COMMUNITY ECOLOGY AND POPULATION DYNAMICS OF THE NEARSHORE MARINE FAUNA IN THE MIDDLE ATLANTIC BIGHT (USA)

by

JUAN CARLOS LEVESQUE

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Dissertation Committee:

Professor James P. Grover, Chair
Professor Sofia Passy, Member
Professor Laura Mydlarz, Member
Professor Arne Winguth, Member
Professor Sandra Diamond-Tissue, Adjunct Member

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ABSTRACT

POPULATION DYNAMICS AND COMMUNITY ECOLOGY OF THE NEARSHORE MARINE FAUNA IN THE MIDDLE ATLANTIC BIGHT (USA)

Juan Carlos Levesque
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Supervising Professor: James P. Grover

Natural resources are among the most valuable commodities on earth. Some natural resources (air, land, and water) are essential for human survival and many often constitute a large percentage of local, regional, and national economies, such as marine resources. Worldwide, marine resources have shaped culture, society, and local, regional, and global economies. Oceanic environmental conditions influence, shape, and control the geographical range, spatial distribution, abundance, and size composition of marine fauna. Thus, marine communities are vulnerable to major changes in the environmental conditions and disturbance (short and long-term), but the response and severity depends on various biological or ecological factors, such as resilience to stress or adaptation. Given the need to describe, understand, and interpret these processes, the broad purpose of this dissertation was to provide community-based marine resource information to fishery managers responsible for conserving, protecting, and restoring fish communities. More specifically, the goal was to examine several disturbances on the population dynamics and community structure of the marine community off the coast of New Jersey. The research in this dissertation developed valuable relative baselines for the nearshore environmental conditions, marine fauna populations, and the marine community in context of fast and slow-acting disturbance.

Chapter One provides an overview, synopsis, and a historical perceptive on the importance of marine resources and highlights some of the issues related to short and long-term disturbances, such as hurricanes and climate variability. The first chapter summarizes how climate variability is affecting individual species and marine communities around the world. The background chapter justifies the dissertation, states the purpose and goals, and describes how the hypotheses were formulated; it also provides an organizational outline for the dissertation.

Chapter two shows the abiotic conditions and marine community is changing with time. Mean surface water temperature increased significantly about 0.6°C per decade, mean salinity decreased about 1.3 psu per decade, and dissolved oxygen (DO) increased 0.09 mg/L per decade during 1988 through 2015. A total of 18.7 million individuals representing 216 species were collected during the 28-year period, and the estimated abundance and biomass of marine fauna decreased and increased over time, respectively. Subtropic-adapted species were the most abundant and coldwater-adapted were the least abundant water temperature preference group. The estimated abundance of coldwater-adapted species declined, warmwater-adapted species slightly increased, and subtropic-adapted species decreased with time.

Chapter three demonstrates marine communities are vulnerable to changes in the environmental conditions associated with hurricane events, but the response and severity depends on various factors, such as ecological resilience. The results show the annual bottom salinity and surface DO varied significantly between pre- (1988−2012) and post- (2013−2015) Hurricane Sandy. The oceanographic and physicochemical conditions in January varied significantly

between pre- and post-Sandy, and the interaction effect varied significantly among factors (year, month, and geographic sampling area), but the significance level depended on the sampling area. For instance, the abiotic conditions pre- and post-Sandy varied significantly in sampling area “19”, which was in the direct path of the storm. The marine community (abundance) in January also varied significantly between pre- and post-Sandy, but the magnitude of the significance level difference in the marine community depended on the sampling area. For example, the marine community pre- and post-Sandy varied significantly in sampling areas “16 and 20”; sampling area “20” was in the direct path of the storm. Overall, there was no significant change in the biomass, and the community structure was similar pre- and post-Sandy.

Chapter four describes the biodiversity (alpha and beta diversity) in the nearshore marine community off New Jersey over the past 28 years. Estimated species richness increased substantially during the first few years of sampling, and reached asymptotic richness in about 13 years. Species richness estimates varied significantly over time, but in general the trend was similar and relatively stable. The lowest mean species richness (n = 121.3 species) was estimated using the mean Michaelis-Menten approach and the highest mean species richness (n = 156.3 species) was estimated using the mean Jackknife 2 approach. Alpha diversity and evenness estimates indicated the community was composed of a few species with high abundance. Fisher’s alpha diversity index best described the marine community, which ranged from 9.04 in 1988 to 15.95 in 1989 with an average of 11.76 (± 1.62 SD). Alpha diversity and evenness indices fluctuated from one year to the next, but remained stable over time. Beta diversity estimates also showed interannual variability, but similarity values were relatively stable over time; approximately 50 percent of the species were shared among samples. Analytical procedures could not detect an association between community stability and the environmental conditions suggesting the community is possibly shaped by other factors, such as inter- and intra-species associations. The findings propose the community is resilient despite the ongoing changes in the environmental and oceanic conditions.

In the final chapter, Chapter five, the findings suggest the variability in the environmental and atmospheric conditions is shifting the marine community. The environmental, oceanic conditions, marine community, and coldwater-adapted community were significantly different among years and geographical sampling areas. The best environmental predictors of the marine community were primarily water temperature (surface and bottom), maximum depth, NAO, and surface salinity. The marine community was significantly different among years and sampling areas. A similarity profile routine test (SIMPROF) showed there was a statistically significant structure (pattern) in the marine community, and the main species representing the greatest similarity percentages were generally longfin squid (*Loligo pealei*; coldwater-adapted), windowpane flounder (*Scophthalmus aquosus*; coldwater-adapted), and little skate (*Leucoraja erinacea*; coldwater-adapted). The primary species contributing to the dissimilarity were Atlantic butterfish (*Peprilus triacanthus*; warmwater-adapted), longfin squid, scup (*Stenotomus chrysops*; warmwater-adapted), and bay anchovy (*Anchoa mitchilli*; subtropic-adapted). Longfin squid consistently contributed the most to within-group similarity and between-group dissimilarities. The coldwater, warmwater, and subtropic-adapted community was significantly different over time. Generally, longfin squid, little skate, and Atlantic herring (*Clupea harengus*) contributed to the difference in the coldwater-adapted community, and Atlantic butterfish, scup, and northern searobin (*Prionotus carolinus*) contributed to the difference in the warmwater-adapted community over time. The sequential order varied by time-series, but bay anchovy, rough scad (*Trachurus lathami*), and striped anchovy (*Anchoa hepsetus*) constituted between 59 and 73 percent of the dissimilarity in the subtropic-adapted community.

DEDICATION

I dedicate this work to my parents, Nina and the late Romeo Levesque, for their unconditional support, sacrifice, and love throughout my life; thank you for encouraging me to pursue a career in marine biology as a young boy. I also bestow this work to my incredible wife, Frances A. Levesque, for her love, reassurance, and understanding throughout this journey. Lastly, I also devote this accomplishment to my boys (Joshua, Christopher, and Corey); the hardest things in life are worth pursuing. Hopefully, I have been a positive example of how hard work, commitment, determination, and faith can shape your life.

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CHAPTER 1. BACKGROUND AND SYNOPSIS

"If in a given community unchecked popular rule means unlimited waste and destruction of the natural resources—soil, fertility, waterpower, forests, game, wild-life generally—which by right belong as much to subsequent generations as to the present generation, then it is sure proof that the present generation is not yet really fit for self-control, that it is not yet really fit to exercise the high and responsible privilege of a rule which shall be both by the people and for the people. The term "for the people" must always include the people unborn as well as the people now alive, or the democratic ideal is not realized."

— Theodore Roosevelt (1916)

1.1 Historical Perspective: Marine Resources and Sustainability

In many ways, natural resources are the most valuable commodities on earth. In fact, some natural resources (air, land, and water) are essential for human survival and many often constitute a large percentage of local, regional, and national economies (Costanza et al. 1997; NJDEP, 2007; FAO, 2010). Costanza et al. (1997) stated that "the economies of the earth would grind to a halt without the services of ecological life-support systems, so in one sense their total value to the economy is infinite." Natural resources are not only valuable commodities (Groot et al. 2002), but they have often influenced, shaped, and directed the development of society since early civilizations (Hart and Reynolds, 2002). Almost every society (e.g., Egyptians, Romans, and Native Americans) has relied upon its natural resources in one way or another (Hart and Reynolds, 2002; Ross, 2003; Lotze et al. 2011).

Powerful groups within a society have often used their political, economic, and social powers (socio-economic) to *capture a resource* by supporting laws and institutions that managed natural resources or geographical areas (e.g., Jordon River Basin [ground water issues of the West Bank]) (Homer-Hixon, 1999). Natural resources are so important to societies (past and present) that many nations have either signed international treaties or implemented their own laws to protect and claim sovereign right over their natural resources (Sanchirico and Wilen, 2007). For example, the United States established the exclusive economic zone (EEZ) in the 1970s to claim power over its marine resources; the United States' EEZ is among the largest of its kind in the world (TWH, 1983). The United States' EEZ extends 200 nautical miles off the coast, encompassing a diversity of marine ecosystems and a variety of natural resources, including fisheries, energy, and minerals (TWH, 1983).

Internationally, the economic control of several natural resources (e.g., oil and hard-rock minerals) has even caused prolonged civil wars in several regions (Homer-Dixon, 1999; Ross, 2003; Tabb, 2007), and many international conflicts (Homer-Dixon, 1999; Ofori-Amoah, 2004). For instance, competition for valuable marine resources off Canada's Grand Banks has caused international hostility between Canada and Spain on several occasions (Nixon, 1997). The general philosophy of competition for natural resources since the beginning of time has been "take all you can before the other person or country". Environmental scarcity of natural resources (cropland, freshwater, and forests) is a growing concern for most nations, including the United States. Some believe violent conflict will continue to rise over the next decades throughout the world because of, or at least associated with, environmental scarcity (Homer-Dixon, 1999). This critical issue is connected with the growth of the human population, which is around 1.3 percent a year (Homer-Dixon, 1999). The debate and concern of population growth, economics, and natural resource shortage has a long history dating back to Confucius and Plato (Homer-Dixon, 1999); societies have struggled with balancing these inter-related relationships for centuries. Despite this bleak history, there is some evidence that common-pool resource (e.g. fisheries) problems can be addressed using innovative approaches, such as establishing polycentric governing systems

(Ostrom, 1999). Actually, complex adaptive governing systems have been successful for managing salmon in the United States (Ostrom, 1998).

Many of our natural resources (e.g., forests, rivers, and wildlife) have been influential in shaping society and history, but one of the most prominent and valuable (dietary, monetary, and socially) natural resources are marine resources (Huxley, 1883; Sanchirico and Wilen, 2002). Human consumption of fish in 2007 accounted for 15.7 percent of the world's animal protein intake and 6.1 percent of all protein consumed (FAO, 2010). As the human population continues to grow, the demand and reliance upon fisheries resources will also increase to some finite limit (FAO, 2010), but what is the limit? Are marine resources sustainable and can marine resources meet the demands of our growing human population? Homer-Dixon (1999) reiterates Thomas Malthus's notion that population growth will continue to the "limit of subsistence and it is adjusted by famine, disease, and war." The worldwide competition for fisheries is currently at different scales. Depending on the species, competition for limited fisheries is between individuals and among countries. Marine resources are such economically valuable and important sources of protein that they are causing fish wars between nations (Jennings et al., 2001).

Marine products are not only the most internationally traded food in the world (USAID, 2003), but commercial and recreational fisheries are among the most economically valuable principle sectors of local, regional, and global economies (Gillet 2003; Mwangi, 2008; FAO, 2010). In 2006, jobs associated with fisheries in Kenya supported around 80,000 and 800,000 residents directly and indirectly, respectively (Mwangi, 2008). Fisheries resources contributed about one percent of Kenya's gross domestic product in 2006 (Mwangi, 2008). In the lower Amazon, commercial fisheries have considerably evolved in the last 30 years making this sector among the most important to local municipalities in terms of jobs and income (Almeida et al. (2001). Commercial fisheries in the United States are also important sectors of many local, regional, and national economies. Commercial fishing landings (4.5 million mt) were valued at $5.4 billion in 2017 (NMFS, 2018); however, this estimate did not include the total number of jobs supported or the total business revenue generated by commercial fishing ventures (e.g., seafood dealers, equipment, restaurants).

The future of marine resources will depend upon the ability of natural resource managers to implement management measures under the notion of sustainable development (Gillet, 2003), which is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Important environmental concepts associated with sustainable development are environmental degradation, traditional development objectives, and process (Conga and Dabelko, 2004). One of the biggest challenges for natural resource managers is emphasizing to society that natural resources need to be managed under the sustainability premise since most natural resources are exhaustible. Historically, this has been a difficult concept for societies to comprehend because almost every generation has assumed it was impossible to deplete their natural resources, especially fisheries resources (Huxley, 1883). In many ways, this false historical perception has been driven by capitalism, free markets, and entrepreneurship philosophies rather than by science (life-history, fishery biology, or population assessments). Because resource managers have historically used economics as the basis to manage fisheries recourses, there are now many marine resources (e.g., elasmobranches [sharks, skates, and rays], sea turtles, and marine mammals) that are dreadful examples of Hardin's (1968) well-cited publication "Tragedy of the Commons."

The topic of sustainable fisheries has a long history that dates back to the days of Darwin. In 1883, one of the first speeches on fisheries and sustainability was presented by Professor Thomas Henry Huxley, an accomplished, prominent, and respected biologist. In his inaugural address to the International Fisheries Exhibition in London, Huxley (1883) stated “I believe... all the great sea-fisheries, are inexhaustible; that is to say that nothing we do seriously affects the number of fish. And any attempt to regulate these fisheries seems consequently… to be useless”. Huxley’s assessment and belief at the time was that overfishing or "permanent exhaustion" was scientifically unfeasible. He specifically pointed out that the cod, herring, pilchard, and mackerel fisheries were inexhaustible. Despite this notion, Huxley acknowledged that some fisheries (e.g., salmon and oysters) could disappear with time under certain scenarios. Even with Huxley’s influential standing in the scientific community, some biologists did not support his simplistic theory on fisheries resources and their sustainability (Lankester, 1884; Cleghorn, 1885). This contentious debate about the sustainability of fisheries continues today even though many marine resources throughout the world are classified by researchers as overfished, approaching collapse, or extinct (i.e., biologically and/or financially). In the United States, the fisheries sustainability debate has recently escalated to various time-consuming legal administration procedures (e.g., Freedom of Information Act and Data Quality Act) and lawsuits. Some of these environmental lawsuits have been initiated from non-profit organizations believing the U.S. government has not done enough to protect fish stocks and prevent overfishing, while other suits have been filed from commercial fishing organizations arguing state and federal government have gone too far in protecting fish stocks and marine resources (Buchsbaum et al. 2005; EarthJustice, 2012).

Based on several legal settlement agreements and other pressing environmental concerns, sustainability, biodiversity, and community ecology are now at the forefront of domestic and international fisheries management. In an attempt to protect, conserve, and recover fragile marine resources, fishery managers are now beginning to explore new management options (Ostrum, 1998) since traditional methods have mostly failed (NMFS, 1998; Tissot, 2005). Fishery management is diverging from the traditional single-species to an ecosystem-based management (EBM) approach in an effort to better understand, predict, and minimize the potential impacts and implications of anthropogenic activities on communities and regions as a whole (ecosystems). Despite this ecological holistic movement in fisheries management to consider various anthropogenic impacts on the whole ecosystem, little progress has been in made toward using an EBM approach for various reasons, including the lack of ecological community-based studies. In general, the scientific literature describing regional marine communities is limited (NMFS, 1998), and long-term marine studies are lacking for most regions around the world.

1.1.1 Statement of the Problem

> "The sustainable development and management of aquaculture and fisheries systems can only occur if these activities are well planned and integrated into the natural and social resource, ecosystems, and farming systems contexts of the larger global context of which they are a part." (USAID, 2003).

The United States Agency for International Development (USAID), Strategic Partnership for Agricultural Research and Education (SPARE), Fisheries and Aquaculture, proposed fisheries and aquaculture sectors, in comparison to other sectors of the world food economy, are inadequately funded, poorly planned, and neglected by all levels of government despite fishing being the largest extractive use of wildlife in the world (USAID, 2003). Marine resources are one of the most valuable natural resources on earth, but natural and anthropogenic stressors are negatively impacting populations around the world. Arguably the greatest concern to fishery managers is the exploitation of fish stocks by commercial fishing operations and overfishing issues. However, climate change or climate variability and other major stressors (e.g., physical alteration, marine pollution, and the introduction of non-native species) are important issues fishery managers need to consider to conserve, protect, and recover fish communities (Norse, 1993). Managers must have a clear understanding of the patterns, causes, and processes associated with individual stressors, especially since some can have compounded impacts on marine communities (Brander, 2013). The effects and associated responses with individual stressors can be classified as additive, synergetic, or antagonistic. Without this information, management measures could be ineffective (Blake, 2011). Community ecology and population dynamics of marine communities are two central concepts in fisheries management; however, research and management have been historically directed at single-species rather than multi-species (an entire ecosystem), which has hindered progress toward estimating the impacts and responses associated with key stressors, such as climate variability.

1.1.1.2 Community Disturbance

Historically, marine communities have been negatively impacted by commercial fishing operations, but relatively recently researchers have shown that climate change is impacting marine resources around the world. According to Duly et al. (2011), global sea surface temperature (SST) has increased 0.6°C, sea level has increased 10−20 cm, and precipitation has increased 1 percent per decade in the northern hemisphere. In addition, global acidity has decreased by more than 0.1 units since the preindustrial period and it is anticipated that pH will continue to decrease by

0.10−0.35 units by the end of the century depending on the region (Doney, 2010; Denman et al. 2011). It is estimated the mean global SST will increase between 1.4 and 5.8°C by 2100 (Duly et al. 2011). Researchers have also predicted hypoxic conditions will increase with time (Stramma et al. 2008); dissolved oxygen levels have already decreased significantly in the high latitudes of the North Pacific Ocean (Whitney et al. 2007).

In some ways, natural climate variability like the El Niño Southern Oscillation (Bjerkness, 1969), and the North Atlantic Oscillation (**Figure 1.1.1.2-1**; Barnston and Livezey, 1987) or decadal variability like the Atlantic Multidecadal Oscillation (Enfield et al. 2001) in ocean climate affect marine ecosystem dynamics, but many researchers have also linked such dynamics to global climate change due to the increase in anthropogenic greenhouse gas emissions associated with fossil fuels (Duly et al. 2011). Although it is sometimes difficult to separate background variation from continuous change, there is substantial scientific evidence proving climate variability is profoundly impacting terrestrial and marine communities. In addition, some scientists have predicted cumulative impacts will be even more distressing to marine ecosystems than individual climate change consequences (Ainsworth et al. 2011). Besides marine communities, climate change has also negatively impacted freshwater species (Ficke et al. 2007; Kaufman and Allen, 2008). In Alaska, pink salmon (*Oncorhynchus gorbuscha*) fry have continued to migrate earlier each year over the past 34 years (Taylor, 2008). Climate change is affecting individual species and aquatic ecosystems all over the world.

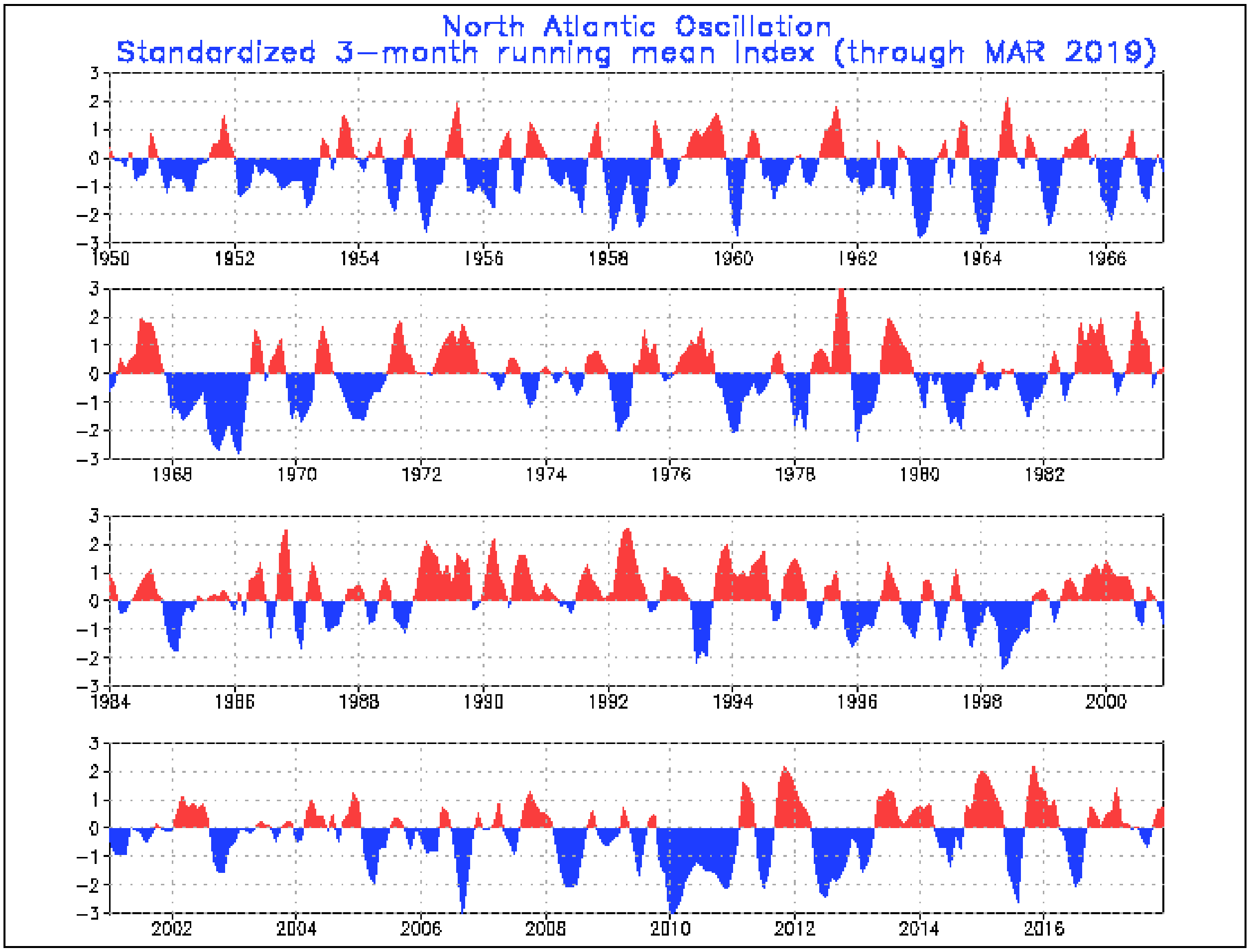

Figure 1.1.1.2-1. The standardized 3-month running mean value of the North Atlantic Oscillation index. The departures are standardized using the 1981−2010 base period statistics (NOAA, 2019).

Numerous researchers have predicted climate change will impact primary production (Gnanadesikan et al. 2011) and fisheries in a variety of ways (Kennedy et al. 2002); some predicted changes (e.g., oceanic temperature rise, sea level rise, increased precipitation, glacial melt, frequency of extreme events [storms], and severity of ENSO) are expected to impact some species more severely than others (Dully et al. 2011). Changes in phytoplankton in the North Pacific are expected to impact fisheries given the predator-prey associations (Jang et al. 2011; Polovina et al. 2011). Depending on the region, fish catch will either decline (temperate and equatorial upwelling) or improve (subtropical) (Polovina et al. 2011). Anticipated changes in climate suggests that even large pelagic species could be impacted, such as bluefin tuna (*Thunnus thynnus*) and blue marlin (*Makaira nigricans*) (Muhling et al. 2011; Su et al. 2011).

Brander (2013) broadly categorized numerous climate variables that could impact marine resources as the following: atmospheric-sea surface (wind, cloud cover, waves, and sea level), chemical and physical (temperature, salinity, pH, and oxygen), and dynamic (currents, stratification, turbulence, upwelling, and frontal processes). However, the scale and response by individual species or communities will depend on the magnitude of the climate change and sensitivity of the species (Brander, 2013). Climate change can either influence an individual species or an entire system directly and/or indirectly (predator-prey relationships).

Over the last decade scientific studies focused on evaluating the impacts associated with climate change on individual fish species and marine communities has steadily increased around the world (e.g., Kleisner et al. 2016). Climate change has even been the focus of various government and academic workshops (Russell et al. 2012), fisheries management reports (e.g., Gregg et al. 2016), and non-profit organization documents. Climate variability has caused water temperature, mixed depth layer, and currents to vary over time, which has led to changes in fish spatial distribution. The basic changes in fish distribution and geographical range related to climate variability include: (1) expanded distributions of warmwater species and contracted distributions of coldwater species (i.e., spatial shift and community structure); (2) occurrence of key prey species in higher latitudes; and (3) dispersal and recruitment of fish larvae (Bell et al. 2009). Climate variability can impact reproductive success, recruitment processes, survival and growth of specific fish and their prey (Bell et al. 2009). Increases in sea level rise, precipitation, and storms caused by climate variability can even impact the structural/complexity of marine habitats, such as coral communities (Bell et al. 2009). In Brander's (2015) review of the scientific literature, he also reported climate change could cause the mean asymptotic size of the fish assemblage to decline over time with rising water temperature. The review showed rising water temperatures could also alter spawning, maturation, and natural mortality.

Combined, climate-induced impacts can alter commercial fishing operations, economics (employment, exports, and gross domestic product), and marine communities around the world. The International Centre for Trade and Sustainable Development (2010) stressed that many fishing fleets around the world were economically vulnerable to climate change-driven impacts, especially those from developing countries (West and Central African countries). The researchers indicated small-scale and artisanal fisheries were the most vulnerable to climate variability given their inability to adapt because of limited resources and capacities. In many developing countries (e.g., Malawi, Bangladesh, and Vietnam), fisheries resources provide not only employment, but nutrition and health benefits (Williams and Rota, 2014; Karim and EnamulHagque, 2015); alternative options are limited in developing countries.

Scientists around the world have predicted and demonstrated climate variation has significantly impacted fisheries resources from the North Sea to the tropics. Primarily, researchers have shown the one of the key responses associated with climate variability is a shift in spatial distribution. Most species inversely react to rising water temperatures (Sydeman and Thompson, 2014), but that depends on the species preferred water temperature. Researchers have predicted changes in species distribution and catch in the Northeast Atlantic Ocean may also be associated with changes in oxygen content, acidity, and phytoplankton community dynamics (Cheung et al. 2011).

In general, scientists have documented warmwater species with smaller maximum body sizes have increased in abundance throughout northwest Europe, while coldwater species with larger body sizes have decreased in abundance (Pinnegar et al. 2016). Using fisheries survey data collected in the North Sea, various researchers have demonstrated fish distribution has shifted between 48 and 403 km, and demersal fish have moved to deeper colder waters at a rate of around 3.6 m per decade over the past 30 years (Beare et al. 2004; Perry et al. 2005; Duly et al. 2008). This pattern has also been documented in small pelagic fish and species that prefer relatively shallower depths. Building upon earlier studies, Dully et al. (2011) highlighted various southern-distribution (warm-temperate) species (John Dory [*Zeus faber*], red mullet [*Mullus surmeletus*], anchovy [*Engraulis encrasicolus*], and sardine [*Sardina pilchardus*]) have expanded their range northward (Quero, 1998; Beare et al. 2004; MacKenzie et al. 2007). Likewise, the extended northern movement and depth range of plaice (*Pleuronectes platessa*), a southern species, was reported in the Northeast Atlantic Ocean (Perry et al. 2005). Engelhard et al. (2011) examined long-term distribution changes of North Sea sole and plaice over 90 years, and demonstrated the distribution shift (direction and depth) in plaice was caused by climate change, but both climate and fishing influenced the distribution shift of sole. In the southern North Sea, warmwater species richness and annual mean size declined during warming periods, which was independent of fishing pressure (Hofstede and Rijnsdorp, 2011). Spatial distributional changes have also been predicted and documented in the Bering Sea for several species, such as sockeye salmon (Perry et al. 2005; Farley et al. 2011) and Walleye pollock (*Theragra chalcogramma*) (Hunt et al. 2011). Climate variability is also anticipated to impact sprat (*Sprattus sprattus*) distribution and associated commercial fisheries in the Baltic Sea (Voss et al. 2011). In Australia, scientists are also concerned about expected shift changes in species assemblages (increase and decrease) caused by ongoing and predicted climate change (Fulton, 2011). Besides particular species and fish communities, researchers have also observed changes in cephalopod populations caused by ongoing climate change; Hastie et al. (2009) indicated squid are becoming more prevalent in the North Sea. Climate variability has impacted a variety of species all over the world.

Understanding and explaining the reasons why species alter their distribution in response to changes in the environment is complicated and unclear. According to Pinnegar et al. (2016), "many processes interact when considering fisheries and climate change, and these are a manifestation of both biological and human processes." They stressed responses to the environment do not occur in isolation, many are synergistic and rarely are they linear. Changes in spatial distribution caused by rising water temperature can either improve or diminish year class strength depending on the species and location (Duly et al. 2011). Many researchers (Brander and Mohn, 2004; Pawson, 1992; Cook and Heath, 2005) have reported changes (negative and positive) in year-class strength (i.e., recruitment) for a variety species (cod, seabass [*Dicentrarchus labrax*], whiting [*Merlangius merlangus*], and saithe [*Pollachius virens*]) from the English Channel to the North Sea. Besides changes in year-class strength, researchers have also reported spawning and recruitment has occurred earlier than usual for various species in the North Sea (Greve et al. 2005; Fincham et al. 2013).

In the North Pacific Ocean, both an increase and decrease in catch (e.g., Pacific halibut [*Hippoglossus stenolepis*] and Pacific cod [*Gadus macrocephalus*]) and regime shifts have been linked to variations in the Pacific Decadal Oscillation and other indices of climate (Noakes and Beamish, 2009). There is clear evidence that climate change has altered valuable fish stocks in the North Pacific Ocean, but the response depends on the species' life history characteristics and state of the ecosystem at the time the climate varied; the response varies by individual species (Noakes and Beamish, 2009). Elucidating the details of why some species migrate and others adapt to climate variability is not a straightforward process (Noakes and Beamish (2009). In the eastern North Pacific Ocean, climate change is positively affecting chum (*Oncorhynchus keta*) and pink salmon (*Oncorhynchus gorbuscha*) abundance, but it is also negatively affecting coho (*Oncorhynchus kisutch*) and Chinook salmon (*Oncorhynchus tshawytscha*) (Irvine and Fukuwaka, 2011). Pinsky and Byler (2015) examined 154 marine fish stocks around the world and found that 25 percent had collapsed; however, they stated the reasons were complicated and not straightforward. Although they indicated overfishing was the primary root cause for the collapse, various other explanatory factors (growth rates and climate change) were also important factors (Pinsky and Byler, 2015). Overall, the collapse was explained by a combination of overfishing, life-history characteristics, and climate variability.

In 2008, an international group evaluating climate change impacts on key species in the North Pacific Ocean (Canada, China, Japan, Korea, Russia and the United States) attempted to link changes in fish stocks to predicted changes in climate associated with ENSO on a 3 to 5, and 30 to 60 year time scale (Beamish 2008). The synopsis by Beamish and Noakes (2008) reported environmental changes and associated commercial yields varied by geographical location and species. Anticipated impacts of ENSO varied from lowering productivity of chub and jack mackerel in Korean and Chinese fisheries to improving Pacific salmon stocks and Pacific ocean perch (*Sebastes alutus*) year-classes off the west coast of Canada. However, they acknowledged the science was unclear, and climate implications were variable and inconsistent.

Climate change has also impacted marine resources in the western North Atlantic Ocean. In the Northeast region of the United States, various climate metrics have altered over the past 116 years, which has caused changes to marine communities. Air temperature (+2°F), precipitation (+5 inches), coastal flooding, and the number of extreme precipitation events (i.e., storms) increased between 1895 and 2011 (Horton et al. 2014). Thus, all of these ongoing changes have and will continue to influence the regional dynamics and community ecology of marine fauna. The impacts of climate change on marine communities has been documented in various regions along the northeast coast of the United States from Long Island to the Gulf Maine (Nye et al. 2009, Wood et al. 2009; Howell and Auster, 2012; Pinsky and Fogarty, 2012; Pinsky et al. 2013). In general, many species expanded their northern range, whereas a few contracted their northern range. Warmwater-adapted species appear to be migrating further north with time (Hare et al. 2012). Besides shifting their distribution northward, some marine species are migrating to deeper colder waters. In Maine, fish assemblages that preferred shallower, warmer waters tended to migrate west-southwest to shallower waters (Gulf of Maine), while those associated with relatively cooler and deeper waters shifted to deeper waters over time off the northeast coast of the United States (Kleisner et al. 2016). Fish assemblages associated with warmer and shallower water along the continental shelf from the Mid-Atlantic Bight to Georges Bank are shifting northeast along latitudinal gradients, but there is minimal change in their depth distribution (Kleisner et al. 2016). Preferred water temperatures for particular assemblages are decreasing over time, which is corresponding to decreases in the spatial extent of some fish assemblages (Kleisner et al. 2016).

Scientists have shown and continue to demonstrate that changes in climate are having drastic impacts on fish communities and fisheries worldwide (Tseng et al. 2011). Despite these documented changes, it is difficult to predict how these changes will ultimately effect biodiversity, ecosystem structure, function, and overall long-term ecological health; "there are substantial areas of uncertainty (Staudinger et al. 2012)." The interactions and pathways of multiple human-induced, environmental, and climate stressors can cause a different responses (linear, non-linear, additive, or synergistic) to species assemblages (Staudinger et al. 2012). As with any natural and anthropogenic impact, the magnitude and intensity of the reaction will depend on the individual species (intra and inter-relationships) and their ability to cope or evolve within their ecosystem (i.e., vulnerability). As previously highlighted, researchers predict climate change will cause assemblages to evolve, but they also expect many species will become extinct (Maclean and Wilson, 2011).

Given these potential profound implications for global marine resources, scientists are attempting to incorporate expected climate change impacts into the fisheries management process, such as preparing for emerging fisheries, accounting for impacts in stock assessments, and considering dynamic spatial boundary changes (Pinsky and Mantua, 2014). Pinsky and Mantua (2014) indicated it will be important to coordinate with other regions and to consider socio-economics since many communities rely heavily on fisheries for employment and diet. Effective management and strategy will depend on having key model inputs, such as mechanisms of change (Link et al. 2015). Establishing reference points will also be important to fishery managers so they can detect early changes (i.e., adaptive management) in the system (Link et al. 2015); it is essential that managers accurately interpret past and present observational data (physical and chemical) trends and consider uncertainty in parameter estimates (Planque et al. 2011). The outcomes of the Sendai Conference, a large international fisheries conference on climate change, emphasized incorporating various impact factors into future stock assessments, such as climate change (Murawski, 2011). Presenters also recommended researchers should focus less on individual species and more on understanding species interactions and integrating trophic dynamics in future climate change studies.

Marine fauna are influenced, shaped, and controlled by the oceanic environmental conditions, which can be altered not only by long-term (e.g., commercial fisheries and climate change), but short-term acute disturbance (e.g., storms and hurricanes). Water temperature, salinity, dissolved oxygen (DO), depth, and sediment type influence and select fish life-history characteristics (Horne et al. 1989). For freshwater and many open-water coastal species (non-estuary dependent), water temperature is usually the most important environmental factor influencing fish distribution, especially along the zoogeographic transition zone or boundary of a particular species (e.g., Hoese and Moore, 1977; Howell and Auster, 2012; Kuczynski et al. 2017). Based on a species' physiology (Hare et al. 2012), marine fauna have an optimal temperature range that limits their behavior, distribution, abundance, and other life-history characteristics (e.g., Howell and Auster, 2012). In most regions, water temperature varies with annual and seasonal warming and cooling conditions, which influences resident and migratory fish behavior, abundance, and distribution (Parker and Dixon, 1998). Natural and human-induced changes in the environment conditions can also shift the food web and affect a variety of ecological community metrics (e.g., diversity, size-composition, relative biomass, and relative abundance).

Besides variations in the annual and seasonal environmental conditions, infrequent, acute, and catastrophic natural events (e.g., droughts, floods, and hurricanes) can also severely affect entire marine communities (Vrancken and O'Connell, 2010). Given these are episodic events, research on the impacts to marine fauna from natural disturbance is limited. Hurricanes, although infrequent at a regional scale, can severely impact fish communities in numerous ways, including destroying habitat, and lowering DO and salinity levels, but that depends on various factors, such as rainfall amounts. In Louisiana, Hurricane Katrina (Category 5; 28 August 2005) significantly changed the fish assemblage in the downstream and upstream reaches of Bayou Lacombe (Vrancken and O'Connell, 2010). At the downstream reaches, centrarchid species (bluegill [*Lepomis macrochirus*], warmouth [*Lepomis gulosus*], and redspotted sunfish [*Lepomis miniatus*]) and several estuary species (inland silverside [*Menidia beryllina*] and striped mullet [*Mugil cephalus*]) increased in abundance after the hurricane. In contrast, longear sunfish (*Lepomis megalotis*) decreased in the upstream reaches after the hurricane and weed shiners (*Notropis texanus*), goldstriped darters (*Etheostoma parvipinne*), and warmouth were absent in post-hurricane samples (one year later). Notwithstanding these potential long-term impacts (one year later), the regional severity depends on the species' ability to tolerate and recover. For instance, Hurricane Charley (Category 4; 13 August 2004) did not prevent or limit the nightly chorusing spawning events of sand seatrout (*Cynoscion arenarius*) in Charlotte Harbor, Florida (Locascio and Mann, 2005). However, the hurricane could have caused delayed impacts associated with lowered dissolved oxygen levels given the increased freshwater inflow (Locascio and Mann. 2005). In Chesapeake Bay, changes in abundance and distribution of pelagic and bentho-pelagic fishes occurred after Hurricane Isabel (Category 2; 18 September 2003) (Houde et al. 2005). The relative abundance of adult bay anchovy (*Anchoa mitchilli*) increased in the lower bay, and relative abundance of juvenile Atlantic croaker (*Micropogonias undulates*) was 30 times higher than mean abundance for the previous decade, which was attributed to a large entrainment of larvae from coastal ocean spawning sites after (one and two months) Hurricane Isabel (Houde et al. 2005). The hurricane also enhanced abundance in some species and shifted distributions without negatively impacting the local fish populations, recruitment of juvenile fishes, or fish communities (Houde et al. 2005). Similarly, the community diversity in the Indian River Lagoon (Florida) decreased, and the fish community in the Sebastian River (Florida) shifted to a predominant freshwater species assemblage after two hurricanes passed through the east coast of Florida (Paperno et al. 2006). Despite these biological changes, they were short-term and temporary. The community structure recovered to pre-hurricane conditions within several weeks, and by mid-December (3 months after the last storm) there was little difference between the pre- and post-hurricane fish community (Paperno et al. 2006).

1.1.1.3 Marine Resources Management

Long-term monitoring programs are among the most important components of the fishery management process in the United States. These data can be used to understand how stressors (e.g., commercial fisheries, climate fluctuation, and coastal development) are shaping the marine community. Fishery resource managers often rely upon fisheries-dependent (e.g., commercial landings and sales) and fisheries-independent (e.g., size, age, and weight) data obtained from long-term monitoring programs for making broad management decisions to evaluate and set commercial fishing limits. Researchers use fisheries-independent monitoring data in a variety of ways, but one of the key applications is for evaluating the population dynamics of local fish communities.

Fisheries-independent monitoring data is also used to identify important fish habitats, which are assessed by estimating relative abundance and distribution over time (King, 1995; Jennings et al. 2001). Managers could also use these data to evaluate climate variability given the robustness of these data, but research progress has been slow because managers have different priorities, which are often associated with fishery economics (i.e., commercial fisheries).

In the United States, federal agencies have been collecting standardized fisheries-independent monitoring (FIM) data through established survey programs for many years (e.g., NMFS fisheries-independent survey programs: Northeast Fisheries Science Center Groundfish Survey [1960s-present]), but it wasn't until the 1970s that university marine science institutes (e.g., Virginia Institute of Marine Science) began developing their own fisheries-independent monitoring programs to study marine fisheries resources within their respected state waters and the 1980s that several state (e.g., Florida, New Jersey, Texas, and Virginia) agencies implemented FIM programs. Today, there are several well-respected and established state funded FIM programs across the United States. One of the oldest and most respected FIM programs in the United States is administered by the New Jersey Department Environmental Protection (NJDEP).

The NJDEP established the Ocean Stock Assessment (OSA) program in August 1988 for several reasons including, but not limited to: (1) developing a comprehensive baseline data for coastal recreational fishes and their forage items; (2) developing a recruitment indices for recreational fishes and documentation of annual relative abundance of young-of-the-year (YOY) fish; (3) providing a scientific basis to formulate or modify existing management plans for recreational fishes; and (4) providing information to complement other state and federal data for estimating populations and developing predictive models for managing fish stocks (Byrne, 1994;

2008). Today, the NJDEP continues to collect fisheries data on regular cycle within state waters, which is a segment of the middle or Mid-Atlantic Bight (MAB).

1.1.1.4 The Mid-Atlantic Bight

The MAB is defined as the offshore area of the U.S. continental shelf between Cape Cod, Massachusetts and Cape Hatteras, North Carolina (Steimle and Zetlin, 2000). One of the most economically valuable oceanic areas in the MAB is the coastal waters off New Jersey. The New Jersey coastline is about 210 km long and represents part of the passive margin that formed when the North American plate was separated from Africa during the Triassic initiation (Smith, 1996; AREC, 2004). The New Jersey coastline consists of many beaches and islands (8−29 km) that serve as a barrier between the Atlantic Ocean and the nearshore waters (Byrnes et al. 2004). The New Jersey nearshore waters (i.e., estuaries, salt marshes, tidal channels) are connected to the Atlantic Ocean by twelve inlets (Cape May Inlet to the South; Shark River Inlet to the North) (Byrnes et al. 2004).

The coast of New Jersey is characterized as a temperate marine system that is influenced by tides, currents, wind, and seasonal warm-core ring events that are often formed by countercurrent eddies from the Gulf Stream Current (AREC, 2004). Off New Jersey coast, the speed and direction of currents are not only variable (50-yr period), but primarily controlled (70%) by local wind patterns (westerly; 7−9 m/s), with the strongest winds occurring in fall and winter and the weakest in spring and summer (Byrnes et al. 2004). Sea swells from the southeast direction are an important hydrological process off the coast of New Jersey, and the tidal range is between 1 and 2 m with a 1 m mean wave height (AREC, 2004). The coast off New Jersey is a relatively shallow area (< 100 m) of the U.S continental shelf; the continental slope is about 75−120 km from the coast and the initial depth is between 120 and 160 m (AREC, 2004). The water depth is generally less than 30 m, and extends a great distance (35.2 km) from shore. The primary benthic habitats found off the coast of New Jersey are sand ridges, but there are also a few scattered rocky reefs, large boulders, and outcrops of glauconitic marl (AREC, 2004).

1.1.1.5 Marine Resources in the Mid-Atlantic Bight

The MAB is among the most important oceanic regions in the United States because it provides habitat for many ecological and economical valuable fishery resources. In 2016, commercial fishing landings and associated value in the MAB were around 76,366 mt and $255.2 million, respectively (NMFS, 2018). Commercial fisheries in New Jersey represented 79 percent of the total landings in the MAB. Over the past 10 years the economic value of commercial fishing landings in New Jersey ranged between $132.9 and $220.4 million with a mean of $164.8 million (NMFS, 2018). In 2016, commercial fisheries in New Jersey ranked tenth in landings and ninth in value ($132.3 million) in the United States (NMFS, 2018). According to the NJDEP, Bureau of Marine Fisheries, living marine resources within New Jersey waters (127 miles of Atlantic coast, 83 miles of shoreline [bays], and 3 nautical miles into the Atlantic Ocean) are valued at $2 billion and help to support a tourism industry worth around $16 billion.

The economy of New Jersey depends on its marine resources (New Jersey Sea Grant Consortium, 2016). In addition to the economic value associated with commercial fisheries, recreational fisheries also have an important economic impact on local and regional communities (Preble, 2001). Recreational fishing from shore, man-made structures, and private and charter vessels is a popular year-round hobby for many New Jersey residents and non-residents. The estimated total number of annual angler trips off the coast of New Jersey ranged from 5.4 million

(2009) to 7.4 million (2007) during 2003 through 2010 (NMFS, 2011b). Moreover, anglers fishing aboard private fishing vessels, New Jersey's recreational fishing fleet consists of about 100 party and 300 charter vessels, which is the largest fleet of its kind on the east coast of the United States (Giordano et al. 2008). New Jersey Sea Grant Consortium (2016) estimates the value of port commerce, coastal tourism, and commercial fisheries and aquaculture is $50 billion, $28 billion, and $1 billion, respectively.

The waters off the New Jersey coast consists of a variety of nearshore (e.g., estuaries, bays, salt marshes, tidal creeks, and coastal beaches) and coastal marine environments (e.g., shoals, sand ridges, continental shelf, canyons, hardbottom, and artificial reefs [e.g., ship wrecks and man-made structures]) that provide important habitat (i.e., spawning, nursery grounds, and feeding,) to many commercial and recreational valuable fish and invertebrates (Able et al. 2010; Slacum et al. 2010; Able et al. 2011). In general, these important fish habitats can be categorized as coastal beaches, nearshore (coastal pelagic), offshore, pelagic, demersal (benthic), and hardbottom (i.e., natural or artificial reef-structures) communities. Because these marine habitats off the New Jersey coast are considered essential to a variety of marine species, some of them have been officially designated by federal Fishery Management Councils (FMCs) as Essential Fish Habitat (EFH) or Habitat Areas of Particular Concern (NMFS, 2002), which are defined as discrete subsets of EFH that provide important ecological functions that are especially vulnerable to degradation (50 CFR 600).

1.2 Purpose and Goals

Marine populations and the habitats they rely upon can be significantly impacted by a variety of natural (e.g., climate variations and storms) and anthropogenic activities, such as coastal development and associated pollution (e.g., nutrients and pH level), habitat alteration or destruction (e.g., sand mining and dredging), and commercial and recreational fishing (Saila and Pratt, 1973; Malakoff, 1997; Lazaroff, 2001; Diez et al. 2004). Nearly every estuarine species including fishes and macroinvertebrates has already been adversely affected to some degree by human activities (Jackson et al. 2001). To say the least, the potential effects on fisheries resources associated with natural and anthropogenic activities are complicated, and our present understanding of these complex and dynamic processes is incomplete for almost every region, including the MAB. It is therefore pressing that we gain further knowledge about marine population dynamics and community structure because short and long-term disturbances are impacting marine resources.

Several studies have already examined and described the estuarine and coastal beach fish communities off the coast of New Jersey (e.g., Able and Fahay, 1998; Able et al. 2010), but detailed information describing the nearshore marine community beyond the surf zone is lacking (Able et al. 2011). Because marine communities and the habitats they rely upon can be potentially impacted by natural and anthropogenic activities, descriptive long-term information on the nearshore marine community must be available to marine resource managers so they can make informed decisions, especially related to climate variation or other disturbances.

To date, few researchers have pursued ecologically focused marine community studies for coastal habitats within the MAB and specifically for marine communities off New Jersey. Because long-term marine community information is unavailable for the nearshore marine community off the coast of New Jersey, it would be challenging to assess and predict potential natural or anthropogenic impacts to marine resources. It would also be difficult to conduct any natural resource damage assessments or any other environmental assessments required under the National Environmental Policy Act for proposed, ongoing, or future projects. Information about population dynamics, community structure, and the environmental factors that influence these processes are essential to managers responsible for making objective informed marine resource decisions. The future of marine communities is dependent upon resource managers balancing economic growth, urban development, and coastal resources (Sea Grant, 2016). Given these pressing needs, the broad purpose of this dissertation was to provide community-based marine resource information to fishery managers responsible for conserving, protecting, and restoring fish communities. More specifically, the goal was to examine several disturbances on the population dynamics and community structure of the marine community off the coast of New Jersey.

This dissertation research focused on several deductive research questions, several directional working hypotheses, and various statistical null and alternative hypotheses designed to examine how disturbance or stress has shaped the population and community structure of the nearshore marine community off the coast of New Jersey over the past 28 years. Specific research questions were developed to assess, measure, and explain whether the nearshore marine community off the coast of New Jersey was resilient to disturbance. Research questions and supporting null hypotheses addressed and tested several aspects of ecological community theory developed by various ecologists (e.g., Odum, 1985; Schindler, 1990; Havens, 1994; Ives, 1995; Warfe et al. 2013). Using this framework, the dissertation focused on four broad goals designed to evaluate the abiotic conditions, disturbance, population dynamics and community structure. The dissertation goals were the following:

- To examine the historical environmental conditions and nearshore marine community by evaluating the spatio-temporal patterns of the ocean conditions and nearshore marine community in the Mid-Atlantic Bight during 1988−2015;
- To assess the impacts (short and long-term) of Hurricane Sandy (29 October 2012) on the environmental conditions and the nearshore marine community in the Mid-Atlantic Bight;
- To investigate the species richness and diversity (alpha and beta) of the nearshore marine community in the Mid-Atlantic Bight during 1988−2015; and
- To evaluate the environmental and atmospheric-oceanic variability and the nearshore marine community in the Mid-Atlantic Bight during 1988−2015.

1.3 Dissertation Overview, Organization, and Outline

The title of this dissertation should be interpreted broadly. “Population dynamics” in traditional fishery science is usually interpreted as the study of the factors that affect growth, stability, and birth and death processes of a population. Although the focus of this dissertation research was not to specifically examine growth, survival, or other biological factors that influence stock dynamics, the motivation was to investigate and examine the spatial and temporal fluctuations in marine populations over time. Part of this dissertation research focused on several biological factors associated with fish population dynamics, such as temporal-spatial numerical abundance and distribution. Another section centered on assessing various environmental and biotic factors associated with community structure, such as species diversity and evenness. An important concept of community dynamics is how organisms utilize their environment; it is a measure of habitat. Understanding how abiotic conditions impact populations is a major issue for fishery management that needs further attention (e.g., Rothschild, 1986). As such, this dissertation also investigated how community structure was influenced by disturbances, such as Hurricane Sandy and climate variability. While independent *per se*, each chapter addresses one or more of the above population and community factors; all the chapters are interrelated. Each chapter was prepared as an independent article for peer review journal consideration. Supplemental information (tables and figures) were presented in appendices found at the end of each chapter.

1.4 Technical Approach

The technical approach for this dissertation research was based upon various standard quantitative methodologies used to explore and make inferences about patterns in biotic communities. The basis for this approach relied not only upon fundamental, quantitative, and ecological procedures to assess population dynamics and community patterns, but it also used more advanced analytical techniques to reveal and support evident ecological principles or patterns. The approach was centered on ecological data collected from an observational perspective rather than an experimental perspective (Ludwig and Reynolds, 1988). It should be noted the focus of this research was not to manipulate/control abiotic or biotic factors through an experiment approach, but rather to report natural fluctuations in these parameters over time (Ludwig and Reynolds, 1988; Krebs, 1999). The focus of this research was to elucidate and describe patterns in the data without imposing or testing laboratory *priori* hypotheses (Ludwig and Reynolds, 1988). The technical approach depended on analytical pattern detection methods to reveal population dynamics and community structure over space and time (Krebs, 1999; Gotelli and Ellison, 2004; Johnson and Wichern, 2007).

A decision to use available fisheries-independent monitoring data was primarily based on the notion and philosophy that data mining is one of best approaches marine researchers can use to help address challenging management questions without having to re-create or design new independent studies, which are costly and usually limited in their statistical power because of the small sample size. The research questions were developed using the FINER (feasible, interesting, novel, ethical, and relevant) criteria and followed the PICOT (population, intervention, comparison group, outcome of interest, and time) format (Farrugia et al. 2010).

Numerous fisheries-independent monitoring datasets are currently available to researchers, but many have yet to be thoroughly evaluated because of the lack of staff, funding, and time. Because fisheries-independent monitoring data are collected through publicly data before conducting additional studies and establishing new fisheries-independent monitoring programs. Given the current research priorities in the United States, and the availability of agency staff to conduct analytical evaluations of existing datasets, local, state and federal agencies are welcoming assistance from outside researchers. As such, the data chosen for this research were obtained, with encouragement and scientific support from one of the longest running fisheries-independent monitoring programs in the United States, the New Jersey Ocean Stock Assessment program.

1.5 Significance and Scientific Merit

The ability to understand, interpret, and predict changes in a population and community structure is dependent upon having sufficient long-term data and understanding the shifting baseline that arises from continuous change in the global climate. Without background data/information, various broad-based biological and population assumptions must be used in analytical models and statistical approaches, which can either overestimate or underestimate changes in the population or community structure, especially in marine communities given their natural variability. At the foundation of marine assessments is having adequate long-term information about the populations and community structure within a designated region and understanding the shifting baseline paradigm; compensating for the shifting baseline is especially needed for assessing and predicting risk in a population or community. Long-term data and information can also be used for monitoring population metrics, assessing management performance measures, and strategic planning, but it is important to understand the shifting baseline paradigm.

In general, the shifting (sliding) baseline paradigm refers to how a system is measured given the ongoing changes in the system from various natural processes (e.g. population variability) and unnatural disturbances (e.g., global climate change, commercial fishing, pollution, physical damage, and introduction of exotic species). In many ways, the fundamental issue is simply perceiving the system from a "snap-shot view" without considering or understanding the ongoing historical changes caused by new and increasing disturbances, such as overexploitation (Pauly, 1995; Campbell et al. 2009; Papworth et al. 2009). For marine researchers, the primary problem that exacerbates the issue is the lack of historical long-term data that pre-dates industrial commercial fishing (pre-1950s) and ongoing disturbances (e.g., commercial fishing and physical damage [loss of habitats]).

Long-term data is used by researchers and fishery managers in a variety of ways, such as assessing fish populations or marine communities, improving stock status (e.g., overfishing and maximum sustainable yield), understanding shifting baselines, defining essential fish habitat, and evaluating the consequences associated with natural (e.g., hurricanes and climate change) or unnatural environmental events, such as an expected oil or toxic spill. Long-term data are important for evaluating not only the extent and nature of an event, but they are necessary for assessing risk to a population or community from a proposed project, management action, or regulation. Long-term information is necessary for establishing biological reference points, performance measures, and meeting broader management objectives; this information can only be acquired by monitoring and assessing the system (Sainsbury et al. 2000).

In many ways, the sustainability of marine communities will depend on the ability of researchers to use the available historical scientific information to first understand the virgin or baseline conditions, and second to use the information to evaluate present or future changes in a population or community. Many researchers have stated the success of marine management is largely reliant on having reliable historical long-term data, mainly on fisheries stock abundance and distribution (Petersen, 1992; Helser and Hayes, 1995; Brodziak and Link, 2002; Thompson and Mapstone, 2002).

As such, this dissertation research was pursed to help state and federal agencies better understand how short and long-term disturbance is shaping the marine community structure off the coast of New Jersey. Although the purpose of this research was not to reconstruct a past "baseline" of the environmental conditions and marine community given the shifting nature of the baseline, the information does support managers with developing long-term management strategies for the state and serve as a model for other regions. Understanding spatial and temporal population dynamics and community structure of the marine resources in this region will help population modelers with choosing biological inputs. More importantly, the findings assist fishery managers with progressing toward managing fisheries by the ecosystem management approach. Overall, the findings not only extend our knowledge of one of the most economically important regions in the United States in terms of marine resources, but this research provides information for long-term conservation planning and management strategy.

1.6 References

Able, K.W., and Fahay, M.P. 1998. The first year in the life of estuary fishes in the Middle Atlantic Bight. New Brunswick, New Jersey: Rutgers University Press.

Able, K.W., Fahay, M.P., Witting, D.A., McBride, R.S., and Hagan, S.M. 2006. Fish settlement in the ocean vs. estuary: Comparison of pelagic larval and settled juvenile composition and abundance from southern New Jersey, U.S.A. Estuarine, Coastal and Shelf Science 66: 280−290.

Able, K.W., Wilber, D.H, Muzeni-Corino, A., and Clarke, D.G. 2010. Spring and summer larval fish assemblages in the surf zone and nearshore off northern New Jersey, USA. Estuaries and Coasts 33(1): 211−222.

Able, K.W., Grothues, T.M., Rowe, P.M., Wuenschel, M.J., and J.M. Vasslides. 2011. Near-Surface larval and juvenile fish in coastal habitats: Comparisons between the inner shelf and an estuary in the New York Bight during summer and fall. Estuaries and Coasts 34: 726–738.

Ainsworth, C.A., Samhouri, J.F., Busch, D.S., Cheung, W.W.L., Dunne, J., and Okey, T.A. 2011. Potential impacts of climate change on Northeast Pacific marine foodwebs and fisheries. ICES Journal of Marine Science 68 (6): 1217–1229. doi:10.1093/icesjms/fsr043.

Almeida, O.T., McGrathm, D.G., and Ruffino, L. 2001. The commercial fisheries of the lower Amazon: an economic analysis. Fisheries Management and Ecology 8: 253–269.

Angelini, R., and Moloney, C.L. 2007. Fisheries, Ecology and Modelling: an historical perspective**.** Pan-American Journal of Aquatic Sciences 2 (2): 75–85.

ASMFC (Atlantic States Marine Fisheries Commission). 1994. Proceedings of the workshop on saltwater fishing tournaments. U.S. Fish and Wildlife Service, Atlantic States Marine Fisheries Commission Special Report Number 46.

Barnston, A.G., and Livezey, R.E. 1987. Classifications, Seasonality, and Persistence of Low-Frequency Atmospheric Circulation Patterns. Monthly Weather Review 115: 1083−1126.

Begon, M., Harper, J.L., and Townsend, C.R. 1986. Ecology: Individuals, Populations, and Communities. Sinauer Associates, Inc. Publishers. Sunderland, Massachusetts. 876 pp.

Beare, D.J., Burns, F., Greig, A., Jones, E.G., Peach, K., Kienzle, M., McKenzie E., and Reid, D.G. 2004. Long-term increases in prevalence of North Sea fishes having southern biogeographic affinities. Marine Ecological Progress Series 284: 269–278.

Bell, J., Batty, M., Ganachaud, A., Gehrke, P., Hobday, A.J., Hoegh Guldberg, O., Johnson, J.E., Le Borgne, R., Lehodey, P., Lough, J.M., Pickering, T., Pratchett, M.S., Sheaves, M.J., and Waycott, M. 2009. Preliminary Assessment of the Effects of Climate Change on Fisheries and Aquaculture in the Pacific. Appendix 4. pp. 451-469. In: Gillett R Fisheries in the economies of the Pacific island countries and territories. Asian Development Bank.

Bjerknes, J. 1969. Atmospheric teleconnections from the equatorial Pacific. Journal of Physical Oceanography 97 (3): 163−172.

Branch T.A., Jensen, O.P., Ricard, D., Yimin, Y., and Hilborn, R. 2011. Contrasting global trends in marine fishery status obtained from catches and from stock assessments. Conservation Biology 25(4): 777–786.

Brander, K.M., and Mohn, R. 2004. Effect of the North Atlantic Oscillation on the recruitment of Atlantic cod (Gadus morhua). Canadian Journal of Fish and Aquatic Science 61:1558–1564.

Brodziak, J. and Link, J. 2002. Ecosystem-based fishery management: what is it and how can we do it? Bulletin of Marine Science 70(2): 589−611.

Buchsbaum, R. Pederson, J., and Robinson, W.E. (eds). 2005. The Decline of Fisheries Resources in New England: Evaluating the Impact of Overfishing, Contamination, and Habitat Degradation. MIT Sea Grant College Program, Cambridge, MA, MITSG 05-5.

Bulleri, F. and Chapmen, M.G. 2010. The introduction of coastal infrastructure as a driver of change in marine environments. Journal of Applied Ecology 47: 26−35.

Byrne, D. 2008. Ocean trawling survey. New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Marine Fisheries Administration, Bureau of Marine Fisheries.

Byrne, D. 1994. Stock assessment of New Jersey’s nearshore recreational fisheries resources. In Proceedings of the workshop on the collection and use of trawl survey data for fisheries management, ed. T. Berger, 36–42. Washington: Atlantic States Marine Fisheries Commission.

Campbell, L.M., Gray, N.J., Hazen, E.L., and Shackeroff, J.M. 2009. Beyond baselines: rethinking priorities for ocean conservation. Ecology and Society 14(1): 14.

CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). 2012. The CITES species. Accessed 23 January 2012. http://www.cites.org/.

Cleghorn, J. 1854. On the fluctuations in the herring fisheries. British Association for Advancement of Science 24: 124.

Code of Federal Regulations (CFR). Title 50 Wildlife and Fisheries. Chapter VI Fishery Conservation and Management, National Oceanic and Atmospheric Administration, Department of Commerce. Part 600 Magnuson-Stevens Act Provisions. 50 CFR 600.

Cook, R.M., and Heath, M.R. 2005. The implications of warming climate for the management of North Sea demersal fisheries. ICES Journal of Marine Science 62: 1322–1326.

Conca, K., and Dabelko, G.D. 2014. Green planet blues: Environmental politics from Stockhom to Johannesburg.Westview Press. 372 pp.

CGER (Commission on Geosciences, Environment and Resources) Ocean Studies Board (OSB). 2000. Improving the Collection, Management, and Use of Marine Fisheries Data. The National Academies Press. 236 pp.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., and van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253–260.

Cross, J.N., Zetlin, C.A., Berrien, P.L., Johnson, D.L., and McBride, C. 1999. Essential fish habitat source document: Butterfish, *Peprilus triacanthus*, life history and habitat characteristics. NOAA Technical Memorandum NMFS-NE-145:1−42.

DAI and MERF (Development Alternatives, Inc. and Marine Environment and Resources Foundation, Inc. 2003. Review of baseline assessment in fisheries. 63 pp.

Denman, K., Christian, J.R., Steiner, N., Portner, H., and Nojiril, Y. 2011. Impacts of future ocean acidification on marine ecosystems and fisheries: current knowledge and recommendations for future research. ICES Journal of Marine Science 68(6): 1019–1029. doi:10.1093/icesjms/fsr074.

Doney, S. C. 2010. The growing human footprint on coastal and open ocean biogeochemistry. Science, 328: 1512–1516.

Dulvy, N.K., Rogers, S.I., Jennings, S., Stelzenmülle, V., Dye, S.R., Skjoldal, H.R. 2008. Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. Journal of Applied Ecology 45:1029–1039.

Dulvy, N., Dulvy, N.K., Reynolds, J.D., Pilling, G.M., Pinnegar, J.K., Phillips, J.S., Allison, E.H., and Badjeck, M.C. 2011. "Fisheries management and governance challenges in a climate change", in The Economics of Adapting Fisheries to Climate Change, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264090415-4-en.

EarthJustice. 2012. Accessed 30 January 2012. http://earthjustice.org/news/press/2012/lawsuit-aims-to-protect-endangered-caribbean-corals-from-overfishing.

Engelhard, G.H., Pinnegar, J.K., Kell, L.T., and Rijnsdorp, A.D. 2011. Nine decades of North Sea sole and plaice distribution ICES Journal of Marine Science 68(6): 1090–1104. doi:10.1093/icesjms/fsr031.

EPA (Environmental Protection Agency). 2006. The Changing Faces of Europe’s Coastal Areas. EEA Report 6⁄2006.

Epifanio, C.E., and Garvin, R.W. 2001. Larval transport on the Atlantic continental shelf of North America: a Review. Estuarine, Coastal and Shelf Science 52 51–77.

Enfield, D.B., Mestas-Nunez, A.M., and Trimble, P.J. 2001. The Atlantic multidecadal oscillation and it’s relation to rainfall and river flows in the continental U.S. Geophysical Research Letters 28: 2077−2080.

ERCO (Energy Resources Company, Inc). 1982. IXTOC oil spill assessment final report. Prepared for Bureau of Land Management. Cambridge, MA. 333 pp.

FAO (Food and Agriculture Organization of the United Nations). 1995. The State of World Fisheries and Aquaculture. FAO Fisheries Department, Rome. 6 pp.

FAO (Food and Agriculture Organization of the United Nations). 2010. State of world fisheries and aquaculture. The State of World Fisheries and Aquaculture. FAO Fisheries Department, Rome. 197 pp.

Farley, E.V., Starovoytov, A., Naydenko, S., Heintz, R., and Trudel, M. 2011. Implications of a warming eastern Bering Sea for Bristol Bay sockeye salmon. ICES Journal of Marine Science 68(6): 1138–1146. doi:10.1093/icesjms/fsr021.

Fincham, J.I., Rijnsdorp, A.D., and Engelhard, GH. 2013. Shifts in the timing of spawning in sole linked to warming sea temperatures. Journal of Sea Research 75: 69–76.

Floeter, S.R., Ferreira, C.E.L., Dominici-Arosemena, A., Zalmon, I.R. 2004. Latitudinal gradients in Atlantic reef fish communities: trophic structure and spatial use patterns Journal of Fish Biology 64: 1680−1699.

Ficke, A.D., Myrick, C.A., and Hansen, L.J. 2007. Potential impacts of global climate change on freshwater fisheries. Review in Fish Biology and Fisheries 17: 581–613.

Fulton, E.A. 2011. Interesting times: winners, losers, and system shifts under climate change around Australia. ICES Journal of Marine Science 68(6): 1329–1342. doi:10.1093/icesjms/fsr032.

Gascuel, D., Bozec, Y-M., Chassot, E., Colomb, A., and Laurans, M. 2005. The trophic spectrum: theory and application as an ecosystem indicator. ICES Journal of Marine Science 62: 443-452.

Gascuel, D., Gue´nette, S., and Pauly, D. 2011. The trophic-level-based ecosystem modelling approach: theoretical overview and practical uses. ICES Journal of Marine Science doi:10.1093/icesjms/fsr062.

Gillet. V. 2003. The fisheries of Belize. Fisheries Centre Research Reports 11(6): 141–147.

Giordano, C., Hartley, S.L., Kurz, K., Michalski, K., and Figley, B. 2008. New Jersey party and charter boat directory 2000: Additions 2001−2008. Trenton, New Jersey: New Jersey Department of Environmental Protection.

Gnanadesikan, A., Dunne, J.P., and John, J. 2011. What ocean biogeochemical models can tell us about bottom-up control of ecosystem variability. ICES Journal of Marine Science 68(6): 1030–1044. doi:10.1093/icesjms/fsr068.

Goode G.B., and Collins. J.W. 1887. "The fresh-halibut fishery". In: The fisheries and fishery industry of the United States. Section V. History and methods of the fisheries, Vol. I, Part I. Government Printing Office, Washington, DC. 3–89.

Gotelli, N.J., and A.M. Ellison. 2004. A Primer of Ecological Statistics. Sinauer Associates, Inc., Publishers. Sunderland, Massachusetts. 510 pp.

Gregg, R.M., A. Score, and Pietri, D. 2016. The State of Climate Adaptation in U.S. Marine Fisheries Management. Ecological Adaption. Bainbridge Island, WA. 120 pp.

Greve, W., Prinage, W.S., Zidowitz, H., Nast J., and Reiners, F. 2005. On the phenology of North Sea ichthyoplankton. ICES Journal of Marine Science 62: 1216–1223.

Groot, R.S., Wilson, M.A., and Boumans, R.M.J. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41 (3): 393–408.

Hagan, S.M. and Able, K.W. 2008. Annual patterns in diel differences for species richness and total abundance were remarkably similar between 1995 and 1996 Estuaries and Coasts: J CERF 31: 33–42.

Hagan, S.M. and Able, K.W. 2003. Seasonal changes of the pelagic fish assemblage in a temperate estuary. Estuarine, Coastal and Shelf Science 56: 15−29.

Hardin, G. 1968. The Tragedy of the Commons. Science, 162: 1243–1248.

Hare, J.A., Wuenschel, M.J., and Kimball, M.E. 2012. Projecting Range Limits with Coupled Thermal Tolerance - Climate Change Models: An Example Based on Gray Snapper (*Lutjanus griseus*) along the U.S. East Coast. PLoS ONE 7(12): e52294. doi:10.1371/journal.pone.0052294.

Hart, P., and Reynolds, J.D. 2002. Handbook of Fish Biology and Fisheries Volume 2 Fisheries, Blackwell Publishing. 385 pp.

Hastie, L.C., Pierce, G.J., Wang, J., Bruno, I., Moreno, A., Piatkowski, U., and Robin, J.P. 2009. Cephalopods in the north-eastern Atlantic: species, biogeography, ecology, exploitation and conservation. Oceanography Marine Biology, Annual Review 47: 111–190.

Helser, T.E. and Hayes, D.B. 1995. Providing quantitative management advice from stock abundance indices based on research surveys. Fishery Bulletin 93: 290-298.

Hoese, H.D. and Moore, R.H. 1977. Fishes of the Gulf of Mexico, Texas, Louisiana and adjacent waters. Texas A. & M. University Press, College Station. 327 pp.

Hofstede, R., and Rijnsdorp, A.D. 2011. Comparing demersal fish assemblages between periods of contrasting climate and fishing pressure. ICES Journal of Marine Science 68(6): 1189–1198. doi:10.1093/icesjms/fsr053.

Homer-Dixon, T.F. 1999. Environmental scarcity and violence. Princeton University Press. Princeton, New Jersey. 253 pp.

Howell, P., and Auster, P.J. 2012. Phase Shift in an Estuarine Finfish Community Associated with Warming Temperatures. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4: 481–495.

Horne, J.K., and Campana, S.E. 1989. Environmental factors influencing the distribution sf juvenile groundfish in nearshore habitats of southwest Nova Scotia. Canadian Journal of Fish and Aquatic Science 46: 1277−1286.

Houde, E.D., Bichy, J., and Jung, S. 2005. Effects of Hurricane Isabel on fish populations and communities in Chesapeake Bay. K.G. Sellner (ed.). 2005. Hurricane Isabel in Perspective. Chesapeake Research Consortium, CRC Publication 05-160, Edgewater, MD.

Hunt, G.L., Coyle, K.O., Eisner, L.B., Farley, E.V., Heintz, R.A., Mueter, F., Napp, J.M., Overland, J.E., Ressler, P.H., Salo, S., and Stabeno, P.J. 2011. Climate impacts on eastern Bering Sea foodwebs: a synthesis of new data and an assessment of the Oscillating Control Hypothesis. ICES Journal of Marine Science 68(6): 1230–1243. doi:10.1093/icesjms/fsr036.

ICTSD (International Centre for Trade and Sustainable Development). 2010. Climate Change and Fisheries: Policy, Trade and Sustainable Development Issues. Information Note Number 15, October 2009. Geneva, Switzerland. 8 pp.

Jang, C. J., Park, J., Park, T., and Yoo, S. 2011. Response of the ocean mixed layer depth to global warming and its impact on primary production: a case for the North Pacific Ocean. ICES Journal of Marine Science, 68: 996–1007.

Irvine, J.R., and Fukuwaka, M. 2011. Pacific salmon abundance trends and climate change. ICES Journal of Marine Science 68(6): 1122–1130. doi:10.1093/icesjms/fsq199.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., and Warner, R.R. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293: 629−638.

Jennings, S., Kaiser, M.J., and Reynolds, J.D. 2001. Marine fisheries ecology. Blackwell Publishing. Malden, Massachusetts. 417 pp.

Johnson, R.A., and Wichern, D.W. 2007. Applied Multivariate Statistical Analysis. Pearson Prentice Hall. Upper Saddle River, New Jersey. 773 pp.

Kaufman, G., and Allen, M.S. 2008. Potential impacts of global change on warmwater fisheries of the USA. Technical Report. Athens, Georgia. 38 pp.

Kennedy, V.S., Twilley, R.R., Kleypas, J.A., Cowan, J.H., and Hare, S.R. 2002. Coastal and Marine Ecosystems: Potential Effects on U.S. Resources and Global Climate Change. Pew Center on Global Climate Change, Arlington. 52 pp.

King, M. 1995. Fisheries biology, assessment and management. Fishing News Books, Oxford. 341 pp.

King, J.R., McFarlane, G.A., and Beamish, R.J. 2001. Incorporating the dynamics of marine systems into the stock assessment and management of sablefish. Progress in Oceanography 49: 619–639.

Kleisner, K.M., Fogarty, M.J., McGee, S., Barnett, A., Fratantoni, P., Greene, J., Hare, J.A., Lucey, S.M., McGuire, C., Odell, J., Saba, V.S., Smith, L., Weaver, K.J., and Pinsky, M.L. 2016. The Effects of Sub-Regional Climate Velocity on the Distribution and Spatial Extent of Marine Species Assemblages. PLoS ONE 11(2): e0149220. doi:10.1371/journal.pone.0149220.

Krebs, C.J. 1999. Ecological Methodology. Addison-Welsey Educational Publishers, Inc. Menlo Park, California. 620 pp.

Kuczynski, L., Chevalier, M., Laffaille, P., Legrand, M., and Grenouillet, G. 2017. Indirect effect of temperature on fish population abundances through phenological changes. PLoS ONE 12(4): e0175735. https://doi.org/10.1371/journal.pone.0175735.

Lackey, R.T. 2005. Fisheries: history, science, and management. pp. 121-129. In: Water Encyclopedia: Surface and Agricultural Water, Jay H. Lehr and Jack Keeley, editors, John Wiley and Sons, Inc., Publishers, New York, 781 pp.

Lankester, E.R. 1884. The scientific results of the exhibition. International Fisheries Exhibition, 1883, Literature 4: 443−446.

Lazaroff, C. 2001. Historic overfishing led to modern ocean problems. Environment News Service. Accessed 20 January 2011. http:www.cgaux1sr.org/msep/fish.htm.

Link, J.S., Griffis, R., and Busch, S. (Editors). 2015. NOAA Fisheries Climate Science Strategy. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-F/SPO-155. 70 pp.

Lotze, H.K., Coll, M., and Dunne, J. 2011. Historical changes in marine resources, food-web structure and ecosystem functioning in the Adriatic Sea, Mediterranean. Ecosystems 14(2): 198−222.

Lucifora L., Garcia V.G., and Worm, B. 2011. Global diversity hotspots and conservation priorities for sharks. PLoS ONE 6(5): e19356. doi:10.1371/journal.pone.0019356.

Ludwig, J.A., and Reynolds, J.F. 1988. Statistical Ecology. A Wiley-Interscience Publication. John Wiley & Sons. New York. 337 pp.

Luiz, O.J., and Edwards, A.J. 2011. Extinction of a shark population in the Archipelago of Saint Paul’s Rocks (equatorial Atlantic) inferred from the historical record. Biological Conservation doi:10.1016/j.biocon.2011.08.004.

Ofori-Amoah, A. 2004.Water wars and international conflict’, University of Wisconsin International Environmental Problems and Policy Centre. http://academic.evergreen.edu.

Paperno, R., Tremain, D.M., Adams, D.H., Sebastian, A.P., Sauer, J.T., and Dutka-Gianelli, J. 2006. The disruption and recovery of fish communities in the Indian River Lagoon, Florida, following two hurricanes in 2004. Estuaries and Coasts 29 (6A): 1004–1010.

MacKenzie, B.R. and Visser, A.W. 2001. "Fisheries and Climate Change: the Danish Perspective", in A.M.K. Jørgensen, J. Fenger and K. Halsnaes (eds.), Climate Change Research - Danish Contributions, Danish Climate Center, Copenhagen.

Maclean IMD, and Wilson RJ. 2011. Recent ecological responses to climate change support predictions of high extinction risk. Proceedings of the National Academy of Sciences 108: 12337-12342.

Malakoff, D. 1997. Extinction on the high seas. Science 277: 486−488.

Mazeaud, M. M., Mazeaud, F., and Mazeaud, E.M. 1977. Primary and secondary effects of stress in fish—some new data with a general review. Transactions of the American Fisheries Society 106: 201–221.

Moline, M.A., Blackwell, S.M., Chant, R., Oliver, M.J., Bergmann, T., Glenn, S., and Schofield, O.E. 2004. Episodic physical forcing and the structure of phytoplankton communities in the coastal waters of New Jersey. Journal of Geophysical Research, 109, C12S05, doi:10.1029/2003JC001985.

Muhling, B.A., Lee, S.K., Lamkin, J.T., and Liu, Y. 2011. Predicting the effects of climate change on bluefin tuna (*Thunnus thynnus*) spawning habitat in the Gulf of Mexico. ICES Journal of Marine Science 68(6): 1051–1062. doi:10.1093/icesjms/fsr008.

Murawski, S.A. 2011. Summing up Sendai: progress integrating climate change science and fisheries. ICES Journal of Marine Science 68(6): 1368–1372. doi:10.1093/icesjms/fsr0861.

Mwangi, M.H. 2008. Aquaculture in Kenya: Status, challenges, and opportunities. Director of Aquaculture Development. Kenya, Africa. 10 pp.

Montgomery, D.C. 2009. Design and Analysis of Experiments. John Wiley & Sons, Inc. Hoboken, New Jersey. 656 pp.

Moser, J. and Shepherd, G.R. 2009. Seasonal distribution and movement of black sea bass (*Centropristis striata*) in the Northwest Atlantic as determined from a mark-recaptured experiment. Journal of the Northwest Atlantic Fishery Science 40: 17−28.

Nellemann, C., Hain, S., and Alder, J. (Eds). 2008. In Dead Water – Merging of climate change with pollution, over-harvest, and infestations in the world's fishing grounds. United Nations Environment Programme, GRID-Arendal, Norway. www.grida.no.

Nixon, A. 1997. World Fisheries: The current crisis. Parliament of Canada. Science and Technology. Parliamentary Research Branch BP-434E. http://www.parl.gc.ca/Content/LOP/researchpublications/bp434-e.htm.

New Jersey Sea Grant Consortium. 2016. 2014-2017 Strategic Plan. Accessed on 29 January 2016. Accessed at: http://njseagrant.org/about-us/strategic-plan/.

NJDEP (New Jersey Department of Environmental Protection). 2007. Valuing New Jersey's Natural Capital: An Assessment of the Economic Value of the State's Natural Resources. Trenton, New Jersey. 54 pp.

NMFS (National Marine Fisheries Service). 1996. Magnuson-Stevens Fishery Conservation and Management Act. United States Department of Commerce, National Oceanic and Atmospheric Administration, NMFS, Technical Memorandum NMFS-F/SPO-23.

NMFS (National Marine Fisheries Service). 1998. Ecosystem-Based Fishery Management. Report to Congress. Ecosystem Principles Advisory Panel. Silver Spring, Maryland. 62 pp.

NMFS (National Marine Fisheries Service). 2002. Essential fish habitat: A marine fish habitat conservation mandate for federal agencies, South Atlantic region. St. Petersburg, Florida: National Marine Fisheries Service, Habitat Conservation Division, Southeast Regional Office.

NMFS (National Marine Fisheries Service). 2011. Annual Report to Congress on the Status of U.S. Fisheries-2010, U.S. Department of Commerce, NOAA, National Marine Fisheries Service, Silver Spring, MD. 21 pp.

NMFS (National Marine Fisheries Service). 2011b. Recreational fisheries. Accessed 10 October 2011. http://www.st.nmfs.noaa.gov/st1/recreational/index.html.

NMFS (National Marine Fisheries Service). 2018. Annual commercial fishery landings. Accessed 19 January 2018. http://www.st.nmfs.noaa.gov/st1/commercial/landings/gc_runc.html.

NOAA (National Oceanographic Atmospheric Administration). National Weather Service. Climate Prediction Center. North Atlantic Oscillation, Historical Time Series. Accessed 1 May 2019. https://www.cpc.ncep.noaa.gov/data/teledoc/nao_ts.shtml.

Noakes, D.J., and Beamish, R.J. 2009. Synchrony of Marine Fish Catches and Climate and Ocean Regime Shifts in the North Pacific Ocean. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science: 155-168.

Norse, E.A. 1993. Global Marine Biological Diversity. Island Press. Washington, D.C. 383 pp.

Orensanz, J.M., Parma, A.M. and Iribarne, O.O. 1991. Population dynamics and management of natural stocks. *In* S.E. Shumway, ed. Scallops: Biology, Ecology and Aquaculture. Developments in Aquaculture and Fisheries Science, 21: 625−713.

Ostrom, V., 1999. Polycentricity (part 1 and 2). In M.D. McGinnis, ed. Polycentricity and Local Public Economies. Michigan: University of Michigan Press. pp. 52-74 and 119-138.

Papworth, S.K., Rist, J., Coad, L., and Milner-Gulland, E.J. 2009. Evidence for shifting baseline syndrome in conservation. Conservation Letters 2: 93–100.

Parkes, G., Young, J. A., Walmsley, S.F., Abel, R., Harman, J., Horvat, P., Lem, A., MacFarlane, A., Mens, M., and Conor, N. 2010. Behind the Signs—A Global Review of Fish Sustainability Information Schemes. Reviews in Fisheries Science 18: (4): 344−356.

Pauly, D. 1995. Anecdotes and the shifting base-line syndrome of fisheries. Trends in Ecology and Evolution 10(10): 430.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F. 1998. Fishing down marine food webs. Science 279: 860–863.

Perry, A.L., P.J. Low, J.R. Ellis and Reynolds, J.D. 2005. Climate Change and Distribution Shifts in Marine Fishes. Science 308: 1912−1915.

Petterson, K. 1992. Fisheries for small pelagic species: an empirical approach to management targets. Reviews in Fish Biology and Fisheries 2: 321−338.

Phelan M.J. and Bajhau H. (Eds). 2006. Monitoring Fish Stocks and Aquatic Ecosystems. Australian Society for Fish Biology Workshop Proceedings, Darwin, Northern Territory, 11-15 July 2005. Fisheries Incidental Publication No 25. Northern Territory Department of Primary Industry, Fisheries and Mines, Darwin. October.

Pinsky, M.L., and Fogarty, M. 2012. Lagged social-ecological responses to climate and range shifts in fisheries. Climatic Change Letters 115(3): 883-891

Pinsky, M.L., Worm, B., Fogarty, M.J., Sarmiento, J.L., and Levin, S.A. 2013. Marine taxa track local climate velocities. Science 341(6151): 1239–1242.

Pinsky, M.L., and Mantua, N.J. 2014. Emerging adaptation approaches for climate ready fisheries management. Oceanography 27(4): 146–159, http://dx.doi.org/10.5670/oceanog.2014.93.

Planque, B., Bellier, E., and Loots, C. 2011. Uncertainties in projecting spatial distributions of marine populations. ICES Journal of Marine Science 68(6): 1045–1050. doi:10.1093/icesjms/fsr007.

Polovina, J.J., Dunne, J.P., Woodworth, P.A., and Howell, E.A. 2011. Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming. ICES Journal of Marine Science, 68: 986–995.

Preble, D. 2001. The fishes of the sea -- Commercial and sport fishing in New England. Dobbs Ferry, New York: Sheridan House.

Quero, J.C. 1998. “Changes in the Euro-Atlantic Fish Species Composition Resulting from Fishing and Ocean Warming”. Italian Journal of Zoology, 65: 493-499.

Richards, R.A., P.C. Nitschke, and Sosebee, K.A. 2008. Population biology of monkfish *Lophius americanus*. ICES Journal of Marine Science 65: 1291−1305.

Ross, M. 2003. Natural Resources and Civil War: An Overview. World Bank Research Observer: 1−37.

Roosevelt, T. 1916. A Book-Lover’s Holidays in the Open. Charles Scribner's Sons. New York. 373 pp.

Roni, P., Beechie, T.J., Bilby, R.E., Leonetti, E.F., Pollock, M.M., and Pess, G.R. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. North American Journal of Fisheries Management 22: 1–20.

Rountree, R.A. and Able, K.W. 1997. Nocturnal fish use of New Jersey marsh creek and adjacent bay shoal habitats. Estuarine, Coastal and Shelf Science 44: 703−711.

Ruiz, D.A., and Roche, E.F. 2011. Cooperative Research Program 2010 Annual Report National Marine Fisheries Service, Southeast Regional Office, State/Federal Liaison Branch, St. Petersburg, Florida. 81 pp.

Russell, B.D., Harley, C.D., Wernberg, T., Mieszkowska, N., Widdicombe, S., Hall-Spencer, J.M., and Connell, S.D. 2012. Predicting ecosystem shifts requires new approaches that integrate the effects of climate change across entire systems. Biology Letters 8: 164−166.

Saila, S.B. and Pratt, S.D. 1973. Mid-Atlantic Bight fisheries. Pages 6-1 to 6-125 in Coastal and offshore environmental inventory: Cape Hatteras to Nantucket Shoals. University of Rhode Island: Marine Publication Series No. 2. Kingston, RI.

Sanchirico, J.N., and Wilen, J.E. 2007. Global marine fisheries resources: status and prospects. International Journal of Global Environmental Issues 7 (3): 106–118.

Sainsbury, K.J., Punt, A.E., and Smith, A.D.M. 2000. Design of operational management strategies for achieving ecosystem objectives. ICES Journal of Marine Science, 57: 731−741.

Schaefer, M.B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Inter-American Tropical Tuna Commission Bulletin 1: 27–56.

Scearce, C. 2009. European Fisheries History: Pre-industrial Origins of Overfishing. ProQuest Discovery Guidelines. http://www.csa.com/discoveryguides/discoveryguides-main.php.

Simon, J., Kaiser, M.J., and Reynolds, J.D. 2001. Marine Fisheries Ecology. Blackwell Publishing, Victoria, Australia. 417 pp.

Slacum, W.H. Burton, W.H., and Methratta, E.T. 2010. Assemblage structure in shoal and flat-bottom habitats on the inner continental shelf of the Middle Atlantic Bight, USA. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 2: 277–298.

Smith, P.C. 1996. Nearshore ridges and underlying upper Pleistocene sediments on the inner continental shelf of New Jersey. New Brunswick, New Jersey. Masters Thesis, Rutgers University, Geological Sciences. 157 pp.

Staudinger, M.D., Grimm, N.D.., Staudt, A., Carter, S.L., Chapin III, F.S., Kareiva, P., Ruckelshaus, M., and Stein, B.A. 2012. Impacts of Climate Change on Biodiversity, Ecosystems, and Ecosystem Services: Technical Input to the 2013 National Climate Assessment. Cooperative Report to the 2013 National Climate Assessment. 296 pp. Available at: http://assessment.globalchange.gov.

Steimle, F.W. and Zetlin, C. 2000. Reef habitats in the Middle Atlantic Bight: abundance, distribution, associated biological communities and fishery resource use. Marine Fisheries Review. 62(2): 24−41.

Stramma, L., Johnson, G. C., Sprintall, J., and Mohrholz, V. 2008. Expanding oxygen-minimum zones in the tropical oceans. Science, 320: 655–658.

Su, N., Sun, C., Punt, A.E., Yeh, S., and DiNardo, G. 2011. Modelling the impacts of environmental variation on the distribution of blue marlin, *Makaira nigricans*, in the Pacific Ocean. ICES Journal of Marine Science 68(6): 1072–1080. doi:10.1093/icesjms/fsr028.

Sydeman W.J., and Thompson, S.A. 2013. Potential Impacts of Climate Change on California's Fish and Fisheries. Institute for Advanced Ecosystem Research. Literature Review. California Ocean Science Trust, Oakland, CA. 45 pp.

Szedlmayer, S.T. and Able, K.W. 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. Estuaries 19(3): 697−709.

Tabb, W.K. 2007. Resource wars. Monthly Review, 1 January 2007, http://monthlyreview.org.

Taylor, S.G. 2008. Climate warming causes phenological shift in pink salmon, *Oncorhynchus gorbuscha*, behavior at Auke Creek, Alaska. Global Change Biology 14: 229−235.

Taylor, D.L., Nichols, R.S., and Able, K.W. 2007. Habitat selection and quality for multiple cohorts of young-of the-year bluefish (*Pomatomus saltatrix*): Comparisons between estuarine and ocean beaches in southern New Jersey. Estuarine, Coastal and Shelf Science 73: 667−679.

Tissot, B.N. 2005. Integral Marine Ecology: Community-Based Fishery Management in Hawai'i. World Futures: Journal of General Evolution: 61: 79−96.

TWH (The White House). 1983. Fact Sheet. United States Oceans Policy. Office of the Press Secretary. Washington D.C. 2 pp.

Thompson, A.A., and Mapstone, B.D. 2002. Intra- versus inter-annual variation in counts of reef fishes and interpretation of long-term monitoring studies. Marine Ecology Progressive Series 247−257.

Tseng, C.T., Sun, C.L., Yeh, S.Z., Chen, S.C., Su, W.C., and Liu, D.C. 2011. Influence of climate-driven sea surface temperature increase on potential habitats of the Pacific saury (*Cololabis saira*). ICES Journal of Marine Science 68(6): 1105–1113. doi:10.1093/icesjms/fsr070.

USAID (United States Agency for International Development). 2003. Review of the Status, Trends and Issues in Global Fisheries and Aquaculture, with Recommendations for USAID Investments. USAID SPARE Fisheries and Aquaculture Panel. Aquaculture and Fisheries. 42 pp.

Van Vrancken, J. and O'Connell, M.T. 2010. Effects of Hurricane Katrina on freshwater fish assemblages in a small coastal tributary of Lake Pontchartrain, Louisiana. Transactions of the American Fisheries Society 139: 1723-1732.

Voss, R., Hinrichsen, H.H., Quaas, M.F., Schmidt, J.O., and Tahvonen, O. 2011. Temperature change and Baltic sprat: from observations to ecological–economic modelling. ICES Journal of Marine Science 68(6): 1244–1256. doi:10.1093/icesjms/fsr063.

Ward, P., and Myers, R. 2005. Shifts in open-ocean fish communities coinciding with the commencement of commercial fishing. Ecology 86: 835–847.

WCED (World Commission on Environmental Development). 1987. Our common future. Oxford University Press. New York.

Whitney, F.A., Freeland, H.J., and Robert, M. 2007. Persistently declining oxygen levels in the interior waters of the eastern Subarctic Pacific. Progress in Oceanography, 75: 179–199.

Worm, B., Lotze, H.K., and Myers, R.A. 2003. Predator diversity hotspots in the blue ocean. Proceedings of the National Academy of Sciences of the United States of America 100 (17): 9884–9888.

Zar, J.H. 1999. Biostatistical analysis, 4th Ed. Prentice Hall, Upper Saddle River, New Jersey. 929 pp.

CHAPTER 2. SPATIO-TEMPORAL PATTERNS OF THE OCEANIC CONDITIONS AND NEARSHORE MARINE COMMUNITY IN THE MID-ATLANTIC BIGHT (NEW JERSEY, USA)

2.1 Abstract

Oceanic environmental conditions influence, shape, and control the geographical range, spatial distribution, abundance, and size composition of marine fauna. Water temperature, salinity, dissolved oxygen, depth, and sediment type influence select fish life-history characteristics and community structure. Marine communities are vulnerable to major changes in environmental conditions, but the response and severity depends on various biological or ecological factors, such as resilience to stress or adaptation. Researchers around the world have predicted and documented numerous alterations in fish communities caused by ongoing significant physicochemical shifts associated with natural and potentially unnatural sources, but published studies describing the baseline conditions are lacking for most regions around the world, including the coastal waters off New Jersey. Given the need to understand these processes, a multifaceted investigation was undertaken to describe, evaluate, and compare the oceanic conditions and nearshore marine fauna community off New Jersey during 1988 through 2015. Findings showed the oceanic conditions varied over time and space. Mean surface water temperature increased significantly about 0.6°C per decade, mean salinity decreased about 1.3 psu per decade, and dissolved oxygen increased 0.09 mg/l per decade. A total of 18.7 million individuals representing 216 species were collected during the 28-year period. The estimated abundance of marine fauna decreased and the estimated biomass increased over time. The estimated abundance of marine fauna decreased from northern to southern areas, and from western to eastern areas. Subtropic-adapted species were the most abundant and coldwater-adapted were the least abundant water temperature preference group. The estimated abundance of coldwater-adapted species declined, warmwater-adapted species slightly increased, and subtropic-adapted species decreased with time, which suggest the environmental conditions are influencing and thereby shifting the marine community.

2.2 Introduction

Oceanic environmental conditions influence, shape, and control the geographical range, spatial distribution, abundance, and size composition of marine fauna. Fish life-history and community structure characteristics are shaped by water temperature, salinity, dissolved oxygen (DO), depth, and sediment type (Horne et al. 1989). For many open-water coastal species (non-estuary dependent), water temperature is usually the most important environmental factor influencing fish distribution, especially along the zoogeographic transition zone (e.g., Hoese and Moore, 1977; Wood et al. 2009; Howell and Auster, 2012). Based on a species' physiology, marine fauna have an optimal temperature range that limits their behavior, distribution, abundance, and other life-history characteristics. In most regions, water temperature varies with seasonal warming and cooling, which influences resident and migratory fish behavior, abundance, and distribution (Parker and Dixon, 1998). Natural and human-induced changes in the environment conditions can also shift the food web and affect a variety of ecological community metrics, such as diversity, size-composition, estimated biomass, and estimated abundance. In Narragansett Bay, Rhode Island, an increased abundance of warmwater fish was positively correlated with an increase in water temperature (Wood et al., 2009), even though Cape Hatteras, North Carolina was classically considered the northern boundary for warm-temperate fauna (Briggs, 1974). In Long Island Sound (New York), a phase shift in the community structure was also associated with warming water temperatures (Howell and Auster, 2012).

In addition to influencing a fish species' distribution (e.g., Hare et al. 2012), mean size, and life span (Mucoid et al. 2011), fluctuations in annual and seasonal physicochemical conditions can also affect the regional fish community structure (Reash and Pigg, 1990; Vinebrooke et al. 2004; Krishnakumar and Bhat, 2008; Azzurro et al. 2011; Aschan et al. 2013), and the associated food-chain length (e.g., Bondavalli et al. 2006). According to Ficke et al. (2007), a major change in the environment conditions causes fish to either "adapt, migrate, or perish". Marine communities are vulnerable to changes in environmental conditions, which have direct and indirect impacts. The response and severity depends on various biological or ecological factors, such as resilience to stress or adaptation thresholds (Daw et al. 2009; Warfe et al. 2013).

Researchers worldwide have predicted and documented numerous changes in fish communities caused by ongoing physicochemical shifts associated with natural and potentially unnatural sources (Rijnsdorp et al. 2009; Crozier and Hutchings, 2014; Pinksky and Mantua, 2014), but fundamental baseline information describing the marine community are lacking for most regions around the world (Johnson, 2012), including the coastal nearshore waters off New Jersey. New Jersey is located within the middle or Mid-Atlantic Bight (MAB) in the western North Atlantic Ocean. The MAB is defined as the offshore waters (i.e., beach to continental shelf) between Cape Cod, Massachusetts and Cape Hatteras, North Carolina (Steimle and Zetlin, 2000). The MAB is among the most important oceanic regions in the United States because it provides habitat and supports many ecologically and economically valuable fisheries resources. In 2016, commercial fishing landings (all species combined) and associated value in the MAB (Delaware, New Jersey, New York, and Pennsylvania) were 76,346 mt and $255.2 million, respectively (NMFS, 2018). Commercial fishing landings in New Jersey (60,017 mt; $191.1 million) represented 78.6 and 74.9 percent of the total landings and value in the MAB during 2016. The economic value of commercial fishing landings in New Jersey over the past 10 years ranged between $132.9 and $220.4 million with a mean of $164.8 million (NMFS, 2018). In 2016, commercial fisheries in New Jersey ranked ninth in value and tenth in landings in the United States (NMFS, 2018).

In spite of the economic value of the state’s fisheries resources, only partial information about the nearshore marine community and environmental conditions is available. As such, the primary goal of this study was to elucidate trends in the environmental conditions and the nearshore marine fauna community off New Jersey over the past 28 years. The main purpose was to provide resource managers and others with a description of the marine fauna and an evaluation of the biological patterns and environmental conditions in the nearshore waters off New Jersey so they can make knowledgeable management decisions about marine resources, predict future changes in populations, and potential reconstruct the past baseline conditions given ongoing disturbance (e.g., commercial fishing and climate change). The secondary purpose was to establish a "relative" baseline of the environmental conditions and marine community during 1988 through 2015. Establishing the "relative" baseline conditions will help resource managers and researchers evaluate potential future impacts to the biological community associated with natural and anthropogenic disturbances in the nearshore waters off New Jersey. Overall, the main objective was to describe, evaluate, and compare the environmental conditions and nearshore marine community off New Jersey over the past 28 years (1988−2015).

The overall theoretical expectation was that the environmental conditions have changed significantly off New Jersey over the past 28 years. Several complex alternative hypotheses based on published literature flow from this basic expectation of ongoing climate variability. For instance, average surface and bottom water temperatures should increase (NOAA, 2016), and average salinity (Barange et al. 2009) and DO should decrease (Matear and Hirst, 2003). The estimated abundance of coldwater-adapted species (e.g., windowpane, winter flounder, and bluefish) should decrease and the estimated abundance of warmwater and subtropic-adapted species (e.g., scup, weakfish, northern kingfish, and summer flounder) should increase with time

(Wood et al., 2009; Hare et al., 2012; Howell and Auster 2012). Specific null and alternative hypotheses consisted of the following:

H_o1: The oceanic conditions are constant with time.

H_{1A}: The average surface and bottom water temperature changed significantly with time (1988−2015).

H_{1B}: The average surface and bottom salinity level changed significantly with time (1988−2015).

H_{1C}: The average surface and bottom dissolved oxygen level changed significantly with time (1988−2015).

H_o2: Species composition/assemblage are constant with space and time.

H_{2A}: The species composition or marine fauna assemblage changed significantly from western to eastern and from southern to northern zones with time (1988−2015).

H_{2B}: The warmwater and subtropic-adapted marine fauna assemblages changed significantly from eastern to western and from northern to southern zones with time (1988−2015).

H_{2C}: The coldwater-adapted marine fauna assemblage changed significantly from western to eastern and from southern to northern zones with time (1988−2015).

H_o3: Estimated abundances are constant with space and time.

H_{3A}: The estimated abundance of marine fauna changed significantly from western to eastern and from southern to northern zones with time (1988−2015).

H_{3B}: The estimated abundance of warmwater and subtropic-adapted assemblage species changed significantly from eastern to western and from northern to southern zones with time (1988−2015).

H_{3C}: The estimated abundance of coldwater-adapted assemblage changed significantly from western to eastern and from southern to northern zones with time (1988−2015).

H_o4: Estimated biomasses are constant with space and time.

H_{4A}: The estimated biomass of marine fauna changed significantly from western to eastern and from southern to northern zones with time (1988−2015).

H_{4B}: The estimated biomass of warmwater and subtropic-adapted assemblages changed significantly from eastern to western and from northern to southern zones with time (1988−2015).

H_{4C}: The estimated biomass of coldwater-adapted assemblage changed significantly from western to eastern and from southern to northern zones with time (1988−2015).

2.3 Material and Methods

2.3.1 Study Area

The New Jersey coastline is about 210 km long and consists of many beaches and islands (8−29 km) that serve as a barrier between the Atlantic Ocean and the nearshore waters (Byrnes et al. 2004). The nearshore waters are connected to the Atlantic Ocean by 12 inlets located between Cape May Inlet to the South and Shark River Inlet to the North (Byrnes et al. 2004). The study area encompassed approximately 4,662 km^2 (1,800 miles^2) (**Figure 2.3.1-1**), which consisted of the nearshore waters from Sandy Hook, Ambrose Channel, New Jersey (i.e., the entrance to New York Harbor) to Cape Henlopen Channel, New Jersey (i.e., the entrance to Delaware Bay). The study area included the nearshore waters between 9.1 (30 ft.) and 27.4 m (90 ft.) (ASMFC, 1994).

2.3.2 Experimental Survey Design

To evaluate spatial marine community dynamics, the survey area (**Figure 2.3.1-1**) was divided into 15 sampling strata (12−26) by depth and geographical location (latitude and longitude). To be consistent with established federal marine resource field-sampling programs, the designers of the New Jersey Ocean Stock Assessment (OSA) survey incorporated the same latitudinal boundaries defined by the National Marine Fisheries Service (NMFS), Northeast Fishery Science Center (NEFSC), Northeast Atlantic Groundfish Survey Program; exceptions were those strata at the northern and southern ends of the New Jersey coastline where NMFS extended its survey into New York and Delaware waters (ASMFC, 1994). The boundaries were also truncated in the northern and southern strata to include only the waters adjacent to the New Jersey coastline and the ocean waters off Delaware Bay. The longitudinal boundaries consisted of the 9.1 (30 ft.), 18.3 (60 ft.), and 27.4 m (90 ft.) isobaths. The bottom contours were somewhat irregular, so the stratum boundaries were smoothed using GIS techniques (ASMFC, 1994).

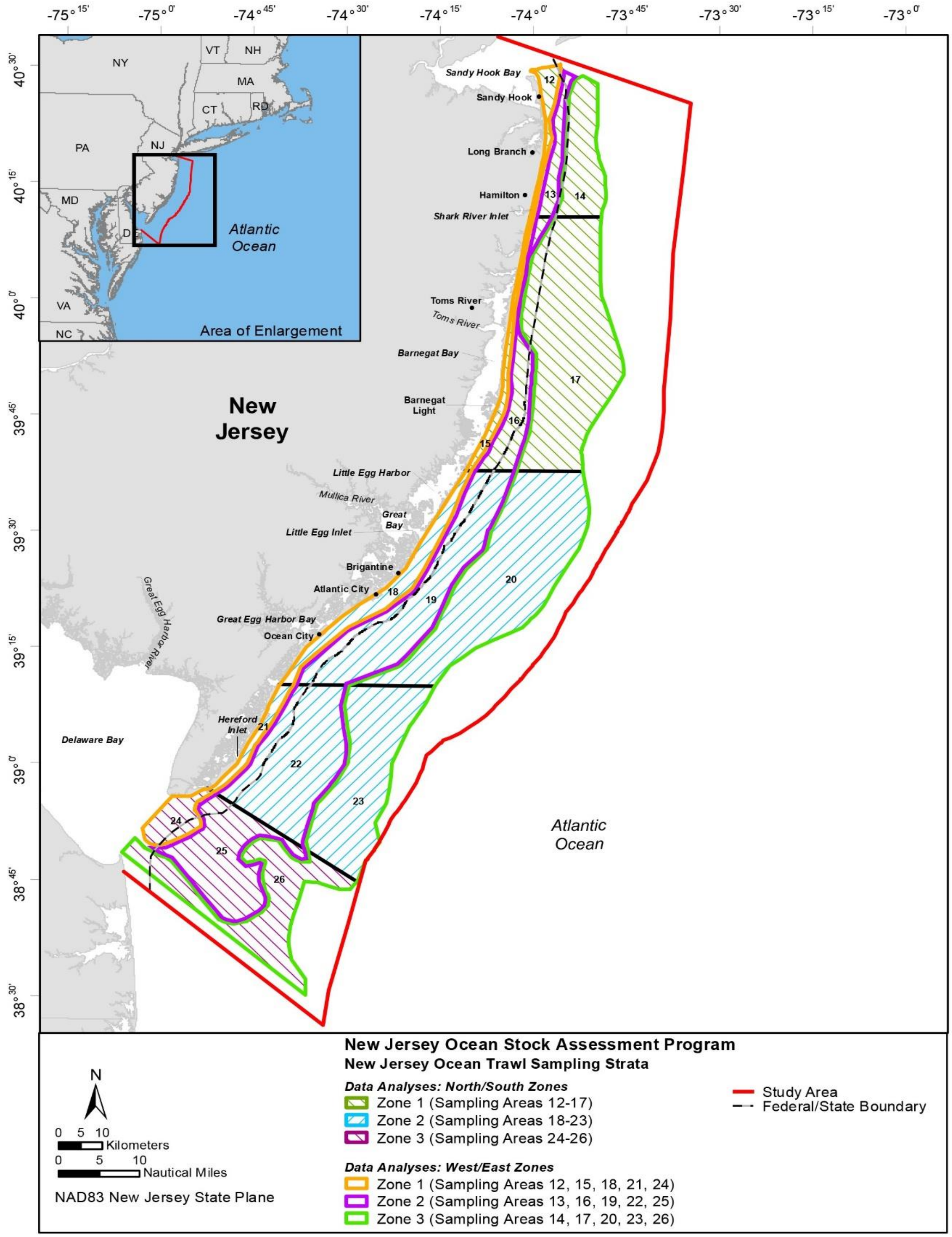

Figure 2.3.1-1. Study Area. New Jersey Ocean Stock Assessment Program.

To reduce potential sampling bias, each sampling area was divided into smaller blocks. Mid-shore blocks (9.1−18.3 m) and offshore (18.3−27.4 m) blocks were 2.0 minute longitude by 2.5 minute latitude, whereas nearshore (5.5−9.1 m) blocks were 1.0 minute longitude by 1.0 minute latitude. Nearshore block dimensions were smaller because the strata were narrower and encompassed a smaller area than the mid and offshore strata; thus, the smaller block size permitted a greater number of potential sampling sites than would be possible with larger dimensions. It should be noted the blocks truncated by stratum boundaries encompassed a smaller area (> 50%) than the whole blocks (Byrne, 1994; 2008).

2.3.3 Experimental Field Sampling Approach

Field sampling was conducted bimonthly (every two months: February, April, June, August, October, and December) from 1988 to 1989. From 1990 to date, the December and February surveys were replaced by a single winter survey in January, followed by surveys in April, June, August, and October (ASMFC, 1994). The annual sampling survey effort during 1988 through 1990 varied slightly because of the budget (high charter vessel costs), but it generally consisted of two hauls per stratum. The sampling effort averaged 39 hauls (i.e., two samples from each strata plus one additional haul in each of the nine larger strata) per survey. The average number of stations sampled each year was around 182.

2.3.4 Station Selection

Constrained randomization was used to select unique sampling stations for each survey trip. Sampling stations (survey site location) were randomly selected by the NJDEP program leader during 1988 through 1991, but this method was replaced in 1992 by a computer generated random number selection program. Because stratum shapes were elongate and the sampling effort was limited, a station selection procedure was used to reduce any spatial distribution sampling bias. The station selection procedure consisted of limiting the first station to only the top half of the block numbers and the second station to the bottom half; however, if a third station was selected then these limitations were not imposed in the procedure process. For instance, haul one would be selected from blocks 1 to 25, haul two from blocks 26 to 50, and haul three from blocks 1 to 50 for a stratum with 50 blocks. For each station, three additional alternate sites were also pre-selected using the same procedures described above to account for any fixed fishing gear (e.g., traps or nets), bottom obstructions, or other impediments that prevented sampling at the initial station (Byrne, 1994; 2008).

2.3.5 Field Sampling Gear

Field sampling was conducted with a three-in-one otter trawl (**Figure 2.3.5-2**) that was constructed of polyethylene twine with forward netting (i.e., wings and belly). The otter trawl was constructed with 12 cm stretch mesh and the rear netting was constructed with 8 cm stretch mesh. The otter trawl cod-end was constructed with 7.6 cm stretch mesh and it was lined with a 6.4 mm bar mesh liner (Byrne, 1994; 2008). The head rope was 25 m long and the footrope was 30.5 m. The trawl bridle was 36.6 m long, and the top of it was stabilized and constructed with a 1.27 cm wire. The bottom leg was constructed with a 1.91 cm wire rope, which was covered with 6.03 cm rubber cookies. The groundline length between the bridle and otter trawl doors was 18.3 m long. The estimated average wing spread was 13 m. The trawl doors were constructed of pressure treated marine grade wood with steel shoes; the trawl doors were 2.44 m x 1.27 m and weighed approximately 453.5 kg (1,000 lbs).

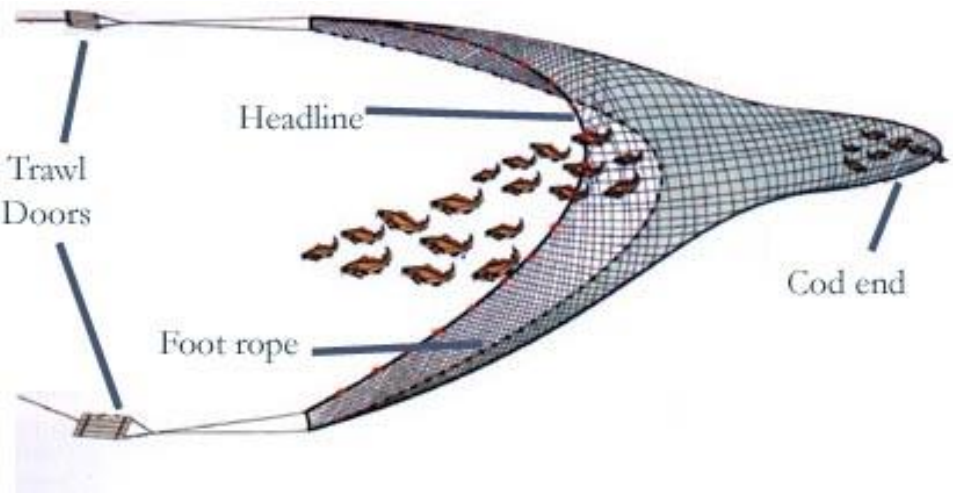

Figure 2.3.5-2. Basic Bottom Trawl Drawing (NOAA, 2018)

2.3.6 Field Sampling Procedures

All tows were conducted during the hours between sunrise and sunset. The trawl tow duration was standardized at 20 minutes (i.e., the time the net was deployed to when the winch brakes were set to begin haul back) and the surface ground vessel speed was maintained between 4.7 and 5.6 kilometers per hour (2.5 and 3.0 knots; 2.9 and 3.5 mph). The swept area (a) was estimated with the following equation: a = D*hr*X2, D =V*t; where V is the velocity of the trawl over the ground when trawling, hr is the length of the head-rope, and t is the time spent trawling. X2 is that fraction of the head-rope length, hr, which is equal to the width of the path swept by the trawl, the "wing spread", hr*X2. Based on vessel speed, one 20 minute tow generally covered a distance of 1.85 km. Given the trawl dimensions and distance towed, the total swept area was around 24,050 m^2 (**Figure 2.6.3-3**).

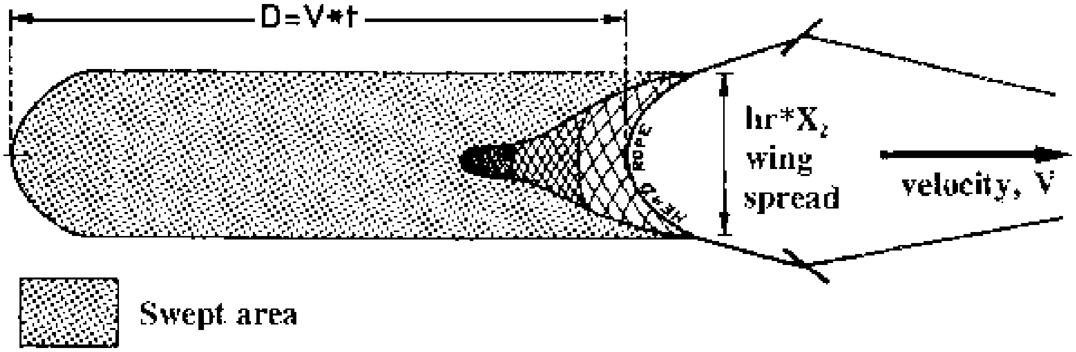

Figure 2.6.3-3. Basic drawing showing how to calculate the area swept by a trawl net (FAO, 1988).

Tow durations were sometimes shortened because of hangs, bottom obstructions, or other issues, but it was considered an adequate sample if the net was not damaged and the tow duration was more than 15 minutes. Tows less than 15 minutes were repeated, unless there were extenuating circumstances (e.g., bottom topography and obstructions). To standardize shorter tow durations, extrapolation was applied under the assumption there was a direct relationship between catch and tow duration; this approach was seldom applied. The cardinal direction of the tow was determined by the oceanic conditions (wind, waves, and current) at the time of deployment; tows were generally made in the direction of the waves, wind, and current. A 91.5 m wire was used to maintain a tow depth ratio of approximately 3:1. The wire length maintained the distance between the vessel and the net when towing in shallow water (Byrne, 1994; 2008). Survey replicates (tow) were considered independent of one another given the random station selection process, and the distance between sampling sites and time between tows; each tow was considered a random sample of the population.

2.3.7 Data Collection Protocol

At each sampling station the surface and bottom environmental conditions (water temperature (degrees Celsius [°C], salinity (parts per thousand [psu], and dissolved oxygen (milligrams per liter [mg/l]) were measured with a CTD and recorded before deploying the trawl. After the 20 minute tow was completed, the trawl was retrieved and the catch (fish and macroinvertebrates) was rough sorted into plastic buckets. Afterwards, the entire catch was identified to species, enumerated, and the length (fork and/or total, as appropriate) was measured to the nearest cm for fish (20 individuals randomly selected); the disk width (cm) was measured for skates and rays. Senior staff were responsible for species identification. All species were identified to the lowest taxa. The total weight was taken using either a hanging or floor scale. The individual weights of every species were determined by weighing individual baskets (total weight) of every species collected and dividing by the total count of individuals in the basket. Various other measurements were recorded depending on the macroinvertebrate species. For example, the carapace width (mm) was measured for crabs, the carapace length (mm) for lobsters and mantle length (mm) for squids. Because some catches were too large to sort in the field, a representative thoroughly mixed sub-sample was randomly selected and weighed. After the sub-sample was sorted, species composition was extrapolated to determine the total catch (Byrne, 1994; 2008).

Following the approach by Howell and Auster (2012), marine species were classified a priori as coldwater-adapted species (primarily distributed in cold temperate regions), warmwater-adapted species (primarily distributed in warm temperate regions), or subtropic-adapted species (primarily distributed in subtropical and tropical regions). Classification followed Froese and Pauly (2018) and published life-history literature (e.g., Murdy et al. 1997; Collette and Klein-MacPhee 2002; Able and Fahay 2010) describing a species' distribution relative to the MAB, water temperature tolerance (minimum and maximum), preferred water temperature range, and preferred spawning water temperature. In general, the mean preferred water temperature was used to select the best water temperature preference group for each species. Species preferring water temperature <15°C were generally classified as coldwater-adapted, while those preferring water temperatures 15−29°C were classified as warmwater-adapted. Species preferring temperatures >30°C were classified as subtropic-adapted.

2.3.8 Data Treatment/Processing

Sample Independence

It was assumed the environmental, oceanic, and biological measurements (samples) were representative of the population within the study area given that the experimental design used randomization to reduce sampling bias. Statistical power was considered high given the balanced sampling approach and the large number of observations over the duration of the study. It was also assumed the environmental and biological data were independent observations (i.e., the measurement of one observation did not affect the value of other observations) given that the experimental design considered time and space (i.e., spatial autocorrelation). The coastal waters off New Jersey are a dynamic oceanographic and biological system; conditions can vary significantly within a short distance or time period. Moreover, it was assumed the number of marine fauna in one year was independent of the number of marine fauna in the previous year given various biological factors, such as the relative short life-span (< 1 year) of many of the species collected in the study area, high mortality, the low annual reproductive success, and low annual recruitment from one year to the next. To minimize any potential spatial non-independence, data were pooled among stations within each individual sampling area.

Before initiating statistical hypothesis tests, environmental and biological data were transformed (e.g., logarithmic, square root, fourth root, or arcsine) to meet normality assumptions, and down-weight the statistical effects (i.e., reduce skewness) of abundant taxa, while allowing less common taxa to contribute to sample discernment (Thorne et al. 1999; Korsman, 2013). Normal probability plots were examined, and Kolmogorov-Smirnov and Bartlett tests were used to assess normality and homoscedacity (Zar, 1999). Outlier observations were investigated to determine whether the outlier occurred by chance; all outliers were retained for these analyses.

To evaluate the nearshore marine community and oceanic conditions, 28 years (1988−2015) of fishery-independent monitoring data (environmental and biological) were compiled, sorted (time [year and month] and space [area and zone]), and summarized. After pooling the data by stations sampled within each area, the marine community (catch characteristics [total number, estimated abundance, and estimated biomass]) was evaluated using two approaches: a single dataset (pooling all the data) and segregating the data in various time-series datasets. The data was segregated into six 5-year time-series periods to help discern patterns and test for potential differences among time and space. This approach was driven from the perspective that most available time-series data for nearshore/offshore fisheries are only two to five years in duration. Data were pooled by stations and segregated by individual sampling areas (12−26) and geographical north/south zones defined as the following: 1 (sampling areas 12−17), 2 (sampling areas 18−23), and 3 (sampling areas 24−26). Data was also segregated by west/east zones defined as the following: 1 (sampling areas 12, 15, 18, 21, and 24), 2 (sampling areas 13, 16, 19, 22, and 25), and 3 (sampling areas 14, 17, 20, 23, and 26). It should be noted the amount of area for each designated geographical zone was a different size in terms of km^2.

The statistical significance level was defined as $P < 0.05$. In the presence of significance at the 95 percent confidence level, *post-hoc* multiple pairwise comparison tests were used to differentiate the specific differences among the population means. Data were evaluated using various software, including Microsoft Access®, Microsoft Excel®, and Statgraphics Centurion XVI®.

2.3.9 Statistical Analyses

2.3.9.1 Physicochemical Conditions

A two-fold approach was taken to analyzing variation over time. Interannual variation of numerous factors was examined by treating observations from individual stations and months as independent, generating a sensitive Analysis of Variance (ANOVA) test of the null hypothesis of no variation due to the high degrees of freedom involved. To test specifically for consistent trends over the entire time series, annual averages were regressed against time (year), generating a conservative test with low degrees of freedom and a weaker independence assumption of no serial correlation between annual averages. The physicochemical conditions were evaluated by univariate procedures to discern patterns over space and time. Descriptive statistics and graphical plots were generated for each individual defined sampling area (12−26; **Figure 2.3.1-1**). Student's *t*-tests were used to test the null hypothesis that the annual average surface and bottom oceanic conditions (water temperature, salinity, and dissolved oxygen [DO]) were equal among years (1988−2015). One-way ANOVAs were used to test the null hypothesis that annual and bimonthly oceanic conditions (water temperature, salinity, and DO) were equal among years and sampling areas. To characterize the physicochemical conditions within the study area (1988−2015), the annual mean surface and bottom water temperature, salinity, and DO readings were individually examined for spatial and interannual patterns using linear regression to categorize the trend as stable, increasing, or decreasing. The strength of the association was examined using the coefficient of determination (r^2). One-way ANOVAs were also used to test the null hypothesis that annual and bimonthly bottom oceanic conditions (water temperature, salinity, and DO) were equal among zones and depth boundaries. Regression was also used to evaluate the association between space (latitude and longitude) and time.

2.3.9.2 Marine Community

To evaluate the historical long-term conditions, the marine community (catch characteristics [total number, estimated abundance, and estimated biomass]) was examined using various univariate procedures. The total number marine fauna collected by individual taxa were tabulated, summarized, and plotted by time and space. Descriptive statistics, histograms, frequency distribution, and cumulative frequency polygon plots were generated to evaluate central tendency, dispersion, and variability. To evaluate seasonal (bimonthly) and annual variability in the estimated abundance (density [number of fauna collected per 100 m^2]), the total number of individuals collected by species were standardized, transformed into nominal catch per unit effort (CPUE) indices, and evaluated using several analytical approaches. For analyses and interpretation of the abundance indices, it was assumed there was a simple direct positive relationship between CPUE and abundance. To estimate abundance as a function of effort, CPUE was calculated by taking the product of the area swept, which was computed from the trawl net width at the wingtips and the distance towed; the trawl wing or horizontal spread was determined using hydroacoustic sensors. Abundance (N_t number per 100 m^2) was estimated using the CPUE, the trawl dimensions, and the vessel speed in the following equation:

$$N_t = \frac{C}{AL} \text{ x } 100$$

where C is catch of species (i) at time $_t$, A is the mouth area of the trawl (24,076 m^2), and L is the distance towed (~1.85 km), which was the product of the vessel speed (92.5 m s^{-1}) and the trawl time (20 min). To estimate biomass (g 100 m^{-3}), W (catch in weight) was substituted for C in each tow.

