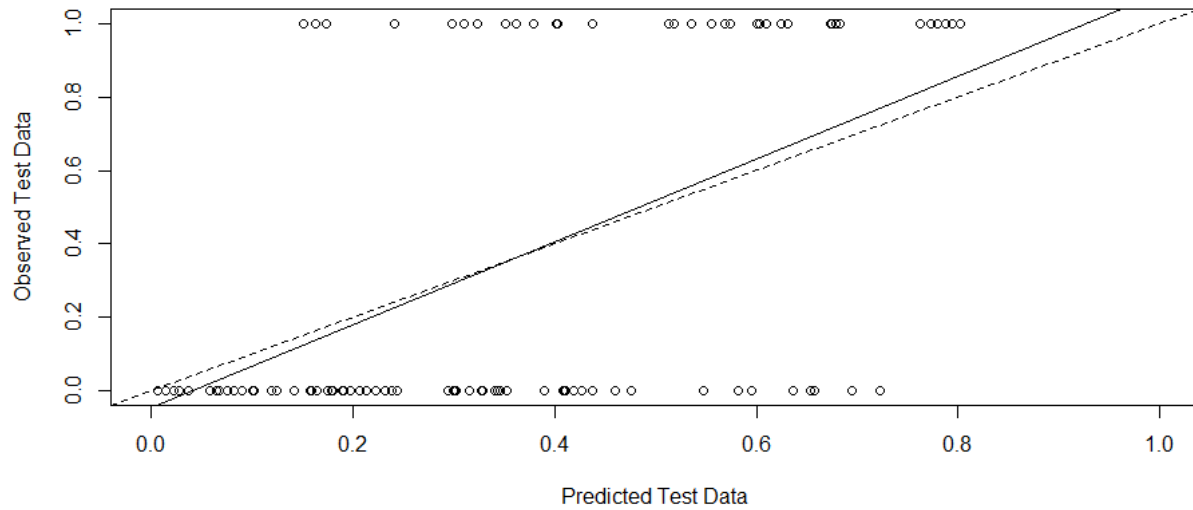


Figure 33. Winter Flounder YOY Spring Presence/Absence Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

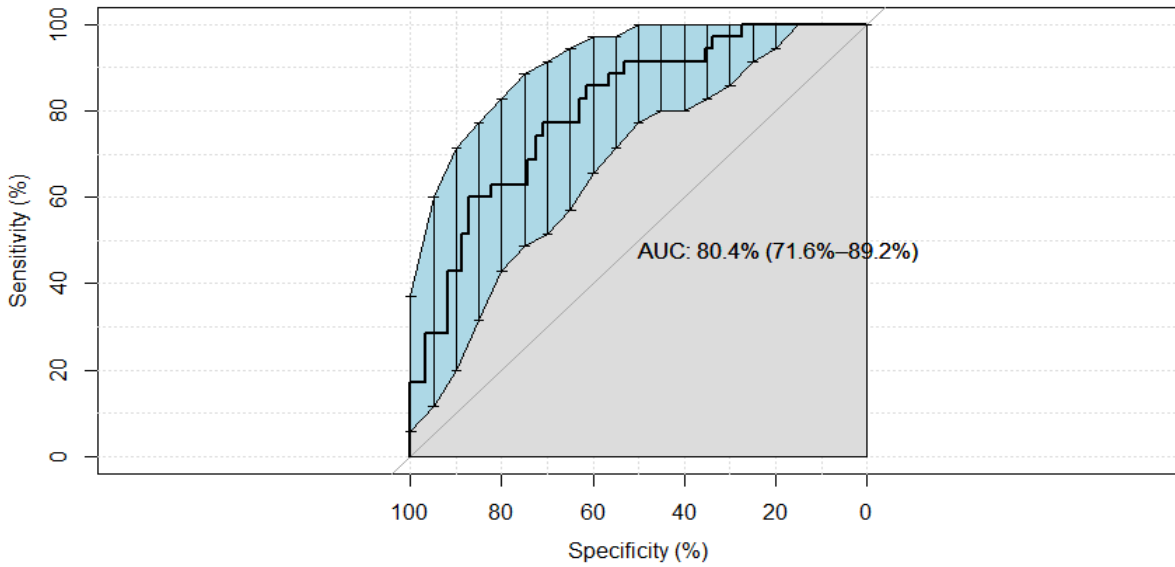


Figure 34. Winter Flounder YOY Spring Presence/Absence Model ROC plot for the validation of the Summer PA Winter Flounder GAM- Solid line is actual values while the blue area indicates the confidence intervals with error bars based on bootstrapping of 5% intervals. The x-axis represents the specificity or the false-positive fraction ($\frac{\# \text{ of false-positives}}{\# \text{ of true-negative} + \# \text{ of false-positives}}$) while the y-axis represents the sensitivity ($\frac{\# \text{ of true-positives}}{\# \text{ of true positives} + \# \text{ of false-negatives}}$) or the true-positive fraction AUC is area under the curve with the confidence intervals in parentheses.

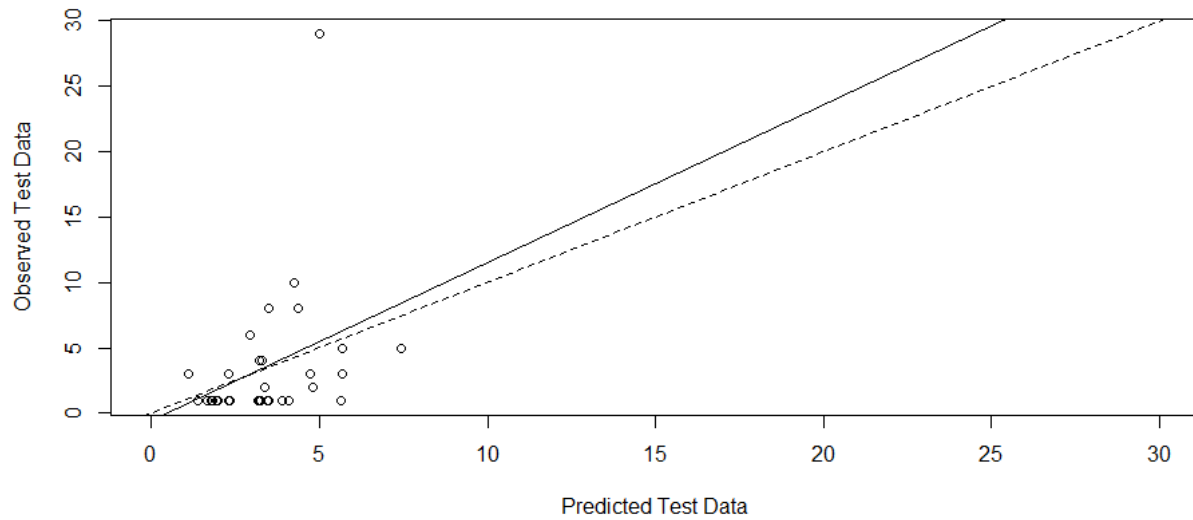


Figure 35. Winter Flounder YOY Spring Abundance Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

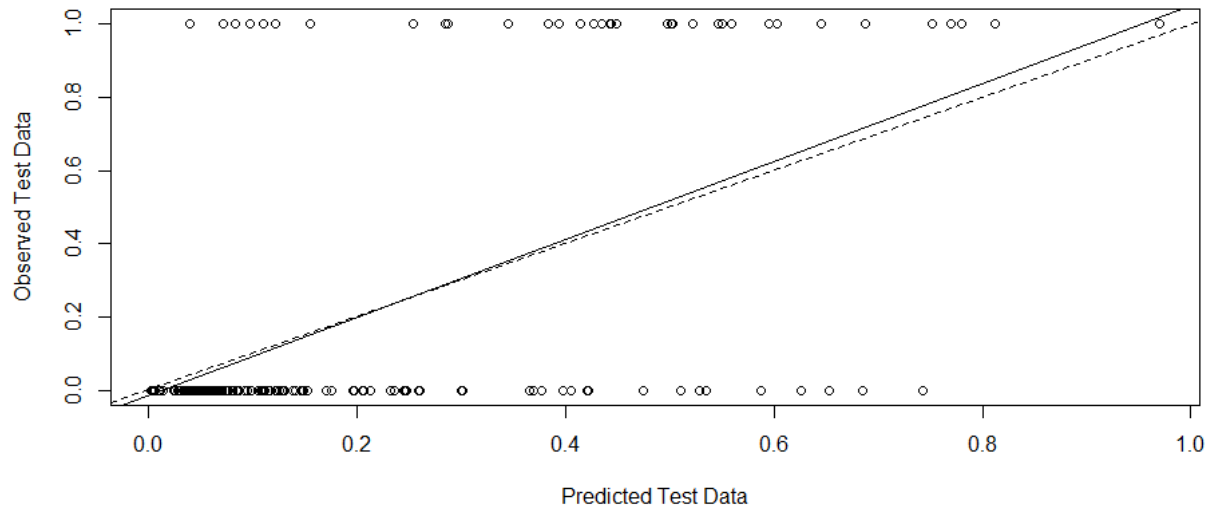


Figure 36. Winter Flounder YOY Summer Presence/Absence Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

