A TEMPORAL AND SPATIAL ANALYSIS OF FISH TRAP CATCHES WITHIN GRAY'S REEF NATIONAL MARINE SANCTUARY, 1993-2005

A thesis submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

in

ENVIRONMENTAL STUDIES

by

ATHAN M. BARKOUKIS

October 2006

at

THE GRADUATE SCHOOL OF THE COLLEGE OF CHARLESTON

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ABSTRACT

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A descriptive study of spatial and temporal variations in fish assemblages at Gray's Reef National Marine Sanctuary (GRNMS) was conducted using chevron trap collections made between 1993 and 2005. Four habitats previously identified, mapped and confirmed with diver observations (i.e. dense live bottom, sparse live bottom, rippled sand and flat sand) were used to determine variations in habitat utilization by fishes. The relative abundance, measured by catch per unit effort (CPUE), and length among habitats were analyzed from 2005 data for *Centropristis striata* (black sea bass) and *Stenotomus chrysops* (scup). CPUE and length among bi-annual sample periods between 1993 and 2002 were analyzed for black sea bass, scup, *Haemulon aurolineatum* (tomtate) and *Lagodon rhomboides* (pinfish). Seasonal analyses were conducted on black sea bass length from 1995. CPUE data indicated a preference for dense and sparse live-bottom habitat for black sea bass, and sparse live-bottom habitat for scup. Total CPUE of traps on rippled-sand habitat tended to increase when these traps were in close proximity (<100 m) to live-bottom habitat. CPUE of black sea bass and scup peaked in 2000-01, CPUE of pinfish increased from 1998 to 2002, and CPUE of tomtate was variable between 1993 and 2002. Black sea bass and scup were significantly longer in dense live-bottom habitat and rippled-sand habitat, respectively. Mean length of black sea bass and tomtate increased in bi-annual sample periods from 1995-97 to 2002 while the mean length of scup and pinfish varied. Seasonal data showed significantly larger black sea bass during the spring season than in summer or fall. Diversity, as denoted by Simpson's Index (1-

D), in the dense live-bottom habitat was lower than in the other less complex sparse live-bottom and rippled-sand habitats, and varied according to whether the traps were surrounded by multiple habitats types or only one type of habitat. Diversity was similar among the sample periods (1993 to 2002). Diver validation of habitats on which traps were deployed revealed discrepancies with habitats mapped prior to this study, as 27% of traps were not on the bottom type classified by previous mapping. However, existing habitat maps of GRNMS can be used as a guide for predicting abundance of fish species in the Sanctuary, relative to habitat types. Records from tag-recapture data confirm limited movement of black sea bass within GRNMS, with larger black sea bass more likely to move out of the Sanctuary and undertake large-scale movements (>100 km).

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Table of Contents

List of Figures

List of Tables

INTRODUCTION

Habitat plays a critical role in affecting recruitment and structure of demersal fish assemblages. Fish distribution, abundance and diversity are often influenced by habitat selection (Sale *et al*., 1984; Levin *et al*., 1997; Tolimieri, *et al*., 1998). However, habitat selection changes during the various life stages in many reef-associated fish (Able and Hales, 1997; Tupper and Boutilier, 1997; Potthoff and Allen, 2003). Additionally, habitat selection is frequently related to the size, type and complexity of habitats on a reef. An increase in the complexity of habitats often results in an increase in recruitment relative to less complex habitats (Jordan *et al*., 1996; Tupper and Boutilier, 1997; Ornellas and Coutinho, 1998; Chapman and Kramer, 1999).

Ecosystems often include the transitional zones or ecotones between simple and more complex habitats. Most commonly, an ecotone is defined as a boundary between systems (Harris, 1988; Winemiller and Leslie, 1992; Kolasa and Zalewski, 1995). However, the notion of an ecotone is somewhat confusing depending on the relative size, spatial scale, and shape by which the ecotone is defined, and the degree that these factors act functionally on the biota (Petts, 1990; Gosz, 1991, 1993). Ecotones are recognized as important environments in the terrestrial landscape, and are often associated with increased diversity (Gosz, 1991; Risser, 1990). In the marine benthic environment, ecotones create gradients that may alter physical attributes, such as sedimentation rate and current velocity. These factors may aid in deposition of nutrients and facilitate changes in the biological communities (Petts, 1990; Gosz, 1991, 1993; Kolasa and

Zalweski, 1995). In reef systems, ecotones can include transition zones between sandy-bottom habitat and rock or coral habitat with varying degrees of vertical relief.

The continental shelf of the South Atlantic Bight (SAB, Cape Hatteras to Cape Canaveral) consists of localized rocky outcroppings and patch reefs that are often surrounded by expanses of sandy bottom (Struhsaker, 1969; Powles and Barans, 1980; Sedberry and Van Dolah, 1984). These outcroppings are covered with diverse assemblages of attached invertebrates, and are known as "live bottom" (Powles and Barans, 1980; Wenner *et al*., 1983). The shelf of the SAB contains only a small fraction of high-relief live-bottom areas (Barans and Henry, 1984), but low-relief live-bottom areas are scattered across the sandy shelf. These live-bottom areas are critical habitats for commercially important species, while fishes of less economic value pervade more of the sandy regions of the SAB (Powles and Barans, 1980). Because of the patchy distribution of live-bottom reefs and the diversity of associated habitats on the shelf there are also areas of ecotones or transition zones. Gray's Reef National Marine Santuary (GRNMS), an example of an inner-shelf (<30 m) live-bottom reef (Sedberry *et al*., 1998), provides a patchwork of sandy, flat, hard, and topographically complex hard-bottom habitats and ecotones.

GRNMS contains various topographic features, and is located in a transition zone between temperate and tropical waters within the inner shelf of the SAB, 32.4 km off the coast of Sapelo Island, Georgia (FR, 1981). One-third of the habitat within GRNMS is classified as "live bottom," as determined from the Gray's Reef Benthic Habitat Map.[1] The live-bottom reef lies on a hard-bottom limestone and sandstone feature at the 20-m

[1] Kendall, M.S., Jensen, O.P., McFall, G., Bohne, R., Field, D., Alexander, C., and Monaco, M.E. (2003) Benthic Habitats of Gray's Reef National Marine Sanctuary. NOAA/NOS/NCCOS/CCMA Biogeography Team Technical Report. 16pp.

isobath (Hunt, 1974; Harding and Henry, 1994). The benthic habitat of Gray's Reef consists of caves, burrows, troughs and overhangs, which provide a moderate relief between 0-3 m[1]. These areas of relief are separated by expanses of fine-grained to medium-grained quartz sand and granule-sized gravel. The depth of sand ranges from a few centimeters in some locations to more than a meter. Further, there are several prominent ridges and troughs, which run in a northeast/southwest direction (Hunt, 1974; Harding and Henry, 1994). The assortment of topographic features has been classified into four distinct habitat types[1]. These habitats include densely colonized live bottom, sparsely colonized live bottom, rippled sand and flat sand. Of these four habitat bottom types, about 75% of GRNMS is covered in flat and rippled sand, about 24% is comprised of sparse live bottom, while 0.6% represents dense live bottom.[1]

Understanding movement of fishes in GRNMS aids in assessing habitat selection preference and is important to their continued protection through better-directed management plans. Movement influences patterns in abundance and community structure (Samoilys, 1996; Kramer and Chapman, 1999). Understanding the extent and area of fish movement offers a tool for managers seeking to understand the effects and potential benefits of closing sections of GRNMS or other live-bottom reefs from fishing activities for conservation and research purposes. Tag-recapture studies provide a measure of the home range that is often calculated with the Convex Polygon method (Anderson, 1982), while linear distances further elucidate movement of fishes. An increase in the linear movement of fishes often positively correlates with an increase in their size, and fishes that utilize more than one habitat often have larger home ranges (Kramer and Chapman, 1999). However, this distance is variable due to random movements seen in many fishes, time of year, and habitat preference (Anderson, 1982; Samoilys, 1996; Kramer and Chapman, 1999).

