TEMPORAL TRENDS IN ABUNDANCE AND HABITAT PREFERENCES OF DEEP REEF FISHES OFF THE COAST OF SOUTH CAROLINA, USA.

by

Sean Paul Yeckley, MD, MHS

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Thesis Advisor

Committee Members

Approved:

Chair, Marine and Environmental Sciences

Dean, College of Sciences and Technology

Director, Graduate Studies

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Abstract

ROV and submersible video footage recorded in 1985, 2002, and 2010 from hard bottom habitat known as the Georgetown Hole or Charleston Lumps located NE of Charleston, SC in depths ranging from 175 – 300 m were reviewed to assess temporal trends in demersal fish abundance and bottom habitat preferences for key species. The main purpose of this long-term assessment of deep reef fish abundance and bottom habitat associations was to determine if deep reef fish populations have recovered since the development and implementation of the snapper/grouper fishery management plan (1983) and its various amendments. The major finding of the study was that Snowy Grouper and Blueline Tilefish were found in higher densities above low relief hard bottom areas than over high relief hard bottom. Snowy Grouper were observed to inhabit low relief hard bottom regions in significantly higher densities (18 fish/1000 m^3) than over high relief hard bottom regions (3 fish/1000 m^3) ($P = .0001$). Blueline Tilefish were found in the highest densities within low relief areas (5 fish/1000 m^3) and mixed hard/soft bottom regions (6 fish/1000m^3). The density of Snowy Grouper *Hyporthodus niveatus* increased from 2 fish per 1000 m^3 in 1985 to 7 fish per 1000 m^3 in 2010 and Blueline Tilefish *Caulolatilus microps* density increased from 0 fish in 1985 to 3 fish per 1000 m^3 in 2010 so both populations are gradually rising. The density of Yellowfin Bass *Anthias nicholsi* decreased from 144 fish per 1000 m^3 in 1985 to 56 fish per 1000 m^3 in 2010. Yellowfin Bass preferred high relief habitat where they were found in the highest densities. Yellowfin Bass density decreased over low relief hard bottom from 199 fish per 1000 m^3 in 1985 to only 15 fish per 1000 m^3 in 2010. Abundance of Snowy Grouper and Blueline Tilefish have both increased from 1985 to 2010 predominantly within low relief bottom regions where they have significantly lowered prey populations of Yellowfin Bass and restored a balanced deep reef ecosystem.

Table of Contents

Introduction

Demersal deep reef stocks are in peril globally from overharvesting due, in part, to life history parameters such as slow growth, late maturation, and longevity that make populations recover slowly (White et al., 1998; Filer and Sedberry, 2008). Currently, there are existing stock assessment data on the abundance of economically important demersal fish of deep reefs, but little is known about habitat preferences and interrelationships with the broader ecosystem (SEDAR Southeast Data Assessment and Review, 2011; Levin et al., 2014; SEDAR 2016). This is largely due to the inaccessibility of rugged continental slope reef depths, hindrance by strong Gulf Stream currents, and the expense and risk of exploring these deep-sea regions by submersible or remotely operated vehicle (ROV) (Ross, 2006; SEDAR, 2016). The few available stock assessments show reduced spawning stock biomass (SSB) and catches during the 1980s and 1990s possibly caused by overharvesting but also by enforcement of strict fishing regulations reducing landings (SEDAR, 2004). In 2011, Blueline Tilefish were still undergoing overfishing (SEDAR, 2011) with a fishing mortality (F = 0.39) greater than the ideal F of 0.3 needed to attain the maximum sustainable yield. The spawning stock biomass (SSB) for Blueline Tilefish in 2011 was 202 metric tons which was below the minimum spawning stock biomass threshold of 222 metric tons indicating that the stock was overfished. Unlike pelagic fish species, such as Dorado *Coryphaena hippurus*, Wahoo *Acanthocybium solandri*, and Yellowfin Tuna *Thunnus albacares*, that are relatively short-lived with rapid growth rates and quick recoveries, demersal fish of deep reefs have such slow growth and maturation rates (White et al., 1998; Filer and Sedberry, 2008) that it can take up to three decades for them to adequately recover from exploitation and population depletion (Rigby and Simpfendorfer, 2015).

Rocky bottom and oceanographic conditions off the southeastern U.S. combine to form productive habitat for several deep-water species that support limited fisheries. Unique oceanographic processes and hydrologic features of the Charleston Lumps (aka Georgetown Hole) (175-300 m in depth) and Charleston Bump (450 -1000 m in depth) located on the continental slope of the South Atlantic Bight off South Carolina and Georgia (Fig. 1), generate turbulent flow in the Gulf Stream after colliding with the rugged, high relief hard bottom topography of the region, creating a highly productive ecosystem with rich biodiversity (Fautin et al., 2010; Gula et al., 2014).

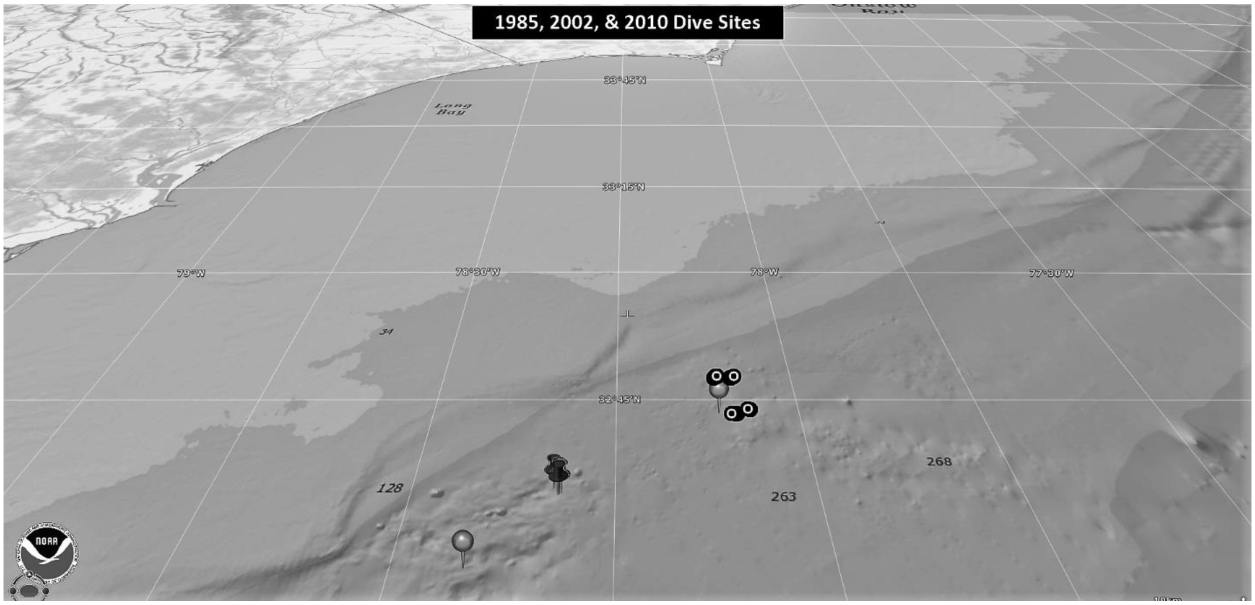

Figure 1. 1985 Johnson Sea Link I submersible dive sites (circular pins located top right, bottom left), 2002 Johnson Sea Link II submersible dives (thumbtack shaped pins located middle), and 2010 ROV dives (black targets located top right) plotted with ArcGIS Explorer depicting bathymetry of the Charleston Lumps North and South regions (aka Georgetown Hole).

The elevated bottom bathymetry offshore causes eastward deflection of the Gulf Stream, turbulent downstream flow, meandering, formation of transient frontal eddies, and creation of a persistent Charleston Gyre directly above the study region of the Charleston Lumps (Bane et al., 2001). These counter-clockwise circulations cause surface waters to diverge and nutrient-rich bottom water to upwell (Lee et al., 1991). This upward transport of nutrients into the euphotic zone stimulates phytoplankton blooms and results in a cascading effect of enhanced biological productivity and energy transfer by prey consumption throughout the water column (Lee et al., 1991; Weaver and Sedberry, 2001).

Dynamic food webs of the Charleston Lumps rely heavily on the nutrient supply from upwelling, strong Gulf Stream currents, and diel vertical migration of zooplankton (Weaver and Sedberry, 2001). The bottom of the Charleston Lumps trophic system consists of phytoplankton within surface water being grazed upon nocturnally by rising zooplankton, predominantly isopods and copepods (Weaver and Sedberry, 2001). During the day, these mobile crustaceans descend to the depths where they are consumed by planktivorous species such as Yellowfin Bass *Anthias nicholsi* (Weaver and Sedberry, 2001). Yellowfin Bass are subsequently preyed upon by Snowy Grouper *Hyporthodus niveatus* (Weaver and Sedberry, 2001). Within the benthos, organic detritus from settled marine snow is consumed by invertebrates, such as echinoderms, polychaete worms, and gastropods (Weaver and Sedberry, 2001). These benthic invertebrates are then preyed upon by Blueline Tilefish *Caulolatilus microps* and Blackfin Codling *Laemonema melanurum* (Weaver and Sedberry, 2001). Crustaceans feed on sea stars and decapods and are consumed by Snowy Grouper, Blueline Tilefish, and octopods (Weaver and Sedberry, 2001). Snowy Grouper gastric content studies found that they predominantly prey upon decapods but also on octopods, squid, and small fish making them the apex predator of the deep reef ecosystem of the Charleston Lumps (Weaver and Sedberry, 2001).

Variability in the strength of Gulf Stream flow, depositional and erosive processes, and iceberg scouring occurring during past ice ages have created complex, high relief hard bottom habitat within the Charleston Lumps study region off the coast of South Carolina. During warm, periods in Earth's history when the sea level was much higher and located at today's Piedmont fall-line, the Gulf Stream was much wider and weaker, flowing directly from the Gulf of Mexico across the present-day low country of Georgia and South Carolina into the South Atlantic Bight region (Hill et al., 2008 and Popenoe and Manheim, 2001). The past slower Gulf Stream current deposited organic phosphates on the continental shelf and slope (Popenoe and Manheim, 2001). When the climate cooled and the sea level descended to below the modern-day coastline, the Gulf Stream's current narrowed, intensified, and eroded soft, fine-grain sediments from the Charleston Lumps bottom (Popenoe and Manheim, 2001). Dense, cemented phosphorite rock ridges that were previously buried were exposed and foundation settling eventually caused hard bottom areas to fracture (Popenoe and Manheim, 2001). The continual, rapid Gulf Stream flow scoured the bottom and created the present day rugged bottom bathymetry of the Charleston Lumps with rocky mounts and ledges that serve as essential habitat for sessile invertebrates and demersal reef fish (Popenoe and Manheim, 2001). Past iceberg scouring during glacial periods most likely contributed to high relief geological formations within the Charleston Lumps region (Hill et al., 2008).