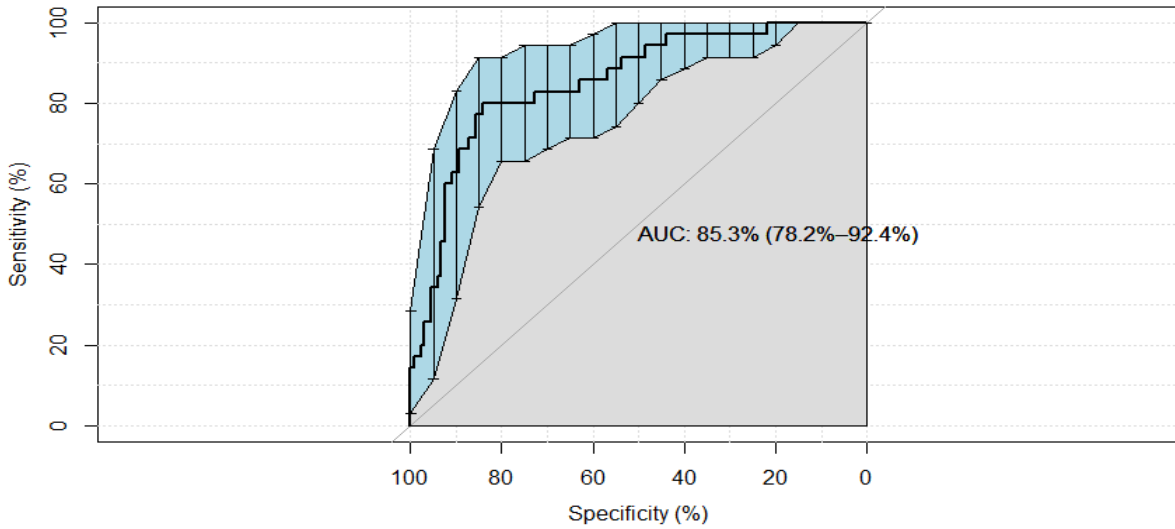


Figure 37. Winter Flounder YOY Summer Presence/Absence Model ROC plot for the validation of the Fall PA Winter Flounder GAM- Solid line is actual values while the blue area indicates the confidence intervals with error bars based on bootstrapping of 5% intervals. The x-axis represents the specificity or the false-positive fraction ($\frac{\# \text{ of false-positives}}{\# \text{ of true-negative} + \# \text{ of false-positives}}$) while the y-axis represents the sensitivity ($\frac{\# \text{ of true-positives}}{\# \text{ of true positives} + \# \text{ of false-negatives}}$) or the true-positive fraction AUC is area under the curve with the confidence intervals in parentheses.

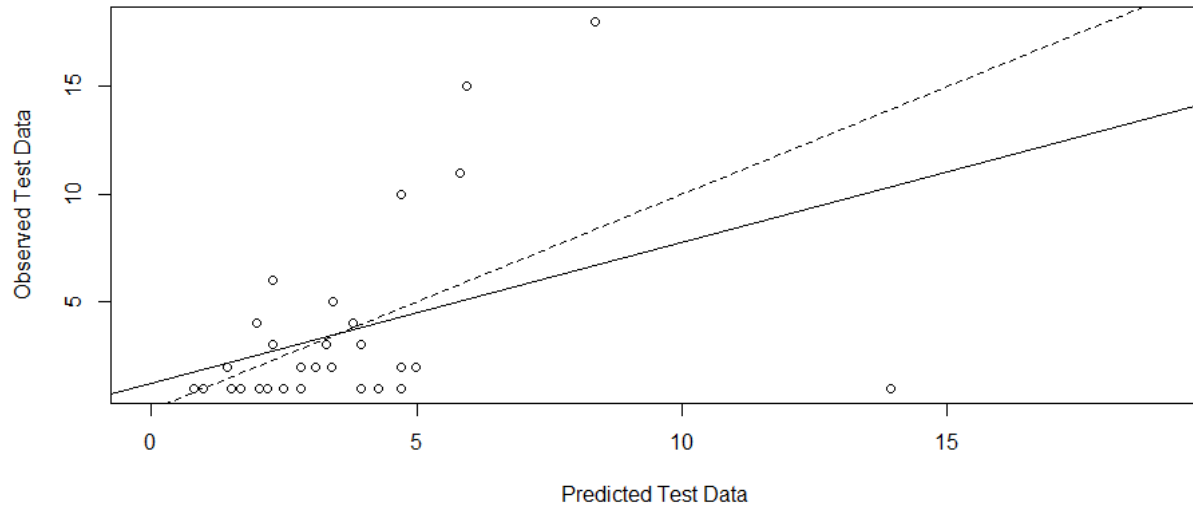


Figure 38. Winter Flounder YOY Summer Abundance Model plot of the observed or independent data (30%) and the predicted values for those data. Solid line is the linear regression of the data while the dashed line is the 1:1 line.