Designation of Gray's Reef as a National Marine Sanctuary provides special management for one of the largest near-shore live-bottom reefs off the coast of Georgia (Sedberry *et al*., 1998). Gray's Reef was designated as a National Marine Sanctuary in 1981 to protect quality of the ecological community, promote scientific understanding and enhance public awareness (FR, 1981). Current regulations focus on preservation of live-bottom habitat. First, the Sanctuary prohibits dredging, drilling or altering the seabed. Second, there is no discharging or depositing of any material. Third, it is illegal to use, deploy or possess wire fish traps. Fourth, breaking, damaging, or removing any bottom formation, invertebrates, plants or tropical fish is prohibited. Fifth, use of poisons, electrical charges and explosives is prohibited (FR, 1981). However, there are no added provisions on fishing restrictions within the Sanctuary other than regulations set forth by state and federal agencies.

Designation of Gray's Reef as a sanctuary may work in a slightly counter-productive fashion. The Sanctuary is well marked on navigation charts, along with visual locators, such as buoys at each corner of the rectangular Sanctuary. (Sedberry *et al*., 1998; personal communication with Sedberry and McFall, 2004). Further, one can easily access information on marine conditions at GRNMS from the National Data Buoy Center buoy in the Sanctuary. These attributes provide fishermen with access to sea conditions at GRNMS that may contribute to increase fishing pressures (Hare *et al*., In prep).

Federal and state agencies have conducted research and monitoring programs at Gray's Reef to assess seasonal diversity, abundance, and biomass of fishes and invertebrates (Wenner *et al*., 1983; Sedberry and Van Dolah, 1984; Sedberry *et al*., 1998). The National Oceanographic Atmospheric Administration[2] and the South Carolina Department of Natural Resources Marine Resources Monitoring Assessment and Prediction program (MARMAP) have been conducting fishery surveys on the continental shelf of the South Atlantic Bight since the 1970s using a variety of gear types, including trawls, fish traps, hook and line, and video census (McGovern *et al*., 1998). These monitoring techniques have included fish trap sampling within GRNMS. Sedberry and Van Dolah (1984) conducted monitoring through the use of trawls and remotely operated video, while Parker (1994) used diver-operated video for fish censuses. Intensive sampling was conducted during the 1990s by the use of chevron fish traps. Catches from these traps were used to determine species composition, length frequency, catch per unit effort (CPUE), and estimates of population size via the Peterson Mark-Recapture method[3] (Sedberry *et al*., 1998).

Results from MARMAP studies indicated temporal changes in abundance of some species. An upward trend in CPUE of black sea bass (*Centropristis striata*) has been documented between 1993 and 1998 with a decrease in CPUE in recent years[3]. Most traps have been dominated by black sea bass, scup (*Stenotomus aculeatus*), and pinfish (*Lagodon rhomboides*) (Sedberry *et al*., 1998). Fish monitoring conducted between 1995 and 2000 using diver counts verified seasonal and inter-annual changes in

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[2] Hare, J., Burke, J., Walsh, H., Woodley, C., and Hyland, J. (2000) Annual Report-FY2000 : Support of monitoring activities and site characterization at Gray's Reef National Marine Sanctuary. NOAA, National Ocean Service. 12pp.

[3] McGovern, J., Sedberry, G.R., Meister, H.S. and Wyanski, D.M. (2002) Annual Report-FY2002: A summary of monitoring and tagging work by the Marine Resources Monitoring and Assessment Program at Gray's Reef National Marine Sanctuary during 2002. NOAA, National Ocean Service. 8pp.

species abundance and composition within GRNMS. Data indicated decreases in abundance of gag (*Mycteroperca microlepis*) and spottail pinfish (*Diplodus holbrooki*).[2]

Studies have compared total abundance, diversity, CPUE and length frequencies between GRNMS and other similar habitats within the SAB (Sedberry and Van Dolah, 1984; Sedberry *et al*., 1998), but have not examined the quantitative relationship between benthic habitat type and species abundance, size and diversity. Therefore, to further understand the relationship among fishes and benthic habitats, this study analyzed data from fish trap catches between 1993 and 2005 at GRNMS. Geographic Information System (GIS) applications and diver validation helped determine habitats associated with each trap while GIS applications determined movement of black sea bass tagged during Tag-Recapture studies using the Peterson Mark-Recapture method. The following hypotheses on the spatial and temporal distribution of fishes within Gray's Reef were examined:

Ho_1) Habitat type will have an effect on fish abundance, length and diversity with increases observed from simple to greater habitat complexity. Studies have shown differences in fishes associated with variations in habitat complexity. Although trends may be species-specific, there will be a general tendency toward increased abundance, length, and diversity of fishes from catches on flat-sand habitat to rippled-sand habitat to sparsely-colonized live-bottom habitat, and finally to densely-colonized live-bottom habitat;

Ho_2) Changes in abundance, length, and diversity have occurred over various temporal scales. There will be a general increasing trend in abundance, length, and diversity over the sample period as a result of region-wide fishery management practices;

Ho_3) Variations in abundance, length, and diversity should be reflected in seasonal differences with larger fish in the spring, more abundant fish in the fall and greater diversity in the summer. These seasonal variations are reflective of spawning times, new recruits to Gray's Reef, and warmer water temperatures bringing tropical fishes to the region;

Ho_4) Tag and recapture data will show limited movement of black sea bass within and outside of the Sanctuary. Previous studies in the South Atlantic Bight have shown limited movement and high site fidelity of black sea bass;

Ho_5) The GRNMS Benthic Habitat Map will provide an accurate tool for mapping fish distribution and abundance. This is in part due to detailed mapping of the benthic habitats and collection of fishes over specific habitats.

MATERIALS AND METHODS

Sampling at GRNMS was conducted through three survey types that utilized chevron fish traps (Collins, 1990). The three survey types were:

1) trap sets used as part of a region-wide annual monitoring program in the South Atlantic Bight, which included traps set at GRNMS (Annual Assessment; May-October, 1993-2004);

2) trap sets that were verified by divers to determine placement of traps with respect to specific habitat types (Ground Truth; May 2005);

3) trap sets used to collect black sea bass for tag-recapture studies (Tag-Recapture; April-November, 1993-2004).

Field Methods

Each trap was baited with clupeids, set on buoyed lines, and soaked on the seafloor for approximately 90 minutes. Both Annual Assessment and Ground Truth survey catches were sorted by species and placed in flow-through holding tanks while abundance, weight (nearest g) and length (TL or FL, nearest cm) were determined. Fishes were visually inspected to determine if swim bladders were bloated. Fishes with bloated swim bladders were degassed using a 20-gauge hypodermic needle to vent gas from the swim bladder and increase survivorship upon release. When catches were large and measurements of all fish would have increased the risk of mortality, species were sub-sampled by weight to obtain abundance and length estimates. All fishes were released back into the Sanctuary.

The Ground Truth survey utilized scuba divers with experience at GRNMS to determine the habitat on which the traps were resting after normal deployment. In order not to disrupt catching effort of the chevron traps, divers did not continue to approach traps once the habitat was verified and dives were immediately discontinued.

Black sea bass collected for Tag-Recapture surveys were treated similarly to methods used in the Annual Assessment and Ground Truth surveys, but the length (TL) was measured to the nearest mm and the fish were individually marked with numbered plastic internal anchor tags (see Sedberry *et al*., 1998 and McGovern *et al*., 2005 for further detail). Recapture data of these black sea bass from Tag-Recapture surveys and recreational fishermen catches were used in analyses of fish movement at GRNMS.