The presence or absence of deep water coral reef colonization within the South Atlantic Bight is determined by environmental and physical changes brought about by the continually changing location of warm Gulf Stream flow. Throughout paleohistory, natural variability of the

Atlantic Multidecadal Oscillation (AMO) driven largely by climate change from intermittent greenhouse gas emissions from volcanic activity, polar ice cap retreat and expansion, and sea level changes have controlled when and where shelf and upper slope reef formation has occurred (Matos et al., 2015). Cold water corals require temperatures > 6°C and sufficient plankton-rich currents to survive (Matos et al., 2015). Deep water slope reefs are established and sustained by strong AMO flow during interglacial periods. Matos et al., observed fossil records of deep water corals within the Cape Lookout region of North Carolina only during interglacial warm periods, including the last 7000 years (2015). During glacial periods the sea level was lower and the Gulf Stream was weaker and farther offshore allowing for greater influence of the cold coastal Labrador Current to limit deep coral growth from its southward flow from Mid-Atlantic Bight shelf waters (Matos et al., 2015).

Shelf edge reefs are relics of past shorelines formed by depositional processes during previous ice ages when glaciation extended to lower latitudes and remaining oceans had drastically lower sea levels (Popenoe and Manheim, 2001). Now submerged at depths averaging 50 m, these hard bottom ledges and outcroppings of compacted sandstone provide essential foraging, spawning, and nursery habitat for shallow-water species of grouper and snapper. These shallow depths closer to shore are more accessible to recreational and commercial fishermen. However, because of high prey availability, warm temperatures, and fast growth rates of fish at shelf edge reefs, these stocks are resilient and recover faster from depletion than deep reef fish communities.

Deep reefs of the upper continental slope of the Charleston Lumps region of the South Atlantic Bight range from 175 m to 300 m in depth. The scarce food availability, cold temperatures, slow metabolisms, and low growth rates of fish at these depths make demersal fish stocks of deep reefs vulnerable to overexploitation. Important species in this ecosystem targeted by recreational and commercial fisheries on the Charleston Lumps and regulated within the deepwater complex include the Snowy Grouper *Hyporthodus niveatus,* Blueline Tilefish *Caulolatilus microps,* Golden Tilefish *Lopholatilus chamaeleonticeps,* Speckled Hind *Epinephelus drummondhayi*, Misty Grouper *Hyporthodus mystacinus,* Warsaw Grouper *Hyporthodus nigritus,* Yellowedge Grouper *Hyporthodus flavolimbatus,* and Queen Snapper *Etelis oculatus.* Some unmanaged bycatch species include the Blackbelly Rosefish *Helicolenus dactylopterus*, Highfin Scorpionfish *Pontinus rathbuni*, and Big Roughy *Gephyrberyx darwinii* landed incidentally by commercial fishermen (NMFS Commercial Fishery Statistics, 2016). But being relatively small fish they make up a much lower percentage of total weight than the catch included within the snapper grouper fishery. The bycatch species are sold dockside to domestic retailers but are worth half as much money per pound (NOAA Fisheries Service, Southeast Fisheries Science Center logbook database, 2010). From 2003 to 2007 the average annual snapper grouper fishery catch for South Carolina was 1,591,000 pounds while the bycatch weighed only 125,000 pounds (NOAA Fisheries Service, Southeast Fisheries Science Center logbook database, 2010). Furthermore, the snapper grouper target species sold for $3,795,000 while the bycatch species only sold for $182,000 (NOAA Fisheries Service, Southeast Fisheries Science Center logbook database, 2010). This works out to $2.40 per pound wholesale for the Snapper Grouper fishery species and only $1.40 per pound wholesale for the bycatch species.

Beginning in the 1960s and continuing throughout the 1970s, the bottom fish stocks of the upper slope reefs within the South Atlantic Bight were heavily exploited (SEDAR, 2004). By the 1980s and 1990s the majority of these deep demersal fish stocks were declining from being overfished (SEDAR, 2004). The annual catch of Snowy Grouper peaked in 1983 at 418,264 kg and then rapidly fell (SEDAR, 2004). By 2002, the yearly catch of Snowy Grouper had dropped to 120,875 kg (Fig. 2) (SEDAR, 2004). Blueline Tilefish annual catch peaked in 1982 at 214,581 kg and by 2002 decreased to 116,959 kg (Fig. 3) (SEDAR, 2004). Yearly catch of Golden Tilefish peaked at 1,495,372 kg in 1982 and declined to only 189,208 kg by 2002 (Fig. 4) (SEDAR, 2004). Speckled Hind annual catch peaked in 1986 at 18,706 kg and by 1995 fell to 7 kg (Fig. 5) (SEDAR, 2004). Warsaw Grouper catch peaked at 57,270 kg in 1971 and declined to only 78 kg by 1995 when commercial sale was banned and other severe fishery restrictions began to be enacted (Fig. 6) (SEDAR, 2004). Yearly catch of Yellowedge Grouper peaked in 1986 at 25,576 kg and by 2002 dropped to only 5,538 kg (Fig. 7) (SEDAR, 2004). This occurred as a result of fishing pressure on South Atlantic Bight continental slope reefs during the 1960s and 1970s from commercial bottom long-lining, gill-netting, and the advent of recreational fishermen "deep dropping". This is a fishing technique using a rig consisting of 5-20 lbs of weight, an attached chemofluorescent light, and multiple non-stainless steel circle hooks baited with squid and fish chunks. Heavy overharvesting led to the decline of the Snowy Grouper, Blueline Tilefish, and Golden Tilefish stocks by the early 1980s and near complete disappearance of Speckled Hind, Yellowedge Grouper, and Warsaw Grouper stocks by the mid-1990s.

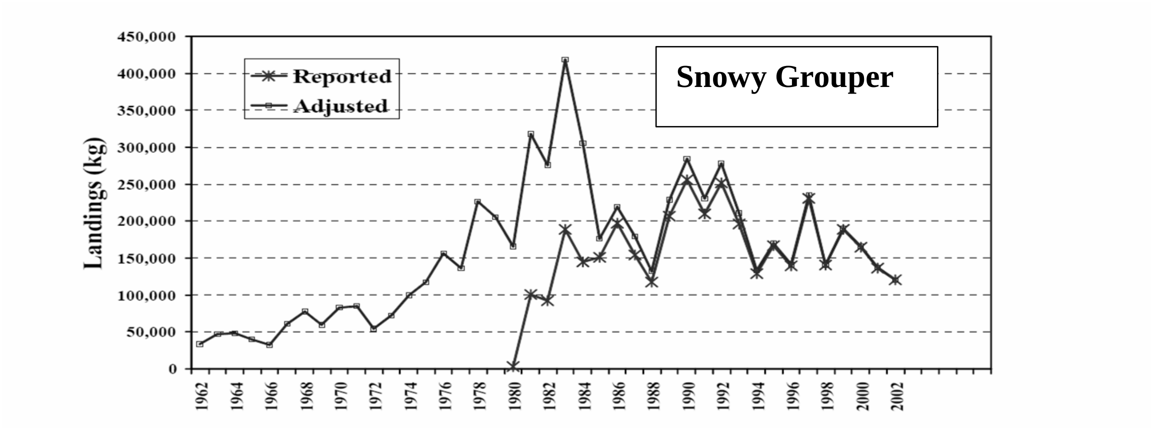

Figure 2. Snowy Grouper reported and adjusted commercial landings (SEDAR, 2004). Reported catch from commercial fishermen began in 1980 when official records began to be kept and adjusted catch from back estimations of landings.

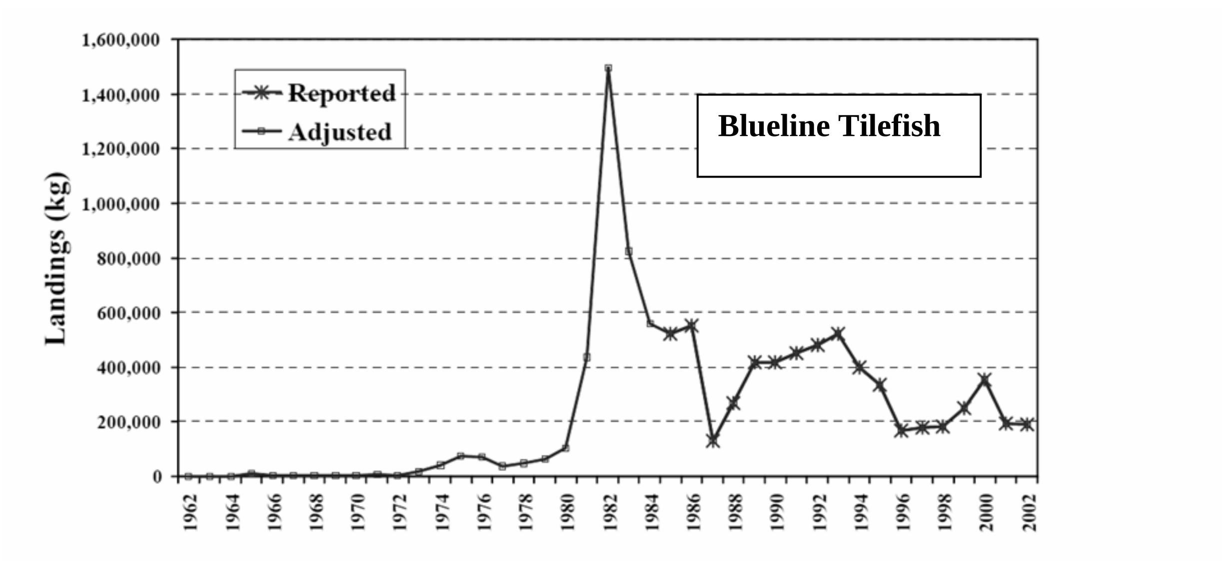

Figure 3. Blueline tilefish reported and adjusted commercial landings (SEDAR, 2004). Reported catch from commercial fishermen began in 1980 when official records began to be kept and adjusted catch from back estimations of landings.