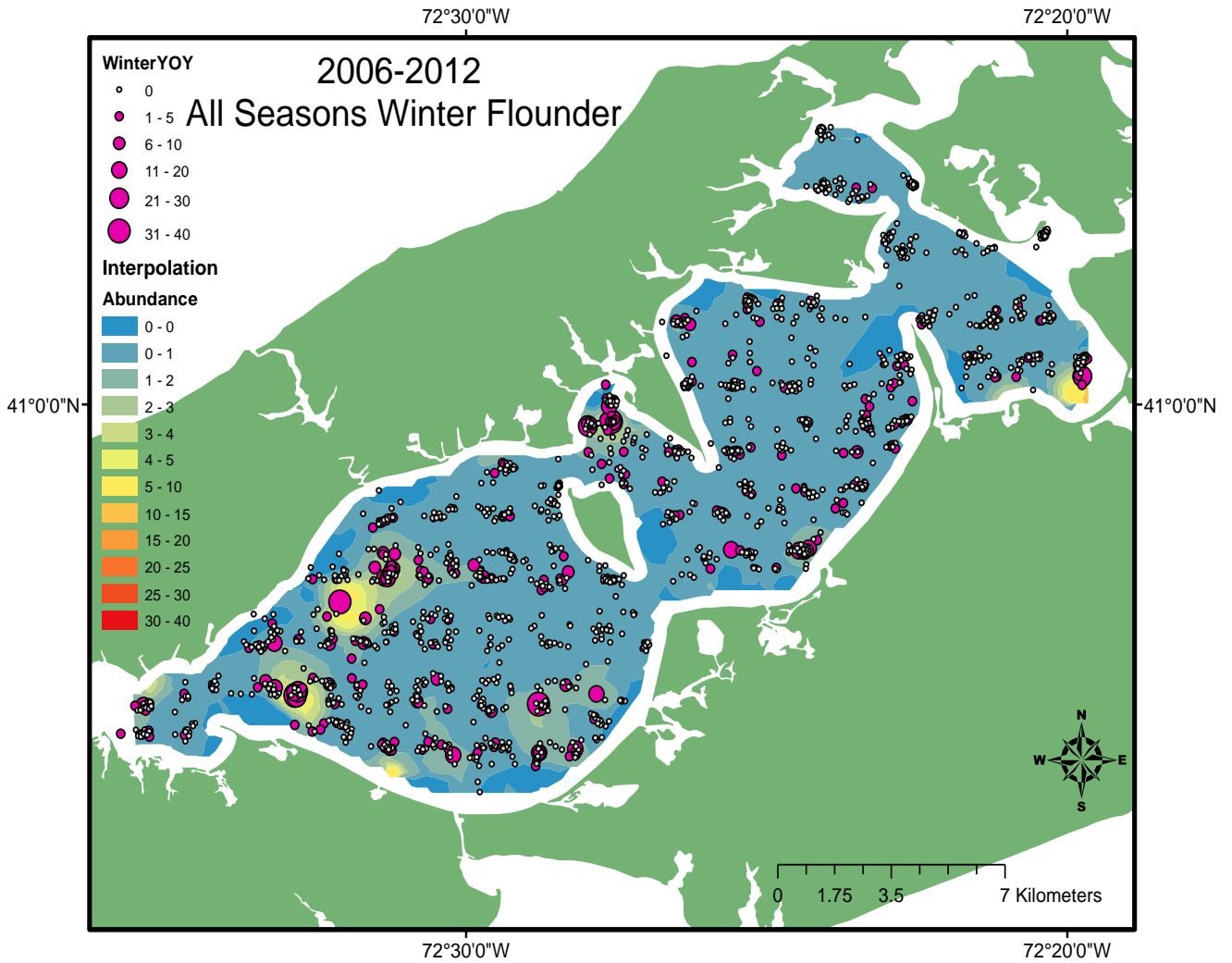


Figure 39. Map of Winter Flounder YOY abundance and interpolations for all seasons from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

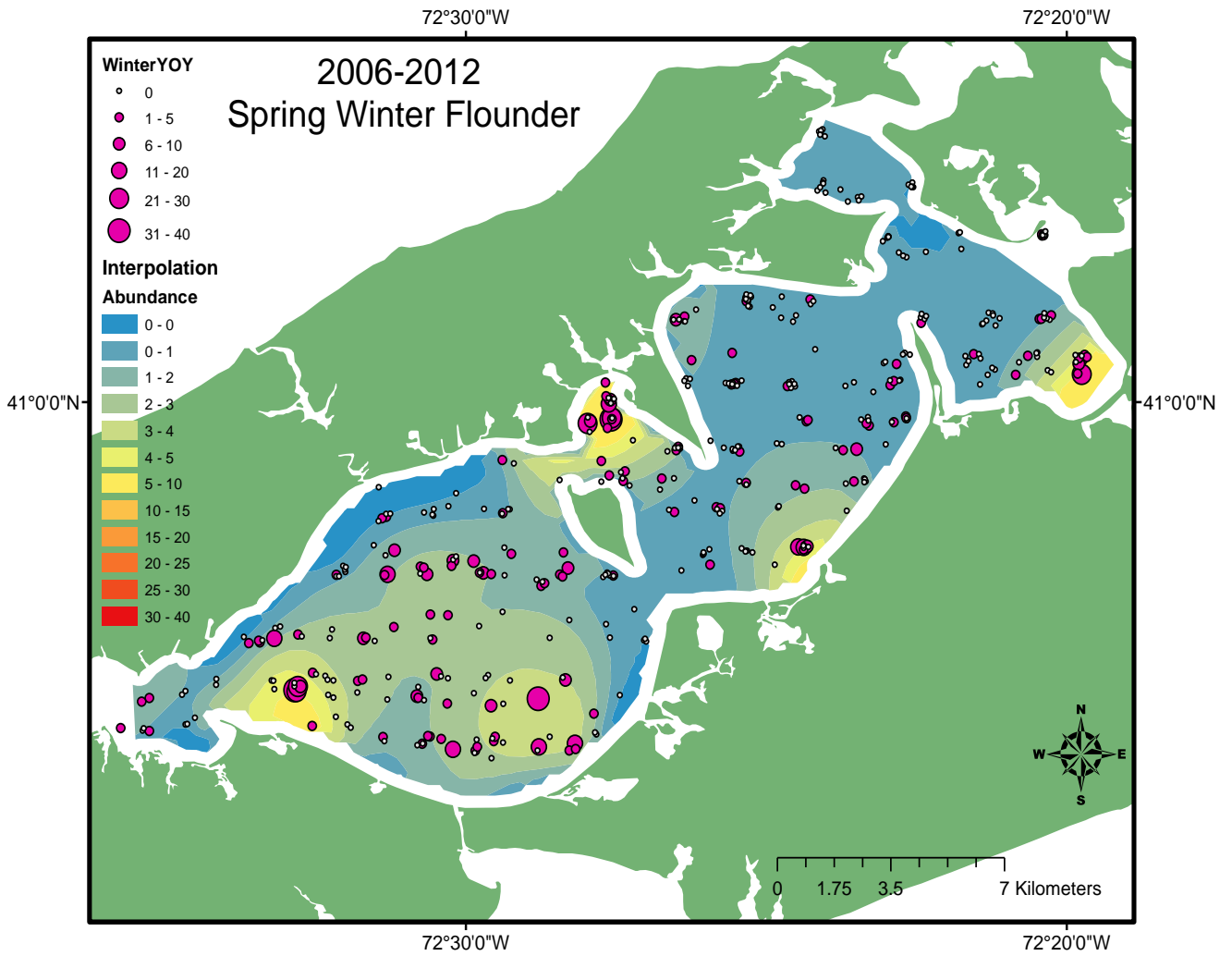


Figure 40. Map of Winter Flounder YOY abundance and interpolations for spring months from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