GIS Methods

Trap collections from the three survey types were assigned habitats using the Geographic Information System (GIS) "Intersect" tool in ArcGIS version 9.0 (Murad-al-shaikh *et al*., 2003). The tool linked the position of the traps (latitude and longitude coordinates) to the habitats within the Benthic Habitat Map[1] shapefile already created by NOAA in conjunction with GRNMS. The Benthic Habitat Map included the designation of four habitat types: dense live bottom, sparse live bottom, rippled sand and flat sand. The latter two habitats consisted entirely of unconsolidated sediment. If the diver's habitat assessment during the Ground Truth Survey (May 2005) differed from the Benthic Habitat Map designation, traps were assigned to the diver-observed habitat.

GIS was also used to measure the distances from traps set on rippled or flat-sand habitats to the nearest dense or sparse live-bottom habitats. These distances were measured with the ArcGIS "ruler" tool to determine if proximity to live-bottom habitats influenced abundance of fishes on sand-bottom habitats. Comparisons of abundance were made between traps on sand-bottom habitats less than and greater than 100 m from live-bottom habitats.

Three aspects of the project provided a degree of spatial uncertainty when assigning traps to habitat types. These aspects included Benthic Habitat Map inaccuracy, ambiguity in knowing the precise location of traps deployed on the seafloor, and a lack of information on the effective area fished by a chevron trap. To address spatial uncertainty in trap placement with respect to habitat, additional analyses were conducted on the traps. Traps were classified to a habitat based on the area surrounding a trap rather than only using the specific point (Point Analysis) at which a trap landed. To do this, a Personal Geodatabase was created in a Geographic Information System (GIS) using ArcGIS version 9.0 (Murad-al-shaikh *et al*., 2003) for all traps deployed in the Annual Assessment surveys. A GIS application was used to create a 20-m radius circle (1257 m^2) around each trap, which provided more information on habitats associated with each catch. Once the circles were created around each trap, the "Intersect, Dissolve and Compute Statistics" tools in ArcToolbox were used to determine the area of all habitats within the 20-m circle. Habitats were assigned to a trap if they consisted of five percent or more of the total area within the circle. Traps that contained more than one habitat were assigned as an "ecotone" trap of multiple habitats. These traps were used in an analysis (Ecotone Analysis) that was separate from the Point Analysis to determine differences in diversity of fishes in traps associated with multiple habitats to those surrounded by only one habitat type. Thus, the Point Analysis and Ecotone Analysis represented two separate analyses conducted on the same data.

A GIS application was used to determine the linear distance movement from tag to recapture locations for black sea bass. The "Projection" tool was used to change the projection of the GRMNS Benthic Habitat Map shapefile from Geographic to UTM NAD 1983 Zone 17, so the resulting distance calculations would be in meters rather than decimal degrees. The distance was calculated with an extension code and tool, "Points to Lines V.2," which converted the XY values between tag and recapture coordinates into a polyline shapefile.

Data Analysis

The categorical variables included habitat (four types), sample period (1993-94; 1995-97; 1998-99; 2000-01; 2002-04; 2005) and season (Spring [April-May], Summer [June-August], Fall [October-November], Table 1). Analyses of CPUE, length and diversity among the categorical variables were only possible for subsets of the entire data set. Use of these subsets was necessary because of the uneven distribution of trap collections among habitats, sample periods and seasons. Data subsets utilized were as follows:

For habitat differences, analyses of species abundance, length and diversity included traps only from the Ground Truth survey (May 2005) because diver observations confirmed the habitat on which each trap landed. Only black sea bass and scup were chosen in analyses of abundance and length due to their high abundance within the survey. The abundances of other fishes in the Ground Truth survey were low, and these fishes were not included in analyses of abundance or length in relation to habitat.

For sample period differences, analyses of species abundance, length and diversity used traps in the Annual Assessment surveys. Black sea bass length analyses also incorporated data from the Tag-Recapture surveys. All traps used in these analyses were set on sparse live-bottom habitat (as determined from the Benthic Habitat Map) during the summer months between 1993 and 2002, excluding 1996 and 2003 when no sampling occurred. This subset of data was chosen to reduce the effects of confounding variables of season and habitat. For these sample periods, black sea bass (*Centropristis striata*), scup (*Stenotomus chrysops*), tomtate (*Haemulon aurolineatum*) and pinfish (*Lagodon rhomboides*) were used in analyses of abundance and length, due to their high abundance within the surveys. The low abundance of other fishes caught prohibited their analyses.

Seasonal comparisons (April, July, October) were restricted to the length of black sea bass on sparse live bottom in 1995 from the Annual Assessment and Tag-Recapture surveys. Black sea bass was the only species that was sampled during more than one season within a year. Seasonal abundance of black sea bass was not analyzed because the Tag-Recapture surveys did not identify all fish associated with each trap collection.

Diversity measures in the Ecotone Analysis were restricted to trap collections in the summer months between 1993 and 1997. Total CPUE was not significantly different among those years; therefore, all years were combined for analysis. Further, comparisons of diversity were made between traps classified in two different ways:

1) traps located on 100% rippled sand versus the ecotone traps dominated (33-95%) by rippled sand, but including multiple habitats;
2) traps located on 100% sparse live bottom versus the ecotone traps dominated (33-95%) by sparse live bottom, but including multiple habitats.

These analyses were used to determine if diversity of trap catches associated with only one habitat were different to those dominated by that same habitat, but including other habitats within the 20-m circle.

Statistical Analysis

Abundance within a habitat, sample period or season was measured as catch per unit effort (CPUE). CPUE was determined as the number of fishes in each trap, as follows:

$$\text{CPUE} = \sum \text{number of fish caught / number of traps}$$

Measures of diversity were determined for Annual Assessment and Ground Truth survey catches. These measures included Simpson's Index of diversity (1-D') (Krebs, 1998), Margalef's species richness (d) (Margalef, 1957), and Pielou's evenness (J') (Pielou, 1977). All diversity measures were performed in Primer version 5.2.9 for Windows (Clarke and Warwick, 2001) and were determined as follows:

$$1\text{- } D' = 1\text{-}\sum_{i=1}^{s}(n_i(n_i\text{-}1) / (N(N\text{-}1));$$

Where $D' = \Sigma p_i^2$, p_i = proportion of species *i* in the community, n_i = number of individuals of species *i* in the sample, N = total number of individuals in the sample, s = number of species in the sample

$$d = (S\text{-}1) / \text{Log}\ (N);$$

Where N = total number of individuals in the sample, S = number of species.

$$J' = (-\Sigma\ p_j \log p_j) / \text{Log}\ (S)$$

Where p_j = proportion of total sample belonging to $_j$th species, S = number of species.

Simpson's Index of diversity was chosen as it is considered a dominance index, weighing toward detecting changes in abundance of the most common species (Krebs, 1998). Diversity measures for each trap were pooled by habitat, sample period, or season, and analyzed by a one-way ANOVA. Rarefaction curves were generated to assess the ability to compare diversity values because of the inequality in sample size among habitats, sample periods and seasons. Statistical comparisons of diversity values were not made when sample sizes were too small. Rank in percent abundance of each species was used to further elucidate changes in community structure.

All data were tested for normality (Shapiro-Wilk Normality Test) and homogeneity of variances (Bartlett Test) (Sokal and Rohlf, 1995). When the data did not meet the assumptions for a standard analysis using ANOVA, significant differences in CPUE and length among the categorical variables (four habitat types, six sample periods and three seasons) were determined using the f-statistic in a linear model Monte Carlo Permutation Test (Good, 2000). The permutation test calculated the f-statistic on the original data. The data were then reorganized (n=1,000), and an f-statistic distribution was generated. The null hypothesis was accepted or rejected based on the location of the original f-statistic on the new distribution ($p<0.05$). All analyses were conducted in R 2.0.1 (Venables *et al*., 2005). Such randomized analyses are robust in detecting significant differences in cases where sample sizes are uneven and test assumptions are not met (Good, 2000).