The annual estimated abundance and biomass index (mean number/weight per tow) were computed, compared, and regressed over the 28-year time series to examine change in estimated abundance and biomass over time and space. To examine annual variability in species composition, ANOVA tests were conducted to test the null hypothesis that the total number, estimated abundance and biomass were equal over time and space. Regression was also used to examine the association between catch characteristics and time and space using the fitted slope to indicate increasing or decreasing trends.

Biological data (abundance and biomass) were segregated by individual sampling area (12−26) and geographical zones. North/south zones were defined as the following: 1 [sampling areas 12−17], 2 [sampling areas 18−23], and 3 [sampling areas 24−26]. West/east zones were defined as the following: 1 [sampling areas 12, 15, 18, 21, and 24], 2 [sampling areas 13, 16, 19, 22, and 25], and 3 [sampling areas 14, 17, 20, 23, and 26]. Regression was used to evaluate the association between space (latitude and longitude) and time. One-way ANOVAs were used to test the null hypothesis that annual and bimonthly catch characteristics (total number, estimated abundance and biomass) were equal among zone and depth boundary. Spatial and temporal patterns were evaluated using regression to categorize the slope of the fitted trend.

Descriptive statistics were generated to examine the number of warmwater, coldwater, and subtropic-adapted species. ANOVAs were used to test the null hypothesis that the catch characteristics (total number, estimated abundance and biomass) by temperature preference category were equal over time and space. Descriptive statistics were also generated to evaluate the ratio of warmwater to coldwater-adapted species. Spatial and temporal patterns were evaluated using regression to categorize the slope of the fitted trend.

Individual descriptive statistics of the catch, and temperature preference category were calculated and plotted by time-series. To examine annual variability in the marine fauna, separate ANOVA tests were conducted to test the null hypothesis that the catch characteristics ([total number, estimated abundance, and biomass]) were equal among time-series, month, and area. Two-way ANOVA tests were conducted to test the null hypothesis that the catch characteristics ([total number, estimated abundance, and biomass]) by individual temperature preference category were equal among time and space. Regression was used to examine the potential association between catch characteristics and time-series, month, and area. Spatial and temporal patterns were evaluated using regression to categorize the slope of the fitted trend. General Linear Models (GLM) were calculated for each time-series (overall and temperature preference category) to examine the pattern of interactions and associations of time and space on the catch characteristics.

2.4 Results

2.4.1 Survey Effort

New Jersey DEP personnel completed a total of 5,106 tows off the coast of New Jersey within 15 strata (areas: 12−26) during 1988 through 2015 (28-years). The total number of tows completed in each year ranged from 68 in 1988 to 193 tows in 1989. The mean annual number of stations or tows completed was 182, and the mean number of tows per sampling area was 12. The total effort (number of tows per bi-monthly event) ranged from 26 in December to 1,026 tows in June with a mean of 425.4 tows per bi-monthly event. The tow duration ranged from 7.7 to 35 minutes per tow with a mean of 20.03 minutes per tow. The overall tow length distance sampled was 5,169.5 km and the mean was 183.8 km per year or 1.01 km per tow (± 0.18 SD). The total swept area ranged from 9,750 to 27,950 m^2 per tow with a mean of 13,163 m^2 per tow; the total swept area was statistically non-significant among years (F [27, 108,221] = 1.72, $P = 0.1885$; **Figure 2.4.1-4**). In general, around 36 tows/month were conducted over a five month annual sampling schedule (bimonthly schedule). The total number of blocks (stations) sampled per area over the 28-year period ranged from 280 in area 14 to 384 in area 15, and the average was 340 blocks sampled per area or 12 blocks per area per year (**Figure 2.4.1-5**). Marginally more blocks were sampled in the northern areas (12, 13, and 14) than in the southern areas (21 and 24).

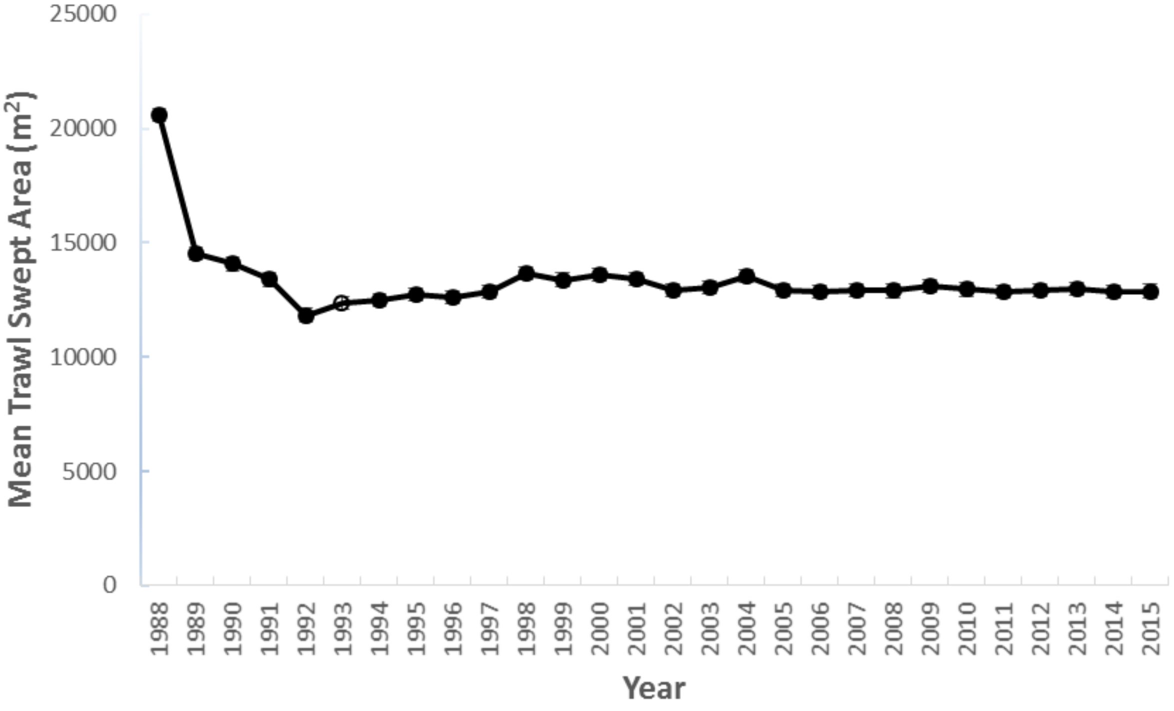

Figure 2.4.1-4. Annual mean trawl swept area in the study area (1988−2015).

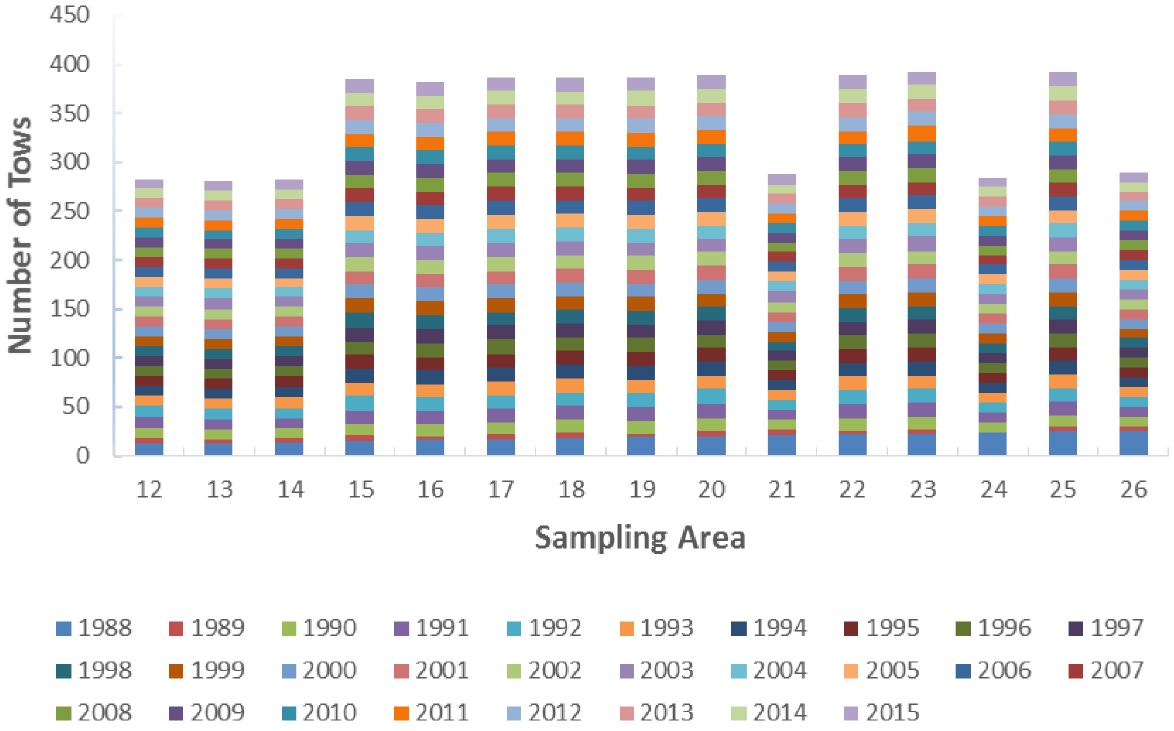

Figure 2.4.1-5. Annual number of tows per area within the study area (1988−2015).

2.4.2 Bottom Depth

The maximum bottom depth off the coast of New Jersey within 15 strata (areas: 12−26) ranged from 2.5 to 39 m, and the mean was 16.9 m (± 0.09 m). The mean maximum depth varied by area (i.e., distance from shore) with the depth gradually increasing from nearshore to offshore. The nearshore areas were the shallowest and the offshore areas were the deepest. The areas (12, 15, 18, 21, and 24) along the shore ranged in depth from 9.2 in area 18 to 11.05 m in area 24, and the mean was 9.74 m. The mid-shore areas (13, 16, 19, 22, and 25) ranged in depth from 15.63 m in area 22 to 17.73 m in area 13, and the mean was 16.47 m. The offshore areas (14, 17, 20, 23, and 26) ranged in depth from 23.31 m in area 14 to 24.34 m in area 26, and the mean was 23.89 m.

2.4.3 Physicochemical Conditions

2.4.3.1 Water Temperature

For this and other response variables, a two-fold approach was taken to analyzing variation over time. Interannual variation of all kinds was examined by treating observations from individual stations and months as independent, generating a sensitive ANOVA test of the null hypothesis of no variation due to the high degrees of freedom involved. To test specifically for consistent trends over the entire time series, annual averages were regressed against time (year), generating a conservative test with low degrees of freedom and a weaker independence assumption of no serial correlation between annual averages.

The overall mean annual surface water temperature off the coast of New Jersey within the 15 strata (areas: 12−26) during 1988 through 2015 ranged from 13.39°C in 2003 to 16.12°C in 2002 with a mean of 14.81°C (± 6.6°C). A paired *t*-test showed the mean surface water temperature was significantly warmer (2.3°C) than the bottom water temperature (t (5096) = 3.72; $P < 0.05$). The mean surface water temperature varied significantly among years (ANOVA, **Table 2.4.3-1**), and there was a weak positive association between the surface water temperature and time (**Figure 2.4.3.1-6**). The mean (0.06°C per year) and maximum (0.02°C per year) surface water temperature increased about 0.6°C and 0.2°C per decade, respectively. Averaging over years, the mean monthly surface water temperature increased from January (4.46°C) to August (22.74°C), and decreased from September (22.24°C) to December (5.65°C). The surface water temperature varied significantly among months (F [11, 5084] = 5942.1, $P < 0.05$).

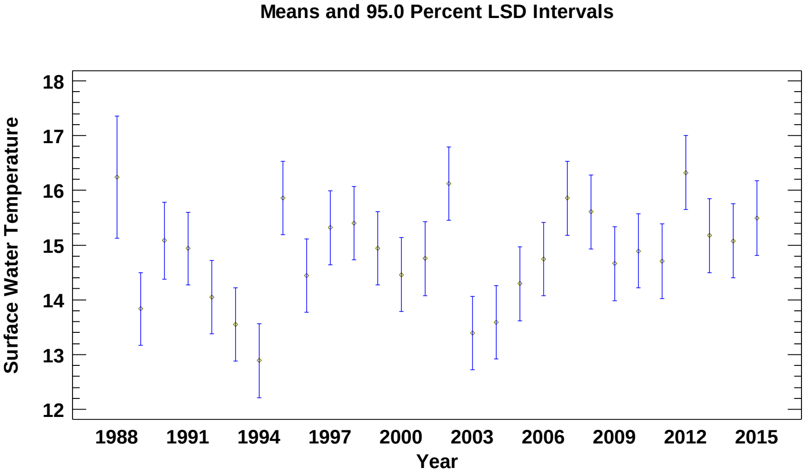

Figure 2.4.3.1-6. The mean annual surface water temperature and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 measurements per year, 12 at each sampling stratum.

The mean surface water temperature ranged from 13.8°C in sampling area 12 to 15.52°C in sampling area 23. In general, the mean surface water temperature was colder in the northern than the southern sampling areas (**Table 2.4.3-2**); the 15 sampling areas were numbered in numerical order from north to south (12−26). However surface water temperature in sampling areas 21 and 24 did not follow this pattern; the surface water temperature in these areas was slightly cooler. The mean water temperature in sampling area 21 was cooler than the water temperature in sampling area 24. A linear model described the strong positive (significant) association between the mean annual surface water temperature and the sampling area (**Table 2.4.3-1**).

The mean bottom water temperature off the coast of New Jersey within the 15 strata (areas: 12−26) during 1988 through 2015 ranged from 10.44°C in 1994 to 14.57°C in 2002 with a mean of 12.53°C (± 5.6°C). The bottom water temperature also varied significantly with time, and there was a weak positive association between bottom water temperature and year (**Table 2.4.3-1, Figure 2.4.3.1-7**). Averaging over years, the bottom water temperature varied significantly among months (F [11, 5084] = 1637.8, $P < 0.05$). The coldest (4.96°C) bottom water temperature was in January and the warmest (20.51°C) was in September.

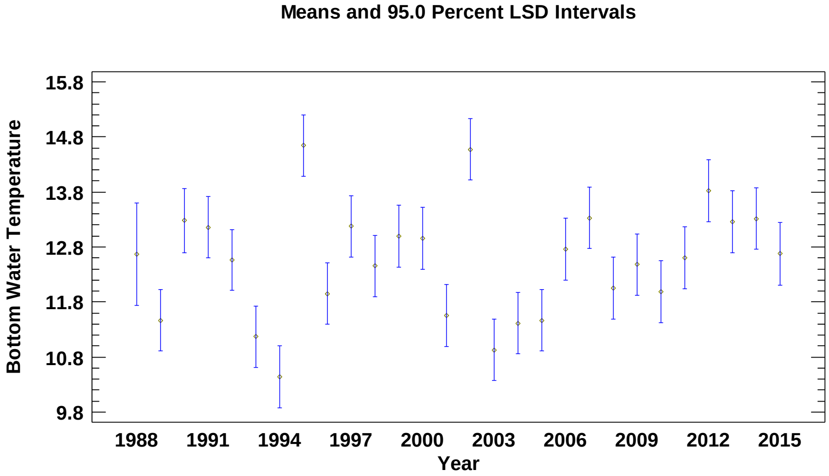

Figure 2.4.3.1-7. The mean annual bottom water temperature and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 measurements per year, 12 at each sampling stratum.

The mean bottom water temperature ranged from 10.67°C in sampling area 14 to 14.25°C in sampling area 24. The mean bottom water temperature varied significantly among sampling areas (**Table 2.4.3-3**), and there was a weak positive association between bottom water temperature and the sampling area (**Table 2.4.3-3**). Segregating the sampling areas into zones (*See Methods*), the mean bottom water temperature was significantly colder in the northern zones than the southern zones (F [2, 5093] = 23.08, $P < 0.05$); a *post-hoc* test showed the mean water temperature varied significantly between zones 1 and 2 (-0.89), 1 and 3 (-1.36), and 2 and 3 (-0.47). The warmest bottom water temperature was found in the sampling areas closest to shore, and the coldest bottom water temperature was detected in areas furthest from shore (F [2, 4828] =

42.11, $P < 0.05$); a *post-hoc* test showed the mean water temperature varied significantly between eastern and western zones 1 and 2 (0.52), 1 and 3 (1.74), and 2 and 3 (1.22).

2.4.3.2 Salinity

The mean annual surface salinity off the coast of New Jersey within 15 strata (areas: 12−26) during 1988 through 2015 ranged from 29.94 in 1996 to 32.11 psu in 1998 with a mean of 30.75 psu (± 2.06 psu). Overall, the mean salinity decreased about 0.13 psu per year or 1.3 psu per decade. The surface salinity varied significantly among years, and there was a weak negative (non-significant) association between the surface salinity and time (**Table 2.4.3-1, Figure 2.4.2-8**). Averaging over years, the mean monthly surface salinity ranged from 30.25 in April to 31.48 psu in November with a mean of 30.73 psu (± 2.07 psu). The surface salinity varied significantly among months (F [11, 5084] = 31.46, $P < 0.05$).

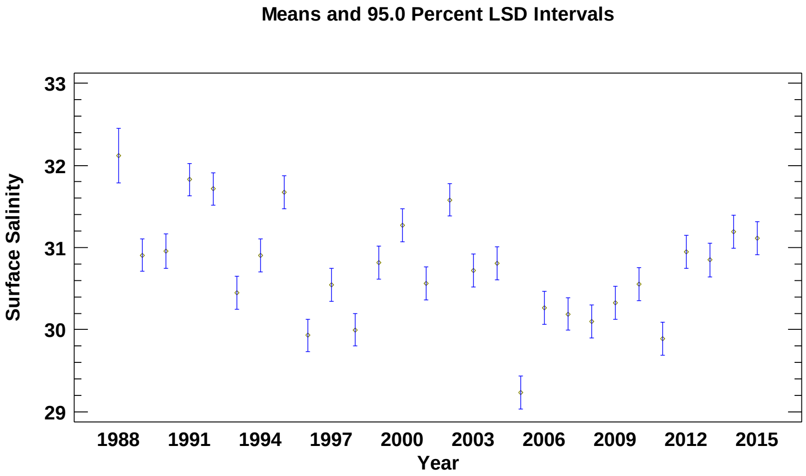

Figure 2.4.2-8. The mean annual surface salinity and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 measurements per year, 12 at each sampling stratum.

The mean surface salinity ranged from 28.92 in sampling area 14 to 31.45 psu in sampling area 26 with a mean of 30.74 psu (± 2.07 psu). The surface salinity varied significantly among sampling areas (**Table 2.4.3-1**), and there was a strong positive (significant) association between the surface salinity and sampling area (**Table 2.4.3-1**). The surface salinity was generally lower in the northern sampling areas than the southern sampling areas (Table **2.4.3-2)**. The surface salinity ranged from 28.13 psu in sampling area 12 to 31.49 psu in sampling area 26. The lowest surface salinity levels were found in the areas closest to shore, and the highest surface salinity levels were detected in areas furthest from shore.

A paired *t*-test showed the mean annual bottom salinity level was higher than the mean annual surface salinity (t (5095) = -34.25; $P < 0.05$). The lowest (30.52 psu) bottom salinity was in 2005 and the highest (32.87 psu) was in 1988 with a mean of 31.66 psu (± 1.4 psu). The bottom salinity varied significantly with time (F [27, 5069] = 50.12, $P < 0.05$), and there was a weak negative (significant) association between the surface salinity and time (**Table 2.4.3-1, Figure 2.4.2-9**). The bottom salinity ranged from 31.09 in December to 31.94 psu in November. Averaging over years, the bottom salinity also varied significantly among months (F [11, 5085] = 5.13, $P < 0.05$).

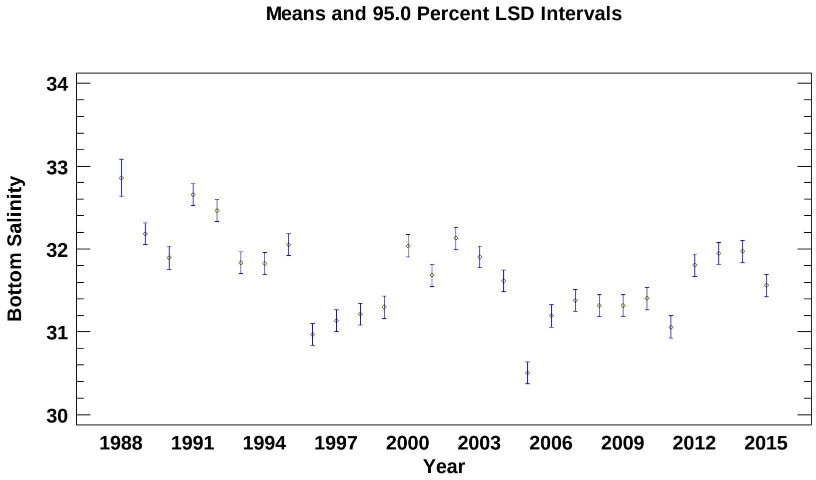

Figure 2.4.2-9. The mean annual bottom salinity and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 measurements per year, 12 at each sampling stratum.

The mean bottom salinity ranged from 30.33 in sampling area 12 to 32.32 in sampling area 23 with a mean of 31.66 psu (± 1.4 psu). The bottom salinity varied significantly among sampling areas (**Table 2.4.3-3**), and there was a weak negative association between the bottom salinity and the sampling area (**Table 2.4.3-3**). Segregating the sampling areas into zones (*See Methods*), the mean bottom salinity varied significantly among northern and southern zones (F [2, 5094] = 14.31, $P < 0.05$); a *post-hoc* test showed mean bottom salinity varied significantly between zones 1 and 2 (-0.18), and 2 and 3 (0.15). The mean bottom salinity level increased from northern to middle sampling areas, and then decreased in the southern sampling areas. The mean bottom salinity varied significantly among eastern and western zones (F [2, 4829] = 373.5, $P < 0.05$); a *post-hoc* test showed mean bottom salinity varied significantly between zones 1 and 2 (-0.54), 1 and 3 (-1.07), and 2 and 3 (-0.52). Mean bottom salinity increased from eastern to western zones.

2.4.3.3 Dissolved Oxygen

The mean surface DO off the coast of New Jersey within 15 strata (areas: 12−26) during 1988 through 2015 ranged from 7.9 in 1995 to 8.98 in 1998 mg/L with a mean of 8.54 mg/L (± 1.52 mg/L), and there was a weak positive association between the surface DO and time (**Table 2.4.3-1, Figure 2.4.3-10**). Overall, the mean DO increased about 0.009 mg/L per year or 0.09 mg/L per decade. Averaging over years, the mean monthly surface DO ranged from 7.17 in September to 10.27 mg/L in December. The surface DO varied significantly among months (*F* [11, 5080] = 608.75, *P* < 0.05).

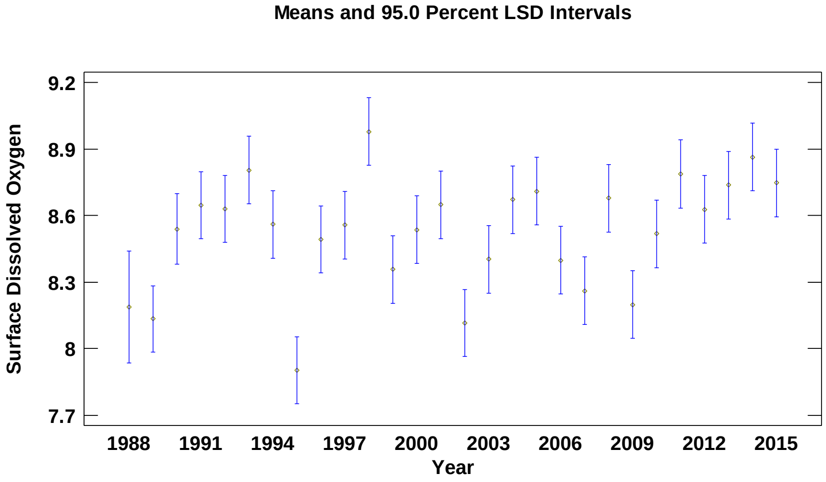

Figure 2.4.3-10. The mean annual surface dissolved oxygen level and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 measurements per year, 12 at each sampling stratum.

The mean surface DO ranged from 8.20 in sampling area 24 to 9.06 mg/L in sampling area 14. The surface DO varied significantly among sampling areas (**Table 2.4.3-3**), and there was a strong negative association between the surface DO and the sampling area (**Table 2.4.3-3**). In general, the surface DO decreased from northern to southern areas, but no pattern was evident for the areas closest and furthest from shore (**Table 2.3.3-2**).

A paired *t*-test showed the annual bottom DO levels were significantly lower (*t* (5091) = 132.17; $P < 0.05$) than the annual surface DO levels suggesting a strong water column stratification. The mean bottom DO off the coast of New Jersey within 15 strata (sampling areas: 12−26) during 1988 through 2015 ranged from 6.64 in 1988 to 8.35 mg/L in 1993 mg/L with a mean of 7.58 mg/L (± 1.84 mg/L), and there was a weak positive association between the bottom DO and time (**Table 2.4.3-1, Figure 2.4.3-11**). The mean monthly bottom DO ranged from 5.55 in August to 9.87 mg/L in January. Averaging over years, the bottom DO varied significantly among months (*F* [11, 5081] = 1121.85, $P < 0.05$).

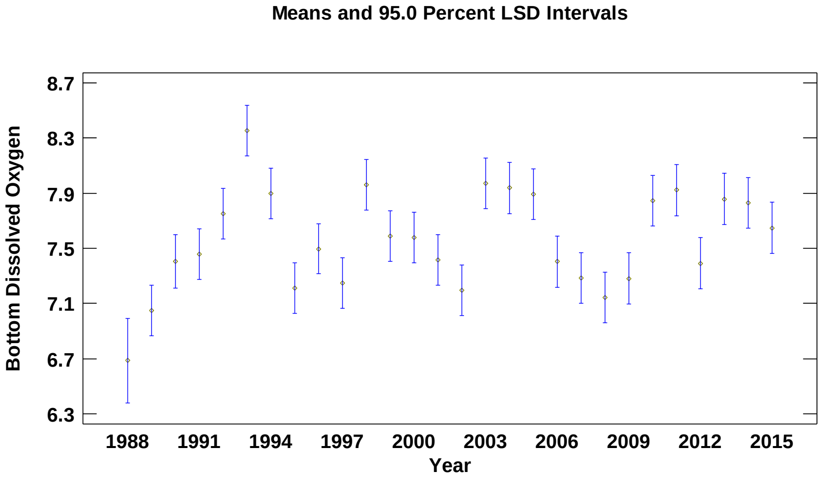

Figure 2.4.3-11. The mean annual bottom dissolved oxygen level and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 measurements per year, 12 at each sampling stratum.

The mean bottom DO ranged from 7.09 in sampling area 16 to 8.13 mg/L in sampling area 24. The surface DO varied significantly among areas (**Table 2.4.3-3**), and there was a strong positive association between the bottom DO and sampling area (**Table 2.4.3-3**). Segregating the sampling areas into zones (*See Methods*), the mean bottom DO varied significantly among northern and southern zones (F [2, 5090] = 54.78, $P < 0.05$); a *post-hoc* test showed mean bottom DO varied significantly between zones 1 and 2 (-0.42), 1 and 3 (-0.69), and 2 and 3 (-0.27). The bottom DO generally increased from northern to southern sampling areas. The mean bottom DO also varied significantly among western and eastern zones (F [2, 4825] = 2.77, $P < 0.05$); a *post-hoc* test showed mean bottom DO varied significantly between zones 1 and 3 (0.15). The mean DO generally decreased from nearshore to offshore sampling areas.

Table 2.4.3-1. The annual physicochemical conditions in the study area (1988–2015).

Environmental Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Regression Model**	**Regression Equation for Time Trend**	**F-test**	**r^2**
Surface Water Temperature	ANOVA	F [26, 5068] = 3.13, $P < 0.05$)	Linear	Surface Temperature = -37.0457 + 0.0259257*Year	F [1, 26] = 1.77, P = 0.1945	6.4%
Bottom Water Temperature	ANOVA	F [26, 5068] = 6.35, $P = < 0.05$	Linear	Bottom Temperature = -22.9444 + 0.0177299*Year	F [1, 26] = 0.54, P = 0.4678	2.0%
Surface Salinity	ANOVA	F [26, 5068] = 18.97, $P < 0.05$	Linear	Surface Salinity = 90.1532 - 0.0296713*Year	F [1, 26] = 4.20, P = 0.0505	13.9%
Bottom Salinity	ANOVA	F [26, 5069] = 26.97, $P < 0.05$	Linear	Bottom Salinity = 90.0402 - 0.0291552*Year	F [1, 26] = 6.87, P = 0.0144	20.9%
Surface Dissolved Oxygen	ANOVA	F [26, 5066] = 5.20, $P < 0.05$	Linear	Surface DO = -10.5943 + 0.0095525*Year	F [1, 26] = 2.74, P = 0.11	9.5%
Bottom Dissolved Oxygen	ANOVA	F [26, 5067] = 6.42, $P < 0.05$	Linear	Bottom DO = -15.1643 + 0.0113536*Year	F [1, 26] = 2.17, P = 0.1526	7.8%

Table 2.4.3-2. The mean annual physicochemical conditions within specific sampling area (1988−2015).

Sampling Area	**Surface Water Temperature**	**Bottom Water Temperature**	**Surface Salinity**	**Bottom Salinity**	**Surface DO**	**Bottom DO**
12	13.8067	12.6383	28.1299	30.3325	8.9739	7.46609
13	13.9227	11.3925	28.5114	31.6522	8.95303	7.09992
14	14.2203	10.6697	29.8132	32.0772	9.06167	7.20421
15	14.6226	13.2393	30.3907	31.1852	8.67297	7.4245
16	14.808	12.1511	30.5195	31.6326	8.80331	7.08529
17	15.0519	10.8999	31.0661	32.1597	8.64415	7.17957
18	14.8423	13.8549	30.9141	31.2409	8.27636	7.76678
19	15.0082	12.72	31.0381	31.7288	8.46681	7.51636
20	15.2472	11.5188	31.5304	32.2017	8.38812	7.55482
21	14.3163	13.5188	31.2977	31.4676	8.40565	7.97236
22	15.2959	13.4806	31.4918	31.7311	8.32289	7.82684
23	15.5203	11.9391	31.7639	32.3242	8.31835	7.69609
24	14.3215	14.2524	30.5373	30.7914	8.19962	8.1259
25	15.2639	13.5825	31.3253	31.7725	8.28575	7.97881
26	15.007	12.0479	31.4876	32.2082	8.40753	7.9244

Table 2.4.3-3. The annual spatial physicochemical conditions in the study area (1988−2015).

Environmental Parameter	Hypothesis Test for Interannual Variation	Test Results	Regression Model for Spatial Trend	Regression Equation	F-test	r^2
Surface Water Temperature	ANOVA	F [14, 5081] = 1.98, $P = 0.016$	Linear	Surface Water Temperature = 13.3292 + 0.0747982*Area	F [1, 13] = 13.95, $P = 0.0025$	51.8%
Bottom Water Temperature	ANOVA	F [14, 5081] = 11.48, $P < 0.05$	Linear	Bottom Water Temperature = 10.5857 + 0.102179*Area	F [1, 13] = 2.65, $P = 0.1276$	16.9%
Surface Salinity	ANOVA	F [14, 5081] = 94.31, $P < 0.05$	Linear	Surface Salinity = 27.0243 + 0.191061*Area	F [1, 13] = 47.99, $P < 0.05$	78.7%
Bottom Salinity	ANOVA	F [14, 5082] = 72.5, $P < 0.05$	Linear	Bottom Salinity = 30.8296 + 0.0423243*Area	F [1, 13] = 2.47, $P = 0.14$	15.9%
Surface Dissolved Oxygen	ANOVA	F [14, 5077] = 10.49, $P < 0.05$	Linear	Surface DO = 9.59736 - 0.0553696*Area	F [1, 13] = 61.62, $P < 0.05$	82.6%
Bottom Dissolved Oxygen	ANOVA	F [14, 5078] = 9.87, $P < 0.05$	Linear	Bottom DO = 6.382 + 0.0634807*Area	F [1, 13] = 29.38, $P = 0.0001$	69.3%

2.4.5 Marine Fauna Community

2.4.5.1 Annual and Spatial Dynamics

A total of 20,674,059 fish and invertebrates (1,338.3 metric tons) representing 248 species (*including unclassified species*) were collected off the coast of New Jersey within 15 sampling areas (12−26) during 1988 through 2015 (**Figure 2.4.5-1**); 32 marine fauna (n = 302,883 or 1.5%) were unclassified.

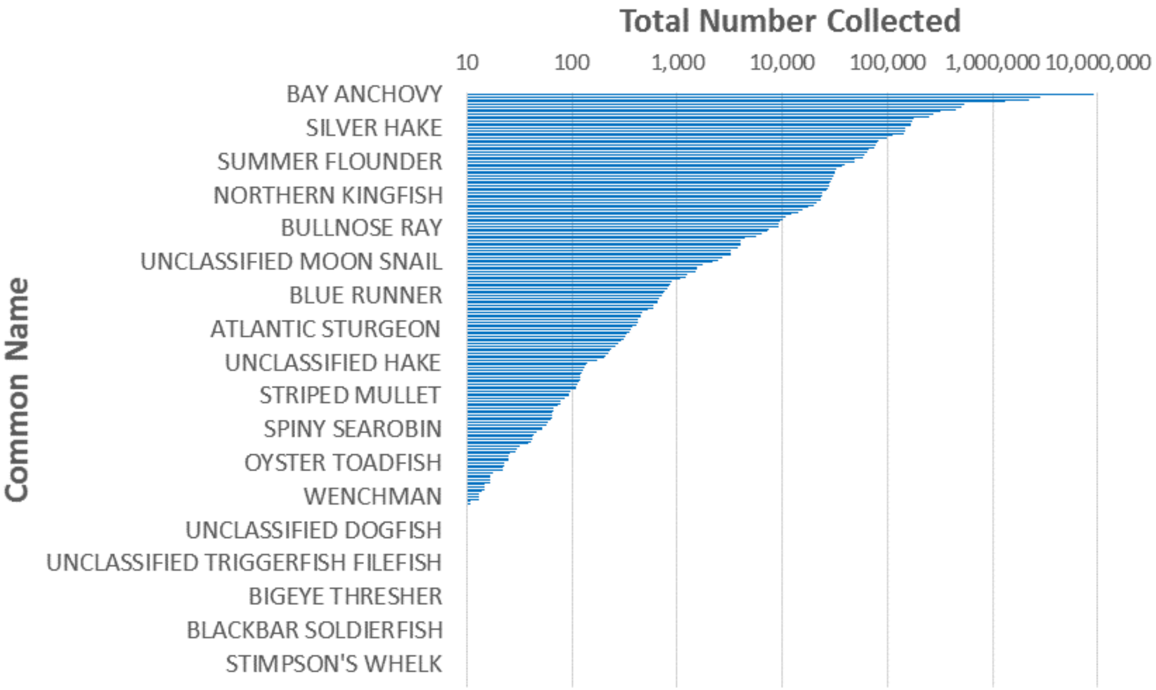

Figure 2.4.5-1. The total number of main marine fauna collected in the study area (1988−2015).

The cumulative number of marine fauna collected ranged from 378,437 individuals (1.83%) in 1998 to 1,209,740 individuals (5.85%) in 2002 with a mean of 738,358 (± 203,926.26 SD) individuals per year during 1988 through 2015 (**Figure 2.4.5-2**). The mean annual total number of individuals collected per species (*averaged over months/sites per year*) varied significantly with time, and there was a weak negative association between total catch and time (**Table 2.4.5-1**).

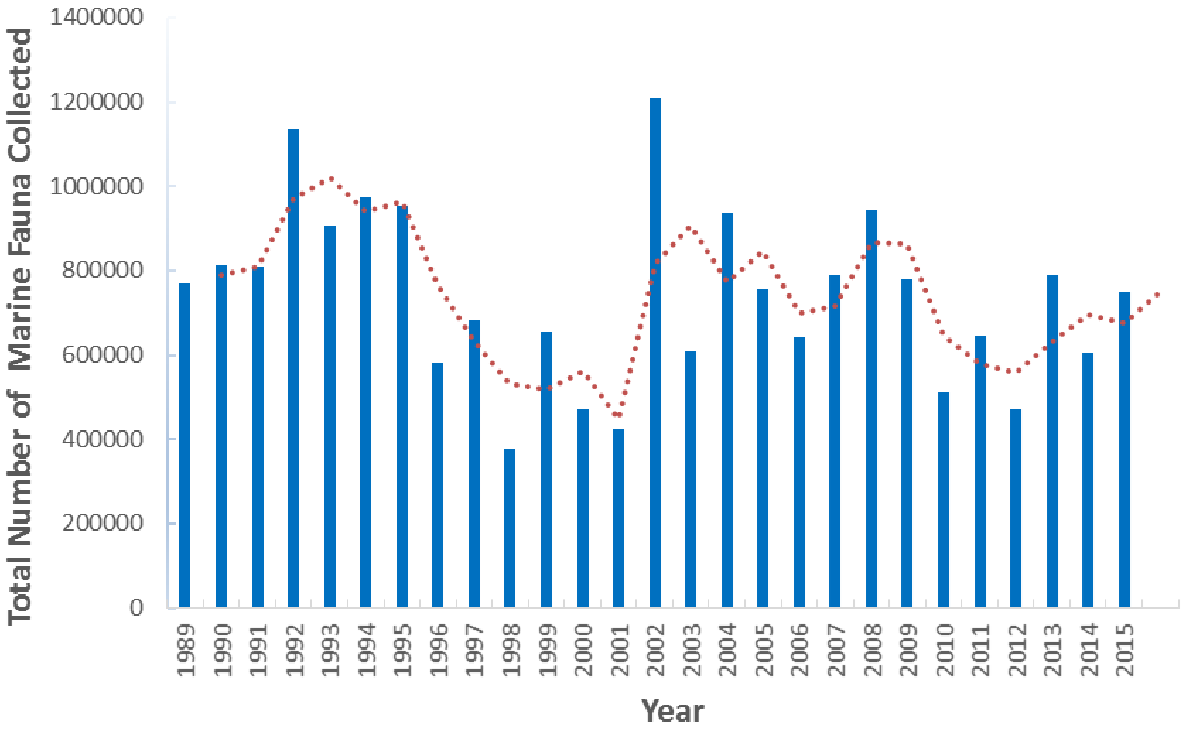

Figure 2.4.5-2. The annual total number of marine fauna collected in the study area (1988−2015). The red dotted line indicates the moving average.

The mean annual total weight of marine fauna (**Figure 2.4.5-4**), and the associated mean annual weight per species (*averaged over months/sites per year*) varied significantly over time, and there was a weak positive association between the mean annual total weight/ mean weight per species and time (**Table 2.4.5-1, Figure 2.4.5-5**).

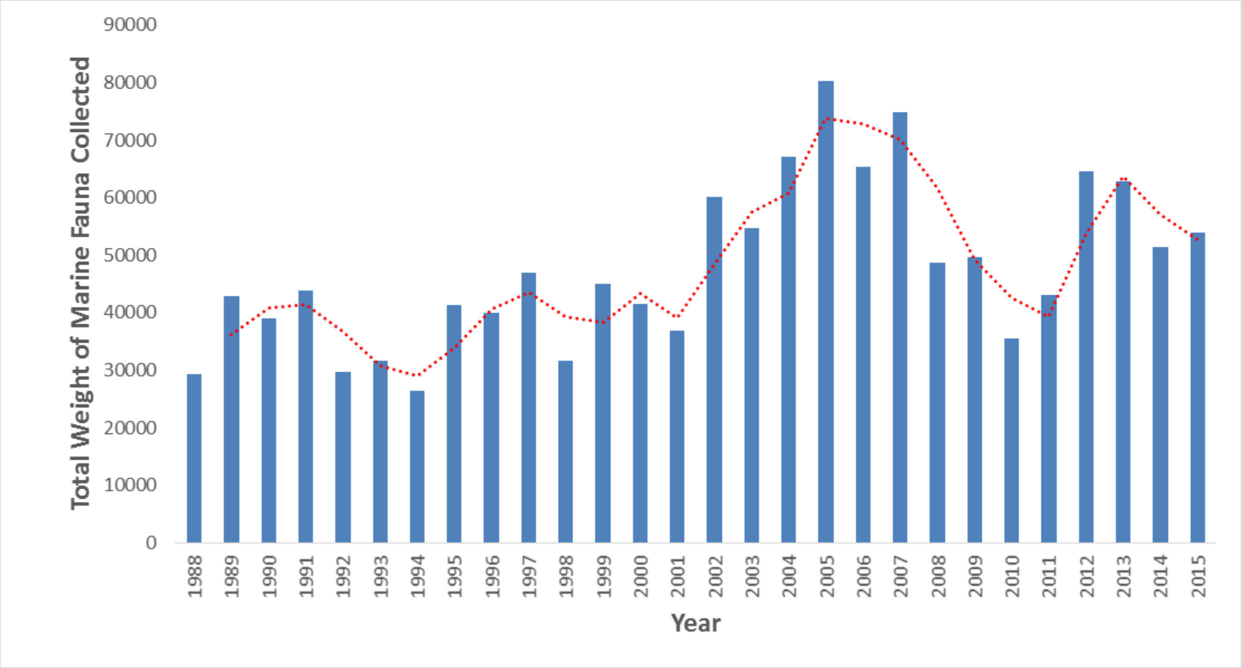

Figure 2.4.5-4. The annual total weight of marine fauna (kg) collected in the study area (1988−2015). The red dotted line indicates the moving average.

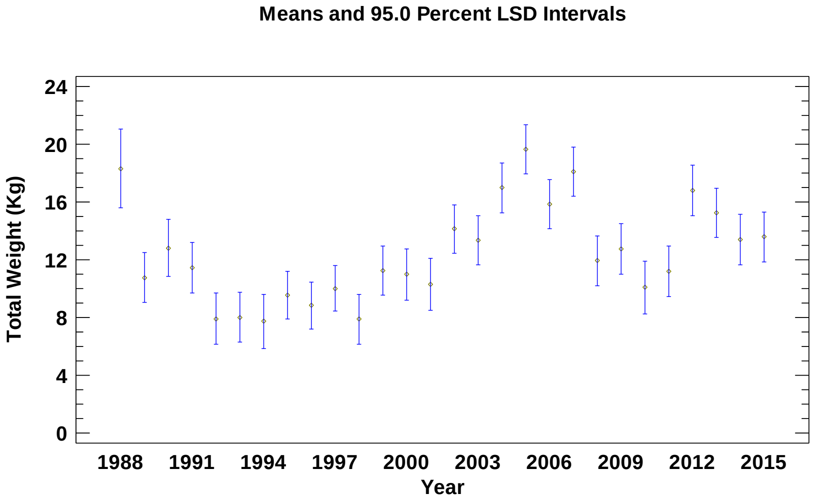

Figure 2.4.5-5. The mean annual total weight of individuals collected per species and associated 95% Fisher’s least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

The mean annual estimated abundance (*number of marine fauna per m^2*) ranged from 3.58 (blue crab [*Callinectes sapidus*], 1988) to 12.64 (butterfish [*Peprilus triacanthus*], 1992) marine fauna per m^2 with the mean of 0.01452 marine fauna per m^2. Pooling the data (**Table 2.4.5-1**), and by individual time-series (**Tables 2.8-3-8**), ANOVAs showed the mean annual estimated abundance (*averaged over months/sites per year*) varied significantly over time, and there was a weak negative association between the mean annual estimated abundance and time (**Figure 2.4.5-6**). The mean annual estimated biomass (*averaged over months/sites per year*) also varied significantly over time, and the weak positive association between the mean annual estimated biomass and time (**Table 2.4.5-1, Figure 2.4.5-7**).

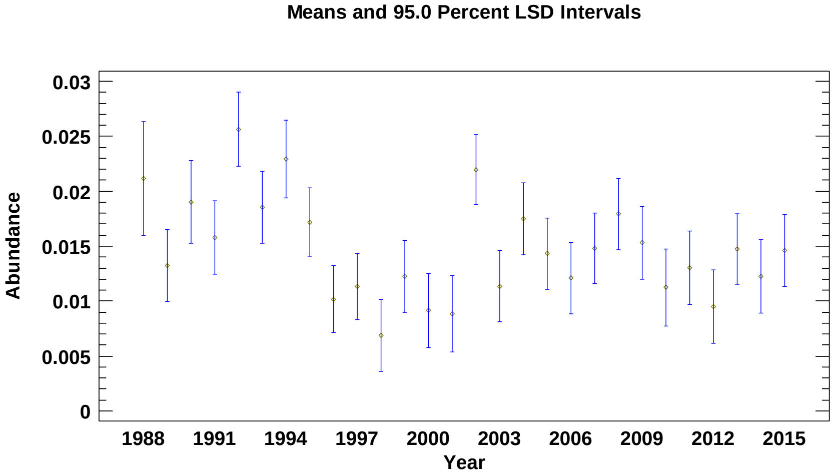

Figure 2.4.5-6. The mean annual estimated abundance (number of marine fauna/m^2) and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

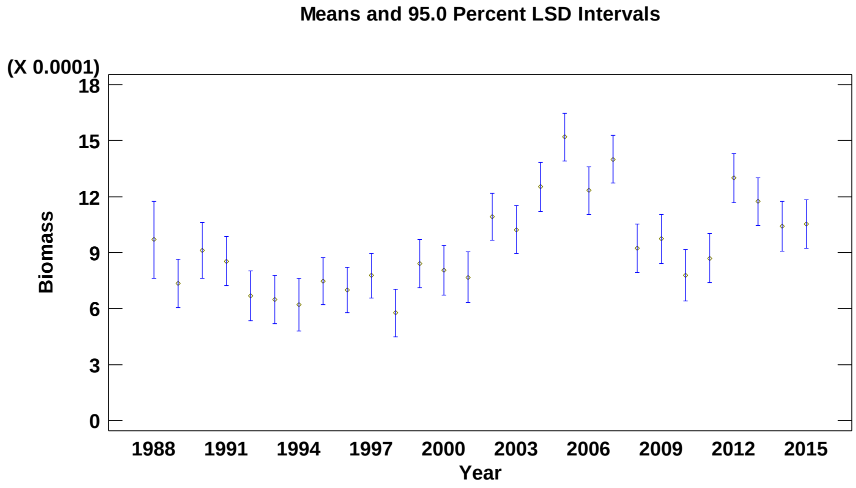

Figure 2.4.5-7. The mean annual estimated biomass (kg/m^2) and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

Of the 216 identified species collected in the study area, 14 species (6.5%) comprised 90.2 percent (*n* = 18.7 million) of the catch (**Figure 2.4.5-8**). Bay anchovy (*Anchoa mitchilli*) (*n* = 9.2 million or 44.6%), butterfish (*n* = 2.9 million or 13.9%), longfin squid (*Loligo pealei*) (*n* = 2.2 million or 10.8%), and scup (*Stenotomus chrysops*) (1.3 million or 6.4%) were the most (75.7%) abundant species collected in the study area during the 28-year period (**Figure 2.8-1** and **Figure 2.8-2** *See Appendix*).

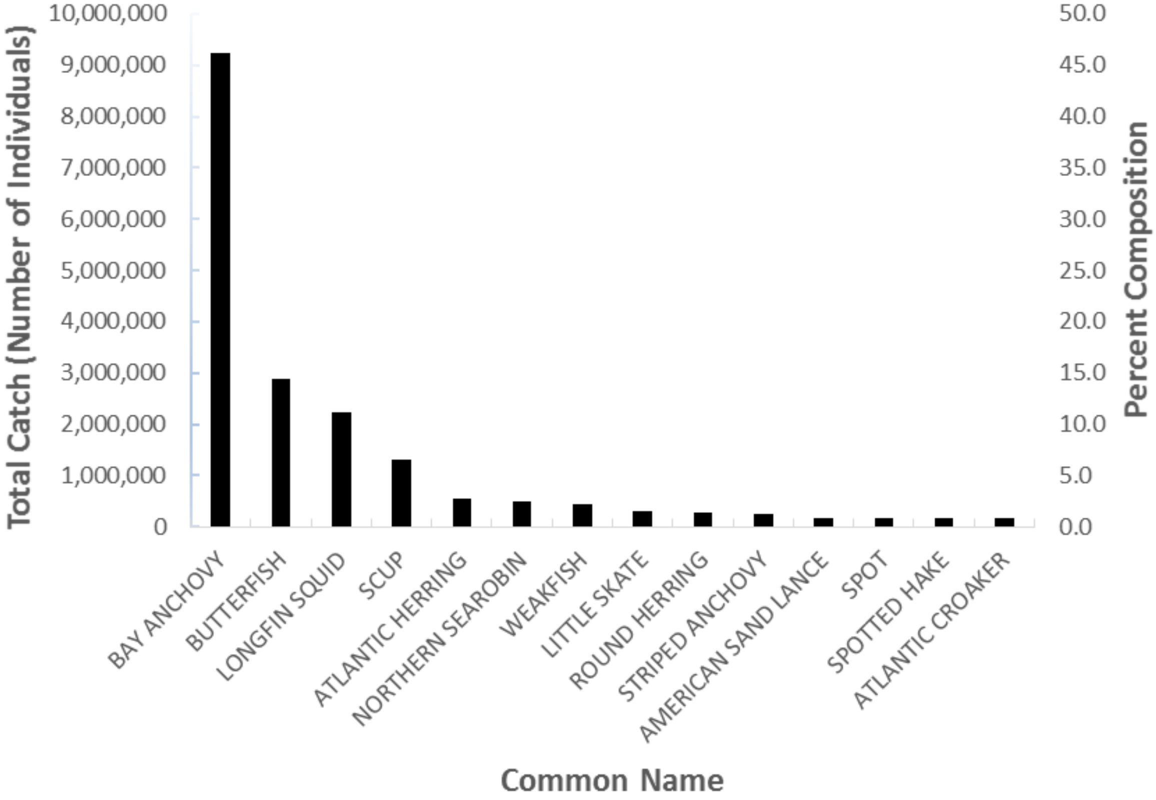

Figure 2.4.5-8. The most common species collected and their associated percent composition in the study area (1988−2015).

The annual total number of individuals collected per species ranged from 1 (uncommon species) to 759,674 (bay anchovy). The annual total number of individuals per species collected varied significantly ($H = 422.3$; $P < 0.05$) among bay anchovy, butterfish, longfin squid, and scup. The total number of bay anchovy ($H = 73.5$; $P < 0.05$), butterfish ($H = 73.5$; $P < 0.05$), longfin squid ($H = 92.2$; $P < 0.05$), and scup ($H = 147.8$; $P < 0.05$) varied significantly among years.

The cumulative number and type of marine fauna collected also varied significantly among seasons over the 28-year period, and there was a strong positive association between total catch and season (**Table 2.4.5-1, Figure 2.4.5-9**). The monthly total number of marine fauna increased from January to October. Overall, the cumulative total varied from 27,919 individuals in December to 9.7 million individuals in October.

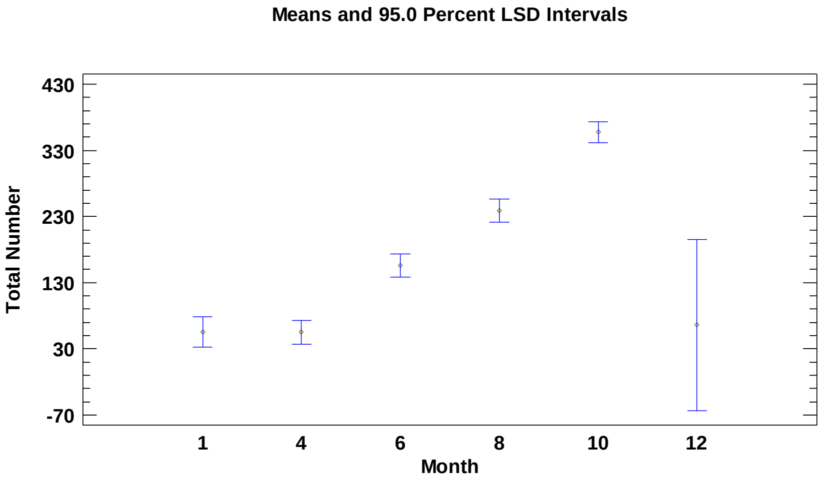

Figure 2.4.5-9. The mean monthly total number of individuals collected per species and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

The mean monthly estimated abundance varied significantly from 0.0195385 individuals per m^2 in December to 0.248619 individuals per m^2 in October (**Table 2.4.5-1**), and there was a strong positive association between the mean monthly estimated abundance and season (**Figure 2.4.5-10**). The most abundant species collected in December were blueback herring (*n* = 6,791), American sand lace (*n* = 5,843), and Atlantic herring (*n* = 2,597), while the most abundant in October were bay anchovy (*n* = 6,803,414), longfin squid (*n* = 821,013), and scup (*n* = 536,134).

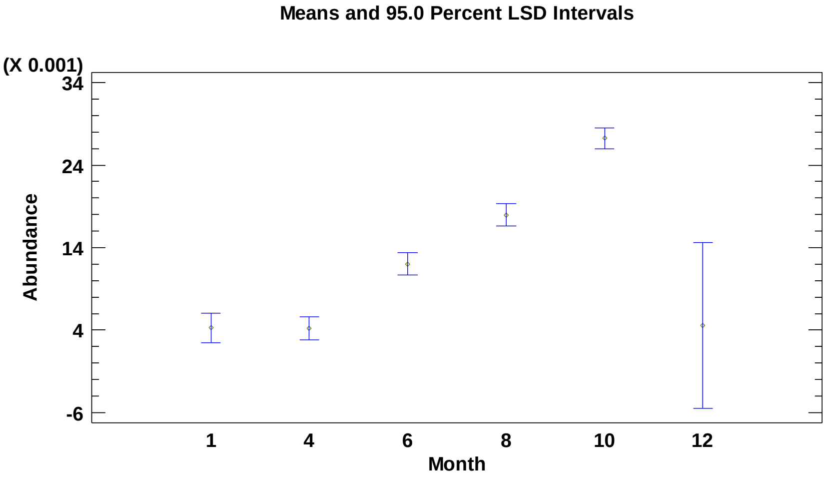

Figure 2.4.5-10. The mean monthly estimated abundance (#marine fauna/m^2) and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

The total number and type of marine fauna (i.e., catch) also varied significantly by sampling area. The total number collected ranged from 797,326 individuals in sampling area 24 to 2.4 million individuals in sampling area 18. Total catch generally increased from northern (12−17) to middle areas (18−20), and decreased from middle to southern areas (24−26). Also, total catch generally decreased from nearshore (areas 12, 15, 18, 21, and 24) to offshore (14, 147, 20, 23, and 26) sampling areas. However, this pattern was not evident in the most southern areas (24−26). The mean annual estimated abundance varied significantly from 0.99739 individuals per m^2 in sampling areas 20 and 25 to 0.997577 individuals per m^2 in area 15 (**Table 2.4.5-1, Figure 2.4.5-11**). The most abundant species collected in area 15 were bay anchovy (*n* = 1.7 million), butterfish (*n* = 236,956), and longfin squid (*n* = 182,491).

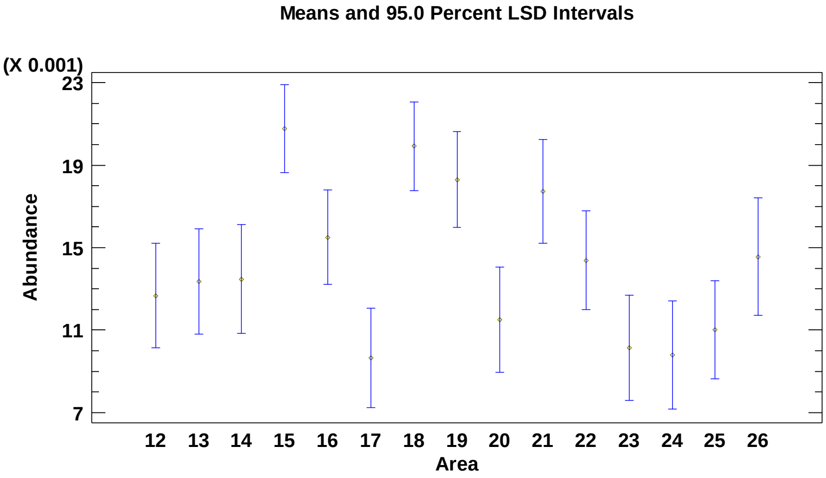

Figure 2.4.5-11. The mean estimated abundance (#marine fauna/m^2) by individual sampling area and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

Pooling the data, GLMs showed the best predictors of the total number, estimated abundance, and estimated biomass varied by individual 5-year time-series. Generally, the best predictor of the total catch was the month or sampling area, and both the month and sampling area were the best predictors of the estimated biomass (**Tables 2.8.17-23**). Examining the individual 5-year time-series data, GLMs showed the best predictor (significant) of the total number and estimated abundance was the sampling area (*F* [1, 99566] = 22.47; *P* < 0.05). The procedure also showed the year (*F* [1, 99566] = 98.8; *P* < 0.05) and sampling area (*F* [1, 99566] = 18.84; *P* < 0.05) were significant predictors of the estimated abundance (**Table 2.8.23**).

Table 2.4.5-1. Catch characteristics within the study area (1988−2015).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Regression Model**	**Regression Equation for Time Trend**	**F-test**	**r^2**
Total Number (Individuals)/Species	ANOVA	(F [27, 108248] = 3.98, $P < 0.05$)	Linear	Total Number = 5688.01 - 2.74596*Year	F [1, 26] = 13.54, $P = 0.0002$	22.5%
Total Weight/Species	ANOVA	(F [27, 108219] = 7.0, $P < 0.05$)	Linear	Total Weight = - 402.848 + 0.207413*Year	F [1, 26] = 46.03, $P < .05$	20.7%
Estimated Abundance	ANOVA	F [27, 108248] = 3.50, $P = < 0.05$	Linear	Estimated Abundance = 0.422835 - 0.000203893* Year	F [1, 26] = 3.96, $P = 0.0572$	13.2%
Estimated Biomass	ANOVA	F [27, 108248] = 6.85, $P = < 0.05$	Linear	Estimated Biomass = - 0.0358328 + 0.0000183695* Year	F [1, 26] = 63.45, $P < 0.05$	33%
Seasonal Total Number	ANOVA	F [5, 108248] = 80.99, $P < 0.05$	N/A	N/A	N/A	N/A
Seasonal Estimated Abundance	ANOVA	F [5, 108248] =77.21, $P < 0.05$	N/A	N/A	N/A	N/A
Spatial Estimated Abundance	ANOVA	F [14, 108248] = 4.68, $P < 0.05$	N/A	N/A	N/A	N/A

2.4.5.2 Segregated Spatial Dynamics

2.4.5.2.1 North/South Spatial Dynamics

Overall, pooling catch data (*across all stations*), the mean annual total number and estimated abundance of marine fauna varied significantly among north/south zones; north/south zones were designated as the following: north (sampling areas 12−17); mid (18−23), and south (24−26) (**Table 2.4.5-2 and Table 2.4.5-3**). The mean annual total number and estimated abundance decreased from northern to southern zones (**Figure 2.4.5-12**). *Post-hoc* analyses found the mean annual total number and the estimated abundance varied significantly between several north/south zones (1 and 2, 1 and 3, and 2 and 3.

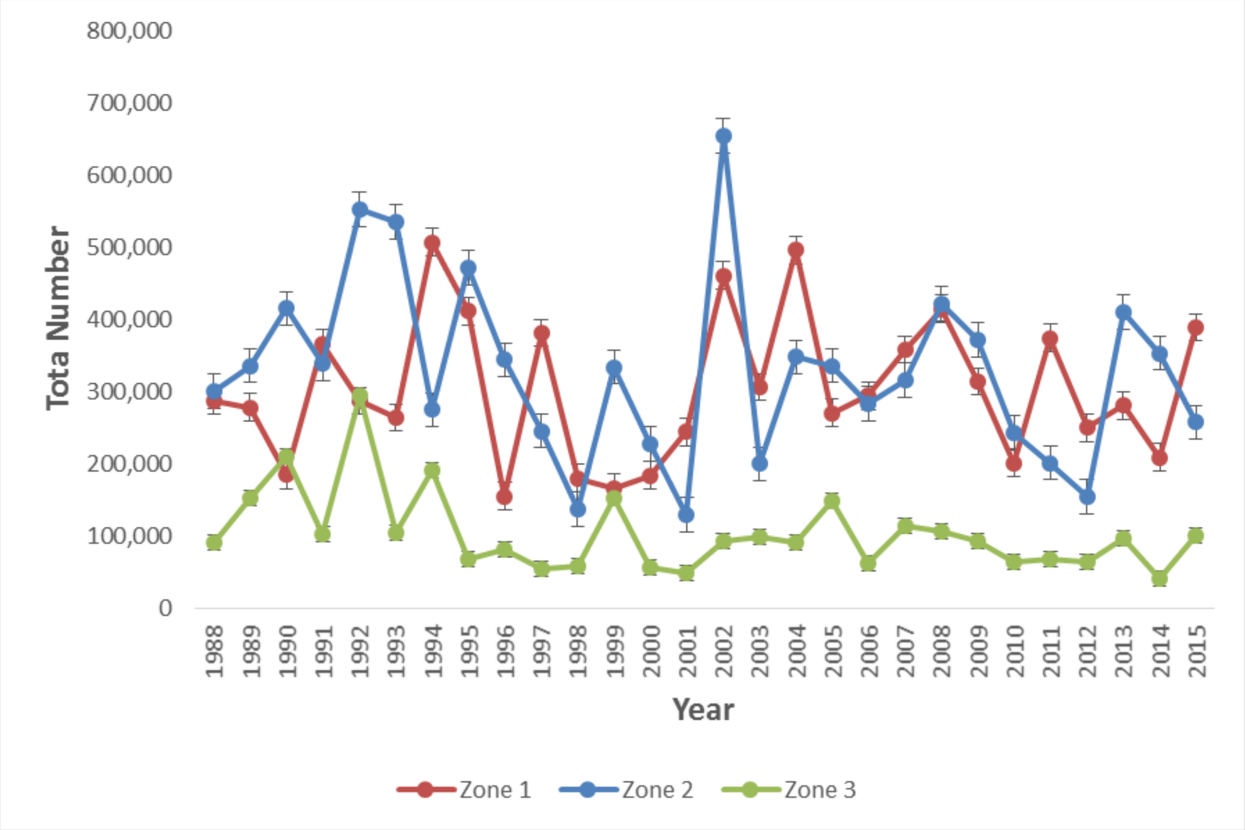

Figure 2.4.5-12. Annual total number of marine fauna collected per North/South zone (1988−2015). Zone 1 = Northern sampling areas (12−14); Zone 2 = Middle sampling areas (18−23); Zone 3 = Southern sampling areas (24−26).

Specifically, the mean annual total number and estimated abundance within individual north/south zones varied significantly among years (**Table 2.4.5-2**, **Figure 2.4.5-13, Figure 2.4.5-14, Figure 2.4.5-15**). The association between the mean annual estimated abundance and time in zones 1 and 2 were weak and negative (non-significant); however, the association was statistically significant (weak and negative) in zone 3.

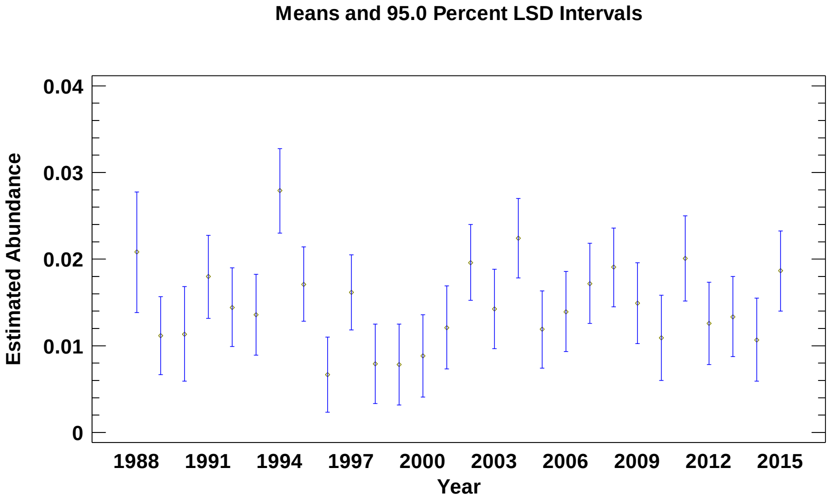

Figure 2.4.5-13. The mean annual estimated abundance (# marine fauna/m^2) collected in zone 1 (northern region) and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

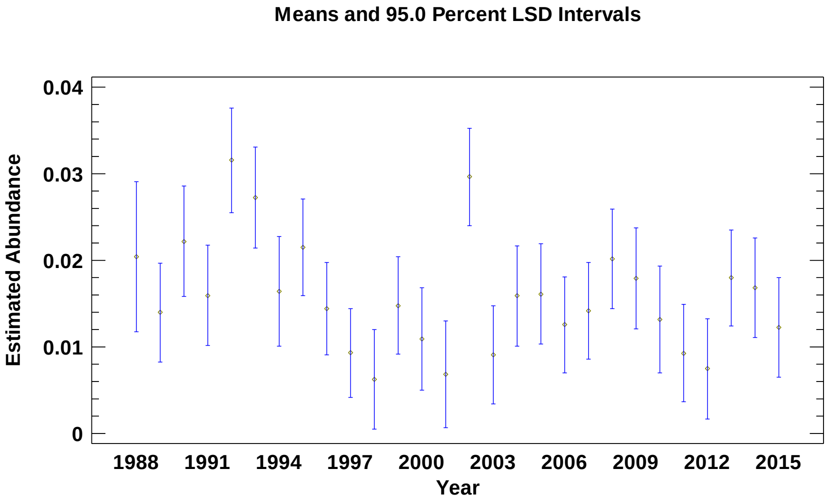

Figure 2.4.5-14. The mean annual estimated abundance (# marine fauna/m^2) collected in zone 2 (middle region) and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

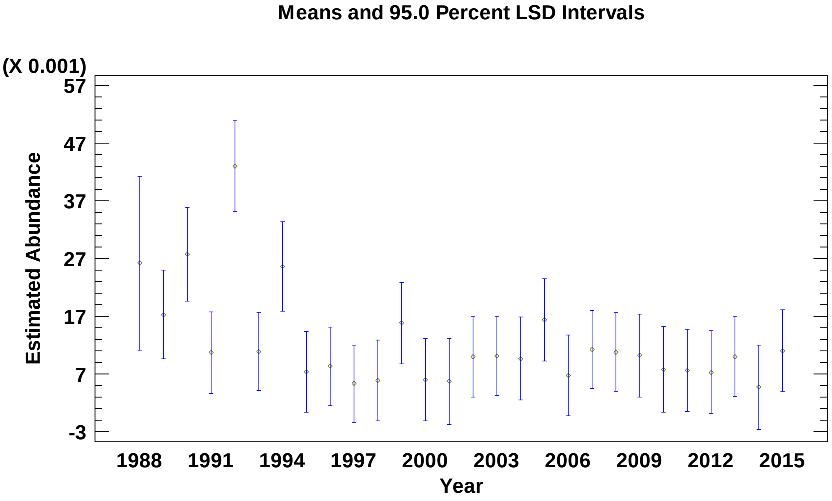

Figure 2.4.5-15. The mean annual estimated abundance (# marine fauna/m^2) collected in zone 3 (southern region) and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

Table 2.4.5-2. North/South Spatial Dynamics. Annual spatial catch characteristics in northern (Zone 1), mid (Zone 2), and southern (Zone 3) zones within the study area (1988–2015). N/A represents there was no association between the catch parameter and time.

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Regression Model**	**Regression Equation for Time Trend**	**F-test**	**r^2**
Total Number (Individuals)	ANOVA	F [2, 108246] = 89.58, $P < 0.05$	N/A	N/A	N/A	N/A
Estimated Abundance	ANOVA	F [2, 108246] = 87.53, $P < 0.05$	N/A	N/A	N/A	N/A
Total Number (Zone 1)	ANOVA	F [27, 38485] = 5.77, $P < 0.05$	N/A	N/A	N/A	N/A
Total Number (Zone 2)	ANOVA	F [27, 37701] = 6.49, $P < 0.05$	N/A	N/A	N/A	N/A
Total Number (Zone 3)	ANOVA	F [27, 31979] = 5.81, $P < 0.05$	N/A	N/A	N/A	N/A
Estimated Abundance (Zone 1)	ANOVA	F [27, 38485] = 2.43, $P < 0.05$	Linear	Estimated Abundance = 0.0272799 - 0.00000625512*Year	F [1, 27] = 0.0, $P = 0.9579$	0.72%
Estimated Abundance (Zone 2)	ANOVA	F [27, 37701] = 1.78, $P = 0.0076$	Linear	Estimated Abundance = 0.543747 - 0.000263739*Year	F [1, 27] = 3.30, $P = 0.0810$	10.2%
Estimated Abundance (Zone 3)	ANOVA	F [27, 31979] = 1.47, $P = 0.0548$	Linear	Estimated Abundance = 1.11394 - 0.000550316*Year	F [1, 27] = 9.87, $P = 0.0042$	27.7%

2.4.5.2.2 West/East Spatial Dynamics

Pooling catch data (*across all stations and areas within zones*), the mean annual total number and estimated abundance of marine fauna varied significantly among west/east zones; west/east zones were designated as the following: west (sampling areas 12, 15, 18, 21, and 24); mid (13, 16, 19, 22, and 25), and east (14, 17, 20, 23, and 26) (**Table 2.4.5-3, Figure 2.4.5-16**). *Post-hoc* analyses showed the mean annual total number and estimated abundance varied significantly between several west/east zones (1 and 2, 1 and 3, and 2 and 3).

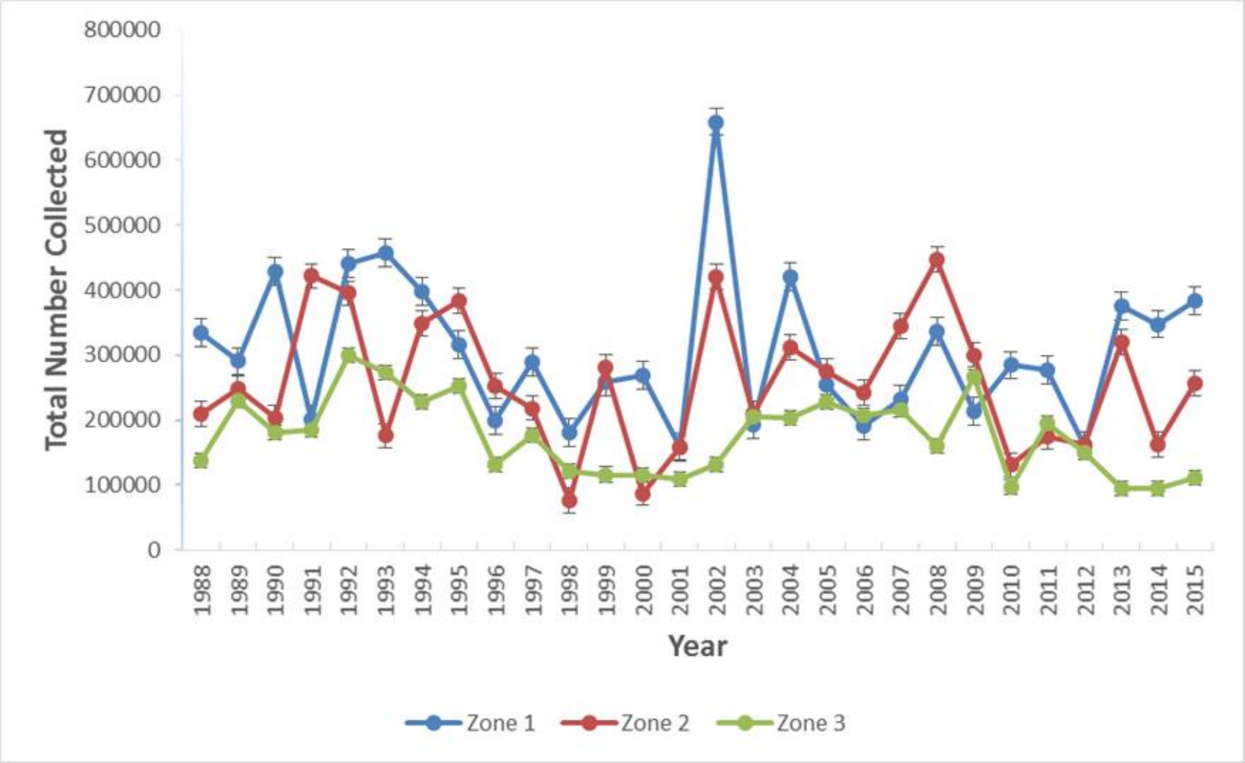

Figure 2.4.5-16. Annual total number of marine fauna collected per West/East zone (1988−2015). Zone 1 = Western sampling areas (12, 15, 18, 21, 24); Zone 2 = Middle sampling areas (13, 16, 19, 22, 25); Zone 3 = Eastern sampling areas (14, 17, 20, 23, 26).

The mean annual total number within individual west/east zones varied significantly among years (**Table 2.4.5-3**). Overall, marine fauna (mean annual total and estimated abundance) decreased from western to eastern zones, and there was no association between the total number in zones (west/east) and time. The mean annual estimated abundance varied significantly among individual zones (west/east), and the association between the mean annual estimated abundance and time in zone 3 was significantly weak and negative (**Table 2.4.5-3, Figure 2.4.5-17, Figure 2.4.5-18, Figure 2.4.5-19**).

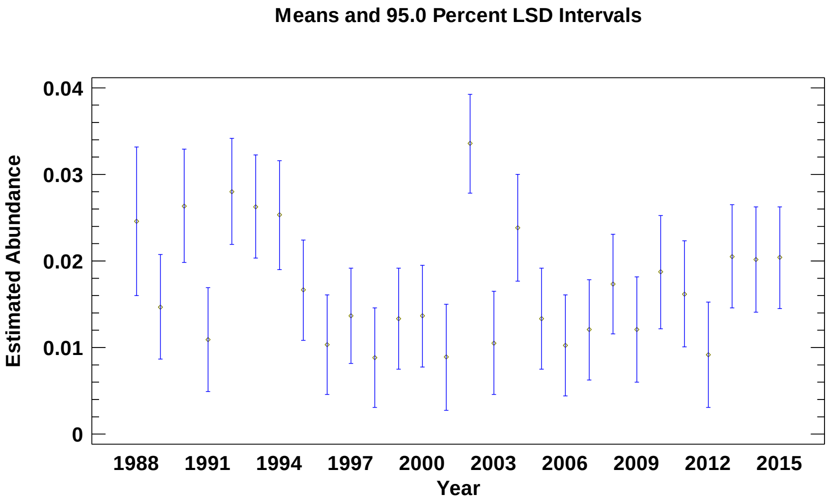

Figure 2.4.5-17. The mean annual estimated abundance (# marine fauna/m^2) collected in zone 1 (western region) and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

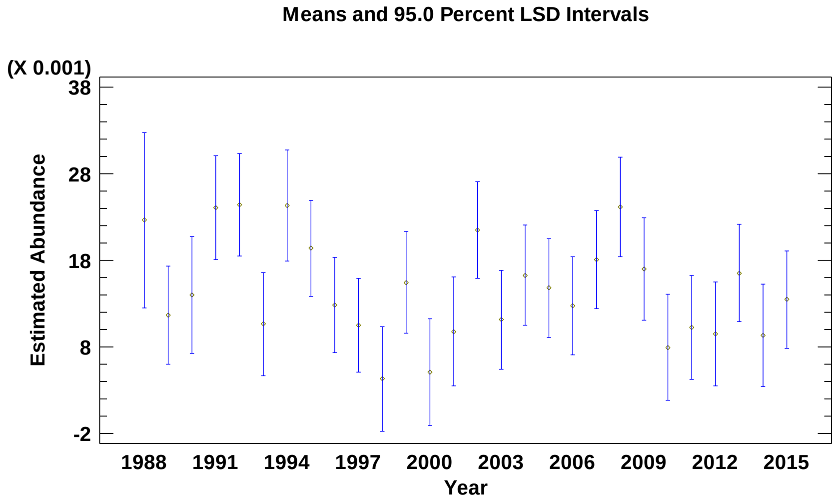

Figure 2.4.5-18. The mean annual estimated abundance (# marine fauna/m^2) collected in zone 1 (mid region) and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

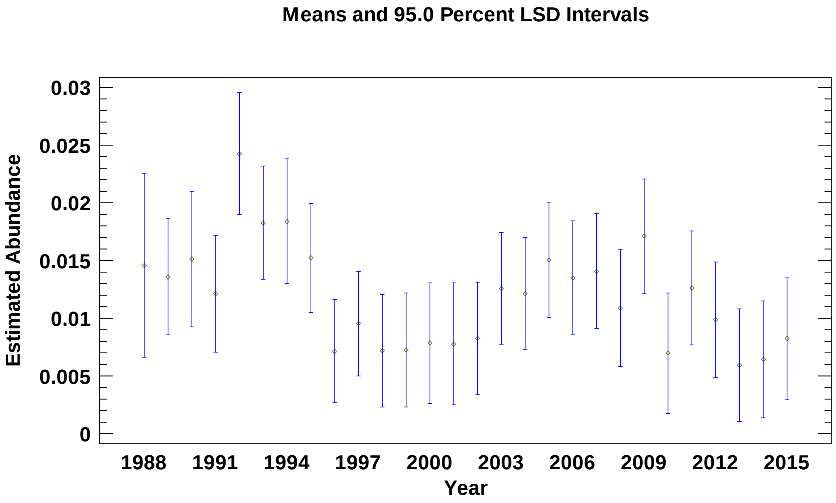

Figure 2.4.5-19. The mean annual estimated abundance (# marine fauna/m^2) collected in zone 2 (eastern region) and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

Table 2.4.5-3. West/East Spatial Dynamics. Annual spatial catch characteristics in western (Zone 1), mid (Zone 2), and eastern (Zone 3) zones within the study area (1988−2015).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Regression Model**	**Regression Equation for Time Trend**	**F-test**	**r^2**
Total Number (Individuals)	ANOVA	F [2, 108246] = 58.05, $P < 0.05$	N/A	N/A	N/A	N/A
Estimated Abundance	ANOVA	F [2, 108246] = 57.84, $P < 0.05$	N/A	N/A	N/A	N/A
Total Number (Zone 1)	ANOVA	F [27, 43123] = 5.83, $P < 0.05$	N/A	N/A	N/A	N/A
Total Number (Zone 2)	ANOVA	F [27, 43667] = 8.15, $P < 0.05$	N/A	N/A	N/A	N/A
Total Number (Zone 3)	ANOVA	F [27, 19178] = 2.63, $P = 0.08$	N/A	N/A	N/A	N/A
Estimated Abundance (Zone 1)	ANOVA	F [27, 44320] = 2.06, $P = 0.001$	Linear	Estimated Abundance = 0.348065 - 0.000165344* Year	F [1, 27] = 1.09, $P = 0.3071$	4%
Estimated Abundance (Zone 2)	ANOVA	F [27, 44667] = 2.36, $P = 0.0001$	Linear	Estimated Abundance = 0.416018 - 0.000200505* Year	F [1, 27] = 2.23, $P = 0.1474$	7.9%
Estimated Abundance (Zone 3)	ANOVA	F [27, 19178] = 2.23, $P = 0.0002$	Linear	Estimated Abundance = 0.500699 - 0.000244239* Year	F [1, 27] = 6.58, $P = 0.0164$	20.3%

2.4.6 Marine Fauna Water Temperature Preference

Over 20.4 million fish and invertebrates (1,338.3 mt) representing 214 (water temperature preference classified) species (*not including unidentified species*) were collected within 15 strata (areas: 12−26) off the coast of New Jersey from 1988 to 2015 (**Table 2.8-1**). Three marine fauna water temperature preference groups (coldwater-adapted, warmwater-adapted, and subtropic-adapted) were identified in the study area (**Figure 2.4.6-1**). The total number of individuals collected ranged from 4.0 million (coldwater-adapted) to 6.8 million (subtropic-adapted). In each temperature preference category, three species represented the majority of the catch (**Table 2.8-1**). The main coldwater-adapted species collected were longfin squid (*n* = 2,225,975), Atlantic herring (*n* = 544,032), and little skate (*n* = 316,356), while butterfish (*n* = 2,873,138), scup (*n* = 1,318,569), and northern sea robin (*n* = 503,230) represented the warmwater-adapted group. Bay anchovy (*n* = 9,227,960), striped anchovy (*n* = 245,214), and Atlantic moonfish (*n* = 38,691) denoted the subtropic-adapted group.

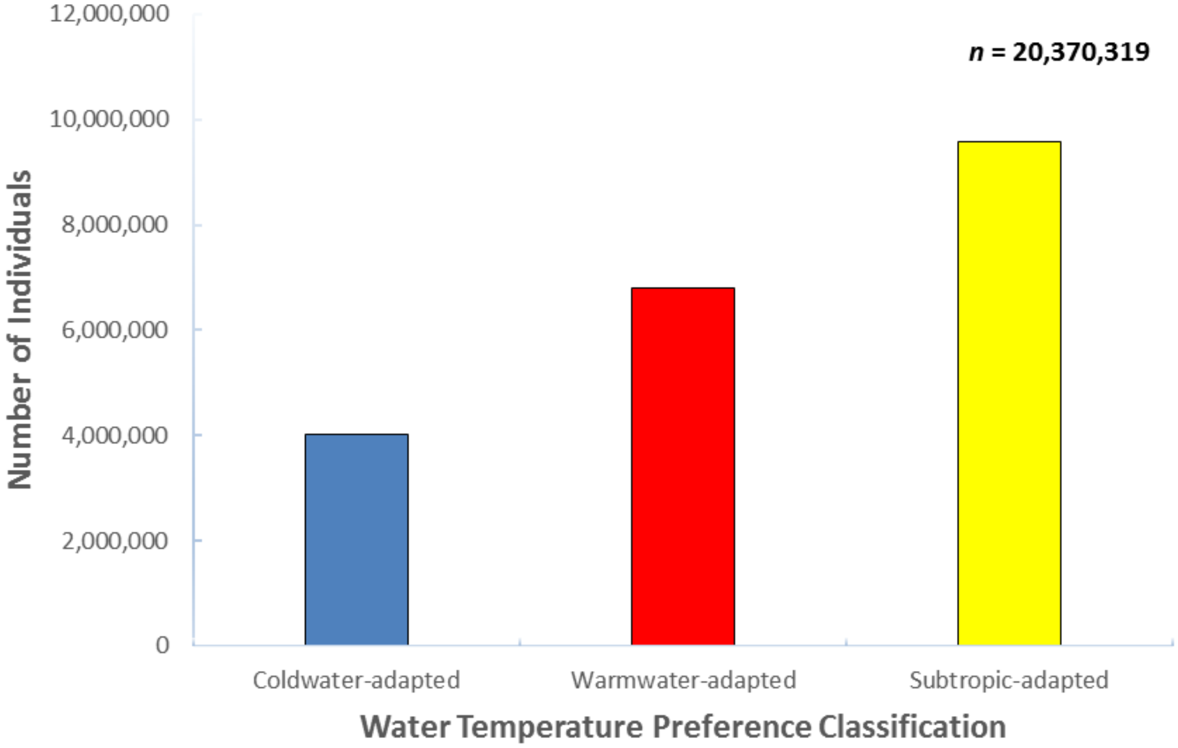

Figure 2.4.6-1. The total number of individuals collected per water temperature preference category in the study area (1988−2015).

The most abundant (*number of individuals per group*) water temperature preference group was the subtropic-adapted and the coldwater-adapted group was the least abundant group in the study area. The number of individuals collected per group varied over time with the coldwater-adapted group slightly decreasing since 2004 (**Figure 2.4.6-2**). In terms of percent composition, coldwater-adapted group declined over time, but in some years (1989, 1990, 1991, 1993, 1995, 1997, 2006, and 2012) it was the second most dominant group (**Figure 2.4.6-3**). In 1998, the coldwater-adapted group was the most abundant group. Overall, the coldwater to warmwater-adapted ratio declined over time, and there was a weak negative association between the coldwater: warmwater-adapted ratio and time (*F* [1, 26] = 10.71, *P* = 0.003; r^2 = 29.2%) (**Figure 2.4.6-4**).

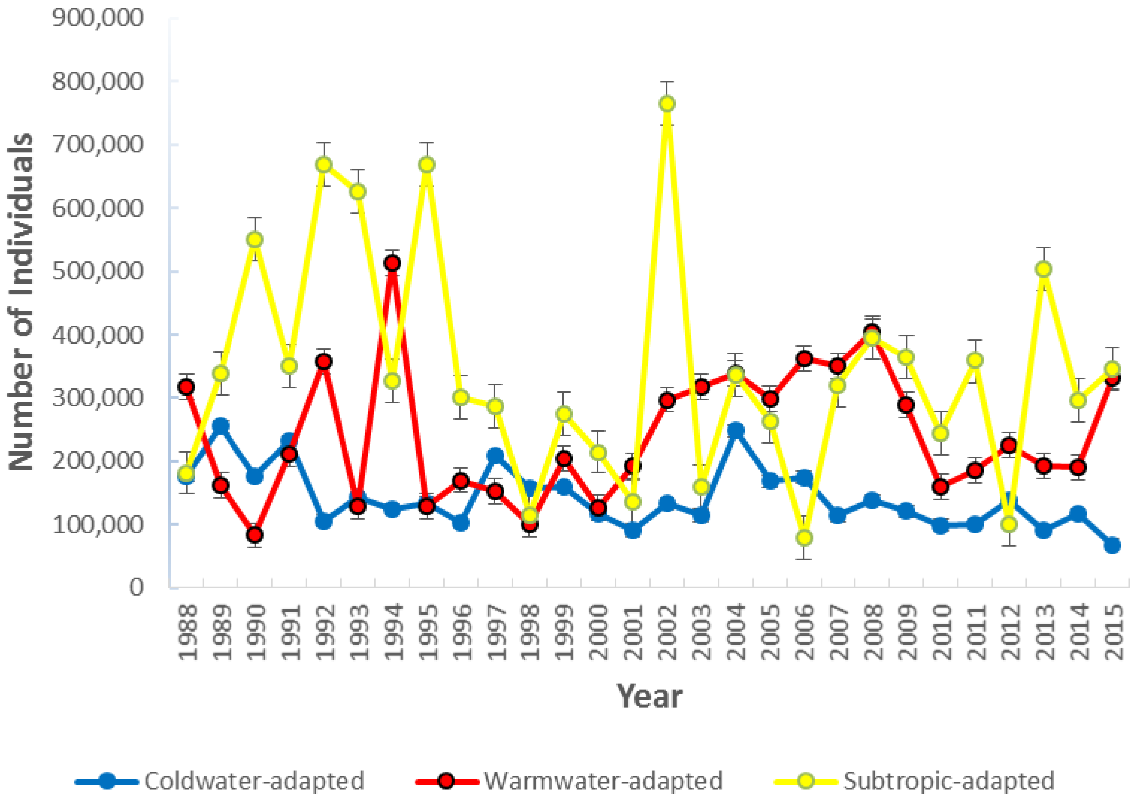

Figure 2.4.6-2. The total number of individuals collected per water temperature preference group within the study area (1988−2015). Error bars represent the standard error.

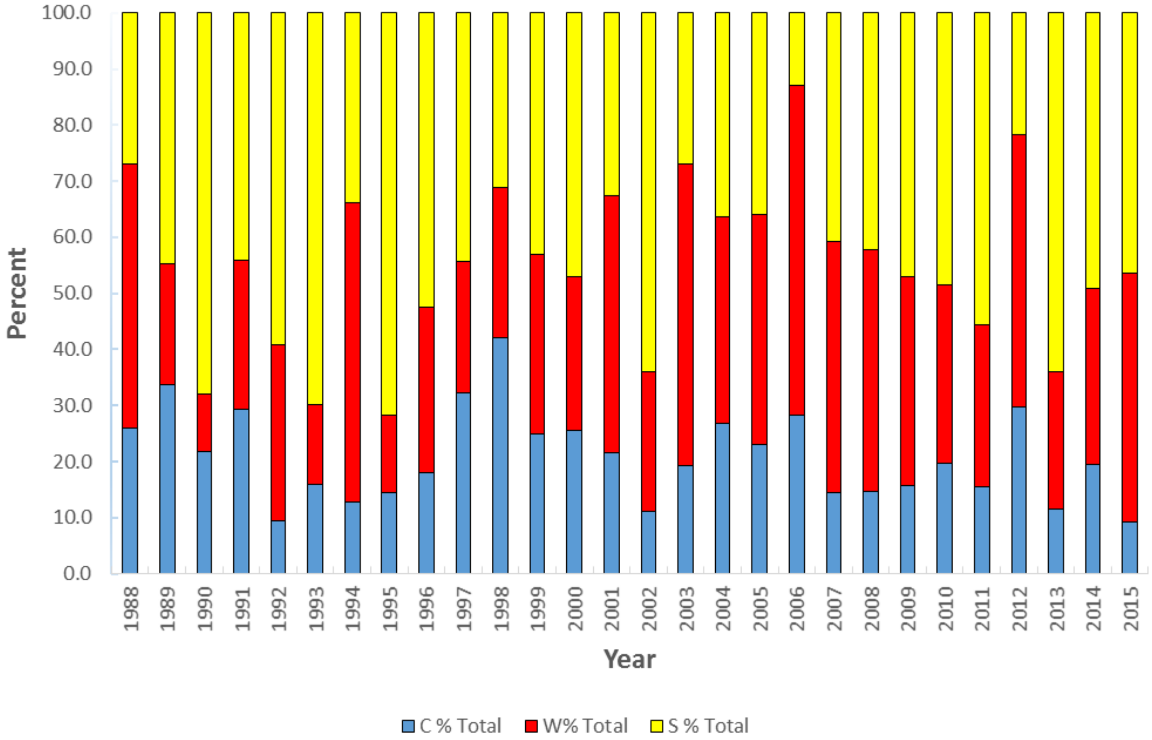

Figure 2.4.6-3. Percent composition of individuals collected by water temperature preference category within the study area (1988−2015). C = coldwater-adapted, W = warmwater-adapted, and S = subtropic-adapted.

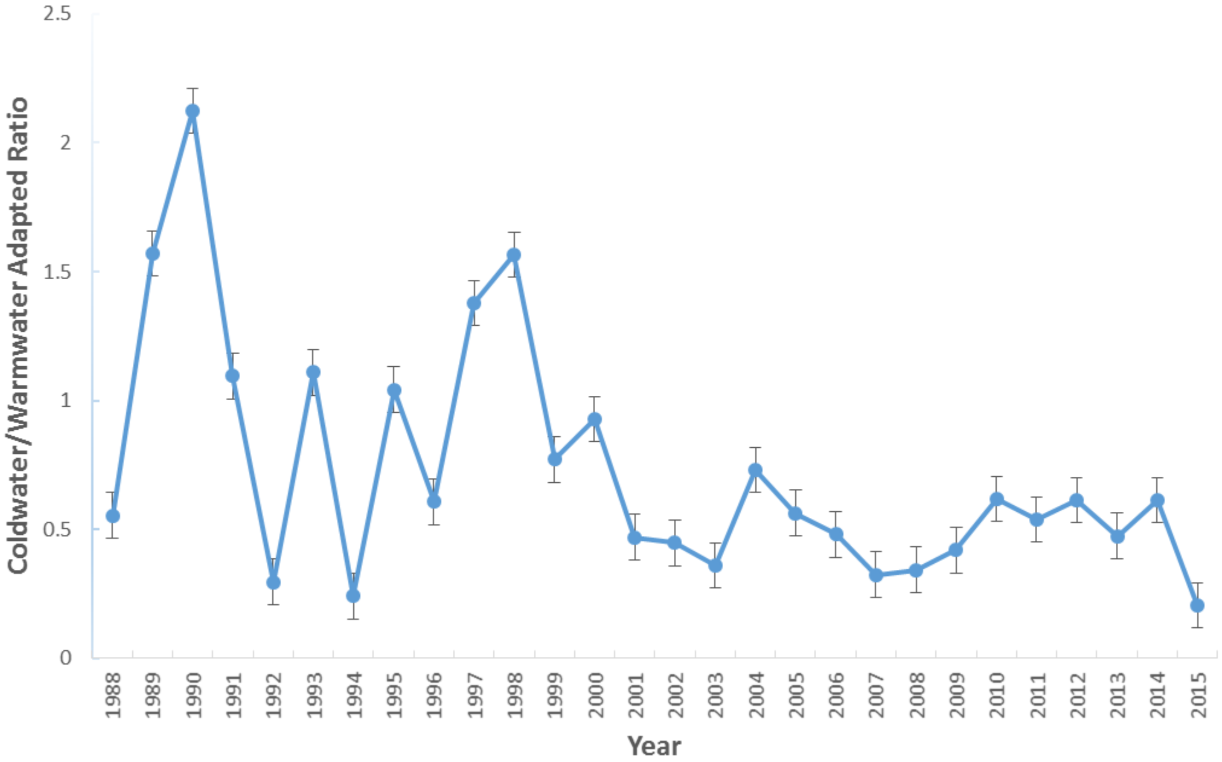

Figure 2.4.6-4. The coldwater to warmwater-adapted ratio of species collected within the study area (1988−2015). Error bars represent the standard error.

Pooling all samples, the lowest (0.1784 individuals per m^2) mean estimated abundance (# individuals/m^2) was the warmwater-adapted group and highest (0.2340 individuals per m^2) was the subtropic-adapted group (F [2, 100201] = 618.47, $P < 0.05$; **Figure 2.4.6-5**). The lowest mean estimated biomass (kg/m^2) was the subtropic-adapted group and the highest was the coldwater-adapted group (F [2, 100201] = 687.35, $P < 0.05$; **Figure 2.4.6-6**).

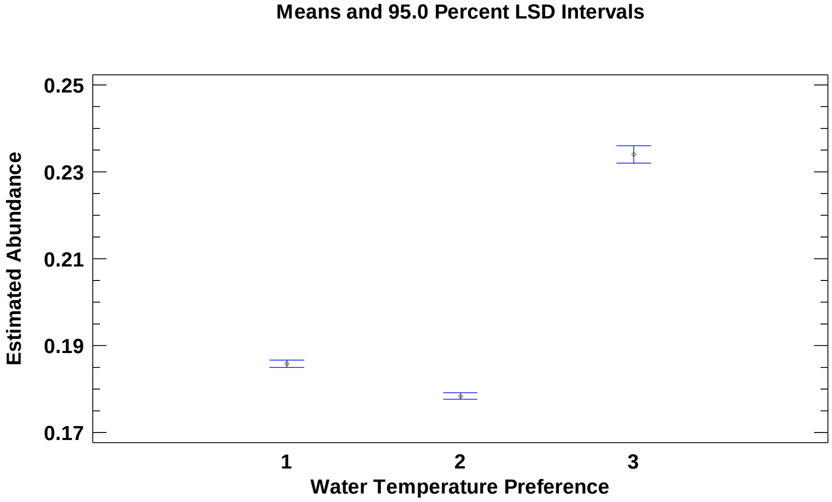

Figure 2.4.6-5. The mean estimated abundance (individuals/m^2) by water temperature preference category (1 = coldwater-adapted, 2 = warmwater-adapted, and 3 = subtropic-adapted) and 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

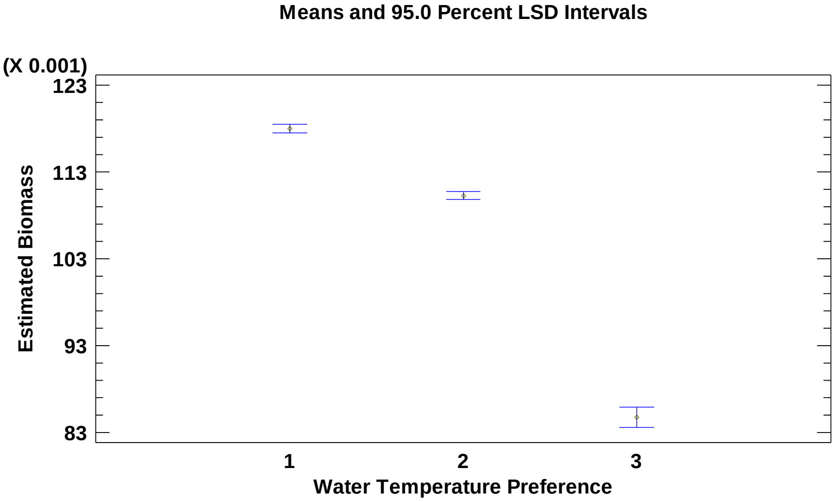

Figure 2.4.6-6. The mean estimated biomass (kg/m^2) by water temperature preference category (1 = coldwater-adapted, 2 = warmwater-adapted, and 3 = subtropic-adapted) and 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year.

The mean estimated abundance of the coldwater-adapted group was consistently lower than the estimated abundance of the warmwater-adapted group over time (**Figure 2.4.6-7**). The mean annual estimated abundance varied significantly by water temperature preference category (F [2, 100203] = 587.86, $P < 0.05$), time (F [27, 100203] = 11.93, $P < 0.05$), and the interaction between the water temperature group and time (F [54, 100203] = 9.33, $P < 0.05$). Overall, pooling the six 5-year time-series, the mean annual estimated abundance of the coldwater-adapted (F [5, 39039] = 8.82, $P < 0.05$) and subtropic-adapted (F [5, 7382] = 8.16, $P < 0.05$) groups decreased, and the warmwater-adapted group slightly increased (F [5, 39039] = 14.10, $P < 0.05$) over time.

The mean estimated abundance of the water temperature groups significantly varied by time (F [2, 100203] = 600.08, $P < 0.05$), space (F [14, 100203] = 3.93, $P < 0.05$), and the interaction between time and space (F [28, 100203] = 3.82, $P < 0.05$). The highest mean estimated abundance for the coldwater-adapted group was in the northern sampling areas (sampling areas 13, 14, and 12), while the highest mean estimated abundance for the warmwater-adapted (sampling areas 20, 18, and 19) and subtropic-adapted (sampling areas 22, 20, and 19) groups was in mid and southern sampling areas.

Similarly, the mean annual estimated biomass varied significantly by water temperature preference category (F [2, 100203] = 705.8, $P < 0.05$), time (F [27, 100203] = 6.49, $P < 0.05$), space (F [14, 100203] = 2.92, $P < 0.05$), and the interaction between time and space (F [54, 100203] = 3.79, $P < 0.05$). The mean annual estimated biomass for all three water temperature preference groups (coldwater-adapted [F [5, 39039] = 38.84, $P < 0.05$]; warmwater-adapted [F [5, 39039] = 44.03, $P < 0.05$]; and subtropic-adapted [F [5, 7382] = 10.35, $P < 0.05$] increased with time, but the mean annual estimated biomass of the subtropic-adapted group increased the most and coldwater-adapted group increased the least. The interaction pattern between the mean annual estimated biomass and space was less clear than the mean annual estimated abundance and time; there was no pattern in the mean annual estimated biomass of the coldwater-adapted [sampling areas 18, 13, and 23], warmwater-adapted [sampling areas 20, 12, and 19], and subtropic-adapted [sampling areas 18, 12, and 22] groups.

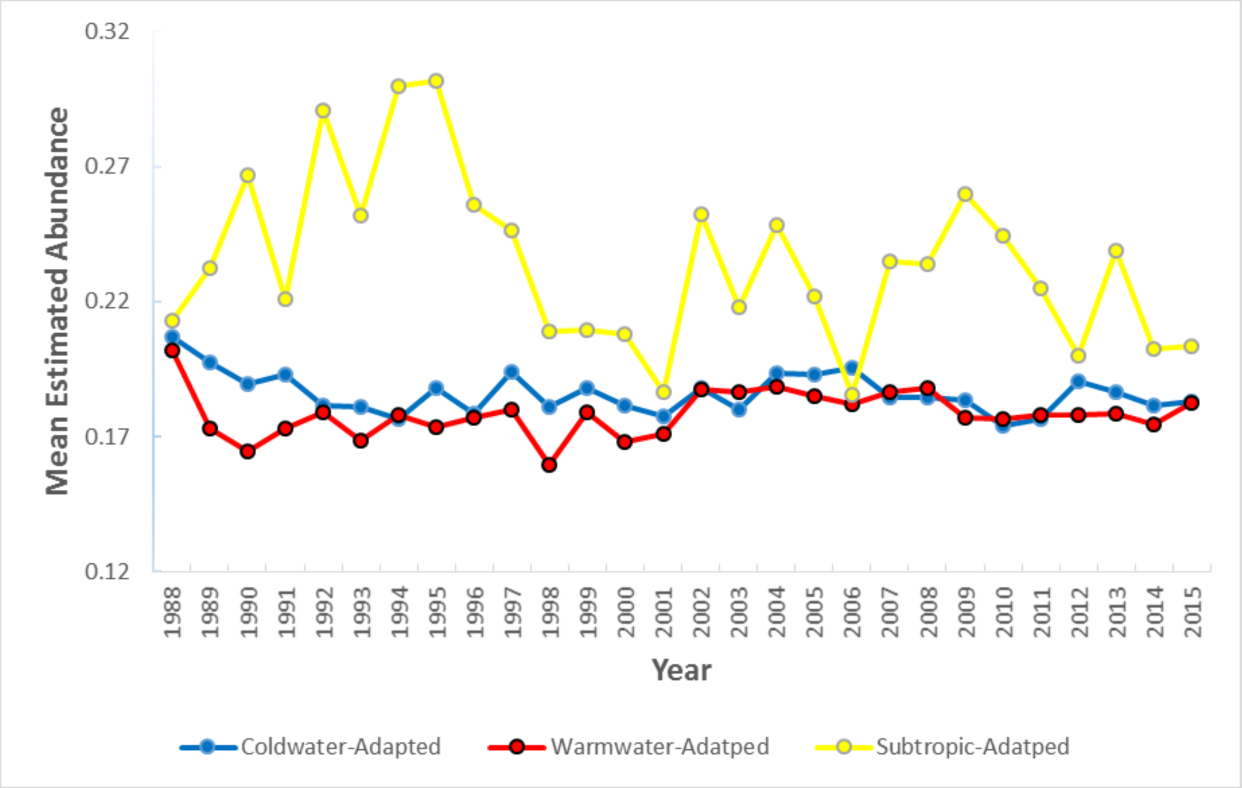

Figure 2.4.6-7. The mean annual estimated abundance (individuals/m^2) by water temperature preference collected within the study area (1988−2015).

Pooling the data (1988−2015), GLMs showed that year and sampling areas were significant predictors of the total number and estimated abundance of the coldwater and warmwater-adapted groups. The total number and estimated abundance of the subtropic-adapted group were significantly predicted by the year, month, and sampling area, whereas the estimated abundance was only significantly predicted by the year and sampling area (**Tables 2.8-42-44**).

Evaluating the individual 5-year time-series for each temperature preference category showed slightly different results (**Tables 2.8-24-41**). The GLMs generally showed the month and sampling area variables significantly predicted the total number and estimated abundance of coldwater, warmwater, and subtropic-adapted groups collected during 1988 through 2007. The estimated biomass of the coldwater and warmwater-adapted groups were primarily predicted by the month and sampling area, whereas the subtropic-adapted group was generally predicted by the sampling area rather than the month or year. The subtropic-adapted groups collected between 2003 and 2007 was non-significantly influenced by time or space; however, the sampling area significantly predicted the estimated biomass. In later years (2008−2012), the total number and estimated abundance of the coldwater-adapted group was significantly predicted by the sampling area, while the warmwater-adapted group was significantly predicted by the month and sampling area. The total number and estimated abundance of the subtropic-adapted group was predicted by the year and sampling area, whereas estimated biomass was predicted by the month and sampling area. During 2013 through 2015, the total number, estimated abundance, and estimated biomass of the coldwater and warmwater-adapted groups were significantly predicted by the sampling area and month. The total number and the estimated abundance of subtropic-adapted group was significantly predicted by all three variables (year, month and sampling area), while estimated biomass was significantly predicted by the sampling area.

2.4.6.2 Segregated Spatial Dynamics

2.4.6.2.1 North/South Spatial Dynamics

Subtropic-adapted species were the most abundant category and coldwater-species were the least abundant category in every north/south zones; north/south zones were designated as the following: north (sampling areas 12−17); mid (sampling areas 18−23), and south (sampling areas 24−26). The total number of coldwater and warmwater-adapted species decreased from north to south, but the mean annual estimated abundance of coldwater (*F* [2, 40368] = 0.21, *P* = 0.81) and warmwater-adapted groups (*F* [2, 40368] = 2.35, *P* = 0.0957) did not vary significantly among north and south zones.

A two-way ANOVA showed the mean annual estimated abundance of coldwater-adapted species varied significantly by time and space (*F* [54, 40368] = 1.87, *P* = 0.0001). The mean annual estimated abundance of coldwater species was highest in zone 1 during a few years (1994, 1997, 2004-2006, 2008, 2011, and 2012). In contrast, the mean annual estimated abundance of coldwater species was highest in zone 3 during 1988-1990, 1992, and 2003.

The mean annual estimated abundance of warmwater species also varied significantly by time and space, including the interaction between time and space (*F* [42, 40368] = 2.71, $P < 0.05$). The highest mean annual estimated abundance in Zone 1 occurred in 1994, 2003, and 2004. In Zone 3, the highest mean annual estimated abundance occurred in 1988, 1992 and 1999.

The mean annual estimated abundance of subtropic-adapted species varied significantly by time (*F* [27, 7474] = 1.74, *P* = 0.01) and space (*F* [2, 7471] = 4.54, *P* = 0.01). The highest mean annual estimated abundance of subtropic-adapted species was in Zone 2 (*F* [2, 7471] = 4.15, *P* = 0.0158) followed by Zone 1 and Zone 3. The highest mean annual estimated abundance in Zone 1 occurred in 1997, 2001, 2003, 2004, 2007, 2008, 2011, and 2015. In Zone 3, the highest mean annual estimated abundance occurred in 1990 and 2005.

The estimated biomass of coldwater-adapted species peaked in Zone 1 during 2000 and 2007, but it did not vary significantly by time (*F* [27, 40368] = 0.58, *P* = 0.95) or space (*F* [2, 40368] = 2.21, *P* = 0.11). Similarly, the estimated biomass of warmwater-adapted species peaked in Zone 2 during 2005, but it did not vary significantly by time *F* [27, 40368] = 0.85, *P* = 0.65) or space (*F* [2, 40368] = 0.61, *P* = 0.82). The estimated abundance of subtropic-adapted species peaked in Zone 3 during 2012, but it did not vary significantly by time F [27, 7471] = 0.89, P = 0.62) or space (F [2, 7471] = 0.86, P = 0.42). The estimated biomass of subtropic-adapted species increased in Zone 2 during 2012 through 2015.

2.4.6.2.2 West/East Spatial Dynamics

The mean annual estimated abundance of subtropic-adapted species was highest and the coldwater-adapted species were lowest in every west/east zone; west/east zones were designated as the following: west (sampling areas 12, 15, 18, 21, and 24); mid (sampling areas 13, 16, 19, 22, and 25), and east (sampling areas 14, 17, 20, 23, and 26). The mean annual estimated abundance of subtropic-adapted species decreased from west (Zone 1) to east (Zone 2) Zones, and coldwater and warmwater-adapted species increased from west to east zones.

The mean annual estimated abundance of coldwater-adapted species varied significantly by time (F [27, 40368] = 2.07, P = 0.0009) and space (F [2, 40368] = 4.81, P = 0.008). The mean annual estimated abundance in Zone 1 was the highest in 1993 and 2004. In Zone 3, the mean annual estimated abundance peaked in 1990 and 2011.

The mean annual estimated abundance of warmwater-adapted species varied significantly by time (F [27, 40368] = 2.09, P = 0.002) and interaction between time and space (F [42, 40368] = 1.64, P = 0.005). The mean annual estimated abundance peaked in Zone 3 during 1992. In Zone 2, the mean annual estimated abundance peaked in 1994, 1996, 1999, 2002, 2004, and 2006.

The mean annual estimated abundance of subtropic-adapted species varied significantly over time (F [27, 7471] = 1.90, P = 0.003). The mean annual estimated abundance in Zone 1 peaked in 1990, 2000, 2002, and 2014. The mean annual estimated abundance in Zone 2 peaked 1992, 1995, 2008, and 2013. In Zone 3, the mean annual estimated abundance peaked in 1993, 2009, and 2011.

Overall, the highest mean annual estimated biomass was warmwater-adapted species, but there was no evidence to suggest that the mean annual estimated biomass among temperature preference categories significantly changed from western to eastern areas.

The mean annual estimated biomass of coldwater-adapted species did not vary significantly by time (*F* [27, 40368] = 1.21, $P = 0.21$) or space (*F* [2, 40368] = 2.90, $P = 0.0552$). The mean annual estimated biomass in Zone 3 peaked in 2000, and in Zone 2 it peaked during 2007; the mean annual estimated biomass in Zone 1 was relatively low throughout the time period.

Similarly, the mean annual estimated biomass of warmwater-adapted species did not vary significantly by time (*F* [27, 40368] = 1.09, $P = 0.35$) or space (*F* [2, 40368] = 0.35, $P = 0.89$). In Zone 1, the mean annual estimated biomass peaked in 2012, and peaked in Zone 2 in 2005. In Zone 3, the mean annual estimated biomass peaked in 1992, 2001, and 2007.

The mean annual estimated biomass of subtropic-adapted species did not vary significantly by time (*F* [27, 7471] = 0.31, $P = 0.99$) or space (*F* [2, 7471] = 0.03, $P = 0.97$). In Zone 1, the estimated biomass peaked in 1991, and increased from 2012 to 2015. In Zone 2, the mean annual estimated biomass peaked in 2004 and 2012. The mean annual estimated biomass in Zone 3 was relatively low during most of the years, but it peaked in 1997 and 2014.

2.5 Discussion

One of the first steps to deciphering community dynamics is recognizing biological patterns and variability (spatial and temporal). Biological pattern recognition helps researchers develop hypotheses about the causes and associations of these patterns (Begon et al. 1986). Besides time and space, biological patterns are often associated with habitat and environmental conditions. Understanding these biological patterns is necessary to differentiate between natural variability in biological factors (e.g., relative abundance, distribution, community structure, and diversity) and potential disturbance impacts. In aquatic environments, the life-history stages, species composition, spatial distribution, abundance, and biomass is influenced, shaped, and limited by environmental conditions, such as water temperature, salinity, DO, and depth (Horne et al. 1989). These are some of the most important environmental and habitat variables that affect fish life-history characteristics (Hoese and Moore, 1977) and community structure. The way marine fauna respond (e.g., shift in distribution) to environmental changes depends on time and space (Kratz et al. 2003). As such, it is essential that researchers and managers have long-term data to understand these associations, correlations, and cause-effect outcomes (Pinsky et al. 2014); a thorough understanding of the oceanic conditions and marine community over time and space is necessary to assess ecological dynamics. This chapter presented a summary of how various environmental factors and aggregated measures of the marine community in the MAB varied over time and space in an extensive data set, setting the stage for a deeper understanding of community robustness.

2.5.1 Physicochemical Conditions

Identifying the annual and seasonal variability in the oceanic conditions and the response of community and component populations within the ecosystem is critical for predicting long-term community dynamics, trends, and evaluating disturbance. Given the broad oceanographic hydrodynamics off New Jersey (Kohut et al. 2004), the water temperature, salinity, and DO levels significantly varied over time and space in the study area. The mean oceanic conditions were highly variable over the 28-year period, but various alternating or cyclic patterns were evident with time, along with increasing or decreasing trends, which verified the first, simple hypothesis that the oceanic conditions vary with time. In general, water temperature increased and the salinity decreased over time within the study area. The rising water temperature and falling salinity trends echoed previous studies for the region (Howell and Auster, 2012; Geiger et al. 2013; Thomas et al. 2017). The trend rates for mean (0.06°C per year) and maximum (0.02°C per year) surface water temperature were similar to published rates (Thomas et al. 2017).

The nearshore waters off New Jersey are a dynamic hydrological system influenced by summer stratification and winter mixing, which are associated with the prevailing wind and buoyancy factors (Glenn et al. 2004; Kohut et al. 2004). Northeast wind often causes downwelling, while southwest wind causes upwelling (Kohut et al. 2004). The physicochemical conditions varied not only by year and season, but among specific sampling areas within the study area. Besides the southeast corner of the study area (sampling areas 21 and 24), water temperature (surface and bottom), salinity (surface), and DO increased from northern to southern sampling areas, and salinity increased from western to eastern sampling areas. Bottom salinity decreased from middle to southern areas, and the surface DO decreased from northern to southern areas. Bottom DO increased from northern to southern sampling areas, and decreased from eastern to western sampling areas.

Upwelling and downwelling events off New Jersey are frequent given the wide continental shelf and gently sloping topography; the continental shelf extends about 200 km off the coast of New Jersey (Song et al. 2001; Kohut et al. 2004). It is possible the relatively warmer water temperature and higher salinity in sampling areas 21 and 24 was influenced by the nearby underlying topography (i.e., topographic bump and oblique sand ridges) or seasonal upwelling events. The nearshore waters (~ 40 m) are more stratified than the offshore waters in June because of the influence of lower salinity water from the Hudson River (Schofield et al. 2008), which could be causing the decreasing salinity trend off the New Jersey coast, noted here. The warmwater period in the MAB is longer than the past and this environmental change has influenced the stratified period (June−September) thereby altering the timing of spring and fall phytoplankton blooms; the warming period is beginning earlier each year over the past decade (Thomas et al. 2017).

The surface and bottom DO varied significantly over time and the positive association between DO and time was explained adequately by regression, but a low correlation coefficient value (0.08) indicates a weak association. This finding contradicted the hypothesis that DO would decrease with time. It is difficult to explain why the DO slightly increased (0.009 mg/L per year) with time in the study area given that research has shown several recurrent hypoxia events (1994, 1996, and 2001) occurring (Barnegat Inlet, Mullica River Estuary, and Townsend/Hereford Inlets) along the southern New Jersey coast (Glenn et al. 2004). Hypoxia is thus relatively common along the New Jersey coast, but these events are somewhat short-term and related to coastal upwelling, which sometimes occurs in summer when the wind is from the southwest (Glenn et al. 2004). The hypoxia centers (~ 150 km^2) are spatially isolated in duration (~ 1 week), frequency (~ 5 times in 9 years), and space (Barnegat Inlet, Mullica River Estuary, and Townsend/Hereford Inlets). These locations are downstream of a series of topographic highs associated with ancient river deltas in the southern waters off New Jersey. The most significant upwelling events occurred after the most severe cooling seasons in 1994, 1996, and 2001 (Glenn et al. 2004). These researchers hypothesized that severe cooling seasons often causes colder and larger Cold Pools, which produce more significant summer upwelling events by summertime wind-driven forces. Upwelling also depends upon wind, precipitation, and storm frequency. Given that water temperature is increasing in the study area, it is possible that summer upwelling events could be less severe than in the past, which is reducing the magnitude of hypoxia events in specific areas within the study area. This hypothesis might explain the slight increase in DO over time in the study area. Then again, it might be related to the ongoing water quality improvements (less pollution) in nearby New York and New Jersey waterbodies (HydroQual, 2010).

2.5.2 Marine Fauna Community

Describing, estimating, and predicting change (negative and positive) and impacts in marine communities requires an understanding of the baseline conditions within the region, and at a local scale (Dunic et al. 2017), which often takes years to acquire (i.e., long-term data) given the annual and internal variability of marine fauna (Kratz et al. 2003). To understand ecological dynamics, the most systematic approach to establish baseline conditions is to use long-term independent data, such as those collected through federal or state-funded monitoring programs, including the New Jersey Ocean Stock Assessment. Long-term measurement of ecosystem and community structure can be used to detect impacts associated with events (natural and anthropogenic) that cause long-term ecological change (Turner et al. 2003). Without long-term observations, it is often difficult and sometimes impossible to decipher ecological (spatial and temporal) interactions associated with potential impacts (Kratz et al. 2003). This chapter is the first study of its kind that uses a long-term data set (28-years) to describe the baseline conditions for the nearshore marine community off the New Jersey coast.

The temperate, mid-latitude, nearshore waters of New Jersey provide year-round and seasonal habitat for over 200 species marine species. Similar to other studies conducted in this region (Colvocoresses and Musick, 1984; Wood et al. 2009; Howell and Auster, 2012), a limited number (*n* = 14) of marine species dominated (90%) the marine community; bay anchovy comprised 45% of the catch. The total number and estimated abundance of individual species was highly variable from year to year, but the dominant species (bay anchovy, butterfish, longfin squid, and scup) and associated abundance was fairly consistent over time, but that depended on the month and sometimes the sampling area. Overall, the abundance of the marine community is slightly declining, and changing by space and time. These findings support the second and third primary hypotheses that the species assemblage and estimated abundance vary with space and time. Researchers working in similar nearshore environments have reported similar observations. Colvocoresses and Musick (1984) also reported some annual, seasonal, and spatial variation in marine fauna composition and distribution in the MAB, but the dominant species composition was fairly consistent over the 9-year period of their study. In Long Island Sound, Howell and Auster (2102) reported a clear seasonal shift in the estimated abundance of 95 fish species during 1984 through 2008, which they attributed to the increase in water temperature. Their research showed the annual abundance of cold-adapted species was negatively correlated with the mean bottom water temperature, while warm-adapted species, but not subtropic-adapted species, showed a positive correlation with water temperature.

This chapter also showed the total number and estimated abundance of marine fauna decreased and the mean estimated biomass increased over time suggesting that larger/heavier and less abundant marine fauna are either slowly replacing smaller more abundant marine fauna, or smaller marine fauna are simply unable to tolerate the rising water temperature and falling salinity levels in the study area. In their shorter study, Colvocoresses and Musick (1984) reported the range and distribution of certain species shifted with water temperature variation, but there was no obvious overall deviation in the species composition, which they attributed to the minimal water temperature change (~ 2°C) relative to the water temperature tolerance of the species. The increase in water temperature has probably exceeded the water temperature tolerance for some of the species encountered in this study, or their prey. It has been predicted climate change will cause many species (50% of the species evaluated) to shift their distribution northward in the MAB over the next 50 years (Hare et al. 2016). This poleward shift in species distribution and biomass associated with warming water temperatures has been predicted and documented not only in the MAB, but in other regions of the northeast coast of North America (Nye et al. 2009). Though findings indicated an overall decrease in estimated abundance when the data was pooled, the individual 5-year time-series data suggest the estimated abundance and biomass have remained stable in recent years. The data suggest the marine community is adapting to changes in the environmental conditions, shifting (distribution), and temperature preference (coldwater vs warmwater-adapted species) replacement is occurring in the MAB. Assuming anthropogenic activities (e.g., fishing and water quality) and natural events (e.g., storms and upwelling/downwelling) have been consistent over time, it appears the marine community could be responding in these ways to changes in the oceanic conditions off the New Jersey coast. Fluctuations in marine communities associated with such oceanic variability have been documented worldwide (Pinsky et al. 2013) and in nearby regions, such as the Long Island Sound and Narraganset Bay (Wood et al., 2009; Howell and Auster, 2012).

As expected, the total and estimated abundance of marine fauna increased from winter to summer, and the dominant species varied across seasons; blueback herring dominated the winter catch and bay anchovy dominated the summer catch. Howell and Auster (2012) also found not only a seasonal difference in the mean catch, but catches in spring significantly decreased and increased in fall in Long Island Sound. Moreover, seasonal and annual differences in relative abundance, especially for warmwater-adapted species have occurred in Narraganset Bay (Wood et al. 2009). Despite the homogeneous bottom habitat in the study area (sand and sand ridge), marine fauna catch (total number and estimated abundance) varied among sampling areas and geographical zones indicating the oceanic conditions could be influencing the spatial distribution of marine fauna off the New Jersey coast. The individual 5-year data showed that the total number and estimated abundance was significantly influenced by the sampling area, whereas estimated biomass was significantly influence by the time and sampling area, which could have been associated with the warming water temperatures. These findings agree with the conclusions of Nye et al. (2009) who found that abundance and biomass was significantly associated with area; their findings showed 66% of species (n = 24) have shifted northward to colder deeper habitats. Wood et al. (2009) also reported differences in warmwater species assemblages between Narragansett Bay and Long Island Sound, which they attributed to water temperature. Thus, it is possible the most abundant year-round species may have shifted or expanded their distributions, and larger seasonal species may be traversing the study area more frequently than the past in search of prey.