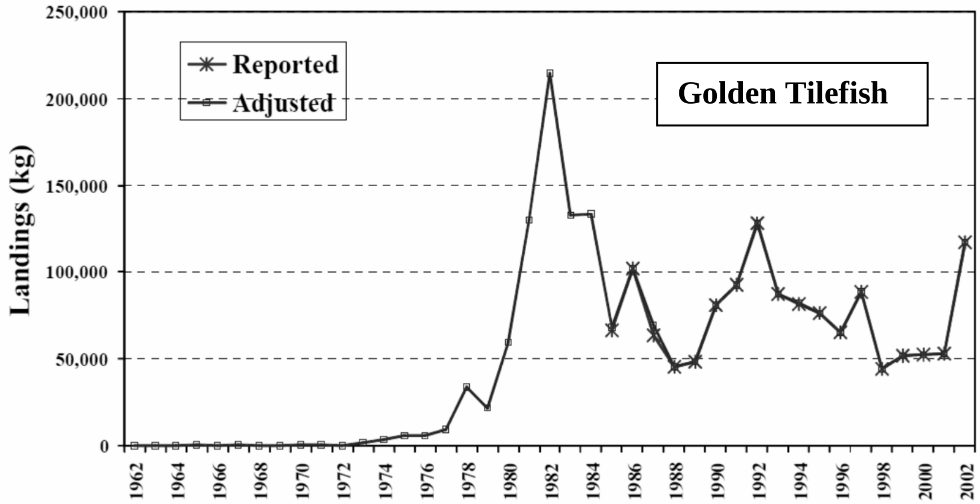

Figure 4. Golden Tilefish reported and adjusted commercial landings (SEDAR, 2004). Reported catch from commercial fishermen began in 1980 when official records began to be kept and adjusted catch from back estimations of landings.

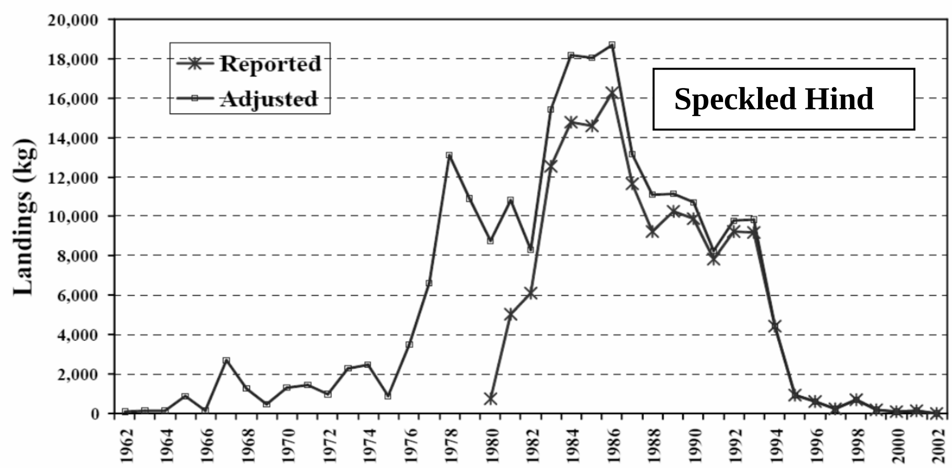

Figure 5. Speckled Hind reported and adjusted commercial landings (SEDAR, 2004). Reported catch from commercial fishermen began in 1980 when official records began to be kept and adjusted catch from back estimations of landings.

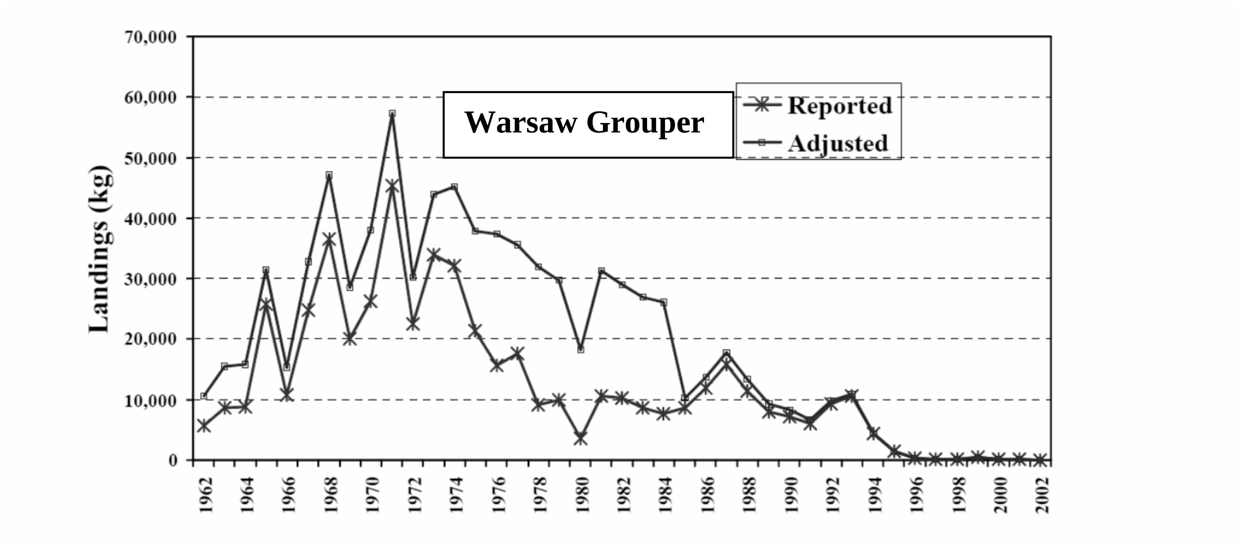

Figure 6. Warsaw Grouper reported and adjusted commercial landings (SEDAR, 2004). Reported catch from commercial fishermen began in 1980 when official records began to be kept and adjusted catch from back estimations of landings.

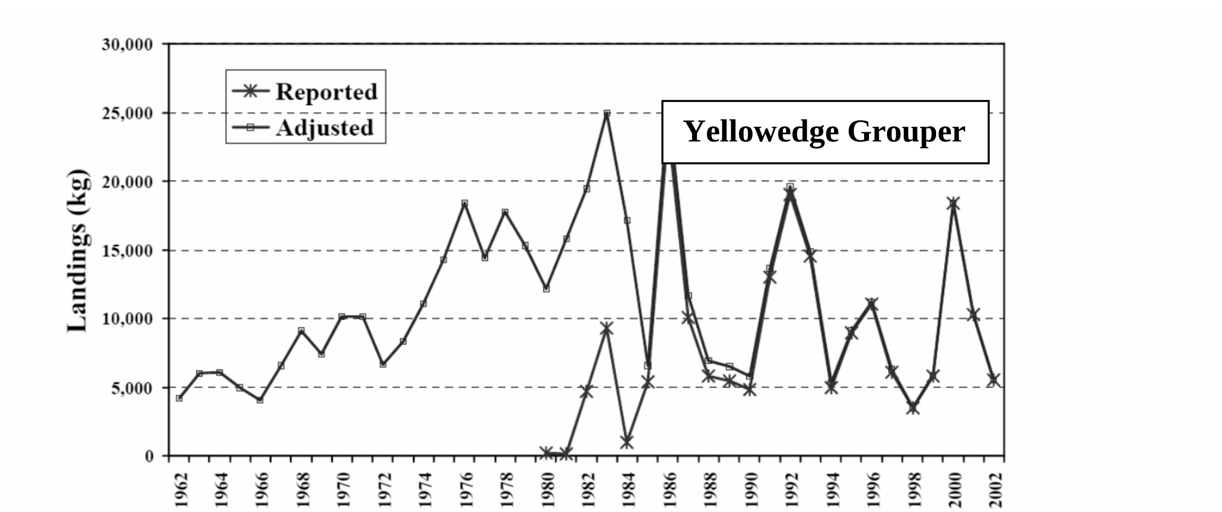

Figure 7. Yellowedge Grouper reported and adjusted commercial catch (SEDAR, 2004). Reported catch from commercial fishermen began in 1980 when official records began to be kept and adjusted catch from back estimations of landings.

The deepwater complex is a subgroup of eight fish species managed within the Snapper/Grouper fishery found within the dysphotic zone in depths between 100 and 1000 m. These deepwater demersal fish species include the Snowy Grouper, Blueline Tilefish, Golden Tilefish, Warsaw Grouper, Yellowedge Grouper, Misty Grouper, Speckled Hind, and Queen Snapper and have evolved to survive in cool, dark environments below the photic zone where foraging opportunities are relatively scarce compared to more productive surface and coastal waters. Therefore, these fish species have low energy requirements, slow growth rates, slow metabolisms, late maturities, and are long-lived (White et al., 1998; Filer and Sedberry, 2008; Rigby and Simpfendorfer, 2015). These life history traits make them susceptible to overharvesting and slow to recover after overfishing or fishery collapse has occurred so they all can be managed similarly (White et al., 1998; Filer and Sedberry, 2008; Rigby and Simpfendorfer, 2015).

Snowy Grouper and Blueline Tilefish stocks were still overfished as of 2011, four decades after overfishing began in the 1970s (SEDAR, 2011). The stock declined rapidly in the late 1970s, leveled out in the 1990s and early 2000s, and has oscillated since the mid-2000s (Fig. 3) (SEDAR, 2011). The spawning stock biomass (SSB) for Blueline Tilefish has been below the minimum spawning stock threshold (MSST) except during the 1970s and 80s and several years in the mid-2000s (SEDAR 32, 2011) indicating that the stock is overfished. The fishing mortality (F) in 2011 was 0.393 which was above the ideal fishing mortality level needed to attain a maximum sustainable yield ($F_{MSY} = 0.302$) indicating that overfishing of Blueline Tilefish was still occurring in 2011 (SEDAR 32, 2011). The spawning stock biomass of Blueline Tilefish in 2011 was 202 MT which was below the SSB needed to achieve a maximum sustainable yield (SSB_{MSY} of 246.6 metric tons) and below the MSST of 221.9 metric tons indicating that the Blueline Tilefish Stock was still overfished in 2011 and had not yet recovered to an ideal sustainable stock biomass at which the population growth rate would be maximized. The 2011 SSB for Blueline Tilefish was 91% of the MSST and 82% of the SSB_{MSY} (SEDAR, 2011). The fishing mortality (F) for Snowy Grouper first exceeded the F_{MSY} (0.14) for the species in 1980 and remained higher than the F_{MSY} until 2012 indicating that Snowy Grouper were undergoing overfishing as of 2012 (SEDAR, 2004; SEDAR, 2013). The SSB for Snowy Grouper first dropped below the SSB_{MSY} in the mid-1980s and remained below it through 2012 showing that Snowy Grouper were still overfished as of 2012 (SEDAR, 2004; SEDAR, 2013). The B_{MSY} for Snowy Grouper was calculated to be 2092 metric tons, the SSB_{MSY} to be 1000 metric tons, and the MSY to be 419 metric tons (SEDAR, 2013). The $F_{2010\text{-}2012}$ for Snowy Grouper was estimated to be 0.59 which was five times the F_{MSY} of 0.14 indicating that the population was undergoing overfishing as of 2012 (SEDAR, 2013).