Significant differences in mean CPUE, length and diversity among habitat, sample period and season were tested *a posteriori* using Tukey-Kramer HSD. This test used the distribution of treatment means and the within-group variance over the entire experiment to find differences in means (Sokal and Rohlf, 1995). All analyses were conducted using JMP 5.0 (Lehman *et al*., 2005)

Cluster analysis was used to determine the similarities in species composition and abundance among trap collections (normal analysis) and to elucidate species assemblages (inverse analysis). Patterns of similarity were determined with [$\log_{10}$ (x+1)] transformed abundance data (Clifford and Stephenson, 1975). Species classifications were determined with the Bray-Curtis similarity measure (Bray and Curtis, 1957) and flexible sorting formed clusters with a cluster intensity coefficient (β) of -0.25 (Clifford and Stephenson, 1975). Cluster analyses were performed with PC-Ord for Windows version 4.10 (McCune and Mefford, 1999).

Regression analysis was used to determine correlations in fish size versus distance traveled. Black sea bass that were recaptured ≤ one-day from original tag date were not included in the analysis since ≤ one-day recaptures may have been influenced by location of their release over such a short duration of time. A one-way ANOVA was used to compare the size of black sea bass recaptured within and outside the Sanctuary.

RESULTS

During sampling at GRNMS between 1993 and 2005, 153 traps were deployed in the Annual Assessment surveys, 221 traps in Tag-Recapture surveys, and 29 traps in the Ground Truth survey (Fig 1; Table 1). In the Point Analysis the subsets of data utilized 29 traps for analyses among habitats, 89 traps for analyses among sample periods, and 54 traps for analyses among seasons. Altogether, there were 65 traps in the Annual Assessment surveys that were used in the comparisons of ecotone traps to sparse live-bottom or rippled-sand traps. Of those traps, 18 were ecotone traps dominated by sparse live-bottom habitat, 33 traps were surrounded by 100% sparse live-bottom habitat, four were ecotone traps dominated by rippled-sand habitat, and ten traps were surrounded by 100% rippled-sand habitat (Fig. 2).

CPUE

Rank in abundance of all species caught among the Annual Assessment surveys showed the four most abundant fish, representing 97% of the total catch, to be black sea bass (53.2%), scup (33.2%), tomtate (6.1%) and pinfish (4.1%) (Table 2). In the Point Analysis of habitat from data in the Ground Truth survey black sea bass and scup comprised 99% of the catch (Table 3). Rank in abundance of species from traps used in analyses among sample periods (Table 4) was similar to those of the Annual Assessment surveys.

There were differences in abundance by habitat in the Ground Truth survey for black sea bass and scup. Black sea bass were found predominantly in dense and sparse live-bottom habitats with CPUE significantly greater than on rippled-sand habitat (Permutation, $p<0.0001$; Tukey-Kramer, $p<0.05$; Fig. 3). CPUE of scup among habitats was significantly greater on sparse live-bottom habitat compared to dense live-bottom habitat, but not rippled-sand habitat (Permutation, $p<0.0001$; Tukey-Kramer, $p<0.05$; Fig. 3). CPUE in flat-sand habitat for black sea bass and scup was significantly different than all other habitats, as no fishes were caught in traps on flat-sand habitat (Permutation, $p<0.0001$; Tukey-Kramer, $p<0.05$; Fig. 3).

CPUE of all fishes on sandy-bottom habitat increased when the traps were in close proximity to live-bottom habitat. The CPUE on rippled-sand habitat (n = 4 traps) in close proximity (<100 m) to live-bottom habitat was 63.5 ±22.0 fish/trap. No fishes were caught in two traps on rippled-sand habitat not in close proximity (>100 m) to live-bottom habitat. All traps (n = 8) on flat-sand habitat were greater than 100 m from live-bottom habitat and had no catch.

Based on data from summer collections over sparse live-bottom habitat there was an increase in CPUE of black sea bass and scup from 1993 through 2001, while catches of tomtate and pinfish were variable between 1993 and 2002. Catches of black sea bass (90.7±11.7 fish/trap) and scup (58.7±10.7 fish/trap) were highest during 2000-01 (Permutation, $p<0.0001$; Tukey-Kramer, $p<0.05$; Fig. 4). There were no significant differences in CPUE of tomtate and pinfish among sample periods; however, CPUE of pinfish showed an increasing trend between 1998 and 2002 (Permutation, $p=0.262$ and $p=0.05$, respectively; Tukey-Kramer, $p<0.05$; Fig. 4).

Length

Relationships between length and habitat in the Ground Truth survey were different for black sea bass and scup. Mean length of black sea bass was significantly greater in the dense live-bottom habitat (24.7±0.17 cm) compared to sparse live-bottom and rippled-sand habitats (Permutation, $p<0.0001$; Tukey-Kramer, $p<0.05$; Fig. 5). Further, the length frequency distributions between the minimum to median lengths (16 to 23-24 cm) were similar for all habitats; however, the distribution of median to maximum lengths (24 to 41 cm) indicated that more larger fish were found in the dense live-bottom habitat. Scup were significantly larger in the rippled-sand habitat (18.9±0.12 cm) than in dense live-bottom and sparse live-bottom habitats (Permutation, $p<0.0001$; Tukey-Kramer, $p<0.05$; Fig. 5). Comparisons could not be made in flat sand because no fishes were caught there.

Based on data of summer collections over sparse live bottom the mean length of black sea bass and tomtate decreased from the first to second sample period and then increased in every sample period to 2002, while mean length of scup and pinfish fluctuated between 1993 and 2002. Black sea bass (23.3±0.15 cm) were largest in 2002, the most recent sampling period in this analysis (Permutation, $p<0.0001$; Tukey-Kramer, $p<0.05$; Fig. 6). There were significant differences in the mean length of scup, tomtate and pinfish among the sample periods (Permutation, $p<0.0001$, $p<0.0001$, and $p<0.0001$, respectively; Tukey-Kramer, $p<0.05$; Fig. 6).

Seasonally, the mean length of black sea bass on sparse live-bottom habitat in 1995 was significantly greater in the spring (30.9±0.1 cm) than in the summer and fall (Permutation, $p<0.0001$; Tukey-Kramer, $p<0.05$). Further, the mean length of black sea bass was significantly smaller in the summer than in the fall (Permutation, $p<0.0001$; Tukey-Kramer, $p<0.05$; Fig. 7).

Community Structure

Rarefaction curves revealed that statistical analyses of diversity indices could not be conducted among the habitats from collections in the Ground Truth survey. Dense live-bottom habitat yielded the highest number of species (S=8), sparse live-bottom habitat had the second highest number of species (S=5) and rippled-sand habitat exhibited the least number of species (S=3). There were no catches in any trap on flat-sand habitat (Table 3). The dense live-bottom habitat had the highest mean species richness (d=0.44). Both the sparse live-bottom and rippled-sand habitats had similar mean evenness values (J'=0.81 and 0.86, respectively). Simpson's Index of diversity revealed lower diversity in dense live-bottom habitat (1-D=0.23) compared to the sparse live-bottom (1-D=0.44) and rippled sand-habitats (1-D=0.48) (Fig. 8a).

In the Ecotone Analysis rarefaction curves revealed that statistical analyses of diversity could not be conducted among the habitats. The number of species was similar for collections in ecotone traps dominated by sparse live bottom (S=12) compared to traps surrounded by 100% sparse live bottom (S=11). Likewise, the number of species was similar for ecotone traps dominated by rippled sand (S=7) and traps surrounded by 100% rippled sand (S=5) (Table 3). Indices of diversity (d, J', 1-D) were similar for ecotone traps dominated by sparse live bottom compared to traps surrounded by 100% sparse live bottom. Species richness (d) and Simpson's Index of diversity (D-1) was greater for ecotone traps dominated by rippled sand compared to traps surrounded by 100% rippled sand (Fig. 8b).