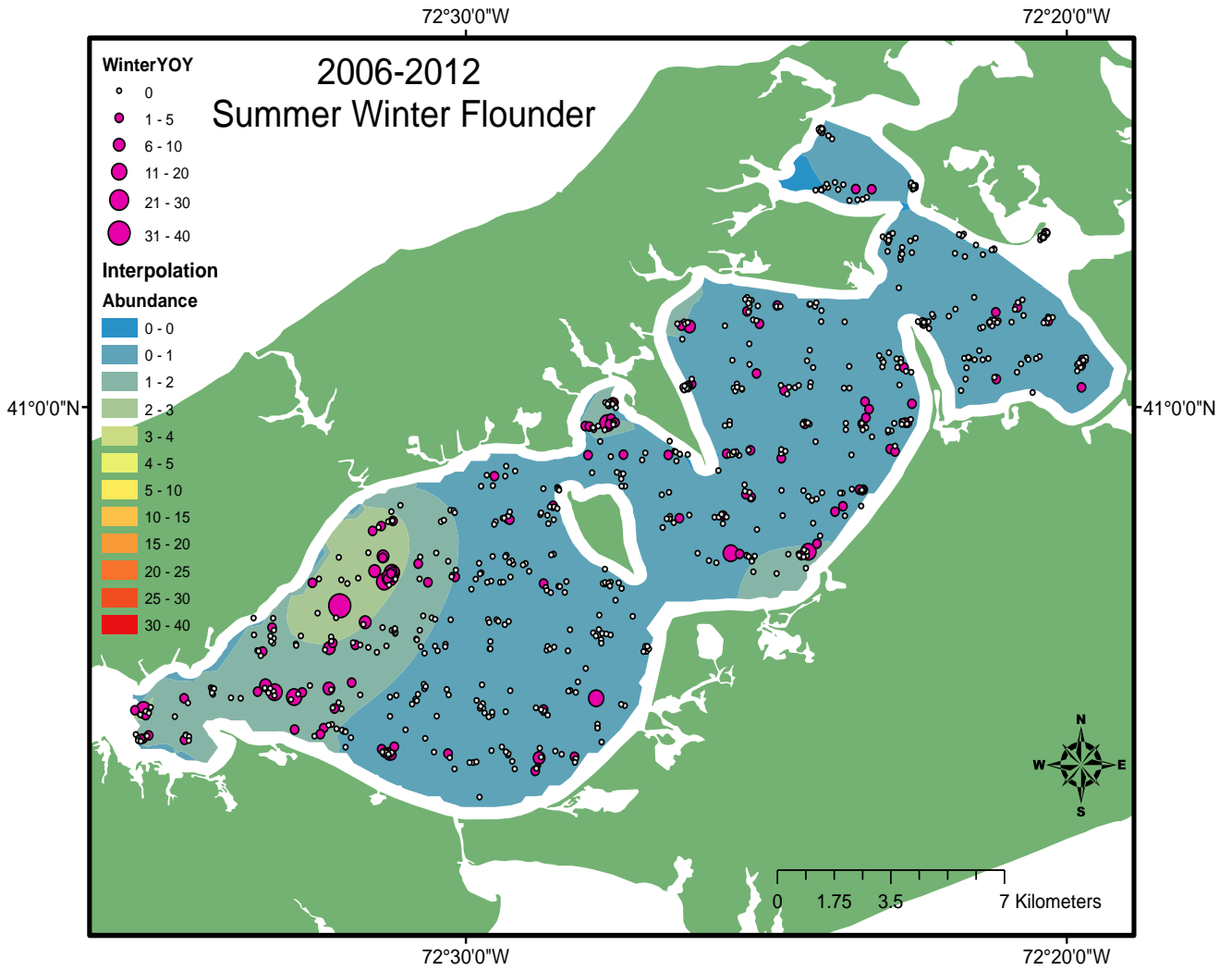


Figure 41. Map of Winter Flounder YOY abundance and interpolations for summer months from 2006-2012. Gray dots reveal tows that contained no YOY. Purple circles specify the abundance of YOY that were caught in that tow (See legend). Interpolation results are also mapped. See legend for colors of abundance estimates.

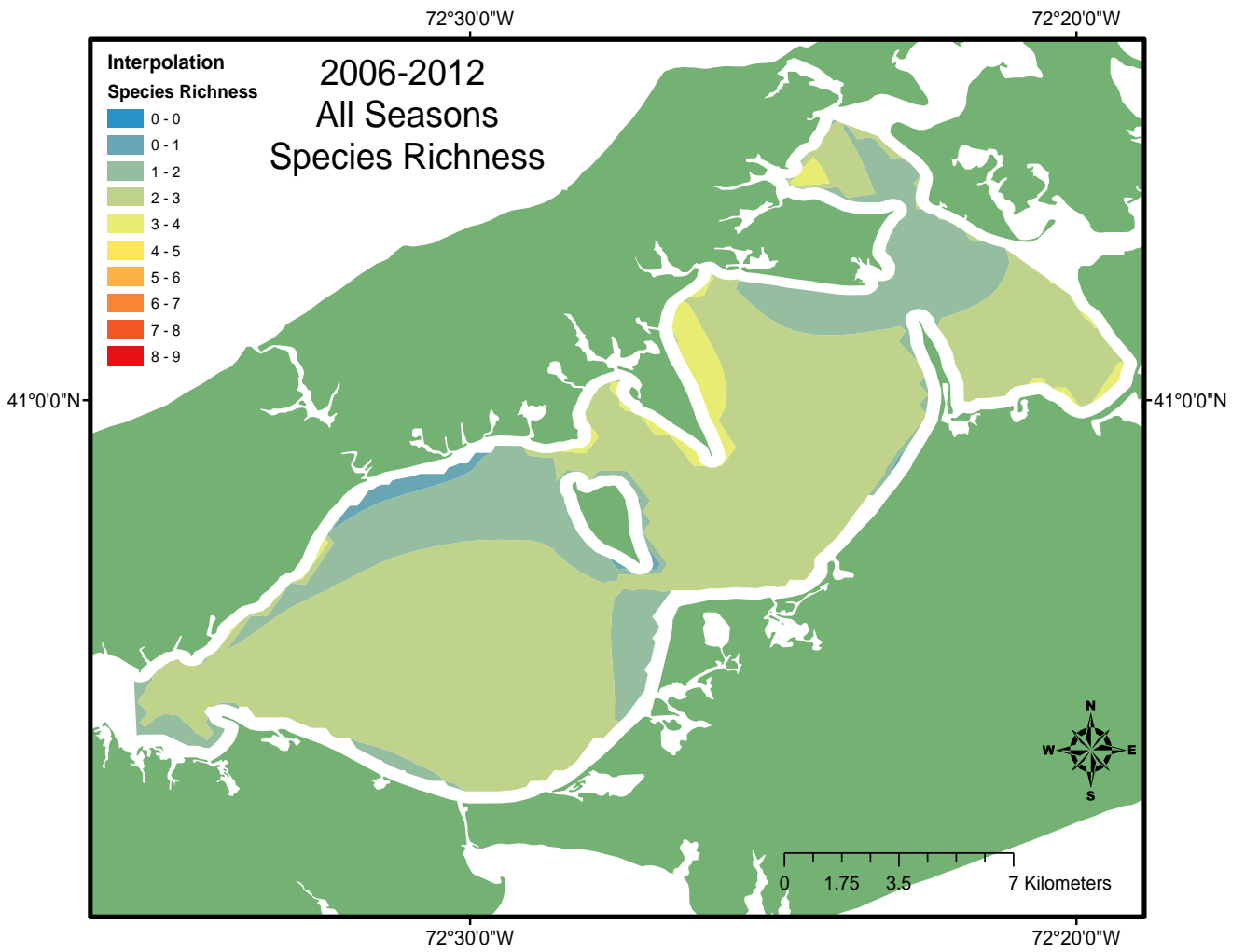


Figure 42. Map of species richness interpolations for all seasons from 2006-2012. See legend for colors of species richness estimates.

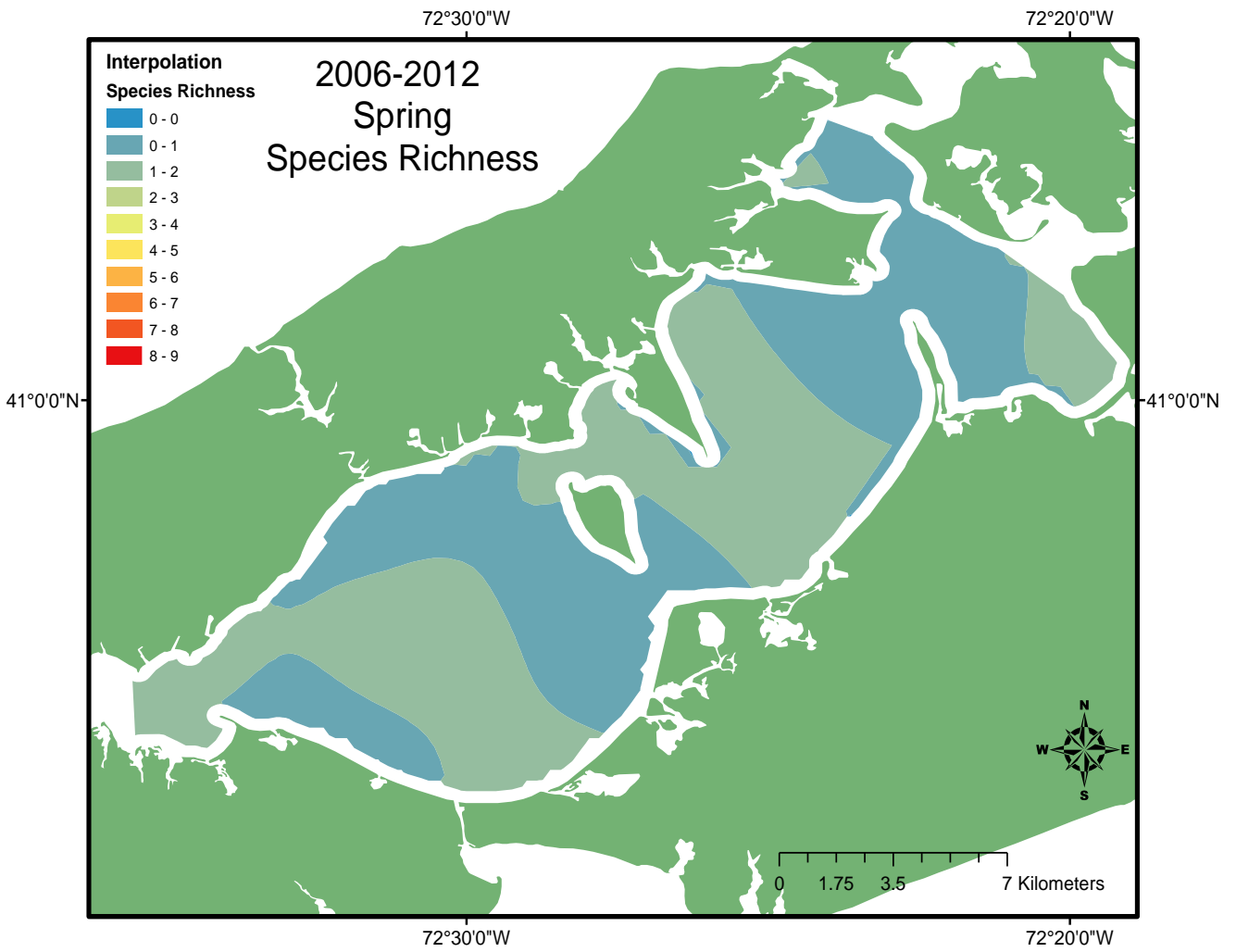


Figure 43. Map of species richness interpolations for spring months from 2006-2012. See legend for colors of species richness estimates.