As a direct response to concerns about perceived diminished landings and biomass, these demersal fish stocks began to be managed collectively as the snapper/grouper management unit in 1983 with implementation of various future amendments such as prohibiting the use of trawl gear, gillnets, and bottom longlines in depths shallower than 91.4 m, enforcing minimum size limits and requiring mandatory catch and effort reports by commercial fishermen in 1990, creating bag limits, establishing annual catch quotas and commercial Total Allowable Catch (TAC) levels, identifying essential fish habitat (EFH) and habitat areas of particular concern (HAPC) in 1998, and demarcating the boundaries of 8 marine protected areas (MPAs) in 2009 along the continental shelf between Cape Hatteras, North Carolina and Port St. Lucie, Florida (SEDAR, 2013). Bottom fishing was strictly prohibited within MPA boundaries to conserve and protect these valuable natural resources important to both deep reef ecosystems and the economy

(SEDAR, 2013). In 2009, the bag limit for a combination of snapper, grouper, and tilefish species was reduced from 5 to 3 fish (SEDAR, 2013). Fishermen were required to use non-stainless steel circle hooks when bottom fishing outside of existing MPAs starting in 2009 so that the hooks would quickly rust out of released fish if swallowed (SEDAR, 2013). In 2011, the recreational limit for Snowy Grouper and Blueline Tilefish was reduced to one fish per vessel (SEDAR, 2013). Blueline Tilefish and Snowy Grouper were added to the Deepwater Complex including Warsaw Grouper, Yellowedge Grouper, Misty Grouper, Queen Snapper, Golden Tilefish, and Speckled Hind in 2011 (SEDAR, 2013).

Today, the snapper/grouper fishery is challenging to manage because it regulates over 59 diverse demersal shallow and deepwater fish species with greatly varying spawning seasons and habitat associations, mostly within the snapper, grouper, and tilefish families (Levin et al., 2014). There is currently lack of data on habitat selectivity and ecosystem interactions, preventing effective adjustment of existing MPAs to protect the most essential habitat. This thesis research was conducted to provide data needed to detect effects of past fishery regulations and to generate findings that can be used to restore valuable deep reef natural resources through effective regulation, management, and utilization of MPAs to foster ecosystem health and economic vitality.

To assess essential bottom habitat of deep reef ecosystems, remotely operated vehicles (ROVs) and submersibles are utilized to observe deep reef habitats important for spawning, protection from predation, and foraging for reef inhabitants. There are several benefits of direct visual assessments of fish abundance and habitat preferences. They enable scientists to directly observe species' interactions within an ecosystem. These include predator/prey dynamics, foraging behavior, courting and spawning displays, territorial competition, and habitat utilization

(Schobernd and Sedberry, 2010; Gomes-Pereira et al., 2014; Ross et al., 2015). Drawbacks of direct visualization include active fish avoidance of submersible lights as witnessed by Barans et al. (1986) of Yellowfin Bass and Big Roughy. Snowy Grouper and Blueline Tilefish did not seem to be frightened by submersible lights (Barans et al., 1986). However, Parker and Ross (1985) observed grouper species being attracted to and actively following submersible lights. These fish behaviors could cause an under or over estimation of actual abundance (Barans et al., 1986). Fishery-dependent and independent population assessments have traditionally relied heavily on longlines, gillnets, and otter trawls to estimate fish abundance. Bias resulting from these methods include gear selectivity through usage of differential hook and mesh sizes, active fish avoidance and evasion from capture, and unnecessary fish and bycatch mortality. Therefore, direct visualization techniques of observing fish abundance and ecosystem interactions unobtrusively through submersible and ROV utilization represent superior and accurate methodologies (Sale and Douglas, 1981).

Currently, additional life history, trophic interactions, and habitat preference information is needed to improve upon existing regulations by making them more ecosystem-based. In an effort to fill this critical gap in scientific knowledge and to assess the effectiveness of past fishery regulations, ROV and submersible video footage filmed in 1985, 2002, and 2010 from the Charleston Lumps hard bottom habitat located 80 nautical miles NE of Charleston, SC in depths ranging from 175 to 300 m were reviewed to assess temporal trends in demersal fish abundance and bottom habitat preferences. The main purpose of this long-term assessment of deep reef fish abundance and bottom habitat associations was to determine if deep reef fish populations have recovered since the development and implementation of the snapper/grouper fishery management plan and amendments since 1983 and to evaluate the effectiveness of these past regulations (SAFMC, 2010). With the results of this research, past regulations can be improved upon to achieve sustainable ecosystem-based fishery management and essential habitat conservation for the benefit of future generations. Additionally, existing MPAs can be expanded or adjusted to protect essential bottom habitat previously excluded and open to commercial and recreational fishing pressures.

Hypotheses

I.

Ho: Snapper/Grouper fishery regulations have not resulted in a gradual increase in the abundance of commercial and recreationally important deep reef demersal reef species such as the Snowy Grouper and Blueline Tilefish over the study period from 1985 – 2010 since regulations were first instituted in 1983.

Ha: Snapper/Grouper fishery regulations have resulted in a gradual increase in the abundance of commercially and recreationally important deep reef demersal reef species such as the Snowy Grouper and Blueline Tilefish over the study period from 1985 – 2010 since regulations were first instituted in 1983.

II.

Ho: Low or high relief coral habitat with live, hard bottom will not have higher densities of deep reef demersal fish species than soft, sandy bottom.

Ha: Low or high relief coral habitat with live, hard bottom will have higher densities of deep reef demersal fish species than soft, sandy bottom.

Materials and Methods

Study Site

Submersible and ROV dives were conducted in 1985, 2002, and 2010 to explore deep reef habitat and associated marine life (Fig. 1) at various sites within the Charleston Lumps north and south regions (32.6° N, 78.3° W) (also known as Georgetown Hole). This rugged hard bottom area was chosen because it is ideally located on the upper continental slope of the South Atlantic Bight off the NE coast of Charleston, South Carolina where it is exposed to oceanographic conditions creating a richly productive fishery.

Field Methods

The R/V *Johnson* deployed the Johnson Sea Link I submersible to conduct dives (14-19 July 1985) at the Charleston Lumps reef north and south, located 74 and 64 miles off the South Carolina coast, respectively. Dive track coordinates and transect lines were supplied from direct communication with the research vessel, which actively tracked the underwater location of the Johnson Sea Link. A total of seven straight-line transects were conducted at 1.5 m sec^{-1} (3 knots) for 91.4 m (100 yds.). The video camera attached to the submersible was held at a downward angle of 45° from the horizontal plane. A wide-angle lens was utilized to obtain a panoramic view of deep reef habitat and marine life. Five hours of video footage was recorded on beta broadcast videocassettes and later transferred to VHS cassettes and DVDs. All fish species were identified and counted, the time was recorded, and the predominant bottom habitat type of each transect was categorized.

On 28 July - 4 August 2002 the Johnson Sea Link II was deployed from the R/V *Seward Johnson* to conduct multiple dives at the Charleston Lumps South region to evaluate deep reef ecosystem health. Submersible positions were tracked by the research vessel, which communicated transect line bearings to the pilot and scientists onboard. Transects were carried out for a duration of 3 min each. A panoramic camera was mounted to the submersible at a 45° downward angle to record all transects onto DVDs. A total of 68 total transects were completed and consisted of 34 h of digital video recording. All fish species were identified and counted, the time was recorded, and the predominant bottom habitat type of each transect was categorized.

On 8-14 April 2010 the NOAA Ship *Pisces* completed a research cruise of upper continental slope reefs of the Charleston Lumps north region. The mission was to map the location of deep coral mounds using high resolution multibeam sonography, assess deep reef community structure and habitat associations of macrofauna with ROV video footage, to sample and age deep coral, and to conduct acoustic surveys of the diel vertical migrations of zooplankton and nekton within the water column above high relief regions of hard bottom. This ROV video footage was utilized to assess deep reef fish abundance, distribution, and habitat preferences. The time and geographic location of each bottom habitat change was recorded during each ROV dive. The distance the ROV travelled (m) within each habitat type was measured using Google Earth © from coordinates recorded from R/V *Pisces* GPS and acoustic tracking of the ROV. All fish species were identified and counted, the time was recorded, and the predominant bottom habitat type of each transect was categorized.

Video Analysis

All fish observed from video footage were either identified to species or to the lowest taxonomic nomenclature possible and counted. Each time a fish appeared on the video, the time and bottom habitat were recorded. The predominant bottom habitat of each transect was noted as one of six possible types (Fig. 8). These included high relief hard bottom (> 1 m vertical rise), low relief hard bottom (< 1 m vertical rise), manganese phosphorite nodules/boulder rubble, dead coral rubble, mixed hard/soft bottom, and soft/sandy bottom (Fig. 8).

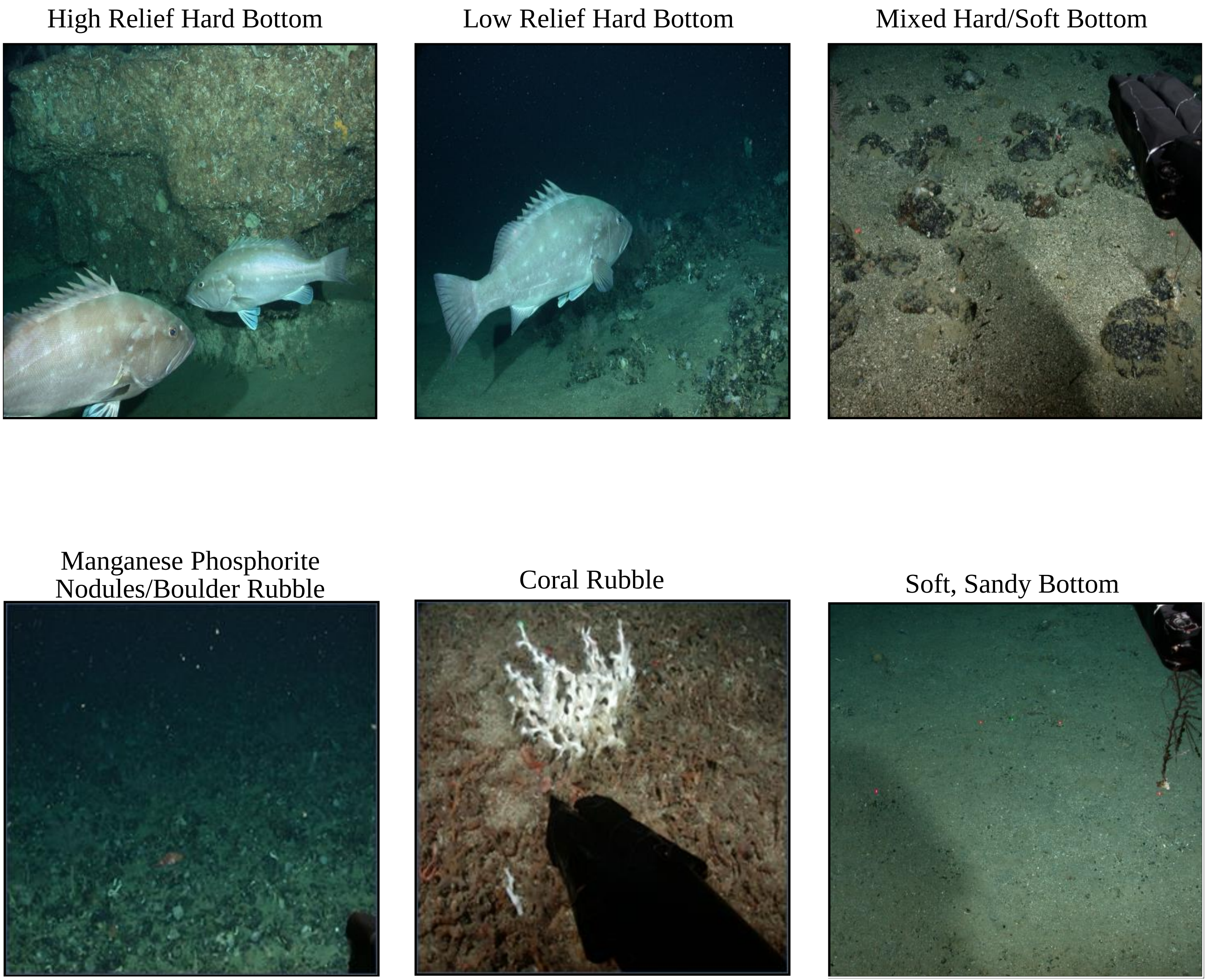

Figure 8. Bottom habitat types of the Charleston Lumps.