Comparisons among sample periods in summer collections on sparse live-bottom habitat showed similarity in diversity indices among the sample periods between 1993 and 2002. The highest number of species occurred during 1993-94 (n=13) and 1995-97 (n=13) with a fewer number of species observed in the other sample periods (Table 4). Mean species richness (d) and species evenness (J') were not significantly different among the sample periods (ANOVA, p=0.706 and p=0.414, respectively). Simpson's Index of diversity (1-D) revealed diversity to be constant among sample periods (ANOVA, p=0.852; Fig. 8c).

Normal cluster analysis demonstrated that assemblages were shaped by the combination of habitat, sample period and season (Fig. 9). Groups A_1 and A_3 were dominated by collections in rippled-sand habitat. Groups A_2, B_1 and B_2 contained predominantly collections in sparse live-bottom habitat. There was a mix of rippled sand and sparse live-bottom collections in group C_1. Groups C_2 and C_3 contained a mix of sparse live-bottom and dense live-bottom collections. Trap collections also clustered by yearly sample periods. Collection groups A_2 and A_3 contained mainly early sampling years (1993-1997). Collections in group B_2 consisted of mid sampling years (1995-1999), and collections in A_1, C_2, and C_3 were characterized by later years (2002-05). There was a mix of years contained within groups B_1 and C_1. Seasonally, groups A_2, A_3, and B_1 were dominated by collections in the summer. Spring and summer collections were mixed together in C_1 and C_3 while C_2 was dominated by spring collections.

Inverse cluster analysis showed the four most abundant species (black sea bass, scup, tomtate, and pinfish) often co-occurred in the same relative abundance (Fig. 10

Group F). The remainder of fishes caught in samples only represented 3% of all catches and similarity among the remaining groups was low.

Black Sea Bass Movement

Between 1993 and 2004 a total of 915 tagged black sea bass were recaptured once, 65 fish were recaptured twice, 10 were recaptured three times, and one was recaptured four times. Length and minimum straight-line distance traveled were not available for all black sea bass because recreational fishermen often did not report the length or location of recaptured fish.

Movement and days at large of black sea bass recaptured within the Sanctuary was variable. Minimum straight-line distance traveled by black sea bass recaptured once within the Sanctuary ranged from 0 to 3,448 meters with a mean of 423.0±18.2 (n=398), while days at large of these fish ranged from 2 to 1,284 with a mean of 293.7±11.3 (n=363). Black sea bass that were recaptured twice moved a distance of 40 to 1,042 meters with a mean of 343.7±45.2 (n=26). Days at large of these fish ranged from 201 to 749 with a mean of 465.2±39.2 (n=21). The distance traveled of black sea bass recaptured three times ranged from 122 to 681 meters with a mean of 367.1±55.1 (n=9) (Fig. 11). Days at large for these black sea bass ranged from 320 to 750 with a mean of 695±53.5 (n=8). One black sea bass was recaptured four times and moved a mean distance of 144±53 meters over a period of 1,045 days (Fig. 11). Regression analysis of TL versus distance traveled indicated no correlation ($y = -0.0331x + 450.84$, $r^2=0.00001$).

Recaptures outside of the Sanctuary indicated long-distance movement by some black sea bass. MARMAP surveys recaptured three black sea bass that traveled a mean distance of 25.7 km over 378 days. Tag returns from recreational fishermen indicated 17 black sea bass traveled a mean distance of 88.4±13 km at a range of 5.7 to 188.5 km. These fish moved north, south and east of GRNMS (Fig. 12). The length data were not available for two of these fish, but the mean size of the 15 reported lengths was 32.8±12.9 cm, ranging from 24.9 to 43.2 cm. There was no correlation between the size and distance traveled of these black sea bass ($y=68.7x+60303$, $r^2=0.0239$). Time spent at large ranged from 28 to 846 days with a mean of 335.4±74 days. There was no correlation between the days at large and distance traveled ($y=12.4x+80064$, $r^2=0.0048$).

A total of 311 black sea bass recaptured inside and outside of the Sanctuary were analyzed to determine overall relationships in size versus distance traveled. Regression analysis revealed no correlation in this relationship ($y= 2.9588x + 2.147$; $r^2 = 0.0423$). However, the mean size of black sea bass recaptured within the Sanctuary (276.7±2.0, n=296) was significantly smaller than the mean of those recaptured outside the Sanctuary (329.0±9.7, n=15) (ANOVA, $p<0.0001$).

Benthic Habitat Map

The use of specified coordinates and diver verification in the Ground Truth survey revealed discrepancies between trap habitat determined from the Benthic Habitat Map and the actual habitat on which the trap landed. Eight of the 29 traps (27.5%) were not on the habitat type determined from the Benthic Habitat Map. Four of the dense live-bottom traps were found on sparse live-bottom or rippled-sand habitats while four of the rippled-sand traps were on sparse live-bottom or flat-sand habitats.

DISCUSSION

Chevron trap data from three survey types conducted in GRNMS between 1993 and 2005 were analyzed to address the hypotheses of this study. Specifically, data demonstrated the following: habitat type did have an affect on abundance, length, and diversity; changes in abundance and length have occurred among the sample periods; variations in mean length of black sea bas were observed among the seasons; black sea bass tag-recapture data showed limited movement within the Sanctuary and large scale movement within the region; and the GRNMS Benthic Habitat Map can be used to map the abundance and distribution of fish assemblages. While addressing these hypotheses additional observations further elucidated patterns between habitats and fish assemblages.

CPUE

Significant differences in CPUE of black sea bass and scup were observed among the habitats. The present study showed that black sea bass were more abundant on dense and sparse live-bottom habitats than on rippled-sand habitat. These observations were consistent with other studies that found black sea bass were more abundant on live-bottom habitat than on sand habitat (Wenner, 1983; Sedberry and Van Dolah, 1984). The large CPUE of scup on sparse live-bottom habitat in this study also agreed with prior research observing scup to be more abundant on live-bottom habitat than sand habitat (Powles and Barans, 1980; Wenner, 1983; Sedberry and Van Dolah, 1984). The significantly larger CPUE of scup on sparse live-bottom habitat compared to dense live-bottom and rippled-sand habitats in this study provides additional information regarding scup habitat preference in the SAB. These observations suggest that there may be factors specifically associated with the sparse live-bottom habitat that contribute to the increased abundance. Thrush *et al*. (2001) found small-scale structures on sand-bottom habitat significantly increased diversity of the macrobenthic community. Thus, the sand associated with the sparse live-bottom habitat may provide a better substrate to forage and feed upon, as studies have shown prey from sand and reef substrata in stomach contents of scup (Sedberry, 1989; Lindquist *et al*., 1994). Furthermore, Posey and Ambrose (1994) found decreased abundance of infauna within 25 m of reef structure attributed to foraging by haemulids and sparids. Therefore, the hypothesis of increasing CPUE from simple to greater habitat complexity was accepted for black sea bass and partially accepted for scup.

Total CPUE on rippled-sand habitat varied according to proximity to live-bottom habitat. The data revealed no catches in rippled-sand habitat that were not in close proximity (>100 m) to any live-bottom habitat. By contrast, catches in rippled sand-habitat in close proximity (<100 m) to live-bottom habitat were comparable to catches directly on live-bottom habitat. Data on CPUE relative to habitat proximity in this study should be viewed as an interesting secondary observation that has also been noted by others. Chapman and Kramer (1999) found a decrease in total density of many reef-associated fishes in Barbados over sandy-bottom habitats compared to catches on reefs. They suggested the importance in proximity of reef habitats to nearby rubble or sandy-bottom habitats in explaining the increase in fish density within sand or rubble. Live-bottom habitat may enhance the input of organic material into the surrounding habitats; thereby, facilitating an increase in the abundance of prey (Steimle and Figley, 1996).

Further, the interaction and avoidance of predators has been attributed to the limited abundance of fishes farther from live-bottom habitat because this habitat provides protection and shelter (Pike and Lindquist, 1994; Posey and Ambrose, 1994; Jordan *et al.*, 1996; Potthoff and Allen, 2003).