The largest catch and highest estimated abundance occurred near the shore in the most northern sampling strata (sampling area 15) of the study area; the northern (sampling areas 12−17) and nearshore (sampling areas 12, 15, 18, 21, 24) sampling areas were the most abundant zones The annual total catch was more variable in the northern sampling areas (12−23) than in the southern sampling areas (24−26), but the annual declining trend was somewhat similar among all sampling areas. Findings showed there was a negative association between the estimated abundance and time in most sampling areas (18−26) suggesting marine fauna are moving away from the study area. However, recent increases in total catch (2012−2015) indicates the marine fauna might be adjusting to the changing oceanic conditions or that warmwater-adapted are replacing coldwater-adapted species, which is likely the case given the rising water temperature. In fact, the data shows the coldwater to warmwater-adapted ratio is decreasing with time. The results of the present study are somewhat different than the conclusions of Nye et al. (2009) who reported a north-east shift in spatial distribution for most species. However, it is should be noted that one of the biggest differences between these two studies was the sampling or study area. In this present study, field-sampling was conducted in nearshore waters (< 90 m), while the data used in the Nye et al. (2009) was collected in offshore waters (> 90 m) making it difficult to compare. Another difference between the studies was that the sampling gear. In the data analyzed by Nye et al. (2009), researchers used a much larger otter trawl net (mesh, and overall size) than in this present study. Although some of the same species were collected in both studies, many were different given the species composition is slightly different between nearshore and offshore environments in the MAB. For instance, the small schooling fauna (e.g., bay anchovy, butterfish, and longfin squid) were only collected in this present study.

The most abundant species collected in the nearshore sampling areas (12, 15, 18, 21, and 24) were bay anchovy, butterfish, and weakfish. Although these species were collected in throughout the study area, it appears their distributional range within the study area has slightly expanded to the north (sampling areas 13 and 14) and east (sampling areas 14 and 17) in recent time (2009−2015), which Nye et al. (2009) reported for several species (e.g., summer flounder). Nye et al. (2009) attributed the distributional shift to a species' preferred temperature range. Butterfish catch has gradually increased along the coast (sampling areas 12, 15, 18, 21, 24) over time, which is likely associated with the change in water temperature (mean 21.7°C) or prey availability (detritus) for these species. The findings support the hypothesis that marine fauna decreases from nearshore to offshore sampling areas, but contradicts the notion that marine fauna decreases from southern to northern sampling areas.

2.5.3 Marine Fauna Temperature Tolerance and Preference

The nearshore coastal waters off New Jersey provide year-round and seasonal habitat for three temperature preference groups (subtropic-adapted, warmwater-adapted, and coldwater-adapted), which complemented previous findings in the MAB (Wood et al. 2009; Howell and Auster, 2012). However, different than Howell and Auster (2012), subtropic-adapted species were the most abundant and coldwater-adapted species were the least abundant in the study area. Bay anchovy was the most abundant subtropic-adapted species and butterfish was the most abundant warmwater-adapted species. These findings did not agree with Howell and Auster (2012) who reported more coldwater-adapted species than warmwater-adapted and subtropic-adapted species in Long Island Sound. New Jersey waters are not only located south of Long Island Sound, but anecdotal information from local fishermen suggest they are sometimes influenced by warmwater eddies and whorls spinning off the Gulf Stream Current, which can provide habitat to subtropic-adapted marine fauna; this phenomenon might explain the reason why there are more subtropic-adapted species in New Jersey than New York.

The estimated abundance of warmwater-adapted species is increasing, coldwater and subtropic-adapted species is decreasing, and the coldwater to warmwater-adapted ratio is decreasing over time in the study area. This ongoing pattern for marine fauna seems to be becoming more common in the MAB (Nye et al., 2009; Wood et al. 2009; Howell and Auster, 2012), and throughout the world (e.g., Polovina et al., 2011). Most researchers attribute this shift in species distribution and composition to climate variability, which is causing the water temperature to rise with time (Cheung et al. 2011; Jang et al. 2011; Polovina et al. 2011; Brander et al. 2013). The abundance of warmwater-adapted species is also increasing with time in Narragansett Bay (Wood et al. 2009). In nearby Long Island Sound, Howell and Auster (2012) reported a shift from a coldwater to warmwater-adapted dominated species community, and an increase in subtropic-adapted species over a 25-year duration (1984−2008). It is possible the present study did not show this same trend for subtropic-adapted species because the environmental conditions off New Jersey are more variable than in the Long Island Sound (a semi-enclosed estuary) given the frequency of upwelling and downwelling events (Glenn et al. 2004; Kohut et al. 2004). Though the mean water temperature is rising, the frequency of upwelling/downwelling is also increasing in the MAB (Kohut et al. 2004), which could explain the decline in estimated abundance of subtropic-adapted species over time. It is possible subtropic-adapted species cannot tolerate abrupt changes in water temperatures caused by these events. These oceanographic events could be having a negative impact on some subtropic-adapted species found in particular sampling areas since the influx of cold water/warm water (± 1−4°C) can often occur in a short period (~ 3 or 4 weeks) given the relatively shallow depth and the effect of wind on the surface waters off the New Jersey coast (Kohut et al. 2004).

The highest estimated abundance of coldwater-adapted species was in northern sampling areas (12−17), and the highest estimated abundance for warmwater and subtropic-adapted species was in mid and southern sampling areas (18−26). Overall, the total number of coldwater and warmwater-adapted species decreased from north to south, but the estimated abundance of coldwater and warmwater-adapted species did not vary significantly among the study area. These findings did not support the hypothesis that the estimated abundance of coldwater-adapted species increased from south to north, and warmwater and subtropic-adapted species increased from north to south. Explaining the distribution of species is not straightforward in terms of water temperature, as it appears to vary by time, space and season given the oceanographic dynamics in the study area. In Narragansett Bay and Long Island Sound, Wood et al. (2009) could not thoroughly explain or understand the processes that lead to the appearance of warmwater fishes in the early summer and to their disappearance in the fall. Despite this variable pattern, the estimated abundance of coldwater-adapted species was generally higher in the southern sampling areas (24−26) during earlier years (1990s) and higher in the northern sampling areas (12−14) during later years (2000s). The estimated abundance of warmwater-adapted species was more variable, but it was higher in the southern sampling areas during a few earlier years (1990s) and higher in the northern sampling areas during a few later years (2000s). The estimated abundance of subtropic-adapted species was highest in the middle sampling areas (18−23), followed by the northern (12−17) and southern sampling (24−26) areas. In general, the highest estimated abundance was higher in the southern sampling areas (24−26) during a few earlier years, and higher in the northern sampling areas (12−17) during later years. In some ways, the findings suggest that the distribution of species, based on their temperature preference, is currently in a transition phase; the period when some individuals cannot tolerate the mean water temperature. For instance, the water temperature preference classification for this study was based on the mean preferred water temperature, which means 50 percent of the individuals can tolerate either a lower or higher water temperature. Assuming the water temperature continues to rise with time, then a full transition from a coldwater dominated community to a warmwater community will occur over time.

The estimated abundance of coldwater and warmwater-adapted species increased from nearshore to offshore and subtropic-adapted species decreased from nearshore (12, 15, 18, 21, 24) to offshore (14, 17, 20, 23, 26) sampling areas. Again, these findings somewhat agree with the hypothesis that the abundance of warmwater and subtropic-adapted assemblage increased, and the coldwater-adapted assemblage decreased from offshore to nearshore sampling areas. The increase in the estimated abundance of warmwater-adapted species from nearshore to offshore sampling areas suggests the environmental conditions are ideal for geographical range expansion within the study area given the rising water temperature. In general, the estimated abundance of coldwater-adapted species was higher in the nearshore sampling areas in a few earlier years (1990s) and higher in the offshore sampling areas in a few later years (2000s). These findings suggest the distribution of coldwater and warmwater-adapted species is shifting north, which agrees with other findings in the MAB (Nye et al. 2009; Howell and Auster, 2012).

The estimated abundance for all three temperature preference categories has changed, but their estimated biomass has remained stable from nearshore to offshore over time. The estimated abundance of subtropic-adapted species decreased from nearshore to offshore sampling areas, and coldwater and warmwater-adapted species increased from nearshore to offshore sampling areas. Despite these general patterns, inter-annual patterns were challenging to decipher given their high annual population and habitat selection variability. For instance, coldwater-adapted species had high abundance in the nearshore sampling areas during 1993 and 2004, and high abundance in the offshore zone during 1990 and 2011. Overall, the findings partially support the hypotheses that the estimated abundance and biomass of warmwater and subtropic-adapted assemblages increased from offshore to nearshore sampling areas, and the estimated abundance and biomass of coldwater-adapted assemblage increased from nearshore to offshore sampling areas with time. Overall, it appears that biomass trends are idiosyncratic to specific areas within the overall study area. These findings could be more related to how the sampling was segregated spatially rather than to biological reasons.

In general, the estimated biomass for all three water temperature preference categories is increasing with time in the study area; however, the estimated biomass of coldwater-adapted species is increasing the most even though they are decreasing in abundance throughout the study area. Larger (i.e., heavier) individuals seem to be replacing smaller individuals, or less abundant larger individuals are more common in the study area, such as bullnose sting ray (*Dasyatis sayi*). It is difficult to explain why the estimated biomass of subtropic-adapted species is increasing the most since their estimated abundance is decreasing with time in the study area. Smaller or younger (juvenile life-stage) coldwater-adapted individuals could be declining, moving away, or maybe the larger less abundant subtropic-adapted species are moving into the study area to feed. Actually, it is possible that juvenile/sub-adults are moving offshore to deeper colder waters, while adults are moving nearshore in pursue of prey. Another potential explanation is that rising water temperature is causing coldwater-adapted species to grow faster (Duffy et al. 2016). It is often difficult to explain or generalize the response of fish populations to climate change given the number of influential factors and individual species broad responses (Rijnsdorp et al. 2009).

The estimated biomass of coldwater and warmwater-adapted species was influenced by month and sampling area, whereas subtropic-adapted species were generally more influenced by the sampling area. This observation seems reasonable since the estimated abundance of most species in the coldwater and warmwater-adapted groups is correlated with season (i.e. water temperature). However, it was somewhat surprising that the subtropic-adapted group was not influenced by season, but it is possible that certain sampling areas have ideal and less fluctuating water temperatures given the oceanic dynamics (upwelling/downwelling and eddies) in the study area (Kohut et al. 2004). The total number and estimated abundance of coldwater-adapted and warmwater-adapted species in recent years (2013−2015) were influenced more by month and sampling area than the previous years (2008−2012) suggesting the seasonal water temperature could be rising and falling faster depending on the sampling area. Actually, the warming period is occurring earlier and lasting longer (Thomas et al. 2017), which could explain the decreasing and increasing abundance in coldwater-adapted and warmwater-adapted groups, respectively.

2.6 Conclusion

Resistance, resilience, and stability determine a community's health. A thorough understanding of the oceanic conditions and marine community over space and time is necessary to assess the associated ecological dynamics; and it is essential that researchers and managers have long-term data. Understanding biological and environmental patterns is necessary to differentiate between background natural variability and potential disturbance impacts.

The nearshore waters off New Jersey provide habitat for a variety of marine fauna, including various warmwater and subtropic-adapted species. As pointed out by this study, marine communities are dynamic systems that are shaped by a variety of intra, inter-related biological and environment factors that vary by time and space. Overall, the findings here suggest the marine community is fairly stable in terms of overall species composition, but estimated abundance is decreasing, estimated biomass is increasing, and the abundance and distribution of coldwater, warmwater, and subtropic-adapted species is changing with time in the study area. In particular, the coldwater-warmwater-adapted species are declining with time. Estimated abundance appears to be more stable in recent time.

The observations presented here have not been previously documented and provide valuable information regarding the nearshore marine community off the New Jersey coast. Besides describing the patterns in the oceanic conditions and marine community, the changes in faunal assemblages noted in this study will become increasingly pertinent for future studies on the impacts associated with natural and anthropogenic disturbance. The information presented in this study will help natural resources understand, predict, and plan for ongoing disturbances.

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2.7 References

Able, K.W., and Fahay. M.P. 1998. The first year in the life of estuary fishes in the Middle Atlantic Bight. New Brunswick, New Jersey: Rutgers University Press.

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

Able, K.W., Fahay, M.P., Witting, D.A., McBride, R.S., and Hagan, S.M. 2006. Fish settlement in the ocean vs. estuary: Comparison of pelagic larval and settled juvenile composition and abundance from southern New Jersey, U.S.A. Estuarine, Coastal and Shelf Science 66: 280−290.

Able, K.W., Wilber, D.H, Muzeni-Corino, A., and Clarke, D.G. 2010. Spring and summer larval fish assemblages in the surf zone and nearshore off northern New Jersey, USA. Estuaries and Coasts 33(1): 211−222.

Able, K.W., Grothues, T.M., Rowe, P.M., Wuenschel, M.J., and Vasslides, J.M. 2011. Near-Surface larval and juvenile fish in coastal habitats: Comparisons between the inner shelf and an estuary in the New York Bight during summer and fall. Estuaries and Coasts 34: 726–738.

Aschan M, Fossheim M, Greenacre M, and Primicerio R. 2013. Change in Fish Community Structure in the Barents Sea. PLoS ONE 8(4): e62748. doi:10.1371/journal.pone.0062748.

Azzurro, E., Moshella, P., and Maynou, F. 2011. Tracking Signals of Change in Mediterranean Fish Diversity Based on Local Ecological Knowledge. PLoS ONE 6(9): e24885. doi:10.1371/journal.pone.0024885.

ASMFC (Atlantic States Marine Fisheries Commission). 1994. Proceedings of the workshop on saltwater fishing tournaments. U.S. Fish and Wildlife Service, Atlantic States Marine Fisheries Commission Special Report Number 46.

Barange, M., and Perry, R.I. 2009. Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. pp. 7–106.

Bondavalli, C., Bodini, A., Rossetti, G., and Allesina, S. 2006. Detecting stress at a whole ecosystem level. The case of a mountain lake: Lake Santo (Italy). Ecosystems 9: 1–56.

Brander, K. 2013. Climate and current anthropogenic impacts on fisheries. Climatic Change 119: 9−21. doi 10.1007/s10584−012−0541−2.

Briggs, J. C. 1974. Marine zoogeography, 475 p. McGraw-Hill Book Co., New York, NY.

Byrne, D. 2008. Ocean trawling survey. New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Marine Fisheries Administration, Bureau of Marine Fisheries.

Byrne, D. 1994. Stock assessment of New Jersey’s nearshore recreational fisheries resources. In Proceedings of the workshop on the collection and use of trawl survey data for fisheries management, ed. T. Berger, 36–42. Washington: Atlantic States Marine Fisheries Commission.

Cheung, W. W. L., Dunne, J., Sarmiento, J. L., and Pauly, D. 2011. Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential under climate change in the Northeast Atlantic. ICES Journal of Marine Science, 68: 1008–1018.

Clarke, K.R., and Warwick, R.M. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2nd edition. PRIMER-E. Plymouth U.K.

Clarke, K.R., and Gorley, R.N. 2006. PRIMER V6: User Manual/ Tutorial. PRIMER-E, Plymouth, UK.

Code of Federal Regulations (CFR). Title 50 Wildlife and Fisheries. Chapter VI Fishery Conservation and Management, National Oceanic and Atmospheric Administration, Department of Commerce. Part 600 Magnuson-Stevens Act Provisions. 50 CFR 600.

Collette, B.B. and Klein-MacPhee, G. (eds.). 2002. Bigelow and Schroeder's fishes of the Gulf of Maine, third ed. Caldwell, N.J. Blackburn Press, 577 pp.

Colvocoresses, J.A., and Musick, J.A. 1984. Species associations and community composition of Middle Atlantic Bight continental shelf demersal fishes. Fishery Bulletin 82 (2): 295−313.

Cross, J.N., Zetlin, C.A., Berrien, P.L., Johnson, D.L., and McBride, C. 1999. Essential fish habitat source document: Butterfish, *Peprilus triacanthus*, life history and habitat characteristics. NOAA Technical Memorandum NMFS-NE-145:1−42.

Crozier, L.G., and Hutchings, J.A. 2014. Plastic and evolutionary responses to climate change in fish. Evolution Applications ISSN 1752–4571.

Daw, T., Adger, W.N., Brown, K., and Badjeck, M.C. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. 107−150.

Duffy, J.E., Lefcheck, J.S., Stuart-Smith, R.D., Navarrete, S.A., and Edgar, G.J. 2016. Biodiversity enhances reef fish biomass and resistance to climate change. PNAS 113 (22): 6230–6235.

Dunic., J.C., Elahi, R., Hensel, M.J. S., Kearns, P.J., O'Connor, M.L., Acuña, D., Honig, A., Wilson, A.R., and Byrnes, J.E.K. 2017. Attributing the variability in direction and magnitude of local-scale marine biodiversity change to human activities. BioRxiv 26 pp.

Elmqvist, T., C. Folke, M. Nystrom, G. Peterson, J. Bengtsson, B. Walker, and J. Norberg. 2003. Response diversity, ecosystem change, and resilience. Frontiers of Ecology and Environment 1(9): 488−494.

Epifanio, C.E., and Garvin, R.W. 2001. Larval transport on the Atlantic continental shelf of North America: a Review. Estuarine, Coastal and Shelf Science 52: 51–77.

Ficke, A.D., Myrick, C.A., and Hansen, L.J. 2007. Potential impacts of global climate change on freshwater fisheries. Reviews in Fish Biology and Fisheries 17: 581–613.

Floeter, S.R., Ferreira, C.E.L., Dominici-Arosemena, A., and I.R. Zalmon. 2004. Latitudinal gradients in Atlantic reef fish communities: trophic structure and spatial use patterns Journal of Fish Biology 64: 1680−1699.

Froese, R. and D. Pauly. 2018. https://www.fishbase.de/search.php. 2018. FishBase. World Wide Web electronic publication.www.fishbase.org, version (10/2018).

Geiger, E.F., Grossi, M.D., Trembanis, A.C., Kohut, J.T., and Oliver, M.J. 2013. Satellite-derived coastal ocean and estuarine salinity in the Mid-Atlantic. Continental Shelf Research 63: S235–S242. DOI: https://doi.org/10.1016/j. csr.2011.12.001.

Giordano, C., Hartley, S.L., Kurz, K., Michalski, K., and Figley, B. 2008. New Jersey party and charter boat directory 2000: Additions 2001−2008. Trenton, New Jersey: New Jersey Department of Environmental Protection.

Glenn, S., Arone, R., Bermann, K., Bissett, P.W., Crowley, M., Cullen, J., Gryzmski, J., Haidvogel, D., Kohut, J., Moline, M., Oliver, M., Orrisco, C., Sherrell, R., Song, T., Weidemann, A., Chang, R., and Schofield, O. 2004. Biogeochemical impact of summertime coastal upwelling on the New Jersey Shelf. Journal of Geophysical Research 109, C12S02, doi:10.1029/2003JC002265.

Hagan, S.M. and Able, K.W. 2008. Annual patterns in diel differences for species richness and total abundance were remarkably similar between 1995 and 1996 Estuaries and Coasts: J CERF 31: 33–42.

Hagan, S.M. and Able, K.W. 2003. Seasonal changes of the pelagic fish assemblage in a temperate estuary. Estuarine, Coastal and Shelf Science 56: 15−29.

Hare J.A, Wuenschel M.J., and Kimball M.E. 2012. Projecting Range Limits with Coupled Thermal Tolerance − Climate Change Models: An Example Based on Gray Snapper (Lutjanus griseus) along the U.S. East Coast. PLoS ONE 7(12): e52294.doi:10.1371/journal.pone.0052294.

Hare, J. A., Morrison, W. E., Nelson, M. W., Stachura, M. M., Teeters, E. J., Griffis, R. B., et al. . 2016. A vulnerability assessment of fish and invertebrates to climate change on the northeast U.S. continental shelf. PLOS ONE 11:e0146756.doi: 0.1371/journal.pone.0146756.

Hoese, H.D. and Moore, R.H. 1977. Fishes of the Gulf of Mexico, Texas, Louisiana and adjacent waters. Texas A. & M. University Press, College Station. 327 pp.

Horne, J.K., and Campana, S.E. 1989. Environmental factors influencing the distribution sf juvenile groundfish in nearshore habitats of southwest Nova Scotia. Canadian Journal of Fish and Aquatic Science 46: 1277−1286.

Howell, P., and Auster, P.J. 2012. Phase Shift in an Estuarine Finfish Community Associated with Warming Temperatures. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4: 481–495.

HydroQual, Inc. 2010. Narrative description of historical dissolved oxygen improvements in NY/NJ harbor related to previous nutrient reduction activities. 49 pp.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., and R.R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293: 629−638.

Jang, C. J., Park, J., Park, T., and Yoo, S. 2011. Response of the ocean mixed layer depth to global warming and its impact on primary production: a case for the North Pacific Ocean. – ICES Journal of Marine Science, 68: 996–1007.Johnson CA. (eds) Climate change 2001: the scientific basis. Cambridge University Press, Cambridge, UK, pp 101–181.

Kratz, T.K., Deegan, L.A., Harmon, M.E., and Lauenroth, W.K. 2003. Ecological Variability in Space and Time: Insights Gained from the US LTER Program. Bioscience 53 (1): 57−67.

King, M. 1995. Fisheries biology, assessment and management. Fishing News Books, Oxford.

Kohut, JT., Glenn, SM., and Chant, R.J. 2004. Seasonal current variability on the New Jersey inner shelf. Journal of Geophysical Research 109: C07S07. doi: 10.1029/2003JC001963,2004.

Korsman, B. 2013. The Spatial and Temporal Community Structure of Ichthyoplankton in a Northeast Florida Estuary: A Study of Ingress at a Faunal Boundary. UNF Theses and Dissertations. Paper 452.http://digitalcommons.unf.edu/etd/452.

Krishnakumar, P.K., and Bhat, G.S. 2008. Seasonal and interannual variations of oceanographic conditions off Mangalore coast (Karnataka, India) in the Malabar upwelling system during 1995–2004 and their influences on the pelagic fishery. Fisheries Oceanography 17 (1): 45–60.

Lazaroff, C. 2001. Historic overfishing led to modern ocean problems. Environment News Service. Accessed 5 January 2005. http:www.cgaux1sr.org/msep/fish.htm.

Li, Y, Fratantoni, P.S., Chen, C., Hare, J.A., and Sun, Y. 2015. Spatio-temporal patterns of stratification on the Northwest Atlantic shelf. Progress Oceanography 134: 123–137. doi: https://doi.org/10.1016/j. pocean.2015.01.003.

Malakoff, D. 1997. Extinction on the high seas. Science 277: 486−488.

Matear, R. J., and Hirst, A.C. 2003. Long−term changes in dissolved oxygen concentrations in the ocean caused by protracted global warming. Global Biogeochemical Cycles 17 (4): 1125 doi:10 1029/2002GB001997.

Moline, M.A., Blackwell, S.M., Chant, R., Oliver, M.J., Bergmann, T., Glenn, S., and Schofield, O.E. 2004. Episodic physical forcing and the structure of phytoplankton communities in the coastal waters of New Jersey. Journal of Geophysical Research 109, C12S05, doi:10.1029/2003JC001985.

Moser, J. and Shepherd, G.R. 2009. Seasonal distribution and movement of black sea bass (*Centropristis striata*) in the Northwest Atlantic as determined from a mark-recaptured experiment. Journal of the Northwest Atlantic Fishery Science 40: 17−28.

Murdy, E., R. Baker, and Musick, J. 1997. Fishes of Chesapeake Bay. Washington, D.C.: Smithsonian Institution Press.

Muyodi, F.J., Mwanuzi, F.L., and Kapiyo, R. 2011. Environmental quality and fish communities in selected catchments of Lake Victoria. The Open Environmental Engineering Journal 4: 54−65.

NMFS (National Marine Fisheries Service). 2002. Essential fish habitat: A marine fish habitat conservation mandate for federal agencies, South Atlantic region. St. Petersburg, Florida: National Marine Fisheries Service, Habitat Conservation Division, Southeast Regional Office.

NMFS (National Marine Fisheries Service). 2011. Recreational fisheries. Accessed 10 October 2011. http://www.st.nmfs.noaa.gov/st1/recreational/index.html.

NMFS (National Marine Fisheries Service). 2018. Commercial Fisheries Statistics. Accessed at: https://www.st.nmfs.noaa.gov/commercial−fisheries/commercial−landings/. Accessed on: 25 January 2018.

Nye, J.A., Link, J.S., Hare, J.A., and Overholtz, W.J. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Marine Ecology Series 393: 111−129. doi: 10.3354/meps08220.

Parker, R.O., Jr., and Dixon, R.L. 1998. Changes in a North Carolina reef−fish community after 15 years of intense fishing: Global−warming implications. Transactions of the American Fisheries Society 127(6): 908–920.

Pinsky, M.L., Worm, B., Fogarty, M.J., Sarmiento, J.L., and Levin, S.A. 2013. Marine taxa track local climate velocities. Science 341: 1239−1242.

Pinsky, M.L., and Mantua, N.J. 2014. Emerging adaptation approaches for climate ready fisheries management. Oceanography 27(4):146–159, http://dx.doi.org/10.5670/ oceanog.2014.93.

Polovina, J. J., Dunne, J. P., Woodworth, P. A., and Howell, E. A. 2011. Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming. – ICES Journal of Marine Science 68: 986–995.

Preble, D. 2001. The fishes of the sea -- Commercial and sport fishing in New England. Dobbs Ferry, New York: Sheridan House.

Reash, R.J., and Pigg, J. 1990. Physicochemcial factors affecting the abundance and species richness of fishes in the Cimarron River. Proceedings Oklahoma Academic Science 70: 23−28.

Richards, R.A., P.C. Nitschke, and Sosebee. K.A. 2008. Population biology of monkfish *Lophius americanus*. ICES Journal of Marine Science 65: 1291−1305.

Rijnsdorp, A.D., Peck, M.A., Engelhard, G.H., Mo¨llmann, C., and Pinnegar, J.K. 2009. Resolving the effect of climate change on fish populations. ICES Journal of Marine Science, 66: 1570–1583.

Rountree, R.A. and Able, K.W. 1997. Nocturnal fish use of New Jersey marsh creek and adjacent bay shoal habitats. Estuarine, Coastal and Shelf Science 44: 703−711.

Saila, S.B. and Pratt, S.D. 1973. Mid-Atlantic Bight fisheries. Pages 6-1 to 6-125 in Coastal and offshore environmental inventory: Cape Hatteras to Nantucket Shoals. University of Rhode Island: Marine Publication Series No. 2. Kingston, RI.

Schofield, O., Chant, R., Cahill, B., Castelao, R., Gong, D., Kahl, A., Kohut, J., Montes-Hugo, M., Ramadurai, R., Ramey, P., and Glenn, S. 2008. The Decadal View of the Mid-Atlantic Bight from the COOLroom: Is Our Coastal System Changing? Oceanogrpahy 21 4: 108-117.

Slacum, W.H. Burton, W.H., and Methratta, E.T. 2010. Assemblage structure in shoal and flat-bottom habitats on the inner continental shelf of the Middle Atlantic Bight, USA. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 2: 277–298.

Song, T.Y., Haidvogel, D.B., and Glenn, S.M. 2001. Effects of topographic variability on the formation of upwelling centers off New Jersey: A theoretical model, Journal of Geophysical Research 106: 9223– 9240.

Steimle, F.W. and Zetlin, C. 2000. Reef habitats in the Middle Atlantic Bight: abundance, distribution, associated biological communities and fishery resource use. Marine Fisheries Review. 62(2): 24−41.

Szedlmayer, S.T. and Able, K.W. 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. Estuaries 19(3): 697−709.

Taylor, D.L., R.S. Nichols, and Able, K.W. 2007. Habitat selection and quality for multiple cohorts of young-of the-year bluefish (*Pomatomus saltatrix*): Comparisons between estuarine and ocean beaches in southern New Jersey. Estuarine, Coastal and Shelf Science 73: 667−679.

Thomas, A.C, Pershing, A.J., Friedland, K.D., Nye, J.A., Mills, K.E., Alexander, M.A., Record, N.R., Weatherbee, R., and Henderson, E.M. 2017. Seasonal trends and phenology shifts in sea surface temperature on the North American northeastern continental shelf. Elem Sci Anth, 5: 48. doi: https://doi.org/10.1525/elementa.240.

Thorne, R.St., J. W.P. Williams and Cao, Y. 1999. The influence of data transformations on biological monitoring studies using macroinvertebrates. Water Resources. 33(2): 343−350.

Turner, B.L, Kasperson, R.E., Matsone, P.A., McCarthy, J.J., Corellg, R.W., Christensene, L., Eckley, N., Kasperson, J.X., Luerse, A., Martellog, M.L., Polskya, C., Pulsiphera, A., and Schillerb, A. 2003. A framework for vulnerability analysis in sustainability science. PNAS 100 (14): 8074–8079.

Vinebrooke, R., K. Cottingham, J.N Orberg, M.S Cheffer, S.Dodson, S. Maberly, and Sommer, U. 2004. Impacts of multiple stressors on biodiversity and ecosystem functioning: The role of species co−tolerance. Oikos104:451–457.doi:10.1111/j.0030−1299.2004.13255.x.

Warfe, D.M., Jardine, T.D., Pettit, N.E., Hamilton, S.K., Pusey, B.J., et al. 2013. Productivity, Disturbance and Ecosystem Size Have No Influence on Food Chain Length in Seasonally Connected Rivers. PLoS ONE 8(6): e66240. doi:10.1371/journal.pone.0066240.

Wood, A.J.M, Collie, J.S., and Hare, J.A. 2009. A comparison between warm-water fish assemblages of Narragansett Bay and those of Long Island Sound waters. Fishery Bulletin 107: 89−100.

Zar, J.H. 1999. Biostatistical analysis, 4th Ed. Prentice Hall, Upper Saddle River, NJ.

2.8 Appendix

Table 2.8-1. The number of individuals collected per water temperature preference category in the study area (1988−2015). The water temperature preference groups were defined as the following: coldwater-adapted group (<15°C), warmwater-adapted group (16-29°C), and subtropic-adapted group (>29°C).

Species	**Coldwater-adapted**	**Subtropic-adapted**	**Warmwater-adapted**
AFRICAN POMPANO		25	
ALEWIFE	60,495		
AMERICAN EEL			39
AMERICAN LOBSTER	3,235		
AMERICAN SAND LANCE	177,256		
AMERICAN SHAD			14,330
ARMORED SEAROBIN			1
ATLANTIC ANGEL SHARK		119	
ATLANTIC ARGENTINE	3		
ATLANTIC BONITO			3
ATLANTIC COD	222		
ATLANTIC CROAKER			164,464
ATLANTIC CUTLASSFISH		131	
ATLANTIC HERRING	544,032		
ATLANTIC MACKEREL	48,907		
ATLANTIC MENHADEN			28,303
ATLANTIC MOONFISH		38,691	
ATLANTIC NEEDLEFISH		4	
ATLANTIC POMFRET		1	
ATLANTIC SHARPNOSE SHARK			13
ATLANTIC SILVERSIDE			24,290
ATLANTIC SPADEFISH		7	
ATLANTIC STURGEON	364		

Species	Coldwater-adapted	Subtropic-adapted	Warmwater-adapted
ATLANTIC THREAD HERRING			471
ATLANTIC TOMCOD	8		
BANDED DRUM		447	
BANDED RUDDERFISH		421	
BARNDOOR SKATE	3		
BAY ANCHOVY		9,227,960	
BAY WHIFF			1
BIGEYE		58	
BIGEYE CIGARFISH			17
BIGEYE SCAD		3,966	
BIGEYE THRESHER			2
BLACK DRUM			453
BLACK SEA BASS			29,451
BLACKBAR SOLDIERFISH		1	
BLACKCHEEK TONGUEFISH		66	1
BLOTCHED CUSK EEL	6		
BLUE CRAB			4,074
BLUE RUNNER		707	
BLUEBACK HERRING			75,846
BLUEFISH			76,875
BLUESPOTTED CORNETFISH			85
BLUNTHEAD PUFFER			1
BLUNTNOSE JACK		15	
BLUNTNOSE STINGRAY		239	
BRIEF SQUID			2,702
BULLET MACKEREL			3
BULLNOSE RAY		7,402	
BUTTERFISH			2,873,138
CHANNELED WHELK	1,507		
CHESTNUT ASTARTE	93		

Species	Coldwater-adapted	Subtropic-adapted	Warmwater-adapted
CHUB MACKEREL		3,209	
CLEARNOSE SKATE			110,379
COBIA			18
COMMON RAZOR CLAM	44		
COMMON SPIDER CRAB	27,971		
CONGER EEL			275
COWNOSE RAY			883
CREVALLE JACK		32	
CUNNER	6,448		
DOG WHELK			3
DOTTEREL FILEFISH			5
DUSKY ANCHOVY			22,961
DUSKY SHARK			65
DWARF GOATFISH		372	
DWARF HERRING		26	
FALSE QUAHOG	17		
FEATHER BLENNY	5		
FINETOOTH SHARK		1	
FLAT ANCHOVY			855
FLORIDA POMPANO		14	
FLYING GURNARD		3	
FOURBEARD ROCKLING	6		
FOURSPINE STICKLEBACK	1		
FOURSPOT FLOUNDER	5,632		
GIZZARD SHAD			125
GOOSEFISH	327		
GRAY TRIGGERFISH			128
GREATER AMBERJACK		2	
GREEN TURTLE			2
GRUBBY	110		

Species	Coldwater-adapted	Subtropic-adapted	Warmwater-adapted
GUAGUANCHE		5	
GULF SHRIMP (PINK,BROWN,WHITE)			598
GULF STREAM FLOUNDER	657		
HADDOCK	1,211		
HARD CLAM			15
HARVESTFISH			79
HICKORY SHAD			531
HOGCHOKER			4,024
HORSESHOE CRAB			31,220
INSHORE LIZARDFISH		1,724	
JONAH CRAB	728		
KNOBBED WHELK	3,278		
LADY CRAB	37,291		
LADY FISH			1
LEATHERBACK TURTLE			1
LEATHERJACKET			2
LESSER AMBERJACK			9
LINED SEAHORSE			257
LITTLE SKATE	316,356		
LITTLE TUNNY			5
LOGGERHEAD TURTLE			9
LONGFIN SQUID	2,225,975		
LONGHORN SCULPIN	135		
LONGSPINE PORGY			6
LOOKDOWN		318	
MACKEREL SCAD		7	
MANTIS SHRIMP			115
MARGINED SEASTAR			1
MUMMICHOG	2		
NAKED GOBY			113

Species	Coldwater-adapted	Subtropic-adapted	Warmwater-adapted
NORTHERN KINGFISH			24,076
NORTHERN MOON SHELL	29,123		
NORTHERN PIPEFISH	1,570		
NORTHERN PUFFER			32,895
NORTHERN SAND LANCE	3		
NORTHERN SEAROBIN			503,230
NORTHERN SENNET		1,264	
NORTHERN STARGAZER	173		
OCEAN POUT	4,439		
OCEAN QUAHOG	22		
OFFSHORE LIZARDFISH			1
OFFSHORE SEAHORSE		7	
ORANGE FILEFISH		15	
OYSTER TOADFISH			23
PASTEL SWIMMING CRAB	411		
PIGFISH			667
PINFISH			296
PLANEHEAD FILEFISH		66	
POLLOCK	208		
RED CORNETFISH		41	
RED DRUM			2
RED GOATFISH		53	
RED HAKE	31,681		
REMORA			4
RIDLEY TURTLE			2
ROCK CRAB			83,028
ROCK GUNNEL	25		
ROUGH SCAD		15,771	
ROUGHTAIL STINGRAY			1,063
ROUND HERRING			274,472

Species	Coldwater-adapted	Subtropic-adapted	Warmwater-adapted
ROUND SCAD		20,954	
SAND TIGER			25
SANDBAR SHARK		29	
SCAMP			1
SCRAWLED FILEFISH			2
SCUP			1,318,569
SEA LAMPREY			122
SEA RAVEN	64		
SEA SCALLOP	1,528		
SEASNAIL	22		
SHARK'S EYE OR LOBED MOON SHELL		19,788	19,788
SHARKSUCKER		11	
SHEEPSHEAD			9
SHORT BIGEYE		11	
SHORTFIN SQUID	9,573		
SHORTNOSE STURGEON	6		
SILVER ANCHOVY			17,459
SILVER HAKE	147,170		
SILVER PERCH			23,009
SKILLETFISH		1	
SMALLMOUTH FLOUNDER			10,754
SMOOTH BUTTERFLY RAY		6	
SMOOTH DOGFISH			78,514
SMOOTH PUFFER			2
SNAKEFISH		10	
SNOWY GROUPER			1
SOUTHERN KINGFISH			26,040
SOUTHERN STINGRAY		429	
SPANISH MACKEREL		353	
SPANISH SARDINE		59	

Species	Coldwater-adapted	Subtropic-adapted	Warmwater-adapted
SPINY BUTTERFLY RAY			204
SPINY DOGFISH	64,153		
SPINY SEAROBIN			53
SPOT			170,802
SPOTFIN BUTTERFLYFISH		30	
SPOTFIN MOJARRA			97
SPOTTAIL PINFISH		1	
SPOTTED HAKE			168,052
SPOTTED TRUNKFISH		1	
SQUIRRELFISH			1
STIMPSON'S WHELK	1		
STRIPED ANCHOVY		245,214	
STRIPED BASS			12,326
STRIPED BURRFISH		316	
STRIPED CUSK EEL			2,455
STRIPED KILLIFISH			3
STRIPED MULLET			93
STRIPED SEAROBIN			57,924
STRIPED SEASNAIL	8		
SUMMER FLOUNDER			48,732
SURF CLAM	9,261		
TAUTOG			3,833
THORNY SKATE	1		
THREESPINE STICKLEBACK	845		
THRESHER SHARK			42
TIGER SHARK			1
TILEFISH	5		
TRUNKFISH			4
WARSAW GROUPER			1
WAVED WHELK	9		

Species	Coldwater-adapted	Subtropic-adapted	Warmwater-adapted
WEAKFISH			448,476
WENCHMAN			13
WHITE HAKE	5		
WHITE PERCH			73
WHITE SHARK	1		
WINDOWPANE	145,048		
WINTER FLOUNDER	66,427		
WINTER SKATE	30,804		
WITCH FLOUNDER	62		
YELLOW JACK		13	
YELLOWTAIL FLOUNDER	231		

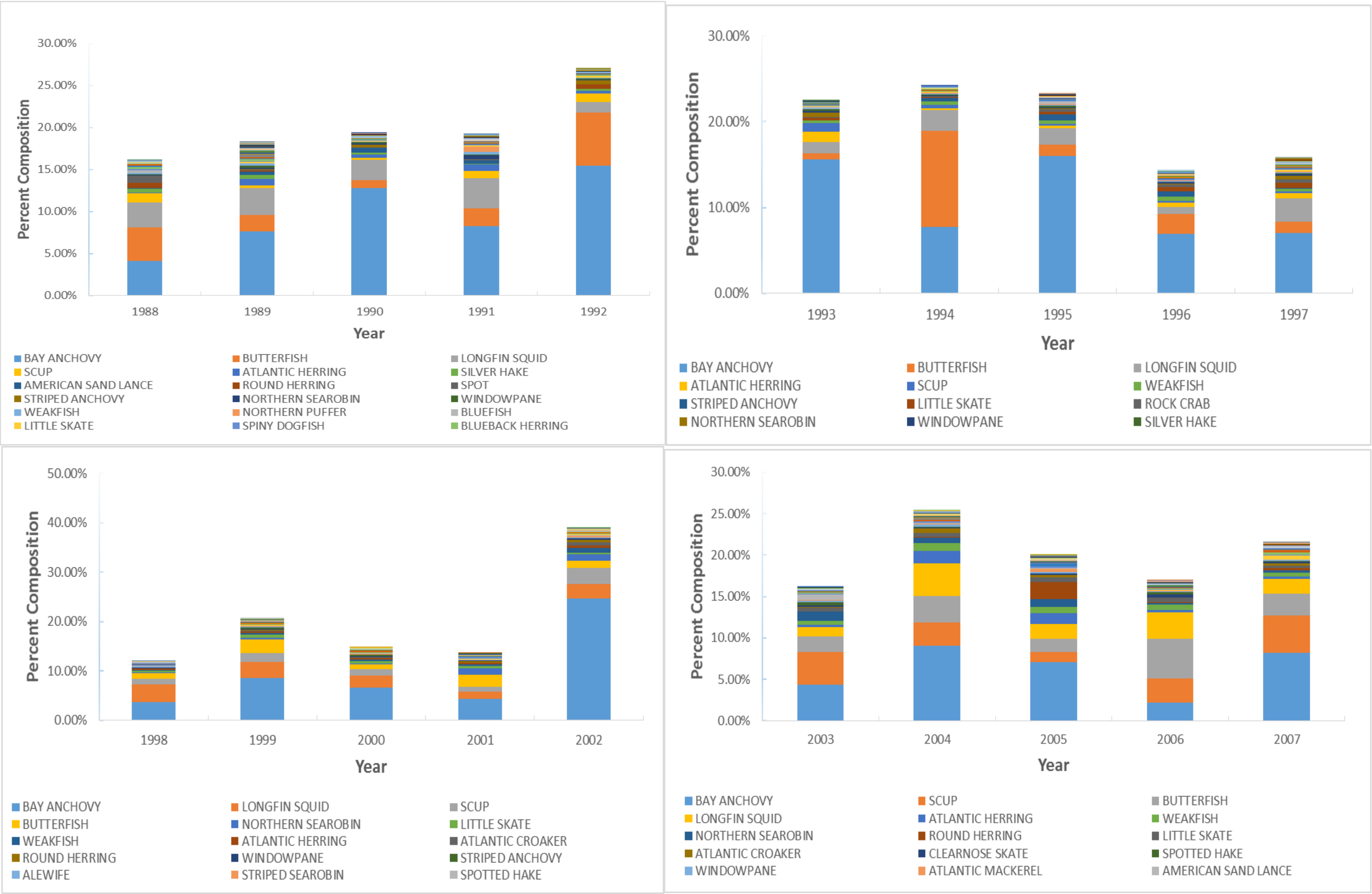


Figure 2.8-1. Total catch and percent composition of marine fauna collected within the study area per 5-year periods (1988–2007). Individual graphs show the overall percent composition of the catch during a 5-year period; data were pooled per 5-year time-series.

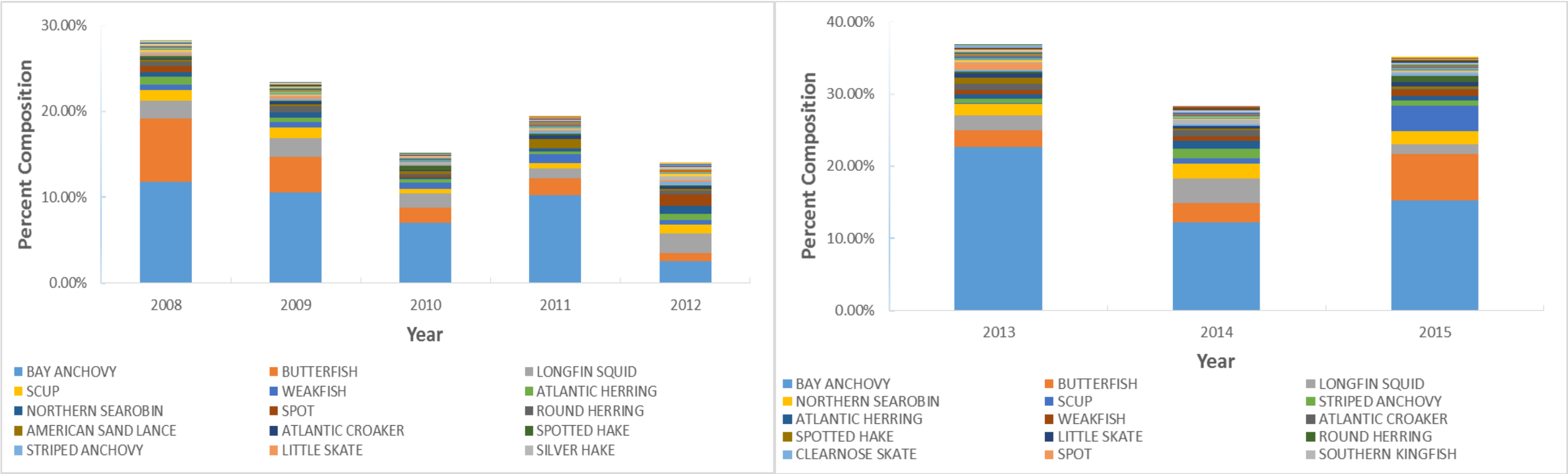


Figure 2.8-2. Total catch and percent composition of marine fauna collected within the study area per 5-year periods (2008–2015). Individual graphs show the overall percent composition of the catch during a 5-year period; data were pooled per 5-year time-series.

Table 2.8-2. Three-way ANOVA. Total number of marine collected in the study area (1988−1992).

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	Fisher’s Least Significant Difference Procedure			
						Contrast	**Sig.**	**Difference**	**+/- Limits**
MAIN EFFECTS						1988 - 1989	*	0.234289	0.0910579
A:Year	169.893	4	42.4732	19.56	0.0000	1988 - 1990	*	0.336326	0.0939087
B:Month	298.07	5	59.6141	27.46	0.0000	1988 - 1991	*	0.340713	0.090885
C:Area	81.1486	14	5.79633	2.67	0.0007	1988 - 1992	*	0.377159	0.0910809
RESIDUAL	35081.5	16160	2.17088			1989 - 1990	*	0.102037	0.0715443
TOTAL (CORRECTED)	35796.6	16183				1989 - 1991	*	0.106424	0.0673245
						1989 - 1992	*	0.14287	0.0677569

Table 2.8-3. Catch characteristics. One-way (annual variation among means) ANOVA (1988−1992).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number	ANOVA	F [4, 16183] = 37.35, $P < 0.05$	1988 - 1989	*	0.371367	0.0859363
			1988 - 1990	*	0.456963	0.0896886
			1988 - 1991	*	0.470181	0.0864232
			1988 - 1992	*	0.503715	0.0867358
			1989 - 1990	*	0.0855951	0.0699203
			1989 - 1991	*	0.0988131	0.0656794
			1989 - 1992	*	0.132348	0.0660901
Annual Estimated Abundance	ANOVA	F [4, 16183] = 9.68, $P < 0.05$	1988 - 1989	*	0.0174469	0.00787233
			1988 - 1990	*	0.023737	0.00821607
			1988 - 1991	*	0.0227131	0.00791694
			1988 - 1992	*	0.0202019	0.00794557
Annual Estimated Biomass	ANOVA	F [4, 16183] = 0.31, $P = 0.8717$	N/A			

Table 2.8-4. Catch characteristics. One-way (annual variation among means) ANOVA (1993−1997).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number	ANOVA	F [4, 18961] = 5.34, P = 0.0003	1993 - 1995	*	-0.116591	0.0602942
			1993 - 1996	*	-0.0631126	0.0601312
			1993 - 1997	*	-0.123633	0.0600025
			1994 - 1997	*	-0.0655766	0.0625138
			1996 - 1997	*	-0.0605201	0.0583863
Annual Estimated Abundance	ANOVA	F [4, 18961] = 3.82, P = 0.0042	1993 - 1995	*	-0.00953427	0.00568863
			1993 - 1997	*	-0.00975415	0.00566111
Annual Estimated Biomass	ANOVA	F [4, 18961] = 7.92, $P < 0.5$	1993 - 1994	*	0.00370907	0.00316189
			1993 - 1995	*	-0.00400308	0.002972
			1993 - 1997	*	-0.00365834	0.00295762
			1994 - 1995	*	-0.00771215	0.00309521
			1994 - 1996	*	-0.00583724	0.0030875
			1994 - 1997	*	-0.0073674	0.00308141

Table 2.8-5. Catch characteristics. One-way (annual variation among means) ANOVA (1998−2002).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number	ANOVA	F [4, 17471] = 15.36, $P < 0.05$	1998 - 1999	*	-0.129399	0.0606409
			1998 - 2002	*	-0.201192	0.0592407
			1999 - 2000	*	0.0881122	0.0615547
			1999 - 2001	*	0.108109	0.0624568
			1999 - 2002	*	-0.071793	0.0594289
			2000 - 2002	*	-0.159905	0.0601757
			2001 - 2002	*	-0.179901	0.0610982
Annual Estimated Abundance	ANOVA	F [4, 17471] = 13.35, $P < 0.05$	1998 - 2000	*	-0.02517	0.0146972
			1998 - 2001	*	-0.0153824	0.0149139
			1998 - 2002	*	-0.0388733	0.0141866
			1999 - 2000	*	-0.0330174	0.0147408
			1999 - 2001	*	-0.0232298	0.0149568
			1999 - 2002	*	-0.0467207	0.0142317
			2001 - 2002	*	-0.0234909	0.0146314
Annual Estimated Biomass	ANOVA	F [4, 17471] = 6.54, $P < 0.5$	1998 - 1999	*	0.0591799	0
			1998 - 2000	*	0.0150512	0
			1998 - 2001	*	0.0535589	0
			1998 - 2002	*	0.15137	0
			1999 - 2000	*	-0.0441287	0
			1999 - 2001	*	-0.00562106	0
			1999 - 2002	*	0.0921905	0
			2000 - 2001	*	0.0385076	0
			2000 - 2002	*	0.136319	0
			2001 - 2002	*	0.0978116	0

Table 2.8-6. Catch characteristics. One-way (annual variation among means) ANOVA (2003−2007).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number	ANOVA	*F* [4, 18285] = 3.87, *P* = 0.0038	2003 - 2004	*	-0.119311	0.0650814
			2004 - 2005	*	0.0741499	0.0649805
			2004 - 2006	*	0.105584	0.0649501
			2004 - 2007	*	0.0817902	0.0647439
Annual Estimated Abundance	ANOVA	*F* [4, 18825] = 2.52, *P* = 0.0389	2003 - 2004	*	-0.00930393	0.00608553
			2004 - 2006	*	0.00731028	0.00607326
Annual Estimated Biomass	ANOVA	*F* [4, 18825] = 1.21, *P* = 0.3037	2004 - 2006	*	0.00371756	0.00371526

Table 2.8-7. Catch characteristics. One-way (annual variation among means) ANOVA (2008−2012).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number	ANOVA	*F* [4, 17569] = 2.29, *P* = 0.057	2008 - 2010	*	0.0878922	0.0657378
			2008 - 2011	*	0.0664381	0.0637379
			2008 - 2012	*	0.0667867	0.0638616
Annual Estimated Abundance	ANOVA	*F* [4, 17569] = 2.24, *P* = 0.0626	2008 - 2010	*	0.00844498	0.0061613
			2008 - 2011	*	0.0061585	0.0059739
			2008 - 2012	*	0.00637383	0.0059854
Annual Estimated Biomass	ANOVA	*F* [4, 17569] = 2.97, *P* = 0.0184	2010 - 2012	*	-0.00589934	0.0035423
			2011 - 2012	*	-0.004267	0.0034369

Table 2.8-8. Catch characteristics. One-way (annual variation among means) ANOVA (2013−2015).

Catch Parameter	**Hypothesis Test**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number	ANOVA	*F* [2, 11092] = 3.73, *P* = 0.0241	2013 - 2014	*	0.083973	0.0616408
Annual Estimated Abundance	ANOVA	*F* [2, 11092] = 3.36, *P* = 0.0347	2013 - 2014	*	0.00743325	0.00578224
Annual Estimated Biomass	ANOVA	*F* [2, 11092] = 3.75, *P* = 0.0237	2013 - 2014	*	0.00457816	0.00351957
			2014 - 2015	*	-0.00392494	0.00356265

Table 2.8-9. Catch characteristics. One-way (annual variation among means) ANOVA (1988−2015). Six 5-year series (pooled).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number	ANOVA	*F* [5, 99566] = 12.47, *P* < 0.05	1988-1992 – 1993-1997	*	0.066748	0.0290054
			1988-1992 – 1998-2002	*	0.0799135	0.0295694
			1988-1992 – 2008-2012	*	0.0416243	0.0295297
			1988-1992 – 2013-2015	*	0.0558608	0.0334085
			1993-1997 – 2003-2007	*	-0.0787699	0.0280916
			1998-2002 – 2003-2007	*	-0.0919354	0.0286736
			1998-2002 – 2008-2012	*	-0.0382892	0.0289576
			2003-2007 – 2008-2012	*	0.0536462	0.0286326
			2003-2007 – 2013-2015	*	0.0678827	0.0326182
Annual Estimated Abundance	ANOVA	*F* [5, 99566] = 10.44, *P* < 0.05	19881992 – 1998-2002	*	0.0052094	0.00275739
			19881992 – 2003-2007	*	-0.0044744	0.00272771
			1993-1997 – 1998-2002	*	0.00385523	0.00265046
			1993-1997 – 2003-2007	*	-0.00582863	0.00261957
			1998-2002 – 2003-2007	*	-0.00968387	0.00267385
			1998-2002 – 2008-2012	*	-0.00504902	0.00270034
			1998-2002 – 2013-2015	*	-0.00386353	0.00306833
			2003-2007 – 2008-2012	*	0.00463485	0.00267003

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
			2003-2007 – 2013-2015	*	0.00582033	0.00304169
Annual Estimated Biomass	ANOVA	F [5, 99566] = 69.61, $P < 0.05$	1988-1992 – 1998-2002	*	-0.00607596	0.00154761
			1988-1992 – 2003-2007	*	-0.0129088	0.00153096
			1988-1992 – 2008-2012	*	-0.00442704	0.00154554
			1988-1992 – 2013-2015	*	-0.00524966	0.00174854
			1993-1997 – 1998-2002	*	-0.0046965	0.0014876
			1993-1997 – 2003-2007	*	-0.0115293	0.00147027
			1993-1997 – 2008-2012	*	-0.00304758	0.00148544
			1993-1997 – 2013-2015	*	-0.0038702	0.00169566
			1998-2002 – 2003-2007	*	-0.0068328	0.00150073
			1998-2002 – 2008-2012	*	0.00164892	0.00151559
			2003-2007 – 2008-2012	*	0.00848172	0.00149859
			2003-2007 – 2013-2015	*	0.0076591	0.00170718

Table 2.8-10. Catch characteristics. Temperature preference. One-way (annual variation among means) ANOVA (1988−1992).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number (Coldwater-adapted)	ANOVA	*F* [4, 8095] = 2.71, *P* = 0.0286	1996 - 1997	*	-53.4989	32.2086
Annual Estimated Abundance (Coldwater-adapted)	ANOVA	*F* [4, 16183] = 2.53, *P* = 0.0388	1994 - 1996	*	0.00275119	0.00273631
			1996 - 1997	*	-0.00406147	0.00256383
Annual Estimated Biomass (Coldwater-adapted)	ANOVA	*F* [4, 8095] = 2.54, *P* = 0.0376	1993 - 1994	*	0.000241622	0.0002186
			1994 - 1995	*	-0.000252245	0.0002199
			1994 - 1997	*	-0.000339303	0.0002156
Annual Total Number (Warmwater-adapted)	ANOVA	*F* [4, 7578] = 33.8, *P* < 0.05	1988 - 1989	*	0.498187	0.1066450
			1988 - 1990	*	0.60625	0.1095150
			1988 - 1991	*	0.535322	0.1063090
			1988 - 1992	*	0.532257	0.1062800
			1989 - 1990	*	0.108063	0.0886930
Annual Estimated Abundance (Warmwater-adapted)	ANOVA	*F* [4, 7578] = 15.45, *P* < 0.05	1988 - 1989	*	0.02892	0.00972639
			1988 - 1990	*	0.0374684	0.00998820
			1988 - 1991	*	0.0288338	0.00969574
			1988 - 1992	*	0.0231082	0.00969316
			1989 - 1990	*	0.00854837	0.00808913
			1990 - 1991	*	-0.0086346	0.00805226
			1990 - 1992	*	-0.0143602	0.00804915
Annual Estimated Biomass (Warmwater-adapted)	ANOVA	*F* [4, 7578] = 4.71, *P* = 0.0008	1988 - 1989	*	0.010781	0.00529619
			1988 - 1990	*	0.00588086	0.00543875
			1988 - 1991	*	0.00759486	0.00527950
			1989 - 1990	*	-0.00490013	0.00440467
			1989 - 1992	*	-0.00631996	0.00420469
Annual Total Number (Subtropic-adapted)	ANOVA	*F* [4, 1141] = 2.00, *P* = 0.0928)	N/A			
Annual Estimated Abundance (Subtropic-adapted)	ANOVA	*F* [4, 1141] = 3.22, *P* = 0.0121	1988 - 1992	*	-0.0779558	0.0537979
			1989 - 1992	*	-0.0583644	0.0472584
			1991 - 1992	*	-0.0699673	0.0495317
Annual Estimated Biomass (Subtropic-adapted)	ANOVA	*F* [4, 1141] = 2.96, *P* = 0.0189	1988 - 1989	*	-0.011523	0.0115151
			1988 - 1990	*	-0.0149959	0.0118700

			1988 - 1991	*	-0.0198024	0.0119584
			1988 - 1992	*	-0.0159097	0.0116992

Table 2.8-11. Catch characteristics. Temperature preference. One-way (annual variation among means) ANOVA (1993−1997).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number (Coldwater-adapted)	ANOVA	F [4, 8095] = 7.42, $P > 0.05$	1993 - 1995	*	-0.094122	0.077262
			1993 - 1997	*	-0.137535	0.0756163
			1994 - 1995	*	-0.142427	0.0810024
			1994 - 1997	*	-0.185839	0.0794343
			1995 - 1996	*	0.0940402	0.07598
			1996 - 1997	*	-0.137453	0.0743059
Annual Estimated Abundance (Coldwater-adapted)	ANOVA	F [4, 16183] = 6.09, $P = 0.0001$	1993 - 1995	*	-0.00740232	0.00728692
			1993 - 1997	*	-0.011036	0.00713171
			1994 - 1995	*	-0.0123822	0.00763969
			1994 - 1997	*	-0.0160158	0.00749179
			1995 - 1996	*	0.00835435	0.00716601
			1996 - 1997	*	-0.011988	0.00700812
Annual Estimated Biomass (Coldwater-adapted)	ANOVA	F [4, 8095] = 4.23, $P = 0.002$	1993 - 1994	*	0.00726766	0.00484306
			1994 - 1995	*	-0.00967455	0.00487122
			1994 - 1997	*	-0.00639786	0.00477692
			1995 - 1996	*	0.00517756	0.00456919
Annual Total Number (Warmwater-adapted)	ANOVA	F [4, 8095] = 3.84, $P = 0.0040$	1993 - 1994	*	-0.104134	0.0760369
			1993 - 1996	*	-0.0978959	0.0717019
			1994 - 1997	*	0.156873	0.109563
			1995 - 1997	*	0.120317	0.105957
			1996 - 1997	*	0.150635	0.1066
Annual Estimated Abundance (Warmwater-adapted)	ANOVA	F [4, 8095] = 3.83, $P = 0.0041$	1993 - 1994	*	-0.00947398	0.00718242
			1993 - 1996	*	-0.00834278	0.00677295
			1994 - 1997	*	0.0161678	0.0103493
			1995 - 1997	*	0.0116997	0.0100087
			1996 - 1997	*	0.0150366	0.0100694
Annual Estimated Biomass (Warmwater-adapted)	ANOVA	F [4, 8095] = 10.17, $P < 0.05$	1993 - 1995	*	-0.00633031	0.00401248
			1993 - 1996	*	-0.00766098	0.0040669
			1993 - 1997	*	0.00778702	0.00612033
			1994 - 1995	*	-0.00680895	0.00415449
			1994 - 1996	*	-0.00813962	0.00420707
			1994 - 1997	*	0.00730838	0.00621435
			1995 - 1997	*	0.0141173	0.00600984
			1996 - 1997	*	0.015448	0.00604631

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number (Subtropic-adapted)	ANOVA	*F* [4, 1160] = 2.01, *P* = 0.09	N/A			
Annual Estimated Abundance (Subtropic-adapted)	ANOVA	*F* [4, 1141] = 2.0, *P* = 0.09	N/A			
Annual Estimated Biomass (Subtropic-adapted)	ANOVA	*F* [4, 1141] = 1.26, *P* = 0.2840	N/A			

Table 2.8-12. Catch characteristics. Temperature preference. One-way (annual variation among means) ANOVA (1998−2002).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number (Coldwater-adapted)	ANOVA	*F* [4, 6948] = 1.81, *P* = 0.1243	1999 - 2001	*	0.1070040	0.0886476
			2001 - 2002	*	-0.0931688	0.0901878
Annual Estimated Abundance (Coldwater-adapted)	ANOVA	*F* [4, 6948] = 2.4, *P* = 0.0479	1999 - 2001	*	0.0100425	0.00823922
			2001 - 2002	*	-0.0103886	0.00838237
Annual Estimated Biomass (Coldwater-adapted)	ANOVA	*F* [4, 6948] = 6.11, *P* = 0.0001	1998 - 1999	*	-0.00762546	0.0048441
			1998 - 2000	*	-0.00711915	0.00501367
			1998 - 2002	*	-0.0110404	0.00493873
			1999 - 2001	*	0.00541523	0.00513943
			2001 - 2002	*	-0.00883016	0.00522872
Annual Total Number (Warmwater-adapted)	ANOVA	*F* [4, 6948] = 11.02, *P* < 0.05	1998 - 1999	*	-0.202405	0.0691171
			1998 - 2000	*	-0.092409	0.0691444
			1998 - 2001	*	-0.0991565	0.074011
			1999 - 2000	*	0.109996	0.0684026
			1999 - 2001	*	0.103249	0.0733185
Annual Estimated Abundance (Warmwater-adapted)	ANOVA	*F* [4, 6948] = 12.16, *P* < 0.05	1998 - 1999	*	-0.0196963	0.00641151
			1998 - 2000	*	-0.00877883	0.00641404
			1998 - 2001	*	-0.0100084	0.00686548
			1999 - 2000	*	0.0109174	0.00634523
			1999 - 2001	*	0.0096879	0.00680124
Annual Estimated Biomass (Warmwater-adapted)	ANOVA	*F* [4, 6948] = 7.61, *P* < 0.05	1998 - 1999	*	-0.00970539	0.00437559
			1998 - 2000	*	-0.00845059	0.00437731
			1998 - 2001	*	-0.00771359	0.00468541
Annual Total Number (Subtropic-adapted)	ANOVA	*F* [4, 1090] = 2.28, *P* = 0.0586	2001 - 2002	*	-0.697	0.478254
Annual Estimated Abundance (Subtropic-adapted)	ANOVA	*F* [4, 1090] = 3.07, *P* = 0.0158	1999 - 2002	*	-0.166501	0.116364
			2000 - 2002	*	-0.142274	0.114623
			2001 - 2002	*	-0.173733	0.120557
Annual Estimated Biomass (Subtropic-adapted)	ANOVA	*F* [4, 1090] = 0.73, *P* = 0.5737	N/A			

Table 2.8-13. Catch characteristics. Temperature preference. One-way (annual variation among means) ANOVA (2003−2007).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number (Coldwater-adapted)	ANOVA	*F* [4, 7129] = 4.93, *P* = 0.0006	2003 - 2004	*	-0.159916	0.0907802
			2003 - 2005	*	-0.129575	0.0892932
			2003 - 2006	*	-0.155717	0.0898234
			2004 - 2007	*	0.119258	0.0928459
			2006 - 2007	*	0.115059	0.0919106
Annual Estimated Abundance (Coldwater-adapted)	ANOVA	*F* [4, 7129] = 4.66, *P* = 0.0009	2003 - 2004	*	-0.0131011	0.00848802
			2003 - 2005	*	-0.012644	0.00834897
			2003 - 2006	*	-0.0153115	0.00839855
			2004 - 2007	*	0.00876026	0.00868116
			2006 - 2007	*	0.0109707	0.0085937
Annual Estimated Biomass (Coldwater-adapted)	ANOVA	*F* [4, 7129] = 0.83, *P* = 0.5089	*N/A*			
Annual Total Number (Warmwater-adapted)	ANOVA	*F* [4, 9933] = 1.3, *P* = 0.2676	2004 - 2006	*	0.0959881	0.0849629
Annual Estimated Abundance (Warmwater-adapted)	ANOVA	*F* [4, 9933] = 0.72, *P* = 0.5781	N/A			
Annual Estimated Biomass (Warmwater-adapted)	ANOVA	*F* [4, 9933] = 1.96, *P* = 0.0972	2003 - 2006	*	0.0052408	0.00502605
			2004 - 2006	*	0.00660224	0.00505954
			2005 - 2006	*	0.00541127	0.00501712
Annual Total Number (Subtropic-adapted)	ANOVA	*F* [4, 1216] = 3.26, *P* = 0.0113	2004 - 2006	*	0.692648	0.405697
			2006 - 2007	*	-0.585834	0.408337
Annual Estimated Abundance (Subtropic-adapted)	ANOVA	*F* [4, 1216] = 3.07, *P* = 0.0158	2004 - 2006	*	0.0617409	0.0379124
			2006 - 2007	*	-0.0547898	0.0381591
Annual Estimated Biomass (Subtropic-adapted)	ANOVA	*F* [4, 1216] = 1.13, *P* = 0.3389	N/A			

Table 2.8-14. Catch characteristics. Temperature preference. One-way (annual variation among means) ANOVA (2008−2012).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number (Coldwater-adapted)	ANOVA	*F* [4, 6407] = 4.11, *P* = 0.0025	2008 - 2010	*	0.102763	0.0885156
			2009 - 2010	*	0.0989544	0.0896755
			2010 - 2012	*	-0.162049	0.0912775
			2011 - 2012	*	-0.14582	0.0932025
Annual Estimated Abundance (Coldwater-adapted)	ANOVA	*F* [4, 6407] = 4.05, *P* = 0.0028	2008 - 2010	*	0.00983338	0.00829619
			2009 - 2010	*	0.00873131	0.00840491
			2010 - 2012	*	-0.0152848	0.00855506
			2011 - 2012	*	-0.0134983	0.00873548
Annual Estimated Biomass (Coldwater-adapted)	ANOVA	*F* [4, 6407] = 2.34, *P* = 0.0524	2008 - 2010	*	0.00612584	0.00535423
			2008 - 2011	*	0.00628165	0.00547422
			2009 - 2010	*	0.0054521	0.00542439
			2009 - 2011	*	0.00560791	0.00554287
Annual Total Number (Warmwater-adapted)	ANOVA	*F* [4, 6407] = 7.19, *P* = 0.0001	2008 - 2009	*	0.112303	0.0814025
			2008 - 2010	*	0.123433	0.0842496
			2008 - 2011	*	0.232706	0.103656
			2009 - 2011	*	0.120403	0.104548
			2010 - 2011	*	0.109273	0.106779
Annual Estimated Abundance (Warmwater-adapted)	ANOVA	*F* [4, 6407] = 7.32, *P* = 0.0001	2008 - 2009	*	0.0112504	0.00762708
			2008 - 2010	*	0.0117732	0.00789384
			2008 - 2011	*	0.0217667	0.00971216
			2009 - 2011	*	0.0105163	0.00979569
Annual Estimated Biomass (Warmwater-adapted)	ANOVA	*F* [4, 6407] = 7.32, *P* = 0.0001	2008 - 2009	*	0.0112504	0.00762708
			2008 - 2010	*	0.0117732	0.00789384
			2008 - 2011	*	0.0217667	0.00971216
			2009 - 2011	*	0.0105163	0.00979569
Annual Total Number (Subtropic-adapted)	ANOVA	*F* [4, 1654] = 3.70, *P* = 0.005	2008 - 2012	*	0.382277	0.381359
			2009 - 2011	*	0.411189	0.33301
			2009 - 2012	*	0.685915	0.370213
			2010 - 2012	*	0.498524	0.3824
Annual Estimated Abundance (Subtropic-adapted)	ANOVA	*F* [4, 1654] = 3.61, *P* = 0.0062	2008 - 2012	*	0.0359848	0.0357422
			2009 - 2011	*	0.0374285	0.0312107
			2009 - 2012	*	0.0634139	0.0346975
			2010 - 2012	*	0.0466248	0.0358397
Annual Estimated Biomass (Subtropic-adapted)	ANOVA	*F* [4, 1654] = 1.39, *P* = 0.2366	2008 - 2012	*	-0.0139509	0.0118136

Table 2.8-15. Catch characteristics. Temperature preference. One-way (annual variation among means) ANOVA (2013−2015).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number (Coldwater-adapted)	ANOVA	*F* [2, 3933] = 1.09, *P* = 0.3370	N/A			
Annual Estimated Abundance (Coldwater-adapted)	ANOVA	*F* [2, 3933] = 0.92, *P* = 0.3993	N/A			
Annual Estimated Biomass (Coldwater-adapted)	ANOVA	*F* [2, 3933] = 7.26, *P* = 0.0007	2013 - 2014 2014 - 2015	* *	0.00726917 -0.0105504	0.0054376 0.00557872
Annual Total Number (Warmwater-adapted)	ANOVA	*F* [2, 3933] = 2.01, *P* = 0.1565	N/A			
Annual Estimated Abundance (Warmwater-adapted)	ANOVA	*F* [2, 3933] = 1.68, *P* = 0.1943	N/A			
Annual Estimated Biomass (Warmwater-adapted)	ANOVA	*F* [2, 3933] = 0.98, *P* = 0.3223	N/A			
Annual Total Number (Subtropic-adapted)	ANOVA	*F* [2, 1114] = 3.41, *P* = 0.0335	2013 - 2014 2013 - 2015	* *	0.410221 0.389635	0.347168 0.34469
Annual Estimated Abundance (Subtropic-adapted)	ANOVA	*F* [2, 1114] = 3.32, *P* = 0.0365	2013 - 2014 2013 - 2015	* *	0.037941 0.0361397	0.0325623 0.0323299
Annual Estimated Biomass (Subtropic-adapted)	ANOVA	*F* [2, 1114] = 0.62, *P* = 0.5386	N/A			

Table 2.8-16. Catch characteristics. One-way (annual variation among means) ANOVA (1988−2015). Temperature preference. 5-yr time-series (pooled).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number (Coldwater-adapted)	ANOVA	*F* [5, 39039] = 14.98, *P* < 0.05	19881992 - 19931997	*	0.138407	0.0389043
			19881992 - 19982002	*	0.0951857	0.0403115
			19881992 - 20082012	*	0.132044	0.0411271
			19881992 - 20132015	*	0.112913	0.047202
			19931997 - 19982002	*	-0.0432213	0.0382382
			19931997 - 20032007	*	-0.104253	0.0379761
			19982002 - 20032007	*	-0.0610322	0.0394164
			20032007 - 20082012	*	0.0978906	0.0402503
			20032007 - 20132015	*	0.0787598	0.0464399
Annual Estimated Abundance (Coldwater-adapted)	ANOVA	*F* [5, 39039] = 8.82, *P* < 0.05	19881992 - 19931997	*	0.00803403	0.00362225
			19881992 - 19982002	*	0.00673884	0.00375327
			19881992 - 20082012	*	0.00861578	0.00382921
			19881992 - 20132015	*	0.00666304	0.00439482
			19931997 - 20032007	*	-0.00821376	0.00353583
			19982002 - 20032007	*	-0.00691857	0.00366993
			20032007 - 20082012	*	0.00879552	0.00374757
			20032007 - 20132015	*	0.00684278	0.00432387
Annual Estimated Biomass (Coldwater-adapted)	ANOVA	*F* [5, 39039] = 38.84, *P* < 0.05	19881992 - 19931997	*	0.00381678	0.00233052
			19881992 - 20032007	*	-0.0108345	0.00239993
			19881992 - 20082012	*	0.00268279	0.00246367
			19931997 - 19982002	*	-0.00603182	0.00229061
			19931997 - 20032007	*	-0.0146513	0.00227491
			19931997 - 20132015	*	-0.00315159	0.00272228
			19982002 - 20032007	*	-0.00861946	0.0023612
			19982002 - 20082012	*	0.00489783	0.00242596
			19982002 - 20132015	*	0.00288023	0.00279478
			20032007 - 20082012	*	0.0135173	0.00241115
			20032007 - 20132015	*	0.0114997	0.00278193
Annual Total Number (Warmwater-adapted)	ANOVA	*F* [5, 39039] = 11.57, *P* < 0.05	19881992 - 19982002	*	0.0496278	0.0417073
			19881992 - 20032007	*	-0.047086	0.0414502
			19881992 - 20082012	*	-0.0692773	0.0425512
			19881992 - 20132015	*	-0.0793906	0.0488364
			19931997 - 20032007	*	-0.0754254	0.0392911
			19931997 - 20082012	*	-0.0976167	0.0404509

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
			19931997 - 20132015	*	-0.10773	0.0470177
			19982002 - 20032007	*	-0.0967138	0.0407813
			19982002 - 20082012	*	-0.118905	0.0418999
			19982002 - 20132015	*	-0.129018	0.04827
Annual Estimated Abundance (Warmwater-adapted)	ANOVA	*F* [5, 39039] = 14.10, *P* < 0.05	19881992 - 19931997	*	-0.00404305	0.00374525
			19881992 - 20032007	*	-0.00857228	0.0038568
			19881992 - 20082012	*	-0.0109732	0.00395924
			19881992 - 20132015	*	-0.0125314	0.00454406
			19931997 - 19982002	*	0.00469166	0.00368113
			19931997 - 20032007	*	-0.00452923	0.0036559
			19931997 - 20082012	*	-0.00693013	0.00376382
			19931997 - 20132015	*	-0.00848834	0.00437483
			19982002 - 20032007	*	-0.00922089	0.00379456
			19982002 - 20082012	*	-0.0116218	0.00389864
			19982002 - 20132015	*	-0.01318	0.00449135
Annual Estimated Biomass (Warmwater-adapted)	ANOVA	*F* [5, 39039] = 44.03, *P* < 0.05	19881992 - 20032007	*	-0.0131912	0.00237137
			19881992 - 20082012	*	-0.0120992	0.00243436
			19881992 - 20132015	*	-0.00888413	0.00279394
			19931997 - 20032007	*	-0.0109896	0.00224785
			19931997 - 20082012	*	-0.00989756	0.0023142
			19931997 - 20132015	*	-0.00668253	0.00268989
			19982002 - 20032007	*	-0.0111154	0.0023331
			19982002 - 20082012	*	-0.0100233	0.0023971
			19982002 - 20132015	*	-0.00680824	0.00276153
			20032007 - 20132015	*	0.00430712	0.00274883
			20082012 - 20132015	*	0.00321504	0.00280335
Annual Total Number (Subtropic-adapted)	ANOVA	*F* [5, 7382] = 8.02, *P* < 0.05	19881992 - 19982002	*	0.333413	0.218945
			19881992 - 20032007	*	0.29058	0.21307
			19881992 - 20132015	*	0.383883	0.217638
			19931997 - 19982002	*	0.519241	0.218068
			19931997 - 20032007	*	0.476409	0.212169
			19931997 - 20082012	*	0.383847	0.197988
			19931997 - 20132015	*	0.569711	0.216756
Annual Estimated Abundance (Subtropic-adapted)	ANOVA	*F* [5, 7382] = 8.16, *P* < 0.05	19881992 - 19931997	*	-0.0244823	0.020146
			19881992 - 19982002	*	0.0274116	0.020464
			19881992 - 20032007	*	0.0224499	0.019915

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
			19881992 - 20132015	*	0.0304543	0.020342
			19931997 - 19982002	*	0.051894	0.020382
			19931997 - 20032007	*	0.0469323	0.019831
			19931997 - 20082012	*	0.0376857	0.018505
			19931997 - 20132015	*	0.0549367	0.020259
Annual Estimated Biomass (Subtropic-adapted)	ANOVA	F [5, 7382] = 10.35, $P < 0.05$	19881992 - 20082012	*	-0.0121283	0.00525733
			19881992 - 20132015	*	-0.0156733	0.00575108
			19931997 - 20082012	*	-0.00748501	0.00523182
			19931997 - 20132015	*	-0.01103	0.00572777
			19982002 - 20082012	*	-0.0123324	0.00532955
			19982002 - 20132015	*	-0.0158774	0.00581717
			20032007 - 20082012	*	-0.00743987	0.00516059
			20032007 - 20132015	*	-0.0109848	0.00566278

Table 2.8-17. General Linear Model and associated ANOVA Type III Sums of Squares (1988−1992).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number	Year	117.418	1	117.418	53.70	0.0000	√√Total Number = 133.747 - 0.0663099*Year + 0.0383658*Month - 0.000171951*Area	1.17%
	Month	210.665	1	210.665	96.35	0.0000		
	Area	0.00836755	1	0.00836755	0.00	0.9507		
	Residual	35378.0	16180	2.18653				
	Total (corrected)	35796.6	16183					
Estimated Abundance	Year	0.0557309	1	0.0557309	3.04	0.0811	√√Estimated Abundance = 3.03951 - 0.00144464*Year + 0.00348499*Month - 0.0000719692*Area	0.68%
	Month	1.73823	1	1.73823	94.91	0.0000		
	Area	0.00146583	1	0.00146583	0.08	0.7772		
	Residual	296.328	16180	0.0183145				
	Total (corrected)	298.361	16183					
Estimated Biomass	Year	0.00631338	4	0.00157834	0.36	0.8375	√√Estimated Abundance = 3.03951 - 0.00144464*Year + 0.00348499*Month - 0.0000719692*Area	0.41%
	Month	0.100741	5	0.0201483	4.59	0.0003		
	Area	0.185435	14	0.0132454	3.02	0.0001		
	Residual	70.9256	16160	0.00438896				
	Total (corrected)	71.2148	16183					

Table 2.8-18. General Linear Model and associated ANOVA Type III Sums of Squares (1993−1997).

Dependent Variable	Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	Fitted Model	R^2
Total Number	Year	22.7786	1	22.7786	12.75	0.0004	√√Total Number = -46.9897 + 0.0244781*Year + 0.0495924*Month - 0.0106243*Area	1.34%
	Month	394.358	1	394.358	220.69	0.0000		
	Area	37.0001	1	37.0001	20.71	0.0000		
	Residual	33876.6	18958	1.78693				
	Total (corrected)	34335.0	18961					
Estimated Abundance	Year	0.133731	1	0.133731	8.41	0.0037	√√Estimated Abundance = -3.56784 + 0.00187556*Year + 0.00468396*Month - 0.000999347*Area	1.31%
	Month	3.51792	1	3.51792	221.19	0.0000		
	Area	0.32737	1	0.32737	20.58	0.0000		
	Residual	301.521	18958	0.0159047				
	Total (corrected)	305.536	18961					
Estimated Biomass	Year	0.0586547	1	0.0586547	13.36	0.0003	√√Estimated Biomass = -2.37076 + 0.00124213*Year + 0.00090917*Month - 0.0002737*Area	0.26%
	Month	0.132541	1	0.132541	30.18	0.0000		
	Area	0.0245558	1	0.0245558	5.59	0.0180		
	Residual	83.25	18958	0.00439129				
	Total (corrected)	83.4682	18961					

Table 2.8-19. General Linear Model and associated ANOVA Type III Sums of Squares (1998−2002).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number	Year	24.1509	1	24.1509	14.35	0.0002	√√Total Number = -49.7354 + 0.0258216*Year + 0.0386975*Month - 0.0106871*Area	0.99%
	Month	225.343	1	225.343	133.92	0.0000		
	Area	34.7603	1	34.7603	20.66	0.0000		
	Residual	29393.4	17468	1.6827				
	Total (corrected)	29685.9	17471					
Estimated Abundance	Year	3.96664	1	3.96664	40.83	0.0000	√√Estimated Abundance = -20.2836 + 0.0104647*Year - 0.0012567*Month + 0.00148549*Area	0.28%
	Month	0.237652	1	0.237652	2.45	0.1178		
	Area	0.671587	1	0.671587	6.91	0.0086		
	Residual	1696.92	17468	0.0971446				
	Total (corrected)	1701.64	17471					
Estimated Biomass	Year	34.1062	1	34.1062	33713.92	0.0000	√√Estimated Biomass = 72.1283 - 0.0306854*Year - 0.0000314303*Month + 0.0000169869*Area	65.99%
	Month	0.000148654	1	0.000148654	0.15	0.7015		
	Area	0.0000878193	1	0.0000878193	0.09	0.7683		
	Residual	17.6712	17468	0.00101163				
	Total (corrected)	51.9533	17471					

Table 2.8-20. General Linear Model and associated ANOVA Type III Sums of Squares (2003−2007).

Dependent Variable	Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	Fitted Model	R^2
Total Number	Year	0.0000869354	1	0.0000869354	0.00	0.9947	√√Total Number = 2.13749 - 0.0000486859*Year + 0.0348901*Month - 0.0117785*Area	0.65%
	Month	191.835	1	191.835	97.08	0.0000		
	Area	43.6559	1	43.6559	22.09	0.0000		
	Residual	36127.1	18282	1.9761				
	Total (corrected)	36362.9	18285					
Estimated Abundance	Year	0.00465775	1	0.00465775	0.27	0.6036	√√Estimated Abundance = - 0.523615 + 0.000356363*Year + 0.00324787*Month - 0.00110134*Area	0.64%
	Month	1.66235	1	1.66235	96.24	0.0000		
	Area	0.381685	1	0.381685	22.10	0.0000		
	Residual	315.8	18282	0.0172738				
	Total (corrected)	317.844	18285					
Estimated Biomass	Year	0.00255663	1	0.00255663	0.39	0.5304	√√Estimated Biomass = 0.659025 - 0.000264021*Year + 0.000287622*Month - 0.00063123*Area	0.12%
	Month	0.0130367	1	0.0130367	2.01	0.1566		
	Area	0.125383	1	0.125383	19.30	0.0000		
	Residual	118.77	18282	0.00649656				
	Total (corrected)	118.912	18285					

Table 2.8-21. General Linear Model and associated ANOVA Type III Sums of Squares (2008−2012).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number	Year	12.6592	1	12.6592	6.62	0.0101	√√Total Number = 39.7485 - 0.0187199*Year + 0.0320967*Month - 0.0181322*Area	0.77%
	Month	151.546	1	151.546	79.28	0.0000		
	Area	100.345	1	100.345	52.49	0.0000		
	Residual	33579.5	17566	1.91162				
	Total (corrected)	33840.5	17569					
Estimated Abundance	Year	0.104066	1	0.104066	6.20	0.0128	√√Estimated Abundance = 3.61038 - 0.00169728*Year + 0.00300979*Month - 0.00169948*Area	0.77%
	Month	1.33259	1	1.33259	79.35	0.0000		
	Area	0.88151	1	0.88151	52.49	0.0000		
	Residual	294.983	17566	0.0167928				
	Total (corrected)	297.271	17569					
Estimated Biomass	Year	0.0059113	1	0.0059113	1.08	0.2976	√√Estimated Biomass = -0.686272 + 0.00040452*Year + 0.000720764*Month - 0.00107901*Area	0.45%
	Month	0.0764206	1	0.0764206	14.02	0.0002		
	Area	0.355341	1	0.355341	65.20	0.0000		
	Residual	95.728	17566	0.00544962				
	Total (corrected)	96.1632	17569					

Table 2.8-22. General Linear Model and associated ANOVA Type III Sums of Squares (2013−2015).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number	Year	1.7933	1	1.7933	0.98	0.3214	√√Total Number = 33.1168 - 0.0154604*Year + 0.035274*Month - 0.0124575*Area	0.70%
	Month	109.122	1	109.122	59.83	0.0000		
	Area	29.3276	1	29.3276	16.08	0.0001		
	Residual	20225.5	11089	1.82392				
	Total (corrected)	20368.5	11092					
Estimated Abundance	Year	0.0123472	1	0.0123472	0.77	0.3804	√√Estimated Abundance = 2.76935 - 0.00128286*Year + 0.00331108*Month - 0.00116818*Area	0.70%
	Month	0.961482	1	0.961482	59.91	0.0000		
	Area	0.25789	1	0.25789	16.07	0.0001		
	Residual	177.963	11089	0.0160486				
	Total (corrected)	179.22	11092					
Estimated Biomass	Year	0.00152243	1	0.00152243	0.25	0.6137	√√Estimated Biomass = 1.02687 - 0.000450467*Year + 0.000766934*Month - 0.000673095*Area	0.21%
	Month	0.0515844	1	0.0515844	8.63	0.0033		
	Area	0.0856181	1	0.0856181	14.33	0.0002		
	Residual	66.2633	11089	0.00597559				
	Total (corrected)	66.4054	11092					

Table 2.8-23. General Linear Model and associated ANOVA Type III Sums of Squares (1988−2015). Pooled 5-yr Time-series.

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number	Time Series	0.504487	1	0.504487	0.26	0.6074	√√ Total Number = 2.7694 - 2.78865E-8*Time Series + 0.0139508*Month - 0.0129715*Area	0.11%
	Month	1.52946	1	1.52946	0.80	0.3710		
	Area	42.9591	1	42.9591	22.47	0.0000		
	Residual	190308.	99563	1.91144				
	Total (corrected)	190509.	99566					
Estimated Abundance	Time Series	0.0295712	1	0.0295712	1.78	0.1822	√√ Estimated Abundance = 0.0716381 + 6.75154E-9*Time Series + 0.0013625*Month - 0.00122446*Area	0.11%
	Month	0.0145884	1	0.0145884	0.88	0.3488		
	Area	0.382792	1	0.382792	23.03	0.0000		
	Residual	1654.68	99563	0.0166194				
	Total (corrected)	1656.46	99566					
Estimated Biomass	Time Series	0.518398	1	0.518398	98.80	0.0000	√√ Estimated Biomass = - 0.443226 + 2.82683E-8*Time Series + 0.000747902* Month - 0.000622177*Area	0.18%
	Month	0.00439569	1	0.00439569	0.84	0.3600		
	Area	0.0988333	1	0.0988333	18.84	0.0000		
	Residual	522.418	99563	0.00524711				
	Total (corrected)	523.358	99566					

Table 2.8-24. General Linear Model and associated ANOVA Type III Sums of Squares. Coldwater Temperature Preference (1988−1992).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Coldwater-adapted)	Year (CW)	47772.9	1	47772.9	0.20	0.6524	√√ Total Number (CW) = -3374.09 + 1.69679*Year (CW) + 9.8524*Month (CW) + 1.03014*Area (CW)	0.38%
	Month (CW)	7.12624E6	1	7.12624E6	30.26	0.0000		
	Area (CW)	150313.	1	150313.	0.64	0.4243		
	Residual	1.90548E9	8092	235477.				
	Total (corrected)	1.91275E9	8095					
Estimated Abundance (Coldwater-adapted)	Year (CW)	0.0000617457	1	0.0000617457	0.04	0.8388	√√ Estimated Abundance (CW) = -0.120877 + 0.0000610014*Year (CW) + 0.000778*Month (CW) + 0.0000849894*Area (CW)	0.37%
	Month (CW)	0.0444361	1	0.0444361	29.78	0.0000		
	Area (CW)	0.00102315	1	0.00102315	0.69	0.4076		
	Residual	12.0734	8092	0.00149202				
	Total (corrected)	12.1186	8095					
Estimated Biomass (Coldwater-adapted)	Year (CW)	0.0000221785	1	0.0000221785	2.40	0.1217	√√ Estimated Biomass (CW) = -0.0715574 + 0.0000365597*Year (CW) - 0.0000105764*Month (CW) - 0.0000259621*Area (CW)	0.17%
	Month (CW)	0.00000821211	1	0.00000821211	0.89	0.3463		
	Area (CW)	0.000095475	1	0.000095475	10.31	0.0013		
	Residual	0.0749336	8092	0.00000926021				
	Total (corrected)	0.0750577	8095					

Table 2.8-25. General Linear Model and associated ANOVA Type III Sums of Squares. Warmwater Temperature Preference (1988−1992).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Warmwater-adapted)	Year (CW)	0.0000221785	1	0.0000221785	2.40	0.1217	√ √ Total Number (WW) (CW) = -0.0715574 + 0.0000365597*Year (CW) - 0.0000105764*Month (CW) - 0.0000259621*Area (CW)	0.17%
	Month (CW)	0.00000821211	1	0.00000821211	0.89	0.3463		
	Area (CW)	0.000095475	1	0.000095475	10.31	0.0013		
	Residual	0.0749336	8092	0.00000926021				
	Total (corrected)	0.0750577	8095					
Estimated Abundance (Warmwater-adapted)	Year (Warmwater)	0.000468984	1	0.000468984	0.03	0.8524	√ √ Estimated Abundance (WW) = 0.516482 - 0.000192053*Year (Warmwater) + 0.0048196*Month (Warmwater) + 0.000377666*Area (Warmwater)	1.34%
	Month (Warmwater)	1.29705	1	1.29705	95.76	0.0000		
	Area (Warmwater)	0.0186931	1	0.0186931	1.38	0.2401		
	Residual	102.597	7575	0.0135441				
	Total (corrected)	103.996	7578					
Estimated Biomass (Warmwater-adapted)	Year (Warmwater)	0.0325732	1	0.0325732	8.24	0.0041	√ √ (Estimated Biomass (WW) = -3.12232 + 0.00160056*Year (Warmwater) + 0.00325703*Month (Warmwater) + 0.00100133*Area (Warmwater)	2.41%
	Month (Warmwater)	0.592348	1	0.592348	149.87	0.0000		
	Area (Warmwater)	0.131409	1	0.131409	33.25	0.0000		
	Residual	29.9386	7575	0.00395228				
	Total (corrected)	30.6775	7578					

Table 2.8-26. General Linear Model and associated ANOVA Type III Sums of Squares. Subtropical Temperature Preference (1988−1992).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Subtropic-adapted)	Year (ST)	26.5597	1	26.5597	2.99	0.0838	√ √ (Total Number (ST) = -224.874 + 0.114174*Year (ST) + 0.08941*Month (ST) - 0.0203613*Area (ST)	0.56%
	Month (ST)	32.1423	1	32.1423	3.62	0.0571		
	Area (ST)	8.09328	1	8.09328	0.91	0.3398		
	Residual	10107.3	1138	8.88165				
	Total (corrected)	10164.9	1141					
Estimated Abundance (Subtropic-adapted)	Year (ST)	0.59511	1	0.59511	7.89	0.0050	√ √ Estimated Abundance (ST) = -33.7991 + 0.0170905*Year (ST) + 0.00839947*Month (ST) - 0.00182837*Area (ST)	0.93%
	Month (ST)	0.283667	1	0.283667	3.76	0.0524		
	Area (ST)	0.0652595	1	0.0652595	0.87	0.3521		
	Residual	85.7864	1138	0.0753835				
	Total (corrected)	86.5993	1141					
Estimated Biomass (Subtropic-adapted)	Year (ST)	0.0282189	1	0.0282189	8.08	0.0045	√ √ Estimated Biomass (ST) = -7.36788 + 0.00372157*Year (ST) - 0.0000410742*Month (ST) + 0.00211605*Area (ST)	2.81%
	Month (ST)	0.00000678334	1	0.00000678334	0.00	0.9649		
	Area (ST)	0.0874115	1	0.0874115	25.02	0.0000		
	Residual	3.97653	1138	0.00349431				
	Total (corrected)	4.09167	1141					

Table 2.8-27. General Linear Model and associated ANOVA Type III Sums of Squares. Coldwater Temperature Preference (1993−1997).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Coldwater-adapted)	Year (CW)	16.8719	1	16.8719	13.46	0.0002	√√ Total Number (CW) = -61.5879 + 0.0318874*Year (CW) + 0.0199521*Month (CW) - 0.0101397*Area (CW)	0.60%
	Month (CW)	29.2249	1	29.2249	23.32	0.0000		
	Area (CW)	14.5632	1	14.5632	11.62	0.0007		
	Residual	10142.9	8092	1.25345				
	Total (corrected)	10204.0	8095					
Estimated Abundance (Coldwater-adapted)	Year (CW)	0.109602	1	0.109602	9.83	0.0017	√ √ Estimated Abundance (CW) = -4.93609 + 0.00257008*Year (CW) + 0.00188677*Month (CW) - 0.000954654*Area (CW)	0.56%
	Month (CW)	0.261344	1	0.261344	23.45	0.0000		
	Area (CW)	0.129092	1	0.129092	11.58	0.0007		
	Residual	90.2023	8092	0.0111471				
	Total (corrected)	90.7071	8095					
Estimated Biomass (Coldwater-adapted)	Year (CW)	0.000586279	1	0.000586279	0.13	0.7189	√ √ Estimated Biomass (CW) = -0.236169 + 0.00018797*Year (CW) - 0.00100456*Month (CW) - 0.000990132*Area (CW)	0.57%
	Month (CW)	0.0740847	1	0.0740847	16.36	0.0001		
	Area (CW)	0.138866	1	0.138866	30.67	0.0000		
	Residual	36.6352	8092	0.00452734				
	Total (corrected)	36.8442	8095					

Table 2.8-28. General Linear Model and associated ANOVA Type III Sums of Squares. Warmwater Temperature Preference (1993-1997).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Warmwater-adapted)	Year (WW)	7.77307	1	7.77307	6.22	0.0126	√ √ Total Number (WW) = -48.6908 + 0.0251951*Year (WW) + 0.0583578*Month (WW) - 0.00591536*Area (WW)	2.17%
	Month (WW)	217.922	1	217.922	174.50	0.0000		
	Area (WW)	4.92527	1	4.92527	3.94	0.0470		
	Residual	10105.4	8092	1.24882				
	Total (corrected)	10330.1	8095					
Estimated Abundance (Warmwater-adapted)	Year (WW)	0.0490582	1	0.0490582	4.40	0.0359	√ √ Estimated Abundance (WW) = -3.84481 + 0.00200159*Year (WW) + 0.00551782*Month (WW) - 0.000556463*Area (WW)	2.18%
	Month (WW)	1.94822	1	1.94822	174.84	0.0000		
	Area (WW)	0.0435853	1	0.0435853	3.91	0.0480		
	Residual	90.1684	8092	0.0111429				
	Total (corrected)	92.1711	8095					
Estimated Biomass (Warmwater-adapted)	Year (WW)	0.0797092	1	0.0797092	20.18	0.0000	√ √ Estimated Biomass (WW) = -5.02296 + 0.00255138*Year (WW) + 0.0045716*Month (WW) + 0.000394426*Area (WW)	4.11%
	Month (WW)	1.33733	1	1.33733	338.53	0.0000		
	Area (WW)	0.0218977	1	0.0218977	5.54	0.0186		
	Residual	31.967	8092	0.00395045				
	Total (corrected)	33.3367	8095					

Table 2.8-29. General Linear Model and associated ANOVA Type III Sums of Squares. Subtropical Temperature Preference (1993-1997).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Subtropic-adapted)	Year (ST)	2.43765	1	2.43765	0.27	0.6065	√ √ Total Number (ST) = 69.7992 - 0.0342086*Year (ST) + 0.225687*Month (ST) - 0.0271165*Area (ST)	2.04%
	Month (ST)	205.099	1	205.099	22.32	0.0000		
	Area (ST)	13.3599	1	13.3599	1.45	0.2279		
	Residual	10631.8	1157	9.18912				
	Total (corrected)	10853.6	1160					
Estimated Abundance (Subtropic-adapted)	Year (ST)	0.0302477	1	0.0302477	0.37	0.5431	√ √ Estimated Abundance (ST) = 7.74799 - 0.00381061*Year (ST) + 0.0213355*Month (ST) - 0.00253855*Area (ST)	2.06%
	Month (ST)	1.83297	1	1.83297	22.41	0.0000		
	Area (ST)	0.117086	1	0.117086	1.43	0.2315		
	Residual	94.6344	1157	0.0817929				
	Total (corrected)	96.6278	1160					
Estimated Biomass (Subtropic-adapted)	Year (ST)	0.00248529	1	0.00248529	0.62	0.4303	√ √ Estimated Biomass (ST) = -2.13911 + 0.00109229*Year (ST) + 0.00311805*Month (ST) + 0.000953437*Area (ST)	1.28%
	Month (ST)	0.0391484	1	0.0391484	9.80	0.0017		
	Area (ST)	0.0165165	1	0.0165165	4.13	0.0420		
	Residual	4.62283	1157	0.00399553				
	Total (corrected)	4.68258	1160					

Table 2.8-30. General Linear Model and associated ANOVA Type III Sums of Squares. Coldwater Temperature Preference (1998-2002).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Coldwater-adapted)	Year (CW)	0.229814	1	0.229814	0.17	0.6826	√ √ Total Number (CW) = 9.94622 - 0.00398707*Year (CW) + 0.0342669*Month (CW) - 0.00871538*Area (CW)	0.88%
	Month (CW)	75.3007	1	75.3007	54.78	0.0000		
	Area (CW)	9.23467	1	9.23467	6.72	0.0095		
	Residual	9546.35	6945	1.37456				
	Total (corrected)	9631.28	6948					
Estimated Abundance (Coldwater-adapted)	Year (CW)	0.000306468	1	0.000306468	0.03	0.8724	√ √ Estimated Abundance (CW) = -0.107919 + 0.000145599*Year (CW) + 0.00318289*Month (CW) - 0.00080686*Area (CW)	0.88%
	Month (CW)	0.649669	1	0.649669	54.69	0.0000		
	Area (CW)	0.079149	1	0.079149	6.66	0.0098		
	Residual	82.493	6945	0.011878				
	Total (corrected)	83.2281	6948					
Estimated Biomass (Coldwater-adapted)	Year (CW)	0.0420694	1	0.0420694	9.08	0.0026	√ √ Estimated Biomass (CW) = -3.26329 + 0.00170588*Year (CW) - 0.000617935*Month (CW) - 0.00130502*Area (CW)	0.85%
	Month (CW)	0.024487	1	0.024487	5.29	0.0215		
	Area (CW)	0.207054	1	0.207054	44.69	0.0000		
	Residual	32.1779	6945	0.00463325				
	Total (corrected)	32.4528	6948					

Table 2.8-31. General Linear Model and associated ANOVA Type III Sums of Squares. Warmwater Temperature Preference (1998-2002).

Dependent Variable	Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value	Fitted Model	R^2
Total Number (Warmwater-adapted)	Year (WW)	4.88927	1	4.88927	4.34	0.0373	√ √ Total Number (WW) = -47.3376 + 0.0245444*Year (WW) + 0.0394522*Month (WW) - 0.00881358*Area (WW)	1.17%
	Month (WW)	82.9615	1	82.9615	73.62	0.0000		
	Area (WW)	9.5201	1	9.5201	8.45	0.0037		
	Residual	7826.68	6945	1.12695				
	Total (corrected)	7919.21	6948					
Estimated Abundance (Warmwater-adapted)	Year (WW)	0.0482997	1	0.0482997	4.98	0.0257	√ √ (Estimated Abundance (WW) = -4.71654 + 0.00243951*Year (WW) + 0.00365874*Month (WW) - 0.000816273*Area (WW)	1.17%
	Month (WW)	0.713505	1	0.713505	73.55	0.0000		
	Area (WW)	0.0816596	1	0.0816596	8.42	0.0037		
	Residual	67.377	6945	0.00970151				
	Total (corrected)	68.1778	6948					
Estimated Biomass (Warmwater-adapted)	Year (WW)	0.0545819	1	0.0545819	12.35	0.0004	√ √ Estimated Biomass (WW) = -5.10909 + 0.00259331*Year (WW) + 0.00417911*Month (WW) + 0.000166378*Area (WW)	3.12%
	Month (WW)	0.930895	1	0.930895	210.57	0.0000		
	Area (WW)	0.00339256	1	0.00339256	0.77	0.3810		
	Residual	30.7027	6945	0.00442084				
	Total (corrected)	31.6917	6948					

Table 2.8-32. General Linear Model and associated ANOVA Type III Sums of Squares. Subtropical Temperature Preference (1998-2002).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Subtropic-adapted)	Year (ST)	9.83415	1	9.83415	1.42	0.2342	√ √ Total Number (ST) = -131.711 + 0.0671699*Year (ST) + 0.109613*Month (ST) - 0.0623554*Area (ST)	1.74%
	Month (ST)	47.897	1	47.897	6.89	0.0087		
	Area (ST)	68.1769	1	68.1769	9.81	0.0017		
	Residual	7552.4	1087	6.94793				
	Total (corrected)	7686.0	1090					
Estimated Abundance (Subtropic-adapted)	Year (ST)	2.5901	1	2.5901	5.84	0.0156	√ √ Estimated Abundance (ST) = -68.5308 + 0.0344719*Year (ST) + 0.00998122*Month (ST) + 0.0179152*Area (ST)	1.62%
	Month (ST)	0.39715	1	0.39715	0.90	0.3439		
	Area (ST)	5.62772	1	5.62772	12.70	0.0004		
	Residual	481.804	1087	0.443242				
	Total (corrected)	489.795	1090					
Estimated Biomass (Subtropic-adapted)	Year (ST)	0.340975	1	0.340975	2.57	0.1092	√ √ Estimated Biomass (ST) = -24.9385 + 0.0125074*Year (ST) - 0.000363172*Month (ST) + 0.0211916*Area (ST)	5.25%
	Month (ST)	0.000525791	1	0.000525791	0.00	0.9498		
	Area (ST)	7.8744	1	7.8744	59.25	0.0000		
	Residual	144.46	1087	0.132898				
	Total (corrected)	152.459	1090					

Table 2.8-33. General Linear Model and associated ANOVA Type III Sums of Squares. Coldwater Temperature Preference (2003-2007).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Coldwater-adapted)	Year	1.00863	1	1.00863	0.66	0.4176	√ √ Total Number = -14.6553 + 0.00844455*Year + 0.0054837*Month - 0.013309*Area	0.23%
	Month	2.0044	1	2.0044	1.31	0.2532		
	Area	21.85	1	21.85	14.23	0.0002		
	Residual	10940.8	7126	1.53534				
	Total (corrected)	10966.0	7129					
Estimated Abundance (Coldwater-adapted)	Year	0.0186195	1	0.0186195	1.39	0.2388	√ √ Estimated Abundance = -2.08745 + 0.00114735*Year + 0.000499438*Month - 0.00124455*Area	0.24%
	Month	0.0166265	1	0.0166265	1.24	0.2657		
	Area	0.191068	1	0.191068	14.24	0.0002		
	Residual	95.6243	7126	0.0134191				
	Total (corrected)	95.8537	7129					
Estimated Biomass (Coldwater-adapted)	Year	0.00507465	1	0.00507465	0.79	0.3748	√ √ Estimated Biomass = -1.02999 + 0.000598983*Year - 0.00210457*Month - 0.00158273*Area	1.33%
	Month	0.295232	1	0.295232	45.82	0.0000		
	Area	0.309013	1	0.309013	47.96	0.0000		
	Residual	45.9102	7126	0.00644264				
	Total (corrected)	46.528	7129					

Table 2.8-34. General Linear Model and associated ANOVA Type III Sums of Squares. Warmwater Temperature Preference (2003-2007).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Warmwater-adapted)	Year (WW)	0.0669989	1	0.0669989	0.04	0.8453	√ √ Total Number (WW) = -4.12624 + 0.002937*Year (WW) + 0.0683748*Month (WW) - 0.0120798*Area (WW)	2.13%
	Month (WW)	242.086	1	242.086	137.58	0.0000		
	Area (WW)	18.0036	1	18.0036	10.23	0.0014		
	Residual	12538.6	7126	1.75955				
	Total (corrected)	12811.6	7129					
Estimated Abundance (Warmwater-adapted)	Year (WW)	0.00336395	1	0.00336395	0.22	0.6397	√ √ Estimated Abundance (WW) = -1.15438 + 0.000658106*Year (WW) + 0.00636194*Month (WW) - 0.0011308*Area (WW)	2.13%
	Month (WW)	2.09583	1	2.09583	136.53	0.0000		
	Area (WW)	0.157765	1	0.157765	10.28	0.0013		
	Residual	109.392	7126	0.0153511				
	Total (corrected)	111.742	7129					
Estimated Biomass (Warmwater-adapted)	Year (WW)	0.00132803	1	0.00132803	0.21	0.6487	√ √ Estimated Biomass (WW) = -0.740495 + 0.0004135*Year (WW) + 0.00508518*Month (WW) - 0.000260595*Area (WW)	2.97%
	Month (WW)	1.33903	1	1.33903	209.29	0.0000		
	Area (WW)	0.00837861	1	0.00837861	1.31	0.2525		
	Residual	45.5913	7126	0.00639788				
	Total (corrected)	46.9877	7129					

Table 2.8-35. General Linear Model and associated ANOVA Type III Sums of Squares. Subtropical Temperature Preference (2003-2007).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Subtropic-adapted)	Year (ST)	1.16467	1	1.16467	0.20	0.6542	√√ Total Number (ST) = 47.2685 - 0.022281*Year (ST) + 0.0326308*Month (ST) - 0.0242912*Area (ST)	0.28%
	Month (ST)	5.78535	1	5.78535	1.00	0.3181		
	Area (ST)	11.553	1	11.553	1.99	0.1583		
	Residual	7039.17	1213	5.80311				
	Total (corrected)	7058.75	1216					
Estimated Abundance (Subtropic-adapted)	Year (ST)	0.00580956	1	0.00580956	0.11	0.7349	√√ Estimated Abundance (ST) = 3.3981 - 0.00157363*Year (ST) + 0.00302782*Month (ST) - 0.00228216*Area (ST)	0.27%
	Month (ST)	0.0498121	1	0.0498121	0.98	0.3214		
	Area (ST)	0.101974	1	0.101974	2.01	0.1559		
	Residual	61.4397	1213	0.050651				
	Total (corrected)	61.6047	1216					
Estimated Biomass (Subtropic-adapted)	Year (ST)	0.000985683	1	0.000985683	0.21	0.6437	√√ Estimated Biomass (ST) = 1.34974 - 0.000648188*Year (ST) + 0.000153854*Month (ST) + 0.00171865*Area (ST)	1.03%
	Month (ST)	0.000128615	1	0.000128615	0.03	0.8673		
	Area (ST)	0.0578324	1	0.0578324	12.55	0.0004		
	Residual	5.58755	1213	0.00460639				
	Total (corrected)	5.64563	1216					

Table 2.8-36. General Linear Model and associated ANOVA Type III Sums of Squares. Coldwater Temperature Preference (2008-2012).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Coldwater-adapted)	Year (CW)	0.230964	1	0.230964	0.17	0.6789	√√ Total Number (CW) = -6.09267 + 0.00418618*Year (CW) - 0.00405396*Month (CW) - 0.0180787*Area (CW)	0.43%
	Month (CW)	0.965931	1	0.965931	0.72	0.3972		
	Area (CW)	36.3914	1	36.3914	27.01	0.0000		
	Residual	8628.51	6404	1.34736				
	Total (corrected)	8666.13	6407					
Estimated Abundance (Coldwater-adapted)	Year (CW)	0.00261554	1	0.00261554	0.22	0.6383	√√ Estimated Abundance (CW) = -0.67782 + 0.000445479*Year (CW) - 0.000380528*Month (CW) - 0.00169422*Area (CW)	0.44%
	Month (CW)	0.00851059	1	0.00851059	0.72	0.3964		
	Area (CW)	0.3196	1	0.3196	27.00	0.0000		
	Residual	75.7945	6404	0.0118355				
	Total (corrected)	76.1253	6407					
Estimated Biomass (Coldwater-adapted)	Year (CW)	0.00816386	1	0.00816386	1.69	0.1931	√√ Estimated Biomass (CW) = 1.74873 - 0.000787035*Year (CW) - 0.00240486*Month (CW) - 0.00199939*Area (CW)	2.54%
	Month (CW)	0.339911	1	0.339911	70.52	0.0000		
	Area (CW)	0.445105	1	0.445105	92.34	0.0000		
	Residual	30.8698	6404	0.0048204				
	Total (corrected)	31.674	6407					

Table 2.8-37. General Linear Model and associated ANOVA Type III Sums of Squares. Warmwater Temperature Preference (2008-2012).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Warmwater-adapted)	Year (WW)	13.9574	1	13.9574	8.45	0.0037	√√ Total Number (WW) = 94.0122 - 0.0459305*Year (WW) + 0.0568073*Month (WW) - 0.00985044*Area (WW)	1.78%
	Month (WW)	149.046	1	149.046	90.21	0.0000		
	Area (WW)	11.0668	1	11.0668	6.70	0.0097		
	Residual	10581.2	6404	1.65228				
	Total (corrected)	10773.3	6407					
Estimated Abundance (Warmwater-adapted)	Year (WW)	0.122135	1	0.122135	8.42	0.0037	√√ Estimated Abundance (WW) = 8.79465 - 0.00429654*Year (WW) + 0.00531133*Month (WW) - 0.000923752*Area (WW)	1.78%
	Month (WW)	1.30292	1	1.30292	89.81	0.0000		
	Area (WW)	0.0973246	1	0.0973246	6.71	0.0096		
	Residual	92.9037	6404	0.0145071				
	Total (corrected)	94.584	6407					
Estimated Biomass (Warmwater-adapted)	Year (WW)	0.00129188	1	0.00129188	0.24	0.6228	√√ Estimated Biomass (WW) = -0.795389 + 0.000441886*Year (WW) + 0.00508665*Month (WW) - 0.000881331*Area (WW)	3.65%
	Month (WW)	1.19502	1	1.19502	223.75	0.0000		
	Area (WW)	0.0885909	1	0.0885909	16.59	0.0000		
	Residual	34.2027	6404	0.00534083				
	Total (corrected)	35.4995	6407					

Table 2.8-38. General Linear Model and associated ANOVA Type III Sums of Squares. Subtropical Temperature Preference (2008-2012).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Subtropic-adapted)	Year (ST)	40.4049	1	40.4049	7.37	0.0066	√√ Total Number (ST) = 233.428 - 0.114319*Year (ST) - 0.0369742*Month (ST) - 0.0447917*Area (ST)	1.19%
	Month (ST)	9.73747	1	9.73747	1.78	0.1827		
	Area (ST)	54.5646	1	54.5646	9.95	0.0016		
	Residual	9056.3	1651	5.48534				
	Total (corrected)	9165.35	1654					
Estimated Abundance (Subtropic-adapted)	Year (ST)	0.348099	1	0.348099	7.23	0.0072	√√ Estimated Abundance (ST) = 21.6697 - 0.0106109*Year (ST) - 0.00345375*Month (ST) - 0.00420066*Area (ST)	1.18%
	Month (ST)	0.0849628	1	0.0849628	1.76	0.1842		
	Area (ST)	0.4799	1	0.4799	9.96	0.0016		
	Residual	79.5387	1651	0.0481761				
	Total (corrected)	80.4894	1654					
Estimated Biomass (Subtropic-adapted)	Year (ST)	0.0146121	1	0.0146121	2.79	0.0949	√√ Estimated Biomass (ST) = -4.27638 + 0.00217398*Year (ST) - 0.00269932*Month (ST) + 0.000995033*Area (ST)	1.10%
	Month (ST)	0.0518988	1	0.0518988	9.91	0.0016		
	Area (ST)	0.0269272	1	0.0269272	5.14	0.0234		
	Residual	8.64976	1651	0.0052391				
	Total (corrected)	8.74616	1654					

Table 2.8-39. General Linear Model and associated ANOVA Type III Sums of Squares. Coldwater Temperature Preference (2013-2015).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Coldwater-adapted)	Year (CW)	1.20481	1	1.20481	1.07	0.2999	√√ Total Number (CW) = 45.2537 - 0.0214313*Year (CW) + 0.019692*Month (CW) - 0.0120211*Area (CW)	0.57%
	Month (CW)	13.7549	1	13.7549	12.27	0.0005		
	Area (CW)	9.69699	1	9.69699	8.65	0.0033		
	Residual	4405.4	3930	1.12097				
	Total (corrected)	4430.54	3933					
Estimated Abundance (Coldwater-adapted)	Year (CW)	0.00888685	1	0.00888685	0.90	0.3426	√√ Estimated Abundance CW) = 3.90316 - 0.00184062*Year (CW) + 0.00184798*Month (CW) - 0.00112755*Area (CW)	0.56%
	Month (CW)	0.121136	1	0.121136	12.28	0.0005		
	Area (CW)	0.0853145	1	0.0853145	8.65	0.0033		
	Residual	38.77	3930	0.00986515				
	Total (corrected)	38.9898	3933					
Estimated Biomass (Coldwater-adapted)	Year (CW)	0.00602958	1	0.00602958	1.18	0.2769	√√ Estimated Biomass (CW) = -2.89228 + 0.00151612*Year (CW) - 0.00207194*Month (CW) - 0.00167806*Area (CW)	1.65%
	Month (CW)	0.152276	1	0.152276	29.85	0.0000		
	Area (CW)	0.188957	1	0.188957	37.05	0.0000		
	Residual	20.0459	3930	0.00510073				
	Total (corrected)	20.3832	3933					

Table 2.8-40. General Linear Model and associated ANOVA Type III Sums of Squares. Warmwater Temperature Preference (2013-2015).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Warmwater-adapted)	Year (WW)	4.08412	1	4.08412	2.93	0.0871	√√ Total Number (WW) = 132.179 - 0.0647371*Year (WW) + 0.0384673*Month (WW) - 0.0109546*Area (WW)	0.93%
	Month (WW)	39.5077	1	39.5077	28.32	0.0000		
	Area (WW)	8.10226	1	8.10226	5.81	0.0160		
	Residual	5482.94	3930	1.39515				
	Total (corrected)	5534.3	3933					
Estimated Abundance (Warmwater-adapted)	Year (WW)	0.0310871	1	0.0310871	2.53	0.1115	√√ Estimated Abundance (WW) = 11.5439 - 0.00564799*Year (WW) + 0.00360833*Month (WW) - 0.00102691*Area (WW)	0.92%
	Month (WW)	0.347624	1	0.347624	28.33	0.0000		
	Area (WW)	0.0711987	1	0.0711987	5.80	0.0160		
	Residual	48.2262	3930	0.0122713				
	Total (corrected)	48.674	3933					
Estimated Biomass (Warmwater-adapted)							√√ Estimated Biomass (WW) = 7.69278 - 0.00377258*Year (WW) + 0.0042043*Month (WW) - 0.000734246*Area (WW)	2.12%
	Year (WW)	0.0138698	1	0.0138698	2.27	0.1322		
	Month (WW)	0.471938	1	0.471938	77.12	0.0000		
	Area (WW)	0.0363993	1	0.0363993	5.95	0.0147		
	Residual	24.0495	3930	0.00611948				

Table 2.8-41. General Linear Model and associated ANOVA Type III Sums of Squares. Subtropical Temperature Preference (2013-2015).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Subtropic-adapted)	Year (ST)	31.1337	1	31.1337	5.46	0.0194	√√ Total Number (ST) = 415.514 - 0.205153*Year (ST) + 0.0929608*Month (ST) - 0.0399268*Area (ST)	1.55%
	Month (ST)	43.4751	1	43.4751	7.63	0.0057		
	Area (ST)	28.374	1	28.374	4.98	0.0257		
	Residual	6332.06	1111	5.69942				
	Total (corrected)	6431.55	1114					
Estimated Abundance (Subtropic-adapted)	Year (ST)	0.268231	1	0.268231	5.35	0.0207	√√ Estimated Abundance (ST) = 38.5701 - 0.0190422*Year (ST) + 0.00872185*Month (ST) - 0.00374497*Area (ST)	1.54%
	Month (ST)	0.382699	1	0.382699	7.63	0.0057		
	Area (ST)	0.249625	1	0.249625	4.98	0.0257		
	Residual	55.7018	1111	0.0501367				
	Total (corrected)	56.572	1114					
Estimated Biomass (Subtropic-adapted)	Year (ST)	0.00692168	1	0.00692168	0.92	0.3386	√√ Estimated Biomass (ST) = 6.22541 - 0.00305892*Year (ST) + 0.000611719*Month (ST) + 0.00133681*Area (ST)	0.51%
	Month (ST)	0.00188254	1	0.00188254	0.25	0.6177		
	Area (ST)	0.0318076	1	0.0318076	4.21	0.0402		
	Residual	8.39647	1111	0.00755758				
	Total (corrected)	8.43951	1114					

Table 2.8-42. General Linear Model and associated ANOVA Type III Sums of Squares. Coldwater Temperature Preference. 5-yr Time-series (1988-2015).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Coldwater-adapted)	Time Series (CW)	11.3453	1	11.3453	7.99	0.0047	√√ Total Number (CW) = 6.3662 - 2.13748E-7*Time Series (CW) + 0.0192003*Month (CW) - 0.0104509*Area (CW)	0.41%
	Month (CW)	136.547	1	136.547	96.15	0.0000		
	Area (CW)	74.3637	1	74.3637	52.36	0.0000		
	Residual	55435.6	39036	1.42011				
	Total (corrected)	55663.8	39039					
Estimated Abundance (Coldwater-adapted)	Time Series (CW)	0.0292921	1	0.0292921	2.38	0.1229	√√ Estimated Abundance (CW) = 0.413077 - 1.0861E-8*Time Series (CW) + 0.00168064*Month (CW) - 0.000971917*Area (CW)	0.36%
	Month (CW)	1.0462	1	1.0462	85.01	0.0000		
	Area (CW)	0.643144	1	0.643144	52.26	0.0000		
	Residual	480.408	39036	0.0123068				
	Total (corrected)	482.161	39039					
Estimated Biomass (Coldwater-adapted)	Time Series (CW)	0.0336629	1	0.0336629	6.63	0.0100	√√ Estimated Biomass (CW) = -0.0790099 + 1.16431E-8*Time Series (CW) - 0.00145997*Month (CW) - 0.00139156*Area (CW)	1.06%
	Month (CW)	0.789501	1	0.789501	155.47	0.0000		
	Area (CW)	1.31841	1	1.31841	259.62	0.0000		
	Residual	198.236	39036	0.00507829				
	Total (corrected)	200.357	39039					

Table 2.8-43. General Linear Model and associated ANOVA Type III Sums of Squares. Warmwater Temperature Preference. 5-yr Time-series (1988-2015).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Warmwater-adapted)	Time Series (WW)	60.3819	1	60.3819	40.24	0.0000	√√ Total Number (WW) = -8.22361 + 4.92926E-7*Time Series (WW) + 0.0550105*Month (WW) - 0.00515665*Area (WW)	1.66%
	Month (WW)	922.387	1	922.387	614.75	0.0000		
	Area (WW)	18.0308	1	18.0308	12.02	0.0005		
	Residual	58570.3	39036	1.50042				
	Total (corrected)	59559.4	39039					
Estimated Abundance (Warmwater-adapted)	Time Series (WW)	0.780301	1	0.780301	60.04	0.0000	√√ Estimated Abundance (WW) = -0.967161 + 5.6035E-8*Time Series (WW) + 0.00501172*Month (WW) - 0.000490182*Area (WW)	1.64%
	Month (WW)	7.65589	1	7.65589	589.07	0.0000		
	Area (WW)	0.162928	1	0.162928	12.54	0.0004		
	Residual	507.331	39036	0.0129965				
	Total (corrected)	515.812	39039					
Estimated Biomass (Warmwater-adapted)	Time Series (WW)	0.800626	1	0.800626	164.43	0.0000	√√ Estimated Biomass (WW) = -1.0566 + 5.67601E-8*Time Series (WW) + 0.00400921*Month (WW) + 0.000216194*Area (WW)	2.91%
	Month (WW)	4.89938	1	4.89938	1006.22	0.0000		
	Area (WW)	0.0316933	1	0.0316933	6.51	0.0107		
	Residual	190.069	39036	0.00486908				
	Total (corrected)	195.747	39039					

Table 2.8-44. General Linear Model and associated ANOVA Type III Sums of Squares. Subtropical Temperature Preference. Pooled 5-yr Time-series (1988-2015).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Subtropic-adapted)	Time Series (ST)	135.366	1	135.366	19.51	0.0000	√√ Total Number (ST) = 34.9198 - 0.00000161118*Time Series (ST) + 0.0682713*Month (ST) - 0.0374255*Area (ST)	0.88%
	Month (ST)	139.303	1	139.303	20.08	0.0000		
	Area (ST)	168.857	1	168.857	24.34	0.0000		
	Residual	51187.0	7379	6.93685				
	Total (corrected)	51642.8	7382					
Estimated Abundance (Subtropic-adapted)	Time Series (ST)	0.992579	1	0.992579	16.37	0.0001	√√ Estimated Abundance (ST) = 3.01224 - 1.37966E-7*Time Series (ST) + 0.00626256*Month (ST) - 0.00351368*Area (ST)	0.83%
	Month (ST)	1.17216	1	1.17216	19.33	0.0000		
	Area (ST)	1.48837	1	1.48837	24.54	0.0000		
	Residual	447.466	7379	0.0606405				
	Total (corrected)	451.214	7382					
Estimated Biomass (Subtropic-adapted)	Time Series (ST)	0.203569	1	0.203569	42.11	0.0000	√√ Estimated Biomass (ST) = -1.19149 + 6.24808E-8*Time Series (ST) - 0.0000933727*Month (ST) + 0.00143838*Area (ST)	1.23%
	Month (ST)	0.00026057	1	0.00026057	0.05	0.8164		
	Area (ST)	0.249422	1	0.249422	51.59	0.0000		
	Residual	35.6733	7379	0.00483444				
	Total (corrected)	36.1178	7382					

CHAPTER 3. EFFECTS OF HURRICANE SANDY ON THE ENVIRONMENTAL CONDITIONS AND THE NEARSHORE MARINE COMMUNITY IN THE MID-ATLANTIC BIGHT (NEW JERSEY, USA)

3.1 Abstract

Marine fauna are influenced, shaped, and controlled by the oceanic environmental conditions. Water temperature, salinity, dissolved oxygen (DO), depth, and sediment type influence and select fish life-history characteristics. Infrequent, acute, and catastrophic natural events can also severely affect marine communities, such as droughts, floods, and hurricanes. Marine communities are vulnerable to changes in environmental conditions, but the response and severity depends on ecological resilience. Researchers around the world have predicted and documented numerous changes in fish communities caused by various natural and potentially unnatural sources, but baseline information is lacking for most regions around the world, including the coastal waters off New Jersey. To recognize these processes, a multifaceted investigation was undertaken to assess whether the oceanic conditions and marine community were temporarily or permanently impacted by Hurricane Sandy in late October, 2012. Findings showed the annual bottom salinity and surface DO varied significantly between pre- and post-Sandy. A three-way (year, month, and area) permutational MANOVA also showed the oceanographic and physicochemical conditions in January varied significantly between pre- and post-Sandy. There was significant interaction effect the abiotic conditions among factors (year, month, and geographic sampling area), but the significance level depended on the sampling area. For instance, the abiotic conditions varied significantly between pre- and post-Sandy in sampling area "19"; sampling area 19 was located in the direct path of the storm. The marine community (abundance) in January also varied significantly between pre- and post-Sandy, but the magnitude of the significance level difference in the marine community depended on the sampling area. For example, the marine community varied significantly between pre- and post-Sandy in sampling areas "16 and 20". Overall, there was no significant change in biomass or the community structure between pre- and post-Sandy.