The width and height of the average field of camera view was calculated in meters using ratios and the known reference length of projected red laser dots in the video (20 cm for submersible video taken in 1985 and 2002 and 40 cm for ROV video taken in 2010). The area of field of camera view (m^2) was multiplied by distance travelled (m) by submersible or ROV to obtain the volume of seawater observed within each transect in m^3. The density of each observed fish species within each transect was calculated by dividing the number of each species observed by the volume of seawater viewed by the camera.

$$\frac{(\#\ fish\ observed)}{(area\ of\ camera\ view\ (m2))\ \ x\ (distance\ travelled\ (m)\ by\ submersible\ or\ ROV)}$$

This fish abundance was multiplied by 1,000 to convert to number of fish/1,000 m^3. The overall density of each species for each study period was calculated to assess temporal trends in abundance. The fish density observations for each habitat type were used to assess demersal reef fish habitat preferences.

Data Analysis

Data were analyzed using Microsoft Excel and SAS version 9.3. Differences between 1985, 2002, and 2010 mean densities of Snowy Grouper, Blueline Tilefish, Big Roughy, Highfin Scorpionfish, Blackbelly Rosefish, and Hakes were compared. The habitat preference of each species was determined by calculating densities within each of the six bottom habitat types for each of the three time periods. Total density of each species observed for each time period observed above any bottom type was used to assess temporal trends in abundance. Data were tested for normality with the Shapiro-Wilk test. The data were not normally-distributed and could not be adjusted to normal distributions by Log, Ln, Ln(n-1), Sin, or Cos transformations. Therefore, the non-normal data was analyzed using the Kruskal Wallis non-parametric statistical test with SAS. The fish density ranks by bottom habitat type and overall ranks of abundance for each time period were analyzed to determine statistical significance among habitats and time periods.

Results

A total of 140 transects were completed, by *Sea Link* submersibles and Phantom model ROV. Of those, 75 transects were conducted above high relief hard bottom, 13 within low relief hard bottom, 30 over mixed hard/soft bottom, 18 within manganese nodule habitat, 1 within coral rubble, and 3 above sandy bottom. The bottom consisted predominantly of boulder slabs, rocky outcrops and ledges, and rubble fields of eroded rock. A diverse array of gorgonian octocorals such as *Primnoidae plumarella* and *Ellisella* spp., sponges within the Demospongiae and Hexactinellida classes, Antipatharians, and sabellid feather duster worms grew on boulder slabs, rocky outcroppings, and ledges.

Numerous anthiins within the seabass family Serranidae were observed, including the Yellowfin Bass (Fig. 9), Apricot Bass *Plectranthias garrupellus*, and the Longtail Bass *Hemanthias leptus*, in the 2002 and 2010 surveys. Misty Groupers *Hyporthodus mystacinus* (Fig. 9) were present at the Charleston Lumps in 2002 and 2010. Three scorpionfish varieties (Fig. 9) were observed fairly commonly in all time periods: Blackbelly Rosefish *Helicolenus dactylopterus*, Highfin Scorpionfish *Pontinus rathbuni*, and Spinycheek Scorpionfish *Neomerinthe hemingwayi*. Blackbelly Rosefish was found at significantly higher densities within manganese nodule habitat than within other bottom types ($p = 0.0341$). Highfin Scorpionfish occupied mixed and manganese nodule habitats at significantly higher densities than over low or high relief areas ($p = 0.0002$). Hakes were found in higher densities within low relief and manganese nodule habitat than over high relief, mixed, or sandy habitat ($p = 0.1816$). Deepbody Boarfish *Antigonia capros* and Longspine Snipefish *Macroramphosus scolopax* (Fig. 9), two butterflyfish-like deep water species were observed within mixed, low, and high relief bottom habitat at similar densities. The Yellowfin Bass *Anthias nicholsi* and Big Roughy *Gephyroberyx* *darwinii* (Fig. 9) were observed to occupy rugged high relief habitat at significantly higher densities than other bottom types ($p = 0.0001$ and $p = 0.001$, respectively). A few species were only observed once, a Red Hogfish *Decodon puellaris* (Fig. 9) within the wrasse Labridae family was observed on the 2010 research survey and a rare deep-sea anglerfish named the Redeye Gaper *Chaunax stigmaeus* (Fig. 9) was identified within high relief habitat on the same cruise in 2010.

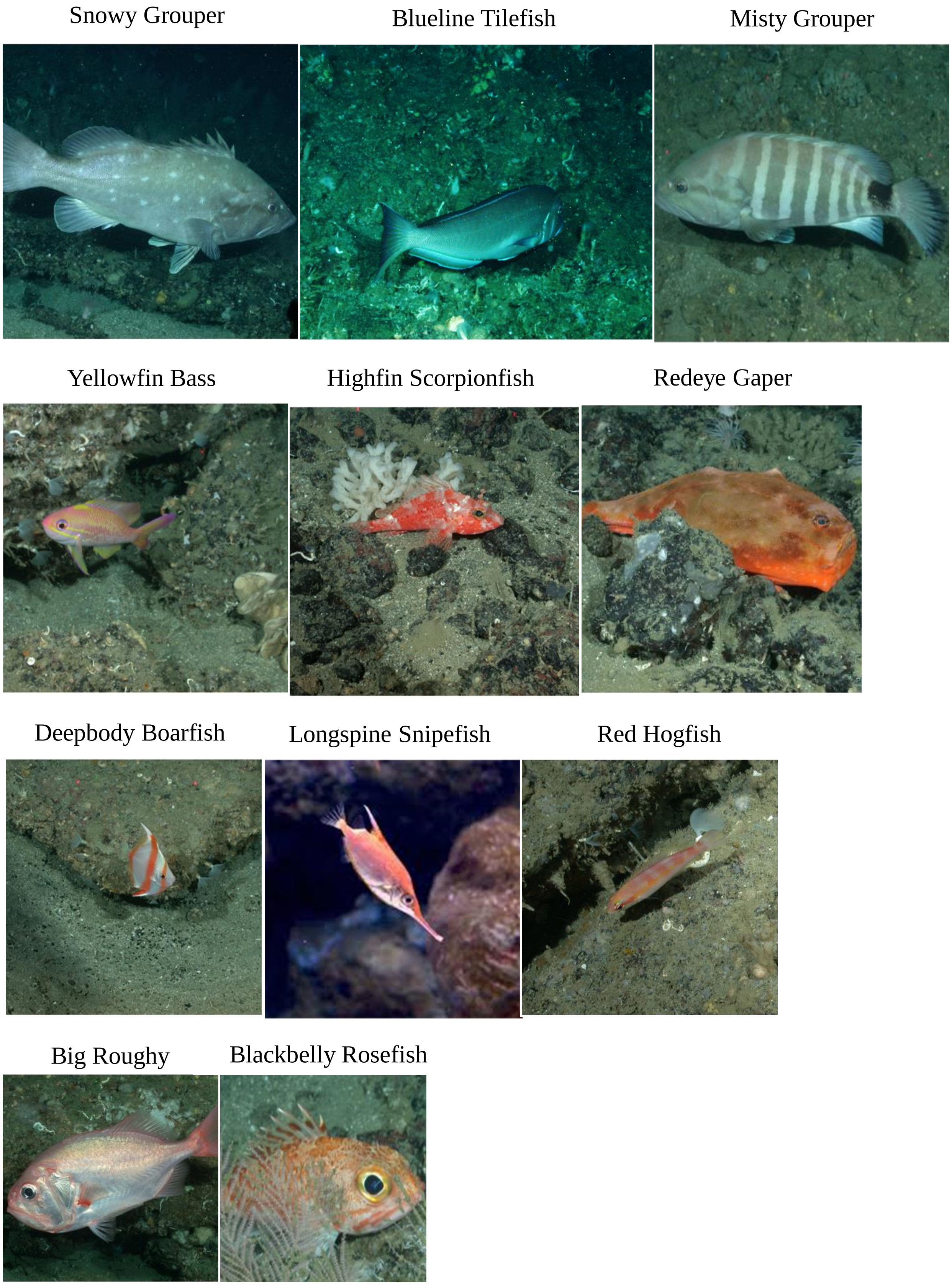

Figure 9. Deep reef fishes observed at the Charleston Lumps.

Snowy Grouper and Blueline Tilefish increased in abundance from 1985 to 2010 (Fig. 10), although not significantly ($p = 0.32$ and $p = 0.56$ respectively). Snowy Grouper inhabited low relief hard bottom at a higher density (9.5 fish/1000 m^3) than over high relief bottom (3 fish/1000m^3) (Fig. 11) ($p = 0.0001$). Blueline Tilefish were found in the highest densities within mixed hard/soft bottom areas (2.9 fish/1000 m^3) and low relief bottom (2.5 fish/1000m^3) (Fig. 11).

Densities of bycatch species such as Blackbelly Rosefish, Highfin Scorpionfish, and Hake all increased significantly between 1985 and 2010 ($p = 0.049$, $p = 0.0003$, and $p = 0.036$ respectively), while abundance of Yellowfin Bass declined significantly ($p = 0.0004$) (Fig. 12). The density of Yellowfin Bass found in low relief bottom declined from upwards of 200 fish per 1000 m^3 in 1985 to less than 10 fish per 1000 m^3 in 2010 (Fig 13). Yellowfin Bass were observed in the highest densities within high relief hard bottom habitat increasing significantly from 90 fish per 1000 m^3 fish in 2002 to 174 fish per 1000 m^3 in 2010 (Fig. 15) ($p = 0.02$).