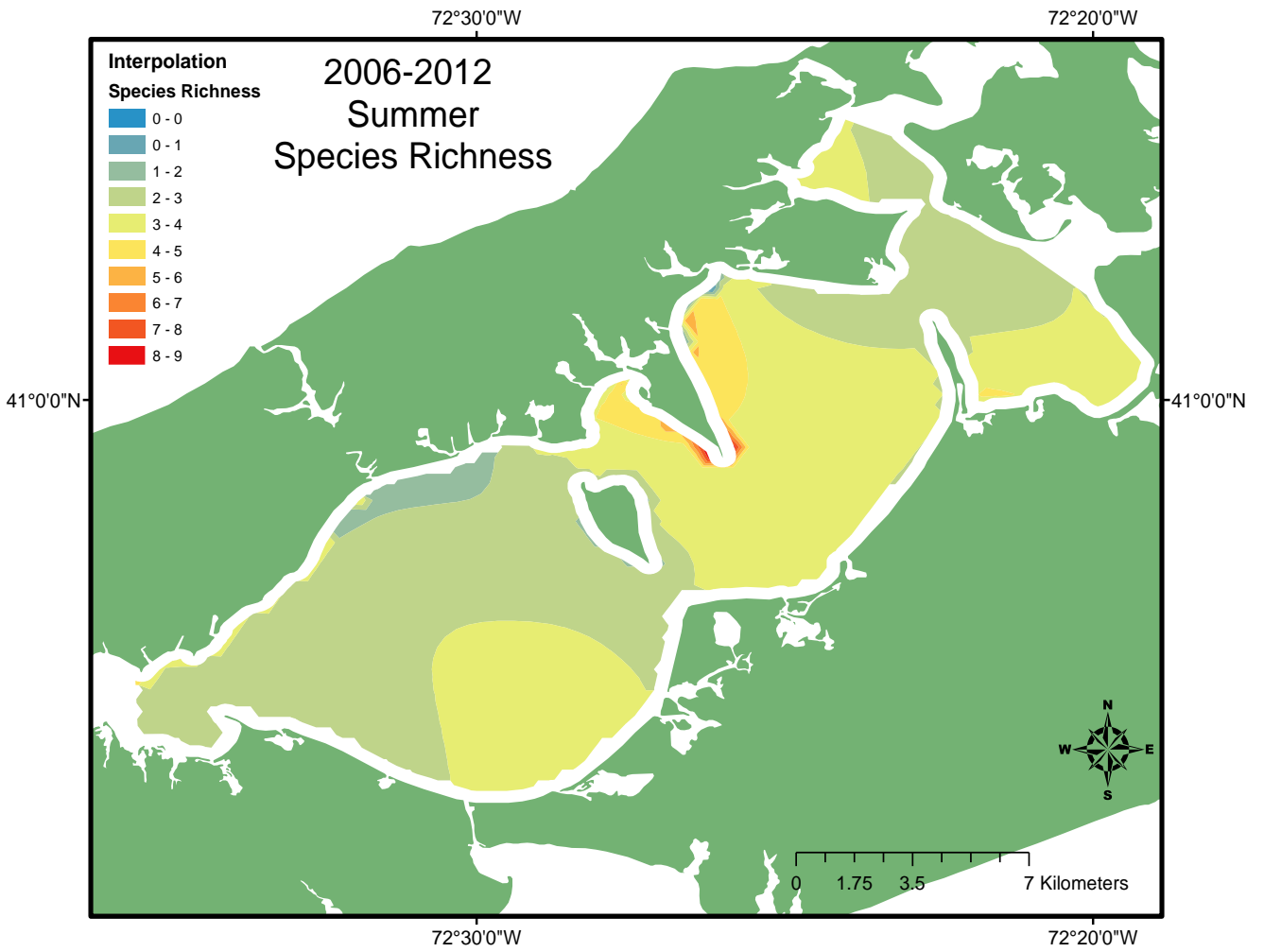


Figure 44. Map of species richness interpolations for summer months from 2006-2011. See legend for colors of species richness estimates.

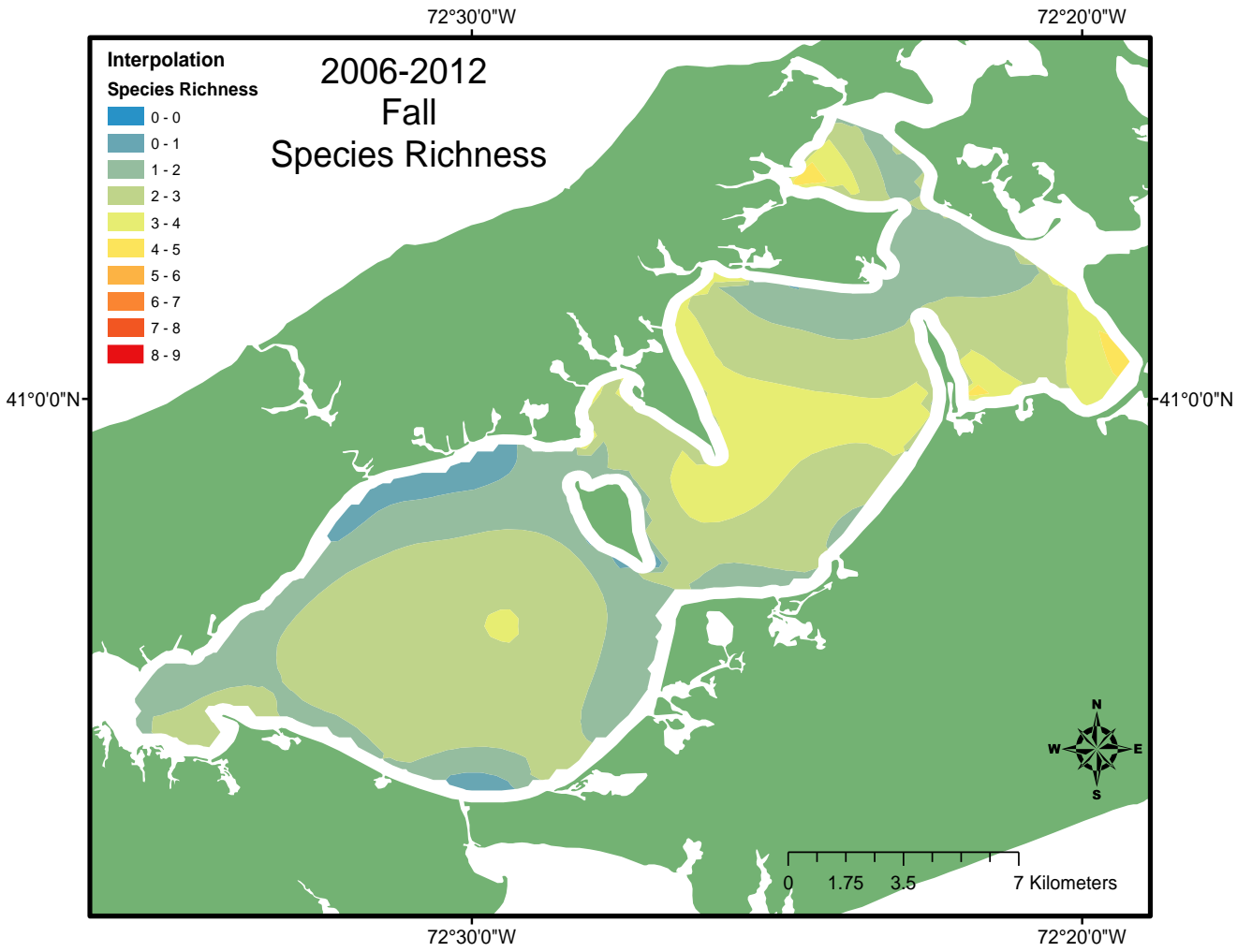


Figure 45. Map of species richness interpolations for fall months from 2006-2012. See legend for colors of species richness estimates.