Another factor that may have contributed to the large catch of fishes in traps on sand-bottom habitat near live-bottom habitat was the presence of bait in the traps attracting fishes from nearby habitats. Miller and Hunte (1987) found the presence of bait in traps to attract fishes from 135 to 345 m^2; however, the soak time in their study was over a period of one to four days. The effective area fished during the 90-minute soak time in the present study is relatively unknown. Thus, further studies are needed to determine reasons for the observed variations in CPUE relative to proximity to live-bottom habitat.

CPUE of black sea bass, scup, tomtate and pinfish in summer collections on sparse live-bottom habitat varied among the sample periods, suggesting that abundance of these fishes fluctuated in the Sanctuary and the region over time. The upward trends in CPUE of black sea bass and scup during the 1990s were consistent with other observations of increased CPUE of these fishes throughout the SAB (McGovern *et al.*, 1998). Dominance of the catches by black sea bass and scup at GRNMS were also typical of catches on the inner shelf throughout the region during the 1990's (McGovern *et al.*, 1998; Vaughan *et al.*, 1995). Likewise, the increase in CPUE of tomtate between 1993 and 1997 was similar to observations by McGovern *et al.* (1998) on the middle shelf (26-35 m). There was an upward trend in CPUE of pinfish from 1997 to 2002; however, comparative observations in the region for this fish were not available.

Therefore, the hypothesis of a general increasing trend in CPUE among the sample periods was accepted for black sea bass, scup and pinfish.

Length

Relationships between length and habitat were species-specific. There were significantly larger black sea bass in the dense live-bottom habitat compared to sparse-live bottom and rippled-sand habitats in the Ground Truth survey. This trend is attributed to more large black sea bass in the dense live-bottom habitat since the length frequency distributions of smaller black sea bass among the habitats were similar. Observations of larger black seas bass on dense live-bottom habitat compared to sparse live-bottom or rippled-sand habitats provides additional information on this length-habitat relationship, and consequently the hypothesis of increasing length as a function of greater habitat complexity was accepted. Studies of habitat utilization by other serranids have shown larger graysby (*Cephalopholis cruentata*) on high-relief coral reefs than smaller graysby (Sluka *el al*., 2001). Additionally, the length-habitat relationship of many species studied on reefs in Barbados indicated a positive correlation between increased length and complexity of habitats (Chapman and Kramer, 1999).

Scup were significantly larger in rippled-sand habitat compared to dense and sparse live-bottom habitats. Possibly, smaller scup prefer the safety of reef habitat and do not roam and forage in more unprotected regions, while larger scup move over sandy-bottom habitat. The size-habitat relationship may be suggestive of an avoidance of predators, as noted by Kramer and Chapman (1999) studying reef-associated fishes. The length-habitat relationship of scup in the present study rejected the hypothesis of scup length increasing with increases in habitat complexity.

Mean length of black sea bass, tomtate, scup, and pinfish in summer collections on sparse live-bottom habitat varied among the sample periods. Decreases in mean length were observed for black sea bass and tomtate from 1993-94 to 1995-97, but then mean length increased in every sample period through 2002, while sizes of scup and pinfish fluctuated. One factor contributing to increased mean length of black sea bass was the change in size limit from 203-mm to 254-mm TL placed on this species in 1997 (McGovern *et al*, 1998). The decrease in mean length of tomtate in early sampling years was similar to trends observed by McGovern *et al*. (1998) on the middle shelf (26-35 m) between 1991-96. Although mean length of tomtate increased from 1997 to 2002, the mean length in these years was not significantly different from the mean length observed in 1993-94. This observation suggests the size of tomtate has remained relatively stable in the Sanctuary over time. The small fluctuations in size of scup and pinfish and the relative stability in size of tomtate among the sample periods may be explained because they are non-managed species, as is not the case with black sea bass, which increased in length due to the implementation of size regulations. Further, these non-managed species are not prone to commercial or recreational fishing pressures that may alter the size classes of fishes.

Seasonal analysis of black sea bass length in 1995 indicated the largest fish were found in spring and the smallest in the summer. The large mean length in spring supported the hypothesis and strengthens other observations that more large black sea bass (>30 cm) are found inshore during the spring (Low and Waltz, 1991). The decline in mean length from spring to summer may be due to an increase in number of small fish becoming vulnerable to the trap, as the peak spawning activity of these protogynous hermaphrodites occurs between February and May (Wenner *et al*., 1986; Vaughan *et al*., 1995; Sedberry *et al*., 2006). Likewise, seasonal fishing activities on Gray's Reef may alter size classes through the depletion of larger black sea bass during peak recreational fishing time (May-September), as has been noted off the South Carolina coast (Low and Waltz, 1991). By the fall, the mean length of black sea bass significantly increased, most likely as a result of growth.

Community Structure

The use of cluster analysis did not further elucidate similarities in species composition and abundance among trap collections beyond patterns that were observed in the CPUE and diversity analyses. There were groupings in the data by habitat, sample period and season; however, the uneven distribution of trap collections among these categorical variables made interpretation of similarities in species composition and abundance difficult to discern.

Diversity values from chevron traps must be considered minimum for the fish assemblages at Gray's Reef due to the selectivity of the traps, but are useful in comparing across spatial and temporal variables. Studies have shown positive correlations between increased habitat complexity and diversity in fish communities (Wenner, 1983; Ornellas and Coutinho, 1998). In the present study diversity, as denoted by Simpson's Index (1-D), in the dense live-bottom habitat was lower than in the other less complex sparse live-bottom and rippled-sand habitats. The low diversity in the dense live-bottom habitat was due to a reduction in species evenness because of the dominance in catch of black sea bass and scup, and it rejected the hypothesis of increased diversity with increases in habitat complexity. Scott and Helfman (2001) noted that interpreting changes in diversity of fish assemblages should focus on the actual species present and differences in overlap in species occurrence. In this study rare fishes such as *Epinephelus morio* (red grouper), *Lutjanus campechanus* (red snapper), and *Mycteroperca microlepis* (gag) were present only in dense live-bottom habitat. Thus, although diversity was low in dense live-bottom habitat species richness was greater than in sparse live-bottom and rippled-sand habitats.

Changes in diversity among the sample periods (1993 to 2002) were not detected by Simpson's Index; therefore, the hypothesis of increasing diversity over time was rejected. In each sample period, except for 1993-94, the top four species caught remained the same (black sea bass, scup, tomtate, and pinfish). This observation was also noted in the inverse cluster analysis. However, rarer species such as *Diplodus holbrooki* (spottail pinfish), *Equetus umbrosus* (cubbyu) and *Opsarus pardus* (leopard toadfish) were twice as abundant in trap collections between 1993 and 1997 compared to collections between 1998 and 2001. The increased frequency of uncommon species between 1993 and 1997 resulted in higher species richness values for trap catches in those years while the sample periods between 1998 and 2002 had catches predominantly dominated by black sea bass and scup.

A pattern of increased diversity in both types of ecotones (dominated by sparse live bottom or rippled sand) relative to the pure habitat was not observed in the Ecotone Analysis. There was greater diversity in ecotone traps dominated by rippled sand compared to traps surrounded by 100% rippled sand; however, diversity was similar between ecotone traps dominated by sparse live bottom compared to traps surrounded by 100% sparse live bottom. Ecotones in the terrestrial landscape are often associated with increased diversity (Odum, 1971; Gosz, 1991; Risser, 1990). Most studies of ecotones in the marine environment have focused on benthic communities rather than fishes. In a study of 16 infaunal species in the Long Island Sound, species richness was highest in many of the transition zones. However, there were no statistical differences to non-transition zone areas, attributed to dissimilarity in habitat composition and physicial factors influencing the transition zones (Zajac *et al*., 2003).