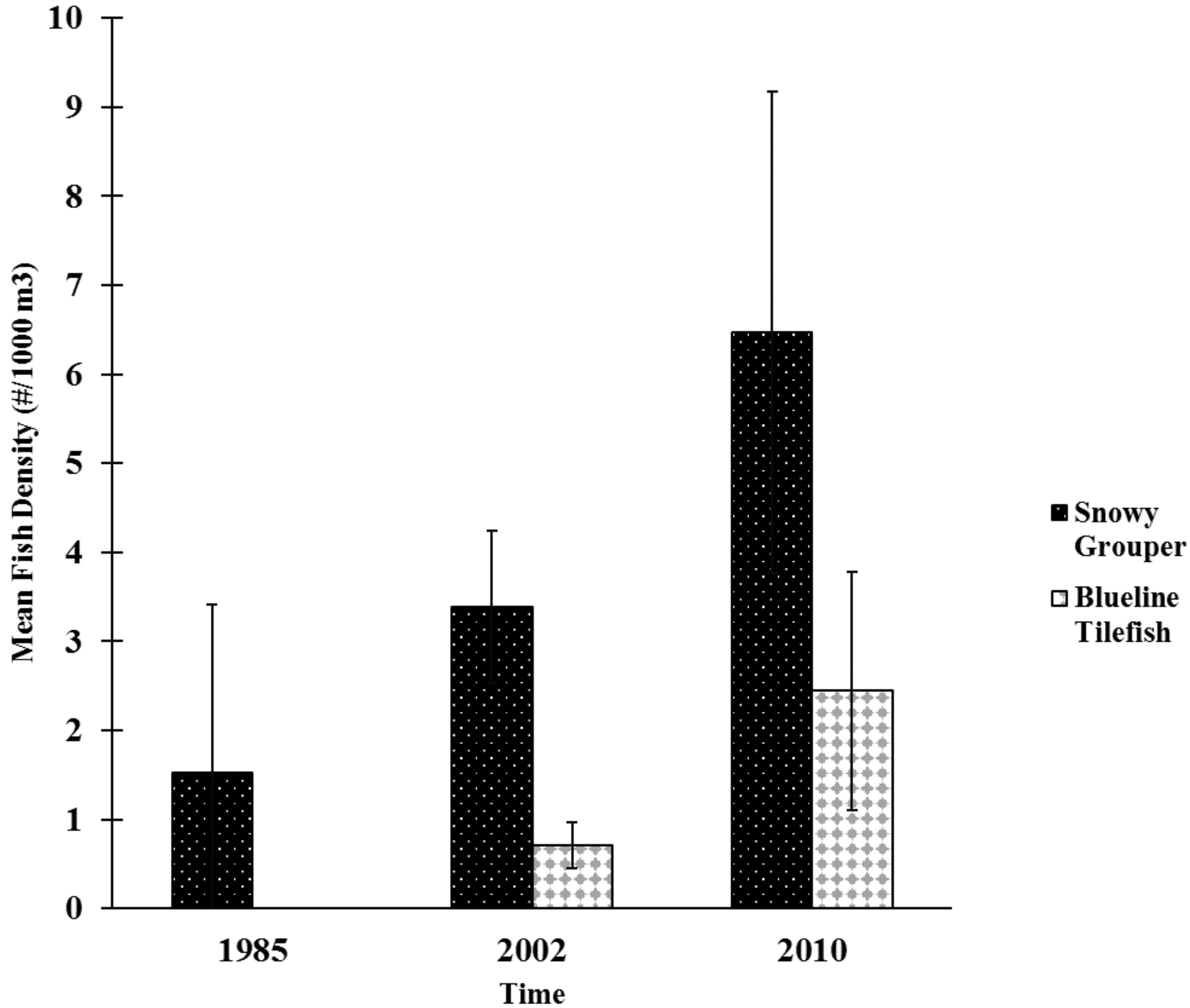

Figure 10. Mean density ± SE of Snowy Grouper and Blueline Tilefish at the Charleston Lumps in 1985 (n = 7), 2002 (n = 68), and 2010 (n = 65). n represents the number of transects performed. Snowy Grouper and Blueline Tilefish densities did not increase significantly throughout the study period (p = 0.3209 and p = 0.5601, respectively). Both population densities did trend upward with time.

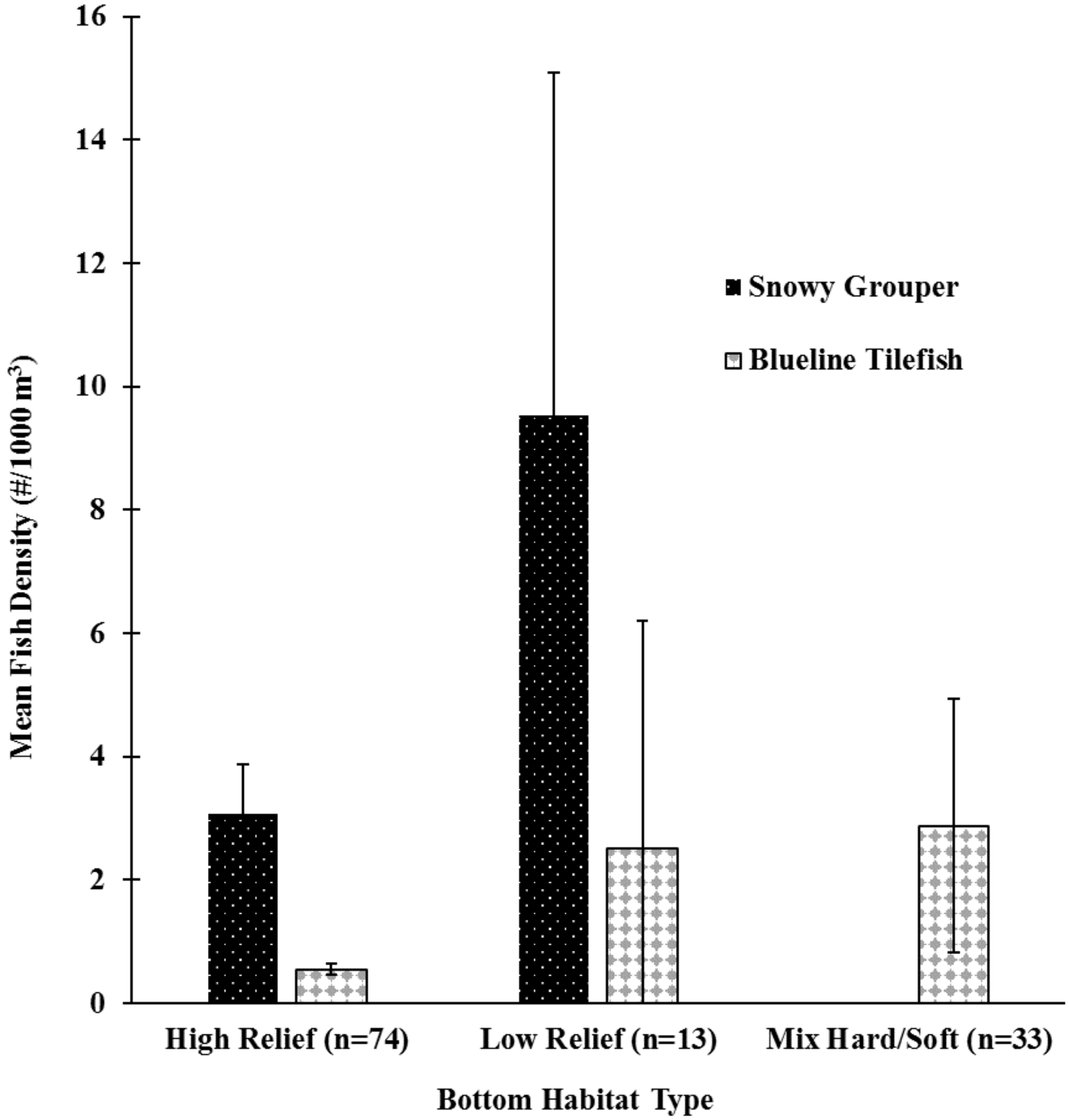

Figure 11. Mean density ± SE of Snowy Grouper and Blueline Tilefish by bottom habitat type at the Charleston Lumps, including high relief (n = 74), low relief (n = 13), and mixed hard, soft bottom (n = 33). Snowy Grouper had statistically significant higher densities within low relief bottom habitat than within high relief bottom habitat (p = 0.0001). Blueline Tilefish did not have significantly higher densities within low relief or mixed hard/soft bottom than within high relief habitat (p = 0.2931). n represents the number of transects performed.

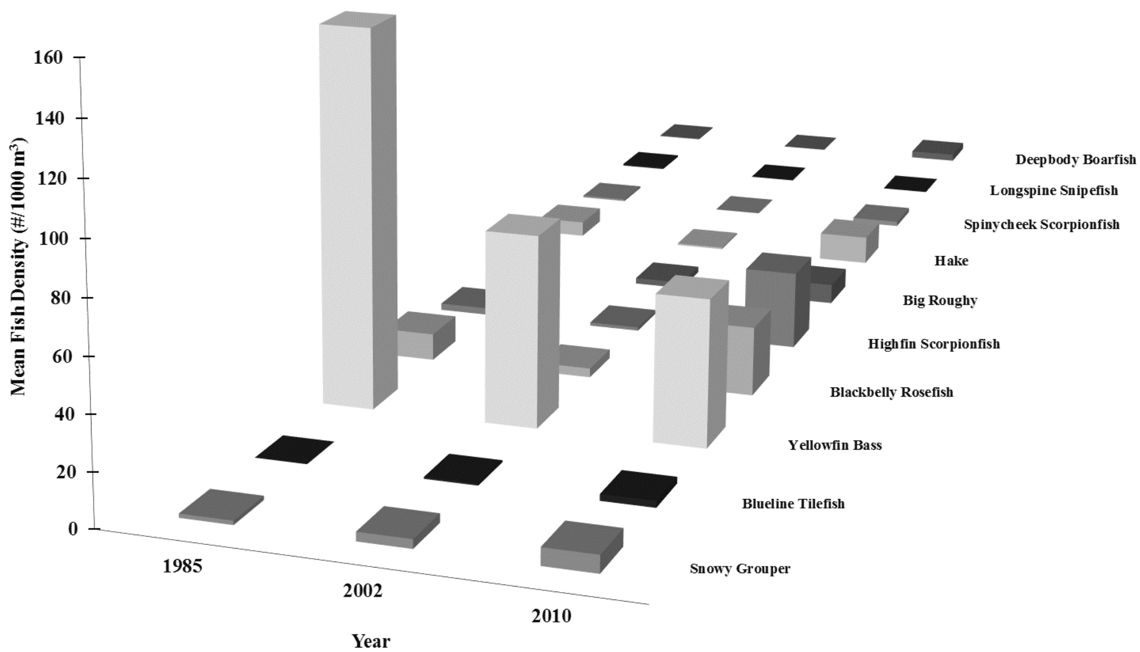

Figure 12. Overall mean fish density ± SE for 1985 (n = 7), 2002 (n = 68), and 2010 (n = 65) at the Charleston Lumps. n represents the number of transects performed. Snowy Grouper and Blueline Tilefish densities did not increase significantly but did trend upwards ($p = 0.3209$ and $p = 0.5601$, respectively). Yellowfin Bass density decreased significantly ($p = 0.0004$) while Blackbelly Rosefish, Highfin Scorpionfish, and Hake densities all increased significantly throughout the study period ($p = 0.049$, $p = 0.0001$, and $p = 0.001$, respectively).