3.2 Introduction

Marine fauna are influenced, shaped, and controlled by the oceanic environmental conditions. Water temperature, salinity, dissolved oxygen (DO), depth, and sediment type influence and select fish life-history characteristics (Horne et al. 1989). For many open-water coastal species (non-estuary dependent), water temperature is usually the most important environmental factor influencing fish distribution, especially along the zoogeographic transition zone or boundary of a particular species (Hoese and Moore, 1977). Based on a species' physiology (Hare et al. 2012), marine fauna have an optimal temperature range that limits their behavior, distribution, abundance, and other life-history characteristics (e.g., Howell and Auster, 2012). In most regions, water temperature varies with annual and seasonal warming and cooling conditions, which influences resident and migratory fish behavior, abundance, and distribution (Parker and Dixon, 1998). Natural and human-induced changes in the environment conditions can also shift the food web and affect a variety of ecological community metrics (e.g., diversity, size-composition, relative biomass, and relative abundance).

Besides variations in the annual and seasonal environmental conditions, infrequent, acute, and catastrophic natural events (e.g., droughts, floods, and hurricanes) can also severely affect entire marine communities (Vrancken and O'Connell, 2010). Given these are episodic events, research on the impacts to marine fauna from natural disturbance is limited. Hurricanes, although infrequent at a regional scale, can severely impact fish communities in numerous ways, including destroying habitat, and lowering DO and salinity levels, but that depends on duration. In Louisiana, Hurricane Katrina (Category 5; 28 August 2005) significantly changed the fish assemblage in the downstream and upstream reaches of Bayou Lacombe (Vrancken and O'Connell, 2010). At the downstream reaches, centrarchid species such as bluegill (*Lepomis macrochirus*), warmouth (*Lepomis gulosus*), and redspotted sunfish [*Lepomis miniatus*]) and several estuary species (inland silverside [*Menidia beryllina*] and striped mullet [*Mugil cephalus*]) increased in abundance after the hurricane. In contrast, longear sunfish (*Lepomis megalotis*) decreased in the upstream reaches after the hurricane and weed shiners (*Notropis texanus*), goldstriped darters (*Etheostoma parvipinne*), and warmouth were absent in post-hurricane samples. Notwithstanding these potential long-term impacts, the regional severity depends on the species' ability to tolerate and recover. For instance, Hurricane Charley (Category 4; 13 August 2004) did not prevent or limit the nightly chorusing spawning events of sand seatrout (*Cynoscion arenarius*) in Charlotte Harbor, Florida (Locascio and Mann. 2005). However, the hurricane could have delayed impacts associated with lowered DO levels given the increased freshwater inflow (Locascio and Mann. 2005). In Chesapeake Bay, changes in abundance and distribution of pelagic and bentho-pelagic fishes occurred after Hurricane Isabel (Category 2; 18 September 2003) (Houde et al. 2005). The relative abundance of adult bay anchovy (*Anchoa mitchilli*) increased in the lower bay, and relative abundance of juvenile Atlantic croaker (*Micropogonias undulates*) was 30 times higher than mean abundance for the previous decade, which was attributed to a large entrainment of larvae from coastal ocean spawning sites after Hurricane Isabel (Houde et al. 2005). The hurricane also enhanced abundance in some species and shifted distributions without negatively impacting the local fish populations, recruitment of juvenile fishes, or fish communities (Houde et al. 2005). Similarly, the community diversity in the Indian River Lagoon (Florida) decreased, and the fish community in the Sebastian River shifted to a predominant freshwater species assemblage after two hurricanes passed through the east coast of Florida (Paperno et al. 2006). Despite these biological changes, they were short-term and temporary. The community structure recovered to pre-hurricane conditions within several weeks, and by mid-December (3 months after the last storm) there was little difference between the pre- and post-hurricane fish community (Paperno et al. 2006).

Researchers worldwide have predicted and documented numerous changes in marine communities caused by ongoing physicochemical shifts associated with natural and potentially unnatural sources (Rijnsdorp et al. 2009; Crozier and Hutchings, 2014; Pinksky and Mantua, 2014), but fundamental baseline information and published studies describing the marine community are lacking for most regions around the world (Johnson, 2012), including the coastal nearshore waters off New Jersey. New Jersey is located within the middle or Mid-Atlantic Bight (MAB) in the western North Atlantic Ocean. The MAB is defined as the offshore waters (i.e., beach to continental shelf) between Cape Cod, Massachusetts and Cape Hatteras, North Carolina (Steimle and Zetlin, 2000). The MAB is among the most important oceanic regions in the United States because it provides habitat and supports many ecologically and economically valuable marine resources (NMFS 2011; NMFS 2018). In 2016, commercial fishing landings (all species combined) and associated value in the MAB (Delaware, New Jersey, New York, and Pennsylvania) were 76,346 mt and $255.2 million, respectively (NMFS, 2018). Commercial fisheries in New Jersey (60,017 mt; $191.1 million) represented 78.6 of the total landings and 74.9 percent of the economic value in the MAB during 2016. The economic value of commercial fishing landings in New Jersey over the past 10 years ranged between $132.9 and $220.4 million with a mean of $164.8 million (NMFS, 2018). In 2016, commercial fisheries in New Jersey ranked ninth in economic value and tenth in landings (NMFS, 2018).

Despite the economic value of New Jersey fisheries resources, only partial information about the nearshore marine community and environmental conditions is available, and no information is available about the impacts associated with Hurricane Sandy. As such, the primary goal of this study was to examine the trends in the environmental conditions and the nearshore marine fauna community off New Jersey pre- and post-Sandy. The main purpose was to provide resource managers and others with environmental and marine community information associated with natural disturbance. The main objective was to assess whether and how the oceanic conditions and marine community off the New Jersey coast were impacted by Hurricane Sandy/Extratropical Cyclone. Hurricane Sandy was the most destructive storm in 2012 and the second costliest hurricane in history. Hurricane Sandy degenerated into an extratropical cyclone just before it made landfall near Brigantine Beach, New Jersey on 29 October 2012.

The overall theoretical expectation was that the environmental and nearshore marine community (species composition and relative abundance/biomass) changed after Hurricane Sandy, but recovered within one year. This notion was based on findings by Houde et al. (2005) who reported temporary changes in the environmental conditions and fish populations post Hurricane Isabel in Chesapeake Bay, and Paperno et al. (2006) who also reported the disruption and recovery of the environmental conditions and fish communities in Florida after two hurricanes. Specific null and alternative hypotheses consisted of the following:

H_o1: The oceanic conditions are constant with time.

H_{1A}: The oceanic conditions changed significantly after Hurricane Sandy/Extratropical Cyclone traversed through the study area.

H_o2: Species composition/assemblage are constant with space and time.

H_{2A}: The species composition or marine fauna assemblage changed significantly after Hurricane Sandy/Extratropical Cyclone traversed through the study area.

H_{2E}: The species composition or marine fauna assemblage recovered two years after Hurricane Sandy/Extratropical Cyclone traversed through the study area.

H_o3: Estimated abundances are constant with space and time.

H_{3A}: The estimated abundance of marine fauna changed significantly after Hurricane Sandy/Extratropical Cyclone traversed through the study area.

H_{3E}: The estimated abundance of marine fauna recovered two years after Hurricane Sandy/Extratropical Cyclone traversed through the study area.

H_o4: Estimated biomasses are constant with space and time.

H_{4A}: The estimated biomass of marine fauna changed significantly after Hurricane Sandy/Extratropical Cyclone traversed through the study area.

H_{1E}: The estimated biomass of marine fauna recovered two years after Hurricane Sandy/Extratropical Cyclone traversed through the study area.

3.3 Material and Methods

3.3.1 Summary

Field-collections were made using standardized sampling gear throughout the New Jersey coastal region (**Figure 3.3.1-1**) at pre-determined stations that were selected under a stratified randomized experimental approach. The methods (study area, experimental survey design, experimental field sampling approach, station selection, field sampling gear, and field sampling and data collection procedures), and the basis for experimental repetition follow the details outlined in Chapter 2 (*Section 2.3 Methods*). Specific data treatment/processing, protocol, and statistical data analysis techniques are discussed below.

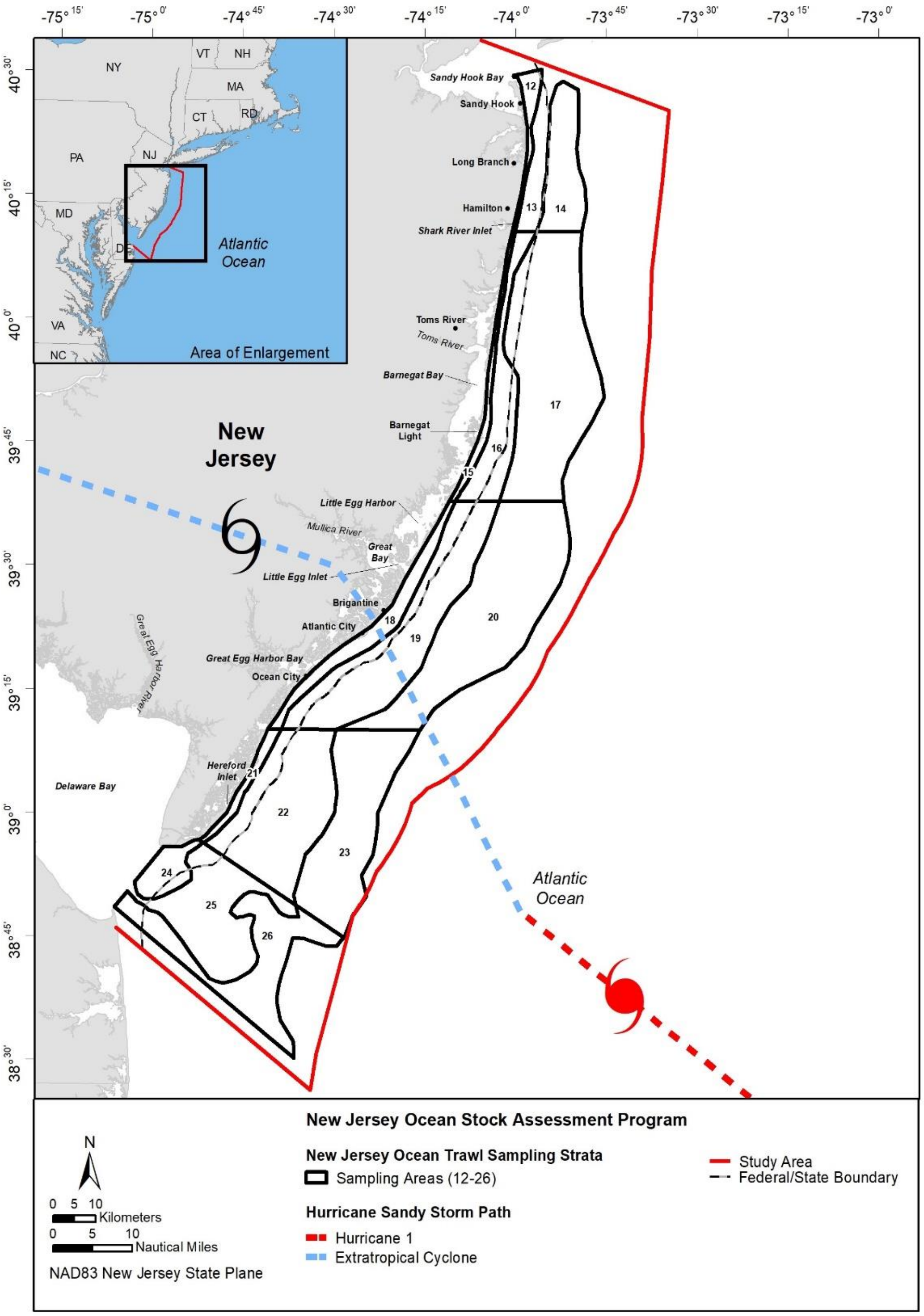


Figure 3.3.1-1. Study Area. The storm path of Hurricane Sandy (Landfall: 29 October 2012).

3.3.2 Data Collection Protocol

Three long-term climatological indices were used to examine the potential changes to the oceanic conditions by Hurricane Sandy: North Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO), and Empirical Orthogonal Function (EOF) of sea surface temperature (SST) in the Atlantic Ocean. Variability in the NAO has been associated with atmospheric, oceanic and biological changes (Deser and Blackmon, 1993; Ottersen et al. 2001; Beaugrand et al. 2003; Auber et al. 2015). The NAO winter index (1822−2016) is calculated as the difference between surface pressure of the subtropical (Azores) high and the subpolar (Iceland) low. The AMO is a 65 to 80 year cycle in the North Atlantic thought to be driven by ocean thermohaline circulation (Sutton and Hodson, 2005). The AMO index is computed as a monthly area-weighted average of SST anomalies over the North Atlantic (from 0 to 70°N). The AMO (1856−2016) is based on the detrended Kaplan SST dataset (5° latitude × 5° longitude grids) from 0 to 70° N. The AMO is driven by thermohaline circulation and is associated with warmer land and ocean temperatures, decreases in summer precipitation, and increases in the number of droughts (Sutton and Hodson, 2007). In the United States, the area relevant to the present study, these climate effects are most pronounced in the summer and somewhat less prominent in the autumn and winter at lower latitudes (Sutton and Hodson, 2007). The Empirical Orthogonal Function (EOF) of SST in the Atlantic Ocean (1940−2010) is a procedure that accounts for the maximum covariance between the SST anomaly time series (Deser et al. 2010). The aim of EOF is to find the linear combination of all the variables (i.e. grid points) that explain maximum variance. This procedure is repeated until all *n* EOF patterns have been computed, where n is equal to the number of grid points (Deser et al. 2010). Climate indices were obtained from NOAA’s Earth System Research Laboratory, Physical Sciences Division (https://www.esrl.noaa.gov/psd/data/climateindices/list/).

3.3.3 Data Treatment/Processing

Sample Independence

It was assumed the environmental, oceanic, and biological measurements (samples) were representative of the population within the study area given that the experimental design used randomization to reduce sampling bias. Statistical power was considered high given the balanced sampling approach and the large number of observations over the duration of the study. It was also assumed the environmental and biological data were independent observations (i.e., the measurement of one observation did not affect the value of other observations) given that the experimental design considered time and space (i.e., spatial autocorrelation). The coastal waters off New Jersey are a dynamic oceanographic and biological system; conditions can vary significantly within a short distance or time period. Moreover, it was assumed the number of marine fauna in one year was independent of the number of marine fauna in the previous year given various biological factors, such as the relative short life-span (< 1 year) of many of the species collected in the study area, high mortality, the low annual reproductive success, and low annual recruitment from one year to the next. To minimize any potential spatial non-independence, data were pooled among stations within each individual sampling area.

To evaluate the nearshore marine community and oceanic conditions pre- and post-Hurricane Sandy, 8 years (2008−2015) of fishery-independent monitoring data (environmental and biological) were compiled, sorted (time [year and month] and space [area]), and summarized. Examining previous data analyses results (see *Chapter 2*) and for the purpose of these analyses, it was determined that a 5-year period adequately described the nearshore marine community and oceanic conditions. Given the ongoing changes in the nearshore marine community and oceanic conditions, a decision was made to use the most current 5-year time-series dataset rather than a 28-year time-series (1988−2015) to examine potential changes in the nearshore marine community and oceanic conditions associated with Hurricane Sandy. A shorter time-series should provide a more recent representation of the conditions in the study area within the context of the shifting baseline syndrome arising from ongoing changes.

Before initiating statistical hypothesis tests, environmental and biological data were transformed (e.g., logarithmic, square root, fourth root, or arcsine) to meet normativity assumptions, and down-weight the statistical effects (i.e., reduce skewness) of abundant taxa, while allowing less common taxa to contribute to sample discernment (Thorne et al. 1999; Korsman, 2013); this technique helped reduce any potential masking impacts. Kolmogorov-Smirnov and Bartlett tests were used to assess normality and homoscedacity (Zar, 1999). To ensure robustness, normality was also be checked by constructing a normal probability plot and examining the residuals. Outlier observations were investigated to determine whether the outlier occurred by chance; all outliers were retained for these analyses.

To evaluate the data using multivariate techniques, environmental data were normalized (mean subtracted and divided by standard deviation), checked for collinearity with a draftsman plot, and an Euclidean distance resemblance matrix was produced using PRIMER (Plymouth Routines in Multivariate Ecological Research) version 7 statistical package (Clarke and Warwick, 2001; Clarke and Gorley, 2006). Raw biological abundance and biomass data were also checked via draftsman plots, transformed (4th root), and a Bray-Curtis similarity resemblance matrix was produced via PRIMER. The statistical significance level was defined as $P < 0.05$ for all analyses. In the presence of significance at the 95 percent confidence level, *post-hoc* multiple pairwise comparison tests were used to differentiate the specific differences among the population means. Data were evaluated using various software, including Microsoft Access®, Microsoft Excel®, Statgraphics Centurion XVI®, and PRIMER®.

3.3.4 Statistical Analyses

3.3.4.1 Physicochemical Conditions

To better discern baseline variation from the effects of Hurricane Sandy, univariate and multivariate procedures were used to investigate annual (time-series) and monthly abiotic data. The surface and bottom oceanic conditions (water temperature, salinity, and DO) pre- (1988−2012) and post-Hurricane Sandy (one-year [2013], two-year [2014], and three-year [2015]) were examined using various univariate and multivariate tests. The month of January was selected because the storm traversed through the study area in October and it was the month standardized sampling was regularly conducted in the study area. January was also the earliest regular sampling period after the storm made landfall in New Jersey. Univariate and multivariate ANOVAs were used to test the null hypothesis that the mean annual and monthly surface and bottom oceanic conditions (water temperature, salinity, and DO) were the same before (1988−2012) and after Hurricane Sandy (2013, 2014, 2015).

Oceanic conditions (water temperature, salinity, DO), depth, and historical oceanic metrics (NAO, AMO, and EOF) were evaluated in conjunction by multivariate procedures to determine potential changes in the abiotic conditions associated with Hurricane Sandy. To derive meaningful distances between samples using the Euclidean distance, the values were normalized by subtracting the mean and dividing by the standard deviation (Clarke and Warwick, 2001). After normalizing the factors, a draftsman plot was constructed to evaluate the normalized oceanographic and physicochemical conditions over time and to inspect for collinearity between factors. A two dimensional (2d) non-multidimensional scaling (nMDS) scatter plot was used to compare potential change in the oceanic conditions pre and post-Sandy. Non-metric multi-dimensional scaling is a distance based procedure that ordinates study units based on rank dissimilarities (Clarke and Warwick, 2001). Because the procedure avoids assumptions of linearity and accurately maps sample units in ordination space by proportion to ecological distance, MDS is considered well suited for examining patterns in environmental and biological structure. These nMDS analyses were conducted on Euclidean distance of annual and monthly resemblance oceanic conditions and oceanic metric data. The Kruskal fit scheme and minimum stress was set at 1 and 0.01, respectively. Stress values indicate how well the resulting two-dimensional plot represent relationships among samples in the multidimensional space; values < 0.15 indicate a good fit (Clarke and Warwick, 2001). A Principle Components Analysis (PCA) ordination procedure was also used to estimate the percent in variance explained by each PC axis (up to five) and examine any patterns in the environmental factors. The maximum number of principal components was set as five because it explained most of the total variation. In general, the first three PC axes explains more than 40-50 percent of the total variation. An empirical rule-of-thumb is to use a procedure that explains about 70-75 percent (Clarke and Warwick, 2001). Unlike nMDS, PCA assumes linear relationships.

The significance of patterns illustrated by nMDS comparisons were tested using an Analysis of Similarities (ANOSIM). One-way and multivariate ANOSIMs were used to conduct pairwise comparisons of the oceanic conditions among time and space. The null hypothesis was there were no differences in the oceanic conditions among factors (year, month, and sampling area). The resultant global *R* value of this test is a measure of variation between groups compared to variation within groups scaled to take values over a fixed range up to 1; high *R* values indicating greater dissimilarity. The Spearman rank correlation method was applied to test for an unordered factor with no replicates correlation. The maximum number of permutations was set at 999. The R or rho values for pairwise tests was calculated to determine the pair-wise differences. Differences in oceanic conditions among time and space were also tested by one-way and multivariate permutational multivariate ANOVA (PERMANOVA). This is a technique that uses label permutation to estimate the distribution of the test statistics under the hypothesis that within-group distances are not significantly different from between-group distances (Clarke and Warwick, 2001). The permutation of residuals under a reduced model applying a type III (partial) sums of squares approach was selected to account for the unbalanced design. A *post-hoc* pair-wise test was used to examine within-group differences in oceanic conditions. Non-metric MDS comparisons illustrating significant trends examined using ANOSIM.

3.3.9.2 Marine Community

To evaluate estimated abundance (number of marine fauna collected per 100 m^2), the total number of individuals collected by species were standardized, transformed into nominal catch per unit effort (CPUE) indices, and evaluated using several analytical approaches. For analyses and interpretation of the abundance indices, it was assumed there was a simple direct positive relationship between CPUE and an estimate of abundance. To estimate abundance as a function of effort, CPUE was calculated by taking the product of the area swept, which was computed from the trawl net width at the wingtips and the distance towed; the trawl wing or horizontal spread was determined using hydroacoustic sensors. The estimated abundance (N_t number per 100 m^2) was calculated using the CPUE, the trawl dimensions, and the vessel speed using the following equation:

$$N_t = \frac{C}{AL} \text{ x } 100$$

where *C* is catch of species (*i*) at time $_t$, *A* is the mouth area of the trawl (24,076 m^2), and *L* is the distance towed (~1.85 km), which was the product of the vessel speed (92.5 m s^{-1}) and the trawl time (20 min). The estimated biomass (g 100 m^{-3}) was calculated by substituting *W* (catch in weight) for *C* in each tow.

To better discern baseline variation from the effects of the Hurricane Sandy, univariate and multivariate procedures were conducted on annual and monthly community marine fauna data. ANOVAs were used to test the hypotheses that catch characteristics (total number, estimate abundance, and estimate biomass) were similar between pre and post-Sandy. GLMs were applied to examine the influence of time and space on the catch characteristics and water temperature preference category between pre- and post-Sandy.

The marine community was also evaluated using various multivariate procedures to determine potential changes associated with Hurricane Sandy. To derive meaningful measures of the Bray-Curtis similarity and normalize skewed catch frequencies, the raw values were fourth-root transformed. After data transformation, a draftsman plot was constructed to evaluate the normalized marine community measures pre- and post-Sandy, and to inspect for collinearity between relative abundance. A 2d nMDS scatter plot was used to examine the potential change in the marine community post-Sandy; nMDS analyses were conducted on the Bray-Curtis similarity measure of the annual and monthly marine community data. The Kruskal fit scheme and minimum stress was set at 1 and 0.01, respectively. The oceanic conditions and oceanic metrics were overlaid using Pearson correlations; the correlation was set at a reasonable 20 percent; biplot vectors with a length greater than 20 percent were displayed because any value greater eliminated other potential factors that could influence the conditions within the study area (Clarke and Warwick, 2001). A PCO ordination procedure was used to discern any patterns pre and post-Sandy. The maximum number of principal components was set as five because it explained most of the total variation. In general, the first three PC axes explains more than 40-50 percent of the total variation. An empirical rule-of-thumb is to use a procedure that explains about 70-75 percent (Clarke and Warwick, 2001). The oceanic conditions and oceanic metrics were overlaid using a Pearson correlation; the correlation was set at a minimum of 20 percent. One-way and multivariate ANOSIMs were used to evaluate potential pairwise comparisons in the marine community among time and space. The null hypothesis for ANOSIM is that there was no statistical difference in the marine community among factors (year, month, and area) pre and post-Sandy. Spearman rank correlation method was applied to test for an unordered factor with no replicates. The maximum number of permutations was set at 999. The *R* or rho values for pair-wise tests was calculated to determine the pair-wise differences. Differences in the marine community among time (pre- and post-Sandy) and space were also tested by one-way and multivariate PERMANOVA. The permutation of residuals under a reduced model applying a type III (partial) sums of squares approach was selected to account for the unbalanced design. A *post-hoc* pair-wise test was used to examine within-group differences. SIMPROF was used to test for structure in the biological data. A two-way SIMPER was used to identify the species that contributed most to the average similarity and dissimilarity between and within groups by time and space. The cumulative percentage cut-off listing the highest-contributing species was set at 70 percent because it reasonably describes the community (Clarke and Warwick, 2001). To help interpret the SIMPER results, individual tables were constructed pre and post-Sandy. A dominance plot was constructed to examine the cumulative dominance of the marine community pre- and post-Sandy. The distance between dominance curves (DOMDIS) pre- and post-Sandy was examined and tested by constructing a resemblance matrix and comparing the similarity among time using a one-way ANOSIM. Various annual and monthly plots (bar, mean, and box) were constructed to examine the relative abundance of the marine community pre and post-Sandy. To examine the association between bottom water temperature and relative abundance, scatter plots were constructed for the three primary species collected (annual and monthly) in the study area pre- and post-Sandy.

3.4 Results

3.4.1 Annual Oceanographic/Physicochemical Conditions Pre- and Post-Hurricane Sandy

A draftsman plot showed the normalized oceanographic and physicochemical conditions were consistent over time with only a few outliers. As expected, there was evidence of collinearity between a few factors (e.g., surface water temperature and bottom DO) (**Figure 3.4.1-1**).

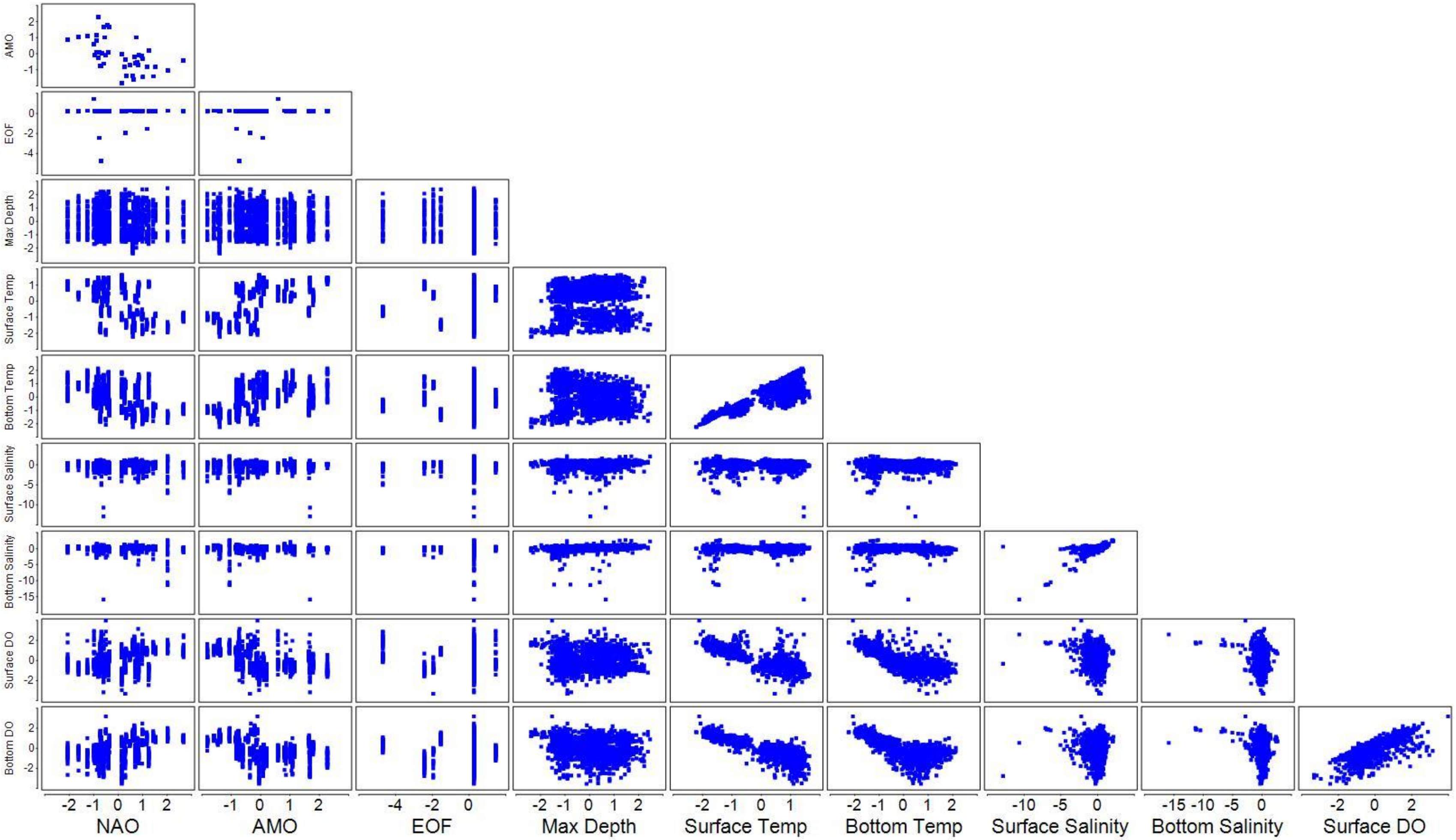


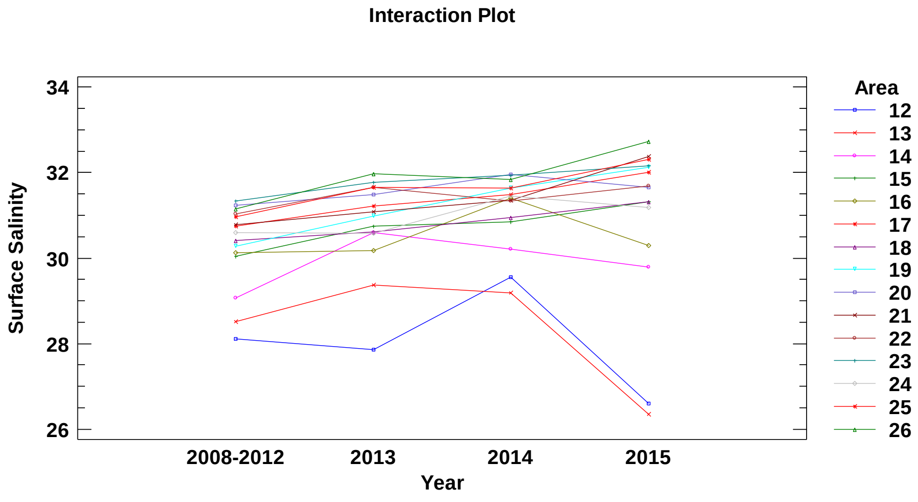
Figure 3.4.1-1. Draftsman plot of the oceanographic and physicochemical conditions in the study area (2008−2015).

A multifactor ANOVA showed that time (*F* [3, 1487] = 13.06, *P* < 0.05) and space (*F* [14, 1487] = 18.86, *P* < 0.05) significantly influenced the surface salinity (**Figures 3.4.1-2, 3.4.1-3**), but there was no interaction effect (*F* [42, 1487] = 1.24, *P* = 0.1374). Although statistically non-significant, surface salinity in sampling areas 12 and 13 in 2015 were slightly different than the other years. Bottom DO was not significantly influenced by the sampling area (*F* [14, 1487] = 1.31, *P* = 0.1964) or the interaction between time and space (*F* [42, 1487] = 0.27, *P* = 1.0); however, it was significantly influenced by the year (*F* [3, 1487] = 2.75, *P* = 0.0415).

Surface and bottom water temperature readings displayed consistent monthly and annual variation, but salinity and DO readings varied significantly pre- and post-Sandy (**Table 3.4.1-1**). In general, the annual mean bottom salinity and DO levels in 2013, one year post-Sandy, were significantly higher than the conditions pre-Sandy (2008−2012). Separate ANOVAs showed that mean annual (2008−2012, 2013, 2014, and 2105) surface and bottom salinity and DO levels were significantly different over time. The mean surface salinity varied significantly among time-series; however, the levels in 2013, 2014, and 2015 did not vary from the average. The mean bottom salinity varied significantly (higher) between pre-Sandy (2008−2012) and post-Sandy (2013), and pre-Sandy (2008−2012) and post-Sandy (2014). The mean bottom salinity was also significantly (lower) different between 2013 and 2015, and 2014 and 2015; but there was no difference between 2013 and 2014. The mean surface DO in 2014 (post-Sandy) was significantly higher than pre-Sandy (2008−2012). The mean bottom DO in 2013 and 2014 were significantly higher than pre-Sandy (2008−2012), but there was no significant difference in DO among any of the recent years (2013, 2014, and 2015).

Table 3.4.1-1. One-way ANOVA. Annual Environmental Conditions. Pre (2008−2012) and post-Sandy (2013, 2014, and 2015).

Environmental Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Surface Water Temperature	ANOVA	F [3, 1487] = 0.13, $P = 0.9445$	N/A			
Bottom Water Temperature	ANOVA	F [3, 1487] = 1.60, $P = 0.1880$	N/A			
Surface Salinity	ANOVA	F [3, 1487] = 11.51,	2008-2012 – 2013	*	-0.48255	0.346548
		$P < 0.05$	2008-2012 – 2014	*	-0.821065	0.346548
			2008-2012 – 2015	*	-0.704555	0.346548
Bottom Salinity	ANOVA	F [3, 1487] = 9.62,	2008-2012 – 2013	*	-0.563287	0.274839
		$P < 0.05$	2008-2012 – 2014	*	-0.586467	0.274839
			2013 – 2015	*	0.380303	0.354816
			2014 – 2015	*	0.403483	0.354816
Surface DO	ANOVA	F [3, 1487] = 3.20, $P = 0.0225$	2008-2012 – 2014	*	-0.295478	0.215201
Bottom DO	ANOVA	F [3, 1487] = 2.80,	2008-2012 – 2013	*	-0.334018	0.28514
		$P = 0.0389$	2008-2012 – 2014	*	-0.307298	0.28514



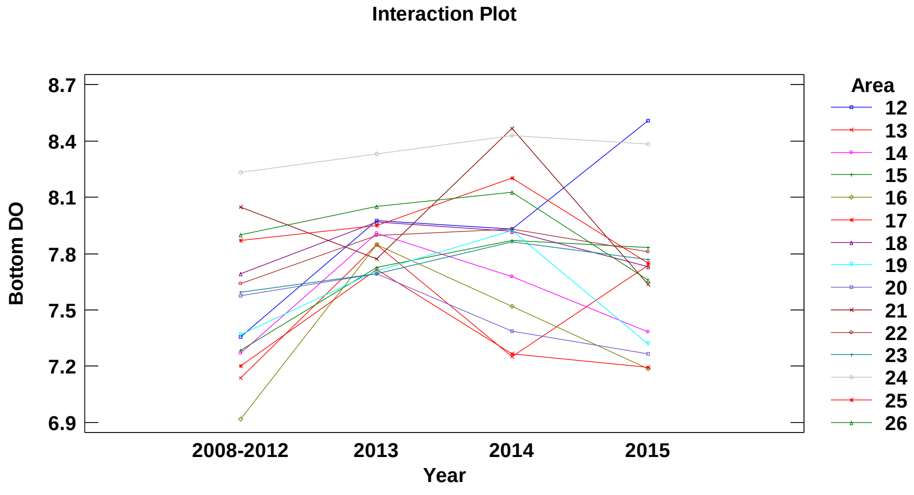


Figure 3.4.1-2. Multifactor ANOVA. Mean surface and bottom salinity by sampling area and time in the study area pre- (2008−2012) and post-Sandy (2013, 2014, and 2015).

Multivariate ordination procedures showed there were similarity associations and correlations among annual oceanographic and physicochemical conditions pre- and post-Sandy. In general, an nMDS ordination map showed overlap (*stress* = 0.08) in the abiotic conditions for most sampling areas and years. However, the environmental data seem to fit better and was easier to interpret using a PCA procedure. A PCA showed that the oceanographic (NAO, AMO, and EOF) and physicochemical conditions pre- (2008−2012) and post-Sandy (2013 and 2014) were not clearly separated among annual groups **(Figure 3.4.1-5**). The percent of variance explained by the first two PC axes was 58.6 percent: 40.7% for PC1 and 17.8% for PC2. The greatest coefficients in the linear combination of variables comprising PC1 were surface (0.463) and bottom temperature (0.435). The surface (0.641) and bottom salinity (0.666) were the greatest coefficients in the linear combination of variables comprising PC2, which also supports the univariate analyses. A Pearson correlation (0.35) procedure showed that the annual oceanographic (NAO, AMO, and EOF) and physicochemical resemblance matrices pre- (2008−2012) and post-Sandy (2013 and 2014) were not strongly correlated with the marine community correlation coefficients.

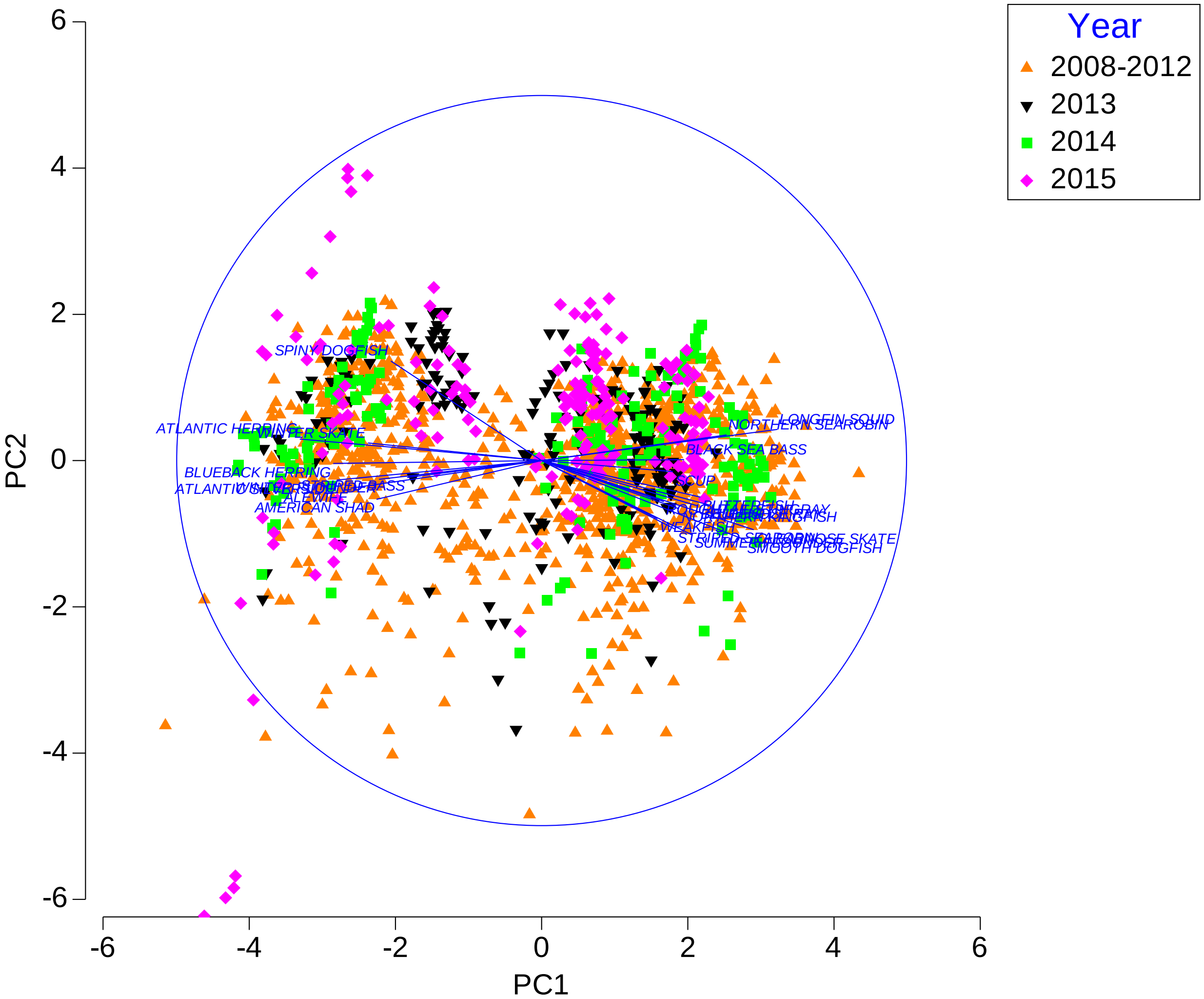


Figure 3.4.1-5. A PCA plot of the annual environmental conditions and association with the biological community pre- and post-Sandy.

Separate one-way ANOSIMs showed there was no significant difference in the oceanographic and physicochemical conditions among years (R = -0.33; P = 0.992), but there were significantly differences among months (R = 0.494; P = 0.001) and sampling areas (R = 0.124; P = 0.001); low R values (strength) showed separation among samples was minimal. *Post-hoc* analysis showed there were no significant differences in the abiotic conditions between pre-

(2008−2012) and post-Sandy (2013, R = -0.061, P = 1; 2014, R = -0.019, P = 0.857; and 2015, R = -0.008, P = 0.67), but the abiotic conditions differed slightly between later years (2013−2014, R = 0.087, P = 0.001; 2013−2015, R = 0.018, P = 0.003; 2014−2015, R = 0.073, P = 0.001). A one-way PERMANOVA showed the oceanographic and environmental conditions were significantly different among years. *Post-hoc* analysis revealed the abiotic conditions were significantly different between every pairwise pair except between 2013 and 2015 (**Table 3.4.1-2**).

Table 3.4.1-2. One-way PERMANOVA. Annual oceanographic and physicochemical conditions pre and post-Sandy.

Groups	***t***	***P* (perm)**	**Unique perms**
2008-2012, 2013	3.8724	0.001	999
2008-2012, 2014	3.6412	0.001	998
2008-2012, 2015	3.9815	0.001	998
2013, 2014	3.5569	0.001	998
2013, 2015	1.4583	0.099	998

3.4.2 Monthly Oceanographic/Physicochemical Conditions Pre and Post-Hurricane Sandy

The pre- (2008−2012) and post-Sandy (2013, 2014, and 2015) physicochemical conditions in January varied significantly in some years. The mean annual surface (F [3, 238] = 13.65, $P < 0.05$) and bottom (F [3, 238] = 10.60, $P < 0.05$) water temperature in January varied significantly over time, and *post-hoc* analysis showed that the mean surface water temperature in 2014 was significantly lower than in 2008−2012 and 2013; the mean bottom water temperature in January 2014 was also significantly lower in January 2015. The mean annual surface (F [3, 238] = 8.60, $P < 0.05$) and bottom (F [3, 238] = 16.05, $P < 0.05$) salinity varied significantly over time; surface and bottom salinity in 2015 was significantly lower than in 2008−2012 and 2013 and bottom salinity also significantly lower in 2015 than 2014. The mean annual surface (F [3, 238] = 10.67, $P < 0.05$) and bottom (F [3, 238] = 14.58, $P < 0.05$) DO varied significantly over time; mean surface DO in 2013 and 2014 was significantly higher than in 2008−2012. The mean surface DO in 2013 was also significantly higher than in 2015. Similarly, the bottom DO in 2013 was significantly higher than in 2008−2012, 2014, and 2015.

A multifactor (year and sampling area) ANOVA showed that the mean surface and bottom DO in January varied significantly over time ($F\ [3, 238] = 13.06$, $P < 0.05$; $F\ [3, 238] = 17.26$, $P < 0.05$), but not by space ($F\ [14, 238] = 1.41$, $P = 0.1533$; $F\ [3, 238] = 1.60$, $P = 0.0828$), or the interaction between time and space ($F\ [42, 238] = 0.68$, $P = 0.9262$; $F\ [3, 238] = 1.06$, $P = 0.3896$).

The results of fitting individual general linear statistical models (GLMs) relating surface and bottom DO to predictive factors (year and sampling area) showed that time and space significantly predicted the surface DO ($F\ [17, 238] = 3.57$, $P < 0.05$) and bottom ($F\ [17, 238] = 4.25$, $P < 0.05$) DO at the 95 percent level. The highest surface and bottom DO levels occurred during 2013 (one year post-Sandy) in sampling areas 17−26 and 16−26, respectively.

Multivariate ordination procedures showed there were some differences among the annual oceanographic and physicochemical conditions in January (pre- and post-Sandy). An nMDS showed some dissimilarity in the ordination among years (*stress* = 0.15) suggesting the annual oceanographic (NAO, AMO, and EOF) and physicochemical conditions pre- (2008−2012) and post-Sandy (2013, 2014, and 2015) were dissimilar. However, the environmental data seem to fit better and was easier to interpret using a PCA procedure. A PCA showed there was some limited separation among the annual variability in the oceanographic (NAO, AMO, and EOF) and physicochemical conditions in January pre- (2008−2012) and post-Sandy (2013 and 2014) **(Figure 3.4.2-1)**. The first two PC axes (PC1 [38.6%] and PC2 [21.3%]) explained 59.9 percent of the variance. The greatest coefficients in the linear combination of variables comprising PC1 were surface (0.430) and bottom DO (0.431). The NAO (0.411) and bottom temperature (0.138) were the greatest coefficients in the linear combination of variables comprising PC2. Pearson correlations >0.35 showed that a few species were correlated with limited annual samples.

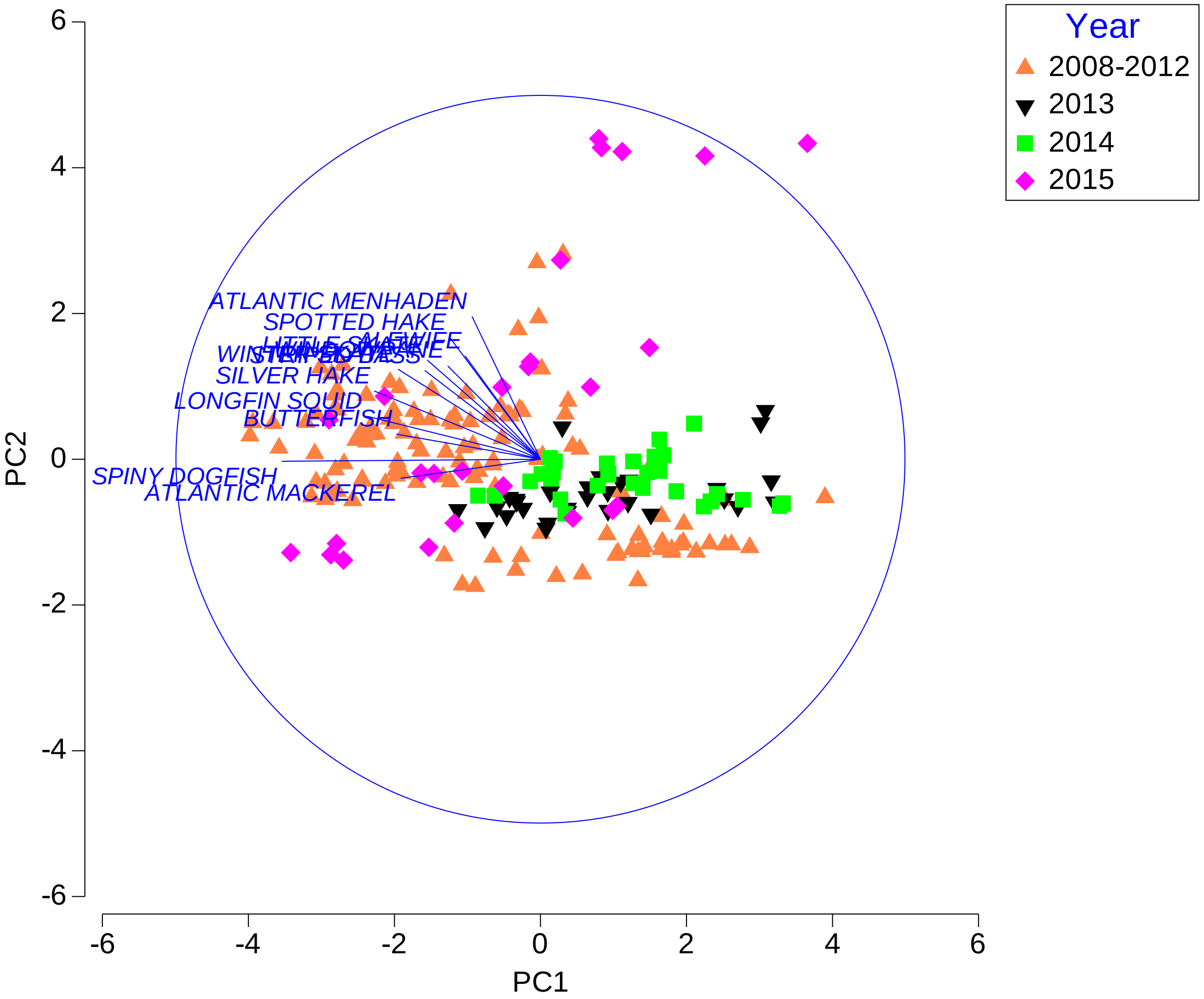


Figure 3.4.2-1. Principal coordinates association between the environmental conditions and individual species in January pre- (2008−2012) and post- Sandy (2013, 2014, and 2015).

A three-way (factors: year, month, and sampling area) permutational MANOVA procedure showed the oceanographic and physicochemical conditions in January varied significantly by year and the interaction effect among factors, but it depended on the sampling area (**Table 3.8-2**). Pair-wise comparison tests revealed the abiotic conditions were not significantly different between pre-

(2008−2012) and post-Sandy (2013), but the abiotic conditions did vary in sampling area 19 (*P* = 0.05). The pre- and post-Sandy abiotic conditions in 2014 varied significantly in most sampling areas (13−17, 19, 20, 22, and 23), whereas the conditions in 2015 varied significantly in a few sampling areas (12, 13, 17, 19, 21−23, and 25). Interestingly, the abiotic conditions in sampling areas 18 and 24 did not vary significantly in every year.

3.4.2 Annual Marine Community Pre and Post-Hurricane Sandy

Separate ANOVAs suggested there were no significant differences in the catch characteristics between pre- and post-Sandy (**Table 3.4.2-1**).

Table 3.4.2-1. One-way ANOVA. Pre- (1988−2012) and post-Sandy (2013).

Catch Parameter	Hypothesis Test for Interannual Variation	Test Results	Fisher's Least Significant Difference Procedure
Annual Total Number	ANOVA	*F* [1, 100440] = 0.00, *P* = 0.9687	N/A
Annual Estimated Abundance	ANOVA	*F* [1, 100440] = 0.14, *P* = 0.7125	N/A
Annual Estimated Biomass	ANOVA	*F* [1, 100440] = 3.6, *P* = 0.0578	N/A

The results of fitting individual general linear statistical models (GLMs) relating various catch metrics to three predictive factors (year, month, and sampling area) showed that month and sampling area significantly predicted the total number, estimate abundance, and estimate biomass pre- and post-Sandy; the fitted models accounted for most of the variation in the total number and abundance (**Table 3.4.2-2**).

Table 3.4.2-2. General Linear Model and associated ANOVA Type III Sums of Squares pre- (1988-2012) and post-Sandy (2013).

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number	Year	0.0947036	1	0.0947036	0.05	0.8193	√√ Total Number = 1.92291 - 2.46135E-10*Year + 0.0382945*Month - 0.0101841*Area	0.800134 percent
	Month	1293.43	1	1293.43	712.67	0.0000		
	Area	180.792	1	180.792	99.62	0.0000		
	Residual	182283.	100437	1.8149				
	Total (corrected)	183753.	100440					
Estimated Abundance	Year	0.00486427	1	0.00486427	0.31	0.5787	√√ Relative Abundance = 0.180799 + 0.0*Year + 0.00347273*Month - 0.000950485*Area	0.762945 percent
	Month	10.6368	1	10.6368	674.32	0.0000		
	Area	1.5748	1	1.5748	99.83	0.0000		
	Residual	1584.31	100437	0.0157741				
	Total (corrected)	1596.49	100440					
Estimated Biomass	Year	0.0201704	1	0.0201704	4.01	0.0452	√√ Relative Biomass = 0.116916 - 1.13592E-10*Year + 0.000668372*Month - 0.000572946*Area	0.193749 percent
	Month	0.394009	1	0.394009	78.35	0.0000		
	Area	0.572219	1	0.572219	113.79	0.0000		
	Residual	505.073	100437	0.00502876				
	Total (corrected)	506.054	100440					

Segregating the marine community fauna by temperature preference group, also showed the catch characteristics did not significantly vary between pre- and post-Sandy. However, the estimated biomass for subtropic-adapted species was significantly higher post-Sandy (**Table 3.4.2-3**).

Table 3.4.2-3. One-way ANOVA. Temperature preference groups pre- (1988–2012) and post-Sandy (2013).

Catch Parameter	**Hypothesis Test for Interannual Variation**	**Test Results**	**Fisher's Least Significant Difference Procedure**			
			Contrast	*Sig.*	*Difference*	*+/- Limits*
Annual Total Number (Coldwater-adapted)	ANOVA	*F* [1, 37754] = 0.03, *P* = 0.8709	N/A			
Annual Estimated Abundance (Coldwater-adapted)	ANOVA	*F* [1, 37754] = 0.01, *P* = 0.9409	N/A			
Annual Estimated Biomass (Coldwater-adapted)	ANOVA	*F* [1, 37754] = 0.19, *P* = 0.6649	N/A			
Annual Total Number (Warmwater-adapted)	ANOVA	*F* [1, 48393] = 0.03, *P* = 0.8712	N/A			
Annual Estimated Abundance (Warmwater-adapted)	ANOVA	*F* [1, 48393] = 0.01, *P* = 0.9324	N/A			
Annual Estimated Biomass (Warmwater-adapted)	ANOVA	*F* [1, 48393] = 1.84, *P* = 0.1755	N/A			
Annual Total Number (Subtropic-adapted)	ANOVA	*F* [1, 6705] = 0.0, *P* = 0.9707	N/A			
Annual Estimated Abundance (Subtropic-adapted)	ANOVA	*F* [1, 6705] = 0.01, *P* = 0.9171	N/A			
Annual Estimated Biomass (Subtropic-adapted)	ANOVA	*F* [1, 6705] =13.52, *P* = 0.0002	2013 – 1988-2012	*	0.0132703	0.00707258

The results of fitting individual GLMs relating various catch metrics to three predictive factors (year, month, and sampling area) showed that month and sampling area were predictor factors of the total number, estimate abundance, and estimate biomass pre- and post-Sandy; however, month was not a predictor value of the biomass for the subtropic-adapted group (*See Appendix*: **Table 3.8-3, Table 3.8-4,** and **Table 3.8-5**).

Multivariate ordination procedures showed there were similarity associations, correlations, and significant differences in the marine community (abundance and biomass) pre- and post-Sandy depending on the factors. Separate nMDS tests adequately fitted (Abundance: *Stress* = 0.17; Biomass: *Stress* = 0.17) the similarity of the marine community samples (abundance and biomass) pre- and post-Sandy. The nMDS showed overlap in the marine community samples over time (pre- and post-Sandy), and the association between the marine community and water temperature (surface and bottom) (**Figure 3.4.2-1**).

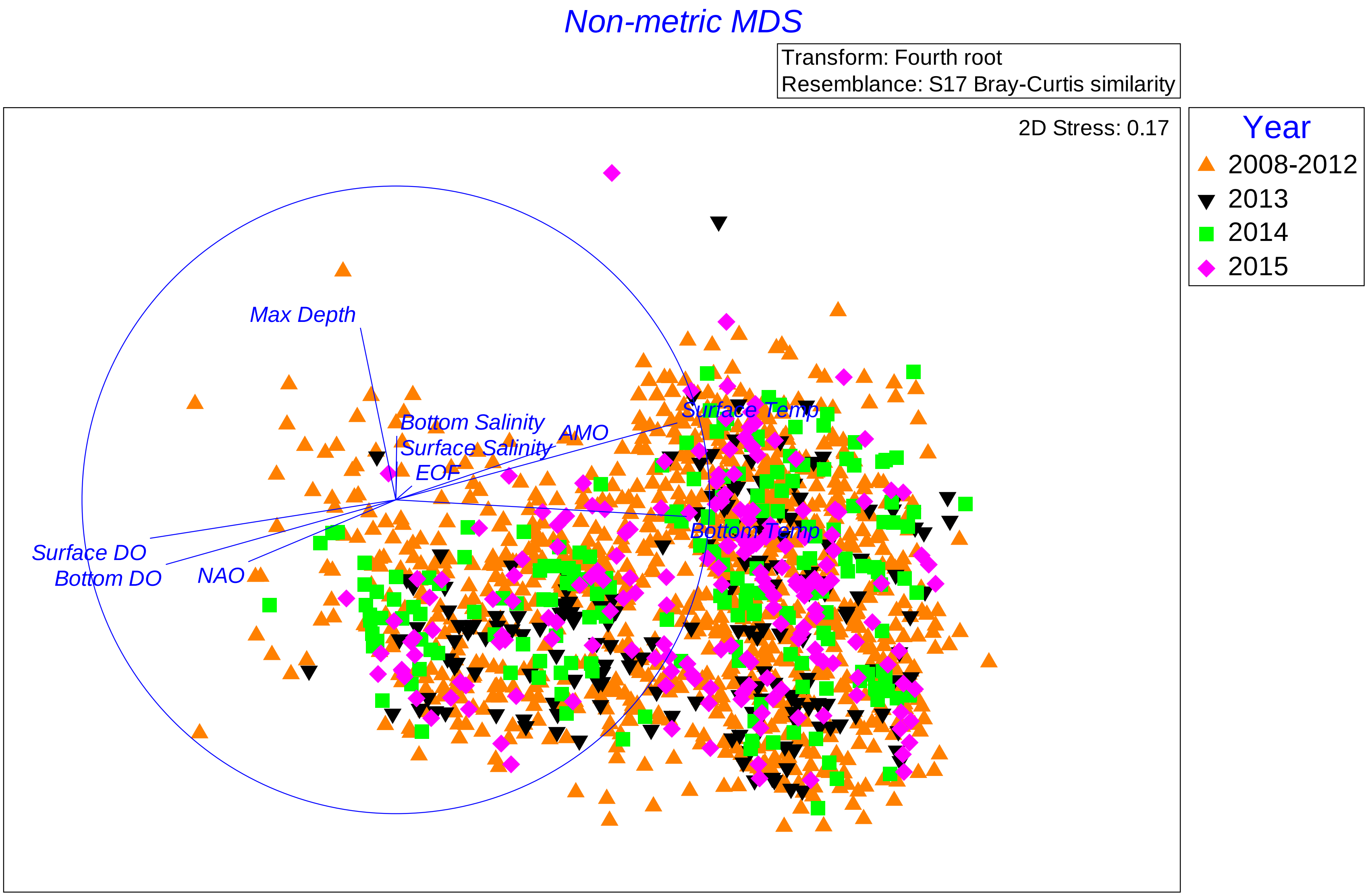


Figure 3.4.2-1. 2-Dimensional non-MDS of the annual marine community (abundance) and the association to the environmental conditions pre- (2008–2012) and post-Sandy (2013, 2014, 2015).

A PCO procedure also showed that the marine community (abundance) was similar pre- and post-Sandy; no clear separation among annual samples (**Figure 3.4.2-2**). Forty-one percent of the total variability in the marine community (abundance) was explained by the ordination procedure (PCO1 axis [27.21%] and PCO2 axis [13.76%]). The PCO explained 41.2 percent (PCO1 [29.74%] and PCO2 [11.48%]) of the variability in the biomass of the marine community. The marine community (abundance and biomass) was primarily associated with the water temperature (surface and bottom) and the AMO index. The PCO also showed that the annual marine community was secondarily associated with the DO (surface and bottom) and the NAO index.

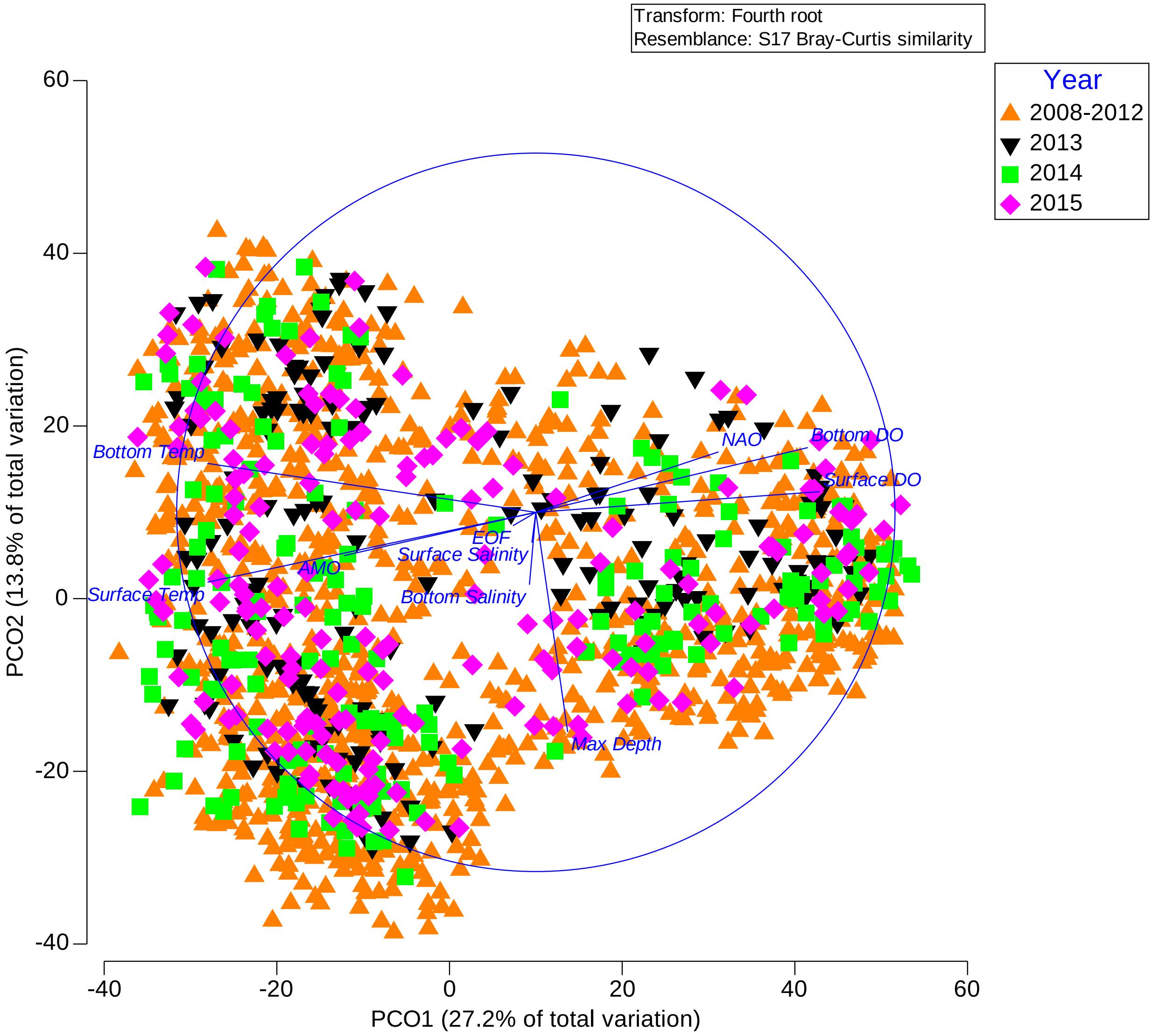


Figure 3.4.2-2. PCO of the annual marine community (abundance) and the association to the environmental conditions pre- (2008−2012) and post-Sandy (2013, 2014, 2015).

A one-way ANOSIM revealed that the marine community (abundance) was significantly different among years (R = 0.027; P = 0.015, 999 permutations). *Post-hoc* analysis showed that the marine community (abundance) was significantly different between pre- (2008−2012) and post-Sandy (2013, R = 0.029, P = 0.048; 2014, R = 0.056, P = 0.002); the marine community was also significantly different between later years (2013 and 2014, R = 0.031, P = 0.001; 2013 and 2015, R = 0.036, P = 0.001; 2014 and 2015, R = 0.024, P =0.003).

One-way PERMANOVA also showed that marine community (abundance) was significantly different pre- and post-Sandy. *Post-hoc* analysis showed that the marine community (abundance) was not only significantly different one year (2013) post-Sandy, but the marine community varied significantly over time (**Table 3.4.2-4.**). A PERMDISP procedure also exposed that the marine community (abundance) was significantly different between pre- (2008−2012) and post-Sandy (2013 and 2015) (**Table 3.4.2-5**).

Table 3.4.2-4. Permutational MANOVA. Annual variability in the marine community (abundance) pre- (2008−2012) and post-Sandy (2013, 2014, 2015).

Groups	*t*	*P* (perm)	Unique Permutations
2008-2012, 2013	4.2771	0.001	998
2008-2012, 2014	3.9565	0.001	998
2008-2012, 2015	4.5117	0.001	999
2013, 2014	2.2734	0.001	997
2013, 2015	2.431	0.001	998
2014, 2015	2.0668	0.002	998

Table 3.4.2-5. Distance-based test for homogeneity of multivariate dispersions among time-series that includes pre- (2008−2012) and post-Sandy (2013, 2014, 2015).

Parameter	Hypothesis Test for Interannual Variation	Test Results	Pairwise Comparisons Groups	*t*	perm
Bray-Curtis Similarity (Estimated Abundance)	PERMDISP	*F* [3, 1488] = 7.8538, *P* = 0.001	2008-2012, 2013	3.1584	0.005
			2008-2012, 2014	0.3219	0.754
			2008-2012, 2015	3.9909	0.001
			2013, 2014	2.3744	0.027
			2013, 2015	0.7185	0.493
			2014, 2015	2.9401	0.012

A three-way (year, month, and sampling area) PERMANOVA procedure showed the marine community (abundance) varied significantly by year and the interaction effect among factors, but it depended on the month and sampling area (**Tables 3.8-6-10**). October had the greatest number of sampling areas (*n* = 12) and January had the least number of sampling areas (*n* = 5) where the marine community (abundance) varied significantly pre- and post-Sandy (**Tables 3.8-10**). October and January also had the most (*n* = 21) and least (*n* = 10) number of pair-wise comparisons (time-series) that displayed significant differences in the marine community (abundance) pre- and post-Sandy, respectively (**Table 3.8-6,** and **Table 3.8-10**). Sampling areas 16, 17, and 23 had the most (*n* = 5 each) and sampling areas 13, 14, 24, and 26 had the least (*n* = 1 each) number of pairwise time-series that showed significant differences in the marine community (abundance) pre- and post-Sandy (**Tables 3.8-6-10**).

SIMPROF showed there was a statistical structure in the marine community (*Pi* = 5.11; *P* = 0.001; *Perms* = 999), and SIMPER analyses (**Tables 3.8-11**) identified a limited group of species (abundance) that were drivers of the grouping patterns. The procedure indicated the average percent similarity of species pre- was lower than post-Sandy. The average percent similarity slightly changed from 34.48 (pre-Sandy) to 38.08 (post-Sandy [2015]). The main species with the greatest percentage of the total catch (pre- and post-Sandy) were longfin squid, windowpane, and little skate. Conversely, *post-hoc* analyses indicated the average percent dissimilarity (pre- and post-Sandy) changed from 66.15 (2008−2012 vs 2013) to 67.02 (2008−2012 vs 2014), including 66.05 (2008−2012 vs 2015). Post-Sandy (2013, 2014, 2015), the primary species contributing to the dissimilarity in the species composition were bay anchovy, longfin squid, and butterfish. The average dissimilarity also differed between 2013 and 2014 (64.71), and 2014 and 2015 (63.31). Interestingly, the average estimated abundance for several species (e.g., bay anchovy, northern searobin, and Atlantic herring) increased post-Sandy (2013). However, in later years (2014 and 2015), there were fewer species with a higher relative abundance post-Sandy than pre-Sandy (2008−2012), and several species had a lower estimated abundance.

Community dominance plot were constructed by ranking species in order of importance along the x-axis, and their percentage contribution to the total was plotted along the y-axis. A one-way ANOSIM showed there was no observed change in the community structure (*k*-dominance curves) pre- and post-Sandy (*R* = 0.011, *P* = 0.182, 999 permutations). Although the community structure (*k*-dominance; abundance) for various non-dominant species (black drum, bluefish, and Northern sennet) decreased post-Sandy (2013), the *k*-dominance of the most abundant (dominant) species did not vary significantly between pre- and post-Sandy.

A one-way ANOSIM revealed the biomass of the marine community was not significantly different pre- and post-Sandy (*R* = -0.001; *P* = 0.536, 999 permutations). However, a two-way PERMANOVA procedure found that marine community (biomass) was significantly different (*t* = 3.1075; *P* = 0.001; *Perms* = 999) pre- (2008-2012) and post-Sandy (2013), but that depended on the sampling area. Actually, sampling area 20 (*t* = 1.73; *P* = 0.002; *Perms* = 999) was the only sampling area significantly different one year (2013) post-Sandy.

SIMPROF showed there was a statistical structure in the marine community (*Pi* = 5.15; *P* = 0.001; *Perms* = 999), and SIMPER analyses identified a limited group of species (biomass) that were drivers of the grouping patterns (**Table 3.8-11**). The procedure indicated the average percent similarity of species contributions pre-Sandy (38.41) was similar to post-Sandy (38.36). The main species contributing the greatest percentage (23.48%) of dissimilarity between pre- and post - Sandy (2013) were clearnose skate, spiny and smooth dogfish, winter skate, northern searobin, and little skate. Evaluating pre- and post-Sandy, little skate, windowpane were the primary species contributing to the greatest percent (~ 26%) in similarity during every year (2008-2012 and 2013-2015). The third and fourth dominant species and associated percent contribution varied somewhat among years, but it generally consisted of summer flounder, longfin squid, and winter or clearnose skate. Based on community dominance plots, the proportion (*k*-dominance) among species did not appear skewed in either a positive or negative direction. Community dominance plot were constructed by ranking species in order of importance along the x-axis, and their percentage contribution to the total was plotted along the y-axis. A one-way ANOSIM showed there was no significant change (R = 0.022, P = 0.054, 999 permutations) in the community structure (*k*-dominance curves) pre- and post -Sandy (2013) (R = 0.007, P = 0.362, 999 permutations).

3.4.3 Monthly Marine Community Pre and Post-Hurricane Sandy

Separate one-way ANOVAs showed that the catch characteristics in January were not significantly different pre- and post-Sandy (**Table 3.4.3-1**).

Table 3.4.3-1. One-way ANOVA. Catch characteristics in January pre- (2008−2012) and post-Sandy (2013).

Catch Parameter	Hypothesis Test for Interannual variation	Test Results	Fisher's Least Significant Difference Procedure *Contrast Sig. Difference +/- Limits*
Annual Total Number	ANOVA	F [1, 12629] = 1.77, P = 0.1832	N/A
Annual Estimated Abundance	ANOVA	F [1, 12629] = 1.60, P = 0.2056	N/A
Annual Estimated Biomass	ANOVA	F [1, 12629] = 0.03, P = 0.8657	N/A

Various multivariate procedures also indicated the marine community was not significantly different pre- and post-Sandy. An nMDS showed there was overlap and similarity (*Stress* = 0.22) in the marine community samples pre- and post-Sandy, and the community was most strongly associated with water temperature (surface and bottom) and bottom depth (**Figure 3.4.3-1**).

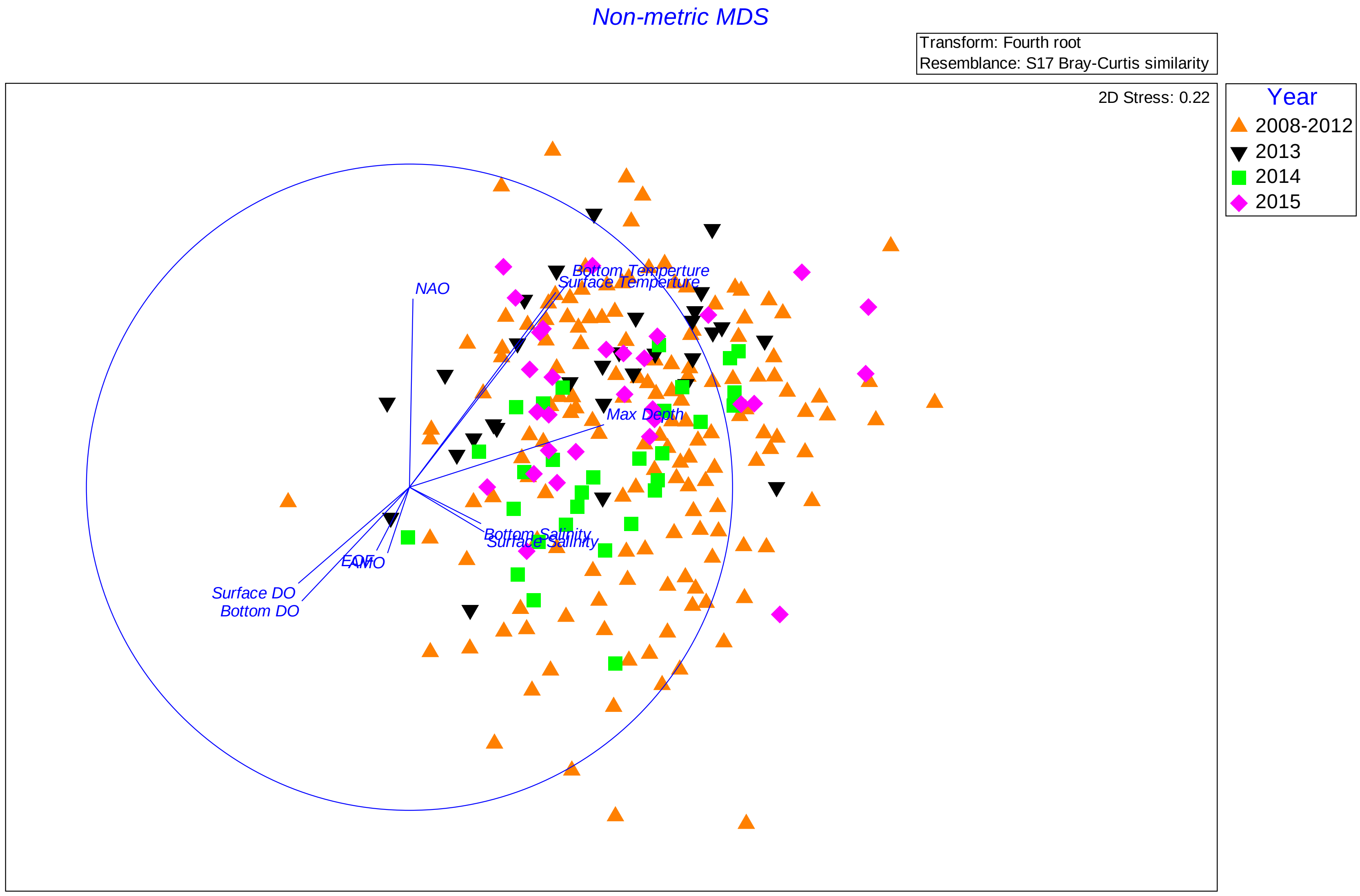


Figure 3.4.3-1. Non-metric multi-dimensional scaling in January pre- (2008−2012) and post-Sandy (2013, 2014, 2015).

A PCO again showed overlap between the marine community pre- and post-Sandy, and the ordination procedure explained 38.42 percent (PCO1 = 22.5% and PCO2 = 15.9%) of the variability in the samples. The test showed weak associations with the oceanic and environmental conditions, but most strongly with temperature and DO (**Figure 3.4.3-2**).

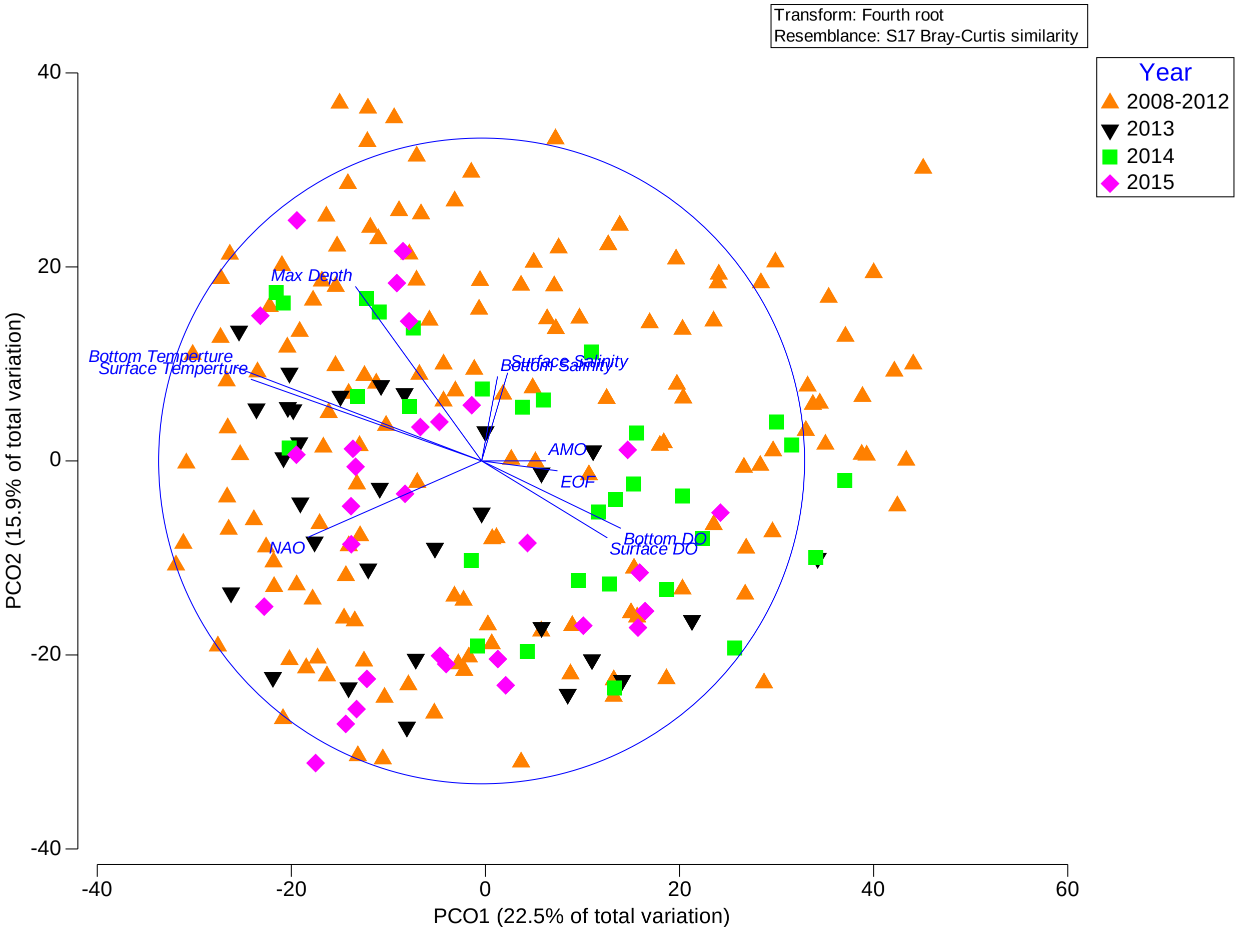


Figure 3.4.3-2. PCO plot of the marine community in January and the association to the environmental conditions pre- (2008−2012) and post-Sandy (2008−2012).

A one-way ANOSIM showed the marine community in January pre- and one year post-Sandy was not significantly different (*R* = -0.011, *P* = 0.63, 999 permutations), but there were significant differences in the marine community between later years (2013 and 2014 [*R* = 0.218, *P* = 0.001]; 2014 and 2015 [*R* = 0.208, *P* = 0.001]). In contrast, one-way PERMANOVA and PERMDISP procedures showed there were significant differences in the January marine community pre- and post-Sandy (**Tables 3.4.3-2** and **3.4.3-3**). PERMDISP *Post-hoc* analysis showed the marine community was not significantly different in later years.

Table 3.4.3-2. Permutational MANOVA. Marine community in January pre- (2008−2012) and post-Sandy (2013, 2014, 2015).

Groups	***t***	***P* (perm)**	**Unique Permutations**
2008-2012, 2013	2.9065	0.001	999
2008-2012, 2014	2.1689	0.001	998
2008-2012, 2015	2.78	0.001	998
2013, 2014	3.1181	0.001	999
2013, 2015	2.2644	0.001	997
2014, 2015	3.22117	0.001	998

Table 3.4.3-3. PERMDISP (Distance-based test for homogeneity of multivariate dispersions). Marine community pre- (2008−2012) and post-Sandy (2013, 2014, 2015).

Groups	***t***	***P* (perm)**
2008-2012, 2013	2.8006	0.014
2008-2012, 2014	3.5903	0.001
2008-2012, 2015	3.2551	0.002
2013, 2014	0.6748	0.492
2013, 2015	0.3832	0.737
2014, 2015	0.2681	0.774

As briefly shown above, a three-way (year, month, and sampling area) PERMANOVA indicated the marine community in January varied significantly by year and the interaction effect among factors, but it depended on the sampling area (Table 3.8-6). The marine community in sampling areas 16 and 20 varied significantly between pre- (2008−2012) and post-Sandy (2013);

it also varied significantly between several other pairs (2008−2012 and 2014; 2008−2012 and 2015).

A one-way Simper procedure indicated the average percent similarity of species contributions in January pre-Sandy was lower than post-Sandy (**Table 3.8-12**). The average percent similarity ranged from 43.98 (pre-Sandy) to 52.38 (post-Sandy [2014]). The main species with the greatest percentage of the total catch (pre and post-Sandy) were Atlantic herring, American sand lace, blueback herring, and Atlantic silverside. Conversely, *post-hoc* analyses indicated the average percent dissimilarity (pre- and post-Sandy) ranged from 54.09 (2014) to 56.54 (2013). The average relative abundance of several species (e.g., Atlantic herring, American sand lace, and Atlantic silverside) decreased and several others (e.g., blueback herring, silver hake, and winter skate) increased post-Sandy (2013). The dominant species order varied, but the species and their percent contribution (>50%) were somewhat similar pre and post-Sandy.

Community dominance plot were constructed by ranking species in order of importance along the x-axis, and their percentage contribution to the total was plotted along the y-axis. A one-way ANOSIM supported there was no observed change in the community structure (*k*-dominance curves) pre- and post-Sandy (R = -0.068, P = 0.992, 999 permutations). *Post-hoc* analyses showed there was a significant difference in the community structure (*k*-dominance curves) between later years post-Sandy; 2013 and 2014 (R = 0.104, P = 0.001), and 2014 and 2015 (R = 0.041, P = 0.036).

3.5 Discussion

3.5.1 Oceanographic/Physicochemical Conditions Pre and Post-Hurricane Sandy

A few abiotic variables and biological community metrics within the study area were significantly different between pre- and post-Sandy (2013). The mean salinity and DO levels were significantly higher and the marine community was significantly different (abundance and species composition) post-Sandy, but it depended on the sampling area and month. Changes in the abiotic conditions and marine community post-Sandy were short-term suggesting there were no long-term impacts to either the abiotic conditions or the marine community. Natural disturbance events (e.g., droughts, floods, and storms) can alter fish assemblage structure (Vrancken and O'Connell, 2010) and oceanic conditions (salinity and DO) because of sudden rainfall, storm surge, and pollution runoff, but impacts are usually temporary and recovery is relatively fast (Houde et al. 2005; Paperno et al. 2006; Vrancken and O'Connell, 2010). This research is the first to use a long-term data set (28-years) to examine the potential impacts of Hurricane Sandy/Extratropical Cyclone on the abiotic conditions and marine community off New Jersey.

Overall, six (86%) alternative hypotheses were confirmed and accepted, and one alternative hypothesis was rejected **(Table 3.5.1)**. In general, the abiotic conditions and the associated marine community was significantly different post-Sandy; however, the impacts were minimal in terms of the statistical significance. Also, the impacts were short-term in duration and did not appear to have any long-term impacts suggesting the community is resilient to short-term disturbance from natural storms, such as hurricanes.

Table 3.5.1. Summary of the confirmation and rejection of the specific null and alternative hypotheses.

Null Hypothesis	Alternative Hypothesis	Accepted	Rejected
The oceanic conditions are constant with time.	The oceanic conditions changed significantly after Hurricane Sandy traversed through the study area.	**X**	
Species composition/assemblage are constant with space and time.	The species composition or marine fauna assemblage changed significantly after Hurricane Sandy traversed through the study area.	**X**	
	The species composition or marine fauna assemblage recovered two years after Hurricane Sandy traversed through the study area.	**X**	
Estimated abundances are constant with space and time.	The estimated abundance of marine fauna changed significantly after Hurricane Sandy traversed through the study area.	**X**	
	The estimated abundance of marine fauna recovered two years after Hurricane Sandy traversed through the study area.	**X**	
Estimated biomasses are constant with space and time.	The estimated biomass of marine fauna changed significantly after Hurricane Sandy traversed through the study area.		**X**
	The estimated biomass of marine fauna recovered two years after Hurricane Sandy traversed through the study area.	**X**	

Despite the enormous economic loss, terrestrial impacts (freshwater swamps), and changes in upland environmental conditions (soil salinity) associated with Hurricane Sandy (Middleton, 2016), the storm seemed to have minimal and no long-term effect on some of the oceanic environmental variables off the New Jersey coast. The univariate analyses showed the mean annual water temperature (surface and bottom) was similar pre- and post-Sandy, but the mean annual mean salinity (surface and bottom) and DO (surface and bottom) levels were significantly higher in the years following Hurricane Sandy (2013, 2014, 2015). Research has shown that hurricanes do not usually alter water temperature, but they can alter other environmental factors. Depending on the disturbance, many health ecosystems are resistant and resilient (Odum 1985; Schindler, 1990). In Florida, the water temperature did not change after several hurricanes traversed through shallow estuaries; however, salinity and DO did decrease temporarily (Paperno et al. 2006). In Louisiana, Hurricane Katrina also caused water quality to temporarily deteriorate in a small coastal tributary of Lake Pontchartrain (Vrancken and O'Connell 2010). The DO was lower in the upstream reaches, and the water temperature and salinity was higher in downstream reaches of Lake Pontchartrain (Vrancken and O'Connell, 2010). It is not surprising the water temperature pre- and post-Sandy was similar because Hurricane Sandy traversed through the study area in October when the water column is generally well-mixed. Off New Jersey, the thermocline peaks in summer (July and August) and stratification breaks down in fall (September and October) (Miles et al. 2017).

The mean salinity (surface and bottom) increased post-Sandy in 2013 and 2014, and then decreased in 2015. It is difficult to explain the reason why the annual mean salinity and DO was significantly higher post-Sandy (2013, 2014, and 2015). Although lower salinity, DO, and hypoxia is usually associated with hurricanes (e.g., Knott and Martore, 1991; VanDolah and Anderson, 1991), it is generally caused by unusual rainfall associated with hurricanes, which can exceed 51 to 76 cm (20-30 inches) (Paperno et al. 2006). Much different than most hurricanes, Hurricane Sandy/Extratropical Cyclone did not cause a significant amount of rainfall in New Jersey; the storm surge was the main destructive factor (Blake et al. 2013). The rainfall amount was elevated for the region (land [18 cm or 7 inches] and open ocean [26 cm or 10.2 inches]), but it was not considered an extreme rainfall event (NASA, 2018), which could explain why salinity and DO levels did not significantly decrease in the study area, but it still doesn't explain why the levels were significantly elevated post-Sandy. Examining the long-term (1988−2015) environmental data (*See Chapter Two*), showed that the salinity increased from 2011 to 2015 and DO increased from 2009 to 2015 within in the study area. Overall, the long-term data (1988−2015) showed the salinity has decreased and DO has slightly increased over time despite some interannual fluctuation. Thus, it is highly possible the increase in salinity and DO was not related to Hurricane Sandy. Precipitation at the Atlantic City Marina (1800-present) is expected to decrease given the rising air temperature, so it is possible that slight changes in the recent climate conditions are increasing salinity (unpublished data) as the atmospheric conditions become dryer near the New Jersey coast. Higher DO levels over time are difficult to explain, but it could be related to the improvements in water quality along the New Jersey and New York coasts (HydroQual, Inc. 2010). The overall short-term salinity and DO levels were higher than the pre-Sandy (2008−2012) mean conditions, but it is possible these levels were not associated or correlated with Hurricane Sandy/Extratropical Cyclone given that upwelling or downwelling was not reported or observed (i.e., water temperature was similar pre- and post-Sandy) in the data; upwelling and downwelling can impact salinity and DO. If upwelling had occurred, the water temperature and salinity would have abruptly decreased because deeper water is colder and less saline. The nearshore waters off

New Jersey are a dynamic hydrological system influenced by the prevailing wind and buoyancy factors (Kohut et al. 2004). Northeast wind often causes downwelling and southwest wind causes upwelling (Kohut et al. 2004). Based on the path of Hurricane Sandy, it made landfall in New Jersey from around the east to the southeast direction, so it is unlikely it cause a major hydrological event, especially since the winds subsided after a few days. It is possible that the hurricane caused some short-term mixing although the nearshore waters off New Jersey are not usually stratified in fall and winter given the colder water temperatures in the region.

Changes in water quality associated with hurricanes have been reported in various mid-Atlantic and southeast regions (Charleston Harbor and Chesapeake Bay), but those changes were temporary and only reported in relatively shallow estuaries (Knott and Martore, 1991; VanDolah and Anderson, 1991; Houde et al. 2005). Also, changes in water quality associated with hurricanes is generally dependent on the regional hydrodynamics. Estuaries and open-ocean coastal waters are hydrologically different given estuaries are not only much shallower than offshore waters, but they are significantly more affected by runoff and freshwater input (rivers) after storm events than offshore waters that are not within a close proximity of a large river output, which can lower salinity and DO, such as the Mississippi River. Despite these reported changes in the abiotic conditions related to hurricanes, the environmental conditions usually return to normal within a short period (several weeks to couple of months) (Knott and Martore, 1991; VanDolah and Anderson, 1991; Houde et al. 2005).

Multivariate ordination procedures showed that oceanographic and physicochemical conditions were reasonably similar pre- and post-Sandy; however, ANOSIM and PERMANOVA procedures produced different results, which was primary influenced by the annual NAO and surface DO conditions. The PERMANOVA procedure showed there were annual differences in the oceanographic and physicochemical conditions pre- and post-Sandy. Despite these findings, it is more plausible that ongoing annual changes in the oceanographic conditions were more related to historical interannual variation than to Hurricane Sandy/Extratropical Cyclone, especially since the magnitude in terms of significance level was low.

Segregating the annual data by month (January), univariate procedures showed that the mean water temperature and salinity in January 2013 were similar pre- and post-Sandy. However, the mean surface water temperature in January 2014 and the salinity (surface and bottom) in 2015 was significantly different than pre-Sandy suggesting the change was ongoing rather than recovering from Hurricane Sandy/Extratropical Cyclone.

Unexpectantly, the mean salinity (surface and bottom) and DO (surface and bottom) increased in January 2013 (three months after Hurricane Sandy), but that was contingent upon the sampling area. It is challenging to explain this unusual observation, but it was probably related to the dramatic hydrological conditions and specific sampling areas within the region. It is possible the strong wind associated with Hurricane Sandy/Extratropical Cyclone caused the surface waters to be agitated, which led to the DO to be temporarily elevated in the study area, but then again it is unlikely given this measurement was recorded three months after Hurricane Sandy/Extratropical Cyclone. It is possible this could clarify the conditions in 2013, but the elevated salinity and DO levels in 2014 are more difficult to interpret and explain, suggesting the elevated change was already ongoing. Hurricane Sandy/Extratropical Cyclone temporarily changed the environmental conditions and hydrology off the New Jersey coast so it is possible it caused the salinity and DO to temporarily rise (Miles et al. 2013; Miles et al. 2017). A few days before the storm made landfall, the prevailing conditions caused the water column thermocline to become well-mixed, sediment was re-suspended, and the cross-shelf currents switched from a two-layer to one-layer flow onshore at ~0.25 m s^{-1}, while along-shore currents were increased toward the southwest in excess of ~1 m s^{-1} (Miles et al. 2013). One day before the storm made landfall, an oceanographic glider recorded the bottom water temperatures rising and surface water temperatures slightly falling, which was consistent with the advection of a downwelling front offshore event. The downwelling transferred cold bottom water offshore, but kept the inner-shelf well-mixed ahead of the storm (Miles et al. 2013; Miles et al. 2017). Hurricane Sandy was one of only five storms since 1889 that have crossed perpendicular to the New Jersey shelf (Miles et al. 2017). It is difficult to speculate whether the DO and salinity elevated levels were related to Hurricane Sandy given the ongoing changes, but Hurricane Sandy/Extratropical Cyclone uniquely changed the oceanic and hydrological conditions off the New Jersey coast (Miles et al. 2017).

Multivariate procedures showed the pre- (2008−2012) and post-Sandy (2013) oceanic conditions were similar, but did vary significantly in sampling area 19, which was in the direct path of the Hurricane Sandy. The conditions in 2014 varied significantly in most sampling areas (13−17, 19, 20, 22, and 23), whereas the conditions in 2015 varied significantly in fewer sampling areas (12, 13, 17, 19, 21−23, and 25). Overall, this suggests the oceanic conditions were temporarily impacted by Hurricane Sandy/Extratropical Cyclone in certain areas within the study area, but returned to the pre-Sandy conditions within a relative short period.

3.5.2 Marine Community Pre- and Post-Hurricane Sandy

Hurricanes can effect marine communities in variety of ways, including altering species diversity, distribution, relative abundance, and habitat, but impacts are usually temporary and localized (Vrancken and O'Connell, 2010). Similar to previous studies (Knott and Martore, 1991; VanDolah and Anderson, 1991; Houde et al. 2005; Paperno et al. 2006), it appears Hurricane

Sandy/Extratropical Cyclone temporarily impacted the nearshore marine community off New Jersey.

Multiple univariate procedures and an nMDS (*Stress* = 0.17) suggest the catch characteristics and marine community (abundance and biomass) were similar between pre- and post-Sandy. However, several multivariate procedures showed there was a significant difference (4.8%) in the annual marine community (distribution and community structure) between pre- and post-Sandy (2013), and between later years (2013 vs 2014 and 2015). Although biomass did not change, the pre- (2008−2012) marine community (abundance) was significantly different than the marine community in 2014. The pre-Sandy marine community was similar to the marine community in 2015, suggesting the marine community was impacted by the hurricane, but recovered two years later. Although the marine community varied significantly pre- and post-Sandy, it depended on the month and sampling area. The annual marine community pre- and post-Sandy varied the most in October and the least in January. Sampling areas 16, 17, and 23 had the most, and sampling areas 13, 14, 24, and 26 had the least number of pair-wise differences in the marine community pre- and post-Sandy. These findings clearly show that Hurricane Sandy/Extratropical Cyclone had a limited impact on the marine community that was specific to space and time, which agrees with previous studies (Houde et al. 2005; Paperno et al. 2006; Vrancken and O’Connell, 2010).

Hurricanes can have drastically different impacts (negative and positive) on individual marine species and communities, which depends on the geographical location, season, and type of water body (e.g., freshwater, marine, estuary, nearshore, and offshore). Hurricane impacts on fish communities are generally short-term and can have minimal, positive, or negative effects (Ritchie, 1977; Bell and Hall, 1994; Houde et al. 2005). The average similarity of species contributions based on abundance varied between pre-and post-Sandy. The average similarity increased in 2013, whereas the difference in the average dissimilarity between pre- and post-Sandy increased in 2014 and then decreased in 2015. The average similarity increased in 2013, decreased in 2014, and increased in 2015. Based on these results, it appears the change in community structure (i.e., percent contribution) post-Sandy lasted about one year before recovering. The SIMPER procedure showed that the community structure (abundance) and associated contribution of species in 2014 was almost identical to pre-Sandy; longfin squid, windowpane, little skate, and butterfish represented ~42% species contribution. Little skate, windowpane, and spotted hake contributed more, and longfin squid and butterfish contributed less to the community structure post-Sandy (2013). Although the oceanic conditions varied only slightly (increase in salinity and DO), the marine community did significantly change after Hurricane Sandy (2013). The change could have either been more related to behavior than to the environmental change associated with Hurricane Sandy/Extratropical Cyclone or it was associated with elevated suspension of sediment (Miles et al. 2013; Miles et al. 2017). It is possible the minimal variation in oceanic conditions or the increase in re-suspended sediment (Miles et al. 203; Miles et al. 2017) caused some species to temporarily move away from the study area (i.e. shift in distribution), which has been reported by others (Houde et al. 2005; Paperno et al. 2006; van Vrancken and O'Connell, 2010). The re-suspension of sediment can alter bottom substrate and availably habitat for benthic organisms (Miles et al. 2017), which is highly possible within the study area given most of the bottom substrate is sand or sand-mud mixture; the region lacks hard bottom.

Interestingly, the average relative abundance for several species (e.g., bay anchovy, northern searobin, and Atlantic herring) increased post-Sandy (2013). However, in later years (2014 and 2015), there were fewer species with a higher relative abundance than pre-Sandy

(2008−2012), and several species had a lower relative abundance. The percent contribution of individual species (abundance) varied somewhat between pre- and post-Sandy, but the proportion across more than one species did not appear skewed in either a positive or negative direction suggesting the community structure in terms of dominance was not impacted by the storm. The species contribution were significantly different between later pair-wise years (2013 and 2014; 2013 and 2015) suggesting the marine community was in the processes of changing. The findings suggested the marine community was sensitive to changes in the bottom water temperature. As such, it is more likely the marine community was probably adjusting to the increasing water temperature rather than conditions associated with the storm. Similar observations have been reported by other researchers. In Chesapeake Bay, Houde et al. (2005) reported no apparent negative effects on fish populations, recruitment of juvenile fishes, or fish communities associated with Hurricane Isabel in Chesapeake Bay. However, the relative abundance of various species (Atlantic croaker [*Micropogonias undulates*], and bay anchovy) increased and few new species (striped bass and white perch) were collected in Chesapeake Bay. These changes in the marine community were attributed to post-Isabel downriver displacement and high freshwater flow in Chesapeake Bay (Houde et al. 2005). In Florida, Paperno et al. (2006) also found short-term moderate impacts to the fish communities in Florida associated with four hurricanes (Charley, Frances, Ivan, and Jeanne).

Segregating the data by month (January) showed that the marine community was significantly different between pre- and post-Sandy; however, it is probable that marine community was impacted minimally by Hurricane Sandy/Extratropical Cyclone. The PERMDISP test showed there was a significant differences in the marine community pre- and post-Sandy. However, a one-way ANOSIM test showed there was no observed change in the community structure (*k*-dominance curves) pre- and post-Sandy. *Post-hoc* analyses did show there was a significant difference in the community structure between recent years post-Sandy (2013 and 2014, and 2014 and 2015) suggesting the marine community is undergoing a change. The average similarity in January ranged from 43.98 (pre-Sandy) to 52.38 (post-Sandy [2014]) suggesting community evenness temporarily increased and dominance decreased in the study area, which was also reported by Paperno et al. (2006). The dominant species varied slightly, but their percent contribution was somewhat similar pre- and post-Sandy suggesting little to no change in community structure dominance.

Overall, it appears the marine community shifted or adjusted to the conditions after Hurricane Sandy, but it fully recovered after one year. Fish communities can generally respond and recover rapidly from natural disturbances, such as hurricanes (Paperno et al. 2006). Estuarine fish communities are able to cope with fluctuating environmental conditions from repeated hurricane events and maintain community structure (Paperno et al. 2006).

Based on the way many state and federal fisheries independent monitoring programs collect data it is often difficult to isolate and independently evaluate the impacts associated with uncommon natural disturbance events, such as hurricanes. Often these natural events occur sporadically over space and time, which may or may not coincide with ongoing monitoring programs. Another issue is that hurricane are generally large, destructive, and life-threating, so it is almost impossible for investigators to organize and carry-out a special sampling event shortly after a hurricane traverses through a region. Given these timing and logistical issues, researchers can usually only conduct regular pre-determined sampling or a limited short-term study after a hurricane traverses through their respected region.

As pointed out, natural variability in the abiotic and biotic conditions must be considered when evaluating potential impacts associated with natural disturbance events, such as hurricanes. It is essential that data analyses consider interannual variation over space and time, especially marine communities; it’s important to use long-term datasets. Failure to consider the natural variability in the abiotic conditions and marine populations can bias the results and the associated interpretation. For instance, as discussed above, comparing the monthly data (January) with the annual data resulted in contrasting outcomes. Another analytical issue was the decision to use a shorter 5-year time-series (2008−2012) to assess the pre-Sandy conditions rather than a longer time-series (1988−2012). The decision was made to use a shorter time-series because it was supposed to provide a more recent representation of the conditions in the study area within the context of the shifting baseline syndrome arising from ongoing changes. Although the analytical approach were adequate for assessing the biological community, it probably would have been better to use a slightly longer time-series to assess the environmental conditions in the study area. Understanding the interannual variability along with the trends are important for interpreting the results. For instance, the findings showed the salinity and DO levels were elevated post-Sandy, but after re-examining the interannual trend in a longer time-series it appeared those levels were actually increasing with time suggesting that climate variability rather than Hurricane Sandy/Extratropical Cyclone was having a greater impact on the abiotic conditions in the study area. Using a snap-shot time-series approach can sometimes give false impressions. Thus, it is important to carefully interpret the results and more importantly to examine the environmental/biological significance within context.

The types of analytical tests are another important aspect to consider when examining the potential impacts associated with natural disturbance events. It is important to have a good understanding of the analytical limitations of each test, the assumptions, and the significance criteria. As shown above, different tests can give contradictory results, so important to have a thorough understanding of the factors being tested in context to the objectives of the study.

Despite these practical and analytical factors, an attempt was made to reasonably design an analytical evaluation of a long-term fisheries independent monitoring dataset to examine the abiotic and biotic impacts associated with Hurricane Sandy. In some ways, the results should be viewed with some reservation since the number of samples in January post-Sandy were limited in terms of sample size. For instance, the degrees of freedom for the univariate analyses were limited to 149 for pre-Sandy (2008−2012) and 30 each for post-Sandy year (2013, 2014, and 2015). Even with this analytical challenge, the analytical approach was robust in terms of statistical hypothesis tests and conservative interpretation. Numerous multivariate procedures were used to test, help understand, and interpret changes in the abiotic and biological community. The approach followed the basic conceptual principles of analytical design, best practices in the field, and recent published studies.

3.6 Conclusion

Contrary to belief, natural disturbance is a normal part of the environment (Begon et al. 1986), so it can sometimes have little to no impact on the biological community. These findings show the nearshore community off New Jersey is resilient and robust to isolated natural disturbance events, such as hurricanes. In fact, it is probable one of the reasons why the marine community was able to reorganize and adjust to the temporary change in the oceanic conditions that was somewhat associated with Hurricane Sandy/Extratropical Cyclone. Another reason the marine community is robust is because the seasonal and year-round species found off New Jersey tend to have wide-ranging environmental tolerances, behaviors, and diets (Froese and Pauly, 2018).

The sensitivity of a community to disturbance is a function of its resistance, resilience, and local stability (Begon et al. 1986). Stability is dependent upon a community's robustness, which defines how a community responds to the environment conditions (Begon et al. 1986). In aquatic environments, species composition, spatial distribution, abundance, and biomass is often influenced, shaped, and limited by the environmental conditions (Horne et al. 1989). Water temperature, salinity, DO, and depth are some of the most important environmental and habitat variables that affect fish life-history characteristics (Hoese and Moore, 1977) and community structure.

Species composition it terms of functional diversity and functional redundancy are important factors of resilience and robustness (Aune et al. 2017). The nearshore waters off New Jersey provide habitat for a variety of marine fauna, including various warmwater and subtropic-adapted species. However, the number of species dominating the community is limited, but similar to other geographical locations within the MAB (Wood et al. 2009; Howell and Auster, 2012). Despite the limited number of species, many have somewhat different functional roles and biology; many are relatively mobile in terms of annual and seasonal coastal migrations. Most of the species found in the study area also have wide-ranging diets (Froese and Pauly, 2018). All of these biological traits play a role in the community's ability to withstand short and long-term disturbance. For instance, Atlantic herring are known to travel an average of 134 km with a minimum of 1 km and a maximum of 684 km in the Gulf of Maine (Kanwit and Libby, 2009). Given this mobile ability, it is highly probable Atlantic herring could migrate to preferred habitat should conditions become inadequate within the study area.

Marine communities are dynamic systems that are shaped by a variety of intra, and inter-related biological and environment factors that vary by time and space (e.g., Aune et al. 2017). Overall, it appears the nearshore marine community off New Jersey can endure interim impacts associated with hurricanes. Biological impacts can vary depending on the location, timing of the storm, and whether it causes heavy rainfall. Hurricane Sandy was a relatively fast moving storm that made landfall in the fall and produced minimal rainfall. The storm could have impacted the marine community differently if it had traversed the study area in spring when fish eggs hatch and many juvenile fishes use the coastal waters off New Jersey as habitat (Able and Fahay, 1998; Able et al. 2006).

The observations presented here have not been previously documented and provide valuable information regarding the potential impacts to the nearshore marine community associated with hurricanes traversing though the coastal waters off New Jersey. Besides describing the patterns in the oceanic conditions and marine community, the changes in the faunal assemblages noted in this study will become increasingly pertinent for future studies on the impacts associated with natural and anthropogenic disturbance. The information presented in this study is expected to help natural resource managers understand, predict, and plan for ongoing disturbances.

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3.7 References

Able, K.W., and Fahay, M.P. 1998. The first year in the life of estuary fishes in the Middle Atlantic Bight. New Brunswick, New Jersey: Rutgers University Press.

Able, K.W., Fahay, M.P., Witting, D.A., McBride, R.S., and Hagan, S.M. 2006. Fish settlement in the ocean vs. estuary: Comparison of pelagic larval and settled juvenile composition and abundance from southern New Jersey, U.S.A. Estuarine, Coastal and Shelf Science 66: 280−290.

Able, K.W., Wilber, D.H, Muzeni-Corino, A., and Clarke, D.G. 2010. Spring and summer larval fish assemblages in the surf zone and nearshore off northern New Jersey, USA. Estuaries and Coasts 33(1): 211−222.

Able, K.W., Grothues, T.M., Rowe, P.M., Wuenschel, M.J., and J.M. Vasslides. 2011. Near-Surface larval and juvenile fish in coastal habitats: Comparisons between the inner shelf and an estuary in the New York Bight during summer and fall. Estuaries and Coasts 34: 726–738.

ASMFC (Atlantic States Marine Fisheries Commission). 1994. Proceedings of the workshop on saltwater fishing tournaments. U.S. Fish and Wildlife Service, Atlantic States Marine Fisheries Commission Special Report Number 46.

Auber, A., Travers-Trolet, M., Villanueva, M.C., and Ernande, B. 2015. Regime Shift in an Exploited Fish Community Related to Natural Climate Oscillations. PLoS ONE 10(7): e0129883. doi:10.1371/journal. pone.0129883

Aune, M., Aschan, M.M., Greenacre, M., Dolgov, A.V., Fossheim, M., and Primicerio, R. 2018. Functional roles and redundancy of demersal Barents Sea fish: Ecological implications of environmental change. PLoS ONE 13(11): e0207451. https://doi.org/10.1371/journal. pone.0207451.

Beaugrand, G., Brander, K.M., Lindley, J.A., Souissi, S., and Reid, P.C. 2003. Plankton effect on cod recruitment in the North Sea. Nature 426: 661–664.

Bell, M., and Hall, J.W. 1994. Effects of Hurricane Hugo on South Carolina’s marine artificial reefs. Bulletin of Marine Science 55: 836–847.

Blake, E.S., Kimberlain, T.B., Ber, R.J., Cangialosi, J.P., and Beven, J.L. 2013. Tropical Cyclone Report. Hurricane Sandy. National Hurricane Center. https://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf.

Byrne, D. 2008. Ocean trawling survey. New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Marine Fisheries Administration, Bureau of Marine Fisheries.

Byrne, D. 1994. Stock assessment of New Jersey’s nearshore recreational fisheries resources. In Proceedings of the workshop on the collection and use of trawl survey data for fisheries management, ed. T. Berger, 36–42. Washington: Atlantic States Marine Fisheries Commission.

Clarke, K.R., and Warwick, R.M. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2nd edition. PRIMER-E. Plymouth U.K.

Clarke, K.R., and Gorley, R.N. 2006. PRIMER V6: User Manual/ Tutorial. PRIMER-E, Plymouth, UK.

Code of Federal Regulations (CFR). Title 50 Wildlife and Fisheries. Chapter VI Fishery Conservation and Management, National Oceanic and Atmospheric Administration, Department of Commerce. Part 600 Magnuson-Stevens Act Provisions. 50 CFR 600.

Cross, J.N., Zetlin, C.A., Berrien, P.L., Johnson, D.L., and C. McBride. 1999. Essential fish habitat source document: Butterfish, *Peprilus triacanthus*, life history and habitat characteristics. NOAA Technical Memorandum NMFS-NE-145: 1−42.

Deser, C., and Blackmon, M.L. 1993. Surface climate variations over the North Atlantic Ocean during winter: 1900-1989. American Meteorological Society 6: 1743−1753.

Deser, C., Michael A. Alexander, Shang-Ping Xie, and Adam S. Phillips. 2010. Sea Surface Temperature Variability: Patterns and Mechanisms. The Annual Review of Marine Science 2: 115-143.

Elmqvist, T., C. Folke, M. Nystrom, G. Peterson, J. Bengtsson, B. Walker, and J. Norberg. 2003. Response diversity, ecosystem change, and resilience. *Frontiers of Ecology and Environment* 1(9):488-494.

Epifanio, C.E., and Garvin, R.W. 2001. Larval transport on the Atlantic continental shelf of North America: a Review. Estuarine, Coastal and Shelf Science 52: 51–77.

Floeter, S.R., Ferreira, C.E.L., Dominici-Arosemena, A., and Zalmon, I.R. 2004. Latitudinal gradients in Atlantic reef fish communities: trophic structure and spatial use patterns Journal of Fish Biology 64: 1680−1699.

Froese, R. and Pauly, D. 2018. FishBase. World Wide Web electronic publication. www.fishbase.org, version (10/2018).

Geiger, E.F., Grossi, M.D., Trembanis, A.C., Kohut, J.T., and Oliver, M.J. 2013. Satellite-derived coastal ocean and estuarine salinity in the Mid-Atlantic. Continental Shelf Research 63: S235–S242. doi: https://doi.org/10.1016/j. csr.2011.12.001

Giordano, C., Hartley, S.L., Kurz, K., Michalski, K., and Figley, B. 2008. New Jersey party and charter boat directory 2000: Additions 2001−2008. Trenton, New Jersey: New Jersey Department of Environmental Protection.

Hagan, S.M. and Able, K.W. 2008. Annual patterns in diel differences for species richness and total abundance were remarkably similar between 1995 and 1996 Estuaries and Coasts: J CERF 31: 33–42.

Hagan, S.M. and Able, K.W. 2003. Seasonal changes of the pelagic fish assemblage in a temperate estuary. Estuarine, Coastal and Shelf Science 56: 15−29.

Howell, P., and Auster, P.J. 2012. Phase Shift in an Estuarine Finfish Community Associated with Warming Temperatures. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4: 481–495.

Horne, J.K., and Campana, S.E. 1989. Environmental factors influencing the distribution sf juvenile groundfish in nearshore habitats of southwest Nova Scotia. Canadian Journal of Fish and Aquatic Science 46: 1277−1286.

Houde, E.D., Bichy, J., and Jung, S. 2005. Effects of Hurricane Isabel on fish populations and communities in Chesapeake Bay. K.G. Sellner (ed.). 2005. Hurricane Isabel in Perspective. Chesapeake Research Consortium, CRC Publication 05-160, Edgewater, MD.

HydroQual, Inc. 2010. Narrative description of historical dissolved oxygen improvements in NY/NJ harbor related to previous nutrient reduction activities. 49 pp.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., and Warner, R.R. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293: 629−638.

Kanwit, J.K., and Libby, D.A. 2009. Seasonal movements of Atlantic herring (Clupea harengus): results from a four year tagging study conducted in the Gulf of Maine and Southern New England. Journal Northwest Atlantic Fishery Science 40: 29–39. doi:10.2960/J.v40.m577.

King, M. 1995. Fisheries biology, assessment and management. Fishing News Books, Oxford.

Knottk, D.M., and Martore, R.M. 1991. The short-term effects of Hurricane Hugo on fishes and decapod crustaceans in the Ashley River and adjacent marsh creeks, South Carolina. Journal of Coastal Research 8: 335−356.

Kohut, JT., Glenn, SM., and Chant, R.J. 2004. Seasonal current variability on the New Jersey inner shelf. Journal of Geophysical Research 109: C07S07, doi:10.1029/2003JC001963,2004.

Lazaroff, C. 2001. Historic overfishing led to modern ocean problems. Environment News Service. Accessed 5 January 2005. http:www.cgaux1sr.org/msep/fish.htm.

Li, Y., Fratantoni, P.S., Chen, C., Hare, J.A., and Sun, Y. 2015 Spatio-temporal patterns of stratification on the Northwest Atlantic shelf. *Prog Oceanogr* 134: 123–137. doi: https://doi.org/10.1016/j. pocean.2015.01.003.

Locascio, J.V., and Mann, D.A. 2005. Effects of Hurricane Charley on fish chorusing. Biological Letters 1: 362–365 doi:10.1098/rsbl.2005.0309.

Malakoff, D. 1997. Extinction on the high seas. Science 277: 486−488.

Middleton, B.A. 2016. Differences in impacts of Hurricane Sandy on freshwater swamps on the Delmarva Peninsula, Mid-Atlantic Coast, USA. Ecological Engineering 87: 62−70.

Miles, T., Glenn, S., Kohut, J., Seroka, G., and Xu, Y. 2013. Observations of Hurricane Sandy from a glider mounted aquadopp profiler. EEE Oceans 2013 – San Diego, San Diego, USA. 1−8.

Miles, T., Seroka, G., and Glenn, S. 2017. Coastal ocean circulation during Hurricane Sandy. Journal of Geophysical Research Oceans, 122: 7095–7114.doi:10.1002/2017JC013031.

Moline, M.A., Blackwell, S.M., Chant, R., Oliver, M.J., Bergmann, T., Glenn, S., and Schofield, O.E. 2004. Episodic physical forcing and the structure of phytoplankton communities in the coastal waters of New Jersey. Journal of Geophysical Research 109: C12S05. doi:10.1029/2003JC001985.

Moser, J. and Shepherd, G.R. 2009. Seasonal distribution and movement of black sea bass (*Centropristis striata*) in the Northwest Atlantic as determined from a mark-recaptured experiment. Journal of the Northwest Atlantic Fishery Science 40: 17−28.

NASA (National Aeronautics and Space Administration). 2018. Precipitation Measurement Missions. Deadly Super Storm Sandy's Rainfall. Accessed on October 20, 2018. https://pmm.nasa.gov/mission-updates/trmm-news/deadly-super-storm-sandys-rainfall.

NMFS (National Marine Fisheries Service). 2002. Essential fish habitat: A marine fish habitat conservation mandate for federal agencies, South Atlantic region. St. Petersburg, Florida: National Marine Fisheries Service, Habitat Conservation Division, Southeast Regional Office.

NMFS (National Marine Fisheries Service). 2011. Recreational fisheries. Accessed 10 October 2011. http://www.st.nmfs.noaa.gov/st1/recreational/index.html.

NMFS (National Marine Fisheries Service). 2018. Commercial Fisheries Statistics. Accessed at: https://www.st.nmfs.noaa.gov/commercial−fisheries/commercial−landings/. Accessed on: 25 January 2018.

Odum, E.P. 1985. Trends expected in stressed ecosystems. Bioscience 35: 419−422.

Ottersen, G., Planque, B., Belgrano, A., Post, E., Reid, P.C., and Stenseth, N.C. 2001. Ecological effects of the North Atlantic Oscillation. Oecologia 128: 1−14.

Paperno, R., Tremain, D.M., Adams, D.H., Sebastian, A.P., Sauer, J.T., and Dutka-Gianelli, J. 2006. The disruption and recovery of fish communities in the Indian River Lagoon, Florida, following two hurricanes in 2004. Estuaries and Coasts 29 (6A): 1004–1010.

Preble, D. 2001. The fishes of the sea -- Commercial and sport fishing in New England. Dobbs Ferry, New York: Sheridan House.

Richards, R.A., P.C. Nitschke, and Sosebee, K.A. 2008. Population biology of monkfish *Lophius americanus*. ICES Journal of Marine Science 65: 1291−1305.

Ritchie, D.E. 1977. Short-term response of fish to Tropical Storm Agnes in mid-Chesapeake Bay. In: The Effects of Tropical Storm Agnes on the Chesapeake Bay Estuarine System. Chesapeake Research Consortium Publication No. 54. The Johns Hopkins University Press, Baltimore, MD. 460–462.

Rountree, R.A. and Able, K.W. 1997. Nocturnal fish use of New Jersey marsh creek and adjacent bay shoal habitats. Estuarine, Coastal and Shelf Science 44: 703−711.