A variety of factors could have contributed to a lack in greater diversity in the ecotone traps dominated by sparse live bottom compared to traps surrounded by 100% sparse live bottom. Fagan *et al*. (2003) discussed complications in statistical comparisons among ecotones. Specifically, the scale at which the ecotone traps were classified (20-m radius) may have been too small or too large to detect differences in diversity. There may have been differences in the structural characteristics, such as the type and percent of habitat, among each defined ecotone trap within the 20-m radius circle. However, attempts were made to distinguish these differences by separating the traps into rippled and sparse live-bottom dominated ecotone traps. Another possibility may be attributed to disconnection among ecotone traps because they were scattered across the Sanctuary. Comparing ecotone traps in similar locations in future studies may aid in alleviating the disconnection among traps. Finally, Fagan *et al*. (2003) noted that ecotones change through time (day, season, year); however, time was handled by comparing traps among similar seasons and years when there was no significant difference in total CPUE. More field experiments on ecotones at GRNMS are needed to address their role on diversity.

Black Sea Bass Movement

In the present study, black sea bass exhibited behavior consisting of limited and large-scale minimum straight-line movement. Most of the recaptures in the Sanctuary displayed limited movement and high site fidelity, as seen by the large number of black sea bass recaptured more than once near their release site. The high site fidelity supported the hypothesis of limited movement and is consistent with previous findings of movement patterns by black sea bass in the SAB[4] (Parker *et al*., 1979; Low and Waltz, 1991; Able and Hales, 1997). It is possible that black sea bass migrate to other areas of the SAB and return to GRNMS, which could not be detected in the data. This may skew the interpretation that the majority of the black sea bass exhibit limited movement within the Sanctuary, as 17 fish were recaptured beyond the Sanctuary in the SAB.

It has been suggested that the large number of short recapture distances were due to most of the sampling occurring predominately in the central sparse live bottom section of the Sanctuary. However, Annual Assessment and Ground Truth surveys included traps set in locations where no fish were tagged during the Tag-Recapture surveys, and these traps did not recapture any tagged black sea bass. The lack of recaptures in traps set in areas where no fish were tagged suggests that most black sea bass tagged within the Sanctuary do stay nearby their release site. A tag-recapture study of black sea bass off the coast of South Carolina revealed most of the recaptures were caught near their initial capture or release site; further, that 90% were recaptured in the same habitat in which they had been released after being tagged (Low and Waltz, 1991).

[4] Myatt, D.O. (1979) Fish tagging of Fripp Island dry dock wreck yield high returns. *Salt Water Conversation*. 5:18.

Regression analysis did not reveal a correlation between time at large or length of black sea bass and the minimum straight-line distance. In a tag-recapture study of gag off the southeastern U.S., McGovern *et al*. (2005) found that the number of days at large was related to distance traveled. In the present study, the lack of relationship between days at large and distance traveled by black sea bass is likely due to the limited movement of this fish. Their limited movement may also explain the lack of correlation in length of black sea bass and minimum straight-line distance traveled. McGovern *et al*. (2005) found that length of gag did not have a significant effect on distance traveled. However, other studies have reported that reef fish movement is positively correlated with increased size of fishes (Samoilys, 1997; Kramer and Chapman, 1999). It is important to note that the large-scale movement of the 15 recaptured black sea bass by recreational fishermen was seen only in larger fish.   Additional data are needed to clarify the relationship between length and distance traveled of black sea bass.

The recapture of ten black sea bass three times over a period of two to three years suggests high retention of plastic internal anchor tags, as well as low mortality of tagged and degassed fishes. Collins *et al*. (1999) found that deflating swimbladders prior to release reduced mortality of black sea bass. My data further support the importance of degassing swimbladders to increased survival of released fish.

Benthic Habitat Map

As technologies become more sophisticated at mapping seafloor characteristics and the interrelationship between fish assemblages and habitat is better defined, our ability to predict one based on the other will be enhanced. In deeper waters off the continental shelf the abundance of species in trawl surveys have become proxies for mapping habitat complexity (Auster *et al*., 2001).

In the case of GRNMS, it may be possible to use the detailed Benthic Habitat Map as a proxy for mapping fish abundance and distribution. The shallow waters at GRNMS have allowed detailed mapping of the benthic habitats and collection of fishes over specific habitats. There were discrepancies in classifying traps to habitats from diver observation and the map. The sampling design could not determine whether the misplacement was due to errors in the Benthic Habitat Map, changes in the habitat since the map was constructed, or misplacement of traps because of drift as the trap descended to the seafloor. However, it has been shown that the deployment of chevron traps in sparse and dense live-bottom habitats within the Sanctuary yields larger catches relative to flat and rippled-sand habitats. Further, traps on rippled sand in close proximity to live bottom also had larger catches than those set farther from live bottom. Thus, data from the Ground Truth survey supported the hypothesis that the Benthic Habitat Map can be used as a guide for predicting abundance of dominant fish species at GRNMS, relative to habitat types.

CONCLUSION

This study incorporated a wide range of data and thus offered an understanding of fish communities at GRNMS over various temporal and spatial scales. These results provide current information on fish assemblages in the Sanctuary.

Identifying and quantifying habitats to better understand their role on relative abundance (CPUE), size and diversity of fishes was complex. Through this study it became clear why research should continue to be directed at qualifying specific habitat composition and structural differences. Utilizing homogeneous habitats in study design reduces confounding effects when trying to understand the categorical variables studied, and mapping of habitats is essential to assuring that sampling occurs over homogenous bottom. However, understanding the role of heterogeneous habitats and ecotones is also important in determining how species assemblages change relative to the interaction among habitat structures. The Ecotone Analysis was incorporated into this study to elucidate differences in diversity in heterogeneous habitats compared to completely homogenous habitats. Many challenges arose in assessing these ecotone habitats; however, these observations still have an important role in understanding fish assemblages at GRNMS. Additional research on ecotones at GRNMS is needed to clarify their role on diversity of species assemblages.

The temporal analyses of CPUE, length and diversity of fishes were restricted to subsets of the data. Using only subsets of the data constrained the sample size and limited some comparisons. However, variability was reduced and this strengthened confidence in trends observed in the categorical variables analyzed among sample periods and seasons.

Tag-Recapture data further supported observations of limited movement by black sea bass. Some constraints to the analyses included the following: movement of black sea bass was not continually monitored, and movement was calculated as minimum straight-line distance. Both of these factors may underestimate the total distance traveled by black sea bass; however, the large sample size of black sea bass that displayed small-scale movement reinforces the findings of this study.

The detailed Benthic Habitat Map may be used as a proxy for mapping fish abundance and distribution. Yet, the discrepancies in classifying traps to habitats from diver observation and the map pose some dilemmas. These results led to the recognition of the importance in utilizing divers, cameras or videos when assessing changes in categorical variables among habitats. Although it may be cost-prohibitive for all surveys, it is too difficult to accurately determine the location of traps on the seafloor without some form of visual observation.

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Figure 1. The GRNMS Benthic Habitat Map and location of all chevron traps deployed between 1993 and 2005. Habitat types include dense live bottom, sparse live bottom, rippled sand and flat sand. Sampling methods include Annual Assessment (n=153), Tag-Recapture (n=221) and Ground Truth (n=29). Some points overlap. Habitat types and sampling methods are differentiated by color.