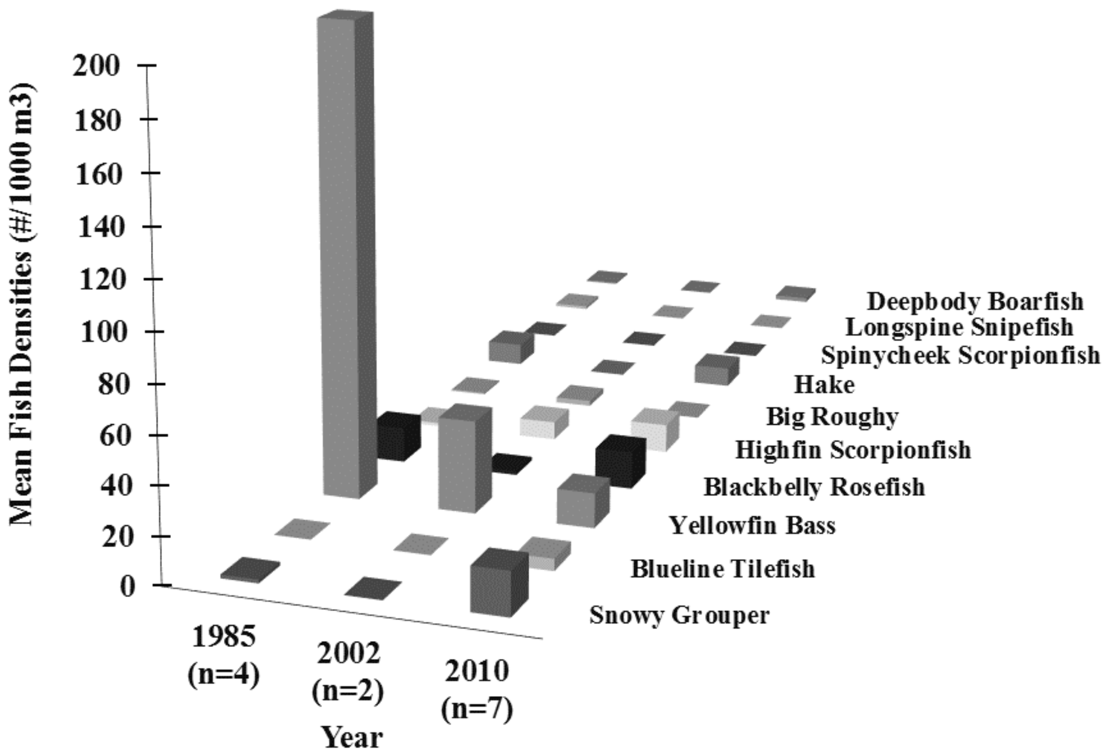

Figure 13. Mean fish density ± SE over low relief hard bottom habitat for 1985, 2002, and 2010 at the Charleston Lumps. Snowy Grouper and Blueline Tilefish densities were higher in 2010 than in 2002 and 1985, although not significantly ($p = 0.4$ and $p = 0.8$, respectively). n represents the number of transects performed.

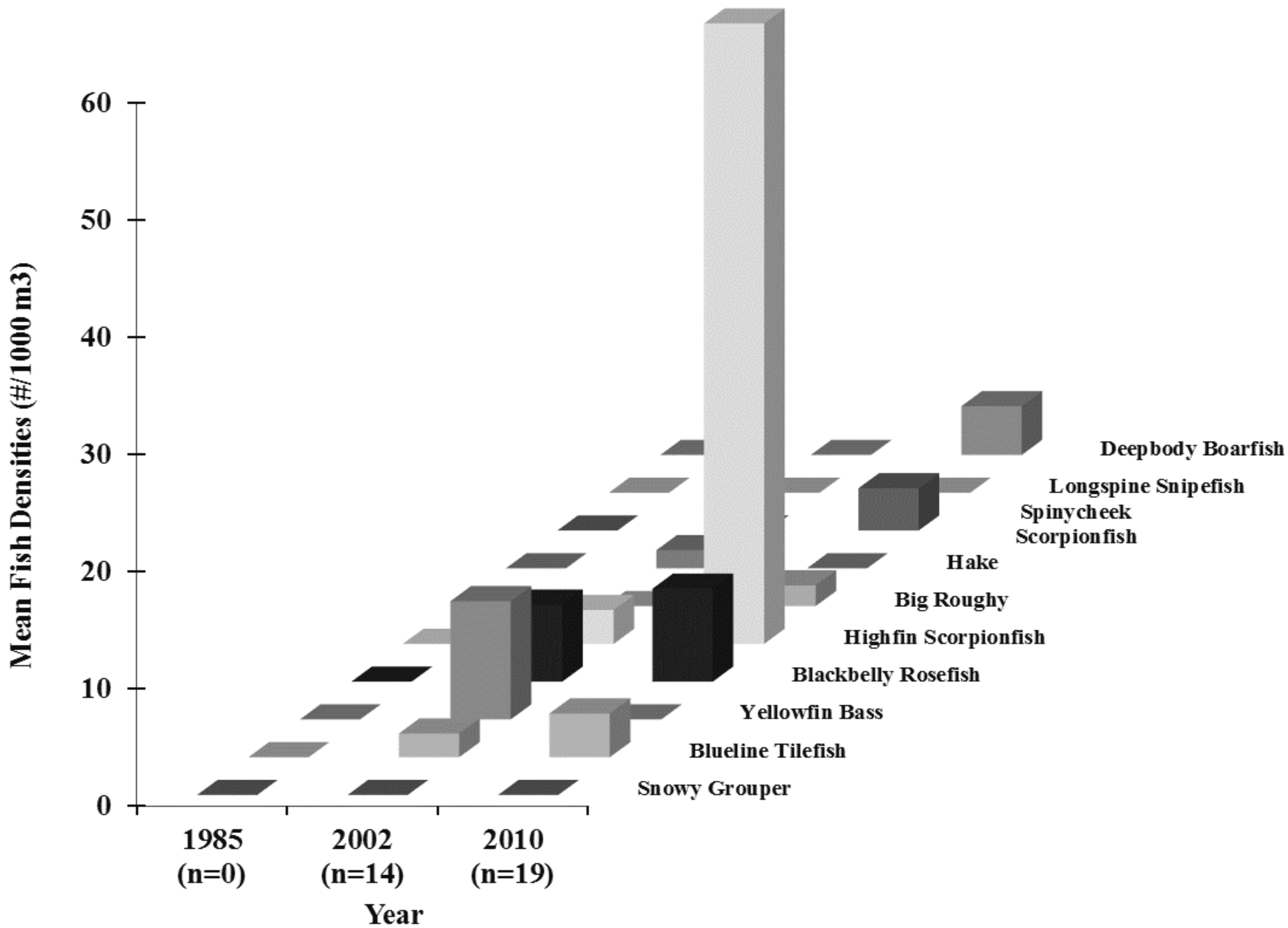

Figure 14. Mean Fish Density ± SE over mixed hard/soft bottom habitat for 1985, 2002, and 2010 at the Charleston Lumps. Blueline Tilefish densities increased throughout the study period although not significantly ($p = 0.58$). n represents the number of transects performed.

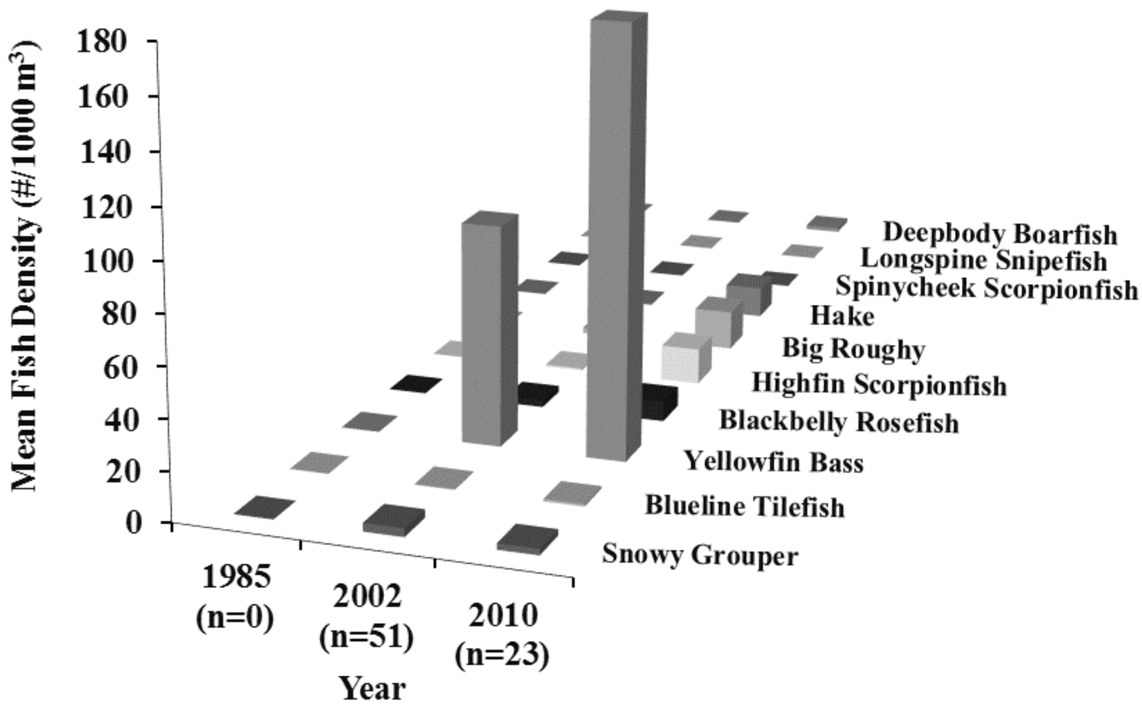

Figure 15. Mean Fish Density ± SE over high relief hard bottom habitat for 1985, 2002, and 2010 at the Charleston Lumps. Yellowfin Bass density increased significantly from 2002 to 2010 (p = 0.02). n represents the number of transects performed.