Saila, S.B. and Pratt, S.D. 1973. Mid-Atlantic Bight fisheries. Pages 6-1 to 6-125 in Coastal and offshore environmental inventory: Cape Hatteras to Nantucket Shoals. University of Rhode Island: Marine Publication Series No. 2. Kingston, RI.

Schindler, D.W. 1990. Experimental perturbations of whole lakes as tests of hypotheses concerning ecosystem structure and function. Oikos 57: 25-41.

Schofield, O., Chant, R., Cahill, B., Castelao, R., Gong, D., Kahl, A., Kohut, J., Montes-Hugo, M., Ramadurai, R., Ramey, P., and Glenn, S. 2008. The Decadal View of the Mid-Atlantic Bight from the COOLroom: Is Our Coastal System Changing? Oceanography (21) 4: 108-117.

Slacum, W.H. Burton, W.H., and Methratta, E.T. 2010. Assemblage structure in shoal and flat-bottom habitats on the inner continental shelf of the Middle Atlantic Bight, USA. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 2: 277–298.

Song, T.Y., D.B. Haidvogel, and Glenn, S.M. 2001. Effects of topographic variability on the formation of upwelling centers off New Jersey: A theoretical model. Journal Geophysical Research 106: 9223– 9240.

Steimle, F.W. and Zetlin, C. 2000. Reef habitats in the Middle Atlantic Bight: abundance, distribution, associated biological communities and fishery resource use. Marine Fisheries Review. 62(2): 24−41.

Sutton, R.T., and Hodson, D.L.R. 2005. Atlantic Ocean forcing of North American and European summer climate. Science 309: 115–118.

Szedlmayer, S.T. and Able, K.W. 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. Estuaries 19(3): 697−709.

Taylor, D.L., R.S. Nichols, and Able, K.W. 2007. Habitat selection and quality for multiple cohorts of young-of the-year bluefish (*Pomatomus saltatrix*): Comparisons between estuarine and ocean beaches in southern New Jersey. Estuarine, Coastal and Shelf Science 73: 667−679.

Therman, H.V. 1990. Essentials of Oceanography. Third Edition. Merrill Publishing Company. 398 pp.

Thomas, A.C., Pershing, A.J., Friedland, K.D., Nye, J.A., Mills, K.E., Alexander, M.A., Record, N.R., Weatherbee, R., and Henderson, E.M. 2017. Seasonal trends and phenology shifts in sea surface temperature on the North American northeastern continental shelf. Elem Sci Anth, 5: 48, DOI: https://doi.org/10.1525/elementa.240

Van Dolah, R.F., and Anderson, G.A. 1991. Effects of Hurricane Hugo on salinity and dissolved oxygen conditions in the Charleston Harbor estuary. Journal of Coastal Research 8: 83−94.

Van Vrancken, J. and O'Connell, M.T. 2010. Effects of Hurricane Katrina on freshwater fish assemblages in a small coastal tributary of Lake Pontchartrain, Louisiana. Transactions of the American Fisheries Society 139: 1723-1732.

Wood, A.J.M, Collie, J.S., and Hare, J.A. 2009. A comparison between warm-water fish assemblages of Narragansett Bay and those of Long Island Sound waters. Fishery Bulletin 107: 89−100.

Zar, J.H. 1999. Biostatistical analysis, 4th Ed. Prentice Hall, Upper Saddle River, NJ.

3.8 Appendix

Table 3.8-2. Three-way (month, year, sampling area) PERMANOVA. Oceanographic and physicochemical conditions in January pre- and post-Sandy.

Area	**Groups**	***t***	***P*(perm)**	**Unique perms**
12	2008-2012, 2013	0.66418	0.844	66
	2008-2012, 2014	1.1725	0.158	66
	2008-2012, 2015	6.2791	0.028	66
	2013, 2014	2.3637	0.32	3
	2013, 2015	14.3	0.352	3
	2014, 2015	34.48	0.356	3
13	2008-2012, 2013	1.1745	0.187	66
	2008-2012, 2014	1.7987	0.032	66
	2008-2012, 2015	9.5964	0.016	66
	2013, 2014	6.1895	0.358	3
	2013, 2015	20.962	0.333	3
	2014, 2015	19.634	0.319	3
14	2008-2012, 2013	1.0459	0.314	66
	2008-2012, 2014	2.2418	0.01	66
	2008-2012, 2015	1.3289	0.156	66
	2013, 2014	5.6845	0.335	3
	2013, 2015	0.64922	1	3
	2014, 2015	0.76537	1	3
15	2008-2012, 2013	1.0098	0.328	55
	2008-2012, 2014	1.7577	0.033	55
	2008-2012, 2015	1.1811	0.287	55
	2013, 2014	5.2276	0.331	3
	2013, 2015	0.53928	1	3
	2014, 2015	0.65074	1	3
16	2008-2012, 2013	1.2637	0.134	45
	2008-2012, 2014	2.2552	0.019	45
	2008-2012, 2015	6.6946	0.019	45
	2013, 2014	8.1256	0.348	3
	2013, 2015	17.273	0.316	3
	2014, 2015	19.391	0.308	3
17	2008-2012, 2013	1.363	0.112	45

Area	**Groups**	***t***	***P*(perm)**	**Unique perms**
	2008-2012, 2014	2.5835	0.025	45
	2008-2012, 2015	2.9951	0.027	45
	2013, 2014	6.8345	0.338	3
	2013, 2015	7.8676	0.345	3
	2014, 2015	14.127	0.322	3
18	2008-2012, 2013	1.4827	0.069	45
	2008-2012, 2014	1.1889	0.35	9
	2008-2012, 2015	1.5613	0.21	45
	2013, 2014	1.948	0.299	3
	2013, 2015	0.76451	1	3
	2014, 2015	0.48431	1	3
19	2008-2012, 2013	1.4595	0.05	45
	2008-2012, 2014	2.4361	0.007	165
	2008-2012, 2015	2.2194	0.02	45
	2013, 2014	3.3522	0.106	10
	2013, 2015	2.9619	0.34	3
	2014, 2015	4.4173	0.097	10
20	2008-2012, 2013	1.5163	0.059	45
	2008-2012, 2014	2.7589	0.018	45
	2008-2012, 2015	1.0976	0.329	45
	2013, 2014	6.4165	0.32	3
	2013, 2015	0.59644	1	3
	2014, 2015	0.93392	0.643	3
21	2008-2012, 2013	1.5687	0.064	45
	2008-2012, 2014	1.556	0.073	45
	2008-2012, 2015	2.3902	0.014	45
	2013, 2014	4.6674	0.366	3
	2013, 2015	5.6077	0.34	3
	2014, 2015	6.1846	0.342	3
22	2008-2012, 2013	1.3791	0.085	45
	2008-2012, 2014	2.0968	0.013	45
	2008-2012, 2015	2.56	0.027	45
	2013, 2014	5.3522	0.34	3
	2013, 2015	6.4624	0.341	3
	2014, 2015	7.9569	0.355	3
23	2008-2012, 2013	1.6496	0.073	45
	2008-2012, 2014	3.1131	0.017	45

Area	Groups	*t*	*P*(perm)	Unique perms
	2008-2012, 2015	2.2686	0.024	45
	2013, 2014	7.2109	0.33	3
	2013, 2015	4.9297	0.314	3
	2014, 2015	6.1695	0.339	3
24	2008-2012, 2013	1.25	0.173	45
	2008-2012, 2014	1.2424	0.157	45
	2008-2012, 2015	1.1608	0.251	45
	2013, 2014	6.7134	0.336	3
	2013, 2015	2.554	0.32	3
	2014, 2015	3.6253	0.358	3
25	2008-2012, 2013	1.0683	0.287	45
	2008-2012, 2014	1.7918	0.052	45
	2008-2012, 2015	1.7831	0.044	45
	2013, 2014	4.885	0.343	3
	2013, 2015	6.5733	0.313	3
	2014, 2015	6.922	0.361	3
26	2008-2012, 2013	0.99852	0.362	45
	2008-2012, 2014	2.3553	0.019	45
	2008-2012, 2015	1.3784	0.063	45
	2013, 2014	15.082	0.348	3
	2013, 2015	1.9897	0.319	3
	2014, 2015	2.7346	0.319	3

Table 3.8-3. General Linear Model and associated ANOVA Type III Sums of Squares. Pre- and post-Hurricane Sandy (1988-2012 vs 2013). Coldwater-adapted species.

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Coldwater-adapted)	Year	0.00597223	1	0.00597223	0.00	0.9482	√√ Total Number = 2.08646 + 1.0509E-10*Year + 0.0190333*Month - 0.0108673*Area	0.389848 percent
	Month	129.572	1	129.572	91.51	0.0000		
	Area	77.9259	1	77.9259	55.03	0.0000		
	Residual	53454.8	37751	1.41598				
	Total (corrected)	53664.0	37754					
Estimated Abundance (Coldwater-adapted)	Year	0.000353515	1	0.000353515	0.03	0.8652	√√ Estimated Abundance = 0.195949 + 0.0*Year + 0.00165356*Month - 0.00100553*Area	0.357107 percent
	Month	0.977961	1	0.977961	79.77	0.0000		
	Area	0.667155	1	0.667155	54.42	0.0000		
	Residual	462.805	37751	0.0122594				
	Total (corrected)	464.463	37754					
Estimated Biomass (Coldwater-adapted)	Year	0.000528753	1	0.000528753	0.10	0.7463	√√ Estimated Biomass = 0.150559 + 0.0*Year - 0.00134015*Month - 0.00136662*Area	0.966571 percent
	Month	0.642382	1	0.642382	127.17	0.0000		
	Area	1.23234	1	1.23234	243.97	0.0000		
	Residual	190.688	37751	0.00505119				
	Total (corrected)	192.549	37754					

Table 3.8-4. General Linear Model and associated ANOVA Type III Sums of Squares Pre- (1988-2012) and post-Hurricane Sandy (2013). Warmwater-adapted species.

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Warmwater-adapted)	Year	0.0944513	1	0.0944513	0.06	0.8020	√√ Total Number = 1.67409 - 3.43399E-10*Year + 0.0530831*Month - 0.00645303*Area	1.45602 percent
	Month	1038.89	1	1038.89	691.70	0.0000		
	Area	34.9822	1	34.9822	23.29	0.0000		
	Residual	72679.0	48390	1.50194				
	Total (corrected)	73752.8	48393					
Estimated Abundance (Warmwater-adapted)	Year	0.00315844	1	0.00315844	0.24	0.6227	√√ Estimated Abundance = 0.157646 + 0.0*Year + 0.00485608*Month - 0.000606527*Area	1.4058 percent
	Month	8.69418	1	8.69418	666.31	0.0000		
	Area	0.309044	1	0.309044	23.68	0.0000		
	Residual	631.403	48390	0.0130482				
	Total (corrected)	640.406	48393					
Estimated Biomass (Warmwater-adapted)	Year	0.0183199	1	0.0183199	3.60	0.0578	√√ Estimated Biomass = 0.0853949 - 1.51237E-10*Year + 0.00401031*Month + 0.0000102238*Area	2.3555 percent
	Month	5.92946	1	5.92946	1165.43	0.0000		
	Area	0.0000878094	1	0.0000878094	0.02	0.8955		
	Residual	246.198	48390	0.0050878				
	Total (corrected)	252.138	48393					

Table 3.8-5. General Linear Model and associated ANOVA Type III Sums of Squares. Pre and Post-Hurricane Sandy (1988-2012 vs 2013). Subtropic-adapted species.

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Total Number (Subtropic-adapted)	Year	0.524883	1	0.524883	0.07	0.7859	√√ Total Number = 2.71092 - 1.95123E-9*Year + 0.0690379*Month - 0.0364799*Area	0.57302 percent
	Month	128.469	1	128.469	18.07	0.0000		
	Area	146.124	1	146.124	20.55	0.0000		
	Residual	47655.6	6702	7.11065				
	Total (corrected)	47930.3	6705					
Estimated Abundance (Subtropic-adapted)	Year	0.00694953	1	0.00694953	0.11	0.7380	√√ Estimated Abundance = 0.25556 - 2.2452E-10*Year + 0.00629056*Month - 0.0034299*Area	0.563724 percent
	Month	1.0666	1	1.0666	17.18	0.0000		
	Area	1.29175	1	1.29175	20.80	0.0000		
	Residual	416.184	6702	0.0620985				
	Total (corrected)	418.543	6705					
Estimated Biomass (Subtropic-adapted)	Year	0.0584931	1	0.0584931	12.95	0.0003	√√ Estimated Biomass = 0.0700696 - 6.51373E-10*Year - 0.000211097*Month + 0.00147575*Area	0.987292 percent
	Month	0.00120112	1	0.00120112	0.27	0.6061		
	Area	0.239132	1	0.239132	52.93	0.0000		
	Residual	30.2769	6702	0.00451759				
	Total (corrected)	30.5788	6705					

Table 3.8-6. Three-way (month, year, sampling area) Permutational MANOVA. Biological community in January pre- and post-Sandy.

Area	**Groups**	***t***	***P*(perm)**	**Unique perms**
13	2008-2012, 2013	1.9622	0.014	66
	2008-2012, 2014	1.7977	0.029	66
	2008-2012, 2015	1.1144	0.262	66
	2013, 2014	1.251	0.332	3
	2013, 2015	1.5059	0.356	3
	2014, 2015	1.4922	0.345	3
16	2008-2012, 2013	1.7317	0.019	66
	2008-2012, 2014	1.2271	0.175	66
	2008-2012, 2015	1.2734	0.131	278
	2013, 2014	1.6418	0.362	3
	2013, 2015	1.5459	0.105	10
	2014, 2015	1.5842	0.199	10
17	2008-2012, 2013	1.8107	0.004	281
	2008-2012, 2014	1.326	0.073	66
	2008-2012, 2015	2.3908	0.018	66
	2013, 2014	1.6577	0.104	10
	2013, 2015	1.468	0.223	10
	2014, 2015	3.3939	0.349	3
20	2008-2012, 2013	1.6776	0.033	78
	2008-2012, 2014	1.7965	0.022	78
	2008-2012, 2015	1.5768	0.047	78
	2013, 2014	1.4267	0.315	3
	2013, 2015	1.3181	0.34	3
	2014, 2015	0.92674	1	3
23	2008-2012, 2013	1.7038	0.034	66
	2008-2012, 2014	1.4282	0.074	66
	2008-2012, 2015	2.1887	0.017	66
	2013, 2014	0.97269	0.66	3
	2013, 2015	1.9285	0.382	3
	2014, 2015	1.6259	0.314	3

Table 3.8-7. Three-way (month, year, sampling area) Permutational MANOVA. Biological community in April pre- and post-Sandy.

Area	**Groups**	***t***	***P*(perm)**	**Unique perms**
12	2008-2012, 2013	1.0132	0.403	66
	2008-2012, 2014	1.1999	0.187	276
	2008-2012, 2015	1.4972	0.013	66
	2013, 2014	0.72467	1	10
	2013, 2015	1.5556	0.328	3
	2014, 2015	1.0532	0.402	10
16	2008-2012, 2013	1.2731	0.086	566
	2008-2012, 2014	1.4605	0.04	577
	2008-2012, 2015	1.3047	0.09	589
	2013, 2014	1.4516	0.101	10
	2013, 2015	1.3139	0.174	10
	2014, 2015	1.1825	0.319	10
17	2008-2012, 2013	1.4029	0.053	136
	2008-2012, 2014	1.1788	0.158	136
	2008-2012, 2015	1.7578	0.004	579
	2013, 2014	1.5545	0.313	3
	2013, 2015	1.3701	0.195	10
	2014, 2015	1.8157	0.093	10
18	2008-2012, 2013	2.0899	0.001	881
	2008-2012, 2014	2.4025	0.003	561
	2008-2012, 2015	1.541	0.009	572
	2013, 2014	1.4131	0.099	35
	2013, 2015	1.4286	0.124	35
	2014, 2015	2.2339	0.11	10
19	2008-2012, 2013	1.7478	0.002	526
	2008-2012, 2014	1.5166	0.009	513
	2008-2012, 2015	1.5194	0.012	524
	2013, 2014	1.7208	0.095	10
	2013, 2015	1.8178	0.095	10
	2014, 2015	1.2441	0.21	10
21	2008-2012, 2013	1.0913	0.242	66
	2008-2012, 2014	2.2163	0.013	66
	2008-2012, 2015	1.015	0.382	66
	2013, 2014	1.7386	0.344	3
	2013, 2015	1.0926	0.339	3
	2014, 2015	3.0783	0.312	3
22	2008-2012, 2013	1.5232	0.02	519
	2008-2012, 2014	1.9783	0.006	532
	2008-2012, 2015	1.4558	0.028	527
	2013, 2014	1.4118	0.191	10
	2013, 2015	1.0082	0.501	10
	2014, 2015	1.0801	0.297	10
23	2008-2012, 2013	1.8655	0.002	627
	2008-2012, 2014	1.8191	0.002	634
	2008-2012, 2015	1.3136	0.048	645
	2013, 2014	2.8154	0.104	10
	2013, 2015	1.8449	0.105	10
	2014, 2015	2.0635	0.111	10
24	2008-2012, 2013	1.2992	0.044	66

Area	**Groups**	***t***	***P*(perm)**	**Unique perms**
	2008-2012, 2014	1.745	0.02	66
	2008-2012, 2015	1.2234	0.095	66
	2013, 2014	1.3207	0.326	3
	2013, 2015	1.4249	0.339	3
	2014, 2015	1.9868	0.343	3
25	2008-2012, 2013	2.0018	0.002	575
	2008-2012, 2014	1.4615	0.031	559
	2008-2012, 2015	1.568	0.009	580
	2013, 2014	1.482	0.097	10
	2013, 2015	1.7341	0.103	10
	2014, 2015	1.5077	0.092	10

Table 3.8-8. Three-way (month, year, sampling area) Permutational MANOVA. Biological community in June pre- and post-Sandy.

Area	**Groups**	***t***	***P* (perm)**	**Unique perms**
16	2008-2012, 2013	1.1225	0.234	575
	2008-2012, 2014	1.6633	0.005	601
	2008-2012, 2015	1.3432	0.052	582
	2013, 2014	1.3569	0.189	10
	2013, 2015	0.95913	0.515	10
	2014, 2015	1.7041	0.109	10
17	2008-2012, 2013	1.871	0.005	885
	2008-2012, 2014	1.3014	0.083	884
	2008-2012, 2015	1.6155	0.018	575
	2013, 2014	1.7513	0.031	35
	2013, 2015	2.0697	0.021	35
	2014, 2015	1.5097	0.062	35
18	2008-2012, 2013	1.622	0.004	580
	2008-2012, 2014	1.2654	0.099	571
	2008-2012, 2015	1.4139	0.034	583
	2013, 2014	1.4158	0.104	10
	2013, 2015	1.506	0.185	10
	2014, 2015	1.1303	0.265	10
19	2008-2012, 2013	1.2547	0.11	621
	2008-2012, 2014	1.4205	0.042	619
	2008-2012, 2015	1.0109	0.372	616
	2013, 2014	1.1934	0.309	10
	2013, 2015	1.3847	0.213	10
	2014, 2015	1.8281	0.111	10
20	2008-2012, 2013	2.5639	0.001	573
	2008-2012, 2014	2.0967	0.011	571
	2008-2012, 2015	1.9254	0.002	568
	2013, 2014	0.78326	0.494	10
	2013, 2015	1.08	0.188	10
	2014, 2015	0.91544	0.517	10
21	2008-2012, 2013	1.412	0.042	66
	2008-2012, 2014	0.95158	0.527	66
	2008-2012, 2015	1.2226	0.16	66
	2013, 2014	1.4857	0.347	3
	2013, 2015	1.6995	0.324	3
	2014, 2015	1.1011	0.694	3
22	2008-2012, 2013	1.5878	0.015	560
	2008-2012, 2014	0.95408	0.532	571
	2008-2012, 2015	1.2599	0.104	566
	2013, 2014	0.97201	0.505	10
	2013, 2015	1.5231	0.096	10
	2014, 2015	1.3069	0.076	10
23	2008-2012, 2013	1.5082	0.032	581
	2008-2012, 2014	1.1903	0.167	581
	2008-2012, 2015	1.4282	0.046	571
	2013, 2014	1.2028	0.203	10
	2013, 2015	1.1929	0.411	10
	2014, 2015	0.95472	0.6	10
25	2008-2012, 2013	1.4196	0.031	572

Area	**Groups**	***t***	***P* (perm)**	**Unique perms**
	2008-2012, 2014	1.45	0.038	581
	2008-2012, 2015	1.264	0.094	871
	2013, 2014	1.2514	0.193	10
	2013, 2015	1.1258	0.254	35
	2014, 2015	1.1823	0.268	35

Table 3.8-9. Three-way (month, year, sampling area) Permutational MANOVA. Biological community in August pre- and post-Sandy.

Area	**Groups**	***t***	***P*(perm)**	**Unique perms**
14	2008-2012, 2013	1.3082	0.103	280
	2008-2012, 2014	1.5014	0.031	66
	2008-2012, 2015	1.3901	0.05	66
	2013, 2014	0.85127	0.604	10
	2013, 2015	1.0248	0.625	10
	2014, 2015	1.0228	0.656	3
15	2008-2012, 2013	1.9774	0.005	580
	2008-2012, 2014	1.402	0.084	877
	2008-2012, 2015	1.1918	0.184	565
	2013, 2014	1.7181	0.036	35
	2013, 2015	1.6723	0.09	10
	2014, 2015	1.3419	0.167	35
16	2008-2012, 2013	1.8386	0.02	136
	2008-2012, 2014	1.2417	0.13	585
	2008-2012, 2015	1.7445	0.012	589
	2013, 2014	0.84158	0.712	10
	2013, 2015	1.0184	0.626	10
	2014, 2015	0.70045	1	10
17	2008-2012, 2013	1.5944	0.021	579
	2008-2012, 2014	1.988	0.003	575
	2008-2012, 2015	1.1139	0.255	587
	2013, 2014	1.7417	0.092	10
	2013, 2015	1.3236	0.097	10
	2014, 2015	1.1712	0.204	10
18	2008-2012, 2013	1.5457	0.044	565
	2008-2012, 2014	1.0318	0.339	561
	2008-2012, 2015	1.2063	0.184	570
	2013, 2014	0.73461	0.677	10
	2013, 2015	0.76786	0.701	10
	2014, 2015	0.59566	0.902	10
19	2008-2012, 2013	1.7142	0.035	567
	2008-2012, 2014	1.1048	0.263	586
	2008-2012, 2015	1.2905	0.134	570
	2013, 2014	0.87238	0.599	10
	2013, 2015	1.7325	0.091	10
	2014, 2015	1.1428	0.296	10
20	2008-2012, 2013	1.4864	0.038	593
	2008-2012, 2014	1.9414	0.002	574
	2008-2012, 2015	1.5153	0.028	571
	2013, 2014	1.2038	0.185	10
	2013, 2015	0.79459	0.519	10
	2014, 2015	1.6949	0.099	10
23	2008-2012, 2013	1.5418	0.046	579
	2008-2012, 2014	1.4766	0.035	570
	2008-2012, 2015	1.3329	0.049	136
	2013, 2014	1.567	0.095	10
	2013, 2015	1.3396	0.198	10
	2014, 2015	0.77842	0.793	10
24	2008-2012, 2013	1.2756	0.071	66

Area	**Groups**	***t***	***P*(perm)**	**Unique perms**
	2008-2012, 2014	1.6545	0.017	66
	2008-2012, 2015	0.94739	0.533	66
	2013, 2014	1.0515	0.666	3
	2013, 2015	0.83067	1	3
	2014, 2015	1.1319	0.308	3
25	2008-2012, 2013	1.4759	0.037	580
	2008-2012, 2014	1.1902	0.187	587
	2008-2012, 2015	1.3246	0.092	574
	2013, 2014	1.5308	0.189	10
	2013, 2015	1.3293	0.394	10
	2014, 2015	1.4192	0.202	10

Table 3.8-10. Three-way (month, year, sampling area) Permutational MANOVA. Biological community in October pre- and post-Sandy.

Area	**Groups**	***t***	***P*(perm)**	**Unique perms**
12	2008-2012, 2013	1.3839	0.032	78
	2008-2012, 2014	2.0237	0.004	343
	2008-2012, 2015	1.5223	0.027	78
	2013, 2014	1.9219	0.101	10
	2013, 2015	1.5408	0.345	3
	2014, 2015	1.4317	0.204	10
15	2008-2012, 2013	1.4807	0.019	572
	2008-2012, 2014	1.3478	0.045	566
	2008-2012, 2015	1.3031	0.064	577
	2013, 2014	1.2281	0.21	10
	2013, 2015	1.3787	0.179	10
	2014, 2015	1.225	0.29	10
16	2008-2012, 2013	1.2472	0.111	889
	2008-2012, 2014	1.7404	0.009	136
	2008-2012, 2015	1.0098	0.386	578
	2013, 2014	1.1663	0.416	15
	2013, 2015	0.83526	0.624	35
	2014, 2015	1.102	0.401	10
17	2008-2012, 2013	1.712	0.008	522
	2008-2012, 2014	1.7098	0.003	523
	2008-2012, 2015	1.116	0.251	120
	2013, 2014	1.3008	0.212	10
	2013, 2015	0.95513	0.512	10
	2014, 2015	0.76998	0.685	10
18	2008-2012, 2013	1.3052	0.062	153
	2008-2012, 2014	1.2473	0.086	622
	2008-2012, 2015	1.646	0.01	628
	2013, 2014	1.424	0.107	10
	2013, 2015	1.3039	0.214	10
	2014, 2015	1.8708	0.109	10
19	2008-2012, 2013	1.6117	0.007	574
	2008-2012, 2014	1.4146	0.029	578
	2008-2012, 2015	1.0327	0.369	573
	2013, 2014	2.265	0.116	10
	2013, 2015	1.4856	0.099	10
	2014, 2015	0.94316	0.503	10
20	2008-2012, 2013	1.2951	0.089	542
	2008-2012, 2014	1.5596	0.039	512
	2008-2012, 2015	1.3128	0.077	523
	2013, 2014	1.4064	0.091	10
	2013, 2015	0.97871	0.486	10
	2014, 2015	1.2111	0.199	10
21	2008-2012, 2013	1.9677	0.009	66
	2008-2012, 2014	1.3582	0.09	66
	2008-2012, 2015	2.7241	0.016	66
	2013, 2014	0.88361	0.688	3
	2013, 2015	1.1074	0.348	3
	2014, 2015	1.2778	0.322	3
22	2008-2012, 2013	1.2336	0.115	558

Area	**Groups**	***t***	***P*(perm)**	**Unique perms**
	2008-2012, 2014	1.2886	0.091	568
	2008-2012, 2015	1.6969	0.003	567
	2013, 2014	0.68826	0.833	10
	2013, 2015	1.4036	0.192	10
	2014, 2015	1.3261	0.283	10
23	2008-2012, 2013	1.6099	0.014	578
	2008-2012, 2014	1.4173	0.017	575
	2008-2012, 2015	2.3437	0.002	574
	2013, 2014	1.5782	0.091	10
	2013, 2015	2.1678	0.1	10
	2014, 2015	1.9291	0.111	10
25	2008-2012, 2013	1.0546	0.312	563
	2008-2012, 2014	1.1344	0.222	570
	2008-2012, 2015	1.5284	0.026	581
	2013, 2014	1.1042	0.389	10
	2013, 2015	1.1503	0.394	10
	2014, 2015	1.3552	0.11	10
26	2008-2012, 2013	2.0726	0.021	66
	2008-2012, 2014	1.4055	0.106	66
	2008-2012, 2015	1.2821	0.097	66
	2013, 2014	1.9064	0.334	3
	2013, 2015	2.0089	0.338	3
	2014, 2015	1.2335	0.32	3

Table 3.8-11. SIMPER. One-way analysis. Annual similarity percentages-species contributions pre and post-Sandy.

Group 2008-2012. Average similarity = 34.48

Species	Mean Abundance	Mean Sim	Sim/SD	Contribution %	Cumulative %
LONGFIN SQUID	2.67	3.80	0.92	11.03	11.03
WINDOWPANE	1.74	3.44	1.78	9.96	20.99
LITTLE SKATE	1.81	3.19	1.31	9.24	30.23
BUTTERFISH	2.48	2.74	0.89	7.95	38.18
SUMMER FLOUNDER	1.33	2.19	1.22	6.36	44.54
UNCLASSIFED STARFISH	1.15	1.67	0.82	4.85	49.39
SPOTTED HAKE	1.34	1.50	0.80	4.34	53.73
NORTHERN SEAROBIN	1.35	1.33	0.56	3.86	57.59
CLEARNOSE SKATE	1.13	1.12	0.65	3.26	60.85
BAY ANCHOVY	2.10	1.05	0.36	3.06	63.91
SCUP	1.33	1.02	0.54	2.96	66.87
SMOOTH DOGFISH	1.01	0.98	0.63	2.86	69.72
WINTER SKATE	0.79	0.82	0.53	2.39	72.11

Group 2013. Average similarity = 37.46

Species	Mean Abundance	Mean Sim	Sim/SD	Contribution %	Cumulative %
LITTLE SKATE	2.28	4.31	1.51	11.50	11.50
WINDOWPANE	1.94	4.11	2.20	10.97	22.46
LONGFIN SQUID	2.49	3.20	0.86	8.53	30.99
SPOTTED HAKE	2.02	2.93	1.37	7.82	38.82
SUMMER FLOUNDER	1.31	2.28	1.39	6.10	44.92
BUTTERFISH	2.03	1.82	0.73	4.85	49.76
WINTER SKATE	1.19	1.56	0.67	4.17	53.93
CLEARNOSE SKATE	1.38	1.38	0.75	3.69	57.62
NORTHERN SEAROBIN	1.59	1.38	0.50	3.68	61.30
BAY ANCHOVY	2.46	1.24	0.39	3.32	64.61
ROCK CRAB	0.86	1.15	0.71	3.07	67.69
SILVER HAKE	1.04	1.12	0.61	3.00	70.68

Group 2014. Average similarity = 35.03

Species	Mean Abundance	Mean Sim	Sim/SD	Contribution %	Cumulative %
LONGFIN SQUID	2.97	4.67	1.01	13.34	13.34
WINDOWPANE	1.82	4.35	2.09	12.43	25.77
LITTLE SKATE	1.78	3.35	1.09	9.57	35.34
SUMMER FLOUNDER	1.25	2.20	1.19	6.29	41.63
BUTTERFISH	1.99	2.08	0.77	5.95	47.58
NORTHERN SEAROBIN	1.65	1.67	0.53	4.78	52.36
CLEARNOSE SKATE	1.36	1.55	0.69	4.44	56.80
WINTER SKATE	1.04	1.47	0.61	4.19	60.99
SPOTTED HAKE	1.21	1.32	0.69	3.77	64.76
ROCK CRAB	0.77	1.10	0.68	3.14	67.90
SCUP	1.17	1.08	0.57	3.09	71.00

Group 2015. Average similarity = 38.08

Species	**Mean Abundance**	**Mean Sim**	**Sim/SD**	**Contribution %**	**Cumulative %**
LITTLE SKATE	2.31	5.14	1.54	13.51	13.51
WINDOWPANE	1.92	4.32	2.23	11.35	24.85
LONGFIN SQUID	2.55	4.21	1.07	11.05	35.90
SUMMER FLOUNDER	1.29	2.18	1.18	5.73	41.64
SPOTTED HAKE	1.66	2.18	0.96	5.72	47.36
SCUP	1.92	2.03	0.79	5.34	52.70
CLEARNOSE SKATE	1.52	1.81	0.79	4.76	57.46
NORTHERN SEAROBIN	1.69	1.78	0.60	4.66	62.12
BUTTERFISH	2.25	1.73	0.61	4.54	66.66
WINTER SKATE	0.89	1.18	0.53	3.11	69.77
ROCK CRAB	0.81	1.10	0.64	2.90	72.67

Groups 2008-2012, and 2013. Average dissimilarity = 66.15

Species	**Mean Abundance (2008-2012)**	**Mean Abundance (2013)**	**Mean Diss**	**Diss/SD**	**Contribution %**	**Cumulative %**
BAY ANCHOVY	2.10	2.46	3.85	0.89	5.82	5.82
LONGFIN SQUID	2.67	2.49	3.07	1.15	4.65	10.47
BUTTERFISH	2.48	2.03	3.01	1.17	4.54	15.01
NORTHERN SEAROBIN	1.35	1.59	2.44	0.96	3.69	18.71
ATLANTIC HERRING	0.92	1.06	2.06	0.81	3.12	21.82
SPOTTED HAKE	1.34	2.02	1.95	1.24	2.95	24.78
SCUP	1.33	0.87	1.77	0.93	2.68	27.46
CLEARNOSE SKATE	1.13	1.38	1.72	1.14	2.61	30.06
LITTLE SKATE	1.81	2.28	1.67	1.24	2.52	32.59
SILVER HAKE	0.91	1.04	1.54	1.06	2.33	34.91
WEAKFISH	0.87	0.95	1.53	0.80	2.32	37.23
UNCLASSIFED STARFISH	1.15	0.00	1.51	1.13	2.28	39.51
WINTER SKATE	0.79	1.19	1.49	1.09	2.25	41.77
SMOOTH DOGFISH	1.01	1.04	1.43	1.08	2.16	43.93
SPINY DOGFISH	0.68	0.84	1.38	0.96	2.08	46.01
SPOT	0.47	0.93	1.26	0.66	1.90	47.91
ATLANTIC CROAKER	0.44	0.88	1.20	0.71	1.82	49.73
BLUEBACK HERRING	0.54	0.50	1.15	0.69	1.74	51.47
HORSESHOE CRAB	0.53	0.79	1.13	0.95	1.71	53.17
AMERICAN SAND LANCE	0.59	0.37	1.13	0.54	1.70	54.88
WINTER FLOUNDER	0.71	0.51	1.13	0.93	1.70	56.58
SUMMER FLOUNDER	1.33	1.31	1.09	1.09	1.65	58.22
ROCK CRAB	0.70	0.86	1.08	1.10	1.64	59.86
BLACK SEA BASS	0.62	0.71	1.06	1.00	1.61	61.46
WINDOWPANE	1.74	1.94	1.06	1.05	1.60	63.06
STRIPED SEAROBIN	0.63	0.65	1.01	0.98	1.53	64.59
NORTHERN KINGFISH	0.51	0.68	1.00	0.91	1.51	66.10
STRIPED ANCHOVY	0.46	0.60	0.99	0.58	1.49	67.59
UNCLASSIFIED SAND DOLLAR	0.72	0.00	0.98	0.67	1.49	69.07
BLUEFISH	0.58	0.50	0.97	0.75	1.46	70.54

Groups 2008-2012, and 2014. Average dissimilarity = 67.02

Species	Mean Abundance (2008-2012)	Mean Abundance (2014)	Mean Diss	Diss/SD	Contribution %	Cumulative %
LONGFIN SQUID	2.67	2.97	3.41	1.17	5.09	5.09
BAY ANCHOVY	2.10	1.54	3.28	0.84	4.89	9.98
BUTTERFISH	2.48	1.99	3.17	1.14	4.73	14.70
NORTHERN SEAROBIN	1.35	1.65	2.67	0.91	3.98	18.68
ATLANTIC HERRING	0.92	1.08	2.34	0.78	3.49	22.17
SCUP	1.33	1.17	2.12	0.95	3.16	25.33
CLEARNOSE SKATE	1.13	1.36	1.86	1.12	2.77	28.10
SPOTTED HAKE	1.34	1.21	1.82	1.15	2.71	30.81
LITTLE SKATE	1.81	1.78	1.73	1.28	2.59	33.40
UNCLASSIFED STARFISH	1.15	0.00	1.62	1.12	2.41	35.81
SMOOTH DOGFISH	1.01	1.03	1.53	1.09	2.29	38.10
WINTER SKATE	0.79	1.04	1.47	1.12	2.19	40.29
AMERICAN SAND LANCE	0.59	0.53	1.42	0.63	2.11	42.41
WEAKFISH	0.87	0.76	1.41	0.74	2.11	44.52
SILVER HAKE	0.91	0.49	1.36	0.90	2.02	46.54
SPINY DOGFISH	0.68	0.58	1.27	0.89	1.90	48.44
SUMMER FLOUNDER	1.33	1.25	1.21	1.10	1.80	50.24
WINTER FLOUNDER	0.71	0.54	1.19	0.96	1.78	52.02
BLUEBACK HERRING	0.54	0.49	1.18	0.74	1.76	53.78
BLACK SEA BASS	0.62	0.60	1.10	0.90	1.64	55.43
ROCK CRAB	0.70	0.77	1.08	1.08	1.62	57.04
WINDOWPANE	1.74	1.82	1.08	1.07	1.61	58.65
BLUEFISH	0.58	0.63	1.08	0.85	1.61	60.26
HORSESHOE CRAB	0.53	0.63	1.07	0.90	1.60	61.87
UNCLASSIFIED SAND DOLLAR	0.72	0.00	1.06	0.66	1.58	63.44
STRIPED SEAROBIN	0.63	0.54	1.00	0.97	1.50	64.94
STRIPED ANCHOVY	0.46	0.56	1.00	0.53	1.48	66.43
ATLANTIC CROAKER	0.44	0.57	0.98	0.56	1.47	67.89
ALEWIFE	0.43	0.36	0.93	0.69	1.38	69.28
NORTHERN KINGFISH	0.51	0.52	0.91	0.84	1.36	70.64

Groups 2013 and 2014. Average dissimilarity = 64.71

Species	Mean Abundance (2013)	Mean Abundance (2014)	Mean Diss	Diss/SD	Contribution %	Cumulative %
BAY ANCHOVY	2.46	1.54	3.57	0.82	5.52	5.52
LONGFIN SQUID	2.49	2.97	3.32	1.16	5.13	10.64
NORTHERN SEAROBIN	1.59	1.65	2.87	0.93	4.43	15.08
BUTTERFISH	2.03	1.99	2.84	1.19	4.39	19.46
ATLANTIC HERRING	1.06	1.08	2.35	0.83	3.63	23.09
SPOTTED HAKE	2.02	1.21	2.11	1.26	3.26	26.35
CLEARNOSE SKATE	1.38	1.36	1.90	1.18	2.93	29.28
LITTLE SKATE	2.28	1.78	1.85	1.32	2.85	32.14
SCUP	0.87	1.17	1.69	0.94	2.62	34.76
WINTER SKATE	1.19	1.04	1.62	1.14	2.50	37.26
SMOOTH DOGFISH	1.04	1.03	1.50	1.14	2.32	39.58
WEAKFISH	0.95	0.76	1.45	0.82	2.24	41.82

Species	Mean Abundance (2013)	Mean Abundance (2014)	Mean Diss	Diss/SD	Contribution %	Cumulative %
SILVER HAKE	1.04	0.49	1.43	1.04	2.20	44.03
SPINY DOGFISH	0.84	0.58	1.40	0.93	2.16	46.19
ATLANTIC CROAKER	0.88	0.57	1.32	0.72	2.03	48.22
HORSESHOE CRAB	0.79	0.63	1.25	0.95	1.93	50.15
BLUEBACK HERRING	0.50	0.49	1.19	0.69	1.83	51.99
BLACK SEA BASS	0.71	0.60	1.14	0.95	1.76	53.74
SUMMER FLOUNDER	1.31	1.25	1.11	1.10	1.72	55.46
ROCK CRAB	0.86	0.77	1.11	1.09	1.72	57.18
STRIPED ANCHOVY	0.60	0.56	1.08	0.58	1.68	58.85
AMERICAN SAND LANCE	0.37	0.53	1.08	0.62	1.67	60.52
WINTER FLOUNDER	0.51	0.54	1.05	0.91	1.62	62.13
NORTHERN KINGFISH	0.68	0.52	1.03	0.93	1.60	63.73
SPOT	0.93	0.11	1.03	0.60	1.59	65.32
BLUEFISH	0.50	0.63	1.01	0.77	1.57	66.88
COMMON SPIDER CRAB	0.67	0.49	0.99	0.97	1.53	68.41
STRIPED SEAROBIN	0.65	0.54	0.99	0.98	1.53	69.94
WINDOWPANE	1.94	1.82	0.97	1.09	1.49	71.43

Groups 2008-2012, and 2015. Average dissimilarity = 66.05

Species	Mean Abundance (2008-2012)	Mean Abundance (2015)	Mean Diss	Diss/ SD	Contribution %	Cumulative %
BAY ANCHOVY	2.10	1.85	3.46	0.85	5.24	5.24
BUTTERFISH	2.48	2.25	3.43	1.17	5.19	10.43
LONGFIN SQUID	2.67	2.55	2.99	1.16	4.53	14.95
NORTHERN SEAROBIN	1.35	1.69	2.56	0.94	3.88	18.83
SCUP	1.33	1.92	2.56	1.01	3.87	22.71
SPOTTED HAKE	1.34	1.66	1.91	1.23	2.89	25.60
CLEARNOSE SKATE	1.13	1.52	1.87	1.18	2.84	28.44
ATLANTIC HERRING	0.92	0.61	1.86	0.68	2.82	31.26
LITTLE SKATE	1.81	2.31	1.70	1.23	2.58	33.84
UNCLASSIFED STARFISH	1.15	0.00	1.58	1.12	2.40	36.24
SMOOTH DOGFISH	1.01	0.98	1.45	1.07	2.20	38.44
WEAKFISH	0.87	0.77	1.40	0.73	2.12	40.56
WINTER SKATE	0.79	0.89	1.37	1.08	2.08	42.63
SPINY DOGFISH	0.68	0.71	1.32	0.93	1.99	44.62
WINTER FLOUNDER	0.71	0.78	1.29	1.02	1.96	46.58
SILVER HAKE	0.91	0.34	1.27	0.85	1.92	48.51
BLUEBACK HERRING	0.54	0.55	1.22	0.73	1.84	50.35
SUMMER FLOUNDER	1.33	1.29	1.20	1.08	1.81	52.16
HORSESHOE CRAB	0.53	0.76	1.12	0.99	1.70	53.86
BLACK SEA BASS	0.62	0.74	1.12	0.99	1.70	55.56
ROCK CRAB	0.70	0.81	1.12	1.09	1.70	57.25
WINDOWPANE	1.74	1.92	1.09	1.06	1.65	58.90
BLUEFISH	0.58	0.58	1.04	0.81	1.58	60.48
STRIPED SEAROBIN	0.63	0.63	1.04	0.99	1.57	62.06
UNCLASSIFIED SAND DOLLAR	0.72	0.00	1.03	0.66	1.57	63.62

Species	**Mean Abundance (2008-2012)**	**Mean Abundance (2015)**	**Mean Diss**	**Diss/ SD**	**Contribution %**	**Cumulative %**
AMERICAN SAND LANCE	0.59	0.09	0.99	0.46	1.51	65.13
NORTHERN KINGFISH	0.51	0.65	0.99	0.89	1.51	66.63
ALEWIFE	0.43	0.40	0.94	0.68	1.42	68.06
SMALLMOUTH FLOUNDER	0.36	0.68	0.92	0.98	1.40	69.46
LADY CRAB	0.29	0.63	0.91	0.77	1.38	70.83

Groups 2013 and 2015. Average dissimilarity = 63.31

Species	**Mean Abundance (2013**	**Mean Abundance (2015)**	**Mean Diss**	**Diss/ SD**	**Contribution %**	**Cumulative %**
BAY ANCHOVY	2.46	1.85	3.73	0.84	5.90	5.90
BUTTERFISH	2.03	2.25	3.08	1.17	4.87	10.77
LONGFIN SQUID	2.49	2.55	2.89	1.16	4.56	15.33
NORTHERN SEAROBIN	1.59	1.69	2.77	0.95	4.37	19.70
SCUP	0.87	1.92	2.23	0.96	3.52	23.22
SPOTTED HAKE	2.02	1.66	2.00	1.25	3.16	26.37
ATLANTIC HERRING	1.06	0.61	1.96	0.75	3.09	29.47
CLEARNOSE SKATE	1.38	1.52	1.89	1.23	2.99	32.46
LITTLE SKATE	2.28	2.31	1.57	1.27	2.48	34.94
WINTER SKATE	1.19	0.89	1.56	1.13	2.47	37.41
WEAKFISH	0.95	0.77	1.44	0.81	2.27	39.68
SMOOTH DOGFISH	1.04	0.98	1.42	1.11	2.25	41.93
SPINY DOGFISH	0.84	0.71	1.41	0.98	2.23	44.15
SILVER HAKE	1.04	0.34	1.39	1.00	2.19	46.34
HORSESHOE CRAB	0.79	0.76	1.27	1.03	2.00	48.34
BLUEBACK HERRING	0.50	0.55	1.22	0.68	1.92	50.27
WINTER FLOUNDER	0.51	0.78	1.18	0.99	1.86	52.13
ROCK CRAB	0.86	0.81	1.14	1.11	1.79	53.93
BLACK SEA BASS	0.71	0.74	1.13	1.03	1.79	55.72
ATLANTIC CROAKER	0.88	0.35	1.13	0.72	1.79	57.51
SUMMER FLOUNDER	1.31	1.29	1.11	1.09	1.75	59.25
NORTHERN KINGFISH	0.68	0.65	1.09	0.96	1.72	60.97
COMMON SPIDER CRAB	0.67	0.58	1.04	0.96	1.64	62.61
SPOT	0.93	0.15	1.03	0.60	1.63	64.25
STRIPED SEAROBIN	0.65	0.63	1.02	1.00	1.61	65.86
SMALLMOUTH FLOUNDER	0.59	0.68	1.00	1.05	1.57	67.43
BLUEFISH	0.50	0.58	0.97	0.73	1.54	68.97
WINDOWPANE	1.94	1.92	0.96	1.06	1.52	70.49

Groups 2014 & 2015. Average dissimilarity = 64.19

Species	Mean Abundance (2014)	Mean Abundance (2015)	Mean Diss	Diss/ SD	Contribution %	Cumulative %
BUTTERFISH	1.99	2.25	3.26	1.15	5.08	5.08
LONGFIN SQUID	2.97	2.55	3.23	1.15	5.03	10.11
BAY ANCHOVY	1.54	1.85	3.03	0.78	4.72	14.84
NORTHERN SEAROBIN	1.65	1.69	3.02	0.91	4.70	19.54
SCUP	1.17	1.92	2.56	0.99	3.98	23.53
ATLANTIC HERRING	1.08	0.61	2.23	0.71	3.47	27.00
CLEARNOSE SKATE	1.36	1.52	2.03	1.18	3.17	30.17
SPOTTED HAKE	1.21	1.66	2.03	1.23	3.17	33.33
LITTLE SKATE	1.78	2.31	1.90	1.33	2.95	36.29
WINTER SKATE	1.04	0.89	1.57	1.15	2.45	38.74
SMOOTH DOGFISH	1.03	0.98	1.53	1.13	2.39	41.13
SPINY DOGFISH	0.58	0.71	1.33	0.91	2.07	43.20
WEAKFISH	0.76	0.77	1.29	0.77	2.00	45.20
BLUEBACK HERRING	0.49	0.55	1.26	0.73	1.96	47.16
HORSESHOE CRAB	0.63	0.76	1.25	0.98	1.95	49.12
WINTER FLOUNDER	0.54	0.78	1.24	1.01	1.94	51.05
SUMMER FLOUNDER	1.25	1.29	1.23	1.10	1.91	52.96
BLACK SEA BASS	0.60	0.74	1.20	0.94	1.86	54.82
ROCK CRAB	0.77	0.81	1.16	1.08	1.81	56.63
BLUEFISH	0.63	0.58	1.10	0.83	1.71	58.34
NORTHERN KINGFISH	0.52	0.65	1.03	0.90	1.60	59.95
SMALLMOUTH FLOUNDER	0.51	0.68	1.03	1.03	1.60	61.54
STRIPED SEAROBIN	0.54	0.63	1.02	0.99	1.58	63.12
WINDOWPANE	1.82	1.92	0.99	1.07	1.55	64.67
AMERICAN SAND LANCE	0.53	0.09	0.95	0.54	1.49	66.16
COMMON SPIDER CRAB	0.49	0.58	0.95	0.91	1.48	67.64
LADY CRAB	0.27	0.63	0.94	0.76	1.46	69.10
ATLANTIC SILVERSIDE	0.31	0.31	0.94	0.52	1.46	70.56

Table 3.8-12. One-way SIMPER. Similarity percentage species contributions in January pre- and post-Sandy.

Group 2008-2012
Average similarity: 43.98

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
ATLANTIC HERRING	3.23	6.99	1.28	15.90	15.90
LITTLE SKATE	1.84	5.18	1.93	11.78	27.68
WINDOWPANE	1.77	4.88	1.64	11.10	38.79
ATL SILVERSIDE	1.63	3.97	0.91	9.03	47.81
BLUEBACK HERRING	1.63	3.17	1.09	7.20	55.02
AM SAND LANCE	1.68	2.60	0.57	5.90	60.92
WINTER FLOUNDER	1.10	2.06	0.86	4.68	65.60
UNCLASSIFED STARFISH	1.04	1.97	0.73	4.48	70.08

Group 2013
Average similarity: 50.29

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
LITTLE SKATE	2.12	7.19	3.91	14.29	14.29
WINDOWPANE	2.11	6.90	2.74	13.71	28.00
ATLANTIC HERRING	2.84	6.68	1.38	13.29	41.29
WINTER SKATE	1.59	4.27	1.41	8.50	49.79
BLUEBACK HERRING	2.04	3.75	1.09	7.45	57.24
ATL SILVERSIDE	1.44	2.96	0.78	5.89	63.12
SILVER HAKE	1.42	2.66	0.93	5.28	68.41
WINTER FLOUNDER	0.97	2.26	0.82	4.48	72.89

Group 2014
Average similarity: 52.38

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
ATLANTIC HERRING	3.58	10.05	1.93	19.19	19.19
WINDOWPANE	1.97	8.04	3.60	15.34	34.53
LITTLE SKATE	1.84	6.89	2.84	13.16	47.69
ATL SILVERSIDE	1.74	5.50	1.49	10.51	58.20
AM SAND LANCE	1.57	4.34	1.17	8.28	66.48
BLUEBACK HERRING	1.47	3.76	1.24	7.18	73.66

Group 2015
Average similarity: 51.48

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
LITTLE SKATE	2.31	7.51	4.17	14.58	14.58
WINDOWPANE	2.00	6.72	3.84	13.05	27.63
ATLANTIC HERRING	2.91	6.39	1.44	12.40	40.03
WINTER SKATE	1.62	5.36	3.17	10.42	50.45
ATL SILVERSIDE	1.92	4.64	1.21	9.02	59.47
BLUEBACK HERRING	1.98	4.36	1.42	8.46	67.93
WINTER FLOUNDER	1.16	2.73	1.02	5.31	73.23

Groups 2008-2012 & 2013
Average dissimilarity = 56.54

	Group 2008-2012	Group 2013				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
ATLANTIC HERRING	3.23	2.84	4.45	1.25	7.87	7.87
AMERICAN SAND LANCE	1.68	0.00	3.39	0.80	5.99	13.86
BLUEBACK HERRING	1.63	2.04	3.13	1.24	5.53	19.40
SILVER HAKE	1.21	1.42	2.67	1.24	4.72	24.11
ATLANTIC SILVERSIDE	1.63	1.44	2.65	1.18	4.69	28.81
SPINY DOGFISH	1.14	1.10	2.35	1.10	4.15	32.96
WINTER SKATE	0.98	1.59	2.25	1.06	3.98	36.94
AMERICAN SHAD	0.95	0.87	2.03	1.14	3.60	40.53
SPOTTED HAKE	0.61	1.07	2.01	1.13	3.55	44.09
ALEWIFE	1.11	0.59	2.00	1.04	3.54	47.63
UNCLASSIFED STARFISH	1.04	0.23	1.91	1.06	3.38	51.01
UND SAND DOLLAR	0.86	0.50	1.80	0.97	3.18	54.19
WINTER FLOUNDER	1.10	0.97	1.79	1.20	3.17	57.36
WINDOWPANE	1.77	2.11	1.79	1.00	3.16	60.52
UNCLASSIFIED SKATE	0.55	0.83	1.76	1.01	3.11	63.62
SUMMER FLOUNDER	0.34	0.97	1.64	1.27	2.90	66.52
LITTLE SKATE	1.84	2.12	1.58	0.98	2.79	69.31
BAY ANCHOVY	0.36	0.57	1.38	0.84	2.43	71.75

Groups 2008-2012 & 2014
Average dissimilarity = 54.09

	Group 2008-2012	Group 2014				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
ATLANTIC HERRING	3.23	3.58	5.24	1.29	9.70	9.70
AMERICAN SAND LANCE	1.68	1.57	3.80	1.06	7.02	16.72
ATLANTIC SILVERSIDE	1.63	1.74	2.63	1.30	4.87	21.59
BLUEBACK HERRING	1.63	1.47	2.58	1.21	4.77	26.36
ALEWIFE	1.11	0.92	2.34	1.15	4.32	30.68
SILVER HAKE	1.21	0.67	2.30	1.06	4.25	34.93
SPINY DOGFISH	1.14	0.44	2.22	1.04	4.10	39.03
UND SAND DOLLAR	0.86	0.76	2.19	1.04	4.06	43.09
UNCLASSIFED STARFISH	1.04	0.11	2.11	1.08	3.90	46.99
WINTER SKATE	0.98	1.21	1.94	1.17	3.58	50.57
AMERICAN SHAD	0.95	0.53	1.93	1.09	3.57	54.14
WINTER FLOUNDER	1.10	0.88	1.87	1.21	3.45	57.59
UNCLASSIFIED SKATE	0.55	0.55	1.69	0.84	3.12	60.72
WINDOWPANE	1.77	1.97	1.67	0.97	3.09	63.81
LITTLE SKATE	1.84	1.84	1.67	1.02	3.09	66.90
ROCK CRAB	0.70	0.64	1.58	1.09	2.92	69.81
ATLANTIC MENHADEN	0.66	0.20	1.31	0.73	2.43	72.24

Groups 2013 & 2014
Average dissimilarity = 53.10

	Group 2013	Group 2014				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
ATLANTIC HERRING	2.84	3.58	4.81	1.28	9.06	9.06
AMERICAN SAND LANCE	0.00	1.57	3.42	1.16	6.45	15.50
BLUEBACK HERRING	2.04	1.47	3.16	1.30	5.96	21.46
ATLANTIC SILVERSIDE	1.44	1.74	2.72	1.33	5.12	26.59
SILVER HAKE	1.42	0.67	2.39	1.30	4.50	31.09
SPINY DOGFISH	1.10	0.44	2.23	1.06	4.19	35.28
WINTER SKATE	1.59	1.21	2.00	1.02	3.77	39.05
SPOTTED HAKE	1.07	0.20	2.00	1.11	3.76	42.81
UNCLASSIFIED SKATE	0.83	0.55	1.99	0.99	3.75	46.56
ALEWIFE	0.59	0.92	1.94	1.09	3.66	50.21
AMERICAN SHAD	0.87	0.53	1.90	0.99	3.58	53.79
UND SAND DOLLAR	0.50	0.76	1.81	0.94	3.41	57.21
WINTER FLOUNDER	0.97	0.88	1.68	1.19	3.16	60.37
SUMMER FLOUNDER	0.97	0.39	1.67	1.26	3.14	63.51
ROCK CRAB	0.78	0.64	1.55	1.17	2.91	66.42
LITTLE SKATE	2.12	1.84	1.39	1.08	2.62	69.04
WINDOWPANE	2.11	1.97	1.34	1.20	2.52	71.56

Groups 2008-2012 & 2015
Average dissimilarity = 55.69

	Group 2008-2012	Group 2015				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
ATLANTIC HERRING	3.23	2.91	4.49	1.25	8.06	8.06
AMERICAN SAND LANCE	1.68	0.00	3.31	0.80	5.94	14.00
BLUEBACK HERRING	1.63	1.98	2.72	1.23	4.89	18.89
ATLANTIC SILVERSIDE	1.63	1.92	2.62	1.21	4.71	23.59
SPINY DOGFISH	1.14	0.86	2.26	1.06	4.06	27.65
ALEWIFE	1.11	0.98	2.25	1.15	4.05	31.70
ATLANTIC MENHADEN	0.66	1.10	2.09	1.13	3.76	35.46
SILVER HAKE	1.21	0.47	2.04	0.99	3.67	39.12
UND SAND DOLLAR	0.86	0.74	1.97	1.02	3.53	42.65
WINTER SKATE	0.98	1.62	1.91	1.13	3.43	46.08
AMERICAN SHAD	0.95	0.95	1.90	1.19	3.42	49.50
UNCLASSIFED STARFISH	1.04	0.21	1.88	1.09	3.37	52.87
WINTER FLOUNDER	1.10	1.16	1.80	1.17	3.24	56.11
SPOTTED HAKE	0.61	0.91	1.78	1.06	3.20	59.31
LITTLE SKATE	1.84	2.31	1.67	1.02	3.01	62.32
ROCK CRAB	0.70	1.05	1.60	1.19	2.87	65.18
LONGFIN SQUID	0.29	0.68	1.49	0.74	2.68	67.87
WINDOWPANE	1.77	2.00	1.47	0.98	2.64	70.51

Groups 2013 & 2015
Average dissimilarity = 51.02

	Group 2013	Group 2015				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
ATLANTIC HERRING	2.84	2.91	3.99	1.24	7.83	7.83
BLUEBACK HERRING	2.04	1.98	3.09	1.30	6.06	13.89
ATLANTIC SILVERSIDE	1.44	1.92	2.68	1.19	5.26	19.15
SILVER HAKE	1.42	0.47	2.30	1.31	4.50	23.65
SPINY DOGFISH	1.10	0.86	2.23	1.09	4.37	28.02
AMERICAN SHAD	0.87	0.95	1.99	1.17	3.91	31.93
SPOTTED HAKE	1.07	0.91	1.99	1.21	3.91	35.83
ATLANTIC MENHADEN	0.12	1.10	1.91	1.08	3.74	39.57
ALEWIFE	0.59	0.98	1.84	1.06	3.60	43.18
UNCLASSIFIED SKATE	0.83	0.45	1.70	1.00	3.33	46.51
UND SAND DOLLAR	0.50	0.74	1.67	0.93	3.28	49.79
WINTER FLOUNDER	0.97	1.16	1.64	1.15	3.21	53.00
SUMMER FLOUNDER	0.97	0.37	1.52	1.25	2.97	55.97
BAY ANCHOVY	0.57	0.65	1.47	1.03	2.88	58.85
ROCK CRAB	0.78	1.05	1.45	1.17	2.85	61.70
WINTER SKATE	1.59	1.62	1.45	0.97	2.85	64.54
LONGFIN SQUID	0.07	0.68	1.34	0.66	2.63	67.18
NORTHERN MOON SHELL	0.57	0.48	1.29	1.00	2.52	69.70
RED HAKE	0.64	0.33	1.27	0.83	2.49	72.19

Groups 2014 & 2015
Average dissimilarity = 52.22

	Group 2014	Group 2015				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
ATLANTIC HERRING	3.58	2.91	4.78	1.25	9.16	9.16
AMERICAN SAND LANCE	1.57	0.00	3.34	1.18	6.39	15.55
BLUEBACK HERRING	1.47	1.98	2.68	1.26	5.14	20.69
ATLANTIC SILVERSIDE	1.74	1.92	2.59	1.26	4.97	25.66
ALEWIFE	0.92	0.98	2.22	1.21	4.25	29.90
UND SAND DOLLAR	0.76	0.74	2.07	0.99	3.97	33.87
ATLANTIC MENHADEN	0.20	1.10	2.02	1.10	3.87	37.74
SPINY DOGFISH	0.44	0.86	2.00	0.92	3.83	41.57
AMERICAN SHAD	0.53	0.95	1.87	1.10	3.59	45.16
ROCK CRAB	0.64	1.05	1.80	1.27	3.44	48.60
WINTER FLOUNDER	0.88	1.16	1.70	1.21	3.26	51.87
SPOTTED HAKE	0.20	0.91	1.68	1.00	3.21	55.07
UNCLASSIFIED SKATE	0.55	0.45	1.56	0.80	2.99	58.07
LITTLE SKATE	1.84	2.31	1.51	1.15	2.89	60.96
LONGFIN SQUID	0.12	0.68	1.47	0.68	2.82	63.77
SILVER HAKE	0.67	0.47	1.47	1.06	2.81	66.58
WINTER SKATE	1.21	1.62	1.45	1.01	2.78	69.36
BAY ANCHOVY	0.19	0.65	1.33	0.91	2.55	71.90

CHAPTER 4. SPECIES RICHNESS AND DIVERSITY OF THE NEARSHORE MARINE COMMUNITY IN THE MID-ATLANTIC BIGHT REGION (NEW JERSEY, USA)

4.1 Abstract

All populations fluctuate in abundance not only because of the natural environmental, biological, and demographic stochasticity, but they often vary with disturbance, stress, or other factors related to anthropogenic activities. Various stressors influence community dynamics, but varying climate and oceanic dynamics are among the most powerful factors; changes in the climate and associated ocean conditions are having profound effects on marine communities around the world. One important question about the impacts of stressors is whether their effects significantly alter community processes (e.g., immigration or emigration) or ecosystem properties, such as abundance, biomass, and community stability (alpha and beta diversity). Marine policymakers and managers charged with handling valuable natural resources are concerned about changes in biodiversity given the premier notion that preserving biodiversity will assist an ecosystem with recovering or adapting following a natural or anthropogenic disturbance; however, studies of biodiversity are lacking for most regions around the world, including the waters of the Mid-Atlantic Bight. The goal of this research was to describe biodiversity (alpha and beta diversity) in the nearshore marine community off New Jersey over the past 28 years. Estimated species richness increased substantially during the first few years of sampling, and reached asymptotic richness in about 13 years. Species richness estimates varied significantly over time, but in general the trend was similar and relatively stable. The lowest mean species richness (n = 121.3 species) was estimated using the mean Michaelis-Menten approach and the highest mean species richness (n = 156.3 species) was estimated using the mean Jackknife 2 approach. Alpha diversity and evenness estimates indicated the community was composed of relatively a few species with high abundance. Fisher's alpha diversity index best described the marine community, which ranged from 9.04 in 1988 to 15.95 in 1989 with an average of 11.76 (± 1.62 SD). Alpha diversity and evenness indices fluctuated from one year to the next, but have remained relatively stable over time. Beta diversity estimates also showed interannual variability, but similarity values were relatively stable over time; approximately 50 percent of the species are shared among samples. Analytical procedures could not detect an association between community stability and the environmental conditions suggesting it is likely shaped by other factors, such as inter- and intra-species associations. The findings propose the community is resilient despite the ongoing changes in the environmental and oceanic conditions.

4.2 Introduction

Marine communities are continuously evolving, adapting, and sometimes expanding depending on the environmental conditions, biological factors, and disturbance. All populations fluctuate in abundance not only because of the natural environmental, biological, and demographic stochasticity (Mutshinda et al. 2009), but they often vary with disturbance, stress, or other factors related to anthropogenic activities. One important question about the impacts of stressors or disturbance is whether their effects significantly alter community processes (e.g., immigration or emigration) or ecosystem properties, such as abundance, biomass, and community stability (alpha and beta diversity).

Among the most important concepts in ecology is community stability, which is related to disturbance sensitivity (Begon et al. 1986). Ecologists often define community stability by the community's ability to avoid displacement (i.e., resistance) or return to its former state (i.e., resilience) after it has been disturbed (Begon et al. 1986). Community stability is shaped by how well the community interacts with the environment (Begon et al. 1986). In general, a fragile community exists within a narrow range of environmental conditions, whereas a robust community functions within a wide range of environmental conditions. To understand, assess, and interpret disturbance (i.e., impacts), one of the most important ecological concepts associated with community structure is biodiversity (Ludwig and Reynolds, 1988).

Biodiversity has several components that include species richness (i.e., the number of groups of phylogenetically), diversity (alpha and beta), and evenness (i.e., proportions of species present on a site). Ecologists define biodiversity through a three (genetic, species, and ecosystem diversity) concept approach (Norse, 1993). The most common method ecologists use to measure biodiversity is to estimate species richness and species diversity, which can be estimated in various ways (e.g. Chao 1 richness estimator, Shannon-Weiner diversity index; Colwell and Elsensohn, 2014). Such indices often combine variables that describe community structure in different ways, which makes the interpretation challenging, sometimes confusing, and difficult to compare among studies (Ludwig and Reynolds, 1988). Quantifying biodiversity is further complicated because results sometimes depend on scale (local, regional, global) and time (e.g., seasonal, annual, short and long-term) (Hildebrand et al. 2017).

Concerning the concept of species richness, a decline in one species and the addition of another (replacement) does not necessarily translate to a neutral change given that each species can have a different function in the system. Interpretation is even more complicated because species turnover can occur naturally without disturbance (Hildebrand et al. 2017). All of these factors makes it almost impossible to interpret community structure change through a simple species richness calculation. Consequently, examining, calculating, and interpreting biodiversity requires a working knowledge of the system in terms of species composition, trophic level structure, and seasonal and annual relative abundance, and also of local stressors (e.g. water quality, habitat loss, fisheries, and climate variability).

Marine policymakers and managers charged with handling valuable natural resources are concerned about changes in biodiversity given the notion that preserving biodiversity will assist ecosystem recovery following a natural or anthropogenic disturbance (Fautin et al. 2010). The link between biodiversity and ecosystem health is incompletely understood, but it is likely that preserving biodiversity is beneficial despite the ongoing diversity-stability debate among ecologists (McCann, 2000). Marine ecosystem health is not necessarily directly proportional to biodiversity because some low diversity communities seem to function as well as high diversity systems (Fautin et al. 2010). Species redundancy, with a number of species performing similar functions, may protect against the loss of one or a few species.

Threats to marine and freshwater biodiversity are rising and biodiversity is declining around the world (Dudgeon et al. 2006; Worm et al. 2006). To make sound management decisions about natural resources, biodiversity (alpha and beta) estimates over time are imperative, especially with ongoing climate change and fishing pressure. Fautin et al. (2010) pointed out that despite the researcher's comprehensive dataset documenting biodiversity throughout the United States, biodiversity data is generally limited over space and time, and information describing the biological and environmental interactions is mostly unavailable.

The waters off New Jersey are located within the MAB in the western North Atlantic Ocean. The MAB is defined as the offshore waters (i.e., beach to continental shelf) between Cape Cod, Massachusetts and Cape Hatteras, North Carolina (Steimle and Zetlin, 2000). The MAB is among the most important oceanic regions in the United States because it supports and provides habitat for many ecologically and economically valuable fisheries resources. In 2016, commercial fishing landings and associated value in the MAB were around 76,366 mt and \$255.2 million, respectively (NMFS, 2018). Commercial fisheries in New Jersey represented 79 percent of the total landings in the MAB. Over the past 10 years the economic value of commercial fishing landings in New Jersey ranged between \$132.9 and \$220.4 million with a mean of \$164.8 million (NMFS, 2018). In 2016, commercial fisheries in New Jersey ranked tenth in landings and ninth in value (\$132.3 million) in the United States (NMFS, 2018).

Information describing community stability in regions that support valuable commercial fisheries is crucial to fishery resource managers so they can make informed management decisions. Odum (1985), a pioneer in exploring changes in a community, found the proportion of *r*-strategists, mean size and life span of an organism, and the food-chain length were linked to physiochemical conditions (i.e., pH, dissolved oxygen, salinity, and water temperature). Odum (1985, 1992) also specified that functional changes in species niches (related to species redundancy) could be among the first sign of environmental stress. In this regard, the nearshore marine community off New Jersey coast provided a unique opportunity to address this informational gap and better understand the link between the varying environmental conditions and the nearshore marine community structure in terms of alpha and beta diversity.

Given the need to assess biodiversity, the goal of this research was to describe biodiversity (alpha and beta diversity) in the nearshore marine community off New Jersey over the past 28 years. The aim was to provide resource managers with community ecological-based information to support knowledgeable decisions, and add to knowledge of community dynamics more generally. The main objective was to estimate species richness, diversity, evenness, and similarity of the nearshore marine community off New Jersey over the past 28 years (1988−2015). The overall theoretical expectation was that the community stability has changed significantly off New Jersey over the past 28 years. Specific null and alternative hypotheses consisted of the following:

$H_0$1: Community structure is constant with time (1988−2015).

H_{1A}: The species richness changed significantly with time (1988−2015).
H_{1B}: The species diversity changed significantly with time (1988−2015).
H_{1C}: The species evenness changed significantly with time (1988−2015).
H_{1D}: The species similarity changed significantly with time (1988−2015).

4.3 Methods

4.3.1 Summary

Field-collections were made using standardized sampling gear throughout the New Jersey coastal region (**Figure 4.3.1-1**) at pre-determined stations that were selected under a stratified randomized experimental approach. The methods (study area, experimental survey design, experimental field sampling approach, station selection, field sampling gear, and field sampling and data collection procedures), and the basis for experimental repetition follow the details outlined in Chapter 2 (*Section 2.3 Methods*). Specific data treatment/processing, protocol, and statistical data analysis techniques are discussed below.

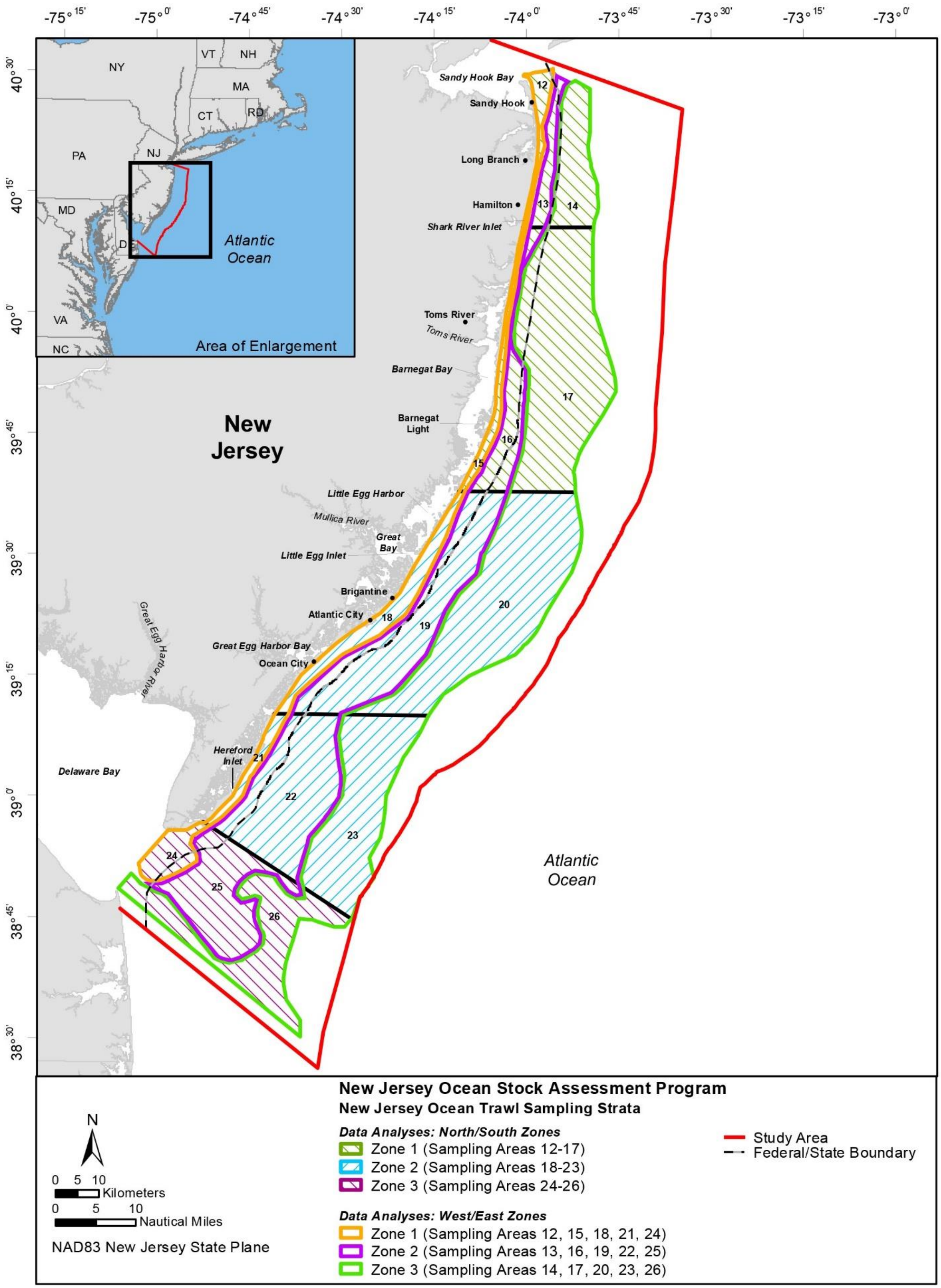

Figure 4.3.1-1. Study Area. New Jersey Offshore Trawl Program.

4.3.2 Data Collection Protocol

Three long-term climatological or oceanic-atmospheric indices were used to examine the variability in the air-sea connection in the North Atlantic Ocean: NAO, AMO, and EOF (*see Chapter 3*). All three climate indices were downloaded from NOAA's Earth System Research Laboratory, Physical Sciences Division (https://www.esrl.noaa.gov/psd/data/climateindices/list/).

Two long-term data sets were examined to evaluate the change in the local (Atlantic City Marina, New Jersey) atmospheric conditions (air temperature and precipitation). Atmospheric climate data for the Atlantic City Marina were collected from the sampling station located in Atlantic County, New Jersey (39.378° North latitude, 74.424° West longitude) at an elevation of 3.05 m (10 feet). Historical statewide (1895−2015) and local (1874−2016) data were downloaded from NOAA's National Centers for Environmental Information, Climate Data Online: Dataset Discovery, and the Office of the New Jersey Climatologist.

4.3.3 Data Treatment/Processing

4.3.3.1 Community Structure

Species richness and diversity were based on counts of individuals for each species in single sample. Applying the abundance-based approach, data were input in EstimateS® and individual species richness, diversity (alpha and beta) estimates were computed by time and space. The four most widely used indices of species diversity (Fisher's alpha, Shannon diversity, exponential Shannon diversity, and Simpson diversity) that combine information on richness and relative abundance were estimated using EstimateS® (Magurran 2004; Jost 2006, 2007). The program applies methods (e.g., extrapolation of species accumulation curves and the application of non-parametric calculations) to overcome inherit bias associated with detecting all species and their relative abundances with a limited number or intensity of samples (Chao et al. 2005). In particular, the non-parametric procedures used are powerful because unseen species are estimated based on the number of rare species observed within the samples (Colwell et al. 2012).

Sample order randomization for these estimators and indices were computed by conducting 100 randomizations (resamples) for rarefaction to evaluate asymptotic richness estimators or diversity indices at all levels of species accumulation (rarefaction). This approach was used to obtain smooth curves for the estimators and indices as a function of the number of samples. Using EstimateS®, rarefaction and extrapolation curves and their unconditional confidence intervals were computed using the formulas of Coldwell et al. (2004), Colwell et al. (2012), and Chao et al. (2013), for which no randomization was required or carried out. For sample-based rarefaction and extrapolation, EstimateS® applied the Bernouilli product model (Colwell et al. 2012). For individual-based rarefaction, computations followed the multinomial model for both rarefaction and extrapolation (Colwell et al. 2012).

The diversity indices estimated were Fisher's alpha (the alpha parameter of a fitted logarithmic series distribution), Shannon diversity (using natural logarithms), exponential Shannon diversity, and Simpson diversity (the "inverse" form). The last two, like species richness itself, were in units of equivalent, equally abundant species. Simple richness is most sensitive to rare species, Simpson diversity least, and Shannon diversity intermediate. These three (when Shannon is its exponential form) represent particular points in a continuum of diversity indices, called Hill numbers, which share the same mathematical form (Jost 2006, 2007). Note that richness was computed analytically, whereas Shannon and Simpson diversities were computed by resampling. The bias-corrected form of the Chao 1 and Chao 2 richness estimators were applied in most cases; however, for some datasets (those with a coefficient of variation of the abundance or incidence distribution > 0.5), the classic uncorrected forms of Chao 1 and Chao 2 were applied.

Also, the ICE (Incidence Coverage-based Estimator) and ACE (Abundance Coverage-based Estimator) estimators were calculated following Chao and Lee (1992) as discussed by Colwell and Coddington (1994). The basic richness estimators (e.g., Chao 1, Chao 2, or jackknife) consider rare species as those with a total abundance of 1 (singletons) or 2 (doubletons) in an abundance-based sample or that occur in only one sampling unit (unique) or in exactly two sampling units (duplicates) in replicated incidence data. In contrast, the ACE estimator uses additional information based on those species with 10 or fewer individuals in the sample and the corresponding ICE estimator is based on species found in 10 or fewer sampling units.

Randomization of sample or individual order without replacement was applied. EstimateS® selects a single sample (for sample-based file types) or a single individual (for individual-based file types) at random, computes the richness estimators and diversity indices based on that sample or individual and then selects a second sample or individual to re-compute the estimators using the pooled data from both samples sample or individuals. It then selects a third, re-computes, and so on until all samples or individuals in the dataset are included in the analysis. Samples or individuals are added to the analysis in random order, without replacement. Each distinct randomization accumulates the samples or individuals in a different order, but all are included in each randomization. The random-order species accumulation curve therefore matches, precisely, the total number of observed species. The drawback with this protocol is that the variance, among randomizations of counts (individuals and singletons) and of estimators for which no analytical variance is provided, goes to zero at the right-hand end of the species accumulation curve. Given the advantages and disadvantages of every species richness estimator, all estimates were reported, including First and Second-order Jackknife, Bootstrap, and Michaelis-Menten richness estimator as defined in Coldwell (2013). In addition to diversity, Hill's evenness indices were calculated. The Hill Evenness Index 4 was calculated by dividing the Simpson Inverse value by the Shannon Exponential index and the Hill Evenness Index 5 was calculated dividing the Simpson Inverse-1value by the Shannon Exponential -1 value (Ludwig and Reynold, 1988).

Beta diversity estimates were derived following Chao et al. (2005). In general, the abundance-based adjusted similarity (Chao) indices were calculated instead of the classical Jaccard and Sorensen indices, which are biased and sensitive to sample size. These classical metrics are based on the presence or absence of species in pair assemblages rather than their association abundance. Also, these metrics are sensitive to the abundance of unseen and uncommon or rare species (Chao et al. 2005). In contrast, the Chao similarity indices adjust for these limitations by compensating for the effects of unseen shared species (Chao et al. 2005); the indices are based on "the probability that two randomly selected individuals, one from each of the two samples both belong to any of the species shared by the two samples." This approach reduces the bias associated with under sampling. The adjusted Chao-Jaccard and Chao-Sorensen indices assess the probability that individuals belong to shared vs unshared species without regard to which species they belong to (Chao et al. 2005), like classic abundance-based indices, such as Morista-Horn or Bray-Curtis. The new methods are more powerful and reliable when samples differ in size, are unknown or suspected to be under sampled, or probably have numerous rare species (Chao et al. 2005).

Sample Independence

It was assumed the environmental, oceanic, and biological measurements (samples) were representative of the population within the study area given that the experimental design used randomization to reduce sampling bias. Statistical power was considered high given the balanced sampling approach and the large number of observations over the duration of the study. It was also assumed the environmental and biological data were independent observations (i.e., the measurement of one observation did not affect the value of other observations) given that the experimental design considered time and space (i.e., spatial autocorrelation). The coastal waters off New Jersey are a dynamic oceanographic and biological system; conditions can vary significantly within a short distance or time period. Moreover, it was assumed the number of marine fauna in one year was independent of the number of marine fauna in the previous year given various biological factors, such as the relative short life-span (< 1 year) of many of the species collected in the study area, high mortality, the low annual reproductive success, and low annual recruitment from one year to the next. To minimize any potential spatial non-independence, data were pooled among stations within each individual area.

Data Preparation

To evaluate the oceanic-atmospheric conditions and indices, long-term historical data were compiled, sorted, and summarized. Before initiating statistical hypothesis tests and if necessary, data were transformed (e.g., logarithmic, square root, fourth root, or arcsine) to meet normativity assumptions. To ensure robustness, normality was also be checked by constructing a normal probability plot and examining the residuals. Outlier observations were investigated to determine whether the outlier occurred by chance; all outliers were retained for these analyses.

The nearshore marine community and oceanic conditions were examined using 28 years (1988−2015) of fishery-independent monitoring data (environmental and biological). Data were compiled, sorted, and summarized. Before initiating statistical hypothesis tests, environmental and biological data were transformed (e.g., logarithmic, square root, fourth root, or arcsine) to meet normativity assumptions, and down-weight the statistical effects (i.e., reduce skewness) of abundant taxa, while allowing less common taxa to contribute to sample discernment (Thorne et al. 1999; Korsman, 2013); this technique helped reduce any potential masking impacts. Annual marine community (species richness, species diversity, and species evenness) data was evaluated using a single dataset (pooling data across all sites) to help discern patterns and test for potential differences among time.

To evaluate the data using multivariate techniques, environmental data were normalized (mean subtracted and divided by standard deviation), checked for collinearity with a draftsman plot, and an Euclidean distance resemblance matrix was produced using PRIMER (Plymouth Routines in Multivariate Ecological Research) version 7 statistical package (Clarke and Warwick, 2001; Clarke and Gorley, 2006). Raw biological abundance and biomass data were also checked via draftsman plots, transformed (4th root), and a Bray-Curtis similarity resemblance matrix was produced via PRIMER. The statistical significance level was defined as $P < 0.05$ for all analyses (Zar, 1999). In the presence of significance at the 95 percent confidence level, *post-hoc* multiple comparison pairwise tests were used to differentiate the specific differences among the population means. Data were evaluated using various software, including Microsoft Access®, Microsoft Excel®, Statgraphics Centurion XVI®, EstimateS®, and PRIMER®.

4.3.4 Statistical Analyses

4.3.4.1 Community Structure

To evaluate the historical trends, the marine community structure (alpha [species richness, species diversity, and species evenness] and beta [Chao-Jaccard and Chao-Sorensen]) was examined using various univariate and multivariate procedures. Descriptive statistics were calculated and examined for each community structure index. Separate one-way ANOVA tests were used to evaluate annual differences in the mean community structure indices over time-series. A LSD multiple range test was used to discriminate among the means. Separate General Linear Models (GLM) were constructed to describe the influence of the climate and atmospheric-oceanic factors (X) on species richness, diversity, evenness index variables (Y). The GLMs were used to construct predictor models of the community structure. Analysis of Variance was applied to test the statistical significance of the model as a whole and the individual predictor variables. The community metrics within the study area (1988−2015) were examined for temporal pattern using regression to categorize the slope of the fitted (mean values) trendline as stable, increasing (positive), or decreasing (negative). The strength of the association (a statistical measure of the goodness of fit of the regression model) was examined using the coefficient of determination (r^2). An ANOVA test was used to examine the statistical significance of the association between the predictor and response values.

One-way Analysis of Similarities (ANOSIMs) were used to conduct pairwise comparisons in the community stability metrics over time. The null hypothesis for ANOSIM was that there were no differences in the community metrics over time. The global R value of this test is a measure of variation between groups compared to variation within groups scaled to take values over a fixed range up to 1; high R values indicating greater dissimilarity. The Spearman rank correlation method was applied to test for an unordered factor with no replicates correlation. The maximum number of permutations was set at 999. The R or rho values for pairwise tests was calculated to determine the pair-wise differences.

4.4 Results

4.4.1 Marine Community Structure

4.4.1.1 Species Richness

A total of 20.7 million fish and invertebrates (1,338.3 mt) representing 216 identified species were collected off the coast of New Jersey within 15 strata (sampling areas: 12−26) during 1988 through 2015. Species richness, diversity (alpha and beta), and evenness indices varied over space and time. Pooling the annual community data by sampling areas and stations, estimated species richness increased substantially during the first few years of sampling as expected, and reached asymptotic richness in about 13 years with only a few unique species added each year after 2000. In general, all of the species richness estimates were somewhat similar over the 28-year period. The Michaelis-Menten richness estimator projected the lowest (247.27) and the Incidence Coverage-based Estimator (mean) projected the highest (256.71) species richness in the study area. As expected, the estimated number of species increased with effort (i.e., stations sampled). Using the sample-based species richness approach, the estimated number of new species added increased sharply and then generally reached the asymptotic level at around 75 or 80 stations sampled per year; 75 or 80 stations sampled represented around 87 percent of the species. The lowest estimated mean number of species collected was in 1994 and the highest was in 2015 (**Figure 4.4.1-1**).

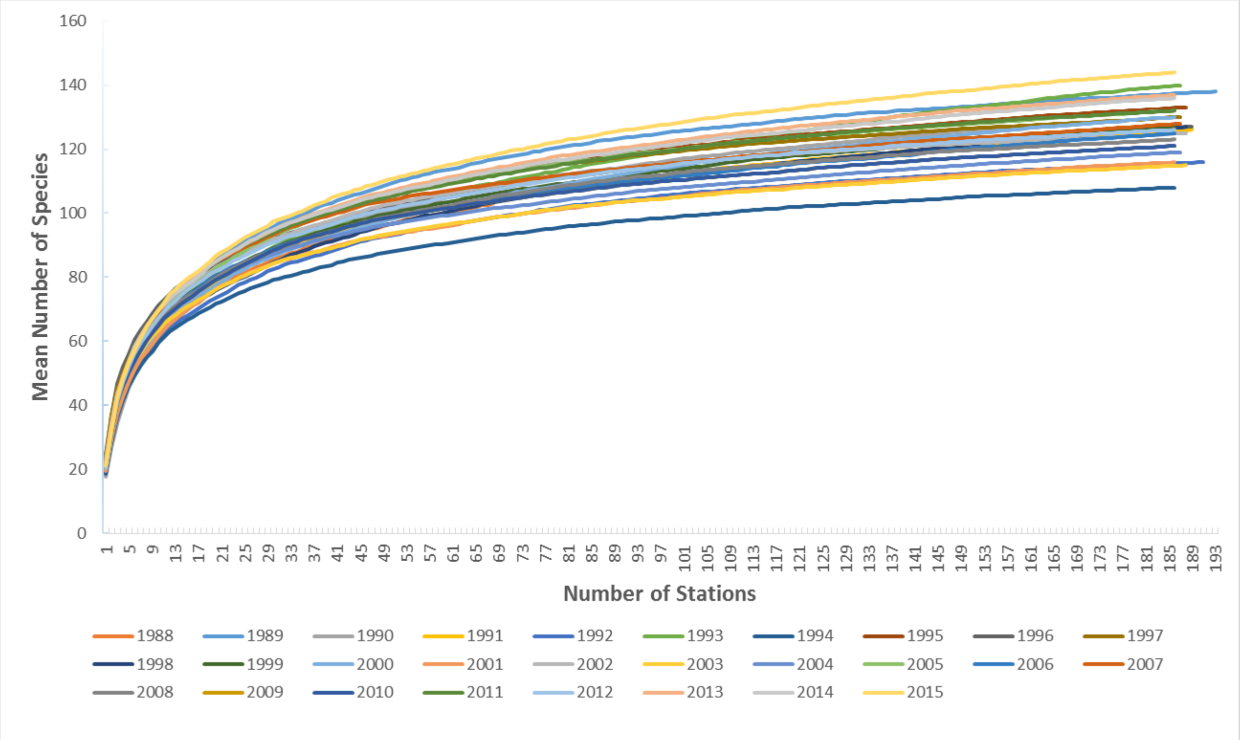

Figure 4.4.1-1. Species richness. The estimated number of species in the study area (1988−2015); annual data pooled by stations. Species richness was based on the sample-based approach.

Annual species richness estimates varied significantly over time (**Table 4.4.1-1**), and estimates varied slightly among analytical methods (**Figure 4.4.1-2**). The lowest mean species richness (*n* = 121.3 species) was estimated using the mean Michaelis-Menten approach and the highest mean species richness (*n* = 156.3 species) was estimated using the mean Jackknife 2 approach. Mean ACE estimated species richness between 118.5 and 163.9 (µ = 139.2 species), whereas mean Chao 1 estimated species richness between 115.5 and 204.5 (µ = 143.2 species). Overall, the lowest estimated species richness estimates were in 1988 and the highest estimated species richness estimates were in 1993. All the species richness trends were somewhat similar over time. Species richness estimates increased from 1988 to 1989, sharply decreased from 1989 to 1992, and then peaked in 1993. Species richness declined sharply in 1994 and then rebounded in 1995. Estimates of species richness trends slightly fluctuated through the late-1990s and mid-2000s, and steadily increased after 2012. The estimated mean number of species (all estimates pooled) in 2015 was around (*n* = 169.55 species), which was 22.2 percent higher than the historical average (*n* = 138.8 species [1988−2014]). Simple linear regression showed there was a weak positive association between most species richness estimates and time. Most of the predicted models did not adequately explain the variability, nor did they show a significant association between the dependent (species richness) and independent (time) variable (**Table 4.4.1-1**).

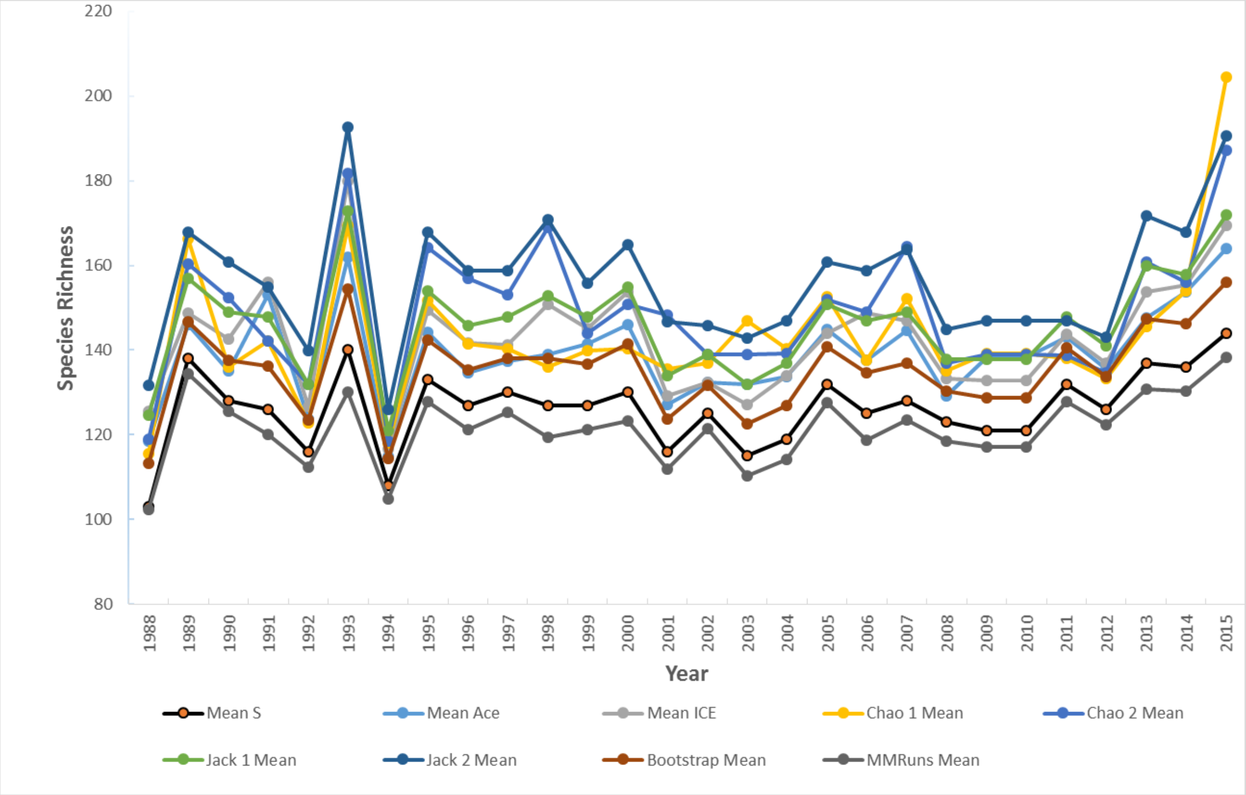

Figure 4.4.1-2. Mean species richness estimates in the study area (1988−2105); annual data pooled by stations and sampling areas.

Table 4.4.1-1. Annual mean species richness estimates. ANOVA and regression summary table. Annual data pooled by stations and sampling areas.

Species Richness	**Hypothesis Test for Interannual Variation**	**Test Results**	**Regression Model**	**Regression Equation**	**F-test**	**R^2**
Mean Sample-based	ANOVA	F [27, 419] = 3.93, P < 0.05	Linear	SB = -274.663 + 0.191796*Year	F [1, 419] = 2.24, P = 0.1350	53.3%
Mean Abundance-based Coverage	ANOVA	F [27, 419] = 5.24, P < 0.05	Linear	ACE = -680.766 + 0.402072*Year	F [1, 419] = 8.63, P = 0.0035	2.00%
Mean Incidence-based Coverage	ANOVA	F [27, 419] = 7.98, P < 0.05	Linear	ICE = 518.01 - 0.194389*Year	F [1, 419] = 1.55, P = 0.2140	36.91%
Mean Chao 1	ANOVA	F [27, 419] = 6.73, P < 0.05	Linear	Chao 1 = -699.506 + 0.412853*Year	F [1, 419] = 9.84, P = 0.0018	22.9%
Mean Chao 2	ANOVA	F [27, 419] = 5.58, P < 0.05	Linear	Chao 2 = 524.286 - 0.197565*Year	F [1, 419] = 1.11, P = 0.2930	26.52%
Mean First-order Jackknife 1	ANOVA	F [27, 419] = 4.70, P < 0.05	Linear	Jack 1 = 71.8815 + 0.0287927*Year	F [1, 419] = 0.03, P = 0.8618	7.23%
Mean First-order Jackknife 2	ANOVA	F [27, 419] = 2.25, P < 0.05	Linear	Jack 2 = 352.338 - 0.109332*Year	F [1, 419] = 0.17, P = 0.6766	4.12%
Mean Bootstrap	ANOVA	F [27, 419] = 4.26, P < 0.05	Linear	Boot = -129.722 + 0.124185*Year	F [1, 419] = 0.74, P = 0.3895	4.24%
Mean Michaelis-Menten	ANOVA	F [27, 419] = 2.32, P < 0.05	Linear	MM = 92.7491 + 0.0134131*Year	F [1, 419] = 0.0, P = 0.9498	0.31%

A one-way ANOSIM also showed the annual species richness estimates (pooled) were significantly different among years (R = 0.148; P = 0.001); however, a low R value (strength) showed separation among samples was minimal with some overlap. *Post-hoc* analysis showed the greatest approximate difference in the Bray-Curtis similarity measures between resemblance groups was primarily between past and more recent years (e.g., 1988, 2015; R = 0.515, P = 0.001, PERM = 999). However, many pairs (past and recent) did not show any difference between resemblance groups (e.g., 2005, 2012; R = -0.047, P = 0.964, PERM = 999; **Table 4.9-1**).

General linear model analyses showed there was a significant relationship between species richness estimators and the set of predictor variables analyzed (oceanographic and climatological) at the 95 percent confidence level (**Table 4.9-2**). Species richness estimators had similar significance values and fit, but the Michaelis-Menten species richness estimator had the best fit with the predictor variables. Only precipitation at the Atlantic City Marina was a significant predictor of species richness in the study area during 1988 through 2015; R^2 values were generally low, and the overall association with predictors was weak (**Table 4.9-3**).

4.4.1.2 Alpha Diversity and Evenness

Annual estimates of alpha diversity and evenness indices varied significantly over time (**Table 4.4.1-2**), and among analytical methods (**Figure 4.4.1-5**, **Figure 4.4.1-6**). Fisher's alpha diversity index alternated between high and low values from 1988 to 1995, and the remained steadier from 1995 to 2001. Fisher's alpha diversity index ranged from 9.04 in 1988 to 15.95 in 1989 with an average of 11.76 (± 1.62 SD). Diversity slightly decreased in the early 2000s and the trend steady increased from 2008 to 2015. The Shannon exponential diversity (Hill 1) and Simpson Inverse (Hill 2) indices had a similar alternating high and low pattern. The Shannon exponential diversity index ranged from 4.38 in 1993 to 12.49 in 2005 with an average of 8.39 (±

2.11). The Simpson Inverse diversity index ranged from 2.06 in 1993 to 6.53 in 2005 with an average of 4.27 (±1.2). In general, the diversity index trends decreased from 1988 to 1990, and increased gradually from 1995 to 2001. In 2002, most diversity indices sharply decreased and then increased significantly in 2003. The diversity indices steadily decreased from 2003 to 2013. In 2014 and 2014, the diversity indices increased to the earlier 2007 estimated diversity values. The Shannon diversity index ranged from 1.15 in 1992 to 2.52 in 2005 with an average of 2.08 (± 0.30). The Shannon diversity index slightly increased and decreased from 1988 to 1991, and remained steady throughout mid 1990s and 2000s. Similar to the other diversity indices, the Shannon diversity index declined in 2002. The species evenness index trends showed a similar alternating high and low pattern from 1988 to 2001. In 1993, 1995, and 2002 the species evenness indices decreased notably. In general, the species evenness indices steadily declined from 2006 to 2013, and increased in 2014 and 2015.

Separate regression procedures showed weak associations between species diversity/evenness indices and time. None of the predicted models adequately explained much of the variability. Hill evenness index 5 was there only metric where there was no significant association between the dependent and independent (time) variable (**Table 4.4.1-2**).

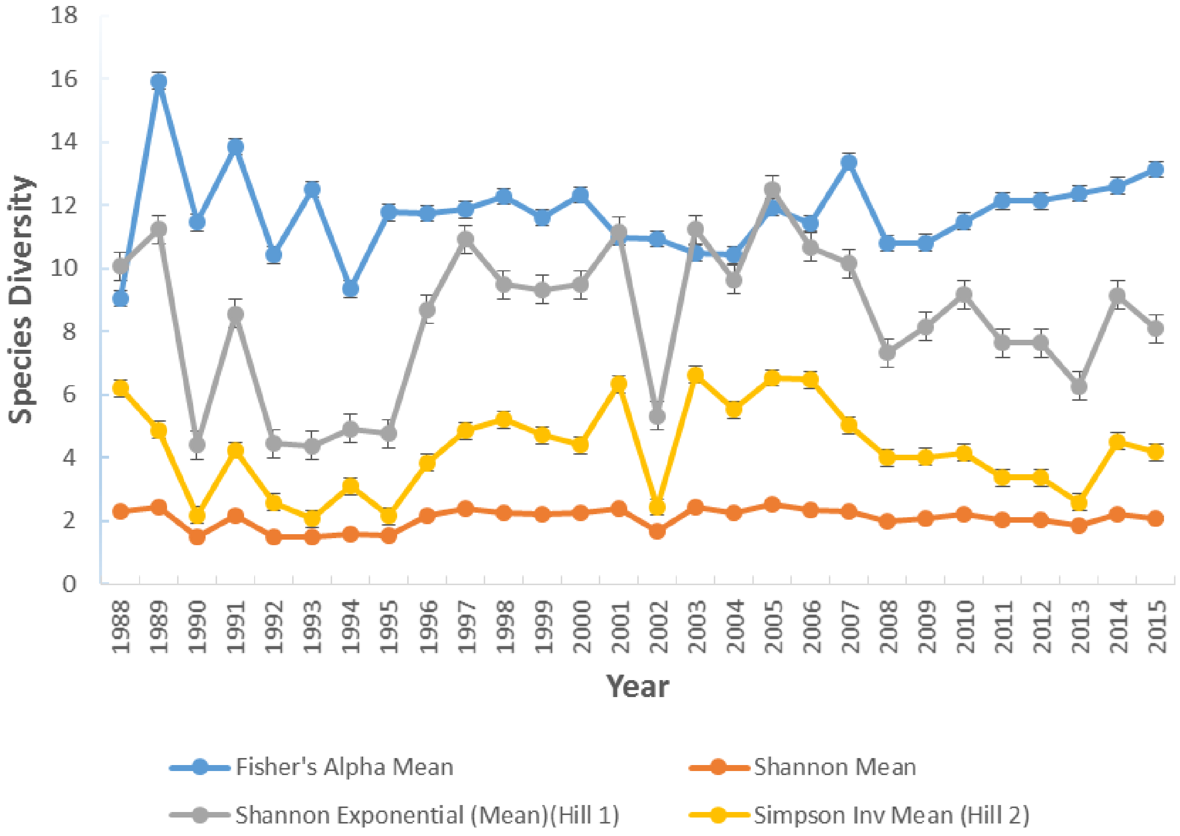

Figure 4.4.1-5. Alpha diversity index estimates in the study area (1988−2105) and associated error bars; annual data pooled by stations and sampling areas.

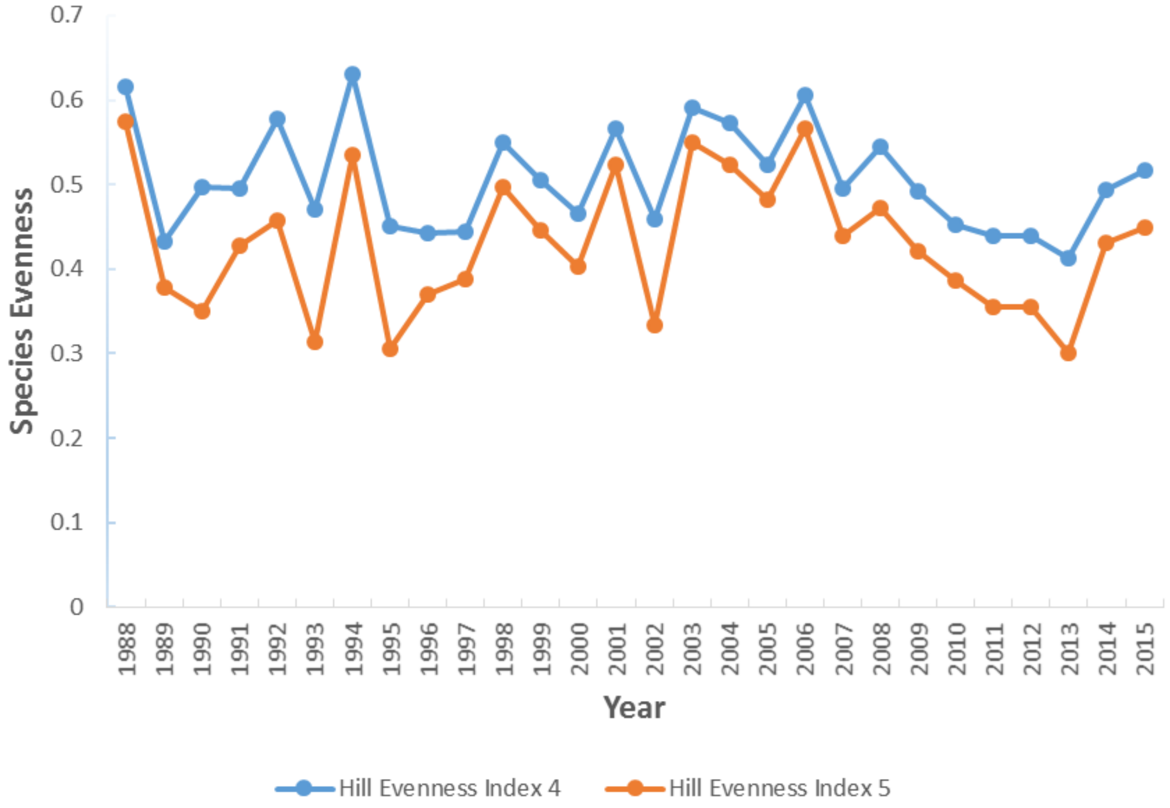

Figure 4.4.1-6. Species evenness index estimates in the study area (1988−2105); annual data pooled by stations and sampling areas.

Table 4.4.1-2. Community alpha diversity and evenness indices. ANOVA and regression summary table.

Species Richness	**Hypothesis Test for Interannual Variation**	**Test Results**	**Regression Model**	**Regression Equation**	**F-test**	**R^2**
Mean Fisher’s Alpha	ANOVA	F [27, 419] = 10.78, $P < 0.05$	Linear	FA = -46.6935 + 0.0286271*Year	F [1, 419] = 8.75, $P = 0.0033$	2.05%
Mean Shannon	ANOVA	F [27, 419] = 100.60, $P < 0.05$	Linear	Shannon = -19.4207 + 0.0107092*Year	F [1, 419] = 36.72, $P < 0.05$	8.11%
Mean Exponential Shannon	ANOVA	F [27, 419] = 102.97, $P < 0.05$	Linear	ES = -109.824 + 0.0588829*Year	F [1, 419] = 22.36, $P < 0.05$	5.11%
Mean Simpson Inverse	ANOVA	F [27, 419] = 111.67, $P < 0.05$	Linear	SI = -50.7226 + 0.0274745*Year	F [1, 419] = 14.76, $P = 0.0001$	3.42%
Mean Hill’s Evenness 4	ANOVA	F [27, 419] = 38.17, $P < 0.05$	Linear	Hill 4 = 2.45647 - 0.00096138*Year	F [1, 419] = 7.68, $P = 0.0058$	0.17%
Mean Hill’s Evenness 5	ANOVA	F [27, 419] = 45.71, $P < 0.05$	Linear	Hill 5 = 0.201834 + 0.000127794*Year	F [1, 419] = 0.09, $P = 0.7678$	0.02%

Table 4.4.1-3. Summary of community alpha diversity and evenness indices.

Year	**Fisher's Alpha**	**Shannon (H)**	**Shannon Exponential (H_1)**	**Simpson Inverse (H_2)**	**Simpson Index**	**Simpson Index of Diversity**	**Hill Evenness Index (H_4)**	**Hill Evenness Index (H_5)**
1988	9.04	2.31	10.06	6.2	0.161290323	0.838709677	0.616302187	0.573951435
1989	15.95	2.42	11.25	4.87	0.205338809	0.794661191	0.432888889	0.377560976
1990	11.46	1.48	4.4	2.19	0.456621005	0.543378995	0.497727273	0.35
1991	13.85	2.15	8.57	4.24	0.235849057	0.764150943	0.494749125	0.428005284
1992	10.43	1.5	4.46	2.58	0.387596899	0.612403101	0.578475336	0.456647399
1993	12.51	1.48	4.38	2.06	0.485436893	0.514563107	0.470319635	0.313609467
1994	9.35	1.59	4.92	3.1	0.322580645	0.677419355	0.630081301	0.535714286
1995	11.77	1.56	4.77	2.15	0.465116279	0.534883721	0.450733753	0.305039788
1996	11.75	2.16	8.69	3.85	0.25974026	0.74025974	0.443037975	0.370611183
1997	11.86	2.39	10.93	4.85	0.206185567	0.793814433	0.443732845	0.387713998
1998	12.29	2.25	9.48	5.21	0.19193858	0.80806142	0.549578059	0.496462264
1999	11.61	2.23	9.33	4.71	0.212314225	0.787685775	0.504823151	0.445378151
2000	12.32	2.25	9.48	4.41	0.22675737	0.77324263	0.465189873	0.402122642

Year	**Fisher's Alpha**	**Shannon (H)**	**Shannon Exponential (H_1)**	**Simpson Inverse (H_2)**	**Simpson Index**	**Simpson Index of Diversity**	**Hill Evenness Index (H_4)**	**Hill Evenness Index (H_5)**
2001	10.98	2.41	11.17	6.33	0.157977883	0.842022117	0.566696509	0.524090462
2002	10.94	1.67	5.32	2.44	0.409836066	0.590163934	0.458646617	0.333333333
2003	10.49	2.42	11.25	6.64	0.15060241	0.84939759	0.590222222	0.550243902
2004	10.43	2.27	9.65	5.52	0.18115942	0.81884058	0.572020725	0.522543353
2005	11.94	2.52	12.49	6.53	0.153139357	0.846860643	0.522818255	0.481288077
2006	11.43	2.37	10.67	6.47	0.154559505	0.845440495	0.606373008	0.565667011
2007	13.38	2.32	10.17	5.03	0.198807157	0.801192843	0.494591937	0.439476554
2008	10.81	1.99	7.33	3.99	0.250626566	0.749373434	0.544338336	0.47235387
2009	10.82	2.1	8.16	4.02	0.248756219	0.751243781	0.492647059	0.421787709
2010	11.49	2.22	9.18	4.16	0.240384615	0.759615385	0.453159041	0.386308068
2011	12.13	2.03	7.65	3.36	0.297619048	0.702380952	0.439215686	0.354887218
2012	12.13	2.03	7.65	3.36	0.297619048	0.702380952	0.439215686	0.354887218
2013	12.38	1.84	6.28	2.59	0.386100386	0.613899614	0.412420382	0.301136364
2014	12.62	2.22	9.16	4.52	0.221238938	0.778761062	0.493449782	0.431372549
2015	13.15	2.09	8.09	4.18	0.23923445	0.76076555	0.516687268	0.448519041
Mean	**11.76**	**2.08**	**8.39**	**4.27**	**0.264**	**0.735**	**0.506**	**0.429**

A one-way ANOSIM showed the annual species diversity estimates (pooled) were significantly different (moderately) among years ($R = 0.412$; $P = 0.001$). *Post-hoc* analysis showed many pairs were significantly different (**Table 4.9-4**). A one-way ANOSIM also showed the annual species evenness estimates (pooled) were significantly different (moderately) among years ($R = 0.585$; $P = 0.001$). *Post-hoc* analysis showed many pairs were significantly different (**Table 4.9-5**).

General linear model analyses showed there was a significant relationship between species diversity estimators and the predictor variables (oceanographic and climatological) at the 95 percent confidence level, and a non-significant relationship between species evenness estimators and the predictor variables at the 95 percent confidence level (**Table 4.9-6**). In general, species richness estimators had similar significance values, but the Shannon exponential species diversity estimator had the best fit with the predictor variables (**Table 4.9-7**). Overall, precipitation at the Atlantic City Marina was usually the best predictor of species diversity estimators and the factor had a negative association. The NAO index was also a significant, positive predictor of the Shannon, Shannon Exponential, and Simpson Inverse indices. Even though the associations were statistically significant, the strength of the association was weak given the low correlation coefficients.

4.4.1.3 Beta Diversity

Annual estimates of beta diversity indices varied significantly over time (**Figures 4.4.1-6-7, Table 4.4.1-4**). The Chao-Jaccard abundance-based similarity index ranged from 0.33442 in 2004 to 0.513015 in 2006 with an average of 0.41061 (± 0.3525 SD). The Chao-Jaccard similarity index alternated between high and low values. The index steadily increased from 1989 to 1998, sharply decreased from 1998 to 2001, and increased from 2001 to 2009. The index steadily increased from 2011 to 2015. The Chao-Sorensen similarity index had a similar alternating high and low pattern. The Chao-Sorensen similarity index ranged from 0.40882 in 2004 to 0.60331 in 2006 with an average of 0.49352 (± 0.3579). Separate regression procedures showed there was no association between beta diversity indices and time.

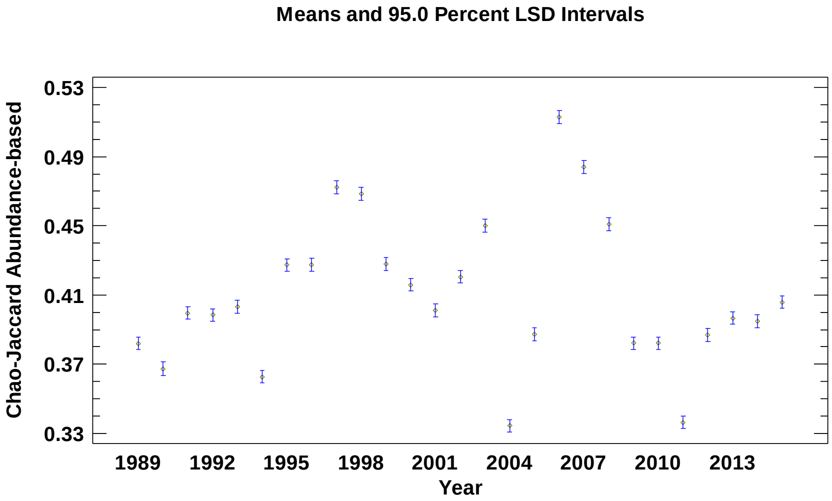

Figure 4.4.1-6. The Chao-Jaccard abundance-based similarity index estimates and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year; annual data pooled by stations and sampling areas.

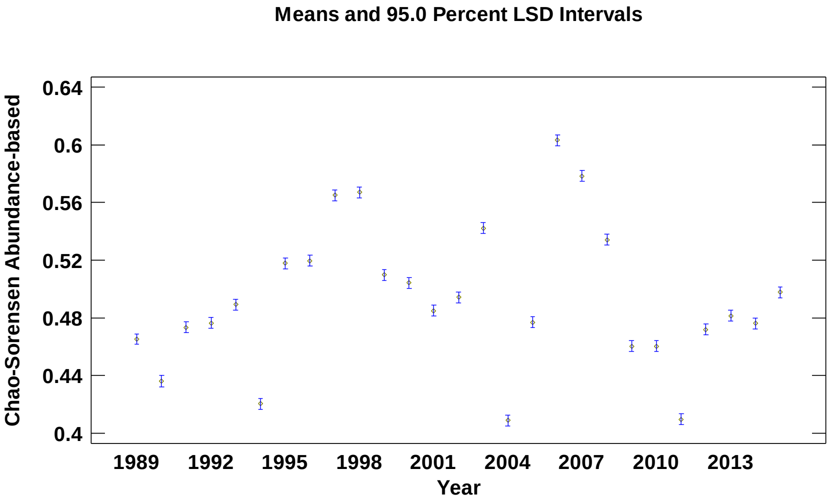

Figure 4.4.1-7. The Chao-Sorensen abundance-based similarity index estimates and associated 95% Fisher's least significant difference (LSD) intervals in the study area (1988−2015). The LSD interval was calculated from approximately 182 samples per year; annual data pooled by stations and sampling areas.

Table 4.4.1-4. Community beta diversity indices. ANOVA and regression summary table.

Similarity Index	**Hypothesis Test**	**Test Results**	**Regression Model**	**Regression Equation**	**F-test**	**R^2**
Chao-Jaccard	ANOVA	F [26, 467485] = 254.56, $P < 0.05$	Linear	Chao-Jaccard = 0.565055 - 0.0000772827* Year	F [1, 26] = 0.01, P = 0.9431	0%
Chao-Sorensen	ANOVA	F [26, 467485] = 333.11, $P < 0.05$	Linear	Chao-Sorensen = 0.236772 + 0.000128246* Year	F [1, 26] = 0.01, P = 0.9187	0%

4.5 Discussion

The nearshore marine community off New Jersey has remarkable resilience, resistance, and stability. Marine communities are directly connected to the abiotic conditions because they influence and control various biological and metabolic functions. As such, changes in the oceanographic conditions can cause community structure alterations (Aschan et al. 2013) and a poor ecological health. As previously shown in Chapters 2 and 3, the environmental conditions are changing in the study area over time. Species richness and diversity (alpha and beta) significantly changed over time in the study area, but overall, community stability appears to be steady despite the ongoing changes in the environmental conditions over the past 28 years.

All four hypotheses were confirmed and accepted **(Table 4.5.1**). In general, the community structure slightly transformed over time; however, the changes were minimal in terms of the statistical significance. Also, the environmental impacts do not seem to have caused any major long-term changes in any of the community metrics suggesting the community is currently resilient to long-term disturbance from climate variability or other stressors in terms of species richness, diversity, evenness, and similarity.

Table 4.5.1. Summary of the confirmation and rejection of the specific null and alternative hypotheses.

Null Hypothesis	**Accepted**	**Rejected**
The species richness changed significantly with time (1988−2015).	**X**	
The species diversity changed significantly with time (1988−2015).	**X**	
The species evenness changed significantly with time (1988−2015).	**X**	
The species similarity changed significantly with time (1988−2015).	**X**	

4.5.1 Species Richness

The nearshore waters off New Jersey support numerous species and the marine community is relatively stable in terms of species richness over time. The data suggest the New Jersey coastal waters are a transitional zone between the more diverse southern and less diverse northern east coast waters of the United States. In total, 20.7 million fish and invertebrates (1,338.3 mt) representing 248 species were collected off the coast of New Jersey within 15 strata (areas: 12−26) over a 28-year period. The total number of species collected is much higher than previously reported by other researchers (Szedlmayer and Able; 1996; Hagan and Able, 2001; Martino and Able, 2002; Able et al. 2009; Able et al. 2011), but the species composition and associated abundance proportions is comprised of a few abundant species, which agrees with previous published work (Colvocoresses and Musick, 1984; Wood et al. 2009; Howell and Auster, 2012). Despite the differences in sampling gear, sampling areas, and other factors, it is likely the main difference in species richness between the present study and others was associated with the much larger sample size, study duration, and the environmental conditions (warmer water temperature) in the study area.

Of the total marine fauna collected, 98 represented warmwater-adapted, 63 coldwater-adapted, and 53 subtropic-adapted species. Similar proportions among water temperature preference groups were reported in Long Island Sound, New York (Howell and Auster, 2012). Howell and Auster (2012) collected 95 fish species consisting of warmwater-adapted (*n* = 34), coldwater-adapted (*n* = 33), and subtropic-adapted (*n* = 28) finfish over a 25-year time-series (1984−2008). Similarly, 44 warmwater-adapted finfish were sampled in Narragansett Bay and Long Island Sound over a 14-year time-series (Wood et al. 2009). Although the sampling effort in these two studies was more than previous studies in the region, and relatively similar to the sampling effort in this present study, species richness was much lower than those demonstrated by the present study for the nearshore waters off New Jersey. In some ways, the higher number of species collected off New Jersey is related to the warmer annual and seasonal waters and ongoing rising water temperature, which allows more warmwater-adapted and subtropic-adapted species to migrate to the area.

The annual species richness estimates varied significantly between a few years, but it generally was relatively stable over time, and there was no positive or negative association between species richness and time. The lowest mean species richness (*n* = 121.3 species) was estimated using the mean Michaelis-Menten approach and the highest mean species richness (*n* = 156.3 species) was estimated using the mean Jackknife 2 approach. These species richness estimates are considerably higher than previously reported for the region (Wood et al. 2009; Howell and Auster, 2012). In Narragansett Bay and Long Island Sound, species richness estimates under the Jackknife 1 approach were 33.9 and 39.2 species, respectively (Wood et al. 2009). Pooling the annual community data by sampling areas and stations, estimated species richness increased substantially during the first few years of sampling as expected, and reached asymptotic richness in about 13 years with only a few unique species added each year after 2000. In Narragansett Bay and Long Island Sound, individual species accumulation curves plateaued in about seven years. The slightly longer time to collect the majority of the species is not surprising since the waters off New Jersey are more diverse in terms of the number of species and associated abundances.

A recent positive trend (2012−2015) suggest there are more species utilizing the study area. It is difficult to explain, but the positive trend could be related to new species or previous documented species returning to the study area; it is highly more probable new previously unreported warmwater-adapted species are slowly invading the study area as the water temperature continues to rise. Warmwater-adapted species are slowly shifting their distribution north throughout the MAB (Wood et al. 2009; Howell and Auster, 2012). Despite the stability in the species richness estimates over time, the estimated species richness is somewhat variable from one year to next (± 10-20 species) and highly sensitive to stressors given the significant decline in 1994. Examining the environmental conditions (1988−1997) indicates water temperature (surface and bottom) declined from 1990 to 1994, and it was significantly colder in 1994 than in 1995, which could explain the increase in estimated species richness in 1995. However, this does not explain why the estimated species richness peaked in 1993 given the water temperature was lower. It is possible the increase in species richness may have been related to the marginal increase (+ 1.3 psu) in salinity in 1992 and 1993. It is also conceivable the mean salinity in 1993 (30.45 psu) was the optimal salinity level for various species. In general, GLM procedures showed precipitation was the best predictors of species richness, which could explain the historical increase in salinity in the study area given the inverse association between precipitation and salinity. However, it is possible the trend in species richness could be related to other factors, such as interspecific or intraspecific associations (e.g., prey availability).