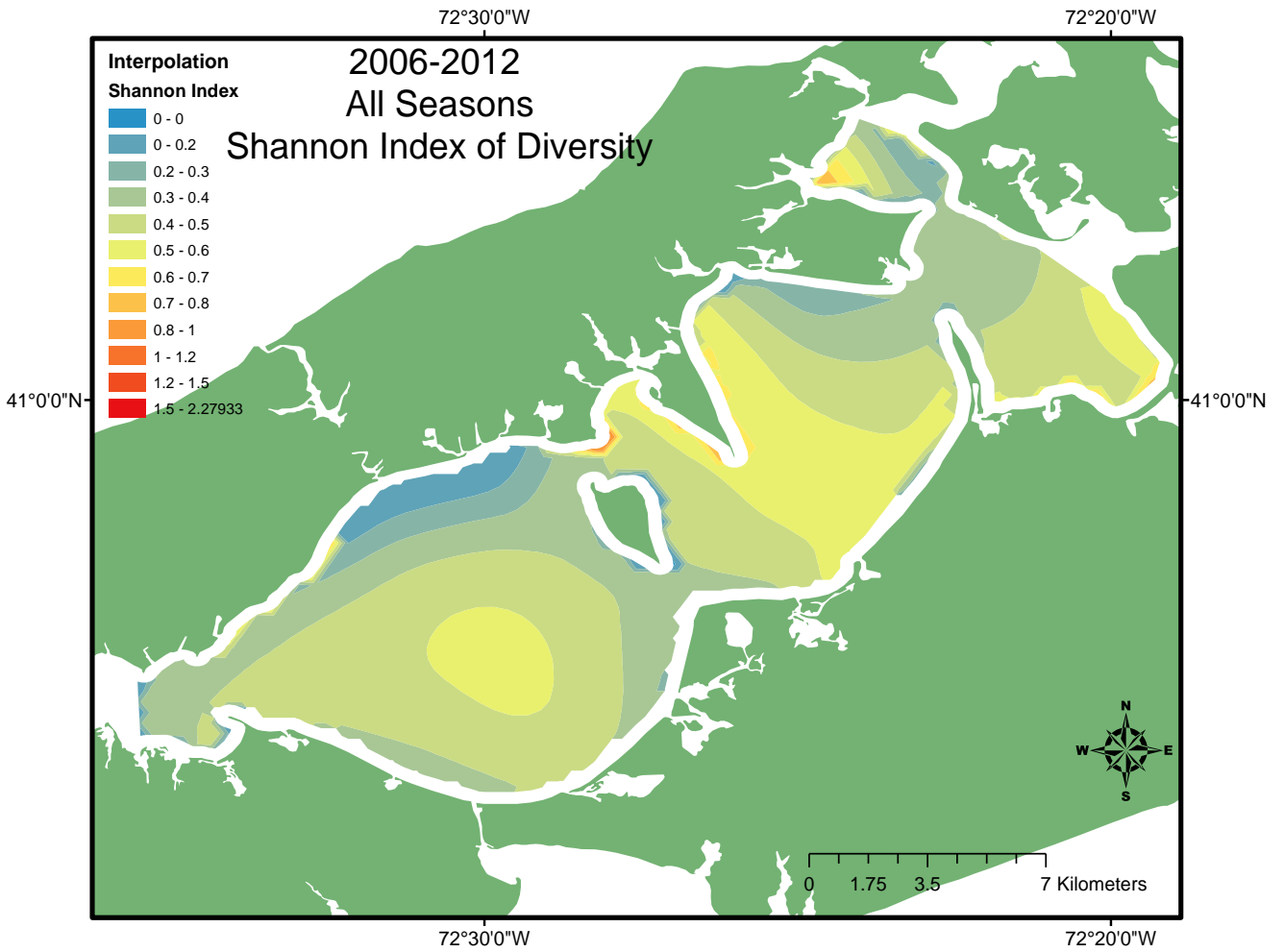


Figure 46. Map of Shannon Index of diversity interpolations for all seasons from 2006-2012. See legend for colors of Shannon diversity indices estimates.

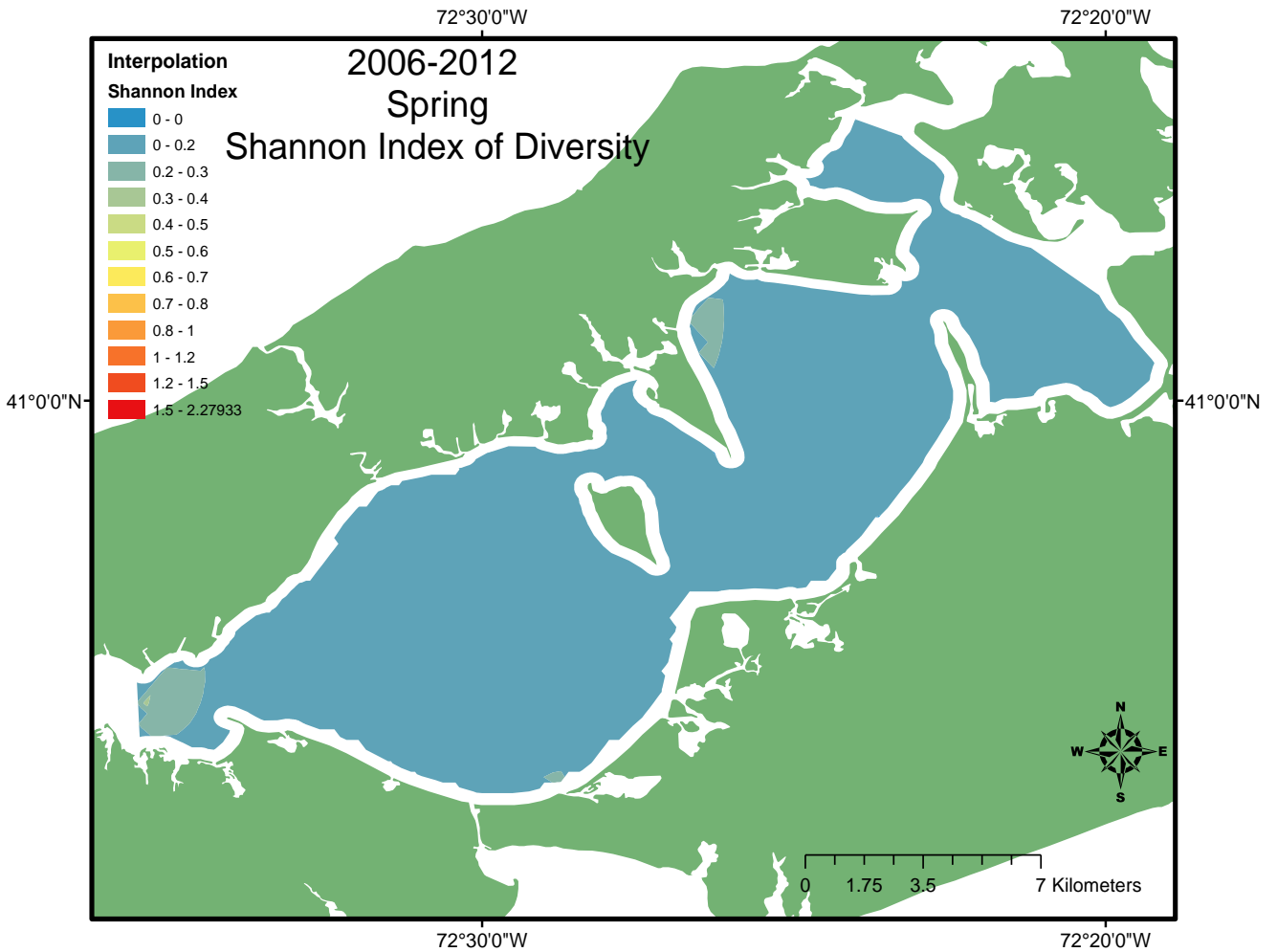


Figure 47. Map of Shannon Index of diversity interpolations for spring months from 2006-2012. See legend for colors of Shannon diversity indices estimates.