Discussion

The major finding of the study was that Snowy Grouper and Blueline Tilefish had higher densities within low relief hard bottom than over high relief rugged regions of the Charleston Lumps (Georgetown Hole). This preferential habitat association can be explained by several different reasons. The first, and foremost, was a successful foraging strategy used by the Snowy Grouper called ambush predation. Adult Snowy Grouper were observed sitting still in the shadows above low relief hard bottom, adjacent to high relief pinnacles, formed from congregated boulder slabs, holding high concentrations of prey such as the Yellowfin Bass. Several successful predatory strikes were observed from Snowy Grouper suspended motionless in the darkness above low relief habitat adjacent to high relief bottom. Secondly, Snowy Grouper and Blueline Tilefish may have occupied low relief habitat due to density dependent factors caused by high concentrations of other fish species within high relief habitat. Thirdly, Blueline Tilefish were observed utilizing low relief habitat and mixed hard, soft bottom for burrowing in soft sediment adjacent to rocky ledges, most likely for predatory avoidance or possibly for spawning or nesting purposes.

The Snowy Grouper can grow to over a meter in length (122 cm) and have a maximum weight of 30 kg while the Yellowfin Bass only reaches 25 cm in length weighing less than a kilogram. Snowy Grouper have been documented to prey predominantly on the swimming crab *Portunus spinicarpus* through gastric content analysis, but also prey upon demersal fishes such as the Yellowfin Bass (Weaver and Sedberry, 2001). Therefore, Snowy Grouper probably consume numerous Yellowfin Bass annually even though metabolic demands are diminished by the cold environment of around 15°C. Located at the apex of the trophic system, even a relatively small increase in abundance of Snowy Grouper could theoretically lead to a reduction in Yellowfin Bass density as was observed in the present study within low relief foraging habitat. This predation is needed to keep prey populations in check.

Blueline Tilefish use a different tactic to both avoid predation and stalk prey. They were observed burrowing in soft sediment underneath ledges and rocky overhangs and sharing burrows with Snowy Grouper. Blueline Tilefish preference for low relief hard bottom and mixed hard/soft bottom can be explained by a known attraction to structure and hard bottom. Ross et al. (2016) observed that Blueline Tilefish in Norfolk Canyon were found in higher densities within natural hard bottom and artificial reef habitat than over soft, sandy habitat. This supports the observation that Blueline Tilefish do prefer the presence of hard structure allowing them to hide in burrows to avoid predation and to feed on readily available prey. However, ideal Blueline Tilefish habitat combines hard bottom with soft bottom to provide them with the benefits of both (Ross et al., 2016). Blueline Tilefish distribution may also be a result of density dependent competition for limited resources within the dysphotic zone of upper slope reefs. By 2010, the high relief hard bottom regions of the Charleston Lumps attracted higher concentrations of prey species (Yellowfin Bass) than in previous years, as well as secondary predators (Highfin Scorpionfish, Blackbelly Rosefish, Hake, Big Roughy, etc.). This may limit the amount of habitat available to the primary apex predators of the Charleston Lumps, Snowy Grouper and Blueline Tilefish, that were possibly driven off high relief areas into low relief regions due to density dependent factors.

The increase observed in prey species (Yellowfin Bass) within high relief regions will allow the Charleston Lumps deep reef to support more commercially important primary predator species such as Snowy Grouper and Blueline Tilefish. The dramatic drop in density of Yellowfin Bass between 1985 and 2010 over low relief hard bottom regions of the Charleston

Lumps, suggests that low relief habitat may serve as the main foraging grounds for the apex predators of the Charleston Lumps ecosystem, Snowy Grouper and Blueline Tilefish. These are keystone species needed to maintain balance within the deep reef trophic system by keeping prey populations in check.

The relatively low equilibrium populations that deep coral habitats can support makes recovery from overfishing of predator populations a slow process (Roberts, 2013). Cold temperatures, slow metabolism, low prey abundance, and slow growth and maturation rates make deep reefs and inhabitant fish communities susceptible to habitat destruction from trawling, dredging, and overharvesting (National Research Council, 2002). Despite this fact, densities of demersal reef fish increased from 1985 to 2010, and Snowy Grouper and Blueline Tilefish populations have risen steadily thanks to effective and timely implementation of regulatory amendments and creation of several successful MPAs within the SAB by the South Atlantic Fishery Management Council. Regulations have also led to a decrease in unnecessary bycatch resulting in statistically significant increases in the densities of Highfin Scorpionfish, Blackbelly Rosefish, and hake throughout the study period. Further supporting the fact that the Charleston Lumps deep reef ecosystem is now healthier, the biodiversity has increased from only nine observed species in 1985 to 26 species in 2010.

Considering the increase in mean deep reef fish density from 1985 to 2010, the effect of natural variation in the intensity of the Gulf Stream driven by atmospheric pressure gradients and the Atlantic Multidecadal Oscillation (AMO) index has to be taken into account. The AMO index was negative from 1985 through roughly 1995, so this would have resulted in a less powerful Gulf Stream with slower currents and less downstream turbulence. Therefore, there would have been fewer eddy and gyre induced upwelling events during this time period resulting in lower biological productivity along continental shelf edge and slope reefs. However, since 1995 the AMO index has been positive causing stronger Gulf Stream currents from high atmospheric pressure gradients. More intense Gulf Stream flow results in more turbulence and an increase in eddy and gyre production. Theoretically this should result in an increase in biological productivity from increased gyre induced upwelling events. This oceanographic change could have contributed to the increase in deep reef fish abundance observed at the Charleston Lumps between 1985 and 2010.

Policy Considerations

Considering that Snowy Grouper preferred low relief habitat and Blueline Tilefish were most often associated with either low relief or mixed hard/soft bottom, expanding existing marine protected areas to incorporate more area of low relief and mixed hard/soft bottom to the already protected high relief regions along the shelf edge and upper continental slope reefs would be a prudent action plan to protect essential spawning, nursery, and foraging habitat. The prohibition of bottom fishing within marine protected areas containing fragile, slow growing, and long-lived cold water coral reef and sponge habitat should be continued to allow for full recovery. Creation of new deep water artificial reefs to increase available hard bottom habitat and to expand existing deep reef ecosystems is encouraged. Lastly, due to climate change and northern range expansion of Blueline Tilefish as well as other demersal deep reef fish, the Middle Atlantic Bight needs to implement regulations for species previously not seen within this region and continue to protect essential fish habitat.

The debate about whether the Gulf Stream will increase or decrease in intensity with climate change is controversial. With increased pressure gradients, more intense trade winds could develop, driving faster currents. Since 1995, the AMO has been positive which should help strengthen the Gulf Stream. This will increase upwelling from Gulf Steam eddies and enhance the biological productivity of the Charleston Lumps. On the other hand, with sea level rising from melting polar ice caps the Gulf Stream may become wider with lower velocity. The decreased salinity of the North Atlantic from arctic ice melting may result in less density dependent downwelling and would weaken the thermohaline circulation as well as the Gulf Stream. This would result in less current to nourish deep corals, less upwelling, and diminished biological productivity of the Charleston Lumps.

Considering the impending threat of climate change and natural decadal variability in the strength of the Gulf Stream resulting from positive and negative AMOs, fishery policies should adjust for possible reduced or increased biomass caused by current and upcoming oceanographic conditions. Fishery policies need to be made more stringent if negative AMOs and weaker Gulf Stream flows are predicted for the near future. In contrast, if beneficial oceanographic conditions are predicted such as positive AMOs, stronger Gulf Stream currents, frequent upwelling events, and resulting high biomass then fishery regulations can be relaxed somewhat. Therefore, scientists' and climatologists' ability to forecast upcoming oceanographic conditions will be essential for developing relevant fishery policies for the future.

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Appendix

Table 1. 1985 fish species observed with mean density ± SE

Fish Species Observed in 1985	Mean Fish Densities (#/1000 m^3) SE
Snowy Grouper	1.52±1.14
Blueline Tilefish	0.00±0
Yellowfin Bass	143.66±100.54
Blackbelly Rosefish	10.29±4.33
Highfin Scorpionfish	2.67±1.93
Big Roughy	1.14±0.79
Hake	6.10±3.38
Spinycheek Scorpionfish	0.76±0.49
Longspine Snipefish	0.76±0.76
Cardinal Soldierfish	0.38±0.38

Table 2. 2002 fish species observed with mean density ± SE

Fish Species Observed in 2002	Mean Fish Density (#/1000 m^3)	SE
Snowy Grouper	3.39	±0.86
Blueline Tilefish	0.71	±0.26
Yellowfin Bass	72.48	±14.50
Blackbelly Rosefish	3.48	±0.80
Highfin Scorpionfish	1.31	±0.30
Big Roughy	2.35	±0.62
Hake	0.69	±0.28
Lizardfish	0.20	±0.10
Deepbody Boarfish	0.21	±0.12
Misty Grouper	0.05	±0.05
Longtail Bass	0.06	±0.06
Deep Sea Peixe	0.90	±0.89
Banded Dogfish	0.06	±0.06
Spinycheek Scorpionfish	0.06	±0.06
Apricot Bass	0.06	±0.06
Shortnose Greeneye	0.07	±0.07

Table 3. 2010 fish species observed with mean density ± SE

Fish Species Observed in 2010	Mean Fish Density (#/1000 m^3)	SE
Snowy Grouper	6.47	±2.71
Blueline Tilefish	2.45	±1.34
Yellowfin Bass	55.46	±22.13
Blackbelly Rosefish	26.43	±10.39
Highfin Scorpionfish	29.93	±7.30
Big Roughy	7.67	±2.73
Blackfin Codling	11.22	±5.04
Deepbody Boarfish	2.91	±1.34
Cardinal Soldierfish	0.69	±0.67
Spinycheek Scorpionfish	1.92	±1.06
Blenny	3.51	±3.51
Wrasse (new species)	0.41	±0.27
Longtail Bass	0.30	±0.30
Lizardfish	0.37	±0.37
Almaco Jack	1.04	±0.81
Atlantic Bigeye	0.10	±0.10
Longspine Snipefish	0.07	±0.07
Bladefin Bass	0.22	±0.22
Apricot Bass	4.84	±4.14
Vermilion Snapper	0.21	±0.21
Misty Grouper	0.07	±0.07
Redeye gaper	0.03	±0.03
Shortnose greeneye	2.79	±2.79
Deepwater Flounder	0.20	±0.20
Southern Codling	0.18	±0.18