Given the substantial sample size and relatively balanced sampling effort over space and time, it is highly plausible that the ACE species richness (μ = 139.2 species) approach is a conservative estimator of species richness in this present study. Species richness estimates varied slightly among analytical methods, despite generally showing the same trend over time. The lowest (Michaelis-Menten) and highest (Jackknife 2) species richness estimators differed by around 35 species, so it is highly probable the realistic species richness method is around the middle range, such as the values (118.5−163.9 species [1988−2015]) estimated under the ACE estimator approach, which considers rare and uncommon species. The non-parametric ACE estimator was specifically developed to estimate species richness in a community that has many species with an abundance between one and 10 individuals, such as the MAB study area (Magurran, 2004). Because the proportion of dominant species, and an uneven species distribution (10 species; 85.5% of the catch), it is likely the ACE estimator is the best approach for estimating species richness in the study area. Depending on the limitation of the study, some analytical approaches estimate species richness better than others (Hortal et al. 2006). For instance, the non-parametric ACE and Chao 1 procedures show a high precision with negligible standard deviations, and the estimated values are biologically reasonable under intense sampling, but become less reliable under lower sampling scenarios (Hortal et al. 2006).

4.5.2 Alpha Diversity

Annual diversity and evenness estimates also changed significantly over time in the study area, and varied among analytical methods. Individual species diversity and evenness index estimates were slightly different, but this was expected since each index differs in their foundation, calculation, and interpretation (Magurran, 2004). Most diversity and evenness indices are based on relative abundance (Heip et al. 1998), alpha estimates vary in their foundation of including or excluding uncommon and rare species (Ludwig and Renolds, 1988). Despite the fluctuation in the indices between years, species diversity and evenness estimates were somewhat stable over time, and there was no association between species diversity or species evenness, and time.

The nearshore community consists of a small number of abundant species and a large proportion of 'rare' species (the class containing one individual is always the largest) predicted by the log series model where one or a few factors dominate the ecology of a community. The mean Fisher's alpha diversity index estimate was 11.76 (± 1.62 SD), which is a relatively low value, but the value is probably valid and reasonable because the index assumes the abundance of species follows a logarithmic series distribution (Beck and Schwanghart, 2010). Based on the mean estimated Fisher's alpha index value, 11 or 12 species dominate the marine community in the study area. Examining the catch showed 12 species represented 88.6 percent of the total catch in the study area during 1988 through 2015. Based on species richness and associated abundance, only a few species are abundant and most are rare in the study area indicating a logarithmic (i.e., less right-skewed) rather than a log-normal abundance distribution (i.e., more right-skewed). Given the number of new species collected, or more importantly the number of individuals uncommon species collected have not increased over the past 10 to 15 years, Fisher's alpha diversity index seems to be a reliable estimate of diversity in the study area. Fisher's alpha diversity index does have its limitations depending on various factors. The procedure becomes less reliable (positively bias) at measuring diversity of a completely inventoried community (Beck and Schwanghart, 2010). Also, the procedure can underestimate the number of species when species display a clumped or uneven distribution, but the approach is highly reliable at estimating diversity when under sampling is suspect (Beck and Schwanghart, 2010).

Although field-sampling was rigorous throughout the study area, it is possible that some species were missed by the sampling gear given it primarily targets demersal species. Another potential issue is the area sampled by the sampling gear is limited in area; the assumption is that every species has the same probability of being captured, which is not the case given most species display a patchy or uneven distribution. Also, the sampling gear's mesh-size is an inherit bias toward a particular size individual. Depending on space, time, and biological processes (growth), the mean size among species in a given area will be different, so some species will be missed by the sampling gear. Given these reasons, it is possible the study area was under-sampled in terms of a complete species richness and diversity inventory. If this is the case, than Fisher's alpha diversity index is perhaps a good estimate of the species diversity in the study area.

The mean Shannon-Wiener diversity index (i.e., intermediate sensitivity to rare species) estimate was 2.01, which is a value within the range (1.5−3.5) for many community studies around the world (e.g., Hossain et al. 2012), and a value suggesting the species distribution is clumped or random in the study area. The Shannon-Wiener diversity index estimate suggests only a few species are abundant, and most are represented by a few individuals. The Shannon-Wiener index (H') is a popular index for estimating diversity because $H' = 0$, if and only if there is one species in the sample and H' is maximum only when all species have an even abundance distribution (Ludwig and Reynolds, 1988). The index is sometimes bias because the number of species in the community is often greater than estimated; however, the bias diminishes as the number of species increases in the community (Ludwig and Reynolds, 1988). The index is equally sensitive to rare and abundant species; thus, it is somewhat of a conservative measurement of diversity (Morris et al. 2014). The calculation is sensitive to rare species as *a* (power in in the generalized entropy formula) decreases from 1, and sensitivity to abundant species increases as *a* increases from 1 (Morris et al. 2014).

In general, all the estimated diversity indices varied more than the Shannon diversity index, which only fluctuated minimally over time. The diversity (Shannon, Shannon exponential, and Simpson inverse) indices declined in 2002 and then rebounded in 2003. Fisher's Alpha diversity index generally increased from 2004 to 2015, and Shannon exponential and Simpson inverse diversity indices decreased from 2003 to 2015 suggesting the number of species dominating (abundance) the community is increasing in recent time. Examining the environmental conditions indicated the water temperature (surface and bottom) and salinity were elevated in 2002, but DO (surface and bottom) levels were relatively low during 1998 through 2002. Also, the surface DO level in 2002 was significantly lower than previous years, including 2001. The bottom DO level in 2002 was significantly different than 1998, but it was similar to the average in 2001. The DO readings in 2003 showed that both surface (+ 0.288) and bottom (+ 0.773) DO levels increased from 2002 levels. The decrease in DO levels in 2002 followed by an increase in 2003 could explain the significant fluctuation in species diversity during those two years. The GLMs demonstrated there were several weak predictors of species diversity. Overall, precipitation at the Atlantic City Marina was the best predictor of Fisher's Alpha diversity index, and the NAO and precipitation at the Atlantic City Marina were weak predictors of the Shannon, Shannon Exponential, and Simpson inverse diversity indices.

Dominance and evenness are important ecological concepts in defining community structure; these metrics are weighted by the abundance of the most common species (Magurran, 2004). Hill's 1 (Shannon exponential index) and Hill's 2 (Simpson inverse index) indices represent the number of effective species in the community where each species is weighed by its abundance (Ludwig and Reynolds, 1988). Hill’s 1 (Shannon exponential index) estimate was 8.39 (± 2.11). The index estimates the number of abundant species; sensitivity to rare species and decreases with increasing *a*. The nearshore marine community off New Jersey is comprised of about eight equally-common species. Examining the number of species collected in the study area and their associated abundance estimates, eight species represented 84.4 percent of the total catch, which confirms Hill’s 1 index is likely a good estimator of dominance in the study area.

Hill’s 2 (Simpson inverse or reciprocal) dominance diversity index (least sensitive to rare species and most sensitive to abundant species) was 4.27 (± 1.2) indicating the number of very abundant species is low in the study area. The value represents the number of equally common species that will produce the observed Simpson’s index (i.e., the probability that two randomly selected individuals belong to the same species). Examining the number of species collected in the study area and their associated abundance estimates, four species represented 75.7 percent of the total catch, which again confirms Hill’s 2 index is good estimator of dominance. The corresponding mean probability that two randomly selected individuals belonged to the same species (Simpson index of diversity) was 0.735.

Hill’s evenness index (i.e., how similar species are in their abundance) values are maximum when all species are equally abundant and minimum (i.e., decrease toward zero) when species have an uneven abundance (Ludwig and Reynolds, 1988). Given the value represents the ratio between very abundant and abundant species, Hill’s evenness index 4 converges toward the value of one when one species tends to dominate. In contrast, Hills’s evenness index 5 converges toward the value of zero when one species tends to dominate (Ludwig and Reynolds, 1988). Hill’s evenness indices are not affected by species richness like other estimates of evennness, which makes this index robut. Hill's mean evenness index 4 for the study area was 0.506, and the Hill's evenness index 5 was 0.429, which supported the notion that the distribution of species is low and skewed toward a few dominate species. The evenness indices showed a significant decline in 2002, rebounded in 2003, and steadily declined from 2004 to 2013; species evenness increased from 2013 to 2015. The 10-year declining trend suggest that dominance increased for a few species, which could indicate the community was under stress during that period, but it is now improving (i.e., evennness increased 2013−2015). Although environmental variables often shape diversity, dominance, and evenness (e.g., Mutshinda et al. 2009; Hossain et al. 2012), GLMs did not detect any predictors of species evenness suggesting other factors besides the environmental conditions could influence and control species evenness, such as predator-prey associations.

4.5.3 Beta Diversity

The mean Chao-Jaccard and Chao-Sorensen similarity indices were 0.411 and 0.494, respectively. These values indicate that almost 50 percent of the species are shared among samples. Beta diversity among stations within all areas is not 1.0 (complete similarity), which indicates there is some diversity among stations within the 15 individual sampling areas. Beta diversity did vary significantly over time, and displayed an increasing and decreasing trend about every 10 years. However, multiple range tests showed that many of the differences in the homogenous pairs were either a few or many years apart, which suggest the pattern observed was relatively consistent over time. The similarity or turnover of species appears to be relatively stable over time in the study area; the average adjusted similarity index values in 1989 were similar to those in 2015. Interestingly, the lowest similarity value was in 2004 and the highest in 2006; two years later. Re-examining the environmental conditions indicated that bottom water temperature increased and bottom salinity and DO decreased from 2004 to 2006. Assuming similarity is connected to the environmental conditions than the highest dissimilarity was associated with lowest water temperature and highest salinity and DO levels, which was not the case. Although there were significant differences in the environmental conditions during 2004 through 2006, the measurements were not the lowest water temperature and highest salinity and DO levels during the 28-year period. This observation suggests that species similarity is more associated with species niches and other ecological processes than the environmental conditions in the study area. It is possible interspecies competition could explain the low similarity values in 2004.

4.6 Conclusion

Rather than striving to maintain some level of diversity, it is better to understand the basic ecological processes that control populations, communities, and ecosystems so the risk of stresses that cause the most serious alterations to the system can be potentially reduced and avoided (Suchanek, 1994). To understand the impacts of disturbance and stress, it is essential to first describe the community structure in terms of species richness, diversity, evennness, and similarity (Ludwig and Reynolds, 1988; Marurran, 2004; Morris et al. 2014). These metrics can be calculated in a variety of ways with each having a number of trade-offs in performance. Choosing the best-performing metric depends on numerous sampling factors, but it is also important to consider whether the value makes sense biologically in terms of the data and the study area.

The nearshore marine community in the MAB is characterized as one dominated by only a few species with high dominance. The number of species (richness) is relatively high for a temperate marine region, but species diversity and evennness is low. Despite having a low species diversity and evenness values, it appears the community is relatively stable despite ongoing climatological changes. Species similarity within the study area is about average and the trend in similarity shows that it increases and decreases every 10 years. Despite this pattern, overall it appears it is consistent, stable, and somewhat predictable. Species richness, diversity, and evenness measurements do not consider functional diversity because the traditional approaches consider all species equal, which is generally not the case given the role each species plays in a community and the complexity of ecosystem processes (Marurran, 2004).

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4.8 References

Aschan M, Fossheim M, Greenacre M, Primicerio R. 2013. Change in Fish Community Structure in the Barents Sea. PLoS ONE 8(4): e62748. doi:10.1371/journal.pone.0062748.

Auber, A., Travers-Trolet, M., Villanueva, M.C., and Ernande, B. 2015. Regime Shift in an Exploited Fish Community Related to Natural Climate Oscillations. PLoS ONE 10(7): e0129883. doi:10.1371/journal. pone.0129883.

Azzurro, E., Moshella, P., and Maynou, F. 2011. Tracking Signals of Change in Mediterranean Fish Diversity Based on Local Ecological Knowledge. PLoS ONE 6(9): e24885. doi:10.1371/journal.pone.0024885.

Beaugrand, G., Brander, K.M., Lindley, J.A., Souissi, S., and Reid, P.C. 2003. Plankton effect on cod recruitment in the North Sea. Nature 426: 661–664.

Barange M., Bernal M., Cercole, M.C., Cubillos, L., De Moor, C.L., Daskalov, G.M., de Oliveira, J.A.A., Dickey-Collas, M., Gaughan, D.J., Hill, K., *et al*. 2009. Current trends in the assessment and management of stocks. In Climate Change and Small Pelagic Fish Stocks, Checkley D, Roy C, Oozeki Y, Alheit J (eds). Cambridge University Press: Cambridge; 191–255.

Barange, M., and Perry, R.I. 2009. Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. 7–106.

Beck, J., and Schwanghar, W. 2010. Comparing measures of species diversity from incomplete inventories: an update. Methods in Ecology and Evolution 1: 38−44.

Begon, M., Harper, J.L., and Townsend, C.R. 1986. Ecology: individuals, populations and communities. Blackwell Scientific Publications, Oxford. 876 pp.

Bondavalli, C., Bodini, A., Rossetti, G., and Allesina, S., 2006. Detecting stress at a whole ecosystem level. The case of a mountain lake: Lake Santo (Italy). Ecosystems 9: 1–56.

Borges, M.F., Hill, L., Mendes, H., Santos, M.A., and Salgado, M. 2004. Regime shift effects on fish community metrics measured in the West Portugal upwelling area. ICES C.M. 2004/M: 11.

Bostrom, P. 2014. NAO Index: An Extreme Pressure Approach. Department of Earth Sciences, Geotryckeriet Uppsala University, Uppsala. 3 ISSN 1650-6553 Nr 28. 35 pp.

Brander, K. 2010. Impacts of climate change on fisheries. Journal of Marine Systems 79: 389–402.

Brander, K. 2013. Climate and current anthropogenic impacts on fisheries. Climatic Change 119: 9-21. doi. 10.1007/s10584-012-0541-2.

Briggs, J. C. 1974. Marine zoogeography. McGraw-Hill Book. 475 pp.

Byrne, D. 1994. Stock assessment of New Jersey's nearshore recreational fisheries resources. In Proceedings of the workshop on the collection and use of trawl survey data for fisheries management, ed. T. Berger, 36–42. Washington: Atlantic States Marine Fisheries Commission.

Castillo-Jordán, C., Cubillos, LA., and Navarrod, E. 2010. Inter-cohort growth rate changes of common sardine (*Strangomera bentincki*) and their relationship with environmental conditions off central southern Chile. Fisheries Research 105: 228-236.

Chao, A., Gotelli, N.J., Hsieh, T.C., Sander, E.L., Ma, K.H., Colwell, R.K., and Ellison, A.M. 2013, online early. Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. Ecological Monographs.

Chao, A., Chazdon, R.L., Colwell, R.K., and Shen, T.J. 2005. A new statistical approach for assessing similarity of species composition with incidence and abundance data. Ecological Letters 8: 148−159.

Chao, A., and Lee, S.M. 1992. Estimating the number of classes via sample coverage. Journal of the American Statistical Association 87: 210-217.

Clarke, K.R., and Warwick, R.M. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2nd edition. PRIMER-E. Plymouth U.K.

Clarke, K.R., and Gorley, R.N. 2006. PRIMER V6: User Manual/ Tutorial. PRIMER-E, Plymouth, UK. Co., New York, NY.

Colwell, R.K., Chao, A., Gotelli, N.J., Lin, S.Y., Mao, C.X., Chazdon, R.L., and Longino, J.T. 2012. Models and estimators linking individual-based and sample-based rarefaction, extrapolation, and comparison of assemblages. Journal of Plant Ecology 5: 3−21.

Colwell, R.K. 2013. EstimateS: Statistical estimation of species richness and shared species from samples. Version 9. User's Guide and application published at: http://purl.oclc.org/estimates.

Colwell, R.K. and Elsensohn, J.E. 2014. EstimateS turns 20: statistical estimation of species richness and shared species from samples, with non-parametric extrapolation. Ecography 37: 609−613.

Colwell, R. K., and Coddington, J.A. 1994. Estimating terrestrial biodiversity through extrapolation. Philosophical Transactions of the Royal Society (Series B) 345: 101−118.

Colwell, R.K., Mao, C.X., and Chang. J. 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology 85: 2717−2727.

Crozier, L.G., and Hutchings, J.A. 2014. Plastic and evolutionary responses to climate change in fish. Evolution Applications: 1752–4571.

Daw, T., Adger, W.N., Brown, K., and Badjeck, M.C. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. 107-150.

Deser, C., and Blackmon, M.L. 1993. Surface climate variations over the North Atlantic Ocean during winter: 1900-1989. American Meteorological Society 6: 1743−1753.

Deser, C., Michael A. Alexander, Shang-Ping Xie, and Adam S. Phillips. 2010. Sea Surface Temperature Variability: Patterns and Mechanisms. The Annual Review of Marine Science 2: 115-143.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata Duncan, Z., Christian, J.K., Robert, J. Anne-Hélène, N., Doris, P., Melanie, S.,Caroline, S., and Sullivan, A. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81 (2): 163-182.

EFARO (European Fisheries and Aquaculture Research Organizations). 2012. Position Paper. Climate change and European fisheries: observed changes and future prospects. EFARO Climate Change Workshop. 14-15 March 2011. Amsterdam. 38 pp.

Fautin, D., Dalton P., Incze L.S., Leong J-A. C., Pautzke C., Rosenberg, A., Sandifer, P., Sedberry, G., Tunnell, J.W., Russell, I.A., Brainard, E., Brodeur, M., Eldredge, L.G., Feldman, M., Moretzsohn, F., Vroom, P.S., Wainstein, M., and Wolff, N. 2010. An Overview of Marine Biodiversity in United States Waters. PLoS ONE. 5(8), e11914.

Ficke, A.D., Myrick, C.A., and Hansen, L.J. 2007. Potential impacts of global climate change on freshwater fisheries. Review in Fish Biology and Fisheries 17: 581–613.

Folland, C.K., and Karl, T.R. 2001. Observed climate variability and change. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Franklin, C.E., Johnston, I.A., Crockford, T., Kamunde, C. 1995. Scaling of oxygen consumption of Lake Magadi tilapia, a fish living at 37°C. Journal of Fish Biology 46: 829–834.

Global Historical Climatology Network (GHCN). 2016. https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn.

Gotelli, N.J., and Anne, C. 2013. Measuring and Estimating Species Richness, Species Diversity, and Biotic Similarity from Sampling Data. In: Levin S.A. (ed.) Encyclopedia of Biodiversity, second edition, Volume 5 195−211.

Hare J.A, Wuenschel M.J., and Kimball M.E. 2012. Projecting Range Limits with Coupled Thermal Tolerance - Climate Change Models: An Example Based on Gray Snapper (*Lutjanus griseus*) along the U.S. East Coast. PLoS ONE 7(12): e52294. doi:10.1371/journal.pone.0052294.

Heip, C.H.R., Herman, P.M.J., and Soetaert, K. 1998. Indices of diversity and evenness. Oceanis 24 (4): 61−87.

Hillebrand, H., Blasius, B., Borer, E.T., Chase, J.M., Downing, J.A., Eriksson, B.K., Filstrup, C.T., Harpole, S., Hodapp, D., Larsen, S., Lewandowska, A.M., Seabloom, E.W., Van de Waal, D.B., and Ryabov, A.B. 2017. Biodiversity change is uncoupled from species richness trends: consequences for conservation and monitoring. Journal of Applied Ecology DOI: 10.1111/1365-2664.12959.

Hoese, H.D. and R.H. Moore, 1977. Fishes of the Gulf of Mexico, Texas, Louisiana and adjacent waters. Texas A. & M. University Press, College Station. 327 pp.

Hossain, S.M., Das, N.G., Sarker, S., and Rahaman, Z.M. 2012. Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh. Egyptian Journal of Aquatic Research 38: 213−226.

Howell, P., and Auster, P.J. 2012. Phase Shift in an Estuarine Finfish Community Associated with Warming Temperatures. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4: 481–495.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: Synthesis Report – Contribution of Working Groups I, II, and III to the Fourth Intergovernmental Panel on Climate Change. Core Writing Team: R.K. Pauchauri and A. Reisinger, eds. IPCC, Geneva, Switzerland, 8 pp.

Johnson, C.A. (eds). 2001. Climate change: the scientific basis. Cambridge University Press, Cambridge, UK. 101–181.

Johnson, T. 2012. Fisheries Adaptions to Climate Change. Living on Alaska’s Changing Coast. Sea Grant Alaska. 8 pp.

Jost, L. 2006. Entropy and diversity. Oikos 113: 363.

Jost, L. 2007. Partitioning diversity into independent alpha and beta components. Ecology 88:2427-2439.

Korsman, B. 2013. The Spatial and Temporal Community Structure of Ichthyoplankton in a Northeast Florida Estuary: A Study of Ingress at a Faunal Boundary. UNF Theses and Dissertations. Paper 452.http://digitalcommons.unf.edu/etd/452.

Krishnakumar, P.K., and Bhat, G.S. 2008. Seasonal and interannual variations of oceanographic conditions off Mangalore coast (Karnataka, India) in the Malabar upwelling system during 1995–2004 and their influences on the pelagic fishery. Fisheries Oceanography 17 (1): 45–60.

Ludwing, J.A., and Reynolds, J.F. 1988. Statistical Ecology: A primer in methods and computing. John Wiley & Sons, Inc. 337 pp.

Magurran AE. 2004. Measuring biological diversity. 2nd ed. Oxford, U.K: Blackwell Science Ltd.

Matear, R. J., and A. C. Hirst. 2003. Long-term changes in dissolved oxygen concentrations in the ocean caused by protracted global warming, Global Biogeochemical Cycles 17: 1125. doi:10.1029/2002GB001997.

McCann, K.S 2000. The diversity-stability debate. Nature 405: 228−233.

McPherson, G. 2009. Chapter 2: Fundamental concepts in ecology. The planners guide to natural resource conservation: The science of land development beyond the metropolitan fringe. Esparza, A.X., and McPherson, G.R. Springer New York.

Morris, K.E., Caruso, T., Buscot, F., Fischer, M., Hancock, C., Maier, T.S., Meiners, T., Muller, C., Obermaier, E., Prati, D., Socher, S.A., Sonnemann, I., Waschke, N., Wubet, T., Wurst, S., and Rillig, M.C. 2014. Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. Ecology and Evolution 4(18): 3514−3524.

Moyle, P.B, and Cech, J.J. 2004. Fishes: an introduction to ichthyology, 5th edn. Prentice Hall, Englewood Cliffs, NJ.

Mutshinda, C.M., O'Hara, R.B., and Woiwod, I.P. 2009. What drives community dynamics? Proceedings of the Royal Society B 276: 2923–2929.

Muyodi, F.J., Mwanuzi, F.L., and Kapiyo, R. 2011. Environmental quality and fish communities in selected catchments of Lake Victoria. The Open Environmental Engineering Journal 4: 54-65.

NCM (Nordic Council of Ministers). 2011. A guide for conducting systematic literature review for the 5th edition of the Nordic nutrition recommendations. Copenhagen. 40 pp.

NMFS (National Marine Fisheries Service). 2018. Commercial Fisheries Statistics. Accessed at: https://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/. Accessed on: 25 January 2018.

NOAA (National Oceanic and Atmospheric Administration). 2016. NOAA Merged Land Ocean Global Surface Temperature Analysis (NOAAGlobalTemp): Global gridded 5° x 5° data. National Centers for Environmental Information. Accessed June 2016. www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp.

Norse, E.A. 1993. Global marine biological diversity: A strategy for building conservation into decision making. Island Press. 690 pp.

Odum, E.P. 1985. Trends Expected in Stressed Ecosystems. BioScience (35) 7: 419–422.

Odum, E.P. 1992. Great Ideas in Ecology for the 1990s. BioScience 42 (7): 542–545.

Ottersen, G., Planque, B., Belgrano, A., Post, E., Reid, P.C., and Stenseth, N.C. 2001. Ecological effects of the North Atlantic Oscillation. Oecologia 128: 1−14.

Parker, R.O., Jr., and Dixon, R.L. 1998. Changes in a North Carolina reef-fish community after 15 years of intense fishing: Global-warming implications. Transactions of the American Fisheries Society 127(6): 908–920.

Perry, A.L., Low, P.J., Ellis, J.R., and Reynolds, J.D. 2005. Climate change and distribution shifts in marine fishes.Science.308: 1912−1915.

Poulard, J., and Blanchard, F. 2005. The impact of climate change on the fish community structure of the eastern continental shelf of the Bay of Biscay. ICES Journal of Marine Science 62: 1463–1443.

Reash, R.J., and Pigg, J. 1990. Physicochemcial factors affecting the abundance and species richness of fishes in the Cimarron River. Proceedings Oklahoma Academic Science 70: 23−28.

Rice, J.C. 2000. Evaluating fishery impacts using metrics of community structure. ICES Journal of Marine Science 57: 682–688. doi:10.1006/jmsc.2000.073.

Rijnsdorp, A.D., Peck, M.A., Engelhard, G.H., Mo¨llmann, C., and Pinnegar, J.K. 2009. Resolving the effect of climate change on fish populations. ICES Journal of Marine Science, 66: 1570–1583.

Snover, M.L. 2008. Ontogenetic habitat shifts in marine organisms: Influencing factors and the impact of climate variability. Bulletin of Marine Science 83(1): 000-000.

Steimle, F.W. and Zetlin, C. 2000. Reef habitats in the Middle Atlantic Bight: abundance, distribution, associated biological communities and fishery resource use. Marine Fisheries Review. 62(2): 24−41.

Sutton, R.T., and Hodson, D.L.R. 2005. Atlantic Ocean forcing of North American and European summer climate. Science 309: 115–118.

Thorne, R.St., Williams, J.W.P., and Cao, Y. 1999. The influence of data transformations on biological monitoring studies using macroinvertebrates. Water Resources. 33(2): 343-350.

Vinebrooke, R., Cottingham, K., Orberg, J.N., Cheffer, M.S., Dodson, S., Maberly, S., and Sommer, U. 2004. Impacts of multiple stressors on biodiversity and ecosystem functioning: The role of species co-tolerance. Oikos104:451–457,doi:10.1111/j.0030-1299.2004.13255.x

Whitfield, P.E., Muñoz, R.C., Buckel, C.A., Degan, B.P., Freshwater, D.W., and Hare, J.A. 2014. Native fish community structure and Indo-Pacific lionfish *Pterois volitans* densities along a depth-temperature gradient in Onslow Bay, North Carolina, USA. Marine Ecology Progress Series 509: 241–254.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, E., Folke, C., Halpern, B.S., Jackson, J., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J., and Watson, R. 2006. Impacts of Biodiversity Loss on Ocean Ecosystem Services. Science 314 787-790; DOl: 10.1126/science.1132294.

Zar, J.H. 1999. Biostatistical analysis, 4th Ed. Prentice Hall, Upper Saddle River, NJ.

4.9 Appendix

Table 4.9-1. ANOSIM. Pairwise comparisons. Species Richness.

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
1988, 1989	0.625	0.1	77558760	999	0
1988, 1990	0.291	0.1	77558760	999	0
1988, 1991	0.537	0.1	77558760	999	0
1988, 1992	0.138	0.3	77558760	999	2
1988, 1993	0.406	0.1	77558760	999	0
1988, 1994	0.036	12.9	77558760	999	128
1988, 1995	0.368	0.1	77558760	999	0
1988, 1996	0.288	0.1	77558760	999	0
1988, 1997	0.342	0.1	77558760	999	0
1988, 1998	0.194	0.2	77558760	999	1
1988, 1999	0.257	0.1	77558760	999	0
1988, 2000	0.328	0.1	77558760	999	0
1988, 2001	0.091	1.7	77558760	999	16
1988, 2002	0.326	0.1	77558760	999	0
1988, 2003	0.113	0.7	77558760	999	6
1988, 2004	0.13	1.1	77558760	999	10
1988, 2005	0.409	0.1	77558760	999	0
1988, 2006	0.234	0.1	77558760	999	0
1988, 2007	0.48	0.1	77558760	999	0
1988, 2008	0.245	0.2	77558760	999	1
1988, 2009	0.218	0.1	77558760	999	0
1988, 2010	0.205	0.2	77558760	999	1
1988, 2011	0.369	0.1	77558760	999	0
1988, 2012	0.369	0.1	77558760	999	0
1988, 2013	0.412	0.1	77558760	999	0
1988, 2014	0.399	0.1	77558760	999	0
1988, 2015	0.515	0.1	77558760	999	0
1989, 1990	0.426	0.1	77558760	999	0
1989, 1991	0.073	4.4	77558760	999	43
1989, 1992	0.525	0.1	77558760	999	0
1989, 1993	0.203	0.1	77558760	999	0
1989, 1994	0.661	0.1	77558760	999	0
1989, 1995	0.392	0.1	77558760	999	0
1989, 1996	0.479	0.1	77558760	999	0
1989, 1997	0.453	0.1	77558760	999	0
1989, 1998	0.432	0.1	77558760	999	0
1989, 1999	0.452	0.1	77558760	999	0
1989, 2000	0.4	0.1	77558760	999	0
1989, 2001	0.581	0.1	77558760	999	0
1989, 2002	0.499	0.1	77558760	999	0
1989, 2003	0.58	0.1	77558760	999	0
1989, 2004	0.561	0.1	77558760	999	0
1989, 2005	0.417	0.1	77558760	999	0
1989, 2006	0.47	0.1	77558760	999	0
1989, 2007	0.133	1.5	77558760	999	14
1989, 2008	0.54	0.1	77558760	999	0
1989, 2009	0.536	0.1	77558760	999	0
1989, 2010	0.482	0.1	77558760	999	0

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
1989, 2011	0.428	0.1	77558760	999	0
1989, 2012	0.428	0.1	77558760	999	0
1989, 2013	0.349	0.1	77558760	999	0
1989, 2014	0.327	0.1	77558760	999	0
1989, 2015	0.212	0.3	77558760	999	2
1990, 1991	0.281	0.2	77558760	999	1
1990, 1992	0.039	11.7	77558760	999	116
1990, 1993	0.11	1.3	77558760	999	12
1990, 1994	0.365	0.1	77558760	999	0
1990, 1995	-0.022	72.6	77558760	999	725
1990, 1996	0	37.4	77558760	999	373
1990, 1997	-0.028	84	77558760	999	839
1990, 1998	-0.023	71.8	77558760	999	717
1990, 1999	-0.018	63.3	77558760	999	632
1990, 2000	-0.02	67.3	77558760	999	672
1990, 2001	0.138	0.6	77558760	999	5
1990, 2002	0.012	27.2	77558760	999	271
1990, 2003	0.181	0.1	77558760	999	0
1990, 2004	0.117	1.3	77558760	999	12
1990, 2005	0.008	30.7	77558760	999	306
1990, 2006	-0.006	46.6	77558760	999	465
1990, 2007	0.146	0.7	77558760	999	6
1990, 2008	0.066	5.2	77558760	999	51
1990, 2009	0.065	5.3	77558760	999	52
1990, 2010	0	38.5	77558760	999	384
1990, 2011	-0.015	60.1	77558760	999	600
1990, 2012	-0.015	61.8	77558760	999	617
1990, 2013	0.021	20.3	77558760	999	202
1990, 2014	0.056	6.5	77558760	999	64
1990, 2015	0.18	0.3	77558760	999	2
1991, 1992	0.405	0.1	77558760	999	0
1991, 1993	0.032	15.5	77558760	999	154
1991, 1994	0.597	0.1	77558760	999	0
1991, 1995	0.243	0.2	77558760	999	1
1991, 1996	0.354	0.1	77558760	999	0
1991, 1997	0.327	0.1	77558760	999	0
1991, 1998	0.284	0.1	77558760	999	0
1991, 1999	0.312	0.1	77558760	999	0
1991, 2000	0.251	0.1	77558760	999	0
1991, 2001	0.484	0.1	77558760	999	0
1991, 2002	0.39	0.1	77558760	999	0
1991, 2003	0.482	0.1	77558760	999	0
1991, 2004	0.459	0.1	77558760	999	0
1991, 2005	0.277	0.1	77558760	999	0
1991, 2006	0.332	0.1	77558760	999	0
1991, 2007	-0.017	61.6	77558760	999	615
1991, 2008	0.443	0.1	77558760	999	0
1991, 2009	0.427	0.1	77558760	999	0
1991, 2010	0.345	0.1	77558760	999	0
1991, 2011	0.295	0.1	77558760	999	0
1991, 2012	0.295	0.1	77558760	999	0
1991, 2013	0.199	0.1	77558760	999	0
1991, 2014	0.168	0.4	77558760	999	3

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
1991, 2015	0.044	10.6	77558760	999	105
1992, 1993	0.224	0.1	77558760	999	0
1992, 1994	0.191	0.3	77558760	999	2
1992, 1995	0.107	1.1	77558760	999	10
1992, 1996	0.019	22.1	77558760	999	220
1992, 1997	0.061	5.2	77558760	999	51
1992, 1998	-0.024	74.2	77558760	999	741
1992, 1999	0.013	26.8	77558760	999	267
1992, 2000	0.084	3.4	77558760	999	33
1992, 2001	-0.018	68	77558760	999	679
1992, 2002	0.038	11.2	77558760	999	111
1992, 2003	0.041	13.2	77558760	999	131
1992, 2004	-0.011	50.4	77558760	999	503
1992, 2005	0.151	0.5	77558760	999	4
1992, 2006	-0.008	49.2	77558760	999	491
1992, 2007	0.287	0.1	77558760	999	0
1992, 2008	-0.007	46.2	77558760	999	461
1992, 2009	-0.006	44.9	77558760	999	448
1992, 2010	-0.016	60.8	77558760	999	607
1992, 2011	0.103	1.5	77558760	999	14
1992, 2012	0.103	1.7	77558760	999	16
1992, 2013	0.169	0.3	77558760	999	2
1992, 2014	0.189	0.4	77558760	999	3
1992, 2015	0.335	0.1	77558760	999	0
1993, 1994	0.465	0.1	77558760	999	0
1993, 1995	0.055	9	77558760	999	89
1993, 1996	0.153	0.7	77558760	999	6
1993, 1997	0.143	0.5	77558760	999	4
1993, 1998	0.106	1.7	77558760	999	16
1993, 1999	0.106	2.3	77558760	999	22
1993, 2000	0.058	8	77558760	999	79
1993, 2001	0.303	0.1	77558760	999	0
1993, 2002	0.187	0.2	77558760	999	1
1993, 2003	0.299	0.1	77558760	999	0
1993, 2004	0.265	0.1	77558760	999	0
1993, 2005	0.083	2.9	77558760	999	28
1993, 2006	0.129	1.1	77558760	999	10
1993, 2007	-0.023	69.5	77558760	999	694
1993, 2008	0.25	0.1	77558760	999	0
1993, 2009	0.221	0.2	77558760	999	1
1993, 2010	0.143	1.4	77558760	999	13
1993, 2011	0.097	3.1	77558760	999	30
1993, 2012	0.097	2.5	77558760	999	24
1993, 2013	0.032	15	77558760	999	149
1993, 2014	-0.001	40.7	77558760	999	406
1993, 2015	-0.016	61.6	77558760	999	615
1994, 1995	0.443	0.1	77558760	999	0
1994, 1996	0.346	0.1	77558760	999	0
1994, 1997	0.425	0.1	77558760	999	0
1994, 1998	0.248	0.1	77558760	999	0
1994, 1999	0.308	0.1	77558760	999	0
1994, 2000	0.396	0.1	77558760	999	0
1994, 2001	0.101	2.4	77558760	999	23

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
1994, 2002	0.392	0.1	77558760	999	0
1994, 2003	0.103	2.2	77558760	999	21
1994, 2004	0.142	0.7	77558760	999	6
1994, 2005	0.49	0.1	77558760	999	0
1994, 2006	0.279	0.1	77558760	999	0
1994, 2007	0.542	0.1	77558760	999	0
1994, 2008	0.303	0.1	77558760	999	0
1994, 2009	0.248	0.1	77558760	999	0
1994, 2010	0.248	0.1	77558760	999	0
1994, 2011	0.442	0.1	77558760	999	0
1994, 2012	0.442	0.1	77558760	999	0
1994, 2013	0.488	0.1	77558760	999	0
1994, 2014	0.472	0.1	77558760	999	0
1994, 2015	0.587	0.1	77558760	999	0
1995, 1996	0.007	33	77558760	999	329
1995, 1997	-0.021	66.1	77558760	999	660
1995, 1998	0.009	31.1	77558760	999	310
1995, 1999	-0.018	60.5	77558760	999	604
1995, 2000	-0.048	97.3	77558760	999	972
1995, 2001	0.212	0.1	77558760	999	0
1995, 2002	0.029	17.2	77558760	999	171
1995, 2003	0.232	0.1	77558760	999	0
1995, 2004	0.164	0.5	77558760	999	4
1995, 2005	-0.047	96.4	77558760	999	963
1995, 2006	0.012	29.4	77558760	999	293
1995, 2007	0.094	2.2	77558760	999	21
1995, 2008	0.113	1.2	77558760	999	11
1995, 2009	0.103	2.2	77558760	999	21
1995, 2010	0.026	17.2	77558760	999	171
1995, 2011	-0.05	97.7	77558760	999	976
1995, 2012	-0.05	97.9	77558760	999	978
1995, 2013	-0.044	93.7	77558760	999	936
1995, 2014	-0.018	63.2	77558760	999	631
1995, 2015	0.108	2.1	77558760	999	20
1996, 1997	-0.013	56.9	77558760	999	568
1996, 1998	-0.005	43.9	77558760	999	438
1996, 1999	-0.04	94.2	77558760	999	941
1996, 2000	0.003	35	77558760	999	349
1996, 2001	0.093	3.4	77558760	999	33
1996, 2002	-0.037	91.3	77558760	999	912
1996, 2003	0.108	0.7	77558760	999	6
1996, 2004	0.045	11.9	77558760	999	118
1996, 2005	0.02	21.9	77558760	999	218
1996, 2006	-0.027	78.3	77558760	999	782
1996, 2007	0.208	0.1	77558760	999	0
1996, 2008	0.022	18.8	77558760	999	187
1996, 2009	-0.008	46.1	77558760	999	460
1996, 2010	-0.032	87.6	77558760	999	875
1996, 2011	-0.009	51.6	77558760	999	515
1996, 2012	-0.009	50.7	77558760	999	506
1996, 2013	0.072	4.4	77558760	999	43
1996, 2014	0.096	2.2	77558760	999	21
1996, 2015	0.242	0.1	77558760	999	0

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
1997, 1998	0.01	30.3	77558760	999	302
1997, 1999	-0.008	49.9	77558760	999	498
1997, 2000	-0.005	42.8	77558760	999	427
1997, 2001	0.177	0.4	77558760	999	3
1997, 2002	-0.017	63.4	77558760	999	633
1997, 2003	0.214	0.2	77558760	999	1
1997, 2004	0.131	1.2	77558760	999	11
1997, 2005	-0.01	56.7	77558760	999	566
1997, 2006	0.009	29.8	77558760	999	297
1997, 2007	0.172	0.4	77558760	999	3
1997, 2008	0.056	9.1	77558760	999	90
1997, 2009	0.076	6.5	77558760	999	64
1997, 2010	0.015	22.9	77558760	999	228
1997, 2011	-0.024	74.9	77558760	999	748
1997, 2012	-0.024	75.9	77558760	999	758
1997, 2013	0.032	15.4	77558760	999	153
1997, 2014	0.076	4.4	77558760	999	43
1997, 2015	0.208	0.1	77558760	999	0
1998, 1999	-0.033	84	77558760	999	839
1998, 2000	-0.006	47.6	77558760	999	475
1998, 2001	0.047	9.9	77558760	999	98
1998, 2002	0.026	19.9	77558760	999	198
1998, 2003	0.093	2.2	77558760	999	21
1998, 2004	0.039	14.5	77558760	999	144
1998, 2005	0.062	5.2	77558760	999	51
1998, 2006	-0.044	94.7	77558760	999	946
1998, 2007	0.168	0.6	77558760	999	5
1998, 2008	0.028	16.4	77558760	999	163
1998, 2009	0.021	22.3	77558760	999	222
1998, 2010	-0.034	82.3	77558760	999	822
1998, 2011	0.017	23	77558760	999	229
1998, 2012	0.017	24.6	77558760	999	245
1998, 2013	0.048	10.4	77558760	999	103
1998, 2014	0.074	5.4	77558760	999	53
1998, 2015	0.204	0.1	77558760	999	0
1999, 2000	-0.042	92.7	77558760	999	926
1999, 2001	0.075	5.4	77558760	999	53
1999, 2002	-0.016	60.2	77558760	999	601
1999, 2003	0.089	3.3	77558760	999	32
1999, 2004	0.034	15.4	77558760	999	153
1999, 2005	0.004	35.5	77558760	999	354
1999, 2006	-0.054	98.3	77558760	999	982
1999, 2007	0.174	0.6	77558760	999	5
1999, 2008	0.02	23.4	77558760	999	233
1999, 2009	-0.013	56.3	77558760	999	562
1999, 2010	-0.048	95.9	77558760	999	958
1999, 2011	-0.029	80.2	77558760	999	801
1999, 2012	-0.029	80.9	77558760	999	808
1999, 2013	0.031	14.9	77558760	999	148
1999, 2014	0.052	10.9	77558760	999	108
1999, 2015	0.202	0.3	77558760	999	2
2000, 2001	0.172	0.4	77558760	999	3
2000, 2002	0.029	15.6	77558760	999	155

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
2000, 2003	0.187	0.5	77558760	999	4
2000, 2004	0.126	1.5	77558760	999	14
2000, 2005	-0.027	80.1	77558760	999	800
2000, 2006	-0.011	52.6	77558760	999	525
2000, 2007	0.117	1.1	77558760	999	10
2000, 2008	0.099	2.7	77558760	999	26
2000, 2009	0.067	5.3	77558760	999	52
2000, 2010	-0.003	46	77558760	999	459
2000, 2011	-0.048	98.6	77558760	999	985
2000, 2012	-0.048	99.2	77558760	999	991
2000, 2013	-0.028	79.7	77558760	999	796
2000, 2014	-0.002	43	77558760	999	429
2000, 2015	0.13	0.5	77558760	999	4
2001, 2002	0.114	1.9	77558760	999	18
2001, 2003	-0.025	74.5	77558760	999	744
2001, 2004	-0.043	92.7	77558760	999	926
2001, 2005	0.262	0.1	77558760	999	0
2001, 2006	0.043	12.4	77558760	999	123
2001, 2007	0.38	0.1	77558760	999	0
2001, 2008	0.034	15.5	77558760	999	154
2001, 2009	-0.002	40.4	77558760	999	403
2001, 2010	0.029	17.1	77558760	999	170
2001, 2011	0.202	0.2	77558760	999	1
2001, 2012	0.202	0.4	77558760	999	3
2001, 2013	0.28	0.1	77558760	999	0
2001, 2014	0.281	0.1	77558760	999	0
2001, 2015	0.431	0.1	77558760	999	0
2002, 2003	0.135	1.2	77558760	999	11
2002, 2004	0.058	5.9	77558760	999	58
2002, 2005	0.038	12.2	77558760	999	121
2002, 2006	-0.01	51.9	77558760	999	518
2002, 2007	0.233	0.2	77558760	999	1
2002, 2008	-0.015	58	77558760	999	579
2002, 2009	-0.002	44	77558760	999	439
2002, 2010	-0.001	44.5	77558760	999	444
2002, 2011	0.013	30.3	77558760	999	302
2002, 2012	0.013	23.7	77558760	999	236
2002, 2013	0.102	2.3	77558760	999	22
2002, 2014	0.13	1	77558760	999	9
2002, 2015	0.278	0.1	77558760	999	0
2003, 2004	-0.038	88.8	77558760	999	887
2003, 2005	0.266	0.1	77558760	999	0
2003, 2006	0.069	5.6	77558760	999	55
2003, 2007	0.38	0.1	77558760	999	0
2003, 2008	0.08	4.9	77558760	999	48
2003, 2009	0.007	35.9	77558760	999	358
2003, 2010	0.053	9.4	77558760	999	93
2003, 2011	0.218	0.2	77558760	999	1
2003, 2012	0.218	0.2	77558760	999	1
2003, 2013	0.298	0.1	77558760	999	0
2003, 2014	0.283	0.2	77558760	999	1
2003, 2015	0.424	0.1	77558760	999	0
2004, 2005	0.197	0.3	77558760	999	2

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
2004, 2006	0.015	27.4	77558760	999	273
2004, 2007	0.342	0.1	77558760	999	0
2004, 2008	0.008	33	77558760	999	329
2004, 2009	-0.034	87.6	77558760	999	875
2004, 2010	0.005	34.9	77558760	999	348
2004, 2011	0.147	0.4	77558760	999	3
2004, 2012	0.147	1.2	77558760	999	11
2004, 2013	0.232	0.2	77558760	999	1
2004, 2014	0.238	0.1	77558760	999	0
2004, 2015	0.387	0.1	77558760	999	0
2005, 2006	0.05	9.7	77558760	999	96
2005, 2007	0.116	1.3	77558760	999	12
2005, 2008	0.147	0.8	77558760	999	7
2005, 2009	0.128	1.6	77558760	999	15
2005, 2010	0.05	7.7	77558760	999	76
2005, 2011	-0.041	92.9	77558760	999	928
2005, 2012	-0.041	94.6	77558760	999	945
2005, 2013	-0.015	58.2	77558760	999	581
2005, 2014	0.001	36.8	77558760	999	367
2005, 2015	0.128	1.1	77558760	999	10
2006, 2007	0.201	0.1	77558760	999	0
2006, 2008	0	39.4	77558760	999	393
2006, 2009	-0.027	78.7	77558760	999	786
2006, 2010	-0.047	95.9	77558760	999	958
2006, 2011	0.007	32.5	77558760	999	324
2006, 2012	0.007	32	77558760	999	319
2006, 2013	0.067	5.5	77558760	999	54
2006, 2014	0.087	4.2	77558760	999	41
2006, 2015	0.237	0.1	77558760	999	0
2007, 2008	0.307	0.1	77558760	999	0
2007, 2009	0.295	0.1	77558760	999	0
2007, 2010	0.215	0.1	77558760	999	0
2007, 2011	0.142	0.6	77558760	999	5
2007, 2012	0.142	0.9	77558760	999	8
2007, 2013	0.062	5.9	77558760	999	58
2007, 2014	0.048	8.4	77558760	999	83
2007, 2015	-0.021	67	77558760	999	669
2008, 2009	-0.019	67.7	77558760	999	676
2008, 2010	0.022	19	77558760	999	189
2008, 2011	0.104	1.6	77558760	999	15
2008, 2012	0.104	1.4	77558760	999	13
2008, 2013	0.188	0.2	77558760	999	1
2008, 2014	0.209	0.1	77558760	999	0
2008, 2015	0.36	0.1	77558760	999	0
2009, 2010	-0.025	73.8	77558760	999	737
2009, 2011	0.084	4.4	77558760	999	43
2009, 2012	0.084	4.2	77558760	999	41
2009, 2013	0.177	0.4	77558760	999	3
2009, 2014	0.186	0.7	77558760	999	6
2009, 2015	0.341	0.1	77558760	999	0
2010, 2011	0.008	31.3	77558760	999	312
2010, 2012	0.008	29.1	77558760	999	290
2010, 2013	0.079	3.2	77558760	999	31

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
2010, 2014	0.098	3.2	77558760	999	31
2010, 2015	0.247	0.1	77558760	999	0
2011, 2012	-0.067	100	77558760	999	999
2011, 2013	-0.022	72.8	77558760	999	727
2011, 2014	0.025	21.7	77558760	999	216
2011, 2015	0.159	0.5	77558760	999	4
2012, 2013	-0.022	69.8	77558760	999	697
2012, 2014	0.025	20.3	77558760	999	202
2012, 2015	0.159	0.8	77558760	999	7
2013, 2014	-0.026	77.3	77558760	999	772
2013, 2015	0.06	6.5	77558760	999	64
2014, 2015	0.033	16.2	77558760	999	161

Table 4.9-2. General Linear Model. ANOVA summary table (1988−2015). The statistical significance between each of the species richness estimators and the predictor variables at the 95% confidence level.

Species Richness	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**
Estimate S	Model	8604.4	5	1720.88	2.74	0.0229
	Residual	66634.0	106	628.623		
	Total (Corr.)	75238.5	111			
ACE Mean	Model	8986.26	5	1797.25	2.54	0.0325
	Residual	74917.7	106	706.77		
	Total (Corr.)	83903.9	111			
Chao 1	Model	7678.15	5	1535.63	2.30	0.0500
	Residual	70784.6	106	667.779		
	Total (Corr.)	78462.7	111			
Jack Knife 1	Model	16928.2	5	3385.63	3.03	0.0136
	Residual	118597.	106	1118.84		
	Total (Corr.)	135525.	111			
Jack Knife 2	Model	34520.9	5	6904.18	2.95	0.0156
	Residual	247988.	106	2339.51		
	Total (Corr.)	282508.	111			
Bootstrap	Model	11985.8	5	2397.17	2.92	0.0164
	Residual	86975.5	106	820.523		
	Total (Corr.)	98961.3	111			
Michaelis-Menton	Model	22728.8	5	4545.77	3.23	0.0093
	Residual	149047.	106	1406.1		
	Total (Corr.)	171776.	111			

Table 4.9-3. General Linear Model and associated ANOVA Type III Sums of Squares (1988−2015). The statistical significance between each of the species richness estimators and the predictor variables at the 95% confidence level.

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Estimate S Mean	NAO	153.074	1	153.074	0.24	0.6227	Estimate (Mean) = 115.723 + 0.586302*NAO - 30.8675*AMO - 2.78157*EOF - 0.0055583*Air Temperature - 3.76815*Precipitation	11.41%
	AMO	469.65	1	469.65	0.75	0.3893		
	EOF	137.45	1	137.45	0.22	0.6410		
	Air Temperature	0.573954	1	0.573954	0.00	0.9760		
	Precipitation	3861.39	1	3861.39	6.14	0.0148		
	Residual	66634.0	106	628.623				
	Total (corrected)	75238.5	111					
ACE Mean	NAO	53.0153	1	53.0153	0.08	0.7847	ACE Mean = 128.925 + 0.345042*NAO - 35.6791*AMO - 2.35521*EOF + 0.00689329*Air Temperature - 3.86639*Precipitation	10.70%
	AMO	627.48	1	627.48	0.89	0.3482		
	EOF	98.5427	1	98.5427	0.14	0.7096		
	Air Temperature	0.882767	1	0.882767	0.00	0.9719		
	Precipitation	4065.36	1	4065.36	5.75	0.0182		
	Residual	74917.7	106	706.77				
	Total (corrected)	83903.9	111					
Chao 1 Mean	NAO	73.9803	1	73.9803	0.11	0.7399	Chao 1 Mean = 133.412 + 0.407595*NAO - 30.8197*AMO - 2.11109*EOF - 0.0229095*Air Temperature - 3.70138*Precipitation	9.82%
	AMO	468.198	1	468.198	0.70	0.4043		
	EOF	79.1731	1	79.1731	0.12	0.7313		
	Air Temperature	9.75041	1	9.75041	0.01	0.9040		
	Precipitation	3725.75	1	3725.75	5.58	0.0200		
	Residual	70784.6	106	667.779				
	Total (corrected)	78462.7	111					
Jack Knife 1 Mean	NAO	433.53	1	433.53	0.39	0.5350	Jack Knife 1 Mean = 145.499 + 0.98669*NAO - 33.4277*AMO - 4.56194*EOF - 0.0286687*Air Temperature -	12.52%
	AMO	550.788	1	550.788	0.49	0.4844		
	EOF	369.713	1	369.713	0.33	0.5666		
	Air Temperature	15.2689	1	15.2689	0.01	0.9072		
	Precipitation	8866.04	1	8866.04	7.92	0.0058		
	Residual	118597.	106	1118.84				
	Total (corrected)	135525.	111					

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
							5.70981*Precipitation	
Jack Knife 2 Mean	NAO	1771.49	1	1771.49	0.76	0.3862	Jack Knife 2 Mean = 166.979 + 1.99453*NAO - 21.6308*AMO - 7.86522*EOF - 0.142499*Air Temperature - 8.83898*Precipitation	12.20%
	AMO	230.631	1	230.631	0.10	0.7542		
	EOF	1098.97	1	1098.97	0.47	0.4946		
	Air Temperature	377.24	1	377.24	0.16	0.6888		
	Precipitation	21246.7	1	21246.7	9.08	0.0032		
	Residual	247988.	106	2339.51				
	Total (corrected)	282508.	111					
Bootstrap Mean	NAO	257.577	1	257.577	0.31	0.5765	Bootstrap Mean = 129.047 + 0.760545*NAO - 33.2188*AMO - 3.45316*EOF - 0.00984694*Air Temperature - 4.61917*Precipitation	12.11%
	AMO	543.926	1	543.926	0.66	0.4174		
	EOF	211.835	1	211.835	0.26	0.6124		
	Air Temperature	1.80134	1	1.80134	0.00	0.9627		
	Precipitation	5802.51	1	5802.51	7.07	0.0090		
	Residual	86975.5	106	820.523				
	Total (corrected)	98961.3	111					
Michaelis-Menten Mean	NAO	NAO	1	1464.54	1.04	0.3098	MM Mean = 136.709 + 1.81352*NAO - 34.2308*AMO - 4.26642*EOF + 0.0162216*Air Temperature - 6.98891*Precipitation	13.20%
	AMO	AMO	1	577.572	0.41	0.5230		
	EOF	EOF	1	323.365	0.23	0.6325		
	Air Temperature	Air Temperature	1	4.88855	0.00	0.9531		
	Precipitation	Precipitation	1	13283.3	9.45	0.0027		
	Residual	Residual	106	1406.1				
	Total (corrected)	Total (corrected)	111					

Table 4.9-4. Pairwise comparisons. Species diversity.

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
1988, 1989	0.977	0.1	77558760	999	0
1988, 1990	0.992	0.1	77558760	999	0
1988, 1991	0.951	0.1	77558760	999	0
1988, 1992	1	0.1	77558760	999	0
1988, 1993	0.952	0.1	77558760	999	0
1988, 1994	1	0.1	77558760	999	0
1988, 1995	1	0.1	77558760	999	0
1988, 1996	0.947	0.1	77558760	999	0
1988, 1997	0.882	0.1	77558760	999	0
1988, 1998	1	0.1	77558760	999	0
1988, 1999	0.913	0.1	77558760	999	0
1988, 2000	1	0.1	77558760	999	0
1988, 2001	0.99	0.1	77558760	999	0
1988, 2002	0.988	0.1	77558760	999	0
1988, 2003	0.902	0.1	77558760	999	0
1988, 2004	0.996	0.1	77558760	999	0
1988, 2005	0.952	0.1	77558760	999	0
1988, 2006	1	0.1	77558760	999	0
1988, 2007	1	0.1	77558760	999	0
1988, 2008	1	0.1	77558760	999	0
1988, 2009	1	0.1	77558760	999	0
1988, 2010	0.943	0.1	77558760	999	0
1988, 2011	0.99	0.1	77558760	999	0
1988, 2012	0.99	0.1	77558760	999	0
1988, 2013	0.931	0.1	77558760	999	0
1988, 2014	0.995	0.1	77558760	999	0
1988, 2015	0.998	0.1	77558760	999	0
1989, 1990	0.881	0.1	77558760	999	0
1989, 1991	0.264	0.1	77558760	999	0
1989, 1992	0.991	0.1	77558760	999	0
1989, 1993	0.729	0.1	77558760	999	0
1989, 1994	0.929	0.1	77558760	999	0
1989, 1995	0.952	0.1	77558760	999	0
1989, 1996	0.082	5.1	77558760	999	50
1989, 1997	0.628	0.1	77558760	999	0
1989, 1998	0.532	0.1	77558760	999	0
1989, 1999	0.379	0.1	77558760	999	0
1989, 2000	0.249	0.3	77558760	999	2
1989, 2001	0.813	0.1	77558760	999	0
1989, 2002	0.73	0.1	77558760	999	0
1989, 2003	0.944	0.1	77558760	999	0
1989, 2004	0.799	0.1	77558760	999	0
1989, 2005	0.91	0.1	77558760	999	0
1989, 2006	0.734	0.1	77558760	999	0
1989, 2007	0.41	0.1	77558760	999	0
1989, 2008	0.664	0.1	77558760	999	0
1989, 2009	0.403	0.1	77558760	999	0
1989, 2010	0.346	0.1	77558760	999	0
1989, 2011	0.406	0.1	77558760	999	0
1989, 2012	0.406	0.1	77558760	999	0
1989, 2013	0.534	0.1	77558760	999	0
1989, 2014	0.29	0.1	77558760	999	0

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
1989, 2015	0.416	0.1	77558760	999	0
1990, 1991	0.781	0.1	77558760	999	0
1990, 1992	0.298	0.1	77558760	999	0
1990, 1993	0.024	19.4	77558760	999	193
1990, 1994	0.715	0.1	77558760	999	0
1990, 1995	0.058	7.7	77558760	999	76
1990, 1996	0.884	0.1	77558760	999	0
1990, 1997	0.961	0.1	77558760	999	0
1990, 1998	0.921	0.1	77558760	999	0
1990, 1999	0.936	0.1	77558760	999	0
1990, 2000	0.93	0.1	77558760	999	0
1990, 2001	0.976	0.1	77558760	999	0
1990, 2002	0.397	0.1	77558760	999	0
1990, 2003	0.985	0.1	77558760	999	0
1990, 2004	0.973	0.1	77558760	999	0
1990, 2005	0.983	0.1	77558760	999	0
1990, 2006	0.968	0.1	77558760	999	0
1990, 2007	0.909	0.1	77558760	999	0
1990, 2008	0.848	0.1	77558760	999	0
1990, 2009	0.909	0.1	77558760	999	0
1990, 2010	0.942	0.1	77558760	999	0
1990, 2011	0.775	0.1	77558760	999	0
1990, 2012	0.775	0.1	77558760	999	0
1990, 2013	0.414	0.1	77558760	999	0
1990, 2014	0.892	0.1	77558760	999	0
1990, 2015	0.806	0.1	77558760	999	0
1991, 1992	0.874	0.1	77558760	999	0
1991, 1993	0.62	0.1	77558760	999	0
1991, 1994	0.692	0.1	77558760	999	0
1991, 1995	0.863	0.1	77558760	999	0
1991, 1996	0.317	0.1	77558760	999	0
1991, 1997	0.722	0.1	77558760	999	0
1991, 1998	0.528	0.1	77558760	999	0
1991, 1999	0.526	0.1	77558760	999	0
1991, 2000	0.508	0.1	77558760	999	0
1991, 2001	0.793	0.1	77558760	999	0
1991, 2002	0.478	0.1	77558760	999	0
1991, 2003	0.908	0.1	77558760	999	0
1991, 2004	0.791	0.1	77558760	999	0
1991, 2005	0.876	0.1	77558760	999	0
1991, 2006	0.755	0.1	77558760	999	0
1991, 2007	0.44	0.1	77558760	999	0
1991, 2008	0.223	0.1	77558760	999	0
1991, 2009	0.443	0.1	77558760	999	0
1991, 2010	0.555	0.1	77558760	999	0
1991, 2011	0.149	1.6	77558760	999	15
1991, 2012	0.149	0.5	77558760	999	4
1991, 2013	0.375	0.1	77558760	999	0
1991, 2014	0.262	0.3	77558760	999	2
1991, 2015	-0.025	66.7	77558760	999	666
1992, 1993	0.341	0.1	77558760	999	0
1992, 1994	0.761	0.1	77558760	999	0
1992, 1995	0.435	0.1	77558760	999	0
1992, 1996	0.986	0.1	77558760	999	0

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
1992, 1997	1	0.1	77558760	999	0
1992, 1998	1	0.1	77558760	999	0
1992, 1999	0.999	0.1	77558760	999	0
1992, 2000	1	0.1	77558760	999	0
1992, 2001	1	0.1	77558760	999	0
1992, 2002	0.414	0.1	77558760	999	0
1992, 2003	1	0.1	77558760	999	0
1992, 2004	1	0.1	77558760	999	0
1992, 2005	1	0.1	77558760	999	0
1992, 2006	1	0.1	77558760	999	0
1992, 2007	1	0.1	77558760	999	0
1992, 2008	0.986	0.1	77558760	999	0
1992, 2009	0.999	0.1	77558760	999	0
1992, 2010	1	0.1	77558760	999	0
1992, 2011	0.886	0.1	77558760	999	0
1992, 2012	0.886	0.1	77558760	999	0
1992, 2013	0.5	0.1	77558760	999	0
1992, 2014	0.997	0.1	77558760	999	0
1992, 2015	0.94	0.1	77558760	999	0
1993, 1994	0.631	0.1	77558760	999	0
1993, 1995	0.071	4.8	77558760	999	47
1993, 1996	0.748	0.1	77558760	999	0
1993, 1997	0.853	0.1	77558760	999	0
1993, 1998	0.798	0.1	77558760	999	0
1993, 1999	0.798	0.1	77558760	999	0
1993, 2000	0.791	0.1	77558760	999	0
1993, 2001	0.886	0.1	77558760	999	0
1993, 2002	0.336	0.1	77558760	999	0
1993, 2003	0.928	0.1	77558760	999	0
1993, 2004	0.885	0.1	77558760	999	0
1993, 2005	0.916	0.1	77558760	999	0
1993, 2006	0.857	0.1	77558760	999	0
1993, 2007	0.788	0.1	77558760	999	0
1993, 2008	0.723	0.1	77558760	999	0
1993, 2009	0.778	0.1	77558760	999	0
1993, 2010	0.807	0.1	77558760	999	0
1993, 2011	0.63	0.1	77558760	999	0
1993, 2012	0.63	0.1	77558760	999	0
1993, 2013	0.314	0.1	77558760	999	0
1993, 2014	0.75	0.1	77558760	999	0
1993, 2015	0.638	0.1	77558760	999	0
1994, 1995	0.819	0.1	77558760	999	0
1994, 1996	0.906	0.1	77558760	999	0
1994, 1997	0.998	0.1	77558760	999	0
1994, 1998	0.998	0.1	77558760	999	0
1994, 1999	0.982	0.1	77558760	999	0
1994, 2000	0.999	0.1	77558760	999	0
1994, 2001	1	0.1	77558760	999	0
1994, 2002	0.525	0.1	77558760	999	0
1994, 2003	1	0.1	77558760	999	0
1994, 2004	1	0.1	77558760	999	0
1994, 2005	1	0.1	77558760	999	0
1994, 2006	1	0.1	77558760	999	0
1994, 2007	0.997	0.1	77558760	999	0

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
1994, 2008	0.942	0.1	77558760	999	0
1994, 2009	0.996	0.1	77558760	999	0
1994, 2010	0.997	0.1	77558760	999	0
1994, 2011	0.746	0.1	77558760	999	0
1994, 2012	0.746	0.1	77558760	999	0
1994, 2013	0.592	0.1	77558760	999	0
1994, 2014	0.975	0.1	77558760	999	0
1994, 2015	0.736	0.1	77558760	999	0
1995, 1996	0.952	0.1	77558760	999	0
1995, 1997	0.994	0.1	77558760	999	0
1995, 1998	0.98	0.1	77558760	999	0
1995, 1999	0.986	0.1	77558760	999	0
1995, 2000	0.983	0.1	77558760	999	0
1995, 2001	0.998	0.1	77558760	999	0
1995, 2002	0.423	0.1	77558760	999	0
1995, 2003	1	0.1	77558760	999	0
1995, 2004	0.997	0.1	77558760	999	0
1995, 2005	1	0.1	77558760	999	0
1995, 2006	0.996	0.1	77558760	999	0
1995, 2007	0.977	0.1	77558760	999	0
1995, 2008	0.951	0.1	77558760	999	0
1995, 2009	0.978	0.1	77558760	999	0
1995, 2010	0.987	0.1	77558760	999	0
1995, 2011	0.839	0.1	77558760	999	0
1995, 2012	0.839	0.1	77558760	999	0
1995, 2013	0.417	0.1	77558760	999	0
1995, 2014	0.973	0.1	77558760	999	0
1995, 2015	0.896	0.1	77558760	999	0
1996, 1997	0.513	0.1	77558760	999	0
1996, 1998	0.529	0.1	77558760	999	0
1996, 1999	0.34	0.1	77558760	999	0
1996, 2000	0.211	0.7	77558760	999	6
1996, 2001	0.741	0.1	77558760	999	0
1996, 2002	0.723	0.1	77558760	999	0
1996, 2003	0.879	0.1	77558760	999	0
1996, 2004	0.761	0.1	77558760	999	0
1996, 2005	0.812	0.1	77558760	999	0
1996, 2006	0.743	0.1	77558760	999	0
1996, 2007	0.443	0.1	77558760	999	0
1996, 2008	0.591	0.1	77558760	999	0
1996, 2009	0.302	0.1	77558760	999	0
1996, 2010	0.223	0.3	77558760	999	2
1996, 2011	0.417	0.1	77558760	999	0
1996, 2012	0.417	0.1	77558760	999	0
1996, 2013	0.538	0.1	77558760	999	0
1996, 2014	0.294	0.1	77558760	999	0
1996, 2015	0.477	0.1	77558760	999	0
1997, 1998	0.859	0.1	77558760	999	0
1997, 1999	0.527	0.1	77558760	999	0
1997, 2000	0.508	0.1	77558760	999	0
1997, 2001	0.8	0.1	77558760	999	0
1997, 2002	0.912	0.1	77558760	999	0
1997, 2003	0.86	0.1	77558760	999	0
1997, 2004	0.835	0.1	77558760	999	0

Groups	**Significance Statistic**	**Possible Level %**	**Actual Permutations**	**Number >= Permutations**	**Observed**
1997, 2005	0.817	0.1	77558760	999	0
1997, 2006	0.827	0.1	77558760	999	0
1997, 2007	0.875	0.1	77558760	999	0
1997, 2008	0.892	0.1	77558760	999	0
1997, 2009	0.77	0.1	77558760	999	0
1997, 2010	0.32	0.1	77558760	999	0
1997, 2011	0.855	0.1	77558760	999	0
1997, 2012	0.855	0.1	77558760	999	0
1997, 2013	0.757	0.1	77558760	999	0
1997, 2014	0.74	0.1	77558760	999	0
1997, 2015	0.852	0.1	77558760	999	0
1998, 1999	0.368	0.1	77558760	999	0
1998, 2000	0.407	0.1	77558760	999	0
1998, 2001	0.999	0.1	77558760	999	0
1998, 2002	0.823	0.1	77558760	999	0
1998, 2003	1	0.1	77558760	999	0
1998, 2004	1	0.1	77558760	999	0
1998, 2005	1	0.1	77558760	999	0
1998, 2006	0.969	0.1	77558760	999	0
1998, 2007	0.081	2.4	77558760	999	23
1998, 2008	0.753	0.1	77558760	999	0
1998, 2009	0.172	0.3	77558760	999	2
1998, 2010	0.518	0.1	77558760	999	0
1998, 2011	0.697	0.1	77558760	999	0
1998, 2012	0.697	0.1	77558760	999	0
1998, 2013	0.652	0.1	77558760	999	0
1998, 2014	0.193	0.1	77558760	999	0
1998, 2015	0.598	0.1	77558760	999	0
1999, 2000	0.067	6.8	77558760	999	67
1999, 2001	0.675	0.1	77558760	999	0
1999, 2002	0.847	0.1	77558760	999	0
1999, 2003	0.835	0.1	77558760	999	0
1999, 2004	0.704	0.1	77558760	999	0
1999, 2005	0.798	0.1	77558760	999	0
1999, 2006	0.625	0.1	77558760	999	0
1999, 2007	0.412	0.1	77558760	999	0
1999, 2008	0.746	0.1	77558760	999	0
1999, 2009	0.265	0.1	77558760	999	0
1999, 2010	0.098	3.1	77558760	999	30
1999, 2011	0.705	0.1	77558760	999	0
1999, 2012	0.705	0.1	77558760	999	0
1999, 2013	0.642	0.1	77558760	999	0
1999, 2014	0.326	0.1	77558760	999	0
1999, 2015	0.639	0.1	77558760	999	0
2000, 2001	0.847	0.1	77558760	999	0
2000, 2002	0.848	0.1	77558760	999	0
2000, 2003	0.991	0.1	77558760	999	0
2000, 2004	0.834	0.1	77558760	999	0
2000, 2005	0.968	0.1	77558760	999	0
2000, 2006	0.764	0.1	77558760	999	0
2000, 2007	0.352	0.1	77558760	999	0
2000, 2008	0.814	0.1	77558760	999	0
2000, 2009	0.266	0.2	77558760	999	1
2000, 2010	0.067	8.4	77558760	999	83

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
2000, 2011	0.702	0.1	77558760	999	0
2000, 2012	0.702	0.1	77558760	999	0
2000, 2013	0.625	0.1	77558760	999	0
2000, 2014	0.285	0.1	77558760	999	0
2000, 2015	0.648	0.1	77558760	999	0
2001, 2002	0.955	0.1	77558760	999	0
2001, 2003	0.69	0.1	77558760	999	0
2001, 2004	0.184	1.2	77558760	999	11
2001, 2005	0.374	0.1	77558760	999	0
2001, 2006	0.299	0.2	77558760	999	1
2001, 2007	1	0.1	77558760	999	0
2001, 2008	1	0.1	77558760	999	0
2001, 2009	0.93	0.1	77558760	999	0
2001, 2010	0.465	0.1	77558760	999	0
2001, 2011	0.93	0.1	77558760	999	0
2001, 2012	0.93	0.1	77558760	999	0
2001, 2013	0.815	0.1	77558760	999	0
2001, 2014	0.853	0.1	77558760	999	0
2001, 2015	0.953	0.1	77558760	999	0
2002, 2003	0.979	0.1	77558760	999	0
2002, 2004	0.952	0.1	77558760	999	0
2002, 2005	0.972	0.1	77558760	999	0
2002, 2006	0.935	0.1	77558760	999	0
2002, 2007	0.805	0.1	77558760	999	0
2002, 2008	0.642	0.1	77558760	999	0
2002, 2009	0.794	0.1	77558760	999	0
2002, 2010	0.865	0.1	77558760	999	0
2002, 2011	0.431	0.1	77558760	999	0
2002, 2012	0.431	0.1	77558760	999	0
2002, 2013	0.049	10.5	77558760	999	104
2002, 2014	0.758	0.1	77558760	999	0
2002, 2015	0.527	0.1	77558760	999	0
2003, 2004	0.917	0.1	77558760	999	0
2003, 2005	0.706	0.1	77558760	999	0
2003, 2006	0.919	0.1	77558760	999	0
2003, 2007	1	0.1	77558760	999	0
2003, 2008	1	0.1	77558760	999	0
2003, 2009	1	0.1	77558760	999	0
2003, 2010	0.823	0.1	77558760	999	0
2003, 2011	0.978	0.1	77558760	999	0
2003, 2012	0.978	0.1	77558760	999	0
2003, 2013	0.905	0.1	77558760	999	0
2003, 2014	0.979	0.1	77558760	999	0
2003, 2015	0.993	0.1	77558760	999	0
2004, 2005	0.785	0.1	77558760	999	0
2004, 2006	0.316	0.1	77558760	999	0
2004, 2007	1	0.1	77558760	999	0
2004, 2008	1	0.1	77558760	999	0
2004, 2009	0.945	0.1	77558760	999	0
2004, 2010	0.491	0.1	77558760	999	0
2004, 2011	0.93	0.1	77558760	999	0
2004, 2012	0.93	0.1	77558760	999	0
2004, 2013	0.81	0.1	77558760	999	0
2004, 2014	0.845	0.1	77558760	999	0

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
2004, 2015	0.952	0.1	77558760	999	0
2005, 2006	0.808	0.1	77558760	999	0
2005, 2007	1	0.1	77558760	999	0
2005, 2008	1	0.1	77558760	999	0
2005, 2009	0.998	0.1	77558760	999	0
2005, 2010	0.685	0.1	77558760	999	0
2005, 2011	0.966	0.1	77558760	999	0
2005, 2012	0.966	0.1	77558760	999	0
2005, 2013	0.883	0.1	77558760	999	0
2005, 2014	0.96	0.1	77558760	999	0
2005, 2015	0.985	0.1	77558760	999	0
2006, 2007	0.98	0.1	77558760	999	0
2006, 2008	0.992	0.1	77558760	999	0
2006, 2009	0.827	0.1	77558760	999	0
2006, 2010	0.504	0.1	77558760	999	0
2006, 2011	0.892	0.1	77558760	999	0
2006, 2012	0.892	0.1	77558760	999	0
2006, 2013	0.768	0.1	77558760	999	0
2006, 2014	0.742	0.1	77558760	999	0
2006, 2015	0.91	0.1	77558760	999	0
2007, 2008	0.651	0.1	77558760	999	0
2007, 2009	0.164	0.9	77558760	999	8
2007, 2010	0.529	0.1	77558760	999	0
2007, 2011	0.648	0.1	77558760	999	0
2007, 2012	0.648	0.1	77558760	999	0
2007, 2013	0.627	0.1	77558760	999	0
2007, 2014	0.081	4.6	77558760	999	45
2007, 2015	0.506	0.1	77558760	999	0
2008, 2009	0.578	0.1	77558760	999	0
2008, 2010	0.812	0.1	77558760	999	0
2008, 2011	0.5	0.1	77558760	999	0
2008, 2012	0.5	0.1	77558760	999	0
2008, 2013	0.591	0.1	77558760	999	0
2008, 2014	0.442	0.1	77558760	999	0
2008, 2015	0.189	0.3	77558760	999	2
2009, 2010	0.363	0.1	77558760	999	0
2009, 2011	0.611	0.1	77558760	999	0
2009, 2012	0.611	0.1	77558760	999	0
2009, 2013	0.608	0.1	77558760	999	0
2009, 2014	0.122	2.3	77558760	999	22
2009, 2015	0.539	0.1	77558760	999	0
2010, 2011	0.727	0.1	77558760	999	0
2010, 2012	0.727	0.1	77558760	999	0
2010, 2013	0.651	0.1	77558760	999	0
2010, 2014	0.405	0.2	77558760	999	1
2010, 2015	0.713	0.1	77558760	999	0
2011, 2012	-0.067	100	77558760	999	999
2011, 2013	0.309	0.1	77558760	999	0
2011, 2014	0.518	0.1	77558760	999	0
2011, 2015	0.253	0.7	77558760	999	6
2012, 2013	0.309	0.1	77558760	999	0
2012, 2014	0.518	0.1	77558760	999	0
2012, 2015	0.253	0.3	77558760	999	2
2013, 2014	0.577	0.1	77558760	999	0

Groups	Significance Statistic	Possible Level %	Actual Permutations	Number >= Permutations	Observed
2013, 2015	0.455	0.1	77558760	999	0
2014, 2015	0.322	0.2	77558760	999	1

Table 4.9-5. ANOSIM. Pairwise comparison. Species evenness.

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1988, 1989	0.959	0.1	77558760	999	0
1988, 1990	0.982	0.1	77558760	999	0
1988, 1991	0.966	0.1	77558760	999	0
1988, 1992	1	0.1	77558760	999	0
1988, 1993	0.883	0.1	77558760	999	0
1988, 1994	0.994	0.1	77558760	999	0
1988, 1995	1	0.1	77558760	999	0
1988, 1996	0.938	0.1	77558760	999	0
1988, 1997	0.887	0.1	77558760	999	0
1988, 1998	0.683	0.1	77558760	999	0
1988, 1999	0.889	0.1	77558760	999	0
1988, 2000	0.953	0.1	77558760	999	0
1988, 2001	0.124	2	77558760	999	19
1988, 2002	0.892	0.1	77558760	999	0
1988, 2003	-0.025	77	77558760	999	769
1988, 2004	0.549	0.1	77558760	999	0
1988, 2005	0.367	0.1	77558760	999	0
1988, 2006	-0.019	70.9	77558760	999	708
1988, 2007	0.774	0.1	77558760	999	0
1988, 2008	0.939	0.1	77558760	999	0
1988, 2009	0.951	0.1	77558760	999	0
1988, 2010	0.792	0.1	77558760	999	0
1988, 2011	0.9	0.1	77558760	999	0
1988, 2012	0.9	0.1	77558760	999	0
1988, 2013	0.838	0.1	77558760	999	0
1988, 2014	0.759	0.1	77558760	999	0
1988, 2015	0.908	0.1	77558760	999	0
1989, 1990	0.943	0.1	77558760	999	0
1989, 1991	-0.032	77.9	77558760	999	778
1989, 1992	1	0.1	77558760	999	0
1989, 1993	0.769	0.1	77558760	999	0
1989, 1994	0.883	0.1	77558760	999	0
1989, 1995	1	0.1	77558760	999	0
1989, 1996	0.536	0.1	77558760	999	0
1989, 1997	-0.037	87.6	77558760	999	875
1989, 1998	0.221	0.1	77558760	999	0
1989, 1999	0.443	0.2	77558760	999	1
1989, 2000	0.009	29.7	77558760	999	296
1989, 2001	0.819	0.1	77558760	999	0
1989, 2002	0.721	0.1	77558760	999	0
1989, 2003	0.891	0.1	77558760	999	0
1989, 2004	0.998	0.1	77558760	999	0
1989, 2005	1	0.1	77558760	999	0
1989, 2006	0.748	0.1	77558760	999	0
1989, 2007	0.456	0.1	77558760	999	0
1989, 2008	0.121	1.8	77558760	999	17
1989, 2009	0.159	0.7	77558760	999	6
1989, 2010	0.125	1.8	77558760	999	17
1989, 2011	0.622	0.1	77558760	999	0
1989, 2012	0.622	0.1	77558760	999	0
1989, 2013	0.604	0.1	77558760	999	0
1989, 2014	0.349	0.1	77558760	999	0

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1989, 2015	0.103	3.7	77558760	999	36
1990, 1991	0.941	0.1	77558760	999	0
1990, 1992	0.626	0.1	77558760	999	0
1990, 1993	0.052	10.8	77558760	999	107
1990, 1994	0.798	0.1	77558760	999	0
1990, 1995	0.337	0.1	77558760	999	0
1990, 1996	0.838	0.1	77558760	999	0
1990, 1997	0.939	0.1	77558760	999	0
1990, 1998	0.926	0.1	77558760	999	0
1990, 1999	0.958	0.1	77558760	999	0
1990, 2000	0.937	0.1	77558760	999	0
1990, 2001	0.978	0.1	77558760	999	0
1990, 2002	0.14	2.5	77558760	999	24
1990, 2003	0.981	0.1	77558760	999	0
1990, 2004	0.979	0.1	77558760	999	0
1990, 2005	0.982	0.1	77558760	999	0
1990, 2006	0.973	0.1	77558760	999	0
1990, 2007	0.94	0.1	77558760	999	0
1990, 2008	0.915	0.1	77558760	999	0
1990, 2009	0.918	0.1	77558760	999	0
1990, 2010	0.926	0.1	77558760	999	0
1990, 2011	0.758	0.1	77558760	999	0
1990, 2012	0.758	0.1	77558760	999	0
1990, 2013	0.095	3.4	77558760	999	33
1990, 2014	0.96	0.1	77558760	999	0
1990, 2015	0.949	0.1	77558760	999	0
1991, 1992	1	0.1	77558760	999	0
1991, 1993	0.759	0.1	77558760	999	0
1991, 1994	0.87	0.1	77558760	999	0
1991, 1995	1	0.1	77558760	999	0
1991, 1996	0.508	0.1	77558760	999	0
1991, 1997	-0.019	61.7	77558760	999	616
1991, 1998	0.209	0.3	77558760	999	2
1991, 1999	0.399	0.1	77558760	999	0
1991, 2000	-0.041	90.6	77558760	999	905
1991, 2001	0.82	0.1	77558760	999	0
1991, 2002	0.704	0.1	77558760	999	0
1991, 2003	0.891	0.1	77558760	999	0
1991, 2004	0.999	0.1	77558760	999	0
1991, 2005	1	0.1	77558760	999	0
1991, 2006	0.742	0.1	77558760	999	0
1991, 2007	0.488	0.1	77558760	999	0
1991, 2008	0.091	4.6	77558760	999	45
1991, 2009	0.108	3.3	77558760	999	32
1991, 2010	0.101	3.6	77558760	999	35
1991, 2011	0.6	0.1	77558760	999	0
1991, 2012	0.6	0.1	77558760	999	0
1991, 2013	0.583	0.1	77558760	999	0
1991, 2014	0.374	0.1	77558760	999	0
1991, 2015	0.074	7.3	77558760	999	72
1992, 1993	0.502	0.1	77558760	999	0
1992, 1994	0.902	0.1	77558760	999	0
1992, 1995	0.933	0.1	77558760	999	0
1992, 1996	0.974	0.1	77558760	999	0

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1992, 1997	1	0.1	77558760	999	0
1992, 1998	1	0.1	77558760	999	0
1992, 1999	1	0.1	77558760	999	0
1992, 2000	1	0.1	77558760	999	0
1992, 2001	1	0.1	77558760	999	0
1992, 2002	0.258	0.2	77558760	999	1
1992, 2003	1	0.1	77558760	999	0
1992, 2004	1	0.1	77558760	999	0
1992, 2005	1	0.1	77558760	999	0
1992, 2006	1	0.1	77558760	999	0
1992, 2007	0.991	0.1	77558760	999	0
1992, 2008	0.992	0.1	77558760	999	0
1992, 2009	1	0.1	77558760	999	0
1992, 2010	1	0.1	77558760	999	0
1992, 2011	0.614	0.1	77558760	999	0
1992, 2012	0.614	0.1	77558760	999	0
1992, 2013	0.368	0.1	77558760	999	0
1992, 2014	1	0.1	77558760	999	0
1992, 2015	1	0.1	77558760	999	0
1993, 1994	0.595	0.1	77558760	999	0
1993, 1995	0.087	4	77558760	999	39
1993, 1996	0.606	0.1	77558760	999	0
1993, 1997	0.772	0.1	77558760	999	0
1993, 1998	0.738	0.1	77558760	999	0
1993, 1999	0.804	0.1	77558760	999	0
1993, 2000	0.749	0.1	77558760	999	0
1993, 2001	0.86	0.1	77558760	999	0
1993, 2002	0.13	2.4	77558760	999	23
1993, 2003	0.875	0.1	77558760	999	0
1993, 2004	0.862	0.1	77558760	999	0
1993, 2005	0.874	0.1	77558760	999	0
1993, 2006	0.855	0.1	77558760	999	0
1993, 2007	0.768	0.1	77558760	999	0
1993, 2008	0.708	0.1	77558760	999	0
1993, 2009	0.712	0.1	77558760	999	0
1993, 2010	0.731	0.1	77558760	999	0
1993, 2011	0.516	0.1	77558760	999	0
1993, 2012	0.516	0.1	77558760	999	0
1993, 2013	0.098	4.1	77558760	999	40
1993, 2014	0.805	0.1	77558760	999	0
1993, 2015	0.773	0.1	77558760	999	0
1994, 1995	0.994	0.1	77558760	999	0
1994, 1996	0.089	1.2	77558760	999	11
1994, 1997	0.804	0.1	77558760	999	0
1994, 1998	0.615	0.1	77558760	999	0
1994, 1999	0.914	0.1	77558760	999	0
1994, 2000	0.822	0.1	77558760	999	0
1994, 2001	0.981	0.1	77558760	999	0
1994, 2002	0.446	0.1	77558760	999	0
1994, 2003	0.989	0.1	77558760	999	0
1994, 2004	0.998	0.1	77558760	999	0
1994, 2005	1	0.1	77558760	999	0
1994, 2006	0.93	0.1	77558760	999	0
1994, 2007	0.779	0.1	77558760	999	0

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1994, 2008	0.715	0.1	77558760	999	0
1994, 2009	0.657	0.1	77558760	999	0
1994, 2010	0.653	0.1	77558760	999	0
1994, 2011	0.34	0.1	77558760	999	0
1994, 2012	0.34	0.1	77558760	999	0
1994, 2013	0.521	0.1	77558760	999	0
1994, 2014	0.923	0.1	77558760	999	0
1994, 2015	0.878	0.1	77558760	999	0
1995, 1996	0.999	0.1	77558760	999	0
1995, 1997	1	0.1	77558760	999	0
1995, 1998	1	0.1	77558760	999	0
1995, 1999	1	0.1	77558760	999	0
1995, 2000	1	0.1	77558760	999	0
1995, 2001	1	0.1	77558760	999	0
1995, 2002	0.587	0.1	77558760	999	0
1995, 2003	1	0.1	77558760	999	0
1995, 2004	1	0.1	77558760	999	0
1995, 2005	1	0.1	77558760	999	0
1995, 2006	1	0.1	77558760	999	0
1995, 2007	0.999	0.1	77558760	999	0
1995, 2008	0.999	0.1	77558760	999	0
1995, 2009	1	0.1	77558760	999	0
1995, 2010	1	0.1	77558760	999	0
1995, 2011	0.972	0.1	77558760	999	0
1995, 2012	0.972	0.1	77558760	999	0
1995, 2013	0.51	0.1	77558760	999	0
1995, 2014	1	0.1	77558760	999	0
1995, 2015	1	0.1	77558760	999	0
1996, 1997	0.489	0.1	77558760	999	0
1996, 1998	0.345	0.1	77558760	999	0
1996, 1999	0.69	0.1	77558760	999	0
1996, 2000	0.464	0.1	77558760	999	0
1996, 2001	0.866	0.1	77558760	999	0
1996, 2002	0.474	0.1	77558760	999	0
1996, 2003	0.912	0.1	77558760	999	0
1996, 2004	0.924	0.1	77558760	999	0
1996, 2005	0.95	0.1	77558760	999	0
1996, 2006	0.812	0.1	77558760	999	0
1996, 2007	0.567	0.1	77558760	999	0
1996, 2008	0.377	0.1	77558760	999	0
1996, 2009	0.312	0.2	77558760	999	1
1996, 2010	0.331	0.1	77558760	999	0
1996, 2011	0.293	0.1	77558760	999	0
1996, 2012	0.293	0.1	77558760	999	0
1996, 2013	0.514	0.1	77558760	999	0
1996, 2014	0.651	0.1	77558760	999	0
1996, 2015	0.544	0.1	77558760	999	0
1997, 1998	0.21	0.1	77558760	999	0
1997, 1999	0.492	0.1	77558760	999	0
1997, 2000	0.024	20.2	77558760	999	201
1997, 2001	0.716	0.1	77558760	999	0
1997, 2002	0.716	0.1	77558760	999	0
1997, 2003	0.81	0.1	77558760	999	0
1997, 2004	0.855	0.1	77558760	999	0

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1997, 2005	0.85	0.1	77558760	999	0
1997, 2006	0.686	0.1	77558760	999	0
1997, 2007	0.514	0.1	77558760	999	0
1997, 2008	0.161	1	77558760	999	9
1997, 2009	0.172	0.4	77558760	999	3
1997, 2010	0.143	0.3	77558760	999	2
1997, 2011	0.634	0.1	77558760	999	0
1997, 2012	0.634	0.1	77558760	999	0
1997, 2013	0.608	0.1	77558760	999	0
1997, 2014	0.352	0.2	77558760	999	1
1997, 2015	0.16	0.5	77558760	999	4
1998, 1999	0.17	0.2	77558760	999	1
1998, 2000	0.152	1.1	77558760	999	10
1998, 2001	0.481	0.1	77558760	999	0
1998, 2002	0.661	0.1	77558760	999	0
1998, 2003	0.635	0.1	77558760	999	0
1998, 2004	0.646	0.1	77558760	999	0
1998, 2005	0.757	0.1	77558760	999	0
1998, 2006	0.515	0.1	77558760	999	0
1998, 2007	0.121	0.5	77558760	999	4
1998, 2008	0.257	0.2	77558760	999	1
1998, 2009	0.123	3.2	77558760	999	31
1998, 2010	-0.036	76.9	77558760	999	768
1998, 2011	0.536	0.2	77558760	999	1
1998, 2012	0.536	0.1	77558760	999	0
1998, 2013	0.586	0.2	77558760	999	1
1998, 2014	0.02	23.1	77558760	999	230
1998, 2015	0.066	8.9	77558760	999	88
1999, 2000	0.293	0.1	77558760	999	0
1999, 2001	0.697	0.1	77558760	999	0
1999, 2002	0.778	0.1	77558760	999	0
1999, 2003	0.791	0.1	77558760	999	0
1999, 2004	0.963	0.1	77558760	999	0
1999, 2005	0.992	0.1	77558760	999	0
1999, 2006	0.681	0.1	77558760	999	0
1999, 2007	0.146	0.6	77558760	999	5
1999, 2008	0.687	0.1	77558760	999	0
1999, 2009	0.477	0.1	77558760	999	0
1999, 2010	0.183	0.1	77558760	999	0
1999, 2011	0.683	0.1	77558760	999	0
1999, 2012	0.683	0.1	77558760	999	0
1999, 2013	0.671	0.1	77558760	999	0
1999, 2014	0.156	0.9	77558760	999	8
1999, 2015	0.064	5.8	77558760	999	57
2000, 2001	0.799	0.1	77558760	999	0
2000, 2002	0.686	0.1	77558760	999	0
2000, 2003	0.876	0.1	77558760	999	0
2000, 2004	0.987	0.1	77558760	999	0
2000, 2005	0.998	0.1	77558760	999	0
2000, 2006	0.724	0.1	77558760	999	0
2000, 2007	0.409	0.1	77558760	999	0
2000, 2008	0.126	2.4	77558760	999	23
2000, 2009	0.069	8.8	77558760	999	87
2000, 2010	0.052	12	77558760	999	119

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2000, 2011	0.572	0.1	77558760	999	0
2000, 2012	0.572	0.1	77558760	999	0
2000, 2013	0.569	0.1	77558760	999	0
2000, 2014	0.316	0.1	77558760	999	0
2000, 2015	0.029	17.2	77558760	999	171
2001, 2002	0.863	0.1	77558760	999	0
2001, 2003	0.022	23.9	77558760	999	238
2001, 2004	0.365	0.1	77558760	999	0
2001, 2005	0.073	6.3	77558760	999	62
2001, 2006	0.051	8.6	77558760	999	85
2001, 2007	0.6	0.1	77558760	999	0
2001, 2008	0.828	0.1	77558760	999	0
2001, 2009	0.824	0.1	77558760	999	0
2001, 2010	0.603	0.1	77558760	999	0
2001, 2011	0.845	0.1	77558760	999	0
2001, 2012	0.845	0.1	77558760	999	0
2001, 2013	0.79	0.1	77558760	999	0
2001, 2014	0.518	0.1	77558760	999	0
2001, 2015	0.721	0.1	77558760	999	0
2002, 2003	0.882	0.1	77558760	999	0
2002, 2004	0.866	0.1	77558760	999	0
2002, 2005	0.885	0.1	77558760	999	0
2002, 2006	0.847	0.1	77558760	999	0
2002, 2007	0.728	0.1	77558760	999	0
2002, 2008	0.63	0.1	77558760	999	0
2002, 2009	0.611	0.1	77558760	999	0
2002, 2010	0.647	0.1	77558760	999	0
2002, 2011	0.319	0.2	77558760	999	1
2002, 2012	0.319	0.1	77558760	999	0
2002, 2013	-0.044	89.1	77558760	999	890
2002, 2014	0.778	0.1	77558760	999	0
2002, 2015	0.728	0.1	77558760	999	0
2003, 2004	0.5	0.1	77558760	999	0
2003, 2005	0.193	0.3	77558760	999	2
2003, 2006	-0.044	98.4	77558760	999	983
2003, 2007	0.708	0.1	77558760	999	0
2003, 2008	0.889	0.1	77558760	999	0
2003, 2009	0.898	0.1	77558760	999	0
2003, 2010	0.73	0.1	77558760	999	0
2003, 2011	0.878	0.1	77558760	999	0
2003, 2012	0.878	0.1	77558760	999	0
2003, 2013	0.82	0.1	77558760	999	0
2003, 2014	0.706	0.1	77558760	999	0
2003, 2015	0.827	0.1	77558760	999	0
2004, 2005	0.474	0.1	77558760	999	0
2004, 2006	0.488	0.1	77558760	999	0
2004, 2007	0.86	0.1	77558760	999	0
2004, 2008	0.896	0.1	77558760	999	0
2004, 2009	0.959	0.1	77558760	999	0
2004, 2010	0.75	0.1	77558760	999	0
2004, 2011	0.89	0.1	77558760	999	0
2004, 2012	0.89	0.1	77558760	999	0
2004, 2013	0.816	0.1	77558760	999	0
2004, 2014	0.749	0.1	77558760	999	0

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2004, 2015	0.958	0.1	77558760	999	0
2005, 2006	0.275	0.1	77558760	999	0
2005, 2007	0.875	0.1	77558760	999	0
2005, 2008	0.928	0.1	77558760	999	0
2005, 2009	0.986	0.1	77558760	999	0
2005, 2010	0.843	0.1	77558760	999	0
2005, 2011	0.909	0.1	77558760	999	0
2005, 2012	0.909	0.1	77558760	999	0
2005, 2013	0.836	0.1	77558760	999	0
2005, 2014	0.891	0.1	77558760	999	0
2005, 2015	0.991	0.1	77558760	999	0
2006, 2007	0.595	0.1	77558760	999	0
2006, 2008	0.746	0.1	77558760	999	0
2006, 2009	0.733	0.1	77558760	999	0
2006, 2010	0.594	0.1	77558760	999	0
2006, 2011	0.814	0.1	77558760	999	0
2006, 2012	0.814	0.1	77558760	999	0
2006, 2013	0.778	0.1	77558760	999	0
2006, 2014	0.597	0.1	77558760	999	0
2006, 2015	0.688	0.1	77558760	999	0
2007, 2008	0.625	0.1	77558760	999	0
2007, 2009	0.425	0.1	77558760	999	0
2007, 2010	0.16	0.6	77558760	999	5
2007, 2011	0.61	0.1	77558760	999	0
2007, 2012	0.61	0.1	77558760	999	0
2007, 2013	0.659	0.1	77558760	999	0
2007, 2014	0.073	5.9	77558760	999	58
2007, 2015	0.139	0.7	77558760	999	6
2008, 2009	0.081	4.7	77558760	999	46
2008, 2010	0.137	1.2	77558760	999	11
2008, 2011	0.513	0.1	77558760	999	0
2008, 2012	0.513	0.1	77558760	999	0
2008, 2013	0.574	0.1	77558760	999	0
2008, 2014	0.512	0.1	77558760	999	0
2008, 2015	0.262	0.3	77558760	999	2
2009, 2010	0.016	26.6	77558760	999	265
2009, 2011	0.512	0.1	77558760	999	0
2009, 2012	0.512	0.1	77558760	999	0
2009, 2013	0.551	0.1	77558760	999	0
2009, 2014	0.411	0.1	77558760	999	0
2009, 2015	0.175	1.2	77558760	999	11
2010, 2011	0.527	0.1	77558760	999	0
2010, 2012	0.527	0.1	77558760	999	0
2010, 2013	0.57	0.1	77558760	999	0
2010, 2014	0.109	3.2	77558760	999	31
2010, 2015	0.022	20.8	77558760	999	207
2011, 2012	-0.067	100	77558760	999	999
2011, 2013	0.388	0.1	77558760	999	0
2011, 2014	0.679	0.1	77558760	999	0
2011, 2015	0.601	0.1	77558760	999	0
2012, 2013	0.388	0.1	77558760	999	0
2012, 2014	0.679	0.1	77558760	999	0
2012, 2015	0.601	0.1	77558760	999	0
2013, 2014	0.67	0.1	77558760	999	0

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2013, 2015	0.605	0.1	77558760	999	0
2014, 2015	0.114	3.2	77558760	999	31

Table 4.9-6. General Linear Model. ANOVA summary table (1988−2015). The statistical significance between each of the species diversity and evenness estimators and the predictor variables at the 95% confidence level.

Species Diversity	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**
Fisher's Alpha Mean	Model	66.1227	5	13.2245	2.85	0.0188
	Residual	492.464	106	4.64589		
	Total (Corr.)	558.587	111			
Shannon Mean	Model	2.51871	5	0.503742	4.36	0.0012
	Residual	12.2459	106	0.115527		
	Total (Corr.)	14.7646	111			
Shannon Exponential Mean	Model	116.372	5	23.2743	4.62	0.0008
	Residual	534.537	106	5.0428		
	Total (Corr.)	650.909	111			
Simpson Inverse mean	Model	24.4579	5	4.89158	3.36	0.0073
	Residual	154.106	106	1.45383		
	Total (Corr.)	178.563	111			
Hill Evenness Index 4	Model	0.0178753	5	0.00357507	0.82	0.5379
	Residual	0.461988	106	0.00435837		
	Total (Corr.)	0.479863	111			
Hill Evenness Index 5	Model	0.0064536	5	0.00129072	0.19	0.9665
	Residual	0.726747	106	0.0068561		
	Total (Corr.)	0.733201	111			

Table 4.9-7. General Linear Model and associated ANOVA Type III Sums of Squares (1988−2015). The statistical significance between each of the species diversity and evenness estimators and the predictor variables at the 95% confidence level.

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
Fisher's Alpha Mean	NAO	1.50471	1	1.50471	0.32	0.5705	Fishers Alpha Mean = 10.6847 + 0.0581297*NAO - 3.33093*AMO - 0.12395*EOF + 0.0040157*Air Temperature - 0.336531*Precipitation	11.80%
	AMO	5.46895	1	5.46895	1.18	0.2804		
	EOF	0.272933	1	0.272933	0.06	0.8090		
	Air Temperature	0.299583	1	0.299583	0.06	0.8000		
	Precipitation	30.799	1	30.799	6.63	0.0114		
	Residual	492.464	106	4.64589				
	Total (corrected)	558.587	111					
Shannon Mean	NAO	0.837661	1	0.837661	7.25	0.0082	Shannon Mean = 1.86743 + 0.0433716*NAO - 0.279728*AMO + 0.004163*EOF + 0.000393946*Air Temperature - 0.0655966*Precipitation	17.14%
	AMO	0.0385694	1	0.0385694	0.33	0.5646		
	EOF	0.000307877	1	0.000307877	0.00	0.9589		
	Air Temperature	0.00288315	1	0.00288315	0.02	0.8748		
	Precipitation	1.17017	1	1.17017	10.13	0.0019		
	Residual	12.2459	106	0.115527				
	Total (corrected)	14.7646	111					
Shannon Exponential Mean	NAO	38.5667	1	38.5667	7.65	0.0067	Shannon Exponential Mean = 7.10952 + 0.294291*NAO - 1.59113*AMO - 0.0799582*EOF + 0.00345965*Air Temperature - 0.441704*Precipitation	17.92%
	AMO	1.24791	1	1.24791	0.25	0.6199		
	EOF	0.113577	1	0.113577	0.02	0.8810		
	Air Temperature	0.22236	1	0.22236	0.04	0.8341		
	Precipitation	53.0578	1	53.0578	10.52	0.0016		
	Residual	534.537	106	5.0428				
	Total (corrected)	650.909	111					
Simpson Inverse Mean	NAO	10.277	1	10.277	7.07	0.0091	Simpson Inverse Mean = 3.82043 + 0.151916*NAO - 0.250236*AMO - 0.0585305*EOF + 0.00131757*Air	13.73%
	AMO	0.0308655	1	0.0308655	0.02	0.8844		
	EOF	0.0608596	1	0.0608596	0.04	0.8383		
	Air Temperature	0.032251	1	0.032251	0.02	0.8819		
	Precipitation	9.87806	1	9.87806	6.79	0.0105		
	Residual	154.106	106	1.45383				
	Total (corrected)	178.563	111					

Dependent Variable	**Source**	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**	**Fitted Model**	**R^2**
							Temperature - 0.190587*Precipitation	
Hill Evenness Index 4	NAO	0.00147682	1	0.00147682	0.34	0.5617	Hill Evenness Index 4 = 0.538226 - 0.00182111*NAO + 0.037926*AMO + 0.00392609*EOF + 0.0000470756*Air Temperature + 0.00526658*Precipitation	3.71%
	AMO	0.000708999	1	0.000708999	0.16	0.6875		
	EOF	0.000273832	1	0.000273832	0.06	0.8026		
	Air Temperature	0.0000411705	1	0.0000411705	0.01	0.9228		
	Precipitation	0.007543	1	0.007543	1.73	0.1912		
	Residual	0.461988	106	0.00435837				
	Total (corrected)	0.479863	111					
Hill Evenness Index 5	NAO	0.0024207	1	0.0024207	0.35	0.5536	Hill Evenness Index 5 = 0.439755 + 0.00233154*NAO - 0.00371522*AMO + 0.00719494*EOF + 0.00019452*Air Temperature + 0.00041495*Precipitation	0.88%
	AMO	0.00000680363	1	0.00000680363	0.00	0.9749		
	EOF	0.000919644	1	0.000919644	0.13	0.7149		
	Air Temperature	0.000702948	1	0.000702948	0.10	0.7494		
	Precipitation	0.0000468251	1	0.0000468251	0.01	0.9343		
	Residual	0.726747	106	0.0068561				
	Total (corrected)	0.733201	111					

CHAPTER 5: ENVIRONMENTAL AND ATMOSPHERIC-OCEANIC VARIABILITY AND THE NEARSHORE MARINE COMMUNITY IN THE MID-ATLANTIC BIGHT REGION (NEW JERSEY, USA)

5.1 Abstract

Community dynamics are influenced by various stressors, but the variability in the climate and oceanic dynamics are among the most powerful factors; changes in the climate and associated ocean conditions are impacting marine communities around the world. The scientific evidence of climate change impacts to specific species and marine communities is mounting, but studies and documented information are lacking for most regions around the world, including the waters of the Mid-Atlantic Bight and specifically off New Jersey. The primary objective of this chapter was to evaluate climate-induced environmental forcing and identify impacts to the marine community off New Jersey over the past 28 years (1988−2015). Environmental and oceanic conditions were significantly different among years and areas. The best environmental predictors of the marine community were primarily water temperature (surface and bottom), maximum depth, NAO, and surface salinity. The marine community was significantly different among years and sampling areas. There was a statistically significant structure in the marine community, and the main species representing the greatest similarity percentages were generally longfin squid (*Loligo pealei*; coldwater-adapted), windowpane flounder (*Scophthalmus aquosus*; coldwater-adapted), and little skate (*Leucoraja erinacea*; coldwater-adapted). The primary species contributing to the dissimilarity were Atlantic butterfish (*Peprilus triacanthus*; warmwater-adapted), longfin squid, scup (*Stenotomus chrysops*; warmwater-adapted), and bay anchovy (*Anchoa mitchilli*; subtropic-adapted). Longfin squid consistently contributed the most to within-group similarity and between-group dissimilarities. The coldwater, warmwater, and subtropic-adapted community was significantly different over time. Generally, longfin squid, little skate, and Atlantic herring (*Clupea harengus*) contributed to the difference in the coldwater-adapted community, and Atlantic butterfish, scup, and northern searobin (*Prionotus carolinus*) contributed to the difference in the warmwater-adapted community over time. The sequential order varied by time-series, but bay anchovy, rough scad (*Trachurus lathami*), and striped anchovy (*Anchoa hepsetus*) constituted between 59 and 73 percent of the dissimilarity in the subtropic-adapted community.

5.2 Introduction

Communities fluctuate in abundance not only because of natural environmental, biological, and demographic stochasticity, but often also with disturbance, stress, or other factors related to anthropogenic activities. Climatological and oceanographic dynamics are among the most powerful factors impacting marine communities around the world (e.g., Brander, 2013).

Environmental conditions influence and control various biological functions, including the geographical range, spatial distribution, and abundance of marine species (Planqué et al. 2011). Water temperature, salinity, dissolved oxygen (DO), depth, and sediment type influence and select fish life-history characteristics (Horne et al. 1989). For freshwater and many open-water coastal species (non-estuary dependent), water temperature is usually the most important environmental factor influencing fish distribution, especially along the zoogeographic transition zone or boundary of a particular species (e.g., Hoese and Moore, 1977; Howell and Auster, 2012; Kuczynski et al. 2017). Water temperature varies annually and seasonal, which usually triggers resident and migratory behavior and spatial distribution (Parker and Dixon, 1998). Based on a species' physiology, all fish have an optimal or preference temperature range that limits their spatial distribution and abundance. Environment conditions can also shift the food web and affect a variety of community metrics (e.g., diversity, size-composition, and relative abundance). Water temperature and oceanic processes are dominant factors that shape species composition (Wood et al. 2009). In Narragansett Bay, Rhode Island, an increase in the abundance of warm-water fish was positively correlated with an increase in water temperature even though Cape Hatteras, North Carolina was classically considered the northern boundary for warm-temperate fauna (Briggs, 1974). The rising water temperature has also recently altered the marine community in Long Island Sound, New York (Howell and Auster, 2012).

Environmental and oceanographic conditions are controlled by the prevailing weather conditions or climate patterns, which seem to be changing at an abnormal rate (Thomas et al. 2017) causing a variety of ecological impacts to marine communities (Pinksky and Mantua, 2014). Climate variation is defined as any significant change in the atmospheric conditions (e.g., air temperature, wind, circulation, and precipitation) considering the historical measures of dispersion (i.e., standard deviation, variance, and mean); climate change has been linked to natural cycles and specific anthropogenic activities (EFARO, 2012; Crozier and Hutchings, 2014; Pinksky and Mantua, 2014). Climate change has caused air temperature, sea surface temperature (SST), and sea level to rise (IPCC, 2007). Slight variations in the environmental conditions caused by changes in climate over the past 40 years have greatly impacted a variety of marine organisms and ecosystems around the world. Some researchers have predicted climate change will increase precipitation, which will slowly change the hydrology in rivers (Folland and Karl, 2001).

Climate change can not only negatively impact individual species and entire marine communities, but it can affect marine fauna in numerous ways. For instance, an increase in sea surface temperature (SST) can affect physiology and biological processes (e.g., growth, reproduction, metabolism, and behavior) because a fish’s body temperature is linked to the environment (Franklin et al. 1995; Moyle and Cech, 2004). Because fish have specific thermal tolerances and ideal/preferred temperature ranges (Hare et al. 2012), any deviation can often lead to changes in distribution, abundance, and seasonal movements. Behavior patterns are often linked to surface or bottom water temperature depending on the species (Krishnakumar and Bhat, 2008). An increase in water temperature can also affect the toxicity of pollutants and the susceptibility of fish to disease (Ficke et al. 2007). Climate change has led to various metabolic changes in fish, such as growth (Castillo-Jordán et al. 2010) and developmental rates, sex ratio, spawning, migration, and seasonal abundance (Daw et al. 2009; Brander, 2010). The severity of the impact is usually associated with the magnitude of the climate change (Hare et al. 2012), and alterations to fish life-history are often region specific (Rijnsdorp et al. 2009). Climate change (e.g., temperature, acidification, and sea level rise) can also alter commercial fishing landings or the susceptibility of fishes (i.e., fishing pressure) to specific fishing fleets (Krishnakumar and Bhat, 2008; Daw 2009; Rijnsdorp et al. 2009). Significant changes in interannual oceanographic conditions (e.g., wind strength and direction) can even influence major upwelling oceanic processes (Rijnsdorp et al. 2009), which affects the local fish community and associated commercial fishing operations (Krishnakumar and Bhat, 2008).

Besides affecting a species' distribution (e.g., Hare et al. 2012), mean size, and life span (Muyodi et al. 2011), fluctuations in seasonal or annual physiochemical conditions can also affect a regional marine community (Reash and Pigg, 1990; Vinebrooke et al. 2004; Krishnakumar and Bhat, 2008; Azzurro et al. 2011; Aschan et al. 2013) and food-chain length (e.g., Bondavalli et al. 2006). Marine communities are vulnerable (direct and indirect impacts) to climate change, but the response and severity depends on various biological or ecological factors, such as resilience to stress or adaptation (Daw et al. 2009; Warfe et al. 2013). Ficke et al. (2007) indicates a major change in the environment conditions can cause fish to either "adapt, migrate, or perish".

Researchers around the world have already predicted and documented numerous abnormalities in marine communities caused by ongoing significant physiochemical shifts (Rijnsdorp et al. 2009; Crozier and Hutchings, 2014; Pinksky and Mantua, 2014). Climate change is causing the spatial distribution and diversity of marine fauna to change around the world (e.g., Poulard and Blanchard, 2005), but much of the published literature has highlighted changes in well-studied areas, such as the North Sea. In general, research in the North Sea has shown that climate change has caused the SST to rise and fish to shift their distribution northward (Perry et al. 2005). In the Bay of Biscay (northeastern Atlantic Ocean), Poulard and Blanchard (2005) found that the relative abundance for fish with a broad distribution expanded, and it contracted for fish with a limited distribution range in latitude. A review by EFARO (2012) found that haddock (*Melanogrammus aeglefinus*) in the North Sea shifted their southern boundary approximately 130 km (northward) in the past 80 to 90 years, while sole (*Solea solea*) migrated southward away from the coast of Holland. The EFARO (2012) also pointed out that cod have shifted their distribution north to northeast, and plaice (*Pleuronectes platessa*) have shifted north to northwest.

Fish commonly found in the western Mediterranean Sea have also been affected by climate change. Based on EFARO's (2012) review, the relative abundance of round sardinella (*Sardinella aurita*) in the Mediterranean Sea has increased from south to north. Moreover, climate change has influenced the range expansion of several invasive species, such as the Indo-Pacific lionfish (*Pterois volitans*). This phenomenon has also been documented in the western North Atlantic Ocean along the east coast of the United States. For instance, Whitfield et al. (2014) reported a connection between warming SSTs in North Carolina waters, and an increase in relative abundance and range expansion of lionfish (*Pterois volitans*), which is an invasive species; it appears the northern range is limited by water temperature (<15.3°C).

The scientific evidence of climate change impacts to specific species and marine communities is mounting (e.g., Wood et al. 2009; Howell and Auster, 2012), but studies describing climate change impacts are lacking for most regions around the world (Johnson, 2012), including the Mid-Atlantic Bight (MAB) and specifically New Jersey coastal waters. The state of New Jersey is located within the MAB in the western North Atlantic Ocean. The MAB is defined as the offshore waters (i.e., beach to continental shelf) between Cape Cod, Massachusetts and Cape Hatteras, North Carolina (Steimle and Zetlin, 2000). The MAB is among the most important oceanic regions in the United States because it supports and provides habitat for many ecological and economical valuable marine resources. In 2016, commercial fishing landings and associated value in the MAB were around 76,366 mt and $255.2 million, respectively (NMFS, 2018). Overall, New Jersey commercial fisheries ranked tenth in landings and ninth in value ($132.3

million) in the United States (NMFS, 2018). Commercial landings in New Jersey represented 79 percent of the total for the MAB. The economic value of commercial fishing landings in New Jersey over the past 10 years ranged between $132.9 and $220.4 million with a mean of $164.8 million (NMFS, 2018).

Information describing the temporary or permanent impacts to marine resources associated with climate variability in regions that support valuable commercial fisheries is crucial to fishery resource managers so they can make informed management decisions. Understanding and managing the impacts of climate variability on fisheries resources is convoluted given the complexity of factors, interactions (inter and intra), and the often unknown biological-environmental connections. The impacts are often dramatically different from one system to the next. Some researchers argue that it is almost impossible to link changes in fish populations to climate change in a given system because of the complexity (Rijnsdorp et al. 2009) of other stressors (e.g., commercial fisheries and coastal development) simultaneously acting on system. Despite the challenges deciphering climate-driven biotic changes, it is conceivable to detect changes in patterns and make generalities by developing appropriate hypotheses and theoretical expectations (Rijnsdorp et al. 2009). Assessing potential impacts (direct and indirect) associated with climate change to a specific species or community can be investigated in variety of ways, but the technical approach should ideally apply an ecological-based perspective (Rice, 2000) that considers both the biological and environmental factors within the community structure (Plinksy and Mantua, 2014). Predicting the distribution and abundance of organisms depends on having adequate ecological knowledge and information (McPherson, 2009).

Given the need to assess the climate-driven biotic change phenomenon, the goal of this research was to describe the connection between climate, atmospheric-ocean variability and the nearshore marine community off New Jersey over the past 28 years. The main objective was to evaluate climate-induced environmental forcing and identify associated changes in the nearshore marine community off New Jersey over the past 28 years (1988−2015). Reviewing the available scientific evidence associated with climate-driven effects on marine communities (e.g., Snover, 2008; Rijnsdorp et al. 2009; Wood et al. 2009; Hare et al. 2012; Howell and Auster, 2012), the overall theoretical expectation was that community structure has changed and the atmospheric-oceanic conditions are linked with specific variations in the marine community off New Jersey over the past 28 years. A set of complex alternative hypothesis was based on published literature. The null and alternative hypotheses consisted of the following:

H_o1: The marine community is constant with time despite the variation in the interannual environmental (DO, salinity, and water temperature) and oceanic (NAO, AMO, and EOF) conditions (1988−2015).

H_{1A}: The marine community changed significantly with time and space (1988−2015).

H_o2: The coldwater, warmwater, and subtropic-adapted community is constant with time despite the variation in the interannual environmental (DO, salinity, and water temperature) and oceanic (NAO, AMO, and EOF) conditions (1988−2015).

H_{2A}: The abundance of coldwater, warmwater, and subtropic-adapted species changed significantly with time and space (1988−2015).

5.3 Methods

5.3.1 Summary

Field-collections were made using standardized sampling gear throughout the New Jersey coastal region (**Figure 5.3.1-1**) at pre-determined stations that were selected under a stratified randomized experimental approach. The methods (study area, experimental survey design, experimental field sampling approach, station selection, field sampling gear, and field sampling and data collection procedures), and the basis for experimental repetition follow the details outlined in Chapter 2 (*Section 2.3 Methods*). Specific data treatment/processing, protocol, and statistical data analysis techniques are discussed below.

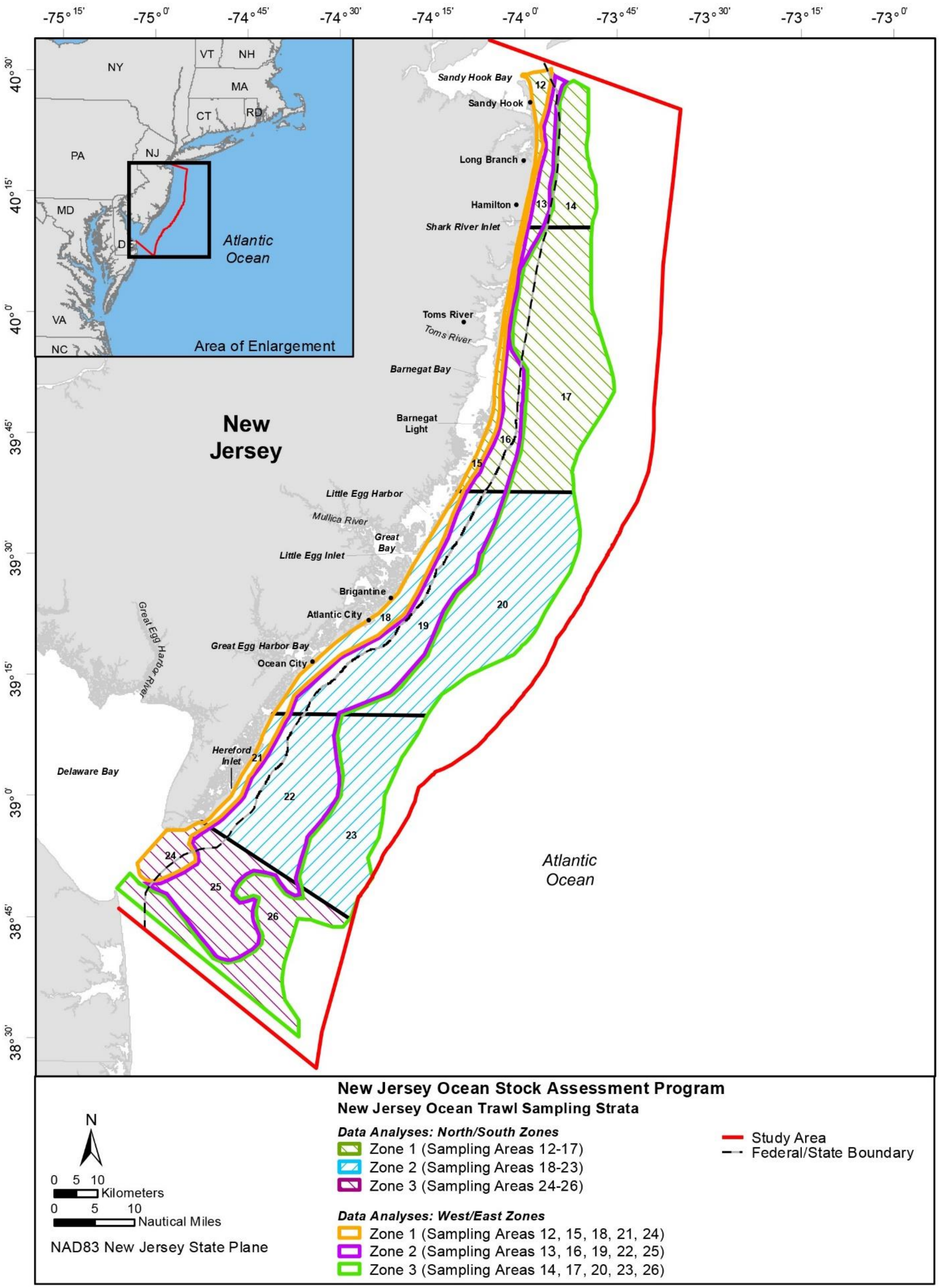

Figure 5.3.1-1. Study Area. New Jersey Offshore Trawl Program.

5.3.2 Data Collection Protocol

Marine species were classified as coldwater-adapted (primarily distributed in cold temperate regions), warmwater-adapted (primarily distributed in warm temperate regions), and subtropic-adapted (primarily distributed in subtropical and tropical regions) species following the approach by Howell and Auster (2012). Marine species were classified by reviewing Froese and Pauly (2018) and available life history literature (Murdy et al. 1997; Collette and Klein-MacPhee 2002; Able and Fahay, 1998; Able and Fahay, 2010) describing a species' distribution relative to the MAB, water temperature tolerance (minimum and maximum), preferred water temperature range, and preferred spawning water temperature. Various marine species had wide-ranging water temperature tolerances, so various procedures were also applied to differentiate and categorize the species into one of the three water temperature groups (coldwater, warmwater, subtropic-adapted). In general, the mean preferred water temperature was used to select the best water temperature preference for a species. Species preferring water temperature <15°C were generally classified as coldwater-adapted, while those preferring water temperatures 15−29°C were classified as warmwater-adapted. Species preferring temperatures >30°C were classified as subtropic-adapted. For the purpose of these analyses, only coldwater-adapted species are reported.

Three long-term climatological or oceanic-atmospheric indices were used to examine the variability in the air-sea connection in the North Atlantic Ocean: NAO, AMO, and EOF (Chapter 3). All three climate indices were downloaded from NOAA's Earth System Research Laboratory, Physical Sciences Division (https://www.esrl.noaa.gov/psd/data/climateindices/list/).

5.3.3 Data Treatment/Processing/Assumptions

Sample Independence

It was assumed the environmental, oceanic, and biological measurements (samples) were representative of the population within the study area given that the experimental design used randomization to reduce sampling bias. Statistical power was considered high given the balanced sampling approach and the large number of observations over the duration of the study. It was also assumed the environmental and biological data were independent observations (i.e., the measurement of one observation did not affect the value of other observations) given that the experimental design considered time and space (i.e., spatial autocorrelation). The coastal waters off New Jersey are a dynamic oceanographic and biological system; conditions can vary significantly within a short distance or time period. Moreover, it was assumed the number of marine fauna in one year was independent of the number of marine fauna in the previous year given various biological factors, such as the relative short life-span (< 1 year) of many of the species collected in the study area, high mortality, the low annual reproductive success, and low annual recruitment from one year to the next. To minimize any potential spatial non-independence, data were pooled among stations within each individual area.

Assumption

For the purpose this study, it was assumed the main stressors impacting the marine community in the study area were the environmental and atmospheric-oceanic conditions. The influence of fisheries and other known stressors (e.g., habitat loss and poor water quality) on the marine community were excluded from these analyses even though many species in the study area were direct and indirect targets of either commercial or recreational fisheries. Thus, the interpretation of the findings should be viewed with some reservation, because possible covariates of the focal stressors were not examined.