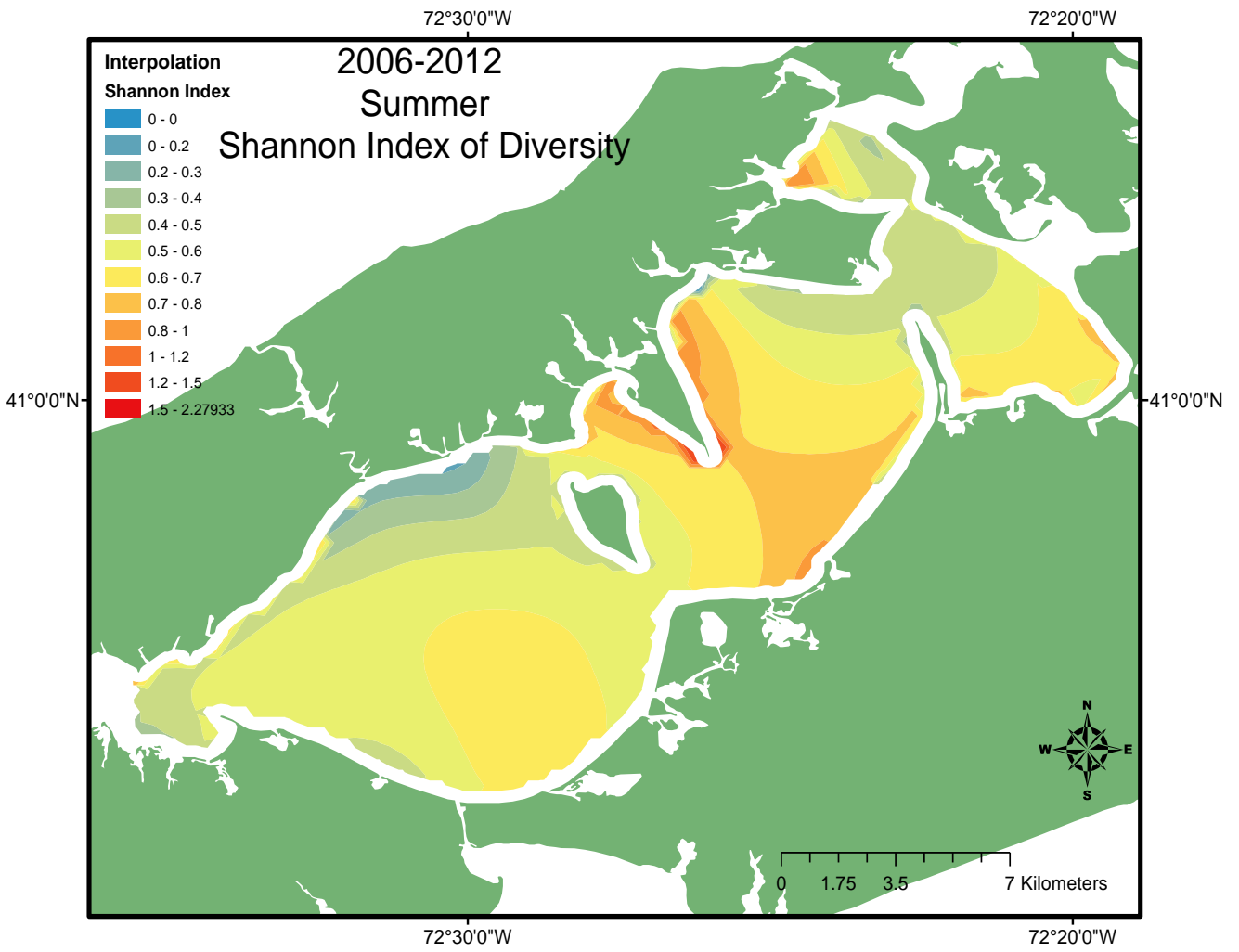


Figure 48. Map of Shannon Index of diversity interpolations for summer months from 2006-2012. See legend for colors of Shannon diversity indices estimates.

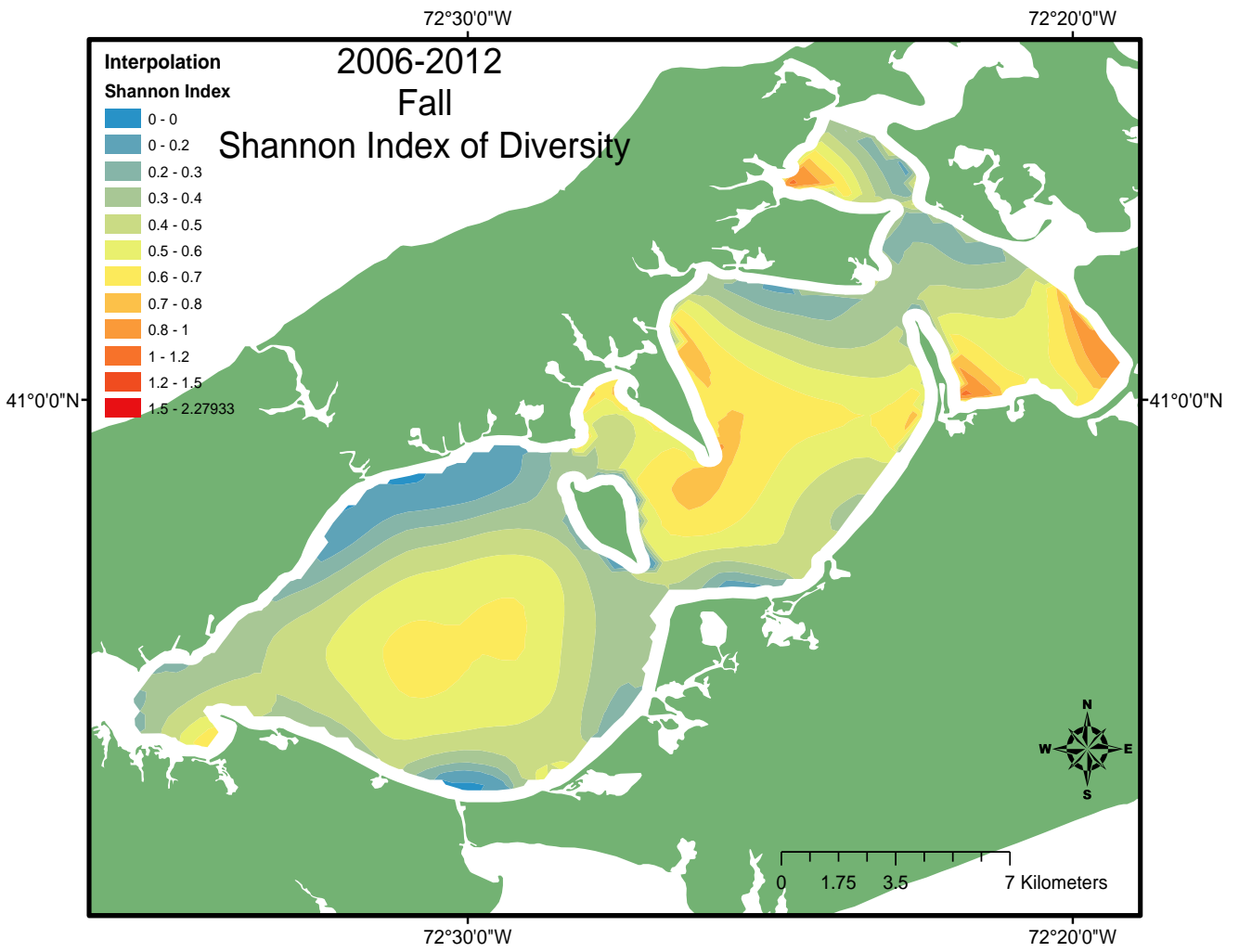


Figure 49. Map of Shannon Index of diversity interpolations for fall months from 2006-2012. See legend for colors of Shannon diversity indices estimates.