5.3.4 Statistical Analysis

To evaluate the oceanic-atmospheric conditions and indices, and long-term historical data were compiled, sorted, and summarized. Before initiating statistical hypothesis tests and if necessary, data were transformed (e.g., logarithmic, square root, fourth root, or arcsine) to meet normativity assumptions. Kolmogorov-Smirnov and Bartlett tests were used to assess normality and homoscedacity (Zar, 1999). To ensure robustness, normality was also be checked by constructing a normal probability plot and examining the residuals. Outlier observations were also investigated before being rejected or retained.

The nearshore marine community and oceanic conditions were examined using 28 years (1988−2015) of fishery-independent monitoring data (environmental and biological). Data were compiled, sorted, and summarized. Before initiating statistical hypothesis tests, environmental and biological data were transformed (e.g., logarithmic, square root, fourth root, or arcsine) to meet normativity assumptions, and down-weight the statistical effects (i.e., reduce skewness) of abundant taxa, while allowing less common taxa to contribute to sample discernment (Thorne et al. 1999; Korsman, 2013). Marine community (estimated abundance, temperature preference [coldwater-adapted species]) data was evaluated using two approaches: single dataset (pooling data) and time-series dataset. The first, single data set (pooling), consisted of pooling the 28-year historical data (1988−2015) into one data set. The second, a time-series approach, consisted of segregating the historical data (1988−2015) into six individual 5-year time-series periods (1988−1992; 1993−1997; 1998−2002; 2003−2007; 2008−2012, and 2013−2015). One of the reasons to segregate the data was to help discern patterns and test for differences among space, and time periods. Another reason to segregate the data is that most available data for fisheries monitoring data is usually only two to five years in length given the associated costs with sampling marine environments. Thus, using this approach could help other researchers around the world to examine, test, and interpret marine community data in their respected region.

To evaluate the data using multivariate techniques, environmental data were normalized (mean subtracted and divided by standard deviation), checked for collinearity with a draftsman plot, and an Euclidean distance resemblance matrix was produced using PRIMER (Plymouth Routines in Multivariate Ecological Research) version 7 statistical package (Clarke and Warwick, 2001; Clarke and Gorley, 2006). The statistical significance level was defined as $P < 0.05$ for all analyses (Zar, 1999). In the presence of significance at the 95 percent confidence level, *post-hoc* multiple comparison tests were used to differentiate the specific differences among the population means. Data were evaluated using various software, including Microsoft Access®, Microsoft Excel®, Statgraphics Centurion XVI®, SYSTAT®, and PRIMER®.

Environmental conditions (water temperature, salinity, DO), depth, historical atmospheric-oceanic metrics (NAO, AMO, and EOF), and marine fauna were evaluated in conjunction by multivariate procedures to determine potential changes over time, using normalized data. A two-dimensional (2d) non-multidimensional scaling (nMDS), non-parametric rank-based, scatter plot was used to examine the measure of dissimilarity in the environmental conditions over time; based on Euclidean distance of monthly measurements. The Kruskal fit scheme and minimum stress were set at 1 and 0.01, respectively. Non-metric MDS is a distance based procedure that ordinates study units based on rank dissimilarities (Clarke and Warwick, 2001). Because the procedure avoids assumptions of linearity and accurately maps sample units in ordination space by proportion to ecological distance, nMDS is considered well suited for examining patterns in environmental and biological structure. Stress values indicate how well the two-dimensional plot represent relationships among samples in the multidimensional space; values < 0.15 indicate a good fit

(Clarke and Warwick, 2001). A Principle Components Analysis (PCA) ordination procedure was also used to estimate the percent in variance explained by each PC axis (up to five) and examine any patterns in the environmental factors. The maximum number of principal components was set as five because it explained most of the total variation. In general, the first three PC axes explains more than 40-50 percent of the total variation. An empirical rule-of-thumb is to use a procedure that explains about 70-75 percent (Clarke and Warwick, 2001). Unlike nMDS, PCA assumes linear relationships. The BEST analysis procedure in Primer® was used to select the species "best explaining" or linked to the environmental conditions by maximizing the Spearman rank correlation between their respective resemblance matrices. The BVSTEP algorithm, a stepwise search over the trial variables, was applied to add and remove one variable at time to get the optimum correlation within levels of time. A permutation significance test was calculated based on random permutations of sample names, and the number of permutation was set at 99 (Clarke and Warwick, 2001). The control parameters (rho and delta) defining when the procedure stopped adding variables were set at > 0.95 and the Delta rho was set at < 0.001, respectively. These criteria are conservative values for choosing the explanatory variables (Clarke and Warwick, 2001).

The significance of patterns illustrated by nMDS comparisons were tested using an Analysis of Similarities (ANOSIM). Separate one-way ANOSIMs were used to conduct pairwise comparisons in conditions among time. The null hypothesis for ANOSIM was there were no differences in the conditions among time periods. The resultant global *R* value of this test is a measure of variation between groups compared to variation within groups scaled to take values over a fixed range up to 1; high *R* values indicating greater dissimilarity. The Spearman rank correlation method was applied to test for an unordered factor with no replicates correlation. The maximum number of permutations was set at 999. The *R* or rho values for pairwise tests were calculated to determine the pair-wise differences. Differences in conditions among time were also tested by one-way and multivariate permutational multivariate ANOVA (PERMANOVA). This is a technique that uses label permutation to estimate the distribution of the test statistics under the hypothesis that within-group distances are not significantly different from between group distances (Clarke and Warwick, 2001). The permutation of residuals under a reduced model applying a type III (partial) sums of squares approach was selected to account for the unbalanced design. A *post-hoc* pair-wise test was used to examine within-group differences in oceanic conditions. Non-metric MDS comparisons illustrating significant trends were examined using ANOSIM.

Normalized biological data were examined using a variety of multivariate approaches. The Bray-Curtis metric was used to handle the large proportion of absent and uncommon species. A Bray-Curtis similarity resemblance matrix was produced via PRIMER. A two dimensional nMDS scatter plot was used to compare potential change in the marine community over time; nMDS analyses were conducted on Bray-Curtis coefficient similarity of the annual marine community resemblance and time. The Kruskal fit scheme and minimum stress was set at 1 and 0.01, respectively. A Principle Coordinates (PCO) ordination procedure was used to estimate the percent in variance explained by each PC axis and examine any patterns in the factors. The maximum number of principal components was set as five because it explained most of the total variation. In general, the first three PC axes explains more than 40-50 percent of the total variation. An empirical rule-of-thumb is to use a procedure that explains about 70-75 percent (Clarke and Warwick, 2001). The PCO procedure was used because the marine community consisted of many uncommon, less abundant marine fauna. The BEST analysis procedure in Primer® was used to select the environmental variables "best explaining" community pattern by maximizing the

Spearman rank correlation between their respective resemblance matrices, using the same BVSTEP algorithm as the one used to examine the environmental variables.

A step-wise distance based analysis on a distance linear model (DLM) for environmental predictors of the marine community was conducted using the AIC selection criterion. The number of permutations for significance tests was 999. The significance of patterns illustrated by nMDS comparisons were tested using an ANOSIM. Separate one-way ANOSIMs were used to conduct pairwise comparisons in the marine community among time and space. The null hypothesis for ANOSIM was there were no differences in the marine community among time periods. The Spearman rank correlation method was applied to test for an unordered factor with no replicates correlation. The maximum number of permutations was set at 999. The *R* or rho values for pairwise tests was calculated to determine the pair-wise differences. Differences in the marine community among time and space were also tested by two-way and multivariate PERMANOVA, as was applied to environmental variables. A *post-hoc* pair-wise test was used to examine within-group differences in the marine community. Non-metric MDS comparisons illustrating significant trends using ANOSIM were then analyzed using SIMPER analysis to determine which individual populations contributed to the significant trends. Similarity profile analysis (SIMPROF) was used to test for structure in the abiotic data. First a resemblance profile was determined by ranking the resemblance matrix for the data. A mean profile was then calculated by randomizing the order of each variable's values and re-calculating the profile. The pi statistic was calculated as the deviation of the actual data profile with the mean one. This value was then compared with the deviations of further randomly generated profiles to test for significance. There was no structure in the data (species composition) was the null hypothesis. A two-way SIMPER was used to identify which species in the marine community contributed the most to the dissimilarity Bray-Curtis similarity between and within groups by time and space. The cumulative percentage cut-off listing the highest-contributing variables was set at 70 percent. Individual tables were constructed to help interpret the SIMPER results over time. To compare differences between k-dominance plot curves for all pairs of the selected samples, a resemblance matrix was computed using DOMDIS procedures in Primer®. A one-way ANOSIM was then used to conduct pairwise comparisons in the *k*-dominance plot curves among time.

5.4 Results

5.4.2 Atmospheric-Oceanic Indices and Marine Community Connection

5.4.2.1 Environmental and Oceanic Conditions

Multivariate ordination procedures showed there were some associations among the environmental and oceanic conditions and the marine community. Draftsman plots showed that associations between variables were approximately linear (**Figure 5.9.1**). Water temperature, DO, salinity surface and bottom pairs displayed a strong linear association. Separate nMDSs showed some overlap in the rank order ordination among years suggesting the environmental conditions were crudely similar (*stress* = 0.18−0.19) in some years (1988−1992, 1993−1997, and 1998−2002), and more similar (*stress* = 0.07−0.15) in other years (2003−2007, 2008−2012, and 2013−2015). However, separate PCAs and associated Pearson correlations overlay vector procedures better explained the data **(Figure 5.9.2**). The annual percent of variance explained by the first two PC axes was between 55.3and 62.0 percent. The explained variance in the abiotic conditions was highest during 1998 through 2002 and lowest during 2013 through 2015. The greatest coefficients in the linear combination of variables comprising PC1 were surface and bottom water, with inverse relationships to surface and bottom DO. Salinity (surface and bottom) was the greatest coefficient in the linear combination of variables comprising PC2, though maximum depth was also related.

The environmental conditions are changing significantly with time. Separate one-way ANOSIMs showed the environmental and oceanic conditions were significantly different among years ($R = 0.107-0.260$; $P = 0.001$; **Table 5.9.1**) and sampling areas ($R = 0.095-0.168$; $P = 0.001$**; Table 5.9.2**); low R values (strength) showed minimal separation among samples per time-series. The lowest R value (0.107) showing separation among time samples was in 1988 through 1992 and the highest (0.260) was in 1993 through 1997. The lowest R value (0.095) showing separation among sampling areas was in 2013 through 2015 and the highest (0.168) was in 2003 through 2007. Separate one-way PERMANOVAs ($P = 0.001$; **Table 5.9.3**), and the less sensitive PERMDISPs also showed the abiotic conditions varied significantly ($P = 0.001$ [1988−1992, 2008−2012]; $P = 0.041$ [2013−2015]) among years (**Table 5.9.4**).

5.4.2.2 Marine Community

Multivariate ordination procedures showed there were associations and significant differences (Bray-Curtis similarity) in the marine community (abundance) over time and space depending on the abiotic factors. Separate 2-dimensional nMDS tests fitted ($Stress = 0.16$) the similarity of the marine community samples (abundance) over time. However, PCO procedures seemed to better explain the biological data. Distinct PCO procedures showed there was some separation in the marine community over time (**Figure 5.9.4**). In general, the total variation explained by PCO1 axis decreased slightly with time. The total variation ranged from 41.9 percent during 2003 through 2007 to 57.2 percent during 2008 through 2012. Overall, around 44.8 percent of the total variability in the marine community (abundance) was explained by the ordination procedure (PCO1 axis [14.3%] and PCO2 axis [30.5%]) during 1988 through 2015. The marine community (abundance) was primarily associated with the water temperature (surface and bottom), maximum depth, and salinity (surface and bottom). The PCOs also showed the marine community was somewhat associated with the DO (surface and bottom) and the EOF Index.

Separate DLMs (μ= $r^2 = 0.413$; $P < 0.05$) significantly determined the sequential order of the environmental factors (surface temperature, maximum depth, bottom temperature, NAO Index, surface salinity, bottom DO, EOF Index, AMO Index, and surface DO) linked with the marine community during 1988 through 2015 (**Table. 5.9.6**). The procedures least explained ($r^2 = 0.39$) the association between the marine community during 2008 through 2112, and best explained ($r^2 = 0.43$) the connection during 2013 through 2015. The order varied between different year groups, but surface water temperature, bottom water temperature, and maximum depth were always the first three factors correlating with the marine community. Overall, water temperature (surface and bottom), maximum depth, NAO, and surface salinity were the best explained the marine community; water temperature was the best predictor representing the greatest proportion (~25%).

The marine community is changing significantly with time. Individual one-way ANOSIMs revealed that the marine community (abundance) was significantly different among time-series ($R = 0.03$-0.038; $P = 0.001$, 999 permutations) except during 1998−2002 ($R = 0.011$; $P = 0.09$, 999 permutations) and 2003−2007 ($R = 0.001$; $P = 0.439$, 999 permutations; **Table 5.9.7**). The marine community also varied significantly among sampling areas ($R = 0.129$-0.176; $P = 0.001$, 999 permutations) during 1988 through 2015. Separate two-way PERMANOVAs (**Table 5.9.8**) also confirmed the marine community was significantly different among time (*P (perm)* = 0.001), space (*P (perm)* = 0.001), and the interaction between time and space (*P (perm)* = 0.001) during every time-series, except the time/space interaction during 1988−1992 (*P (perm)* = 0.998) and 2008−2012 (*P (perm)* = 0.996). *Post-hoc* analysis showed the marine community was marginally different between various pairs of time by sampling area. In general, most of the pairs among time-series were not significantly different by sampling area; there were only a few pairs among time-series that were significantly different within specific sampling areas. For instance, in sampling area 21, the marine community was significantly different between the following years: 1988-1989 (*t* = 1.97; *P (perm)* = 0.014), 1988-1990 (*t* = 1.63; *P (perm)* = 0.033), and 1988-1991 (*t* = 1.81; *P (perm)* = 0.016).

Table 5.9.8. Two-way PERMANOVA (Year and Area). Summary of Results. Biological community.

Time Series	Source	Df	SS	MS	Pseudo-F	P(perm)	Perms
1988−1992	Year	4	68076	17019	8.7956	0.001	999
	Area	14	2.2005E+05	15718	8.1232	0.001	999
	Year/Area	55	86865	1579.4	0.81623	0.998	996
	Res	738	1.428E+06	1935			
	Total	811	1.8297E+06				
1993−1997	Year	4	73223	18306	9.7732	0.001	997
	Area	14	2.3191E+05	16565	8.8438	0.001	998
	Year/Area	56	72577	1296	0.69193	1	997
	Res	862	1.6146E+06	1873.1			
	Total	936	1.9965E+06				
1998−2002	Year	4	45437	11359	6.1265	0.001	997
	Area	14	2.6208E+05	18720	10.096	0.001	997
	Year/Area	56	70794	1264.2	0.68182	1	995
	Res	859	1.5927E+06	1854.1			
	Total	933	1.9723E+06				
2003−2007	Year	4	44934	11234	6.3777	0.001	997
	Area	14	2.5144E+05	17960	10.196	0.001	996
	Year/Area	56	62473	1115.6	0.63336	1	995
	Res	859	1.513E+06	1761.4			
	Total	933	1.8741E+06				
2008−2012	Year	4	50209	12552	6.2481	0.001	999
	Area	14	2.2677E+05	16198	8.0627	0.001	993
	Year/Area	56	93900	1676.8	0.83465	0.996	995
	Res	855	1.7177E+06	2009			
	Total	929	2.0908E+06				
2013−2015	Year	2	20040	10020	5.2262	0.001	999
	Area	14	1.547E+05	11050	5.7634	0.001	998
	Year/Area	28	31041	1108.6	0.57822	1	995
	Res	513	9.8357E+05	1917.3			
	Total	557	1.1903E+06				

Separate SIMPROFs showed there was a statistical significant structure in the marine community (*Pi* = 5.103−5.603; *P* = 0.001; *Perms* = 999), and distinct two-way SIMPER analyses identified a limited group of species whose abundances were drivers of similarity across time and space (**Table 5.9.9**). The average percent similarity ranged from 35.55 in 2011 to 56.26 percent in 1988; percent similarity often decreased with time per individual time-series, but the trend was generally stable over time (**Figure 5.4.1**). The main species representing the percent similarity in groupings were generally longfin squid (*Loligo pealei*), windowpane flounder (*Scophthalmus aquosus*), and little skate (*Leucoraja erinacea*); all were coldwater-adapted species representing between 43 and 51 percent of the similarity in groupings. Conversely, *post-hoc* analyses indicated the primary species contributing to dissimilarity were Atlantic butterfish (*Peprilus triacanthus*; warmwater-adapted), longfin squid, scup (*Stenotomus chrysops*; warmwater-adapted), bay anchovy (*Anchoa mitchilli*; subtropic-adapted), northern searobin (*Prionotus carolinus*;

warmwater-adapted), and Atlantic herring (*Clupea harengus*; coldwater-adapted); the cumulative percentage was around 13.9−19.2 percent.

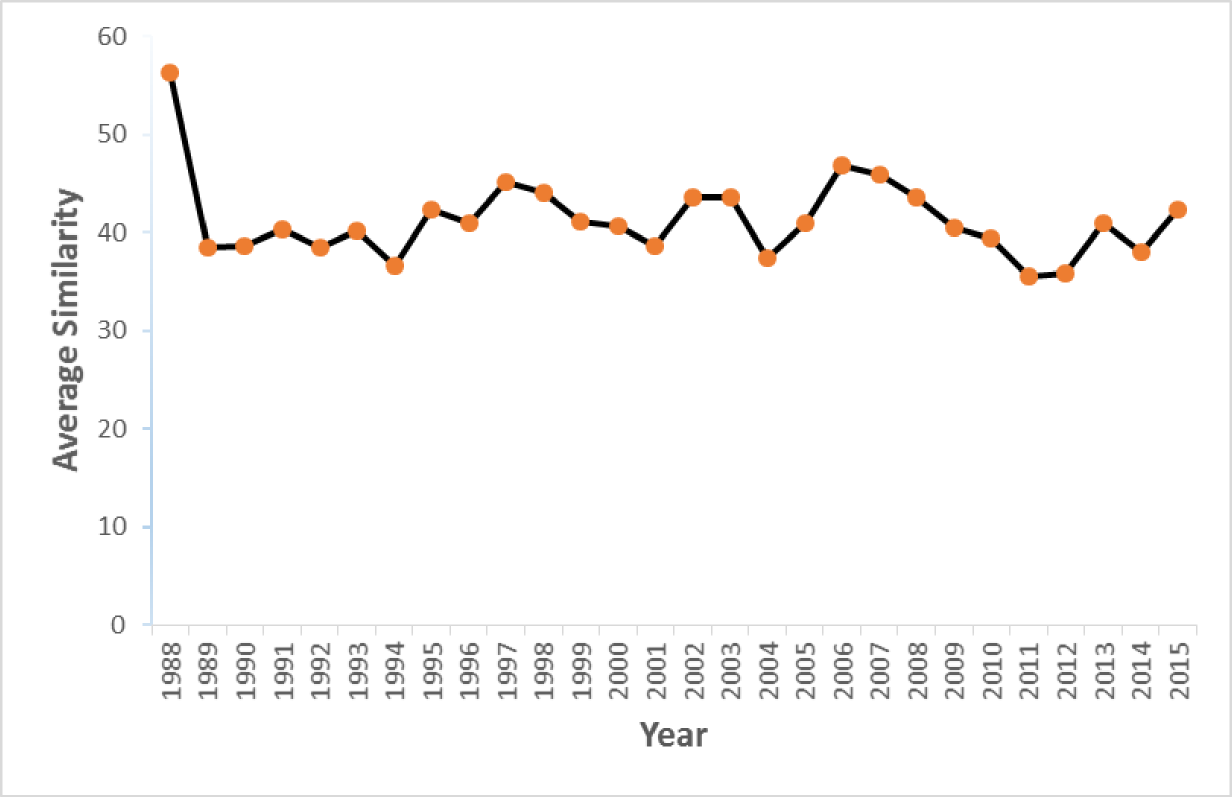

Figure 5.4.1. The average similarity value (percent) among marine species per year within individual time-series. Similarity was based on Bray-Curtis similarity measure.

Community dominance plot were constructed by ranking species in order of importance along the x-axis, and their percentage contribution to the total was plotted along the y-axis. Separate one-way ANOSIMs confirmed there was a significant difference in the community structure (*k*-dominance curves) over time (R = 0.01−0.37, P = 0.001, 999 permutations; **Table 5.9.10**). However, there was no significant difference in the community structure during 2003−2007 (R = 0.002, P = 0.115, 999 permutations). *Post-hoc* analyses showed there was a significant difference in the community structure between varies pairs of time, indicating the marine community changed with time; the marine community was generally similar earlier and dissimilar later in time within individual time-series. However, it should be noted that several pairs did not follow this pattern (2003, 2006; 2003, 2007; 2008, 2012).

Table 5.9.9. Two-way SIMPER analysis. The average similarity and associated percent contributions by time-series based on Bray-Curtis similarity measure.

Time-Series	Year	Average similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
1988−1992	1988	**56.26**	BUTTERFISH	5.84	8.69	2.26	15.45	15.45
			LONGFIN SQUID	5.05	8.09	1.39	14.38	29.83
			LADY CRAB	2.53	3.81	1.93	6.78	36.61
			BAY ANCHOVY	3.33	3.35	0.79	5.95	42.56
			WINDOWPANE	2.29	3.33	2.42	5.92	48.48
	1989	38.40	WINDOWPANE	2.22	4.67	2.19	12.17	12.17
			LONGFIN SQUID	3.07	4.29	0.83	11.16	23.33
			ROCK CRAB	1.60	3.02	1.34	7.87	31.21
			SILVER HAKE	1.82	2.58	0.93	6.71	37.92
			BUTTERFISH	2.31	2.33	0.72	6.06	43.97
	1990	38.69	LONGFIN SQUID	3.12	6.21	0.88	16.06	16.06
			BUTTERFISH	2.55	4.26	0.98	11.00	27.06
			WINDOWPANE	1.71	3.45	1.26	8.92	35.99
			LITTLE SKATE	1.40	2.74	0.91	7.08	43.07
			ROCK CRAB	1.21	2.23	0.98	5.77	48.84
	1991	40.33	LONGFIN SQUID	3.36	6.34	0.98	15.72	15.72
			BUTTERFISH	2.55	3.76	0.97	9.33	25.05
			WINDOWPANE	1.77	3.35	1.57	8.31	33.36
			LITTLE SKATE	1.63	3.00	1.23	7.44	40.80
			ROCK CRAB	1.28	2.41	1.20	5.99	46.79
	1992	**38.48**	LONGFIN SQUID	2.39	4.16	0.72	10.80	10.80
			WINDOWPANE	1.73	3.52	1.29	9.14	19.94
			LITTLE SKATE	1.81	3.48	1.23	9.03	28.97
			BUTTERFISH	2.66	2.97	0.70	7.72	36.70
			BAY ANCHOVY	2.62	2.51	0.57	6.52	43.21
1993−1997	1993	40.16	LITTLE SKATE	2.17	4.53	1.58	11.27	11.27
			WINDOWPANE	1.81	3.76	1.64	9.36	20.63
			ROCK CRAB	1.75	3.73	1.77	9.28	29.91
			LONGFIN SQUID	1.94	2.47	0.64	6.14	36.05
			WINTER FLOUNDER	1.28	2.45	0.87	6.11	42.16
	1994	**36.66**	LITTLE SKATE	1.95	4.88	1.83	13.32	13.32
			LONGFIN SQUID	2.76	4.68	0.62	12.78	26.10
			ROCK CRAB	1.33	3.39	1.35	9.25	35.35
			BUTTERFISH	2.98	3.33	0.63	9.07	44.42
			WINDOWPANE	1.35	2.50	1.06	6.82	51.24

Time-Series	Year	Average similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
	1995	42.37	LONGFIN SQUID	3.02	5.56	1.32	13.12	13.12
			BUTTERFISH	2.52	3.73	1.07	8.81	21.93
			LITTLE SKATE	2.11	3.68	1.36	8.67	30.60
			WINDOWPANE	1.70	2.90	1.57	6.84	37.45
			ROCK CRAB	1.76	2.66	1.28	6.27	43.72
	1996	40.88	LITTLE SKATE	2.51	4.84	1.83	11.84	11.84
			ROCK CRAB	1.97	3.62	1.75	8.86	20.69
			WINDOWPANE	1.74	3.11	1.53	7.61	28.31
			LONGFIN SQUID	2.11	2.86	0.70	7.00	35.30
			SPOTTED HAKE	1.55	2.19	1.09	5.36	40.66
	1997	**45.14**	LITTLE SKATE	2.71	4.95	1.55	10.96	10.96
			LONGFIN SQUID	2.83	3.86	0.75	8.55	19.51
			ROCK CRAB	2.18	3.76	1.82	8.34	27.85
			WINDOWPANE	2.00	3.45	2.08	7.64	35.49
			NORTHERN SEAROBIN	1.77	2.57	1.06	5.69	41.18
1998−2002	1998	**44.06**	LONGFIN SQUID	2.99	5.72	0.99	12.99	12.99
			LITTLE SKATE	2.38	5.52	1.57	12.53	25.52
			WINDOWPANE	1.70	3.54	1.61	8.03	33.55
			BUTTERFISH	2.03	3.08	0.79	7.00	40.54
			ROCK CRAB	1.41	2.71	1.34	6.15	46.69
	1999	41.18	LITTLE SKATE	2.64	5.85	1.79	14.20	14.20
			LONGFIN SQUID	2.68	4.13	0.71	10.02	24.22
			WINDOWPANE	1.75	3.38	1.50	8.22	32.44
			ROCK CRAB	1.49	2.71	1.28	6.59	39.03
			SUMMER FLOUNDER	1.37	2.21	0.97	5.36	44.39
	2000	40.62	LONGFIN SQUID	2.82	5.79	0.94	14.25	14.25
			LITTLE SKATE	2.19	5.02	1.39	12.37	26.62
			WINDOWPANE	1.53	2.91	1.20	7.16	33.78
			BUTTERFISH	1.80	2.62	0.77	6.45	40.23
			SUMMER FLOUNDER	1.27	2.35	1.11	5.80	46.02
	2001	**38.59**	LONGFIN SQUID	2.55	5.20	0.85	13.48	13.48
			LITTLE SKATE	2.17	5.18	1.47	13.41	26.89
			WINDOWPANE	1.52	3.25	1.34	8.42	35.31
			SUMMER FLOUNDER	1.23	2.34	1.03	6.07	41.39
			BUTTERFISH	1.86	2.30	0.66	5.96	47.34
	2002	43.64	LONGFIN SQUID	3.30	6.03	1.22	13.82	13.82
			LITTLE SKATE	2.17	4.14	1.34	9.48	23.29
			WINDOWPANE	1.91	3.61	1.99	8.26	31.55

Time-Series	Year	Average similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
			BUTTERFISH	2.43	3.12	1.09	7.15	38.71
			SCUP	2.47	2.87	0.84	6.58	45.29
2003−2007	2003	43.52	LITTLE SKATE	2.75	6.26	2.58	14.38	14.38
			WINDOWPANE	2.04	4.15	1.98	9.53	23.91
			LONGFIN SQUID	2.27	3.64	0.92	8.37	32.28
			SPOTTED HAKE	1.88	3.05	1.24	7.01	39.29
			SUMMER FLOUNDER	1.39	2.45	1.24	5.63	44.91
	2004	**37.41**	LITTLE SKATE	2.53	5.39	1.55	14.41	14.41
			WINDOWPANE	2.06	4.20	1.75	11.21	25.62
			LONGFIN SQUID	2.42	2.49	0.60	6.65	32.27
			SUMMER FLOUNDER	1.36	2.03	1.18	5.44	37.71
			BUTTERFISH	2.25	2.00	0.65	5.35	43.06
	2005	41.01	LITTLE SKATE	2.80	6.21	1.79	15.15	15.15
			LONGFIN SQUID	2.50	4.02	0.87	9.81	24.96
			WINDOWPANE	1.86	3.64	1.65	8.87	33.82
			SUMMER FLOUNDER	1.38	2.32	1.29	5.66	39.49
			BUTTERFISH	2.09	2.17	0.74	5.30	44.79
	2006	**46.78**	LONGFIN SQUID	3.55	7.09	1.14	15.15	15.15
			LITTLE SKATE	2.71	5.86	1.94	12.54	27.69
			BUTTERFISH	2.86	4.14	1.12	8.84	36.53
			WINDOWPANE	1.64	3.07	1.83	6.56	43.09
			SCUP	2.06	2.29	0.83	4.89	47.97
	2007	45.89	LONGFIN SQUID	2.99	6.24	1.28	13.61	13.61
			BUTTERFISH	2.89	4.79	1.35	10.44	24.05
			LITTLE SKATE	2.22	4.52	1.48	9.86	33.91
			WINDOWPANE	1.90	3.74	2.07	8.16	42.06
			SCUP	2.93	3.61	0.84	7.87	49.93
2008−-2012	2008	**43.61**	LONGFIN SQUID	2.94	4.71	1.07	10.80	10.80
			BUTTERFISH	3.44	4.21	1.07	9.65	20.45
			LITTLE SKATE	2.13	4.08	1.96	9.35	29.80
			WINDOWPANE	1.79	3.31	1.98	7.60	37.39
			STARFISH	1.54	3.18	1.21	7.29	44.69
	2009	40.44	LONGFIN SQUID	2.76	4.22	0.92	10.44	10.44
			WINDOWPANE	1.74	3.39	1.74	8.39	18.83
			LITTLE SKATE	1.96	3.28	1.27	8.11	26.94
			BUTTERFISH	2.51	2.84	0.89	7.03	33.97
			SUMMER FLOUNDER	1.44	2.68	1.51	6.62	40.59
	2010	39.42	LONGFIN SQUID	2.37	3.99	0.90	10.13	10.13

Time-Series	Year	Average similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
			LITTLE SKATE	1.83	3.83	1.53	9.72	19.85
			WINDOWPANE	1.64	3.82	1.80	9.70	29.55
			BUTTERFISH	2.30	3.20	0.97	8.12	37.67
			SUMMER FLOUNDER	1.41	2.49	1.17	6.31	43.97
	2011	**35.55**	WINDOWPANE	1.73	3.34	1.54	9.39	9.39
			BUTTERFISH	2.52	2.82	0.89	7.94	17.32
			LITTLE SKATE	1.51	2.82	1.12	7.93	25.25
			LONGFIN SQUID	2.08	2.54	0.73	7.15	32.40
			SUMMER FLOUNDER	1.23	1.97	1.10	5.53	37.94
	2012	35.85	LONGFIN SQUID	3.22	5.89	1.19	16.43	16.43
			WINDOWPANE	1.80	3.67	2.00	10.24	26.67
			LITTLE SKATE	1.61	2.70	1.13	7.53	34.20
			SUMMER FLOUNDER	1.30	2.14	1.21	5.97	40.17
			CLEARNOSE SKATE	1.49	1.75	0.76	4.87	45.04
2013−2015	2013	40.97	LITTLE SKATE	2.28	4.62	1.62	11.27	11.27
			WINDOWPANE	1.94	4.11	2.26	10.02	21.29
			LONGFIN SQUID	2.49	3.51	0.83	8.57	29.86
			SPOTTED HAKE	2.02	3.04	1.36	7.43	37.29
			SUMMER FLOUNDER	1.31	2.34	1.41	5.71	43.00
	2014	**38.03**	LONGFIN SQUID	2.97	5.14	1.01	13.51	13.51
			WINDOWPANE	1.82	4.38	2.08	11.53	25.03
			LITTLE SKATE	1.78	3.49	1.11	9.17	34.21
			BUTTERFISH	1.99	2.23	0.77	5.85	40.06
			SUMMER FLOUNDER	1.25	2.22	1.16	5.83	45.89
	2015	**42.31**	LITTLE SKATE	2.31	5.58	1.55	13.18	13.18
			LONGFIN SQUID	2.55	4.66	1.04	11.00	24.18
			WINDOWPANE	1.92	4.48	2.26	10.58	34.76
			SUMMER FLOUNDER	1.29	2.24	1.15	5.28	40.04
			SCUP	1.92	2.23	0.79	5.28	45.32

The SIMPER test also showed the average similarity between species varied among space. The average percent similarity ranged from 36.15 (2008−2012) in sampling area 12 to 46.20 (2003−2007) in sampling area 23 (**Table 5.9.11**). The average percent similarity varied among sampling areas during the separate time-series, but the lowest percent values occurred in sampling areas 12 (1993−1997; 2008−2012) and 22 (1998−2002; 2003−2007) and the highest values occurred in sampling areas 14 (1988−1992; 1993−1997; 1998−2002) and 17 (2008−2012; 2013−2015). In general, three species (little skate, windowpane, and longfin squid) represented the greatest similarity contribution of the marine community, which was around 23.2−46.1%. Bay anchovy and Atlantic butterfish also contributed to the similarity among groups depending on the year and sampling area. Likewise, *post-hoc* analyses indicated the primary species contributing to dissimilarity were butterfish, longfin squid, scup, bay anchovy, northern searobin, and Atlantic herring.

Community dominance plots were constructed by ranking species in order of importance along the x-axis, and their percentage contribution to the total was plotted along the y-axis. Separate one-way ANOSIM tests also established there was a significant difference in the marine community structure (*k*-dominance curves) among sampling areas (R = 0.05−0.73, P = 0.001, 999 permutations). *Post-hoc* analyses showed there was a significant difference in the marine community structure between varies pairs of space (sampling area) during individual time-series. Generally, some of the differences were between pairs that were geographically further apart (e.g., sampling areas 15 and 20 [1988-1992]), but patterns were inconsistent (e.g., sampling areas 12 and 20 (R = 0.222, P = 0.001); 12 and 21 (R = -0.011, P = 0.856) [1993-1997]).

Table 5.9.11. Two-way SIMPER analysis. The average similarity and associated percent contributions by sampling area based on Bray-Curtis similarity measure.

Area	**Time-Series**					
	1988−1992	1993−1997	1998−2002	2003−2007	2008−2012	2013−2015
12	40.61	**39.52**	40.12	41.43	**36.15**	37.01
	WINDOWPANE, WINTER FLOUNDER, LITTLE SKATE	WINDOWPANE, LITTLE SKATE, ROCK CRAB	LITTLE SKATE, ROCK CRAB, WINDOWPANE	LITTLE SKATE, WINDOWPANE, WINTER FOUNDER	LITTLE SKATE, WINDOWPANE, BAY ANCHOVY	WINDOWPANE, LITTLE SKATE, BAY ANCHOVY
13	41.91	42.89	44.36	45.76	38.91	43.56
	WINDOWPANE, WINTER FLOUNDER, LITTLE SKATE	LITTLE SKATE, WINTER FLOUNDER, WINDOWPANE	LITTLE SKATE, WINDOWPANE, LONGFIN SQUID	LITTLE SKATE, WINDOWPANE, WINTER FLOUNDER	LITTLE SKATE, WINDOWPANE, BUTTERFISH	LITTE SKATE, WINDOWPANE, LONGFIN SQUID
14	**42.91**	**44.65**	**45.70**	45.06	41.21	44.77
	WINTER FLOUNDER, LITTLE SKATE, LONGFIN SQUID	WINTER FLOUNDER, LITTLE SKATE, ROCK CRAB	LITTLE SKATE, LONGFIN SQUID, WINTER FLOUNDER	LITTE SKATE, LONGFIN SQUID, WINTER FLOUNDER	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE	LITTLE SKATE, WINDOWPANE, LONGFIN SQUID
15	39.98	42.30	43.64	43.62	38.46	40.90
	WINDOWPANE, LITTLE SKATE, BAY ANCHOVY	LITTLE SKATE, WINDOWPANE, BAY ANCHOVY	WINDOWPANE, LITTLE SKATE, BAY ANCHOVY	LITTLE SKATE, BAY ANCHOVY, WINDOWPANE	BAY ANCHOVY, WINDOWPANE, LITTLE SKATE	BAY ANCHOVY, WINDOWPANE, LITTLE SKATE
16	38.89	40.86	40.23	44.00	37.16	40.25
	LONGFIN SQUID, BUTTERFISH, WINDOWPANE	LITTLE SKATE, ROCK CRAB, WINDOWPANE	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE.	LITTE SKATE, LONGFINS SQUD, BUTTERFISH	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE	LITTE SKATE, WINDOWPANE, LONGFIN SQUID
17	41.03	42.31	45.70	46.86	**43.21**	**46.18**
	LONGFIN SQUID, BUTTERFISH, LITTLE SKATE	LITTLE SKATE, LONGFIN SQUID, WINTER FLOUNDER	LITTE SKATE, LONGFIN SQUID, BUTTERFISH	LITTLE SKATE, LONGFIN SQUID, BUTTERFISH	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE
18	42.42	42.87	42.61	41.91	38.67	39.74

Area	**Time-Series**					
	1988−1992	1993−1997	1998−2002	2003−2007	2008−2012	2013−2015
	BAY ANCHOVY, WINDOWPANE, BUTTERFISH	BAY ANCHOVY, LITTLE SKATE, WINDOWPANE	WINDOWPANE, BAY ANCHOVY, LITTLE SKATE	BAY ANCHOVY, LITTLE SKATE, WINDOWPANE	BAY ANCHOVY, WINDOWPANE, BUTTERFISH	BAY ANCHOVY, SPOTTED HAKE, WINDOWPANE
19	38.05	39.74	40.24	43.32	36.94	38.98
	LONGFIN SQUID, BUTTERFISH, WINDOWPANE	LITTLE SKATE, LONGFIN SQUID, BUTTERFISH	LONGFIN SQUID, LITTLE SKATE, BUTTERFISH	LITTE SKATE, LONGFIN SQUID, WINDOWPANE	LONGFIN SQUID, WINDOWPANE, BUTTERFISH	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE
20	41.28	40.72	41.88	43.70	43.15	42.18
	LONGFIN SQUID, BUTTERFISH, LADY CRAB	LONGFIN SQUID, LITTLE SKATE, ROCK CRAB	LONGFIN SQUID, LITTLE SKATE, BUTTERFISH	LITTLE SKATE, LONGFIN SQUID, BUTTERFISH	LONGFIN SQUID, LITTLE SKATE, STARFISH	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE
21	42.26	41.96	40.81	39.69	35.26	**36.63**
	BAY ANCHOVY, WINDOWPANE, BUTTERFISH	BAY ANCHOVY, WINDOWPAINE, LITTLE SKATE	WINDOWPANE, BAY ANCOVY, LITTLE SKATE	BAY ANCHOVY, WINDOWPANE, LITTLE SKATE	BAY ANCHOVY, WINDOWPANE, BUTTERFISH	BAY ANCHOVY, WINDOWPANE, CLEARNOSE SKATE
22	35.33;	38.71	**38.68**	**38.75**	36.68	37.85
	LONGFIN SQUID, BUTTERFISH, LADY CRAB	LONGFIN SQUID, LITTLE SKATE, ROCK CRAB	LONGFIN SQID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, WINDOWPANE, BUTTERFISH	LONGFIN SQUID, WINOWPANE, LITTE SKATE
23	38.23	40.92	42.10	**46.20**	42.85	40.84
	LONGFIN SQUID, BUTTERFISH, ROCK CRAB	LONGFIN SQUID, LITTLE SKATE, ROCK CRAB	LONGFIN SQUID, LITTLE SKATE, BUTTERFISH	LONGFIN SQID, LITTLE SKATE, BUTTERFISH	LONGFIN SQUID, STARFISH, WINDOWPANE	LONGFIN SQUID, LITTE SKATE, WINDOWPANE
24	39.64	39.57	38.88;	39.69	36.82	37.87
	BAY ANCHOVY, WINDOWPANE,	WINDOWPANE, ROCK CRAB, HORSESHOE CRAB	WINDOWPANE, SPIDER CRAB, LITTLE SKATE	BAY ANCHOVY, WINDOWPANE, LITTLE SKATE	WINDOWPANE, BAY ANCHOVY,	WINDOWPANE, SUMMER FLOUUNDER,

Area	**Time-Series**					
	1988−1992	1993−1997	1998−2002	2003−2007	2008−2012	2013−2015
	LONGFIN SQUID				SUMMER FLOUNDER	LONGFIN SQUID
25	35.94	40.92	39.83	40.21	37.34	38.92
	LONGFIN SQUID, WINDOWPANE, BUTTERFISH	LONGFIN SQUID, LITTLE SKATE, ROCK CRAB	LONGFIN SQUID, LITTLE SKATE, SUMMER FLOUNDER	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE	LONGFIN SQUID, WINDOWPANE, BUTTERFISH	LONGFIN SQUID, WINDOWPANE, CLEARNOSE SKATE
26	**36.24**	37.46	39.31	42.11	37.83	39.24
	LONGFIN SQUID, BUTTERFISH, ROCK CRAB	LITTLE SKATE, LONGFIN SQUID, ROCK CRAB	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, N. SEAROBIN	LONGFIN SQUID, WINDWPANE, LITTE SKATE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE

5.4.2.3 Marine Fauna Temperature Tolerance and Preference

5.4.2.3.1 Coldwater-adapted Community

Multivariate ordination procedures showed there were associations and significant differences in the coldwater-adapted community (abundance) over time and space. Separate 2-dimentional nMDS procedures fitted ($\mu = 0.19.5$ *Stress*) the similarity of the coldwater-adapted samples (abundance) over time. However, PCO tests better explained the data. Discrete PCO procedures showed the total variation (PCO1) ranged from 49.37 percent (2003−2007) to 63.21 percent (1998−2002). Overall, around 51.9 percent of the total variability in the coldwater-adapted community (abundance) was explained by the ordination procedure (PCO1 axis [37.5%] and PCO2 axis [14.4%]) during 1988 through 2015. The coldwater-adapted community (abundance) was primarily associated with the water temperature (surface and bottom) and salinity (surface and bottom). The PCOs also showed that the coldwater-adapted community was somewhat associated with the DO (surface and bottom) in some years (2008−2012; 2013−2015).

Separate DLMs ($\mu = r^2 = 0.431$) significantly determined the sequential order of the environmental predictors (surface temperature, maximum depth, bottom temperature, the NAO Index, surface salinity, bottom DO, the EOF Index, the AMO Index, and the surface DO) of the coldwater-adapted community during 1988 through 2015. The procedure least explained ($r^2 = 0.387$) the association between the coldwater-adapted community during 2008 through 2012, and best explained ($r^2 = 0.463$) the connection during 2013 through 2015. The best environmental predictors (sequential order) of the coldwater-adapted community were primarily water temperature (surface) and maximum depth; water temperature was the best predictor representing the greatest proportion (~30%).

The coldwater-adapted community is changing significantly with time. Separate one-way ANOSIMs confirmed the coldwater-adapted community (abundance) was significantly different among all the time-series (*R* = 0.02−0.047; *P* = 0.001, 999 permutations), and among areas (*R* = 0.145−0.185; *P* = 0.001, 999 permutations) during 1988 through 2015. Separate two-way PERMANOVA procedures also demonstrated the coldwater-adapted community was significantly different among time (*P (perm)* = 0.001), space (*P (perm)* = 0.001), but not the interaction between time and space (*P (perm)* = 1). *Post-hoc* analysis showed that the coldwater-adapted community was marginally different between various pairs of time by sampling area. Most of the pairs were similar; there were only a few time-series pairs that were significantly different by sampling area. For instance, in sampling area 23, the coldwater-adapted community was significantly different between the following years: 1993−1995 (*t* = 1.56; *P (perm)* = 0.048), 1998−2001 (*t* = 1.49; *P (perm)* = 0.042), 2004−2006 (*t* = 1.87; *P (perm)* = 0.02), and 2008−2011 (*t* = 1.55; *P (perm)* = 0.041).

Separate SIMPROFs showed there was a statistical significant structure in the coldwater-adapted community (*Pi* = 5.87−6.28; *P* = 0.001; *Perms* = 999), and individual two-way SIMPER analyses identified a limited group of coldwater-adapted species (abundance) whose abundances were drivers of similarity across time and space (**Tables 5.9.12; 5.9.13**). The average percent similarity ranged from 41.05 in 2011 to 60.91 in 1988. No pattern was detected between the lowest and highest average percent similarity within individual time-series. Generally, three species (longfin squid, little skate, and windowpane) represented around 65 to 75 percent of the similarity in the coldwater-adapted community. Depending on the time-series, butterfish, winter skate or lady crab also contributed to the similarity among groups. Conversely, *post-hoc* analyses indicated longfin squid, little skate, and Atlantic herring contributed to the dissimilarity; silver hake (*Merluccius bilinearis*), winter skate (*Leucoraja ocellata*), lady crab (*Ovalipes ocellatus*), Atlantic spiny dogfish (*Squalus acanthias*), and scup also contributed to the dissimilarity between some pairs; the cumulative percentage was around 30−35 percent.

Community dominance plot were constructed by ranking species in order of importance along the x-axis, and their percentage contribution to the total was plotted along the y-axis. Separate one-way ANOSIMs showed there was a significant difference in the community structure (*k*-dominance curves) over time ($R = 0.007{-}0.026$, $P = 0.001{-}0.009$, 999 permutations). *Post-hoc* analyses showed there was a significant difference in the community structure between varies pairs of time, but generally no patterns were evident. In some pairs, a difference was detected in pairs that were earlier in the time-series, later in the time-series, or 2−3 or 3−4 years apart.

Table 5.9.12. Two-way SIMPER analysis. The average similarity and species percent contributions (coldwater-adapted) by time-series based on Bray-Curtis similarity measure.

Time-Series	Year	Average Similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
1988−1992	1988	**60.91**	LONGFIN SQUID	5.05	19.32	1.81	31.72	31.72
			LADY CRAB	2.53	10.89	1.93	17.87	49.59
			WINDOWPANE	2.29	9.96	1.49	16.35	65.94
			LITTLE SKATE	1.96	6.63	1.81	10.88	76.82
	1989	46.26	WINDOWPANE	2.22	9.58	2.08	20.70	20.70
			LONGFIN SQUID	3.07	9.07	0.82	19.60	40.30
			SILVER HAKE	1.82	4.51	0.95	9.75	50.05
			LADY CRAB	1.37	4.31	0.74	9.31	59.36
			LITTLE SKATE	1.44	3.99	0.90	8.62	67.97
	1990	**44.23**	LONGFIN SQUID	3.12	15.29	0.95	34.56	34.56
			WINDOWPANE	1.71	8.47	1.23	19.14	53.70
			LITTLE SKATE	1.40	5.54	0.93	12.52	66.22
			LADY CRAB	1.23	5.46	0.74	12.33	78.55
	1991	46.83	LONGFIN SQUID	3.36	14.47	1.01	30.90	30.90
			WINDOWPANE	1.77	7.45	1.40	15.92	46.82
			LITTLE SKATE	1.63	5.84	1.23	12.47	59.28
			LADY CRAB	1.22	5.03	0.72	10.74	70.02
	1992	44.85	LONGFIN SQUID	2.39	10.63	0.76	23.71	23.71
			WINDOWPANE	1.73	8.63	1.28	19.24	42.95
			LITTLE SKATE	1.81	7.95	1.29	17.72	60.67
			LADY CRAB	0.99	3.65	0.56	8.15	68.82
1993−1997	1993	46.16	LITTLE SKATE	2.17	9.36	1.61	20.29	20.29
			WINDOWPANE	1.81	8.45	1.62	18.30	38.58
			LONGFIN SQUID	1.94	6.19	0.65	13.40	51.99
			WINTER FLOUNDER	1.28	4.31	0.92	9.33	61.32
			WINTER SKATE	1.07	3.39	0.82	7.35	68.67
	1994	**45.85**	LONGFIN SQUID	2.76	11.61	0.69	25.32	25.32
			LITTLE SKATE	1.95	11.01	1.93	24.02	49.34
			WINDOWPANE	1.35	6.11	1.05	13.34	62.67
			WINTER FLOUNDER	1.05	4.11	0.82	8.95	71.63

Time-Series	Year	Average Similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
	1995	47.20	LONGFIN SQUID	3.02	13.97	1.24	29.59	29.59
			LITTLE SKATE	2.11	8.23	1.35	17.43	47.02
			WINDOWPANE	1.70	7.50	1.49	15.88	62.90
			LADY CRAB	0.97	3.21	0.55	6.81	69.71
			WINTER FLOUNDER	1.14	2.47	0.63	5.23	74.94
	1996	46.80	LITTLE SKATE	2.51	10.26	2.01	21.91	21.91
			LONGFIN SQUID	2.11	7.08	0.73	15.14	37.05
			WINDOWPANE	1.74	7.07	1.60	15.10	52.15
			WINTER SKATE	1.07	3.18	0.83	6.79	58.94
			COMMON SPIDER CRAB	1.03	3.03	0.68	6.48	65.42
	1997	**48.23**	LITTLE SKATE	2.71	10.31	1.70	21.38	21.38
			LONGFIN SQUID	2.83	9.74	0.76	20.19	41.57
			WINDOWPANE	2.00	8.34	1.67	17.30	58.87
			COMMON SPIDER CRAB	1.38	4.75	1.00	9.85	68.72
			SURF CLAM	0.79	2.23	0.59	4.62	73.34
1998−2002	1998	48.34	LONGFIN SQUID	2.99	12.39	0.94	25.63	25.63
			LITTLE SKATE	2.38	10.33	1.68	21.36	46.99
			WINDOWPANE	1.70	7.62	1.52	15.77	62.77
			COMMON SPIDER CRAB	0.93	3.32	0.70	6.86	69.63
			WINTER FLOUNDER	1.06	2.90	0.75	6.00	75.62
	1999	47.28	LITTLE SKATE	2.64	12.65	1.84	26.76	26.76
			LONGFIN SQUID	2.68	11.09	0.72	23.46	50.22
			WINDOWPANE	1.75	8.30	1.39	17.56	67.78
			COMMON SPIDER CRAB	1.06	3.80	0.64	8.03	75.80
	2000	46.94	LONGFIN SQUID	2.82	15.02	0.93	32.01	32.01
			LITTLE SKATE	2.19	10.78	1.38	22.97	54.98
			WINDOWPANE	1.53	7.46	1.20	15.90	70.88
	2001	**46.40**	LONGFIN SQUID	2.55	13.20	0.86	28.45	28.45
			LITTLE SKATE	2.17	11.41	1.54	24.60	53.04
			WINDOWPANE	1.52	8.46	1.18	18.23	71.27
	2002	**52.85**	LONGFIN SQUID	3.30	17.94	1.24	33.95	33.95
			LITTLE SKATE	2.17	10.55	1.36	19.96	53.91
			WINDOWPANE	1.91	10.46	1.96	19.78	73.70

Time-Series	Year	Average Similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
2003−2007	2003	51.56	LITTLE SKATE	2.75	15.15	2.50	29.38	29.38
			WINDOWPANE	2.04	10.39	1.94	20.15	49.53
			LONGFIN SQUID	2.27	9.21	0.90	17.86	67.39
			WINTER SKATE	0.94	3.22	0.78	6.25	73.64
	2004	**45.50**	LITTLE SKATE	2.53	12.14	1.67	26.69	26.69
			WINDOWPANE	2.06	10.96	1.64	24.09	50.78
			LONGFIN SQUID	2.42	7.15	0.61	15.71	66.49
			WINTER SKATE	1.10	3.81	0.85	8.38	74.87
	2005	48.17	LITTLE SKATE	2.80	13.38	1.91	27.77	27.77
			LONGFIN SQUID	2.50	9.98	0.83	20.73	48.50
			WINDOWPANE	1.86	8.81	1.64	18.28	66.78
			WINTER SKATE	1.22	4.02	0.90	8.34	75.12
	2006	**53.85**	LONGFIN SQUID	3.55	17.08	1.20	31.72	31.72
			LITTLE SKATE	2.71	13.36	1.94	24.81	56.54
			WINDOWPANE	1.64	7.95	1.48	14.76	71.30
	2007	52.21	LONGFIN SQUID	2.99	16.81	1.37	32.19	32.19
			WINDOWPANE	1.90	11.00	1.72	21.07	53.26
			LITTLE SKATE	2.22	10.94	1.50	20.95	74.22
2008−2012	2008	**49.60**	LONGFIN SQUID	2.94	14.18	1.11	28.59	28.59
			LITTLE SKATE	2.13	10.81	2.00	21.80	50.39
			WINDOWPANE	1.79	9.78	1.82	19.71	70.11
	2009	46.25	LONGFIN SQUID	2.76	13.30	0.85	28.75	28.75
			WINDOWPANE	1.74	10.06	1.56	21.75	50.50
			LITTLE SKATE	1.96	8.47	1.27	18.30	68.80
			WINTER FLOUNDER	0.85	2.42	0.63	5.24	74.04
	2010	44.10	LONGFIN SQUID	2.37	11.67	0.92	26.46	26.46

Time-Series	Year	Average Similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
			WINDOWPANE	1.64	11.19	1.59	25.37	51.82
			LITTLE SKATE	1.83	9.62	1.53	21.81	73.63
	2011	**41.05**	WINDOWPANE	1.73	12.04	1.36	29.33	29.33
			LONGFIN SQUID	2.08	9.95	0.77	24.23	53.56
			LITTLE SKATE	1.51	7.91	1.14	19.27	72.83
	2012	48.62	LONGFIN SQUID	3.22	18.93	1.26	38.95	38.95
			WINDOWPANE	1.80	10.61	1.97	21.83	60.77
			LITTLE SKATE	1.61	7.07	1.12	14.54	75.31
2013–2015	2013	49.75	LITTLE SKATE	2.28	11.31	1.77	22.74	22.74
			WINDOWPANE	1.94	11.12	2.47	22.35	45.09
			LONGFIN SQUID	2.49	10.76	0.86	21.63	66.73
	2014	**46.60**	LONGFIN SQUID	2.97	14.81	1.03	31.79	31.79
			WINDOWPANE	1.82	11.37	2.18	24.40	56.18
			LITTLE SKATE	1.78	7.61	1.15	16.34	72.52
	2015	**53.24**	LITTLE SKATE	2.31	13.73	1.74	25.78	25.78
			LONGFIN SQUID	2.55	13.52	1.10	25.40	51.19
			WINDOWPANE	1.92	12.47	2.64	23.43	74.62

The SIMPER tests also showed the average percent similarity between species varied among space. The average percent similarity ranged from 39.49 (2008−2012) in sampling area 21 to 53.93 (2003−2007) in sampling area 17 (**Table 6.9.13**). The average percent similarity varied among sampling areas during the separate time-series, but the lowest values occurred in sampling areas 12 (1998−2002; 2013−2015), 22 (1998−2002; 2003−2007), 26 (1988−2002; 1993−1997) and the highest percentage values occurred in sampling area 17 (1998−2002; 2003−2007; 2013−2015). In general, three species (winter flounder, lady crab, and common spider crab [*Libinia emarginata*]) represented between 52 and 80 percent of the similarity in the coldwater-adapted community. Conversely, *post-hoc* analyses indicated longfin squid, Atlantic herring, winter flounder, and little skate contributed to the dissimilarity. Depending on the time-series, silver hake, lady crab, and winter skate also contributed to the dissimilarity which represented between 30 and 40 percent.

Community dominance plot were constructed by ranking species in order of importance along the x-axis, and their percentage contribution to the total was plotted along the y-axis. Separate one-way ANOSIMs also showed there was a significant difference in the community structure (*k*-dominance curves) among areas (R = 0.031−0.054, P = 0.001, 999 permutations). *Post-hoc* analyses showed there was a significant difference in the coldwater-adapted community structure between varies pairs of space (sampling area) during individual time-series. Generally, the differences were between pairs that were geographically further apart (e.g., sampling areas 18 and 23 [1988−1992]), but patterns were inconsistent (e.g., sampling areas 12 and 14 (R = 0.0852, P = 0.001); 15 and 16 (R = 0.033, P = 0.012) [1993−1997]).

Table 5.9.13. Two-way SIMPER analysis. The average percent similarity and species contributions (coldwater-adapted) by sampling area based on Bray-Curtis similarity measure.

Area	**Time-Series**					
	1988−1992	1993−1997	1998−2002	2003−2007	2008−2012	2013−2015
12	47.40	47.60	**45.87**	50.31	41.22	**44.87**
	WINDOWPANE, WINTER FLOUNDER, LITTLE SKATE	WINDOWPANE, LITTLE SKATE, WINTER FLOUNDER	LITTLE SKATE, WINDOWPANE, SPIDER CRAB	LITTLE SKATE, WINDOWPANE, WINTER SKATE	LITTLE SKATE, WINDOWPANE, LONGFIN SQUID	WINDOWPANE, LITTE SKATE, WINTER FLOUNDER
13	**49.61**	50.45	52.84	52.66	47.10	54.95
	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID	LITTLE SKATE, WINDOWPANE WINTER FLOUNDER	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE	LITTLE SKATE, WINDOWPANE, WINTER FLOUNDER	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE	LITTLE SKATE, WINDOWPANE, LONGFIN SQUID
14	48.58	**51.44**	51.63	53.27	50.23	52.81
	LONGFIN SQUID, LITTLE SKATE, WINDER FLOUNDER	WINTER FLOUNDER, LITTLE SKATE, LONGFIN SQUID	LITTLE SKATE, LONGFIN SQUID, WINTER FLOUNDER	LITTE SKATE, LONGFIN SQUID, WINTER FLOUNDER	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE
15	49.58	49.68	49.80	51.09	44.58	51.47
	WINDOWPANE, LITTE SKATE, LONGFIN SQUID	LITTLE SKATE, WINDOWPANE, LONGFIN SQUID	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID	LITTLE SKATE, WINDOWPANE, WINTER FLOUNDER	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID
16	44.69	46.97	47.87	52.88	44.76	51.16
	LONGFIN SQUID, WINOWPANE, LITTLE SKATE	LITTLE SKATE, WINDOWPANE, LONGFIN SQUID	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LITTLE SKATE, WINDOWPANE, LONGFIN SQUID
17	44.43	47.94	**52.86**	**53.93**	50.30	**54.65**
	LONGFIN SQUID, LITTE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINTER FLOUNDER	LITTLE SKATE, LONGFIN SQUID, WINTER FLOUNDER	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LITTLE SKATE, LONGFIN SQUID, WINDOWPANE
18	48.46	47.89	47.86	48.02	40.99	46.43

Area	**Time-Series**					
	1988−1992	1993−1997	1998−2002	2003−2007	2008−2012	2013−2015
	WINDOWPANE, LADY CRAB, LITTLE SKATE	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID	WINDOWPANE, LITTLE SKATE, SPIDER CRAB	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID
19	45.36	45.86	46.23	51.39	47.11	49.64
	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE
20	47.20	44.97	47.87	51.36	49.56	51.76
	LONGFIN SQUID, LADY CRAB, LITTLE SKATE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGIFN SQUID, LITTLE SKATE, WINDOWPANE
21	48.13	47.62	47.58	47.54	**39.49**	45.13
	WINDOWPANE, LADY CRAB, LONGFIN SQUID	WINDOWPANE, LITTLE SKATE, LADY CRAB	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID	WINDOWPANE, LONGFIN SQUID, LITTLE SKATE	WINDOWPANE, LONGFIN SQUID, LADY CRAB
22	45.08	44.08	**46.95**	**46.12**	45.78	48.18
	LONGFIN SQUID, LADY CRAB, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE
23	43.46	45.52	47.90	53.24	**50.66**	50.59
	LONGFIN SQUID, LADY CRAB, LITTLE SKATE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE
24	42.94	45.15	46.93	42.30	41.92	46.79
	LONGFIN SQUID, WINDOWPANE, LADY CRAB	WINDOPANE, LADY CRAB, SPIDER CRAB	WINDOWPANE, SPIDER CRAB, LONGFIN SQUID	WINDOWPANE, LITTLE SKATE, LONGFIN SQUID	WINDOWPANE, LONGFIN SQUID, LITTLE SKATE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE
25	44.39	47.08	47.44	47.16	44.91	47.11

Area	**Time-Series**					
	1988−1992	1993−1997	1998−2002	2003−2007	2008−2012	2013−2015
	LONGFIN SQUID, LADY CRAB, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE
26	**40.89**	**41.60**	46.43	49.05	44.48	50.13
	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, LITTLE SKATE, WINDOWPANE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE	LONGFIN SQUID, WINDOWPANE, LITTLE SKATE

5.4.2.3.2 Warmwater-adapted Community

Multivariate ordination procedures showed there were associations and significant differences in the warmwater-adapted community (abundance) over time and space. Discrete PCO procedures showed the total variation (PCO1) ranged from 40.8 percent (2013−2015) to 43.66 percent (1993−199). Overall, around 41.5 percent of the total variability in the warmwater-adapted community (abundance) was explained by the ordination procedure (PCO1 axis [31.2%] and PCO2 axis [10.3%]) during 1988 through 2015. The warmwater-adapted community (abundance) was primarily associated with the water temperature (surface and bottom) and salinity (surface and bottom).

Separate DLMs ($\mu = r^2 = 0.356$) significantly determined the sequential order of the environmental predictors (surface temperature, maximum depth, bottom temperature, the NAO Index, surface salinity, bottom DO, the EOF Index, the AMO Index, and the surface DO) of the warmwater-adapted community during 1988 through 2015. The procedure least explained ($r^2 = 0.339$) the association between the warmwater-adapted community during 2008 through 2112, and best explained ($r^2 = 0.375$) the connection during 1993 through 1997. The best environmental predictors (sequential order) of the warmwater-adapted community were primarily water temperature (surface and bottom) and maximum depth; water temperature was the best predictor representing the greatest proportion (~29%).

The warmwater-adapted community is changing significantly with time. Separate one-way ANOSIMs confirmed the warmwater-adapted community (abundance) was significantly different among all the time-series ($R = 0.016−0.06$; $P = 0.001$, 999 permutations) during 1988 through 2015. Separate two-way PERMANOVA procedures also demonstrated the warmwater-adapted community was significantly different among time (*P (perm)* = 0.001), space (*P (perm)*

= 0.001), but not the interaction between time and space (*P (perm)* = 1). *Post-hoc* analysis showed that the warmwater-adapted community was marginally different between various pairs of time by individual sampling area. Most of the pairs among time-series were similar with only a few time-series pairs varying significantly by sampling area.

Separate SIMPROFs showed there was a statistical significant structure in the warmwater-adapted community (*Pi* = 5.16−6.28; *P* = 0.001; *Perms* = 999), and distinct one-way SIMPER analyses identified a limited group of warmwater-adapted species (abundance) whose abundances were drivers of dissimilarity across time. The sequential order varied slightly by time-series, but butterfish (*Peprilus triacanthus*), scup (*Stenotomus chrysops*), and northern searobin (*Prionotus carolinus*) represented between 23 and 28 percent of the dissimilarity in the warmwater-adapted community.

5.4.2.3.3 Subtropic-adapted Community

Multivariate ordination procedures showed there were associations and significant differences in the subtropic-adapted community (abundance) over time and space. Discrete PCO procedures showed the total variation (PCO1) ranged from 44.7 percent (2013−2015) to 53.91 percent (1988−1992). Overall, around 49.71 percent of the total variability in the subtropic-adapted community (abundance) was explained by the ordination procedure (PCO1 axis [32.5%] and PCO2 axis [12.2%]) during 1988 through 2015. The subtropic-adapted community (abundance) was primarily associated with the water temperature (surface and bottom) and salinity (surface and bottom).

Separate DLMs ($\mu = r^2 = 0.296$) significantly determined the sequential order of the environmental predictors (surface temperature, maximum depth, bottom temperature, the NAO Index, surface salinity, bottom DO, the EOF Index, the AMO Index, and the surface DO) of the subtropic-adapted community during 1988 through 2015. The procedure least explained (r^2 = 0.232) the association between the subtropic-adapted community during 1993 through 1997, and best explained (r^2 = 0.333) the connection during 2013 through 2015. The best environmental predictors (sequential order) of the subtropic-adapted community were primarily water temperature (surface and bottom) and maximum depth; water temperature was the best predictor representing the greatest proportion (~15.5%).

The subtropic-adapted community is changing significantly with time. Separate one-way ANOSIMs confirmed the subtropic-adapted community (abundance) was significantly different among all the time-series (*R* = 0.016−0.036; *P* = 0.001, 999 permutations). Moreover, two-way PERMANOVAs demonstrated the subtropic-adapted community was significantly different among time (*P (perm)* = 0.001), space (*P (perm)* = 0.001), but not the interaction between time and space (*P (perm)* = 1). *Post-hoc* analysis showed that the subtropic-adapted community was marginally different between various pairs of time by sampling area and various pairs of sampling area by time.

Separate SIMPROFs showed there was a statistical significant structure in the subtropic-adapted community (*Pi* = 1.46−2.23; *P* = 0.001; *Perms* = 999) and distinct one-way SIMPER analyses identified a limited group of subtropic-adapted species (abundance) whose abundances were drivers of similarity across time and space. The sequential order varied by time-series, but bay anchovy (*Anchoa mitchilli*), rough scad (*Trachurus lathami*), and striped anchovy (*Anchoa hepsetus*) between 59 and 73 percent of the dissimilarity in the subtropic-adapted community. Depending on the time-series, round scad (*Decapterus punctatus*), bullnose ray (*Myliobatis *freminvillei*), and Atlantic moonfish (*Vomer setapinnis*) also contributed to the dissimilarity among groups, especially in the later years (2003−2015).

5.5 Discussion

The nearshore marine community and the abundance of the coldwater, warmwater, and subtropic-adapted community structure off the New Jersey coast is changing with time, which is linked with the water temperature (surface and bottom), maximum depth, NAO, and surface salinity. Thus, there appears to be a signature of climate change on these biological communities.

All the hypotheses and alternative hypotheses were confirmed and accepted **(Table 5.5.1**). In general, the marine community was significantly different among years and sampling areas. There was a statistically significant structure in the marine community, and several species contributed to the similarity and dissimilarity. Moreover, the coldwater, warmwater, and subtropic-adapted community was significantly different over time. Similarly, several species contributed to the similarity and dissimilarity. The main environmental predictor of the marine community, and the individual water temperature preference communities was water temperature.

Table 5.5.1. Summary of the confirmation and rejection of the specific null and alternative hypotheses.

Null Hypothesis	**Alternative Hypothesis**	**Accepted**	**Rejected**
The marine community is constant with time despite the variation in the interannual environmental (DO, salinity, and water temperature) and oceanic (NAO, AMO, and EOF) conditions (1988−2015).	The marine community changed significantly with time and space (1988−2015).	**X**	

Null Hypothesis	Alternative Hypothesis	Accepted	Rejected
The coldwater, warmwater, and subtropic-adapted community is constant with time despite the variation in the interannual environmental (DO, salinity, and water temperature) and oceanic (NAO, AMO, and EOF) conditions (1988−2015).	The coldwater, warmwater, and subtropic-adapted community changed significantly with time and space (1988−2015).	**X**	

Changes in climate and the associated atmospheric-oceanic indices are having wide ranging ecological effects on marine systems around the world (e.g., Rijnsdorp et al. 2009; Polovina et al. 2011; Engelhard et al. 2014). Researchers around the world have documented various changes in the marine community related to climate change, but most have reported a northern shift in distribution based on their temperature preference or upper thermal level limit. In the eastern North and Central Atlantic Ocean, the abundance and seasonal migration of small pelagic clupeoid fish (anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*), sardinella (*Sardinella aurita*), sprat (*Sprattus sprattus*) and Atlantic herring (*Clupea harengus*) was connected to the warm and cool phases of the AMO (Alheit et al. 2014). The most northern distribution of anchovy was the English Channel area and the southeastern edge of the North Sea during the cold AMO phase, whereas anchovies migrated farther north during the warm AMO phase. Despite the connection between the marine community and water temperature (i.e., AMO), Alheit et al. (2014) speculated the change in the local current's strength and direction also impacted the small pelagic fish populations. The variation in the atmospheric-ocean processes and its impact on marine communities is not straight forward correlation or causation process; its complex in terms of the region, oceanographic and marine community dynamics. Although many researchers have reported changes in marine species associated with climate variability, most have focused their investigations on a single species or a specific life-stage (Hufnagl and Peck, 2011), few have examined the effects on key species (Wernberg et al. 2010) or marine communities as a whole. As marine resource managers begin to develop methods to consider climate variability and embrace governing ecosystems rather than single species, holistic marine community data will become more critical with time (Russell et al. 2012).

5.5.1 Atmospheric-Oceanic Indices and Marine Community Connection

5.5.1.1 Environmental and Oceanic Conditions

Multivariate comparison procedures showed the environmental and oceanic conditions significantly changed over time and space, but low *R* values showed negligible separation among samples, which indicated the change in the abiotic conditions was minimal and gradual. Pairwise tests showed most pairs (time) were significantly different within individual time-series accept several early time-series (1988−1992) pairs. The coastal waters off New Jersey are a dynamic system in terms of the environmental and atmospheric-oceanic conditions, oceanic processes (Schofield et al. 2008). Besides the variability in the annual abiotic conditions over time, the environmental conditions varied significantly within individual sampling areas, which was somewhat surprising given the relatively small study area. The environmental conditions in sampling areas located closer in distance were more similar than those further away.

These findings agree with much of the scientific literature demonstrating the connection and associated change in the primary atmospheric-oceanic indices (e.g., Botsford et al. 2011; Hofsted and Rijnsdorp, 2011). While these metrics can provide valuable insight into the link between the abiotic conditions and marine community, specific environmental factors can play a role in shaping (similarity [water temperature] and dissimilarity [salinity]) the abiotic conditions within a given region.

The environmental conditions shape the local marine community, but it is possible the primary atmospheric-oceanic metrics (NAO and AMO) are a better predictor of the marine community in some biogeographic regions where the marine community lives close to their upper thermal limit, such as segments of the Western Atlantic and Eastern Atlantic and warm regions (Nye et al. 2014; Toonen et al. 2016). In general species found on the boundary between regions tend to live near their upper or lower temperature tolerance limit (Norse, 1993); every species lives within their preferred temperature ranges. For instance, cod (*Gadus morhua*), located 83°N - 35°N, 95°W - 86°E, prefer water temperatures between 0.5 and 10.3°C (μ= 6.6°C), while black seabass (*Centropristis striata*), located 45°N - 25°N, prefer water temperatures between 10.8 and 24.9°C, (μ= 23.6°C) (Froese and Pauly, 2018). Given the importance of water temperature to various biological processes (Pankhurst and Munday, 2011), a minimal fluctuation in water temperature can impact species with a restricted temperature tolerance range, and an even greater impact on a species living in an region with a water temperature at a species' lower or upper temperature tolerance level. For example, gray snapper (*Lutjanus griseus*) is expected to shift northwards as water temperatures continues to rise, but the magnitude in the shift will depend on the magnitude of climate change (Hare et al. 2012). Understanding the species composition and their associated life history biology forming the marine community is essential to predicting, estimating, and interpreting how species' are influenced by the seasonal, annual, and long-term variability in the environmental conditions.

5.5.1.2 Marine Community

The variability in the water temperature, maximum depth, NAO, and surface salinity has altered the nearshore marine community off the New Jersey. Overall, water temperature is the best predictor of the marine community representing the greatest proportion (~25%). Moderate changes in abiotic stress seem to be altering the structure of the nearshore community. Investigators around the world have proved the environmental conditions are shifting with time, but most research has focused on the effect of climate-related water temperature change on marine communities (e.g., Hunt et al. 2011; Voss et al. 2011). In some ways, water temperature is among the easiest environmental factors to examine because of the availability of data and metrics (indices) that date back to the 1800s (Deser et al. 2010). Despite the availability of long-term data, water temperature is also one of the main environmental factors used to classify marine species into biogeographical regions around the world (Toonen et al. 2016). Researchers also use the variability in water temperature to examine potential changes in a marine community because published studies show water temperature is directly associated to global warming, oceanic conditions, and marine communities (Flanagan et al. 2019). Increasing air and associated water temperature anomalies have also been shown to cause mortality events in marine communities, such as the rocky benthic communities in the Mediterranean (Crisci et al. 2011). Water temperature is a key environmental factor that is a link between the atmospheric, ocean, and marine communities. The findings from this present study agree with other researchers whom have shown the increase in water temperature along the U.S east coast is influencing and changing the marine community by shifting the distribution of warmwater species (e.g., Wood et al., 2009; Howell and Auster, 2012).

The ANOSIM procedures revealed the marine community (abundance) varied significantly among every sampling area and time-series accept during 1998−2002 and 2003−2007 time-series suggesting the marine community is evolving, but it was stable in some years despite the varying environmental conditions. It is possible the marine community did not vary during 1998−2002 and 2003−2007 because the main species were able to adjust to the environmental conditions or the environmental levels were still within their tolerance range. This could explain the marginally difference (low *R* values) between many of the individual time-series pairs. A significant difference was usually detected between pairs that were three to five years apart indicating the change in the marine community was gradual with time. The marine community varied significantly between most time-series pairs during 2008−2012 and 2013−2015 indicating the marine community has recently evolved. The test also showed the most significant difference between sampling area pairs was also during the 2008−2012. As such, it is possible the environmental conditions could be reaching levels that are beyond the preferred temperature tolerance levels for many of the species defining the nearshore marine community off New Jersey. Given the marine community varied significantly in some sampling areas during 2013−2015, it is conceivable some species were able to adjust their distribution within the study area to areas with more tolerable environmental conditions.

The less sensitive, two-way PERMANOVA procedures did not show the change in the marine community was influenced by the sampling area. In other words, the marine community is evolving similarly through the study area. Assuming the environmental conditions will continue to change with time, this implies the marine community could have difficulty tolerating, adapting, and shifting (abundance and distribution) within the study area. In some regions, species shift their distribution to move away from areas with warm water temperatures (e.g., Tseng et al. 2011). As such, it is likely the marine community will continue to evolve with time, especially if the progressing abiotic conditions reach a level that cause the majority of the species defining the marine community to re-adjustment their distribution and zoogeographical groupings (species composition, distribution, and relative abundance). Similar predictions have been made by various researchers for several regions (e.g., Cheug et al. 2011; Polovina et al. 2011), and numerous researchers have already documented regime shifts in the marine community associated with increasing water temperatures throughout the world, including the eastern North and Central Atlantic Ocean, and Mediterranean Sea (Alheit et al. 2014). Even with low significance values, the findings in this present study agree with the majority of the scientific literature indicating climate change is effecting marine communities around the world (e.g., King et al. 2011; Howell and Auster, 2012). As such, it is reasonable to expect more biological changes will occur in the MAB and other regions along the east coast of the United States as ocean temperatures progressively increase with time (Nye et al. 2009).

The SIMPER analyses identified several species whose abundances shaped the nearshore marine community over time and space. The average Bray-Curtis similarity value ranged from 35.55 in 2011 to 56.26 in 1988, which indicates the marine community is shifting with time in terms of species composition and associated abundance. The marine community is becoming more dissimilar with time. In general, the lowest average similarity (highest dissimilarity) occurred later and the highest average similarity (lowest dissimilarity) occurred earlier within individual time-series, which demonstrates the marine community is evolving with time. The main species contributing (43−51%) to the similarity among time and space were primarily longfin squid, windowpane flounder, and little skate. Conversely, *post-hoc* analyses demonstrated Atlantic butterfish (warmwater-adapted), longfin squid (coldwater-adapted), scup (warmwater-adapted), bay anchovy (subtropic-adapted), northern searobin (warmwater-adapted), and Atlantic herring (coldwater-adapted) contributed (14−19%) to the dissimilarity over time. Water temperature influences certain species. Scup are sensitive to cold water temperature (Howell and Auster, 2012), while windowpane can tolerate wide-ranging water temperatures, but continuous spawning only occurs during colder summers (Wilk et al. 1990). Although coldwater-adapted species influenced the similarity, warmwater-adapted species shaped the dissimilarity of the marine community in the study area. These findings confirm the evolving marine community is in sync with the changing abiotic conditions, which agrees with Wood et al. (2009) and Howell and Auster (2012) for nearby Narragansett Bay, Rhode Island and Long Island Sound, New York, respectively.

The nearshore marine community off New Jersey is comprised of many species, but it is influenced by a limited number of species; its low in diversity (limited number of species dominating [abundance]) community. The marine community is evolving with time as the EOF, salinity (surface and bottom), and AMO re-adjust to climate change. Given the EOF and AMO are metrics based on water temperature, water temperature is the primary environmental factor shaping and controlling the marine community off New Jersey. The rising water temperature is changing the community structure of the nearshore marine fauna off New Jersey. Similar to previous studies (Wood et al. 2009; Howell and Auster, 2012), the nearshore marine community is highly influenced by several warmwater-adapted species (Atlantic butterfish, scup, and northern searobin). In terms of the primary species influencing the similarity in the marine community, it has changed very little over time, which suggest the abiotic conditions are still within the physiological thermal range for these species. For instance, longfin squid water temperatures between 0.3 and 26°C, and little skate (3.3−11.9°C) and windowpane flounder (0.9−10.4°C) have more restricted temperature range (Froese and Pauly, 2018). As such, it is presumable the average abiotic conditions are still within the temperature preference range for these species, and/or the availability of prey or other life history requirements is sufficient in the study area. It is also possible that either the availability of prey has remained unchanged or these key species have a broad, diversified, and non-specific diet. Atlantic butterfish, scup, and northern searobin prey on a variety of crustaceans and fish, and have similar trophic levels averaging 3.6 or 3.7. ± 0.1 S.E (Froese and Pauly, 2018). Longfin squid consistently contributed the most to within-group similarity and between-group dissimilarities. This species was by far the most dominant in terms of abundance. The high contribution of longfin squid to dissimilarities between factors (time and space) was probably associated with water temperature. Longfin squid are a coldwater-adapted species that have an upper thermal limit of 26°C (Froese and Pauly, 2018).

The ANOSIM procedures demonstrated there was a significant difference in the marine community structure (*k*-dominance curves) in every time-series, accept during 2003−2007; the difference was minor in terms of strength (low *R* values). Overall, the *post-hoc* analyses showed there was a significant difference in the community structure between varies pairs of time indicating the marine community changed with time; the marine community was generally similar earlier and dissimilar (significantly different) later in time within individual time-series. The adjustment in the marine community appears to be occurring at a slow rate mimicking the slow rate of change in the water temperature. Examining the mean environmental conditions during 2003−2007, did not explain why the marine community was similar in this period since the environmental conditions did display interannual variability; the mean bottom water temperature increased from 10.9°C in 2003 to 13.2°C in 2007. The SIMPER analyses showed the average percent similarities (37.4−46.8%) were relatively comparable during this period (2003−2007), and little skate contributed the most to the percent similarity (~13−15%) among years. It is possible that the abiotic conditions during this period were ideal for little skate. Since the percent contributions were similar among years, it is possible this is the reason why the ANOSIM procedure could not detect a difference in the community structure during 2003 through 2007.

The SIMPER test also showed the average similarity varied among sampling areas during the separate time-series with the lowest percent values (highest dissimilarity) occurring in sampling areas 12 (1993−1997; 2008−2012) and 22 (1998−2002; 2003−2007) and the highest percent values (lowest dissimilarity) occurring in sampling areas 14 (1988−1992; 1993−1997; 1998−2002) and 17 (2008−2012; 2013−2015). These findings suggest that sampling areas 12 and 22 could have more erratic conditions, while sampling areas 14 and 17 could have more stable conditions than the other sampling areas at certain times. *Post-hoc* analyses indicated the primary species contributing to the dissimilarity were butterfish, longfin squid, scup, bay anchovy, northern searobin, and Atlantic herring. The ANOSIM procedures showed there was a significant difference in the community structure (k-dominance curves) among areas, and *post-hoc* analyses showed some of the differences were between pairs that were geographically further apart, but patterns were inconsistent.

It is difficult to speculate what factors are contributing to differences in the marine community among sampling areas given the environmental conditions are generally similar among many sampling areas (minimal differences); sampling areas that are situated closer (e.g., sampling areas 12 and 13 or sampling areas 12 and 15) are similar. Conceivably the difference in the marine community among sampling areas could be associated with the oceanographic conditions (upwelling or eddies) in specific years that either benefited or deterred changes in the marine community. Howell and Auster (2012) pointed out that water temperature was the key contributing factor to the change in the marine community over time, but also acknowledged it was probable linked to other physical, behavioral, and physiological factors in Long Island Sound, New York. Based on the fact that the primary species contributing to the similarity among groups (time-series) has remained relatively unchanged over time, it appears the ecological health of the marine community is relatively stable (species composition and abundance), but it is slowly transitioning from a coldwater to warmwater-adapted species community as the water temperature increasing with time.

5.5.1.3 Marine Fauna Temperature Tolerance and Preference

5.1.3.1 Coldwater-adapted Community

Multivariate ordination procedures showed there were associations and significant differences in the coldwater-adapted community (abundance) over time and space. The nMDS and PCO procedures demonstrated many samples were dissimilar and the Pearson correlation (> 0.20) overlay vector procedures showed the coldwater-adapted community is reasonably correlated with the water temperature (surface and bottom), salinity (surface and bottom), and somewhat associated with DO (surface and bottom) in some time-series (2008−2012; 2013−2015). The scientific evidence has overwhelming shown that various sectors of the marine community and individual species are linked to water temperature (e.g., Jang et al. 2011; Muhling et al. 2011), especially coldwater-adapted species that are sensitive to increasing temperatures (Woods et al. 2009; Howell and Auster, 2012). The best environmental predictors (sequential order) of the coldwater-adapted community varied somewhat by time-series, but were primarily temperature (surface) and maximum depth; water temperature is the best predictor representing the greatest proportion (~30%). These findings agree with previous researchers whom have shown the distribution of coldwater-adapted species is influenced by water temperature (e.g., Engelhard et al. 2011). Engelhard et al. (2011) reported long-term water temperature (Hadley SST, NAO, and AMO) provided an adequate predictor of plaice (*Pleuronectes platessa*) abundance and distribution; plaice is a coldwater species that prefers water temperatures between 6.8 and 12.4°C (μ = 10.2°C).

The ANOSIM procedures confirmed the coldwater-adapted community (abundance) was significantly different among all the time-series and sampling areas indicating the community has shifted with time. It should be noted that the change across all time-series was minimal in terms of calculated low R values. *Post-hoc* analysis showed many time pairs were significantly different, but a few pairs were similar within individual time-series (2004, 2005; 2008, 2009). The test also showed the further in distance the sampling areas (pairs) were to each other, the higher the probability there was significantly difference in the coldwater-adapted community over time. This suggests the coldwater-adapted community is significantly different among sampling areas because the abiotic conditions or other factors are better in some sampling areas than others for certain species. Given the multivariate tests showed the coldwater-adapted community has changed with time, it is highly likely some species have been replaced by warmwater or subtropic-adapted species over time. The marine community is shifting in relation to the rising water temperature around the world (Pinsky and Byler, 2015), including various regions along the east coast of the U.S (e.g., Wood et al. 2009; Howell and Auster, 2012). In nearby Long Island Sound, the abundance of the cold-adapted group was lower than the warm-adapted group when the mean temperature was above 6°C in spring and 19.5°C in autumn in a few years (Howell and Auster, 2012). The two-way PERMANOVA procedures also proved the coldwater-adapted community was significantly different among time and space, but it did not vary by the interaction between time and space. *Post-hoc* analysis showed that the coldwater-adapted community was only marginally different between various pairs of time by individual sampling area. Actually, there were only a few time-series pairs that were significantly different by sampling area. Again, this less sensitive test proves the coldwater-adapted species has shifted minimally in the study area over time and space, but it did not demonstrate the change in the coldwater-adapted community was linked with the sampling area by a specific time-series. The marine community is shifting over time as the abiotic conditions change within the study area; however, it is somewhat difficult to pattern the shift in spatial distribution by individual time-series given the relatively small sample size per sampling area (n = 12); a larger sample size per sampling area would be necessary to detect a spatial pattern.

The SIMPER analyses identified several coldwater-adapted species (abundance) were drivers of the grouping patterns in terms of time and space. The average Bray-Curtis similarity percent value ranged from 41.05 in 2011 to 60.91 in 1988, which mimicked the findings for the marine community analyses. However, unlike the marine community findings, no pattern was detected between the lowest and highest average percent similarity within individual time-series suggesting the coldwater-adapted community is relatively stable. The main species contributing between 65 and 75 percent of the similarity among time and space were longfin squid, windowpane flounder, and little skate. Conversely, *post-hoc* analyses indicated the longfin squid, little skate, and Atlantic herring contributed to the dissimilarity (30−35 percent); silver hake, winter skate, lady crab, spiny dogfish, and scup also contributed to the difference between some pairs. Longfin squid and little skate consistently contributed the most to within-group similarity and between-group dissimilarities. This agrees with previous work by Howell and Auster (2012) whom found that little skate and Atlantic herring contributed to the dissimilarity in the coldwater-adapted group in Long Island Sound. However, the primary coldwater-adapted species contributing the most to the dissimilarity were windowpane, spotted hake, and silver hake (Howell and Auster 2012). Off the coast of New Jersey, Longfin squid and little skate were consistently the most dominant in terms of abundance. The high contribution of longfin squid and little skate to dissimilarities between factors (time and space) was probably associated with water temperature. These two species are also primary species shaping the marine community as a whole, which demonstrates how important coldwater-adapted species are off the coast of New Jersey. It also shows how vulnerable the marine community is given the context of climate change. In nearby Long Island and Narragansett Bay, more significant shifts in the marine community have already occurred in recent years with the rising water temperature (Wood et al. 2009; Howell and Auster, 2012).

The ANOSIM procedures also showed there was a significant difference in the coldwater-adapted community structure (*k*-dominance curves) over time. *Post-hoc* analyses showed there was a significant difference in the community structure between several pairs of time, but generally no pattern was evident. In some pairs (time), a difference was detected in pairs that were earlier in the time-series, later in the time-series, or 2−3 or 3−4 years apart. This indicates the change in the coldwater-adapted community is slow, but ongoing with time. Similar to the marine community, the species representing the similarity in the coldwater-adapted community were dominated by the same three coldwater-adapted species. It is important to note that different groups of marine organisms respond differently to climate forcing. In Australia, Fulton (2011) reported that climate change (water temperature) will favor some species and disdain others depending on their ecosystem level. For instance, Fulton's (2011) models predicted that pelagic fish biomass would increase, while demersal fish biomass would decrease as water temperature continues to rise with time. Pelagic species have the ability to migrate great distance, whereas demersal species are restricted because of their preferred (e.g., bottom substrate and structure) habitat (Fulton, 2011). Demersal species generally only migrate short distances and their diet can be more degraded by environmental conditions than pelagic species (Fulton, 2011).

All the key coldwater-adapted species representing the dissimilarity in groupings in this present study are classified as demersal species, which have limited coastal movements. Although the main dissimilarity species have remained relatively stable over time, it is possible they will change their spatial distribution if abiotic conditions exceed their upper tolerance level. Species vulnerable to water temperature will either adapt or migrate from the region. Actually, examining the 2008−2012 and 2013−2015 time-series, the data suggests the community could be transitioning (i.e., shift in coldwater-adapted species distribution) in the study area. The species contributing to the dissimilarity were not only longfin squid, little skate, and Atlantic herring, but silver hake during 2008−2012 and winter skate during 2013−2015. This is noteworthy because it shows that the abiotic conditions have likely caused this change in the biological community over the past 10 years. The only other time silver hake was a key (top four) dissimilarity species was during 1993−1997; winter skate has never been one of the top four species at any time. Silver hake and winter skate prefer cold water (silver hake: 0.9−7.8°C; $\mu = 4.9$°C) (winter skate: 4−9°C; $\mu = 6$°C) (Scott, 1982; Cohen et al. 1990). Examining the mean water temperature (surface and bottom) in the study area showed it was above the upper limit for these species during 2008−2012 and 2013−2015. The mean surface and bottom temperature was 15.2°C and 12.6°C during 2008−2012. In the following time-series (2013−2015) the mean water temperature was 15.2°C (surface) and 13.1°C (bottom), which was 3.9 percent (+ 0.5°C) warmer. The marine community and in particular the coldwater-adapted community is changing with time in the study area.

The SIMPER analyses also showed the average similarity between species varied among space. The average percent similarity ranged from 39.49 (2008−2012) in sampling area 21 to

53.93 (2003−2007) in sampling area 17. The average percent similarity varied among sampling areas during the separate time-series, but the lowest (highest dissimilarity) percent values occurred in sampling areas 12 (1998−2002; 2013−2015), 22 (1998−2002; 2003−2007), 26 (1988−2002; 1993−1997) and the highest (lowest dissimilarity) percent values occurred in sampling area 17 (1998−2002; 2003−2007; 2013−2015). These findings suggest the inshore (sampling area 12) waters are influenced more by water temperature than the offshore waters (sampling area 17), which is expected. Although sampling areas 22 and 26 were located offshore, they were situated in the southern region of the study area and were likely influenced by the oceanographic conditions associated with Delaware Bay. Examining the mean bottom water temperature data indicated it was 13.3°C (+ 2°C or 15% warmer) in sampling area 12 and 11.3°C in sampling area 17 during 2013−2015.

In general, three species (winter flounder (*Pseudopleuronectes americanus*), lady crab (*Ovalipes ocellatus*), and common spider crab) represented between 52 and 80 percent of the similarity in the coldwater-adapted community among sampling areas. These species are different than those shaping the coldwater-adapted community as a whole indicating coldwater-adapted species are distributed differently throughout the study area. It is highly probable the difference in the marine community among sampling areas was associated with not only the changing abiotic conditions, but available habitat within individual sampling areas. For instance, the common spider crab in Great Bay (New Jersey) prefers a sand mixed bottom, and are low and high temperature sensitive (O'Brian et al. 1995). Lady crab in New Jersey prefer sand over mud substrate to avoid predators (Barshaw and Able, 1990) and winter flounder prefer sand, mud, and hardbottom substrate and water temperature between 0.7 and 13.1°C (μ = 6.1°C) (Kaschner et al. 2016). This is important concept to consider because demersal species cannot simply migrate to other locations with preferred abiotic conditions, they also require specific bottom habitat, which may or may not be within the vicinity. Demersal species have numerous biotic and abiotic factors that determine their abundance, distribution, and habitat (Johnson et al. 2012).

Post-hoc analyses demonstrated longfin squid, Atlantic herring, winter flounder, and little skate contributed to the dissimilarity (30−40 percent); silver hake, lady crab, and winter skate also contributed to the difference in groups depending on the time-series; these species were similar to the marine community as a whole. The ANOSIM test also showed there was a significant difference in the coldwater-adapted community structure (*k*-dominance curves) among sampling areas. The differences were between pairs that were geographically further apart (e.g., areas 18 and 23 [1988−1992]), but patterns were inconsistent. This suggests these coldwater-adapted species might not be able to easily adjust their distribution within the study to cope with changing abiotic conditions. Perhaps the behavior (limited movements) life-history characteristics (water temperature) and limited habitat (substrate) requirements of demersal (Johnson et al. 2013) coldwater-adapted marine species makes than more vulnerable to climate variability than other marine ecological groups (e.g., coastal pelagic species) off the coast of New Jersey (Hare et al. 2016).

5.5.1.3.2 Warmwater-adapted Community

Multivariate ordination procedures showed there were associations and significant differences in the warmwater-adapted community (abundance) over time and space. Similar to the coldwater-adapted community, the warmwater-adapted community (abundance) is primarily associated with the water temperature (surface and bottom) and salinity (surface and bottom). The best environmental predictors (sequential order) of the warmwater-adapted community were primarily water temperature (surface and bottom) and maximum depth; water temperature was the best predictor representing the greatest proportion (~29%). Warmwater-adapted species are sensitive to cold water temperatures. In general, warmwater-adapted species prefer water temperatures between 15 and 29°C (Murdy et al. 1997; Collette and Klein-MacPhee 2002; Able and Fahay, 1998; Able and Fahay, 2010; Froese and Pauly, 2018). As global water temperatures continue to increase (Deser et al. 2010), the abundance, distribution, and species composition defining the warmwater-adapted community is shifting northward worldwide (e.g., Rijnsdorp et al. 2010), including throughout the United States (e.g., Wood et al. 2008; Nye et al. 2009; Howell and Auster, 2012; Morley et al. 2018)

The warmwater-adapted community is changing significantly with time. Separate one-way ANOSIMs and two-way PERMANOVAs confirmed the warmwater-adapted community (abundance) was significantly different among time-series and sampling areas in the study area during 1988 through 2015. *Post-hoc* analysis revealed the warmwater-adapted community was marginally different between various pairs of time by individual sampling area. Most of the pairs among time-series were similar with only a few time-series pairs varying significantly by sampling area. This agrees with previous research in the MAB. In Long Island Sound, seasonal mean catch of the coldwater-adapted community decreased, and warmwater-adapted community increased during 1984 through 2008 (Howell and Auster, 2012). The warmwater-adapted group exhibited a positive correlation with the mean bottom water temperature. Wood et al. (2009) also found warmwater species were more common and abundant over time (1987−2000) in Narragansett Bay and Long Island Sound.

Based the two-way PERMANOVAs, the warmwater-adapted species are also slightly adjusting their distribution over time within specific areas of the study area. Although the abiotic conditions vary only slightly among sampling areas, it is possible the conditions are better suited (i.e., within the tolerance range) in certain sampling areas within the study area, which agrees with previous research. Butterfish, a common warmwater-adapted schooling species, prefers water temperatures between 5.1 and 24.7°C with a 21.7°C mean preferred water temperature (Howell and Auster, 2012; Froese and Pauly, 2018). Along the continental shelf of the northeast, butterfish are found farther northeast and deeper over time (1982−2013), especially for age 3 indicating spatial segregation depends on age and water temperature (Adams, 2017). Interestingly, butterfish have not progressively shifted their distribution northward (1982−2013), but have shifted more inshore indicating the current abiotic conditions and other biological requirements are ideal along the northeast coast of the United States (Adams, 2017). It is probable that butterfish have not shifted further north because of the lower water temperatures.

Separate SIMPROFs showed there was a statistical significant structure in the warmwater-adapted community and distinct one-way SIMPER analyses identified a limited group of warmwater-species (abundance) whose abundances were drivers of dissimilarity across time. The sequential order varied slightly by time-series, but butterfish, scup, and northern searobin represented between 23 and 28 percent of the dissimilarity in the warmwater-adapted community. This somewhat agrees with Howell and Auster (2012) who reported scup, butterfish, and summer flounder were the primary warmwater-adapted species in Long Island Sound representing the dissimilarity in the community during spring. It was not surprising butterfish, scup, and northern searobin contributed to the dissimilarity since these species are among the most dominant in terms of abundance. Butterfish abundance and the spawning stock biomass is relatively stable despite the high interannual variability in recruitment; the latest stock assessment indicates butterfish is not overfished and overfishing is not occurring (NMFS, 2018b). Scup is also an abundant migratory warmwater species whose abundance and spawning stock biomass is stable; the current stock assessment indicates scup stock status is rebuilt and overfishing is not occurring (ASMFC, 2015). Similarly, northern searobin are a common warmwater species found along the coastal waters of the eastern United States (Howell and Auster, 2012).

5.5.1.3.3 Subtropic-adapted Community

Multivariate ordination procedures showed there were associations and significant differences in the subtropic-adapted community (abundance) over time and space. Following the other two temperature preference groups, the subtropic-adapted community (abundance) was primarily associated with the water temperature (surface and bottom) and salinity (surface and bottom). The best environmental predictors (sequential order) of the subtropic-adapted community were primarily water temperature (surface and bottom) and maximum depth; water temperature was the best predictor representing the greatest proportion (~15.5%). In general, subtropic-adapted species prefer water temperatures greater than 30°C (Murdy et al. 1997; Collette and Klein-MacPhee 2002; Able and Fahay, 1998; Able and Fahay, 2010; Froese and Pauly, 2018).

The subtropic-adapted community is changing significantly with time. Separate one-way ANOSIMs and two-way PERMANOVAs confirmed the subtropic-adapted community (abundance) was significantly different among all the time-series, which agrees with the published literature (Wood et al. 2009; Howell and Auster, 2012). *Post-hoc* analysis showed that the subtropic-adapted community was marginally different between various pairs of time by sampling area and various pairs of sampling area by time. This clearly demonstrates the subtropic-adapted community is changing off New Jersey over time, and subtropic-adapted species are found in certain areas within the study area. In some ways similar to the coldwater-adapted community, their spatial distribution is limited by water temperature. However, instead of being limited by higher water temperatures like the coldwater-adapted community, the subtropic-adapted community is limited by lower water temperatures. As water temperatures continue to rise, subtropic species are migrating further north along the northeast coast with time. Wood et al. (2009) and Howell and Auster (2012) demonstrated the increase in the annual abundance of subtropic species in Narragansett Bay and Long Island Sound was positively correlated with the water temperature.

Separate SIMPROFs showed there was a statistical significant structure in the subtropic-adapted community and distinct one-way SIMPER analyses identified a limited group of subtropic-adapted species (abundance) whose abundances were drivers of similarity across time and space. The sequential order varied by time-series, but bay anchovy, rough scad, and striped anchovy between 59 and 73 percent of the dissimilarity in the subtropic-adapted community. Depending on the time-series, round scad, bullnose ray, and Atlantic moonfish also contributed to the dissimilarity among groups, especially in the later years (2003−2015). Bay and striped anchovy are among the most abundant schooling short-lived species in the coastal waters of the western North Atlantic Ocean (Robinette, 1983; Newberger and Houde, 1995; Lapolla, 2011). Similar SIMPER analysis were reported for rough scad and Atlantic moonfish in Narragansett Bay and Long Island Sound, respectively (Wood et al. 2009; Howell and Auster, 2012). However, the species contributing most to the dissimilarity between Narragansett Bay and Long Island Sound were rough scad, crevalle jack (*Caranx hippos*), blue runner (*Caranx chrysos*), flying gurnard (*Dactylopterus volitans*), bluespotted coronetfish (*Fistularia tabacaria*), and the orange filefish (*Aluterus schoepfi*) (Wood et al. 2009). In Long Island Sound, the primary subtropic-adapted species contributing to the dissimilarity in the community in the fall was the Atlantic moonfish (Howell and Auster, 2012). Distinct geographical regions may have a similar general community response, but individual species responses will vary from one region to another (Wood et al. 2009;

Howell and Auster, 2012). Interestingly, neither Wood et al. (2009) or Howell and Auster (2012) reported collecting bay or striped anchovies, which is surprising given their relative abundance and distribution range (Lapolla, 2011). It is possible that these species are generally found in those regions, but not within those particular designated study areas. Atlantic moonfish prefer water temperatures between 12° and 27.9°C with a mean of 24.4°C (Froese and Pauly, 2018) so it's possible they have been able to migrate further north than other subtropic species because of their lower temperature limit (12°C or 53.6°F). As the water temperature continues to increase, the species contributing to the dissimilarity are changing with time. Along with Atlantic moonfish, bullnose rays are now distinguishing the subtropic-adapted community off New Jersey. The coastal migratory bullnose ray is distributed from Massachusetts to Florida (Froese and Pauly, 2018), so perhaps the relative recent increase in abundance off New Jersey could be related to diet; bullnose ray prey on various crustaceans and mollusks (Froese and Pauly, 2018).

5.6 Conclusion

The observations presented here have not been previously documented and provide valuable information regarding the nearshore marine community structure off New Jersey. Besides adding to our knowledge of the changes in the marine community over time, the research demonstrates climate variability is impacting nearshore marine community in the MAB. Climate variability is shifting the marine community, and in particular the coldwater, warmwater, and subtropic-adapted species off the coast of New Jersey over the past 28 years. As expected, and agreeing with previous published work, the best predictor of the marine community was water temperature.

Despite these observed changes in the marine community, it is difficult to speculate whether the shift from a coldwater to a predominately warmwater/subtropic-adapted community will cause any negative long-term permanent impacts in terms of ecological health. Ecologists have debated what constitutes a healthy marine community because it is not a straightforward principle (Tett et al. 2013). Similarly, ecological climate change impacts in the context of ecological health are not fully understood, but managers are beginning to consider various management actions (Selkow et al. 2015). Is a dominant coldwater-adapted species community ecologically "healthier" than a community dominated by warmwater-adapted species? These ecological theoretical questions are difficult to answer given the complexity of the biological and community factors, but it is probably more associated with community stability and disturbance sensitivity (Begon et al. 1986; Tett et al. 2013). Given the latitude location of New Jersey and the associated biogeographical zone, one of the key stressors of the marine community is water temperature, especially a rapid change in water temperature. As such, it is probable that a rapid fluctuation in water temperature could decrease the overall health of the community in terms of resistance (i.e., ability to cope with disturbance). Until, or if, water temperatures reaches some climax thermal level, it's possible that the transitional period (coldwater-adapted to warmwater-adapted community) could be detrimental to the marine community given the risk of acute mortality events (Crisci et al. 2011) and other biological factors associated with drastic changes in water temperature. The climate warming trend is expected to continue (NOAA, 2018), so it is likely the variability in the oceanic conditions will also continue to increase with time, which will cause extreme or extended periods of warmer water temperatures in certain seasons or years. These limited and extreme temperature anomalies could pose a risk to many life-stages of species and their associated prey in the MAB since various biological mechanisms (e.g., growth, spawning, and respiration) have upper thermal limits. For example, the hatching percentage for American sand lance (*Ammodytes americanus*; a coldwater-adapted species found in the study area; preferred water temperature 2.7−14.2°C; μ = 7.9°C) eggs decreased with an increase in water temperature (Smigielski et al. 1984). Various reproductive factors (i.e., 50% hatch, hatch duration, hatch time, and yolk sac and oil absorption) are negatively impacted with an increase in water temperature, such as the hatch rate decreased 75 percent at 10°C vs 2°C (Smigielski et al. 1984).

Presently, fisheries management is focused on sustaining marine resources for commercial fisheries by implementing management options focused on various biological metrics, such as size/age-at-catch, maximum stainable yield, and stock size (King, 1995). Although these are essential fisheries management variables, it will be important to include other factors affecting marine populations, such as habitat loss and climate variability. In many ways, considering the impacts of climate change will be important for managing commercial fisheries given many species are shifting their distribution and movement patterns in response to changing abiotic conditions (e.g., Lan et al. 2011). For instance, anadromous (salmon) fishery managers will need to use models that incorporate environmental factors associated with climate change in commercial harvest areas to predict seasonal migration patterns, implement fishing seasons, and prevent the risk of overharvesting in Alaska (Mundy and Evenson, 2011). Information describing the temporary or permanent impacts to marine resources associated with climate variability in regions that support valuable commercial fisheries is crucial to fishery resource managers so they can make informed management decisions. Understanding and managing the impacts of climate variability on marine resources is convoluted given the complexity of factors, interactions (inter and intra), and the often unknown biological-environmental connections. Despite numerous researchers reporting some change in marine species and communities associated with climate variability, most have focused their research on a single species or life-stage (Hufnagl and Peck, 2011), few have examined the effects on key species (Wernberg et al. 2010) or marine communities as a whole. As managers begin to develop management methods to consider climate variability and embrace governing ecosystems rather than single species, marine community data will become more critical with time (Russell et al. 2012).

Besides adding to our knowledge of climate variability, the changes in faunal assemblages noted in this study will become increasingly pertinent for future studies given climate is predicted to change with time in the MAB and other regions around the world (Najjar et al. 2000). Given climate is steadily changing and thereby can impact marine communities, it will be essential that climate science and fisheries management become integrated under the management process, especially since commercial fisheries and global atmospheric change are two of the most severe threats to biodiversity (Norse, 1993). One of the outcomes of the Sendai Conference was the support for integrated science (Murawski, 2011). Presenters stressed the need to manage fisheries using an ecosystem approach given the ongoing complex issues associated with climate change. In the MAB, research on climate change and the Atlantic surfclam (*Spisula solidissima solidissima*) fishery is in its early stages, but McCay et al. (2011) recommended that climate forcing impacts be integrated into future ecosystem-based fisheries management. Many marine populations are currently undergoing a variety of natural and human-induced stressors and threats that are disturbing marine communities, which could lead to the collapse of marine resources around the world unless fishery managers charged with sustaining populations for future generations begin to implement climate variability metrics and associated impacts into their management models.

Marine communities are negatively impacted by numerous stressors acting independently or in concert, such as overexploitation (fisheries), physical alteration, marine pollution, introduction of exotic species, and global atmospheric change (Norse, 1993). Therefore, to holistically manage marine resources all of these threats should be considered in future research studies and under the management process. Although the approach for this research was holistic in terms of examining the entire marine community and subgroups of the marine community, one of the main limitations was excluding to consider the potential role commercial fisheries have on local populations within the study area. Future analyses could include an exploitation index or some measure of fishing pressure as a predictor variable. Another community factor future research studies should consider is community dynamics in terms of species interactions, such as trophic dynamics, competition, and predator-prey associations.

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5.8 References

Able, K.W., and M.P. Fahay. 1998. The first year in the life of estuarine fishes in the Middle Atlantic Bight. New Brunswick. Rutgers University Press.

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

Adams, C.F. 2017. Age-specific differences in the seasonal spatial distribution of butterfish (*Peprilus triacanthus*). ICES Journal of Marine Science 74(1): 170–179. doi:10.1093/icesjms/fsw128.

Alheit, J., Licandro, P., Coombs, S., Garcia, A., Giráldez, A., Santamaría, M.T.G, Slotte, A., and Tsikliras, A.C. 2014. Reprint of “Atlantic Multidecadal Oscillation (AMO) modulates dynamics of small pelagic fishes and ecosystem regime shifts in the eastern North and Central Atlantic” Journal of Marine Systems 133: 88–102.

Aschan, M., Fossheim, M., Greenacre, M., and Primicerio, R. 2013. Change in Fish Community Structure in the Barents Sea. PLoS ONE 8(4): e62748. doi:10.1371/journal.pone.0062748.

ASMFC (Atlantic States Marine Fisheries Commission). 2015. Scup Benchmark Stock Assessment for 2015. 60th SAW Assessment Report. 323 pp.

Azzurro, E., Moshella, P., and Maynou, F. 2011. Tracking Signals of Change in Mediterranean Fish Diversity Based on Local Ecological Knowledge. PLoS ONE 6(9): e24885. doi:10.1371/journal.pone.0024885.

Barange, M., Bernal, M., Cercole, M.C., Cubillos, L., De Moor, C.L., Daskalov, G.M., de Oliveira, J.A.A., Dickey-Collas, M., Gaughan, D.J., and Hill, K., *et al*. 2009. Current trends in the assessment and management of stocks. In Climate Change and Small Pelagic Fish Stocks, Checkley D, Roy C, Oozeki Y, Alheit J (eds). Cambridge University Press: Cambridge; 191–255.

Barange, M., and Perry, R.I. 2009. Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. 7–106.

Barshaw, D.E., and Able, K.W. 1990. Deep burial as a refuge for lady crabs *Ovalipes ocellatus*: comparisons with blue crabs *Callinectes sapidus.* Marine Ecology Progress Series 66: 75−79.

Begon, M., Harper, J.L., and Townsend, C.R. 1986. Ecology: individuals, populations and communities. Blackwell Scientific Publications, Oxford. 876 pp.

Bondavalli, C., Bodini, A., Rossetti, G., and Allesina, S., 2006. Detecting stress at a whole ecosystem level. The case of a mountain lake: Lake Santo (Italy). Ecosystems 9: 1–56.

Borges, M.F., Hill, L., Mendes, H., Santos, M.A., and Salgado, M. 2004. Regime shift effects on fish community metrics measured in the West Portugal upwelling area. ICES C.M. 2004/M: 11.

Bostrom, P. 2014. NAO Index: An Extreme Pressure Approach. Department of Earth Sciences, Geotryckeriet Uppsala University, Uppsala. 3 ISSN 1650−6553 Nr 28. 35 pp.

Botsford, L. W., Holland, M. D., Samhouri, J. F., White, J. W., and Hastings, A. 2011. Importance of age structure in models of the response of upper trophic levels to fishing and climate change. ICES Journal of Marine Science 68: 1270–1283.

Brander, K. 2010. Impacts of climate change on fisheries. Journal of Marine Systems 79: 389–402.

Brander, K. 2013. Climate and current anthropogenic impacts on fisheries. Climatic Change 119: 9−21. doi 10.1007/s10584−012−0541−2.

Briggs, J. C. 974. Marine zoogeography, 475 p. McGraw−Hill Book

Byrne, D. 1994. Stock assessment of New Jersey's nearshore recreational fisheries resources. In Proceedings of the workshop on the collection and use of trawl survey data for fisheries management, ed. T. Berger, 36–42. Washington: Atlantic States Marine Fisheries Commission.

Castillo−Jordán, C., Cubillos, LA., and Navarrod, E.2010. Inter−cohort growth rate changes of common sardine (*Strangomera bentincki*) and their relationship with environmental conditions off central southern Chile. Fisheries Research 105: 228−236.

Cheung, W. W. L., Dunne, J., Sarmiento, J. L., and Pauly, D. 2011. Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential under climate change in the Northeast Atlantic. ICES Journal of Marine Science 68: 1008–1018.

Clarke, K.R., and Warwick, R.M. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2nd edition. PRIMER−E. Plymouth U.K.

Collette, B.B. and Klein-MacPhee, G. (eds.). 2002. Bigelow and Schroeder's fishes of the Gulf of Maine, third ed. Caldwell, N.J. Blackburn Press. 577 pp.

Crisci, C., Bensoussan, N., Romano J-C., and Garrabou, J. 2011. Temperature Anomalies and Mortality Events in Marine Communities: Insights on Factors behind Differential Mortality Impacts in the NW Mediterranean. PLoS ONE 6(9): e23814. doi:10.1371/journal.pone.0023814.

Crozier, L.G., and Hutchings, J.A. 2014. Plastic and evolutionary responses to climate change in fish. Evolution Applications: 1752–4571.

Daw, T., Adger, W.N., Brown, K., and Badjeck, M.C. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. pp. 107−150.

Desser, C., Alexander, M.A., Xie, S.P., and Phillips, A.S. 2010. Sea surface temperature variability: Patterns and Mechanisms. Annual Reviews in Marine Science 2: 115−143.

Dudgeon, D., et al. 2006. Freshwater Biodiversity: Importance, Threats, Status and Conservation Challenges. Biological Reviews, 81: 163−182. doi.org/10.1017/S1464793105006950.

EFARO (European Fisheries and Aquaculture Research Organizations). 2012. Position Paper. Climate change and European fisheries: observed changes and future prospects. EFARO Climate Change Workshop. 14−15 March 2011. Amsterdam. 38 pp.

Engelhard, G.H., Pinnegar, J.K., Kell, L.T., and Rijnsdorp, A.D. 2011. Nine decades of North Sea sole and plaice distribution. ICES Journal of Marine Science 68: 1090–1104.

Fautin, D., Dalton P., Incze, L.S., Leong, J.A., Pautzke, C., Rosenberg, A., Sandifer, P., Sedberry, G., Tunnell, J.W., Abbott, I., Brainard, R.E., Brodeur, M., Eldredge, L.G., Feldman, M., Moretzsohn, F., Vroom, P.S., Wainstein, M., and Wolff, N . 2010. An Overview of Marine Biodiversity in United States Waters. PLoS ONE 5(8), e11914.

Feary, D. A., Pratchett, M. S., Emslie, M. J., Fowler, A. M., Figueira, W. F., Luiz, O. J., Nakamura, Y., and Booth, D.J. 2014. Latitudinal shifts in coral reef fishes: why some species do and others do not shift. Fish and Fisheries 15: 593–615. doi: 10.1111/faf.12036.

Ficke, A.D., Myrick, C.A., and Hansen, L.J. 2007. Potential impacts of global climate change on freshwater fisheries. Rev Fish Biol Fisheries 17: 581–613.

Flanagan, P.H., Jensen, O.P., Morley, J.W., and Pinsky, M.L.2019. Ecography 42: 214–224, 2019doi: 10.1111/e c og.039 61.

Folland, C.K., and Karl, T.R. 2001. Observed climate variability and change. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 99−181.

Franklin, C.E., Johnston, I.A., Crockford, T., Kamunde, C. 1995. Scaling of oxygen consumption of Lake Magadi tilapia, a fish living at 37°C. Journal of Fish Biology 46: 829–834.

Froese, R. and Pauly, D. 2018. https://www.fishbase.de/search.php. 2018. FishBase. World Wide Web electronic publication.www.fishbase.org, version (10/2018).

Fulton, E.A. 2011. Interesting times: winners, losers, and system shifts under climate change around Australia. ICES Journal of Marine Science 68: 1329–1342.

Global Historical Climatology Network (GHCN). 2016. https://www.ncdc.noaa.gov/data−access/land−based−station−data/land−based−datasets/global−historical−climatology−network−ghcn.

Gotelli, N.J., and Anne, C. 2013. Measuring and Estimating Species Richness, Species Diversity, and Biotic Similarity from Sampling Data. In: Levin S.A. (ed.) Encyclopedia of Biodiversity, second edition, Volume 5: 195−211.

Hare J.A, Wuenschel M.J., and Kimball M.E. 2012. Projecting Range Limits with Coupled Thermal Tolerance − Climate Change Models: An Example Based on Gray Snapper (*Lutjanus griseus*) along the U.S. East Coast. PLoS ONE 7(12): e52294.doi:10.1371/journal.pone.0052294.

Hare, J.A., Morrison, W.E., Nelson, M.W., Stachura, M.M., Teeters, E.J., and Griffis, R.B., et al. 2016. A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PLoS ONE 11(2): e0146756. doi:10.1371/journal.pone.0146756.

Hillebrand, H., Blasius, B., Borer, E.T., Chase, J.M., Downing, J.A., Eriksson, B.K., Filstrup, C.T., Harpole, S.W., Hodapp, D., Larsen, S., Lewandowska, A.M., Seabloom, E.W., Van de Waal, D.B., and Ryabov, A.B. 2017. Biodiversity change is uncoupled from species richness trends: consequences for conservation and monitoring. Journal of Applied Ecology DOI: 10.1111/1365−2664.12959.

Hoese, H.D. and Moore, R.H. 1977. Fishes of the Gulf of Mexico, Texas, Louisiana and adjacent waters. Texas A. & M. University Press, College Station. 327 pp.

Hofstede, R., and Rijnsdorp, A.D. 2011. Comparing demersal fish assemblages between periods of contrasting climate and fishing pressure. ICES Journal of Marine Science 68 (6): 1189–1198. doi:10.1093/icesjms/fsr053.

Howell, P., and Auster, P.J. 2012. Phase Shift in an Estuarine Finfish Community Associated with Warming Temperatures. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4: 481–495.

Hufnagl, M., and Peck, M.A. 2011. Physiological individual-based modelling of larval Atlantic herring (*Clupea harengus*) foraging and growth: insights on climate-driven life-history scheduling. – ICES Journal of Marine Science, 68: 1170–1188.

Hunt, G.L., Coyle, K.O., Eisner, L.B., Farley, E.V., Heintz, R.A., Mueter, F., Napp, J.M., Overland, J.E., Ressler, P.H., Salo, S., and Stabeno, P.J. 2011. Climate impacts on eastern Bering Sea foodwebs: a synthesis of new data and an assessment of the Oscillating Control Hypothesis. – ICES Journal of Marine Science 68: 1230–1243.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: Synthesis Report – Contribution of Working Groups I, II, and III to the Fourth Intergovernmental Panel on Climate Change. Core Writing Team: R.K. Pauchauri and A. Reisinger, eds. IPCC, Geneva, Switzerland. 8 pp.

Jang, C.J., Park, J., Park, T., and Yoo, S. 2011. Response of the ocean mixed layer depth to global warming and its impact on primary production: a case for the North Pacific Ocean. – ICES Journal of Marine Science, 68: 996–1007.Johnson CA. (eds) Climate change 2001: the scientific basis. Cambridge University Press, Cambridge, UK. 101–181.

Johnson, T. 2012. Fisheries Adaptions to Climate Change. Living on Alaska’s Changing Coast. Sea Grant Alaska. 8 pp.

Johnson, A.F., Jenkins, S.R., Hiddink, J.G., and Hinz, H. 2013. Linking temperate demersal fish species to habitat: scales, patterns and future directions. Fish and Fisheries 14(3): 256−280.

Kaschner, K., Kesner-Reyes, K., Garilao, C., Rius-Barile, J., Rees, T., and Froese, R. 2016. AquaMaps: predicted range maps for aquatic species. World Wide Web electronic publication, www.aquamaps.org, Version 08/2016.

King, M. 1995. Fisheries Biology, Assessment, and Management. Fishing News Books. Blackwell Science Publishing, K.K. 341 pp.

King, J. R., Agostini, V.N., Harvey, C.J., McFarlane, G.A., Foreman, M.G.G., Overland, J.E., Di Lorenzo, E., Bond, N.A., and Aydin, K.Y. 2011. Climate forcing and the California Current ecosystem. ICES Journal of Marine Science 68: 1199–1216.

Kleisner, K.M., Fogarty, M.J., McGee, S., Barnett, A., Fratantoni, P., Greene, J., Hare, J.A., Lucey, S.M., McGuire, C., Odell, J., Saba, V.S., Smith, L., Weaver, K.J., and Pinsky, M.L. 2016. The Effects of Sub-Regional Climate Velocity on the Distribution and Spatial Extent of Marine Species Assemblages. PLoS ONE 11(2): e0149220. doi:10.1371/journal.pone.0149220

Korsman, B. 2013. The Spatial and Temporal Community Structure of Ichthyoplankton in a Northeast Florida Estuary: A Study of Ingress at a Faunal Boundary.UNF Theses and Dissertations. Paper 452.http://digitalcommons.unf.edu/etd/452.

Krishnakumar, P.K., and Bhat, G.S. 2008. Seasonal and interannual variations of oceanographic conditions off Mangalore coast (Karnataka, India) in the Malabar upwelling system during 1995–2004 and their influences on the pelagic fishery. Fisheries Oceanography 17 (1): 45–60.

Lan, K.W., Lee, M.A., Lu, H.J., Shieh, W.J., Lin, W.K., and Kao, S.C. 2011. Ocean variations associated with fishing conditions for yellowfin tuna (*Thunnus albacares*) in the equatorial Atlantic Ocean. ICES Journal of Marine Science, 68: 1063–1071.

Lapolla, A.E. 2001. Bay anchovy *Anchoa mitchilli* in Narragansett Bay, Rhode Island. I. Population structure, growth and mortality. Marine Ecology Progress Series, 217, 93-102. doi: 10.3354/meps217093. http://dx.doi.org/10.3354/meps217093.

Ludwing, J.A., and Reynolds, J.F. 1988. Statistical Ecology: A primer in methods and computing. John Wiley & Sons, Inc. 337 pp.

Magurran AE. 2004. Measuring biological diversity. 2nd ed. Oxford, U.K: Blackwell Science Ltd.

Matear, R.J., and Hirst, A.C. 2003. Long−term changes in dissolved oxygen concentrations in the ocean caused by protracted global warming. Global Biogeochemical Cycles 17: 1125. doi: 10.1029/2002GB001997.

McCann, K.S 2000. The diversity−stability debate. Nature 405: 228−233.

McCay, B.J., Brandt, S., and Creed, C.F. 2011. Human dimensions of climate change and fisheries in a coupled system: the Atlantic surfclam case. ICES Journal of Marine Science 68: 1354–1367.

McPherson, G. 2009. Chapter 2: Fundamental concepts in ecology. The planners guide to natural resource conservation: The science of land development beyond the metropolitan fringe. Esparza, A.X., and McPherson, G.R. Springer New York.

Morley, J.W., Selden, R.L., Latour, R.J., Frölicher, T.L., Seagraves, R.J., and Pinsky, M.L. 2018. Projecting shifts in thermal habitat for 686 species on the North American continental shelf. PLoS ONE 13(5): e0196127. doi.org/10.1371/journal.pone.0196127.

Moyle, P.B., and Cech, J.J. 2004. Fishes: an introduction to ichthyology, 5th edn. Prentice Hall, Englewood Cliffs, NJ.

Muhling, B. A., Lee, S-K., Lamkin, J. T., and Liu, Y. 2011. Predicting the effects of climate change on bluefin tuna (*Thunnus thynnus*) spawning habitat in the Gulf of Mexico. – ICES Journal of Marine Science 68: 1051–1062.

Mundy, P.R., and Evenson, D.F. 2011. Environmental controls of phenology of high-latitude Chinook salmon populations of the Yukon River, North America, with application to fishery management. ICES Journal of Marine Science 68: 1155–1164.

Murawski, S. A. 2011. Summing up Sendai: progress integrating climate change science and fisheries. ICES Journal of Marine Science 68: 1368–1372.

Murdy, E., Baker, R., and Musick. J. 1997. Fishes of Chesapeake Bay. Washington, D.C.: Smithsonian Institution Press.

Muyodi, F.J., Mwanuzi, F.L., and Kapiyo, R. 2011. Environmental quality and fish communities in selected catchments of Lake Victoria. The Open Environmental Engineering Journal 4: 54−65.

Najjar, R., H Walker, P. J. Anderson, E. J. Barron, R. J. Bord, J. R. Gibson, V. S. Kennedy, C. G. Knight, P. Megonigal, R. E. O'Connor, C. D. Polsky, N. P. Psuty, B. A. Richards, L. G. Sorenson, E. M. Steele, AND R. S. Swanson. 2000. The potential impacts of climate change on the mid-Atlantic coastal region. Climate Research 14: 219−233.

NCM (Nordic Council of Ministers). 2011. A guide for conducting systematic literature review for the 5th edition of the Nordic nutrition recommendations. Copenhagen. 40 pp.

Newberger, T.A., and Houde, E.D. 1995. Population biology of bay anchovy *Anchoa mitchilli* in the mid Chesapeake Bay. Marine Ecology Progress Series 116: 25−37.

NMFS (National Marine Fisheries Service). 2018. Commercial Fisheries Statistics. Accessed at: https://www.st.nmfs.noaa.gov/commercial−fisheries/commercial−landings/. Accessed on: 25 January 2018.

NMFS (National Marine Fisheries Service). 2018b. Butterfish 2017 Stock Assessment Update. Northeast Fisheries Science Center Reference Document 18-05. NOAA Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543.

NOAA (National Oceanic and Atmospheric Administration). 2016. NOAA Merged Land Ocean Global Surface Temperature Analysis (NOAAGlobalTemp): Global gridded 5° x 5° data. National Centers for Environmental Information. Accessed June 2016. www.ncdc.noaa.gov/data−access/marineocean−data/noaa−global−surface−temperature−noaaglobaltemp.

NOAA (National Oceanic and Atmospheric Administration). National Centers for Environmental Information. 2018. State of the Climate: Global Climate Report for Annual 2017. Retrieved on November 3, 2018 from https://www.ncdc.noaa.gov/sotc/global/201713.

Norse, E.A. 1993. Global marine biological diversity: A strategy for building conservation into decision making. Island Press. 690 pp.

Nye, J.A., Link, J.S., Hare, J.A., and Overholtz, W.J. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Marine Ecology Series 393: 111−129. doi: 10.3354/meps08220.

Nye, J.A., Baker, M.W., Bill, R., Kenny, A., Kilborune, H.K., Friedland, K.V., Marino, E., Stachura, M.M., Van Houtan, K.S., and Wood, R. 2014. Ecosystem effects of the Atlantic Multidecadal Oscillation. Journal of Marine Systems 133: 103−116.

O’Brian, S.B., Landau, M., and Able, K. 1995. Seasonal and spatial distribution of two species of spider crab in Great Bay, New Jersey. American Zoology 35: 67A.

Pankhurst, N.W., and Munday, P.L. 2011. Effects of climate change on fish reproduction and early life stages. Marine and Freshwater Research 62: 1018−1026.

Parker, R.O., Jr., and Dixon, R.L. 1998. Changes in a North Carolina reef−fish community after 15 years of intense fishing: Global−warming implications. Transactions of the American Fisheries Society 127(6): 908–920.

Perry, A.L., Low, P.J., Ellis, J.R., and Reynolds, J.D. 2005. Climate change and distribution shifts in marine fishes.Science.308: 1912−1915.

Pinsky, M.L., and Mantua, N.J. 2014. Emerging adaptation approaches for climate ready fisheries management. Oceanography 27(4): 146–159. http://dx.doi.org/10.5670/ oceanog.2014.93.

Pinsky, M.L., and Byler, D. 2015. Fishing, fast growth and climate variability increase the risk of collapse. Proceeding of the Royal Society B 282: 1−9. 20151053. http://dx.doi.org/10.1098/rspb.2015.1053.

Planque, B., Loots, C., Petitgas, P., Lindstrom, U., and Vaz, S. 2011. Understanding what controls the spatial distribution of fish populations using a multi-model approach. Fisheries Oceanography 20 (1): 1−17.

Polovina, J.J., Dunne, J.P., Woodworth, P.A., and Howell, E.A. 2011. Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming. ICES Journal of Marine Science 68: 986–995.

Poulard, J., and Blanchard, F. 2005. The impact of climate change on the fish community structure of the eastern continental shelf of the Bay of Biscay. ICES Journal of Marine Science 62: 1463–1443.

Reash, R.J., and Pigg, J. 1990. Physicochemical factors affecting the abundance and species richness of fishes in the Cimarron River. Proceedings Oklahoma Academic Science 70: 23−28.

Rice, J.C. 2000. Evaluating fishery impacts using metrics of community structure. ICES Journal of Marine Science 57: 682–688. doi:10.1006/jmsc.2000.073.

Rijnsdorp, A.D., Peck, M.A., Engelhard, G.H., Mo¨llmann, C., and Pinnegar, J.K. 2009. Resolving the effect of climate change on fish populations. ICES Journal of Marine Science, 66: 1570–1583.

Rijnsdorp, A.D., Peck, M.A., Engelhard, G.H., Mollmann, C., and Pinnegar, J.K. 2010. Resolving climate impacts on fish stocks. ICES Cooperative Research Report 301. 372 pp.

Robinette, H.R. 1983. Species profiles: 1ife histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico) – bay anchovy and striped anchovy. U.S. Fish and Wildlife Service, Division of Biological Services, FWS/OBS-82/11.14. U.S. Army Corps of Engineers, TR EL-82-4. 15 pp.

Russell, B.D., Harley, C.D.G., Wernberg, T., Mieszkowska, N., Widdicombe, S., Hall-Spencer, J.M., and Connell, S.D. 2012. Predicting ecosystem shifts requires new approaches that integrate the effects of climate change across entire systems. Biology Letters 8: 164−166.

Selkoe, K. A., et al. 2015. Principles for managing marine ecosystems prone to tipping points. Ecosystem Health and Sustainability 1(5): 17. http://dx.doi.org/10.1890/EHS14-0024.1.

Schofield, O., Chant, R., Cahill, B., Castelao, R., Gong, D., Kahl, A., Kohut, J., Montes-hugo, M., Ramadurai, R., Ramey, P., Yi, X., and Glenn. S. 2008. The Decadal View of the Mid-Atlantic Bight from the COOLroom: Is Our Coastal System Changing? Oceanography 21 (4): 108−117.

Scott, J.S. 1982. Depth, Temperature and Salinity Preferences of Common Fishes of the Scotian Shelf. Journal Northwest Atlantic Fishery Science 3: 29−39.

Smigielski, A.S., Halavik, T.A., Buckley, L.J., Drew, S.M., and Laurence, G.C. 1984. Spawning, embryo development and growth of the American sand lance *Ammodytes americanus* in the laboratory. Marine Ecology Progress Series 14: 287−292.

Snover, M.L. 2008. Ontogenetic habitat shifts in marine organisms: Influencing factors and the impact of climate variability. Bulletin of Marine Science 83(1): 000−000.

Steimle, F.W., and Zetlin, C. 2000. Reef habitats in the Middle Atlantic Bight: abundance, distribution, associated biological communities, and fishery resource use. Marine Fisheries Review 62: 24-42.

Tett, P., Gowen, R.J., Painting, Elliott, M. Forster, R. Mills, DK Bresnan, E. Capuzzo, E. Fernandes, T.F., Foden, J., Geider, R.J., Gilpin, L.C., Huxham, M., McQuatters-Gollop, AL, Malcolm, Saux-Picart, S., Platt, T., Racault, M.F., Sathyendranath, S., van der Molen, J., and Wilkinson, M. 2013. Framework for understanding marine ecosystem health. Marine Ecology Progress Series 494: 1−27.

Thomas, A.C., Pershing, A.J., Friedland, K.D., Nye, J.A., Mills, K.E., Alexander, M.A., Record, N.R., Weatherbee, R., and Henderson, M.E. 2017. Seasonal trends and phenology shifts in sea surface temperature on the North American northeastern continental shelf. Elem Sci Anth 5: 48, DOI: https://doi.org/10.1525/elementa.240.

Thorne, R., Williams, J.W., and Cao, Y. 1999. The influence of data transformations on biological monitoring studies using macroinvertebrates. Water Resources. 33(2): 343−350.

Toonen, R.J., Bowen, B.W., Iacchei, M., and Briggs, J.C. 2016. Biogeography, Marine. In: Kliman, R.M. (ed.), Encyclopedia of Evolutionary Biology. Oxford: Academic Press. Volume 1: 166–178.

Tseng, C.T., Sun, C.L., Yeh, S.Z., Chen, S.C., Su, W.C., and Liu, D.C. 2011. Influence of climate-driven sea surface temperature increase on potential habitats of the Pacific saury (*Cololabis saira*). ICES Journal of Marine Science 68: 1105–1113.

Vinebrooke, R., Cottingham, K., Orberg, J.N., Cheffer, M.S., Dodson, S., Maberly, S., and Sommer, U. 2004. Impacts of multiple stressors on biodiversity and ecosystem functioning: The role of species co−tolerance. Oikos 104: 451–457. doi:10.1111/j.0030−1299.2004.13255.x

Voss, R., Hinrichsen, H., Quaas, M.F., Schmidt, J.O., and Tahvonen, O. 2011. Temperature change and Baltic sprat: from observations to ecological–economic modelling. ICES Journal of Marine Science 68 (6): 1244–1256. doi:10.1093/icesjms/fsr063.

Warfe, D.M., Jardine, T.D., Pettit, N.E., Hamilton, S.K., Pusey, B.J., et al. 2013. Productivity, Disturbance and Ecosystem Size Have No Influence on Food Chain Length in Seasonally Connected Rivers. PLoS ONE 8(6): e66240. doi:10.1371/journal.pone.0066240.

Wernberg, T., Thomsen, M.S., Tuya, F., Kendrick, G. A., Staehr, P.A., and Toohey, B.D. 2010. Decreasing resilience of kelp beds along a latitudinal temperature gradient: potential implications for a warmer future. Ecological Letters 13: 685–694.

Whitfield, P.E., Muñoz, R.C., Buckel, C.A., Degan, B.P., Freshwater, D.W., and Hare, J.A. 2014. Native fish community structure and Indo−Pacific lionfish *Pterois volitans* densities along a depth−temperature gradient in Onslow Bay, North Carolina, USA. Marine Ecology Progress Series 509: 241–254.

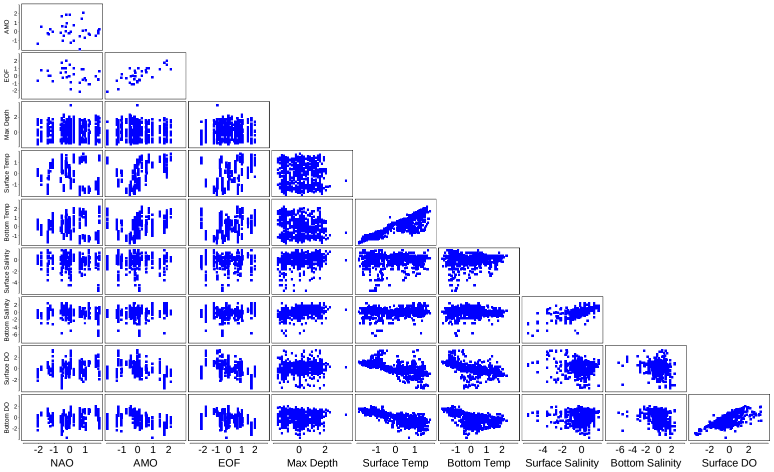
Wilk, S.J., Morse, W.W., and Stehlik, L.L. 1990. Annual cycles of gonadsomatic indices as indicators of spawning activity for selected species of finfish collected from the New York Bight. U.S. National Marine Fisheries Service. Fishery Bulletin 88: 775–786.

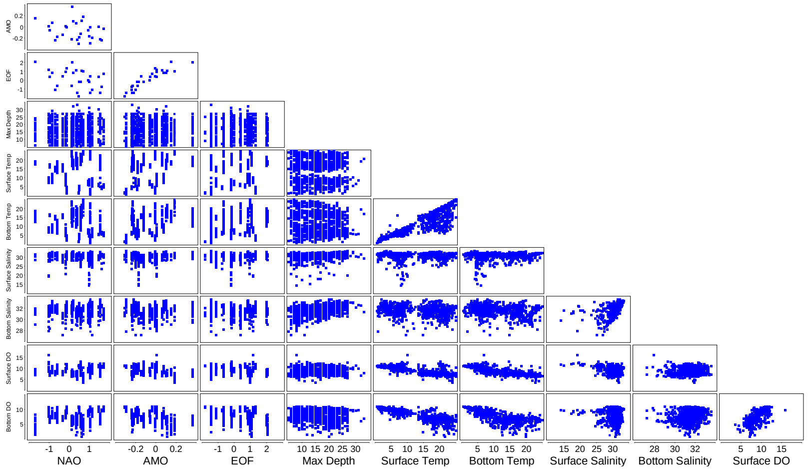
Worm, B., Barbier, E.B., Beaumont, N., Duffy, E., Folke, C., Halpern, B.S., Jeremy, B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Kimberley, E.S., Selkoe A., Stachowicz, J., and Watson, R. 2006. Impacts of Biodiversity Loss on Ocean Ecosystem Services. Science 314 787−790. doi: 10.1126/science.1132294.

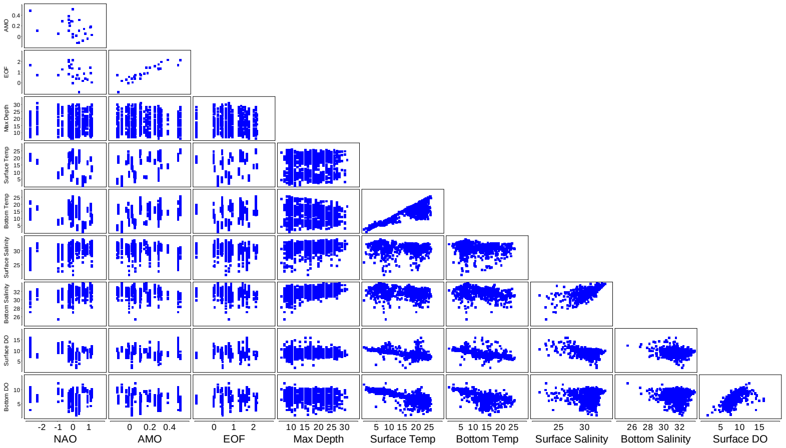
Zar, J.H. 1999. Biostatistical analysis, 4th Ed. Prentice Hall, Upper Saddle River, NJ.

5.9 Appendix

5.9.1 Environmental and Oceanic Conditions







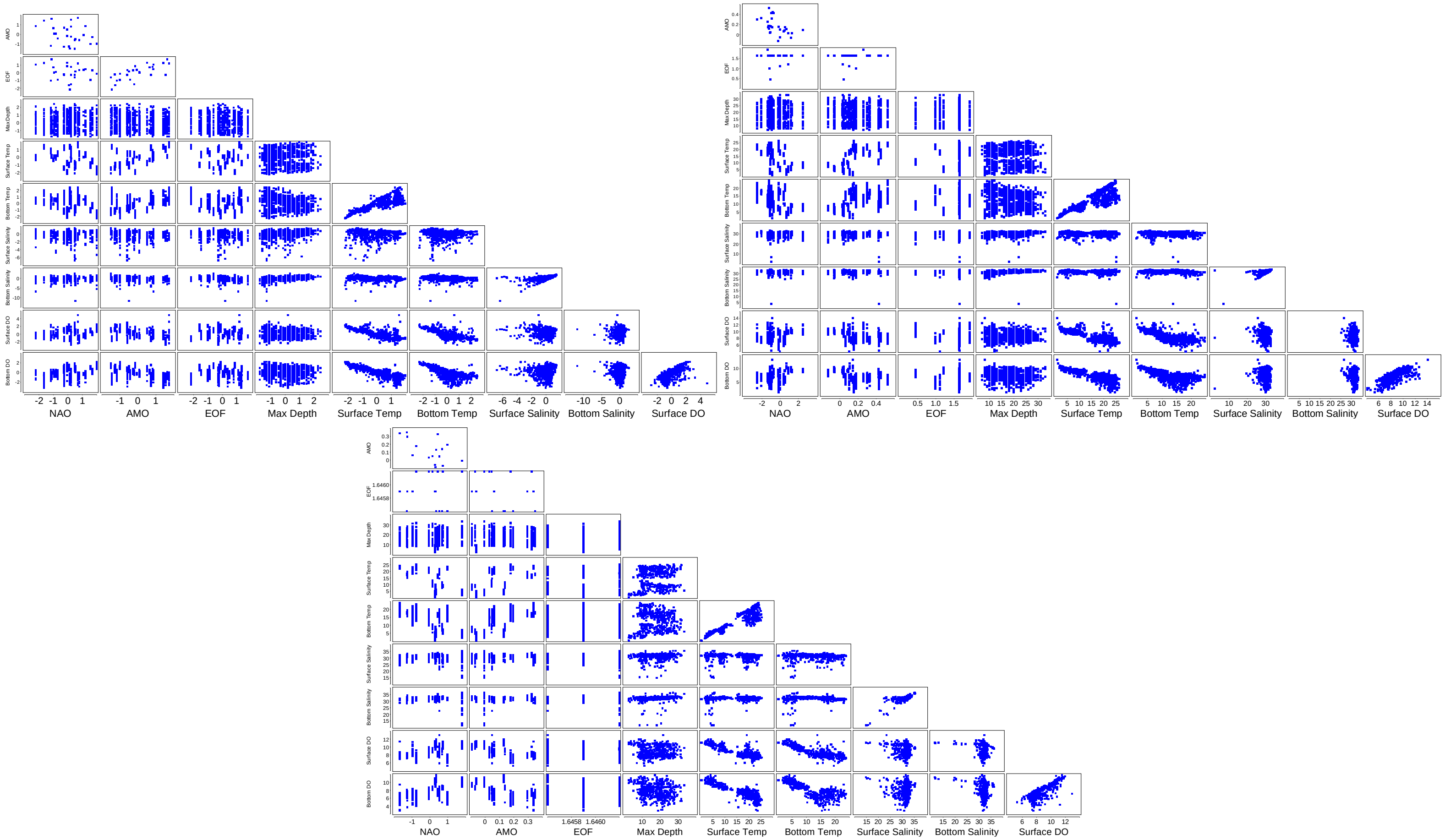


Figure 5.9.1. Draftsman plot of the environmental and oceanic conditions.

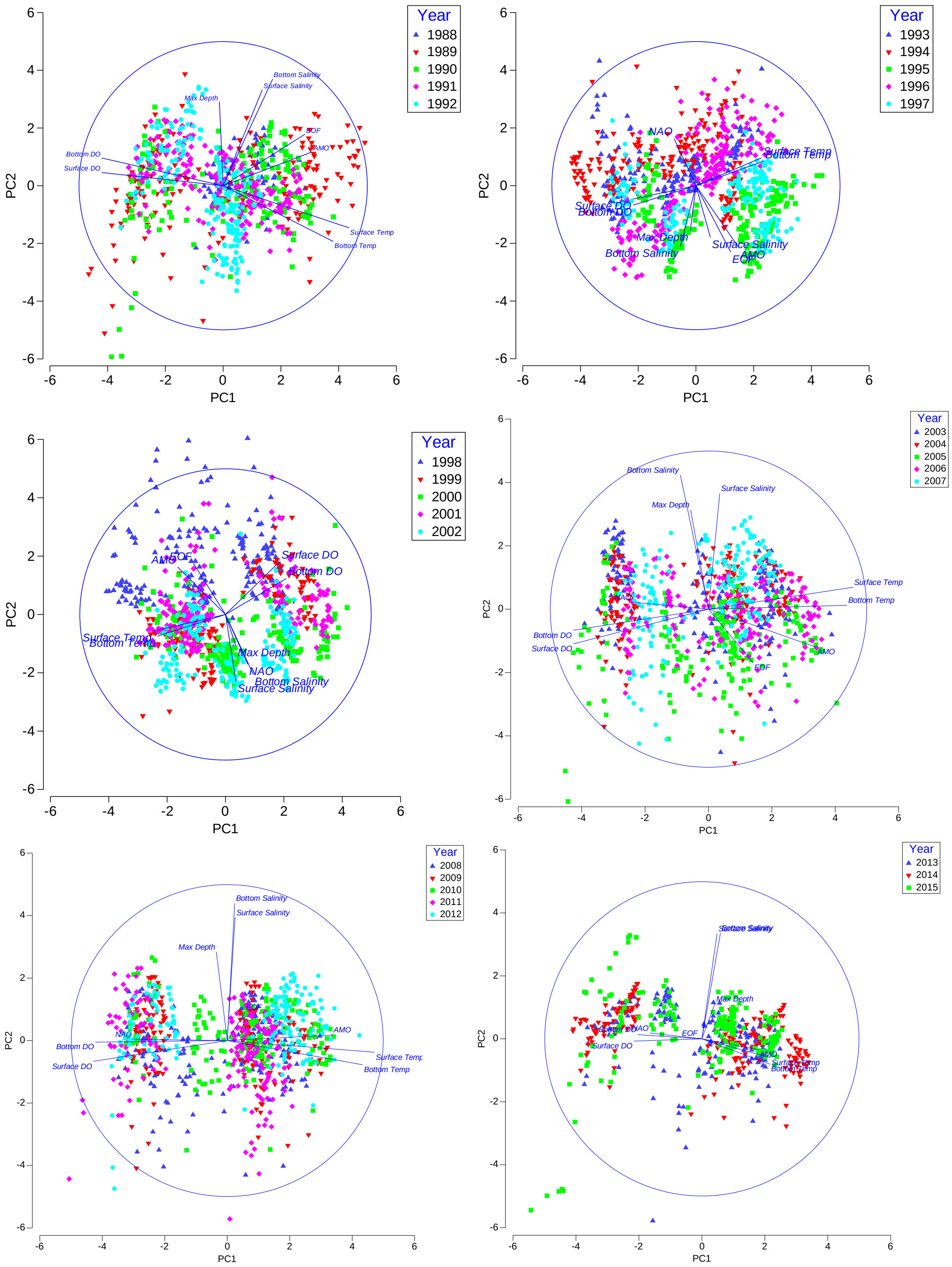


Figure. 5.9.2. A PCA plot of the environmental and oceanic conditions.

Table 5.9.1. Separate one-way ANOSIM. Pairwise tests of the environmental and oceanic conditions between years.

Groups	**R Statistic**	**Significance Level %**	**Possible Permutations**	**Actual Permutations**	**Number >= Observed**
1988, 1989	-0.106	100	Very large	999	999
1988, 1990	0.032	15.9	Very large	999	158
1988, 1991	0.015	29.6	Very large	999	295
1988, 1992	0.017	23.6	Very large	999	235
1989, 1990	0.041	0.1	Very large	999	0
1989, 1991	0.132	0.1	Very large	999	0
1989, 1992	0.153	0.1	Very large	999	0
1990, 1991	0.169	0.1	Very large	999	0
1990, 1992	0.234	0.1	Very large	999	0
1991, 1992	0.059	0.1	Very large	999	0
1993, 1994	0.056	0.1	Very large	999	0
1993, 1995	0.43	0.1	Very large	999	0
1993, 1996	0.219	0.1	Very large	999	0
1993, 1997	0.375	0.1	Very large	999	0
1994, 1995	0.428	0.1	Very large	999	0
1994, 1996	0.242	0.1	Very large	999	0
1994, 1997	0.376	0.1	Very large	999	0
1995, 1996	0.269	0.1	Very large	999	0
1995, 1997	0.112	0.1	Very large	999	0
1996, 1997	0.11	0.1	Very large	999	0
1998, 1999	0.272	0.1	Very large	999	0
1998, 2000	0.491	0.1	Very large	999	0
1998, 2001	0.161	0.1	Very large	999	0
1998, 2002	0.465	0.1	Very large	999	0
1999, 2000	0.109	0.1	Very large	999	0
1999, 2001	0.05	0.1	Very large	999	0
1999, 2002	0.105	0.1	Very large	999	0
2000, 2001	0.155	0.1	Very large	999	0
2000, 2002	0.025	0.3	Very large	999	2
2001, 2002	0.152	0.1	Very large	999	0
2003, 2004	0.03	0.1	Very large	999	0
2003, 2005	0.167	0.1	Very large	999	0
2003, 2006	0.094	0.1	Very large	999	0
2003, 2007	0.117	0.1	Very large	999	0
2004, 2005	0.157	0.1	Very large	999	0
2004, 2006	0.083	0.1	Very large	999	0
2004, 2007	0.046	0.1	Very large	999	0
2005, 2006	0.048	0.1	Very large	999	0
2005, 2007	0.242	0.1	Very large	999	0
2006, 2007	0.218	0.1	Very large	999	0
2008, 2009	0.167	0.1	Very large	999	0
2008, 2010	0.278	0.1	Very large	999	0
2008, 2011	0.189	0.1	Very large	999	0
2008, 2012	0.174	0.1	Very large	999	0
2009, 2010	0.239	0.1	Very large	999	0
2009, 2011	0.067	0.1	Very large	999	0
2009, 2012	0.113	0.1	Very large	999	0
2010, 2011	0.244	0.1	Very large	999	0
2010, 2012	0.129	0.1	Very large	999	0
2011, 2012	0.13	0.1	Very large	999	0
2013, 2014	0.188	0.1	Very large	999	0
2013, 2015	0.394	0.1	Very large	999	0

Groups	**R Statistic**	**Significance Level %**	**Possible Permutations**	**Actual Permutations**	**Number >= Observed**
2014, 2015	0.17	0.1	Very large	999	0

Table 5.9.2. Separate one-way ANOSIM. Pairwise tests of the environmental and oceanic conditions between areas.

Time Series	Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1988-1992	12, 13	0.064	0.3	Very large	999	2
1988-1992	12, 14	0.261	0.1	Very large	999	0
1988-1992	12, 15	0.078	0.2	Very large	999	1
1988-1992	12, 16	0.156	0.1	Very large	999	0
1988-1992	12, 17	0.335	0.1	Very large	999	0
1988-1992	12, 18	0.12	0.1	Very large	999	0
1988-1992	12, 19	0.161	0.1	Very large	999	0
1988-1992	12, 20	0.384	0.1	Very large	999	0
1988-1992	12, 21	0.123	0.1	Very large	999	0
1988-1992	12, 22	0.212	0.1	Very large	999	0
1988-1992	12, 23	0.415	0.1	Very large	999	0
1988-1992	12, 24	0.054	3.8	Very large	999	37
1988-1992	12, 25	0.212	0.1	Very large	999	0
1988-1992	12, 26	0.316	0.1	Very large	999	0
1988-1992	13, 14	0.047	0.5	Very large	999	4
1988-1992	13, 15	0.111	0.1	Very large	999	0
1988-1992	13, 16	0.055	0.2	Very large	999	1
1988-1992	13, 17	0.119	0.1	Very large	999	0
1988-1992	13, 18	0.178	0.1	Very large	999	0
1988-1992	13, 19	0.079	0.4	Very large	999	3
1988-1992	13, 20	0.18	0.1	Very large	999	0
1988-1992	13, 21	0.163	0.1	Very large	999	0
1988-1992	13, 22	0.145	0.1	Very large	999	0
1988-1992	13, 23	0.216	0.1	Very large	999	0
1988-1992	13, 24	0.101	0.1	Very large	999	0
1988-1992	13, 25	0.14	0.1	Very large	999	0
1988-1992	13, 26	0.121	0.1	Very large	999	0
1988-1992	14, 15	0.262	0.1	Very large	999	0
1988-1992	14, 16	0.087	0.1	Very large	999	0
1988-1992	14, 17	0.026	7.3	Very large	999	72
1988-1992	14, 18	0.345	0.1	Very large	999	0
1988-1992	14, 19	0.121	0.1	Very large	999	0
1988-1992	14, 20	0.083	0.1	Very large	999	0
1988-1992	14, 21	0.323	0.1	Very large	999	0
1988-1992	14, 22	0.184	0.1	Very large	999	0
1988-1992	14, 23	0.11	0.1	Very large	999	0
1988-1992	14, 24	0.284	0.1	Very large	999	0
1988-1992	14, 25	0.179	0.1	Very large	999	0
1988-1992	14, 26	0.043	1.5	Very large	999	14
1988-1992	15, 16	0.057	0.4	Very large	999	3
1988-1992	15, 17	0.257	0.1	Very large	999	0
1988-1992	15, 18	-0.006	71	Very large	999	709
1988-1992	15, 19	0.041	0.9	Very large	999	8
1988-1992	15, 20	0.257	0.1	Very large	999	0
1988-1992	15, 21	-0.013	77.7	Very large	999	776
1988-1992	15, 22	0.051	0.4	Very large	999	3
1988-1992	15, 23	0.279	0.1	Very large	999	0
1988-1992	15, 24	-0.016	69.1	Very large	999	690
1988-1992	15, 25	0.052	0.2	Very large	999	1
1988-1992	15, 26	0.241	0.1	Very large	999	0
1988-1992	16, 17	0.058	0.1	Very large	999	0
1988-1992	16, 18	0.092	0.1	Very large	999	0

Time Series	**Groups**	**R Statistic**	**Significance Level %**	**Possible Permutations**	**Actual Permutations**	**Number >= Observed**
1988-1992	16, 19	-0.007	73.9	Very large	999	738
1988-1992	16, 20	0.074	0.2	Very large	999	1
1988-1992	16, 21	0.088	0.1	Very large	999	0
1988-1992	16, 22	0.03	2	Very large	999	19
1988-1992	16, 23	0.107	0.1	Very large	999	0
1988-1992	16, 24	0.082	0.5	Very large	999	4
1988-1992	16, 25	0.024	4.5	Very large	999	44
1988-1992	16, 26	0.081	0.2	Very large	999	1
1988-1992	17, 18	0.32	0.1	Very large	999	0
1988-1992	17, 19	0.08	0.1	Very large	999	0
1988-1992	17, 20	0.001	36	Very large	999	359
1988-1992	17, 21	0.312	0.1	Very large	999	0
1988-1992	17, 22	0.133	0.1	Very large	999	0
1988-1992	17, 23	0.028	3.2	Very large	999	31
1988-1992	17, 24	0.302	0.1	Very large	999	0
1988-1992	17, 25	0.128	0.1	Very large	999	0
1988-1992	17, 26	0.013	20.2	Very large	999	201
1988-1992	18, 19	0.06	0.1	Very large	999	0
1988-1992	18, 20	0.301	0.1	Very large	999	0
1988-1992	18, 21	-0.013	75.6	Very large	999	755
1988-1992	18, 22	0.053	0.1	Very large	999	0
1988-1992	18, 23	0.317	0.1	Very large	999	0
1988-1992	18, 24	-0.01	62.8	Very large	999	627
1988-1992	18, 25	0.057	0.1	Very large	999	0
1988-1992	18, 26	0.294	0.1	Very large	999	0
1988-1992	19, 20	0.075	0.2	Very large	999	1
1988-1992	19, 21	0.049	1.1	Very large	999	10
1988-1992	19, 22	0	40.3	Very large	999	402
1988-1992	19, 23	0.091	0.1	Very large	999	0
1988-1992	19, 24	0.037	10	Very large	999	99
1988-1992	19, 25	-0.003	53.5	Very large	999	534
1988-1992	19, 26	0.071	0.2	Very large	999	1
1988-1992	20, 21	0.29	0.1	Very large	999	0
1988-1992	20, 22	0.1	0.1	Very large	999	0
1988-1992	20, 23	-0.005	65.2	Very large	999	651
1988-1992	20, 24	0.295	0.1	Very large	999	0
1988-1992	20, 25	0.093	0.1	Very large	999	0
1988-1992	20, 26	0.01	28	Very large	999	279
1988-1992	21, 22	0.031	4.5	Very large	999	44
1988-1992	21, 23	0.29	0.1	Very large	999	0
1988-1992	21, 24	0.009	29	Very large	999	289
1988-1992	21, 25	0.039	3.6	Very large	999	35
1988-1992	21, 26	0.269	0.1	Very large	999	0
1988-1992	22, 23	0.098	0.1	Very large	999	0
1988-1992	22, 24	0.041	7.9	Very large	999	78
1988-1992	22, 25	-0.015	99.8	Very large	999	997
1988-1992	22, 26	0.098	0.1	Very large	999	0
1988-1992	23, 24	0.297	0.1	Very large	999	0
1988-1992	23, 25	0.095	0.1	Very large	999	0
1988-1992	23, 26	0.005	33.8	Very large	999	337
1988-1992	24, 25	0.043	7.5	Very large	999	74
1988-1992	24, 26	0.24	0.1	Very large	999	0
1988-1992	25, 26	0.091	0.2	Very large	999	1
1993-1997	12, 13	0.086	0.1	Very large	999	0

Time Series	Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1993-1997	12, 14	0.285	0.1	Very large	999	0
1993-1997	12, 15	0.085	0.2	Very large	999	1
1993-1997	12, 16	0.156	0.1	Very large	999	0
1993-1997	12, 17	0.34	0.1	Very large	999	0
1993-1997	12, 18	0.186	0.1	Very large	999	0
1993-1997	12, 19	0.228	0.1	Very large	999	0
1993-1997	12, 20	0.429	0.1	Very large	999	0
1993-1997	12, 21	0.107	0.2	Very large	999	1
1993-1997	12, 22	0.26	0.1	Very large	999	0
1993-1997	12, 23	0.44	0.1	Very large	999	0
1993-1997	12, 24	0.057	0.4	Very large	999	3
1993-1997	12, 25	0.231	0.1	Very large	999	0
1993-1997	12, 26	0.335	0.1	Very large	999	0
1993-1997	13, 14	0.05	1.1	Very large	999	10
1993-1997	13, 15	0.105	0.1	Very large	999	0
1993-1997	13, 16	0.034	4	Very large	999	39
1993-1997	13, 17	0.113	0.1	Very large	999	0
1993-1997	13, 18	0.219	0.1	Very large	999	0
1993-1997	13, 19	0.101	0.1	Very large	999	0
1993-1997	13, 20	0.186	0.1	Very large	999	0
1993-1997	13, 21	0.15	0.1	Very large	999	0
1993-1997	13, 22	0.16	0.1	Very large	999	0
1993-1997	13, 23	0.193	0.1	Very large	999	0
1993-1997	13, 24	0.116	0.1	Very large	999	0
1993-1997	13, 25	0.122	0.1	Very large	999	0
1993-1997	13, 26	0.11	0.1	Very large	999	0
1993-1997	14, 15	0.228	0.1	Very large	999	0
1993-1997	14, 16	0.055	1.1	Very large	999	10
1993-1997	14, 17	0.001	43.1	Very large	999	430
1993-1997	14, 18	0.366	0.1	Very large	999	0
1993-1997	14, 19	0.119	0.1	Very large	999	0
1993-1997	14, 20	0.055	0.3	Very large	999	2
1993-1997	14, 21	0.318	0.1	Very large	999	0
1993-1997	14, 22	0.201	0.1	Very large	999	0
1993-1997	14, 23	0.055	0.6	Very large	999	5
1993-1997	14, 24	0.278	0.1	Very large	999	0
1993-1997	14, 25	0.158	0.1	Very large	999	0
1993-1997	14, 26	0.02	8.4	Very large	999	83
1993-1997	15, 16	0.039	0.8	Very large	999	7
1993-1997	15, 17	0.219	0.1	Very large	999	0
1993-1997	15, 18	0.011	10.7	Very large	999	106
1993-1997	15, 19	0.05	0.2	Very large	999	1
1993-1997	15, 20	0.266	0.1	Very large	999	0
1993-1997	15, 21	-0.017	81.4	Very large	999	813
1993-1997	15, 22	0.056	0.1	Very large	999	0
1993-1997	15, 23	0.282	0.1	Very large	999	0
1993-1997	15, 24	-0.01	70.3	Very large	999	702
1993-1997	15, 25	0.048	0.3	Very large	999	2
1993-1997	15, 26	0.242	0.1	Very large	999	0
1993-1997	16, 17	0.059	0.1	Very large	999	0
1993-1997	16, 18	0.101	0.1	Very large	999	0
1993-1997	16, 19	0.005	23.9	Very large	999	238
1993-1997	16, 20	0.094	0.1	Very large	999	0
1993-1997	16, 21	0.065	0.4	Very large	999	3

Time Series	Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1993-1997	16, 22	0.034	0.7	Very large	999	6
1993-1997	16, 23	0.104	0.1	Very large	999	0
1993-1997	16, 24	0.055	0.7	Very large	999	6
1993-1997	16, 25	0.017	5.8	Very large	999	57
1993-1997	16, 26	0.068	0.4	Very large	999	3
1993-1997	17, 18	0.315	0.1	Very large	999	0
1993-1997	17, 19	0.083	0.1	Very large	999	0
1993-1997	17, 20	0.002	30.9	Very large	999	308
1993-1997	17, 21	0.277	0.1	Very large	999	0
1993-1997	17, 22	0.143	0.1	Very large	999	0
1993-1997	17, 23	0.006	21.9	Very large	999	218
1993-1997	17, 24	0.249	0.1	Very large	999	0
1993-1997	17, 25	0.116	0.1	Very large	999	0
1993-1997	17, 26	-0.009	68.8	Very large	999	687
1993-1997	18, 19	0.074	0.1	Very large	999	0
1993-1997	18, 20	0.346	0.1	Very large	999	0
1993-1997	18, 21	-0.01	70	Very large	999	699
1993-1997	18, 22	0.053	0.1	Very large	999	0
1993-1997	18, 23	0.358	0.1	Very large	999	0
1993-1997	18, 24	0.025	8.6	Very large	999	85
1993-1997	18, 25	0.062	0.1	Very large	999	0
1993-1997	18, 26	0.36	0.1	Very large	999	0
1993-1997	19, 20	0.087	0.1	Very large	999	0
1993-1997	19, 21	0.064	0.6	Very large	999	5
1993-1997	19, 22	-0.006	68.2	Very large	999	681
1993-1997	19, 23	0.095	0.1	Very large	999	0
1993-1997	19, 24	0.068	0.2	Very large	999	1
1993-1997	19, 25	-0.01	91.7	Very large	999	916
1993-1997	19, 26	0.095	0.1	Very large	999	0
1993-1997	20, 21	0.332	0.1	Very large	999	0
1993-1997	20, 22	0.135	0.1	Very large	999	0
1993-1997	20, 23	-0.013	97.5	Very large	999	974
1993-1997	20, 24	0.301	0.1	Very large	999	0
1993-1997	20, 25	0.112	0.1	Very large	999	0
1993-1997	20, 26	0.001	43.2	Very large	999	431
1993-1997	21, 22	0.057	0.4	Very large	999	3
1993-1997	21, 23	0.344	0.1	Very large	999	0
1993-1997	21, 24	0.005	26.1	Very large	999	260
1993-1997	21, 25	0.054	0.6	Very large	999	5
1993-1997	21, 26	0.33	0.1	Very large	999	0
1993-1997	22, 23	0.144	0.1	Very large	999	0
1993-1997	22, 24	0.075	0.2	Very large	999	1
1993-1997	22, 25	-0.009	85	Very large	999	849
1993-1997	22, 26	0.161	0.1	Very large	999	0
1993-1997	23, 24	0.318	0.1	Very large	999	0
1993-1997	23, 25	0.123	0.1	Very large	999	0
1993-1997	23, 26	0.001	40.3	Very large	999	402
1993-1997	24, 25	0.057	0.7	Very large	999	6
1993-1997	24, 26	0.272	0.1	Very large	999	0
1993-1997	25, 26	0.12	0.1	Very large	999	0
1998-2002	12, 13	0.111	0.1	Very large	999	0
1998-2002	12, 14	0.295	0.1	Very large	999	0
1998-2002	12, 15	0.067	0.6	Very large	999	5
1998-2002	12, 16	0.166	0.1	Very large	999	0

Time Series	**Groups**	**R Statistic**	**Significance Level %**	**Possible Permutations**	**Actual Permutations**	**Number >= Observed**
1998-2002	12, 17	0.408	0.1	Very large	999	0
1998-2002	12, 18	0.154	0.1	Very large	999	0
1998-2002	12, 19	0.241	0.1	Very large	999	0
1998-2002	12, 20	0.425	0.1	Very large	999	0
1998-2002	12, 21	0.1	0.2	Very large	999	1
1998-2002	12, 22	0.27	0.1	Very large	999	0
1998-2002	12, 23	0.445	0.1	Very large	999	0
1998-2002	12, 24	0.064	0.1	Very large	999	0
1998-2002	12, 25	0.254	0.1	Very large	999	0
1998-2002	12, 26	0.343	0.1	Very large	999	0
1998-2002	13, 14	0.057	0.4	Very large	999	3
1998-2002	13, 15	0.126	0.1	Very large	999	0
1998-2002	13, 16	0.046	1.2	Very large	999	11
1998-2002	13, 17	0.142	0.1	Very large	999	0
1998-2002	13, 18	0.241	0.1	Very large	999	0
1998-2002	13, 19	0.12	0.1	Very large	999	0
1998-2002	13, 20	0.182	0.1	Very large	999	0
1998-2002	13, 21	0.198	0.1	Very large	999	0
1998-2002	13, 22	0.192	0.1	Very large	999	0
1998-2002	13, 23	0.213	0.1	Very large	999	0
1998-2002	13, 24	0.186	0.1	Very large	999	0
1998-2002	13, 25	0.167	0.1	Very large	999	0
1998-2002	13, 26	0.135	0.1	Very large	999	0
1998-2002	14, 15	0.277	0.1	Very large	999	0
1998-2002	14, 16	0.071	0.3	Very large	999	2
1998-2002	14, 17	0.019	12.2	Very large	999	121
1998-2002	14, 18	0.409	0.1	Very large	999	0
1998-2002	14, 19	0.146	0.1	Very large	999	0
1998-2002	14, 20	0.058	0.5	Very large	999	4
1998-2002	14, 21	0.373	0.1	Very large	999	0
1998-2002	14, 22	0.234	0.1	Very large	999	0
1998-2002	14, 23	0.076	0.2	Very large	999	1
1998-2002	14, 24	0.37	0.1	Very large	999	0
1998-2002	14, 25	0.214	0.1	Very large	999	0
1998-2002	14, 26	0.02	7.3	Very large	999	72
1998-2002	15, 16	0.063	0.1	Very large	999	0
1998-2002	15, 17	0.307	0.1	Very large	999	0
1998-2002	15, 18	0.003	27.7	Very large	999	276
1998-2002	15, 19	0.082	0.1	Very large	999	0
1998-2002	15, 20	0.3	0.1	Very large	999	0
1998-2002	15, 21	-0.025	92.2	Very large	999	921
1998-2002	15, 22	0.085	0.1	Very large	999	0
1998-2002	15, 23	0.325	0.1	Very large	999	0
1998-2002	15, 24	-0.017	80.5	Very large	999	804
1998-2002	15, 25	0.078	0.1	Very large	999	0
1998-2002	15, 26	0.275	0.1	Very large	999	0
1998-2002	16, 17	0.077	0.2	Very large	999	1
1998-2002	16, 18	0.108	0.1	Very large	999	0
1998-2002	16, 19	0	37.2	Very large	999	371
1998-2002	16, 20	0.079	0.2	Very large	999	1
1998-2002	16, 21	0.071	0.2	Very large	999	1
1998-2002	16, 22	0.032	1	Very large	999	9
1998-2002	16, 23	0.099	0.1	Very large	999	0
1998-2002	16, 24	0.084	0.2	Very large	999	1

Time Series	Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1998-2002	16, 25	0.022	2.6	Very large	999	25
1998-2002	16, 26	0.06	0.8	Very large	999	7
1998-2002	17, 18	0.393	0.1	Very large	999	0
1998-2002	17, 19	0.101	0.1	Very large	999	0
1998-2002	17, 20	-0.003	56.3	Very large	999	562
1998-2002	17, 21	0.369	0.1	Very large	999	0
1998-2002	17, 22	0.165	0.1	Very large	999	0
1998-2002	17, 23	0.009	14.8	Very large	999	147
1998-2002	17, 24	0.38	0.1	Very large	999	0
1998-2002	17, 25	0.154	0.1	Very large	999	0
1998-2002	17, 26	-0.004	52.6	Very large	999	525
1998-2002	18, 19	0.101	0.1	Very large	999	0
1998-2002	18, 20	0.367	0.1	Very large	999	0
1998-2002	18, 21	-0.014	77.6	Very large	999	775
1998-2002	18, 22	0.078	0.1	Very large	999	0
1998-2002	18, 23	0.386	0.1	Very large	999	0
1998-2002	18, 24	0.007	31.3	Very large	999	312
1998-2002	18, 25	0.079	0.1	Very large	999	0
1998-2002	18, 26	0.381	0.1	Very large	999	0
1998-2002	19, 20	0.08	0.1	Very large	999	0
1998-2002	19, 21	0.09	0.1	Very large	999	0
1998-2002	19, 22	-0.002	47.1	Very large	999	470
1998-2002	19, 23	0.096	0.1	Very large	999	0
1998-2002	19, 24	0.114	0.1	Very large	999	0
1998-2002	19, 25	-0.008	77.5	Very large	999	774
1998-2002	19, 26	0.103	0.1	Very large	999	0
1998-2002	20, 21	0.351	0.1	Very large	999	0
1998-2002	20, 22	0.125	0.1	Very large	999	0
1998-2002	20, 23	-0.011	96	Very large	999	959
1998-2002	20, 24	0.366	0.1	Very large	999	0
1998-2002	20, 25	0.12	0.1	Very large	999	0
1998-2002	20, 26	-0.004	54.4	Very large	999	543
1998-2002	21, 22	0.076	0.2	Very large	999	1
1998-2002	21, 23	0.365	0.1	Very large	999	0
1998-2002	21, 24	0.017	10.9	Very large	999	108
1998-2002	21, 25	0.074	0.1	Very large	999	0
1998-2002	21, 26	0.359	0.1	Very large	999	0
1998-2002	22, 23	0.134	0.1	Very large	999	0
1998-2002	22, 24	0.116	0.1	Very large	999	0
1998-2002	22, 25	-0.011	94.5	Very large	999	944
1998-2002	22, 26	0.167	0.1	Very large	999	0
1998-2002	23, 24	0.382	0.1	Very large	999	0
1998-2002	23, 25	0.131	0.1	Very large	999	0
1998-2002	23, 26	-0.004	56.4	Very large	999	563
1998-2002	24, 25	0.108	0.1	Very large	999	0
1998-2002	24, 26	0.352	0.1	Very large	999	0
1998-2002	25, 26	0.155	0.1	Very large	999	0
2003-2007	12, 13	0.136	0.1	Very large	999	0
2003-2007	12, 14	0.331	0.1	Very large	999	0
2003-2007	12, 15	0.126	0.1	Very large	999	0
2003-2007	12, 16	0.246	0.1	Very large	999	0
2003-2007	12, 17	0.503	0.1	Very large	999	0
2003-2007	12, 18	0.19	0.1	Very large	999	0
2003-2007	12, 19	0.279	0.1	Very large	999	0

Time Series	Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2003-2007	12, 20	0.503	0.1	Very large	999	0
2003-2007	12, 21	0.139	0.1	Very large	999	0
2003-2007	12, 22	0.304	0.1	Very large	999	0
2003-2007	12, 23	0.589	0.1	Very large	999	0
2003-2007	12, 24	0.067	0.1	Very large	999	0
2003-2007	12, 25	0.315	0.1	Very large	999	0
2003-2007	12, 26	0.488	0.1	Very large	999	0
2003-2007	13, 14	0.06	0.4	Very large	999	3
2003-2007	13, 15	0.175	0.1	Very large	999	0
2003-2007	13, 16	0.084	0.3	Very large	999	2
2003-2007	13, 17	0.213	0.1	Very large	999	0
2003-2007	13, 18	0.277	0.1	Very large	999	0
2003-2007	13, 19	0.151	0.1	Very large	999	0
2003-2007	13, 20	0.241	0.1	Very large	999	0
2003-2007	13, 21	0.234	0.1	Very large	999	0
2003-2007	13, 22	0.205	0.1	Very large	999	0
2003-2007	13, 23	0.327	0.1	Very large	999	0
2003-2007	13, 24	0.18	0.1	Very large	999	0
2003-2007	13, 25	0.22	0.1	Very large	999	0
2003-2007	13, 26	0.244	0.1	Very large	999	0
2003-2007	14, 15	0.277	0.1	Very large	999	0
2003-2007	14, 16	0.045	1.7	Very large	999	16
2003-2007	14, 17	0.029	6.9	Very large	999	68
2003-2007	14, 18	0.37	0.1	Very large	999	0
2003-2007	14, 19	0.107	0.1	Very large	999	0
2003-2007	14, 20	0.053	1	Very large	999	9
2003-2007	14, 21	0.335	0.1	Very large	999	0
2003-2007	14, 22	0.156	0.1	Very large	999	0
2003-2007	14, 23	0.111	0.1	Very large	999	0
2003-2007	14, 24	0.276	0.1	Very large	999	0
2003-2007	14, 25	0.181	0.1	Very large	999	0
2003-2007	14, 26	0.064	0.4	Very large	999	3
2003-2007	15, 16	0.085	0.1	Very large	999	0
2003-2007	15, 17	0.349	0.1	Very large	999	0
2003-2007	15, 18	0.004	27.1	Very large	999	270
2003-2007	15, 19	0.072	0.1	Very large	999	0
2003-2007	15, 20	0.338	0.1	Very large	999	0
2003-2007	15, 21	-0.006	61.3	Very large	999	612
2003-2007	15, 22	0.078	0.1	Very large	999	0
2003-2007	15, 23	0.423	0.1	Very large	999	0
2003-2007	15, 24	0.042	2.4	Very large	999	23
2003-2007	15, 25	0.08	0.1	Very large	999	0
2003-2007	15, 26	0.37	0.1	Very large	999	0
2003-2007	16, 17	0.08	0.1	Very large	999	0
2003-2007	16, 18	0.134	0.1	Very large	999	0
2003-2007	16, 19	-0.001	45.6	Very large	999	455
2003-2007	16, 20	0.081	0.1	Very large	999	0
2003-2007	16, 21	0.106	0.1	Very large	999	0
2003-2007	16, 22	0.018	3.9	Very large	999	38
2003-2007	16, 23	0.143	0.1	Very large	999	0
2003-2007	16, 24	0.132	0.1	Very large	999	0
2003-2007	16, 25	0.031	1.4	Very large	999	13
2003-2007	16, 26	0.104	0.1	Very large	999	0
2003-2007	17, 18	0.406	0.1	Very large	999	0

Time Series	Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2003-2007	17, 19	0.106	0.1	Very large	999	0
2003-2007	17, 20	-0.009	83.1	Very large	999	830
2003-2007	17, 21	0.378	0.1	Very large	999	0
2003-2007	17, 22	0.131	0.1	Very large	999	0
2003-2007	17, 23	0.007	17.4	Very large	999	173
2003-2007	17, 24	0.357	0.1	Very large	999	0
2003-2007	17, 25	0.15	0.1	Very large	999	0
2003-2007	17, 26	-0.006	58.7	Very large	999	586
2003-2007	18, 19	0.097	0.1	Very large	999	0
2003-2007	18, 20	0.385	0.1	Very large	999	0
2003-2007	18, 21	-0.015	83.1	Very large	999	830
2003-2007	18, 22	0.085	0.1	Very large	999	0
2003-2007	18, 23	0.459	0.1	Very large	999	0
2003-2007	18, 24	0.058	1.1	Very large	999	10
2003-2007	18, 25	0.08	0.1	Very large	999	0
2003-2007	18, 26	0.419	0.1	Very large	999	0
2003-2007	19, 20	0.096	0.1	Very large	999	0
2003-2007	19, 21	0.081	0.1	Very large	999	0
2003-2007	19, 22	-0.009	89.7	Very large	999	896
2003-2007	19, 23	0.151	0.1	Very large	999	0
2003-2007	19, 24	0.118	0.1	Very large	999	0
2003-2007	19, 25	-0.004	56.8	Very large	999	567
2003-2007	19, 26	0.125	0.1	Very large	999	0
2003-2007	20, 21	0.358	0.1	Very large	999	0
2003-2007	20, 22	0.11	0.1	Very large	999	0
2003-2007	20, 23	-0.002	52.3	Very large	999	522
2003-2007	20, 24	0.338	0.1	Very large	999	0
2003-2007	20, 25	0.129	0.1	Very large	999	0
2003-2007	20, 26	-0.013	79.2	Very large	999	791
2003-2007	21, 22	0.071	0.1	Very large	999	0
2003-2007	21, 23	0.442	0.1	Very large	999	0
2003-2007	21, 24	0.028	3.6	Very large	999	35
2003-2007	21, 25	0.075	0.3	Very large	999	2
2003-2007	21, 26	0.393	0.1	Very large	999	0
2003-2007	22, 23	0.158	0.1	Very large	999	0
2003-2007	22, 24	0.115	0.1	Very large	999	0
2003-2007	22, 25	-0.011	95.6	Very large	999	955
2003-2007	22, 26	0.139	0.1	Very large	999	0
2003-2007	23, 24	0.415	0.1	Very large	999	0
2003-2007	23, 25	0.175	0.1	Very large	999	0
2003-2007	23, 26	-0.006	61.8	Very large	999	617
2003-2007	24, 25	0.118	0.1	Very large	999	0
2003-2007	24, 26	0.328	0.1	Very large	999	0
2003-2007	25, 26	0.161	0.1	Very large	999	0
2008-2012	12, 13	0.115	0.1	Very large	999	0
2008-2012	12, 14	0.276	0.1	Very large	999	0
2008-2012	12, 15	0.067	0.4	Very large	999	3
2008-2012	12, 16	0.18	0.1	Very large	999	0
2008-2012	12, 17	0.425	0.1	Very large	999	0
2008-2012	12, 18	0.11	0.3	Very large	999	2
2008-2012	12, 19	0.214	0.1	Very large	999	0
2008-2012	12, 20	0.458	0.1	Very large	999	0
2008-2012	12, 21	0.083	0.1	Very large	999	0
2008-2012	12, 22	0.234	0.1	Very large	999	0

Time Series	**Groups**	**R Statistic**	**Significance Level %**	**Possible Permutations**	**Actual Permutations**	**Number >= Observed**
2008-2012	12, 23	0.484	0.1	Very large	999	0
2008-2012	12, 24	0.079	0.2	Very large	999	1
2008-2012	12, 25	0.249	0.1	Very large	999	0
2008-2012	12, 26	0.379	0.1	Very large	999	0
2008-2012	13, 14	0.036	1.8	Very large	999	17
2008-2012	13, 15	0.119	0.2	Very large	999	1
2008-2012	13, 16	0.033	4.9	Very large	999	48
2008-2012	13, 17	0.141	0.1	Very large	999	0
2008-2012	13, 18	0.19	0.1	Very large	999	0
2008-2012	13, 19	0.082	0.1	Very large	999	0
2008-2012	13, 20	0.187	0.1	Very large	999	0
2008-2012	13, 21	0.21	0.1	Very large	999	0
2008-2012	13, 22	0.122	0.1	Very large	999	0
2008-2012	13, 23	0.207	0.1	Very large	999	0
2008-2012	13, 24	0.17	0.1	Very large	999	0
2008-2012	13, 25	0.139	0.1	Very large	999	0
2008-2012	13, 26	0.144	0.1	Very large	999	0
2008-2012	14, 15	0.249	0.1	Very large	999	0
2008-2012	14, 16	0.06	0.5	Very large	999	4
2008-2012	14, 17	0.031	6.2	Very large	999	61
2008-2012	14, 18	0.319	0.1	Very large	999	0
2008-2012	14, 19	0.101	0.1	Very large	999	0
2008-2012	14, 20	0.063	0.6	Very large	999	5
2008-2012	14, 21	0.346	0.1	Very large	999	0
2008-2012	14, 22	0.149	0.2	Very large	999	1
2008-2012	14, 23	0.076	0.2	Very large	999	1
2008-2012	14, 24	0.295	0.1	Very large	999	0
2008-2012	14, 25	0.17	0.1	Very large	999	0
2008-2012	14, 26	0.033	2.6	Very large	999	25
2008-2012	15, 16	0.071	0.1	Very large	999	0
2008-2012	15, 17	0.306	0.1	Very large	999	0
2008-2012	15, 18	-0.005	61.5	Very large	999	614
2008-2012	15, 19	0.071	0.1	Very large	999	0
2008-2012	15, 20	0.32	0.1	Very large	999	0
2008-2012	15, 21	-0.013	76	Very large	999	759
2008-2012	15, 22	0.065	0.3	Very large	999	2
2008-2012	15, 23	0.341	0.1	Very large	999	0
2008-2012	15, 24	-0.014	77.3	Very large	999	772
2008-2012	15, 25	0.071	0.1	Very large	999	0
2008-2012	15, 26	0.275	0.1	Very large	999	0
2008-2012	16, 17	0.079	0.1	Very large	999	0
2008-2012	16, 18	0.111	0.1	Very large	999	0
2008-2012	16, 19	-0.002	48.5	Very large	999	484
2008-2012	16, 20	0.102	0.1	Very large	999	0
2008-2012	16, 21	0.132	0.1	Very large	999	0
2008-2012	16, 22	0.018	5.4	Very large	999	53
2008-2012	16, 23	0.118	0.1	Very large	999	0
2008-2012	16, 24	0.103	0.4	Very large	999	3
2008-2012	16, 25	0.031	1.9	Very large	999	18
2008-2012	16, 26	0.085	0.1	Very large	999	0
2008-2012	17, 18	0.353	0.1	Very large	999	0
2008-2012	17, 19	0.086	0.1	Very large	999	0
2008-2012	17, 20	-0.006	70.3	Very large	999	702
2008-2012	17, 21	0.404	0.1	Very large	999	0

Time Series	Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2008-2012	17, 22	0.122	0.1	Very large	999	0
2008-2012	17, 23	0	38.6	Very large	999	385
2008-2012	17, 24	0.344	0.1	Very large	999	0
2008-2012	17, 25	0.135	0.1	Very large	999	0
2008-2012	17, 26	-0.002	47.9	Very large	999	478
2008-2012	18, 19	0.094	0.1	Very large	999	0
2008-2012	18, 20	0.356	0.1	Very large	999	0
2008-2012	18, 21	-0.019	87.4	Very large	999	873
2008-2012	18, 22	0.075	0.1	Very large	999	0
2008-2012	18, 23	0.374	0.1	Very large	999	0
2008-2012	18, 24	-0.01	67.7	Very large	999	676
2008-2012	18, 25	0.076	0.1	Very large	999	0
2008-2012	18, 26	0.321	0.1	Very large	999	0
2008-2012	19, 20	0.091	0.1	Very large	999	0
2008-2012	19, 21	0.121	0.1	Very large	999	0
2008-2012	19, 22	-0.008	83	Very large	999	829
2008-2012	19, 23	0.103	0.1	Very large	999	0
2008-2012	19, 24	0.085	0.1	Very large	999	0
2008-2012	19, 25	-0.003	50.6	Very large	999	505
2008-2012	19, 26	0.083	0.2	Very large	999	1
2008-2012	20, 21	0.408	0.1	Very large	999	0
2008-2012	20, 22	0.115	0.1	Very large	999	0
2008-2012	20, 23	-0.014	99.9	Very large	999	998
2008-2012	20, 24	0.341	0.1	Very large	999	0
2008-2012	20, 25	0.124	0.1	Very large	999	0
2008-2012	20, 26	-0.011	70.6	Very large	999	705
2008-2012	21, 22	0.101	0.2	Very large	999	1
2008-2012	21, 23	0.428	0.1	Very large	999	0
2008-2012	21, 24	-0.001	41	Very large	999	409
2008-2012	21, 25	0.108	0.1	Very large	999	0
2008-2012	21, 26	0.37	0.1	Very large	999	0
2008-2012	22, 23	0.126	0.1	Very large	999	0
2008-2012	22, 24	0.066	0.9	Very large	999	8
2008-2012	22, 25	-0.012	99.2	Very large	999	991
2008-2012	22, 26	0.111	0.2	Very large	999	1
2008-2012	23, 24	0.357	0.1	Very large	999	0
2008-2012	23, 25	0.133	0.1	Very large	999	0
2008-2012	23, 26	-0.008	64.7	Very large	999	646
2008-2012	24, 25	0.067	0.4	Very large	999	3
2008-2012	24, 26	0.305	0.1	Very large	999	0
2008-2012	25, 26	0.124	0.1	Very large	999	0
2013-2015	12, 13	0.053	3	Very large	999	29
2013-2015	12, 14	0.147	0.1	Very large	999	0
2013-2015	12, 15	0.074	1.5	Very large	999	14
2013-2015	12, 16	0.123	0.2	Very large	999	1
2013-2015	12, 17	0.327	0.1	Very large	999	0
2013-2015	12, 18	0.098	0.8	Very large	999	7
2013-2015	12, 19	0.179	0.1	Very large	999	0
2013-2015	12, 20	0.327	0.1	Very large	999	0
2013-2015	12, 21	0.046	3.7	Very large	999	36
2013-2015	12, 22	0.181	0.1	Very large	999	0
2013-2015	12, 23	0.351	0.1	Very large	999	0
2013-2015	12, 24	0.043	5.3	Very large	999	52
2013-2015	12, 25	0.209	0.1	Very large	999	0

Time Series	Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2013-2015	12, 26	0.279	0.1	Very large	999	0
2013-2015	13, 14	0.005	30.5	Very large	999	304
2013-2015	13, 15	0.131	0.2	Very large	999	1
2013-2015	13, 16	0.036	9	Very large	999	89
2013-2015	13, 17	0.12	0.2	Very large	999	1
2013-2015	13, 18	0.176	0.1	Very large	999	0
2013-2015	13, 19	0.091	0.5	Very large	999	4
2013-2015	13, 20	0.132	0.2	Very large	999	1
2013-2015	13, 21	0.128	0.4	Very large	999	3
2013-2015	13, 22	0.136	0.1	Very large	999	0
2013-2015	13, 23	0.17	0.1	Very large	999	0
2013-2015	13, 24	0.11	0.3	Very large	999	2
2013-2015	13, 25	0.175	0.1	Very large	999	0
2013-2015	13, 26	0.118	0.3	Very large	999	2
2013-2015	14, 15	0.166	0.1	Very large	999	0
2013-2015	14, 16	0.015	25.4	Very large	999	253
2013-2015	14, 17	0.021	15.4	Very large	999	153
2013-2015	14, 18	0.211	0.1	Very large	999	0
2013-2015	14, 19	0.054	3.3	Very large	999	32
2013-2015	14, 20	0.03	13.1	Very large	999	130
2013-2015	14, 21	0.172	0.1	Very large	999	0
2013-2015	14, 22	0.11	0.1	Very large	999	0
2013-2015	14, 23	0.049	4.7	Very large	999	46
2013-2015	14, 24	0.153	0.1	Very large	999	0
2013-2015	14, 25	0.139	0.2	Very large	999	1
2013-2015	14, 26	0.013	20.9	Very large	999	208
2013-2015	15, 16	0.046	1.7	Very large	999	16
2013-2015	15, 17	0.227	0.1	Very large	999	0
2013-2015	15, 18	-0.014	87.5	Very large	999	874
2013-2015	15, 19	0.05	2.2	Very large	999	21
2013-2015	15, 20	0.23	0.1	Very large	999	0
2013-2015	15, 21	-0.024	85.8	Very large	999	857
2013-2015	15, 22	0.035	3	Very large	999	29
2013-2015	15, 23	0.228	0.1	Very large	999	0
2013-2015	15, 24	-0.015	68.9	Very large	999	688
2013-2015	15, 25	0.034	5.3	Very large	999	52
2013-2015	15, 26	0.194	0.1	Very large	999	0
2013-2015	16, 17	0.031	5.1	Very large	999	50
2013-2015	16, 18	0.074	0.1	Very large	999	0
2013-2015	16, 19	-0.014	87.2	Very large	999	871
2013-2015	16, 20	0.038	3.5	Very large	999	34
2013-2015	16, 21	0.055	3.2	Very large	999	31
2013-2015	16, 22	0.008	24.6	Very large	999	245
2013-2015	16, 23	0.051	1.8	Very large	999	17
2013-2015	16, 24	0.046	7.1	Very large	999	70
2013-2015	16, 25	0.027	5.2	Very large	999	51
2013-2015	16, 26	0.023	16.8	Very large	999	167
2013-2015	17, 18	0.269	0.1	Very large	999	0
2013-2015	17, 19	0.039	3.8	Very large	999	37
2013-2015	17, 20	-0.019	93	Very large	999	929
2013-2015	17, 21	0.265	0.1	Very large	999	0
2013-2015	17, 22	0.098	0.1	Very large	999	0
2013-2015	17, 23	-0.012	71.9	Very large	999	718
2013-2015	17, 24	0.241	0.1	Very large	999	0

Time Series	Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2013-2015	17, 25	0.11	0.1	Very large	999	0
2013-2015	17, 26	-0.019	75.7	Very large	999	756
2013-2015	18, 19	0.077	0.7	Very large	999	6
2013-2015	18, 20	0.265	0.1	Very large	999	0
2013-2015	18, 21	-0.012	68.1	Very large	999	680
2013-2015	18, 22	0.041	3.2	Very large	999	31
2013-2015	18, 23	0.26	0.1	Very large	999	0
2013-2015	18, 24	-0.01	58.3	Very large	999	582
2013-2015	18, 25	0.033	5.4	Very large	999	53
2013-2015	18, 26	0.236	0.1	Very large	999	0
2013-2015	19, 20	0.045	2.2	Very large	999	21
2013-2015	19, 21	0.068	2.6	Very large	999	25
2013-2015	19, 22	-0.009	64.7	Very large	999	646
2013-2015	19, 23	0.05	1.6	Very large	999	15
2013-2015	19, 24	0.059	3.8	Very large	999	37
2013-2015	19, 25	0.002	33.7	Very large	999	336
2013-2015	19, 26	0.034	7.6	Very large	999	75
2013-2015	20, 21	0.256	0.1	Very large	999	0
2013-2015	20, 22	0.098	0.2	Very large	999	1
2013-2015	20, 23	-0.016	87.8	Very large	999	877
2013-2015	20, 24	0.233	0.1	Very large	999	0
2013-2015	20, 25	0.109	0.1	Very large	999	0
2013-2015	20, 26	-0.026	88.1	Very large	999	880
2013-2015	21, 22	0.051	4	Very large	999	39
2013-2015	21, 23	0.265	0.1	Very large	999	0
2013-2015	21, 24	-0.02	80.3	Very large	999	802
2013-2015	21, 25	0.052	3.5	Very large	999	34
2013-2015	21, 26	0.225	0.1	Very large	999	0
2013-2015	22, 23	0.094	0.1	Very large	999	0
2013-2015	22, 24	0.03	12	Very large	999	119
2013-2015	22, 25	-0.018	94.9	Very large	999	948
2013-2015	22, 26	0.079	1.7	Very large	999	16
2013-2015	23, 24	0.233	0.1	Very large	999	0
2013-2015	23, 25	0.097	0.4	Very large	999	3
2013-2015	23, 26	-0.028	92.7	Very large	999	926
2013-2015	24, 25	0.036	9.8	Very large	999	97
2013-2015	24, 26	0.203	0.1	Very large	999	0
2013-2015	25, 26	0.091	0.9	Very large	999	8

Table 5.9.3. Separate one-way PERMANOVA. Pairwise tests of the environmental and oceanic conditions between years.

Time-Series	**Groups**	***t***	***P* (perm)**	**Unique perms**
1988-1992	1988, 1989	2.8255	0.001	999
1988-1992	1988, 1990	4.6979	0.001	998
1988-1992	1988, 1991	3.7057	0.001	999
1988-1992	1988, 1992	4.327	0.001	997
1988-1992	1989, 1990	2.5837	0.002	997
1988-1992	1989, 1991	3.9775	0.001	999
1988-1992	1989, 1992	4.7581	0.001	999
1988-1992	1990, 1991	5.6896	0.001	998
1988-1992	1990, 1992	6.8991	0.001	998
1988-1992	1991, 1992	2.8062	0.001	998
1993-1997	1993, 1994	2.8013	0.001	999
1993-1997	1993, 1995	10.43	0.001	999
1993-1997	1993, 1996	6.2035	0.001	999
1993-1997	1993, 1997	8.7779	0.001	999
1993-1997	1994, 1995	10.917	0.001	999
1993-1997	1994, 1996	7.1291	0.001	998
1993-1997	1994, 1997	9.8301	0.001	999
1993-1997	1995, 1996	7.454	0.001	999
1993-1997	1995, 1997	4.8926	0.001	996
1993-1997	1996, 1997	3.8564	0.001	999
1998-2002	1998, 1999	8.1596	0.001	998
1998-2002	1998, 2000	11.354	0.001	999
1998-2002	1998, 2001	6.6001	0.001	999
1998-2002	1998, 2002	10.996	0.001	999
1998-2002	1999, 2000	4.1124	0.001	998
1998-2002	1999, 2001	2.8205	0.001	997
1998-2002	1999, 2002	4.432	0.001	996
1998-2002	2000, 2001	5.1099	0.001	999
1998-2002	2000, 2002	2.2551	0.003	999
1998-2002	2001, 2002	5.5317	0.001	997
2003-2007	2003, 2004	1.5899	0.047	998
2003-2007	2003, 2005	6.3625	0.001	999
2003-2007	2003, 2006	4.7825	0.001	998
2003-2007	2003, 2007	4.4703	0.001	998
2003-2007	2004, 2005	6.1775	0.001	999
2003-2007	2004, 2006	4.7418	0.001	999
2003-2007	2004, 2007	4.0151	0.001	998
2003-2007	2005, 2006	4.0875	0.001	998
2003-2007	2005, 2007	7.4473	0.001	999
2003-2007	2006, 2007	6.4781	0.001	998
2008-2012	2008, 2009	6.0813	0.001	999
2008-2012	2008, 2010	7.9448	0.001	997
2008-2012	2008, 2011	6.5253	0.001	998
2008-2012	2008, 2012	5.4797	0.001	999
2008-2012	2009, 2010	7.3308	0.001	999
2008-2012	2009, 2011	3.8269	0.001	999
2008-2012	2009, 2012	3.6224	0.001	999
2008-2012	2010, 2011	7.0633	0.001	999
2008-2012	2010, 2012	3.2221	0.001	999
2008-2012	2011, 2012	4.3052	0.001	999
2013-2015	2013, 2014	5.8267	0.001	998
2013-2015	2013, 2015	8.4034	0.001	998
2013-2015	2014, 2015	5.3129	0.001	998

Table 5.9.4. One-way PERMDISP (Distance-based test for homogeneity of multivariate dispersions). Pairwise tests of the environmental and oceanic conditions and years

Time-Series	**Groups**	***t***	***P* (perm)**
1988-1992	1988,1989	11.051	0.001
1988-1992	1988,1990	6.1103	0.001
1988-1992	1988,1991	4.8712	0.001
1988-1992	1988,1992	9.3758	0.001
1988-1992	1989,1990	5.9012	0.001
1988-1992	1989,1991	11.161	0.001
1988-1992	1989,1992	7.3082	0.001
1988-1992	1990,1991	3.9543	0.001
1988-1992	1990,1992	0.016381	0.99
1988-1992	1991,1992	5.3137	0.001
1993-1997	1993,1994	1.6876	0.13
1993-1997	1993,1995	1.5037	0.178
1993-1997	1993,1996	0.63912	0.573
1993-1997	1993,1997	1.658	0.148
1993-1997	1994,1995	4.1888	0.001
1993-1997	1994,1996	1.2172	0.254
1993-1997	1994,1997	0.13008	0.901
1993-1997	1995,1996	2.6251	0.013
1993-1997	1995,1997	3.7722	0.004
1993-1997	1996,1997	1.2076	0.284
1998-2002	1998,1999	1.3731	0.221
1998-2002	1998,2000	2.8117	0.009
1998-2002	1998,2001	0.78767	0.45
1998-2002	1998,2002	0.352	0.733
1998-2002	1999,2000	1.5938	0.125
1998-2002	1999,2001	0.6246	0.558
1998-2002	1999,2002	2.156	0.044
1998-2002	2000,2001	2.1894	0.048
1998-2002	2000,2002	3.9782	0.001
1998-2002	2001,2002	1.3911	0.17
2003-2007	2003,2004	4.2608	0.001
2003-2007	2003,2005	3.1508	0.005
2003-2007	2003,2006	3.3602	0.003
2003-2007	2003,2007	1.2889	0.221
2003-2007	2004,2005	0.24536	0.816
2003-2007	2004,2006	1.1062	0.305
2003-2007	2004,2007	1.9405	0.065
2003-2007	2005,2006	0.6367	0.546
2003-2007	2005,2007	1.4836	0.188
2003-2007	2006,2007	1.1406	0.296
2008-2012	2008,2009	5.9406	0.001
2008-2012	2008,2010	7.6379	0.001
2008-2012	2008,2011	2.2924	0.036
2008-2012	2008,2012	0.33922	0.801
2008-2012	2009,2010	2.2198	0.049
2008-2012	2009,2011	3.3398	0.003
2008-2012	2009,2012	3.2501	0.001
2008-2012	2010,2011	5.2085	0.001
2008-2012	2010,2012	4.3738	0.001
2008-2012	2011,2012	1.4865	0.183
2013-2015	2013,2014	4.082	0.001
2013-2015	2013,2015	2.0244	0.071
2013-2015	2014,2015	0.39851	0.717

5.9.2 Marine Community. Multivariate analysis.

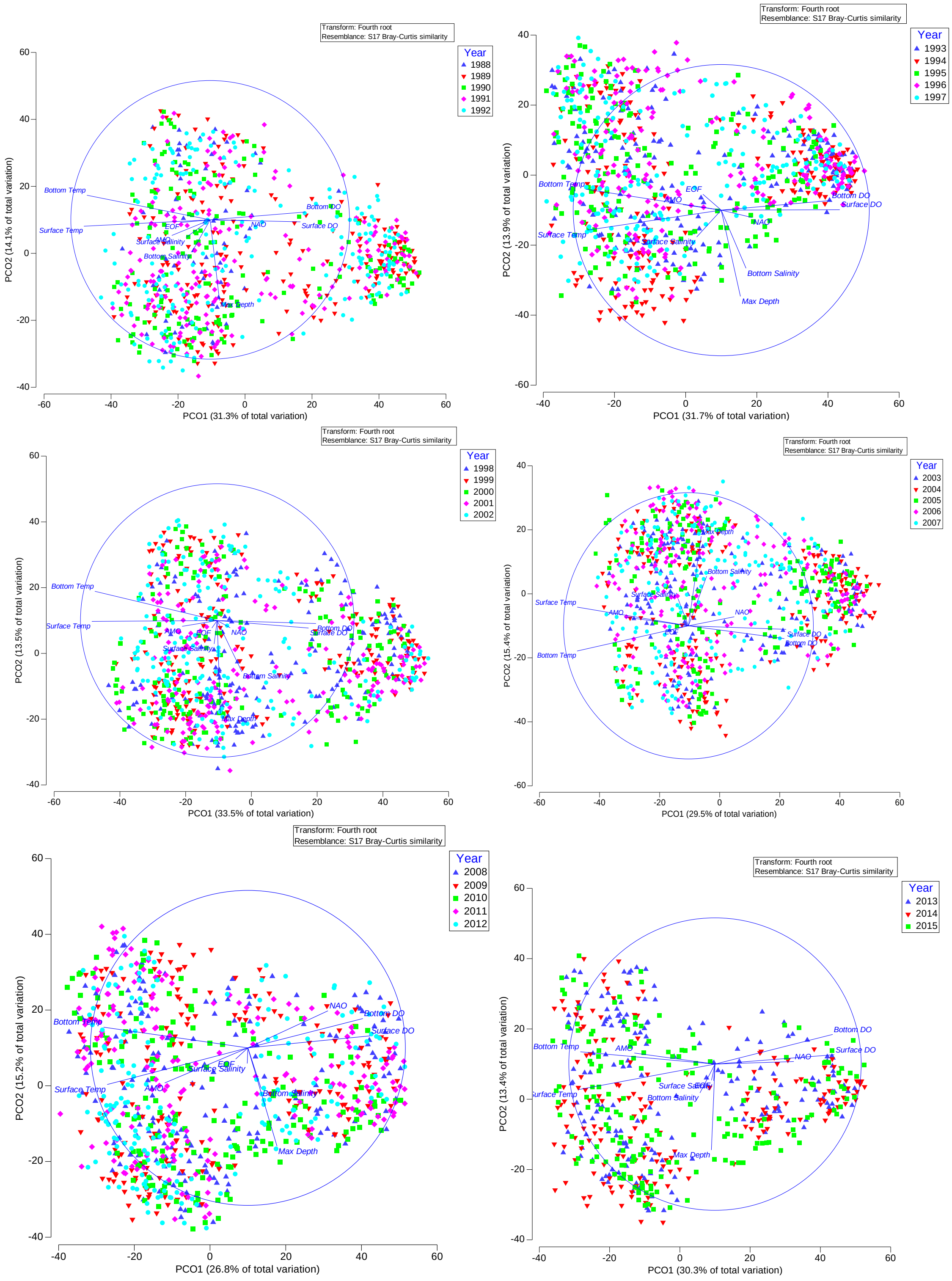


Figure. 5.9.5. Separate PCO plots of the marine community during 1988 through 2015.

Table 5.9.6. Distance based linear model. Sequential tests. Environmental and oceanic predictors of the marine community.

Time Series	Variable	AICc	SS(trace)	Pseudo-F	P	Prop.	Cumul.	res.df
1988-1992	Surface Temp	6028.3	4.7571E+05	284.58	0.001	0.25999	0.25999	810
1988-1992	Max Depth	5966.1	1.0291E+05	66.546	0.001	0.056244	0.31623	809
1988-1992	Bottom Temp	5919.5	72715	49.859	0.001	0.039741	0.35598	808
1988-1992	NAO	5901.2	29162	20.478	0.001	0.015938	0.37191	807
1988-1992	Surface Salinity	5886	24223	17.355	0.001	0.013239	0.38515	806
1988-1992	Bottom DO	5877.9	13905	10.074	0.001	0.0075996	0.39275	805
1988-1992	EOF	5873.9	8238	6.0056	0.001	0.0045023	0.39725	804
1988-1992	AMO	5867.9	10808	7.9469	0.001	0.0059066	0.40316	803
1988-1992	Surface DO	5866	5305	3.915	0.001	0.0028993	0.40606	802
1993-1997	Bottom Temp	6892.5	5.3587E+05	343.03	0.001	0.2684	0.2684	935
1993-1997	Surface Temp	6810.2	1.2571E+05	87.957	0.001	0.062966	0.33137	934
1993-1997	Max Depth	6761.4	70417	51.957	0.001	0.035271	0.36664	933
1993-1997	NAO	6742.8	27484	20.707	0.001	0.013766	0.38041	932
1993-1997	EOF	6726.9	23503	18.032	0.001	0.011772	0.39218	931
1993-1997	Surface Salinity	6712.6	20889	16.289	0.001	0.010463	0.40264	930
1993-1997	AMO	6702.2	15695	12.389	0.001	0.0078613	0.4105	929
1993-1997	Bottom DO	6694.5	12121	9.6566	0.001	0.006071	0.41658	928
1993-1997	Bottom Salinity	6690.8	7096.6	5.6824	0.001	0.0035545	0.42013	927
1998-2002	Surface Temp	6842.7	5.5904E+05	368.66	0.001	0.28344	0.28344	932
1998-2002	Max Depth	6746.6	1.409E+05	103.1	0.001	0.071439	0.35488	931
1998-2002	Bottom Temp	6693.1	73444	56.97	0.001	0.037237	0.39212	930
1998-2002	Surface Salinity	6679.1	20356	16.045	0.001	0.010321	0.40244	929
1998-2002	AMO	6670.2	13647	10.872	0.001	0.0069194	0.40936	928
1998-2002	NAO	6664	10197	8.1861	0.001	0.0051701	0.41453	927
1998-2002	Bottom DO	6658.6	9136.9	7.3854	0.001	0.0046325	0.41916	926
1998-2002	Bottom Salinity	6653.7	8414.9	6.8447	0.001	0.0042665	0.42343	925
1998-2002	EOF	6649.5	7460.4	6.1018	0.001	0.0037825	0.42721	924
2003-2007	Bottom Temp	6847.3	4.538E+05	297.79	0.001	0.24215	0.24215	932
2003-2007	Max Depth	6747.9	1.4611E+05	106.76	0.001	0.077963	0.32011	931
2003-2007	Surface Temp	6672	1.0201E+05	80.933	0.001	0.05443	0.37454	930
2003-2007	Surface Salinity	6658.4	19409	15.642	0.001	0.010357	0.3849	929
2003-2007	EOF	6649.8	12994	10.58	0.001	0.0069338	0.39183	928
2003-2007	AMO	6638.3	16293	13.444	0.001	0.0086939	0.40053	927
2003-2007	Bottom DO	6630.9	11257	9.3729	0.001	0.006007	0.40653	926
2003-2007	Bottom Salinity	6626.9	7185.3	6.0148	0.001	0.0038341	0.41037	925
2003-2007	Surface DO	6623.3	6531.8	5.4943	0.001	0.0034854	0.41385	924
2008-2012	Bottom Temp	6939.5	4.7934E+05	276.04	0.001	0.22926	0.22926	928

Time Series	Variable	AICc	SS(trace)	Pseudo-F	P	Prop.	Cumul.	res.df
2008-2012	Surface Temp	6837.7	1.7017E+05	109.45	0.001	0.081388	0.31065	927
2008-2012	Max Depth	6779.8	89979	61.657	0.001	0.043035	0.35368	926
2008-2012	NAO	6768.9	18587	12.901	0.001	0.0088899	0.36257	925
2008-2012	Surface Salinity	6758.9	17077	11.993	0.001	0.0081674	0.37074	924
2008-2012	Bottom DO	6754	9894.2	6.9937	0.001	0.0047322	0.37547	923
2008-2012	EOF	6749	9823.5	6.9888	0.001	0.0046984	0.38017	922
2008-2012	Surface DO	6744.6	8895.8	6.3656	0.001	0.0042546	0.38442	921
2008-2012	AMO	6741.2	7570.8	5.4436	0.001	0.0036209	0.38805	920
2013-2015	Surface Temp	4106.1	3.2076E+05	205.09	0.001	0.26947	0.26947	556
2013-2015	Bottom Temp	4055.8	77769	54.51	0.001	0.065333	0.3348	555
2013-2015	Max Depth	4026.7	42911	31.744	0.001	0.036049	0.37085	554
2013-2015	AMO	4018	14230	10.711	0.001	0.011955	0.38281	553
2013-2015	EOF	4009.4	13829	10.59	0.001	0.011618	0.39443	552
2013-2015	NAO	4003.3	10433	8.0916	0.001	0.0087643	0.40319	551
2013-2015	Surface Salinity	3997.5	9825.1	7.7133	0.001	0.008254	0.41144	550
2013-2015	Bottom Salinity	3992.1	9247.2	7.3434	0.001	0.0077686	0.41921	549
2013-2015	Bottom DO	3989.7	5368.6	4.2888	0.001	0.0045102	0.42372	548

Table 5.9.7. Separate one-way ANOSIM. Pairwise tests of the marine community between unordered year groups. Individual ANOSIM performed on individual time series.

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
1988, 1989	0.023	15.6	Very large	999	155
1988, 1990	-0.006	58.3	Very large	999	582
1988, 1991	0.009	34.8	Very large	999	347
1988, 1992	0.021	16.7	Very large	999	166
1989, 1990	0.056	0.1	Very large	999	0
1989, 1991	0.032	0.1	Very large	999	0
1989, 1992	0.057	0.1	Very large	999	0
1990, 1991	0.019	0.2	Very large	999	1
1990, 1992	0.027	0.1	Very large	999	0
1991, 1992	0.027	0.1	Very large	999	0
1993, 1994	0.006	32.7	Very large	999	326
1993, 1995	0.018	11.4	Very large	999	113
1993, 1996	0.017	14.2	Very large	999	141
1993, 1997	0.04	1.5	Very large	999	14
1994, 1995	0.031	3.8	Very large	999	37
1994, 1996	0.029	4.5	Very large	999	44
1994, 1997	0.108	0.1	Very large	999	0
1995, 1996	0.011	23.6	Very large	999	235
1995, 1997	0.051	0.6	Very large	999	5
1996, 1997	0.006	35	Very large	999	349
1998, 1999	-0.022	93.6	Very large	999	935
1998, 2000	-0.001	49.3	Very large	999	492
1998, 2001	0.024	6.7	Very large	999	66
1998, 2002	0.077	0.1	Very large	999	0
1999, 2000	-0.016	87.3	Very large	999	872
1999, 2001	-0.001	46.9	Very large	999	468
1999, 2002	0.039	1.3	Very large	999	12
2000, 2001	-0.022	94.8	Very large	999	947
2000, 2002	0.005	35	Very large	999	349
2001, 2002	0.038	1.3	Very large	999	12
2003, 2004	-0.024	96.4	Very large	999	963
2003, 2005	-0.023	95	Very large	999	949
2003, 2006	0.008	27.8	Very large	999	277
2003, 2007	0.026	5.4	Very large	999	53
2004, 2005	-0.029	99.3	Very large	999	992
2004, 2006	0.03	2.3	Very large	999	22
2004, 2007	0.03	2.9	Very large	999	28
2005, 2006	0.001	44.2	Very large	999	441
2005, 2007	0.015	15.1	Very large	999	150
2006, 2007	-0.013	79.1	Very large	999	790
2008, 2009	0.016	0.7	Very large	999	6
2008, 2010	0.039	0.1	Very large	999	0
2008, 2011	0.055	0.1	Very large	999	0
2008, 2012	0.051	0.1	Very large	999	0
2009, 2010	0.018	0.2	Very large	999	1
2009, 2011	0.028	0.1	Very large	999	0
2009, 2012	0.038	0.1	Very large	999	0

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2010, 2011	0.03	0.1	Very large	999	0
2010, 2012	0.047	0.1	Very large	999	0
2011, 2012	0.052	0.1	Very large	999	0
2013, 2014	0.031	0.1	Very large	999	0
2013, 2015	0.036	0.1	Very large	999	0
2014, 2015	0.024	0.2	Very large	999	1

Table 5.9.10. One-way ANOSIM. Pairwise tests of the biological community k-dominance curves between unordered year groups.

Groups	**R Statistic**	**Significance Level %**	**Possible Permutations**	**Actual Permutations**	**Number >= Observed**
1988, 1989	0.146	0.1	Very large	999	0
1988, 1990	0.192	0.1	Very large	999	0
1988, 1991	0.175	0.1	Very large	999	0
1988, 1992	0.155	0.1	Very large	999	0
1989, 1990	0.023	0.3	Very large	999	2
1989, 1991	-0.003	91	Very large	999	909
1989, 1992	0.003	14	Very large	999	139
1990, 1991	0.019	0.6	Very large	999	5
1990, 1992	0.002	26.9	Very large	999	268
1991, 1992	0.001	27.7	Very large	999	276
1993, 1994	0.041	0.1	Very large	999	0
1993, 1995	0.025	0.2	Very large	999	1
1993, 1996	0.015	0.2	Very large	999	1
1993, 1997	0.024	0.2	Very large	999	1
1994, 1995	0.095	0.1	Very large	999	0
1994, 1996	0.063	0.1	Very large	999	0
1994, 1997	0.101	0.1	Very large	999	0
1995, 1996	0.011	2.1	Very large	999	20
1995, 1997	-0.001	54.3	Very large	999	542
1996, 1997	0.007	4.4	Very large	999	43
1998, 1999	0.004	12.7	Very large	999	126
1998, 2000	0.029	0.1	Very large	999	0
1998, 2001	0.03	0.1	Very large	999	0
1998, 2002	0.014	0.6	Very large	999	5
1999, 2000	0.008	4.3	Very large	999	42
1999, 2001	0.013	1	Very large	999	9
1999, 2002	0.007	6	Very large	999	59
2000, 2001	0.002	20.7	Very large	999	206
2000, 2002	0.017	0.4	Very large	999	3
2001, 2002	0.023	0.1	Very large	999	0
2003, 2004	0.011	1	Very large	999	9
2003, 2005	0.007	4.5	Very large	999	44
2003, 2006	0	41.7	Very large	999	416
2003, 2007	0.002	21.3	Very large	999	212
2004, 2005	0	35.2	Very large	999	351
2004, 2006	0.004	11.5	Very large	999	114
2004, 2007	0.001	28.3	Very large	999	282
2005, 2006	0.001	31.3	Very large	999	312
2005, 2007	-0.002	72.1	Very large	999	720
2006, 2007	-0.004	97.1	Very large	999	970
2008, 2009	0.006	5.2	Very large	999	51
2008, 2010	0.021	0.3	Very large	999	2
2008, 2011	0.014	1	Very large	999	9
2008, 2012	0.005	7.7	Very large	999	76
2009, 2010	0.004	12.1	Very large	999	120
2009, 2011	0.01	2.5	Very large	999	24
2009, 2012	-0.002	71.5	Very large	999	714
2010, 2011	0.025	0.1	Very large	999	0

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
2010, 2012	0.002	21.6	Very large	999	215
2011, 2012	0.017	0.4	Very large	999	3
2013, 2014	0.027	0.1	Very large	999	0
2013, 2015	0.016	0.6	Very large	999	5
2014, 2015	-0.002	62.2	Very large	999	621

CHAPTER 6. SUMMARY AND CONCLUSION

6.1 Dissertation Overview and Summary

This dissertation research focused on several deductive research questions, several directional working hypotheses, and various statistical null hypotheses developed to examine how disturbance or stress has molded the populations and community structure of the nearshore marine community off the coast of New Jersey over the past 28 years (1988−2015). Specific research questions were developed to assess, measure, and explain whether the nearshore marine community off the coast of New Jersey has been resilient to disturbance over time. The goals of this dissertation were to (1) examine the spatio-temporal patterns of the ocean conditions and nearshore marine community in the Mid-Atlantic Bight; (2) assess the impacts of Hurricane Sandy on the environmental conditions and the nearshore marine community in the Mid-Atlantic Bight; (3) investigate the species richness and diversity of the nearshore marine community in the Mid-Atlantic Bight; and (4) evaluate the environmental and atmospheric-oceanic variability, and the nearshore marine community in the Mid-Atlantic Bight.

Marine resources are one of the most valuable natural resources on earth. Worldwide, marine resources have shaped culture, society, and local, regional, and global economies. Chapter one provided an overview, synopsis, and a historical perceptive on the importance of marine resources and highlighted some of the issues related to short and long-term disturbances, such as hurricanes and climate variability. The review summarized how climate variability is affecting individual species and marine communities around the world. The first chapter described how the dissertation hypotheses were formulated and provided an outline for the dissertation.

Analyses presented in Chapter two demonstrated the abiotic conditions and marine community are changing with time. Mean surface water temperature increased significantly about 0.6°C per decade, mean salinity decreased about 1.3 psu per decade, and dissolved oxygen (DO) increased 0.009 mg/L per decade during 1988 through 2015. A total of 18.7 million individuals representing 216 identified species were collected during the 28-year period, and the estimated abundance and biomass of marine fauna decreased and increased over time, respectively. Subtropic-adapted species were the most abundant and coldwater-adapted were the least abundant water temperature preference group. The estimated abundance of coldwater-adapted species declined, warmwater-adapted species slightly increased, and subtropic-adapted species decreased with time.

Results highlighted in Chapter three showed the abiotic conditions and the nearshore marine community were temporarily impacted by Hurricane Sandy (29 October 2012), but there were no long-term impacts. The annual bottom salinity and surface DO varied significantly between pre- (1988−2012) and post- (2013−2015) Hurricane Sandy. The oceanographic and physicochemical conditions in January varied significantly between pre- and post-Sandy. The abiotic conditions varied significantly among factors (year, month, and geographic sampling area), but the significance level depended on the sampling area. For instance, the abiotic conditions pre- and post-Sandy varied significantly in sampling area “19”, which was in the direct path of the storm. The marine community (abundance) in January also varied significantly between pre- and post-Sandy, but the magnitude of the significance level difference in the marine community depended on the sampling area. For example, the marine community pre- and post-Sandy varied significantly in sampling areas “16” and “20”. Overall, there was no change in the biomass or in the community structure pre- and post-Sandy.

In Chapter four, the findings described the biodiversity (alpha and beta diversity) in the nearshore marine community off New Jersey over the past 28 years. Estimated species richness increased substantially during the first few years of sampling, and reached asymptotic richness in about 13 years. Species richness estimates varied significantly over time, but in general the trend was similar and relatively stable. The lowest mean species richness (n = 121.3 species) was estimated using the mean Michaelis-Menten approach and the highest mean species richness (n = 156.3 species) was estimated using the mean Jackknife 2 approach. Alpha diversity and evenness estimates indicated the community was composed of relatively a few species with high abundance. Fisher’s alpha diversity index best described the marine community, which ranged from 9.04 in 1988 to 15.95 in 1989 with an average of 11.76 (± 1.62 SD). Alpha diversity and evenness indices fluctuated from one year to the next, but remained relatively stable over time. Beta diversity estimates also showed interannual variability, but similarity values were relatively stable over time; approximately 50 percent of the species are shared among samples. Analytical procedures could not detect an association between community stability and the environmental conditions suggesting it is likely shaped by other factors, such as inter- and intra-species associations. The findings propose the community is resilient despite the ongoing changes in the environmental and oceanic conditions.

In the final Chapter, the findings of the dissertation suggest the variability in the environmental and atmospheric conditions is shifting the marine community. The environmental, oceanic conditions, marine community, and coldwater-adapted community were significantly different among years and geographical sampling areas. The best environmental predictors of the marine community were primarily water temperature (surface and bottom), maximum depth, NAO, and surface salinity. The marine community was significantly different among years and sampling areas. There was a statistical significant structure in the marine community, and the main species representing the greatest similarity percentages were generally longfin squid (coldwater-adapted), windowpane flounder (coldwater-adapted), and little skate (coldwater-adapted). The primary species contributing to the dissimilarity were Atlantic butterfish (warmwater-adapted), longfin squid (coldwater-adapted), scup (warmwater-adapted), and bay anchovy (subtropic-adapted). Longfin squid consistently contributed the most to within-group similarity and between-group dissimilarities. The coldwater, warmwater, and subtropic-adapted community was significantly different over time. Generally, longfin squid, little skate, and Atlantic herring contributed to the difference in the coldwater-adapted community, and butterfish, scup, and northern searobin contributed to the difference in the warmwater-adapted community over time. The sequential order varied by time-series, but bay anchovy, rough scad, and striped anchovy constituted between 59 and 73 percent of the dissimilarity in the subtropic-adapted community.

6.2 Synthesis and Conclusion

The climate, the environmental conditions, and the atmospheric-oceanic indices off the New Jersey are slowly changing with time. These abiotic deviations along with other disturbances have caused the marine fauna abundance to decrease and the biomass to decrease within the nearshore waters of New Jersey over the past 28 years. The decline of the coldwater-adapted and the increase of the warmwater-adapted species appear to be linked to the fluctuation in the abiotic conditions. Water temperature (surface and bottom), maximum depth, NAO, and surface salinity are environmental predictors of the marine community, but the best predictor is water temperature. Atlantic butterfish (warmwater-adapted), longfin squid, scup (warmwater-adapted), and bay anchovy (subtropic-adapted) dominate the dissimilarity of the nearshore marine community off New Jersey. However, the primary species shaping the community vary by individual temperature preference group. The marine community continues to slowly shift from a coldwater-adapted to warmwater-adapted community. Despite the deviations in the community structure, species richness and similarity metrics are stable within the study area. Alpha diversity and evenness estimates demonstrate the marine community is composed of a few species with high abundance; 50 percent of the species are shared among samples. Short-term disturbance associated with hurricanes can temporally alter some of the environmental conditions (increase in salinity and DO), and temporarily vary the community structure (i.e., percent contribution), but the conditions and marine community recover relatively quickly, and do not permanently alter the community structure within the study area.

Overall, the nearshore marine community off New Jersey appears to be resistant and resilient to short-term disturbance with only minor responses in abundance and community structure, but long-term disturbance in the form of climate change is causing the marine community structure to permanently change in abundance and community structure despite remaining stable in terms of biodiversity. Annual estimates of species richness, diversity, and evenness are variable from one year to the next, but appear to be stable within the nearshore waters of New Jersey. However, the species dominating the similarity and dissimilarity of the nearshore marine community are changing over time as water temperature continues to increase along the coast of New Jersey. Given the connection between the marine community and the oceanic conditions, the severity of climate change not only depends on the community structure and the individual species dominating the community, but their tolerance levels and lethal limits for the physicochemical conditions and concentrations. In many ways, the oceanographic hydrology and biogeography off New Jersey is very different than other regions (e.g., eastern North and Central Atlantic Ocean) that are being impacted by rising water temperature associated with climate variability (Alheit et al. 2014). The waters of New Jersey are constantly subjective to upwelling and downwelling events that are generally trigged by seasonal wind speed and direction (Kohut et al. 2004). In increase in the inter- and intra-annual extremes in climate is predicted for the mid-Atlantic region (Polsky et al. 2000). Thus, it is possible the change in climate will cause the magnitude of upwelling/downwelling events to change in frequency and duration, which could negatively impact some warm or subtropic-adapted species. Upwelling events causes the water temperature to abruptly drop. Thus, species found in the area at the time of an upwelling event will need to either move temporarily away from the region or be able to tolerate suboptimal colder water temperature for at least a relatively short duration (days to weeks). Warm and subtropical-adapted species are vulnerable to coldwater. For instance, adult bay anchovy can tolerate a wide range in water temperature (3.4° and 26.3°C), but eggs and larvae require warmer water temperatures for development (Zastrow and Houde, 1989). Given the spawning season (Lapolla, 2001) and warmer water temperature requirements of larvae and juveniles, it is possible upwelling could negatively impact these fragile life-stages should upwelling events become erratic along the

New Jersey coast under climate change forcing. Climate change can ultimately impact specific life-stages, species, and marine communities.

6.3 Dissertation Research Uncertainties

As discussed in Chapter one, the dissertation solely relied upon observational data to examine the environmental conditions and marine community off the New Jersey coast during 1988 through 2015. The primary motivation of the dissertation research was to elucidate and describe patterns in the data rather than to formally test *a prioroi* hypotheses.

Ecologists rely on data either collected in the laboratory or in the field, but each data type has its own individual limits or trade-offs in terms of application (Ludwig and Reynolds, 1988). One of the biggest differences between the observational and experimental approach is the inability for researchers to control various environmental (e.g., water temperature, salinity, and dissolved oxygen) and biological factors (e.g., movement, gear avoidance, and recruitment); no treatments or controls can be imposed (Ludwig and Reynolds, 1988). It goes without saying that marine communities are highly variable in terms of abundance, species composition, and annual/seasonal biological processes, such as spawning and migration. Adding to the problem, is the lack of sophisticated technologies, sampling methods, and sampling gears to efficiently capture every individual in a given sample area, especially mobile species. As such, much of the data used to examine marine communities is evaluated under various assumptions that have the potential to under- or over-estimate the approximations, which increases the uncertainties in the outcomes.

To examine patterns in biological communities and individual marine fauna, researchers attempt to minimize potential sampling bias by designing sampling protocols and gears that consider the variability in the environmental conditions and biological communities, which often includes some local knowledge of the individual species and sizes (i.e., length) found in the study area. Besides attempting to minimize sampling bias (Byrne, 2008), researchers also use various analytical techniques to reduce the uncertainties and increase the confidence levels in the outcomes, such as increasing the sample size and applying data transformations (Zar, 1999). In every marine study that relies upon observational data, there is some sort of bias or uncertainty in the data and outcomes. Two major sources of uncertainties researchers need to consider when using observation data to examine marine populations are the sampling and analytical approaches.

The NJDEP attempted to minimize the uncertainty in the data (sampling bias) by designing a stratified random sampling (SRS) approach that considered depth (9.1 m, 18.3 m, and 27.4 m) and geographical location; the study area (4,662 km^2) was divided into 15 sampling areas encompassing the New Jersey coast. Besides depth and location, the SRS approach also considered the seasonality of marine fauna; samples were collected bimonthly (five sampling events per year). Sampling was based on randomly selecting a limited number of sampling stations in each sampling area. Two stations in each sampling area and an extra station in the larger sampling areas were conducted during each sampling event for a total of 182 stations per year. The sampling gear was an otter trawl and the sampling unit was a standardized tow, which was based on vessel tow speed and tow duration (20 min).

Despite these attempts to minimize sampling bias, there were various sampling issues that created some uncertainties in the experimental approach that need to be acknowledged. In general, the study area encompasses a large geographical region (4,662 km^2), which was challenging to sample given the sampling logistics, limited sampling schedule, and ever changing weather. Because the bottom depth (one of the strata considered in defining the 15 sampling areas) was not uniform throughout the study, individual sampling areas were different size areas making for comparison between sampling areas somewhat challenging. Also, it should be pointed out that depth varied slightly within each defined area, which could have added to some sampling bias since demersal individuals tend to be distributed different with depth (King, 1995). More importantly, the number of samples was limited in terms of space (39 hauls [i.e., two samples from each strata plus one additional haul in each of the nine larger strata] per survey) and time (bimonthly), which increased the sample variance. The sampling was based on the populations having a clumped distribution pattern, which was likely a good assumption, but with the limited sample size it is possible many individuals were missed by the gear since some of the species collected display schooling behavior. Another issue with sampling mobile species or those that display a clumped distribution (non-random or non-uniform) is choosing the correct size of the sampling unit. As indicated above, the sampling unit was one tow (~ 1.85 km), which is likely another reason why there was so much variability in the samples; increasing the number of tows (i.e., stations) per sampling area could have minimized the variance. Increasing the tow duration could have potentially reduced the variance, but there is a “breaking point”. Gear avoidance can be problematic when the tow duration is extended because the hydrodynamics of the net traveling along the bottom changes as more individuals are collected in the bag portion of the net (Krag et al. 2014). Thus, it is likely the current approach is the most appropriate. Besides variability in the individual samples, bimonthly samples also limit the ability to examine temporal changes in the populations. The marine fauna off the coast of New Jersey are highly variable in terms of abundance over time (seasonality); many species change their spatial distribution depending on the water temperature. Changing from a bimonthly to a monthly collection procedure would reduce temporal uncertainty in the data, but adding sampling events would significantly increase the cost of implementing the program so bimonthly is likely a good compromise given the research budget. Depth was probably the best strata to divide the study area given the bottom substrate (sand and sand/mud) was homogenous; the substrate is almost completely uniform and the area lacks any substantial hard structure. However, it is highly possible the bottom topography has changed over time, which could be causing some species to aggregate in some locations. If this has occurred, the limited number of samples could be misrepresenting the population.

To sample marine fauna populations, one of the most important aspects of designing a research study with limited uncertainties is choosing the most appropriate and efficient sampling gear. The NJDEP selected the otter trawl, which is the most appropriate gear for sampling demersal species; however, this type of gear is one of the most complicated gears to design and use given various factors including, but not limited to, the hydrodynamics of the gear, the bottom substrate (rock, sand, and mud) of the sampling area, and the behavior of the species interacting with the gear. Researchers around the world have documented gear bias and the other sources of error (performance [catchability]) associated with bottom trawls (e.g., King, 1995; Kotwicki et al. 2011). Besides choosing the best components of the gear (e.g., trawl door size, mesh size, spread size, head rope length, and net material) to sample a given area/species/populations, deploying, towing, and retrieving the gear takes experience. Without this experience, the gear will not operate correctly, which leads to sampling bias and uncertainties in the catch data. In general, towing the gear is based on vessel speed, but the gear and associated catch can be impacted by the prevailing current and oceanographic conditions. For instance, if the vessel tow speed is too slow because of wind and waves, fish could avoid the net and/or cause the net not to open correctly. This would reduce the amount of area covered by the gear (i.e., swept area) and the associated catch. Conversely, if the vessel tow speed is too fast, the net could potential miss some species because of the hydrodynamics caused by the water funneling through net. Generally, the vulnerability of the species in relation to the path of the net is not constant (King, 1995), which can lead to under and over-estimates. Another potential source of error in bottom sampling gear is the substrate type. Bottom trawls travel over the bottom somewhat differently according to the substrate type, which either reduce or increase catch. Also, bottom trawls have an inherit size bias and are usually species selective; species can behavior differently to the gear (Krag et al. 2014). Given the limited information about the sampling used to collect the data for this dissertation research (lack of gear testing), it is highly possible there are various sources of errors and bias associated with the gear despite the tow duration and the type of net being standardized. For instance, one definite source of error is the size of individuals collected by the state's trawl. A specific gear efficiency or size selectivity study should have been conducted since every type of sampling gear, especially bottom trawls have a limit in terms catch (e.g., species composition and size-at-catch). As such, the dissertation findings should be viewed with caution in terms of species composition and associated weights (i.e., biomass). The otter trawl is designed to capture demersal species of a particular size so many coastal migratory and coastal pelagic species were not captured by the gear; thus, the outcomes of the dissertation primarily describe the demersal community; otter trawls can capture non-demersal species during deployment and retrieval.

The other potential major source of uncertainty in marine studies originates from the analytical approaches used to examine the observation data, which can either minimize or increase the confidence levels in the outcomes. At the foundation of the data is the sampling unit and the associated assumptions. As discussed above, the dissertation relied upon the tow, which was based on vessel speed and tow duration. The swept area covered by the net was then converted to abundance (the number of individuals collected in a given area [density]). For analyses and interpretation of the abundance indices, it was assumed there was a simple direct positive relationship between catch per unit of effort (CPUE) and abundance ($CPUE = q\ N$; where q is the catchability coefficient and N is the stock abundance). Although this is the most widely used approach (King, 1995), the catchability coefficient is usually unknown and thus it is impossible to calculate the absolute abundance. As such, CPUE is often used to describe differences in "relative" abundance among space and time. The problem with the index is that the catchability of a given species is not constant over space and time and often varies by species; it's often linked to both environmental and biological factors, such as time of day or lunar phase (King, 1995). Given the limited number of samples over space and time in this dissertation research, the CPUE (abundance) was often highly variable because the samples (catches) represented a small fraction of the total stock (King, 1995). Based on this notion, is highly probable the data suffered from some accuracy and precision issues even though the sample size over time was large (28 years).

The independence of the observations is another issue that statisticians need to consider with using observational data. It was assumed the environmental, oceanic, and biological measurements (samples) were representative of the population within the study area given that the experimental design used randomization to reduce sampling bias. Statistical power was considered high given the balanced sampling approach and the large number of observations over the duration of the study. It was also assumed the environmental and biological data were independent observations (i.e., the measurement of one observation did not affect the value of other observations) given that the experimental design considered time and space (i.e., spatial autocorrelation). The coastal waters off New Jersey are a dynamic oceanographic and biological system; conditions can vary significantly within a short distance or time period. Moreover, it was assumed the number of marine fauna in one year was independent of the number of marine fauna in the previous year given various biological factors, such as the relative short life-span (< 1 year) of many of the species collected in the study area, high mortality, the low annual reproductive success, and low annual recruitment from one year to the next. To minimize any potential spatial non-independence, data were pooled among stations within each individual sampling area. Despite these efforts, it is possible there were some independence of data problems that caused some uncertainties (Type I or Type II errors).

Data transformation is one of the most important aspects of data preparation. Generally, most measurements recorded in the field do not follow a normal distribution, especially those collected from marine systems. For some of the reasons discussed above, observational marine fauna data are highly skewed depending on the species (very abundant, common, and rare); thus, it is essential that the data is properly transformed. Based on exploratory analyses, fourth root transformation was selected for the analyses in this dissertation, which reduced the influence of very abundant species and increased the influence of common and rare species. It is possible that other types of transformations (e.g., log) could have led to better outcomes (i.e., improved normality and homoscedastic) (Zar, 1999). It is possible that better analytical procedures could have been applied to estimate the significance value and improve the probability of obtaining the observed results in the various statistical hypothesis tests; however, an attempt was made to duplicate hypothesis tests using multiple analytical techniques that considered both parametric and non-parametric approaches. Nonetheless, it is still possible that various null hypothesis tests were falsely rejected since null hypothesis tests are based on the *P* value (critical value), which is defined as the probability of getting the observed result; there is always a chance of false positives and false negatives (Zar, 1999). In some ways, the likelihood of committing these errors was reduced given the large sample size (28 years); however, the number of samples per year (n = 182) was still limited given the size of the study area and the variability of the marine fauna so it is possible there are some uncertainties in the outcomes.

Researchers often segregate data to examine specific biological questions, which can sometimes bias the outcomes. In the analyses for the dissertation, the main data set was segregated by time (5-year time-series) and type (temperature preference groups) in some of the analyses, which could have increased some uncertainties. For instance, a decision was made to examine the 28-year data set by segregating the data into 5-year time-series, which can often lead to the perception and associated conclusion that changes are more severe in the short-term than the long-term trend. Although careful inspection of the individual results were executed and the interpretations of the findings were discussed, it is possible there were some uncertainties related to the outcomes of using this approach. Another segregation issue was the way the three individual temperature preference categories (coldwater, warmwater, and subtropic-adapted) were pre-determined in the observation data used in this dissertation. In general, the individual categories were based on the literature, but in many cases the literature was not only limited, but the individual studies were limited in scope (i.e., space and time). A decision was made to use the mean temperature preference, but it is highly likely the outcomes would have been different if a difference approach had been used to categorize the species within temperature preference groups, such as the entire temperature range or the minimum or maximum extremes of the individual species.

Much of the dissertation findings were based on multivariate techniques that are designed to not only examine multiple variables in one procedure, but some of the procedures can link the environmental measures to the biological samples (biomass, abundance, presence/absence), which is often the goal of ecologists. Despite the flexibility in these non-parametric procedures and the ability to test for a differences among samples using the either the rank (ANOSIM) or the actual similarity (e.g., Bray-Curtis coefficient) value (PERMANOVA), uncertainties can come from the way the results are interpreted given the statistical power of the test (Clarke and Warwick, 2001). Attempts were made to reduce the interpretation uncertainties by conducting multiple tests and examining the outcomes of pairwise tests, but it is still possible there were some false conclusions made across all the various tests despite the large samples and permutations. It is also possible there was some uncertainty in the outcomes because of the way the data was treated (pooled and segregated by water temperature groups). According to Clarke and Warwick (2001), it is sometimes better to examine marine communities from a higher (family) taxonomic level than from a lower (species) perspective because of potential species redundancy issues (taxonomic similarity); dissimilarity should be higher among families than individual species classified under the same family. The dissertation analyses was based on examining the data by species, so it is possible that led to failing to reject the null hypothesis. It is conceivable that this potential issue was balanced out in terms of the number of species recorded and sample size (robustness); however, there is still a potential that the results of testing for a difference in the community over space and time was bias or problematic. It is also possible that applying cluster analyses techniques and segregating the data by family rather than be individual species could have produced slightly different results.

For these analyses, a decision was made to include all species in the data. However, it is sometimes advisable to eliminate some species from analyses (Clarke and Warwick, 2001). A common approach is to remove species that only represent 1 or 2 percent of the catch because it is possible those species were collected by simply mere chance (Clarke and Warwick, 2001). In some multivariate tests (e.g., PCA), retaining less common species can distort the ordination plot (Clarke and Warwick, 2001). However, Clarke and Warwick (2001) indicate that omitting uncommon species from analyses can be problematic when total abundance between sites is highly variable, which is often the case; this was the case the present study area.

The above sources of uncertainties are not comprehensive list, but it does lay out the main potential data issues encountered in the analyses for this dissertation research. As with any marine research study, there are various sources of error that need to be accounted for through either the sampling or analytical approaches. However, despite these painstaking efforts, it is often advisable to interpret all findings conservatively, especially given the ongoing shifting baseline paradigm.

6.4 Management Implications

The ability to understand, interpret, and predict changes in marine populations and community structure is dependent upon having sufficient long-term data. Without background data, various broad-based biological and population assumptions must be used in analytical models and statistical approaches, which can either over or under-estimate changes in the populations or community structure, especially since annual and seasonal marine species abundances are highly variable. At the foundation of marine assessments is having adequate historical information about the populations and community structure within a designated region and understanding the shifting baseline notion; shifting baseline information is especially needed for assessing and predicting risk in a population or community. This type of information can also be used for monitoring population metrics, assessing management performance measures, and strategic planning.

In many ways, the sustainability of marine communities will depend on the ability of researchers to use the available long-term scientific information to first understand the virgin or baseline conditions, and second to use the information to evaluate present or future changes in populations and the community. As such, this dissertation research was pursed to help state and federal agencies better understand how natural and anthropogenic disturbances are shaping the marine community structure off the coast of New Jersey. It is expected the findings of this dissertation will support managers with developing long-term management strategies for the state and serve as a model for other regions. Understanding spatial and temporal population dynamics and community structure of the marine resources in this region will help population modelers with choosing biological inputs. More importantly, the findings will assist fishery managers with progressing toward managing fisheries by the ecosystem based management approach. Overall, the outcomes not only extend our knowledge of one of the most economically important regions in the United States in terms of marine resources, but this research provides information for long-term conservation planning and management strategy.

In general, the findings of this dissertation show how important long-term fisheries-independent monitoring programs are for monitoring past and present populations, and predicting the status of future marine communities within in a given region. The analyses demonstrate long-term data time-series (> 3 years) are essential for examining marine communities given the natural variability in marine community abundance over space and time. The dissertation results validate the importance and ecological value in monitoring marine communities as a whole rather than single-species given their dynamics within a designated region or habitat. Lastly, the dissertation research shows how long-term disturbance (i.e., climate change) can impact marine communities.

6.5 Future Research

Despite the various findings of this comprehensive dissertation, the analyses was limited in scope in terms of evaluating wide-ranging potential disturbances. Thus, future researchers should examine other known stressors on marine communities, such as fisheries (commercial and recreational), habitat loss, and poor water quality. Although researchers have investigated some of these stressors individually, and the impacts of individual stress on specific species, it is recommended future research consider various stressors in synchronicity since they are not independent of each other; cumulative effects are known to impact natural resources. Future research should focus on evaluating whole marine communities rather than individual species.

Analytical procedures in this dissertation could not detect an association between community stability and the environmental conditions suggesting the marine community is likely shaped by other factors, such as inter- and intra-species associations. Therefore, it is recommended future research examine the predator-prey (e.g., phytoplankton/zooplankton and adult/juvenile fish life-stages) associations for dominant species within a given region because climate variability is probably impacting these ecological interactions. Funding agencies should consider administrating monies toward research that focuses on applied ecology given the wide-ranging implications of climate change and other stressors.

Future research should also consider exploring the impacts of climate variability on the biomass of individual water temperature preference groups (coldwater, warmwater, and subtropic-adapted species). Information on biomass will help managers detect whether climate change is selecting for smaller short-lived species with high reproductive potential.

Lastly, stock assessments are generally developed for single species rather than entire communities. Thus, it is recommend that future researchers examine developing stock assessments that encompass not only whole marine communities, but they should include climate-induced inputs into their models. Moreover, Fishery management councils (FMCs) should consider developing cooperative management options with other regionally-located FMCs given the known impacts of climate change, such as shifting the distribution of many managed-species stocks. As we improve our understanding of the connection between the atmosphere and the ocean, better analytical approaches can be developed to derive a general relationship between climate variability and ocean dynamics, which will ultimately help ecologists recognize potential impacts to marine ecosystems. Policymakers and natural resource managers acknowledge climate variability has the potential to impact natural resources, but inevitably, more sophisticated and proactive management approaches are essential to protect marine ecosystems. No single approach will work everywhere, but future work should address developing a comprehensive, multisector, and multi-objective management approach that considers cumulative impacts.

Ultimately, the sustainability of marine resources will depend on how managers implement measures that incorporate both biological processes and ongoing disturbances (natural and anthropogenic).

6.6 References

Alheit, J., Licandro, P., Coombs, S., Garcia, A., Giráldez, A., Santamaría, M.T.G, Slotte, A., and Tsikliras, A.C. 2014. Reprint of "Atlantic Multidecadal Oscillation (AMO) modulates dynamics of small pelagic fishes and ecosystem regime shifts in the eastern North and Central Atlantic" Journal of Marine Systems 133: 88–102.

Byrne, D. 2008. Ocean trawling survey. New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Marine Fisheries Administration, Bureau of Marine Fisheries.

Clarke, K.R., and Warwick, R.M. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2nd edition. PRIMER−E. Plymouth U.K.

King, M. 1995. Fisheries biology, assessment and management. Fishing News Books, Oxford. 341 pp.

Krag, L.A., Hermann, B., and Karlsen, J.D. 2014. Inferring Fish Escape Behavior in Trawls Based on Catch Comparison Data: Model Development and Evaluation Based on Data from Skagerrak, Denmark. PLoS One 9(2): e88819.

Kohut, JT., Glenn, SM., and Chant, R.J. 2004. Seasonal current variability on the New Jersey inner shelf. Journal of Geophysical Research 109: C07S07, doi: 10.1029/2003JC001963.

Kotwicki, S., Martin, M.H., and Laman, E.A. 2011. Improving area swept estimates from bottom trawl surveys. Fisheries Research 110: 198−206.

Lapolla, A.E. 2001. Bay anchovy Anchoa mitchilli in Narragansett Bay, Rhode Island.: II. Spawning season, hatch-date distribution and young-of-the-year growth. Marine Ecology 217: 103−109.

Polsky, C., Allard, J., Currit, N., Crane, R., and Yarnal, B. 2000. The mid-Atlantic region and its climate: past, present, and future. Climate Research 14:161−173.

Zar, J.H. 1999. Biostatistical analysis, 4th Ed. Prentice Hall, Upper Saddle River, NJ.

Zastrow, C.E., Houde, E.D., Morin, L.G., 1991. Spawning, fecundity, hatch-date frequency and young-of-the-year growth of bay anchovy Anchoa mitchilli in mid-Chesapeake Bay. Marine Ecology Progress Series 73, 161e171.

BIOGRAPHICAL INFORMATION

Juan Carlos Levesque was born in New Orleans, Louisiana to Colombian parents. He is the son of Nina Levesque and the late Romeo Levesque. Juan has one younger sister, Martha, who has two boys (Hunter and Tucker). After spending his first 6 years of life in Cocoa Beach, Florida, he moved to Bucksport, Maine. Graduating Bucksport High School with honors, he received an academic scholarship to the University of Miami and moved back to the Sunshine State to pursue his dream of becoming a marine biologist. Juan received a B.A degree in Biology at the University of South Florida in 1992, and a M.S degree in Marine Biology at Nova Southeastern University in 2007. In 2009, he was admitted to the University of Texas at Arlington in the Department of Earth and Environmental Sciences. In his professional career, he has worked on numerous projects for various non-profit, state and federal governments, and small and large businesses. Juan has worked on several high-profile confidential projects, including the Deepwater Horizon oil spill in the Gulf of Mexico and a proposed Canal Development project in Nicaragua. He has also worked with a variety of freshwater and marine species from the offshore waters of the Grand Banks, Newfoundland to streams and rivers in Colorado, Kentucky, New York, Ohio, and West Virginia. Juan has published numerous peer-review and magazine articles on various species of fish, sharks, and marine mammals. His research interests include fisheries (commercial and recreational) and community dynamics. Currently, he and his wife, Frances, reside outside of Tampa, Florida. They have three boys (Joshua, Christopher, and Corey), six grandchildren (Maddox, Niah, Gabriel, Liam, Lydia, and Kennedy), and a Maine Coon cat named Ragnor. Juan is employed by ERM in Tampa, Florida as a Senior Consultant in the Impact and Assessment Practice.