Season	Summer	Summer	Fall	Fall
Model	PA	Abundance	PA	Abundance
N _{Total}	558	229	459	128
N ₇₀	391	160	321	90
N ₃₀	167	69	138	38
df	8.88	3.00	13.10	6.84
R ² adj	0.09	0.01	0.29	0.14
Dev (%)	9.03	4.56	28.2	41.8
AIC	495.49	744.91	299.57	392.27
Temp.	<0.001		<0.001	
Sal.	<0.05			<0.1
Depth	<0.05			<0.05
DO	<0.05			
Secchi	<0.01			
% Sand			<0.01	<0.01
% Mud	<0.1	<0.1	<0.05	
SOM		<0.05	<0.01	

Table 1. GAM Results for Northern Puffer Models. N_{total}= total number of tows. N₇₀= number of observations included in the model (70% of total). N₃₀= number of observations included in the validation of the model (30% of total). Df= degrees of freedom. R² adj= adjusted R² value. Dev= the percent of deviance explained by the model. AIC= Akaike Information Criterion. All variables that were available for use in the models are listed (bottom temperature, bottom salinity, depth, dissolved oxygen, secchi depth, percent sand, percent mud and sediment organic matter). Variable values indicate the p-level at which they were significant. A blank space means they were not included in the model and ns means they were not significant but included in the model. Bolded terms indicate variables that were significant at the 0.001 level.

Season	Summer	Summer	Fall	Fall
Model	PA	Abundance	PA	Abundance
N _{Total}	558	280	459	340
N ₇₀	391	196	321	238
N ₃₀	167	84	138	102
df	21.44	5.80	14.50	13.31
R ² adj	0.30	0.12	0.21	0.12
Dev (%)	27.6	8.29	21.3	21.4
AIC	435.25	1534.09	319.52	1651.24
Temp.	<0.001		<0.01	<0.001
Sal.	<0.001	ns	<0.001	<0.05
Depth			<0.05	<0.1
DO	<0.1	ns	ns	ns
Secchi	<0.05			<0.01
% Sand	<0.01			ns
% Mud	<0.05			
SOM		<0.1	<0.01	

Table 2. GAM Results for Scup Models. N_{total}= total number of tows. N₇₀= number of observations included in the model (70% of total). N₃₀= number of observations included in the validation of the model (30% of total). Df= degrees of freedom. R² adj= adjusted R² value. Dev= the percent of deviance explained by the model. AIC= Akaike Information Criterion. All variables that were available for use in the models are listed (bottom temperature, bottom salinity, depth, dissolved oxygen, secchi depth, percent sand, percent mud and sediment organic matter). Variable values indicate the p-level at which they were significant. A blank space means they were not included in the model and ns means they were not significant but included in the model. Bolded terms indicate variables that were significant at the 0.001 level.

Season	Summer	Summer	Fall	Fall
Model	PA	Abundance	PA	Abundance
N _{Total}	558	309	459	160
N ₇₀	391	216	321	112
N ₃₀	167	93	138	48
df	10.15	6.23	15.87	7.28
R ² adj	0.26	0.18	0.31	0.29
Dev (%)	22.3	15.9	30.7	38
AIC	438.88	1656.5	312.85	729.71
Temp.			<0.001	<0.01
Sal.		<0.001	<0.01	<0.001
Depth	<0.001	ns	<0.01	<0.05
DO	ns			
Secchi		<0.1	ns	
% Sand	<0.1		ns	<0.01
% Mud			<0.05	<0.01
SOM	<0.05	<0.01		

Table 3. GAM Results for Weakfish Models. N_{total}= total number of tows. N₇₀= number of observations included in the model (70% of total). N₃₀= number of observations included in the validation of the model (30% of total). Df= degrees of freedom. R² adj= adjusted R² value. Dev= the percent of deviance explained by the model. AIC= Akaike Information Criterion. All variables that were available for use in the models are listed (bottom temperature, bottom salinity, depth, dissolved oxygen, secchi depth, percent sand, percent mud and sediment organic matter). Variable values indicate the p-level at which they were significant. A blank space means they were not included in the model and ns means they were not significant but included in the model. Bolded terms indicate variables that were significant at the 0.001 level.

Season	Spring	Spring	Summer	Summer
Model	PA	Abundance	PA	Abundance
N _{Total}	322	107	558	95
N ₇₀	225	75	391	66
N ₃₀	97	32	167	29
df	7.49	9.14	13.21	6.47
R ² adj	0.28	0.08	0.20	0.21
Dev (%)	26.8	32.6	24.7	37.5
AIC	221.34	404.05	278.89	307.77
Temp.	<0.001			<0.1
Sal.	<0.001	<0.1	<0.001	
Depth	ns	<0.01	<0.1	
DO			ns	
Secchi		ns		
% Sand		ns	ns	<0.05
% Mud			<0.1	<0.05
SOM	<0.05			

Table 4. GAM Results for Winter Flounder Models. N_{total}= total number of tows. N₇₀= number of observations included in the model (70% of total). N₃₀= number of observations included in the validation of the model (30% of total). Df= degrees of freedom. R² adj= adjusted R² value. Dev= the percent of deviance explained by the model. AIC= Aikaike Information Criterion. All variables that were available for use in the models are listed (bottom temperature, bottom salinity, depth, dissolved oxygen, secchi depth, percent sand, percent mud and sediment organic matter). Variable values indicate the p-level at which they were significant. A blank space means they were not included in the model and ns means they were not significant but included in the model. Bolded terms indicate variables that were significant at the 0.001 level.

Species	PA			
	AUC (%)	m	b	p
Spring				
Winter Flounder	80.4 ± 8.8	1.13	-0.05	0.49
Summer				
Northern Puffer	77.8 ± 7.1	1.04	-0.02	0.79
Scup	85.1 ± 6.0	1.04	-0.02	0.67
Weakfish	73.6 ± 7.8	1.07	-0.04	0.69
Winter Flounder	85.3 ± 7.1	1.06	-0.01	0.61
Fall				
Northern Puffer	87.6 ± 5.9	1.04	-0.01	0.72
Scup	73.1 ± 9.2	1.01	-0.01	0.96
Weakfish	89.0 ± 5.1	1.04	-0.01	0.66

Table 5a

Species	Abundance						
	r	r _{sp}	m	b	RMSE	AVE	p
Spring							
Winter Flounder	0.35	0.48	1.21	-0.59	4.86	-0.12	0.73
Summer							
Northern Puffer	0.26	0.23	1.22	-0.80	5.11	-0.06	0.70
Scup	0.30	0.32	1.13	-2.57	12.41	-0.03	0.74
Weakfish	0.59	0.60	1.00	0.25	10.33	-0.31	0.98
Winter Flounder	0.38	0.40	0.65	1.23	4.07	0.05	0.26
Fall							
Northern Puffer	0.29	0.24	0.94	0.11	1.31	0.00	0.90
Scup	0.49	0.53	0.81	2.23	9.48	0.05	0.20
Weakfish	0.79	0.82	0.90	1.15	6.42	-0.24	0.33

Table 5b

Tables 5a & b: Model validation values for each seasonal model (PA and Abundance). AUC = area under the receiver operating characteristic curve ± standard error; m = slope and b = y intercept of the fitted calibration line: observed = m(predicted) + b; p= p-value of the difference between the slopes of the predicted vs observed test data and a 1:1 line (indicating a perfect fit); r = Pearson's correlation coefficient; r_{sp} = Spearman's rank correlation coefficient; RSME = root mean square error of prediction; and AVE = average error (See from Sagarese et al. 2014).