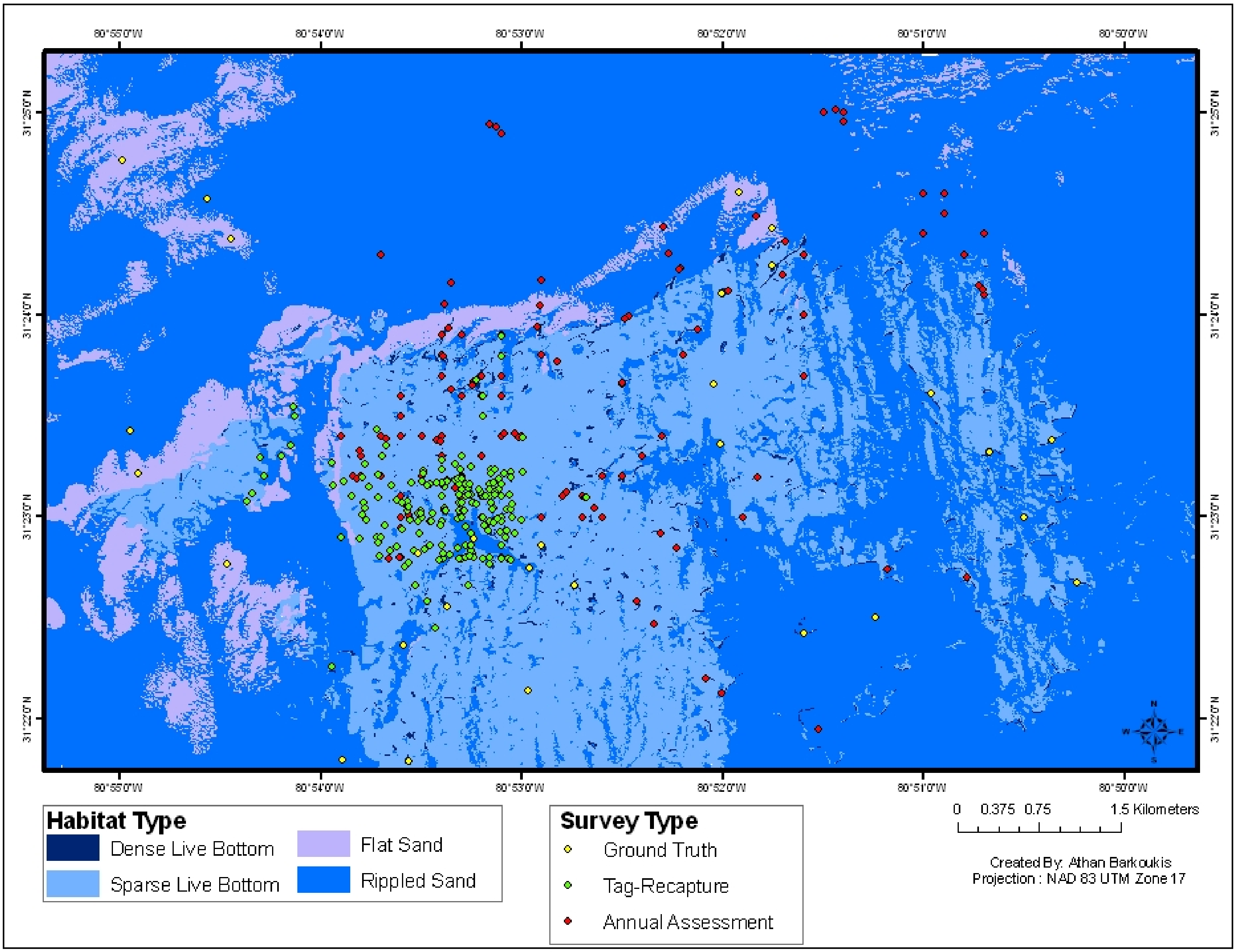

80°55'0"W
80°54'0"W
80°53'0"W
80°52'0"W
80°51'0"W
80°50'0"W
31°25'0"N
31°24'0"N
31°23'0"N
31°22'0"N
Habitat Type
Dense Live Bottom
Sparse Live Bottom
Flat Sand
Rippled Sand
Survey Type
Ground Truth
Tag-Recapture
Annual Assessment
0 0.375 0.75 1.5 Kilometers
Created By: Athan Barkoukis
Projection : NAD 83 UTM Zone 17

Figure 2. The GRNMS Benthic Habitat and location of 65 traps used in the Ecotone Analysis. Comparisons were made between ecotone traps dominated (33-95%) by sparse live bottom (n=18) or rippled sand (n=4) habitats and traps surrounded by 100% sparse live bottom (n=33) or rippled sand (n=10) habitats. Some points overlap. Habitat types and sampling methods are differentiated by color.

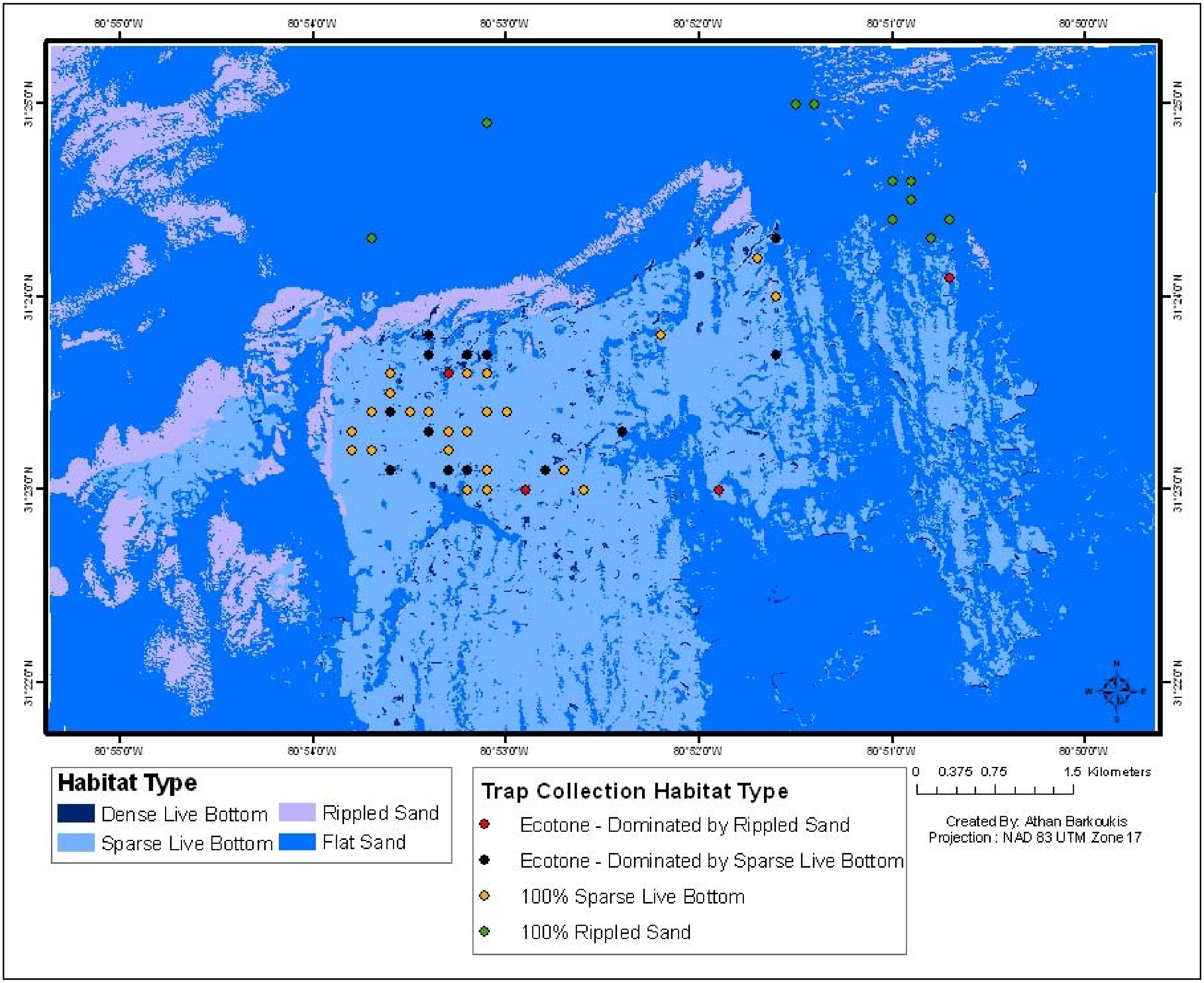
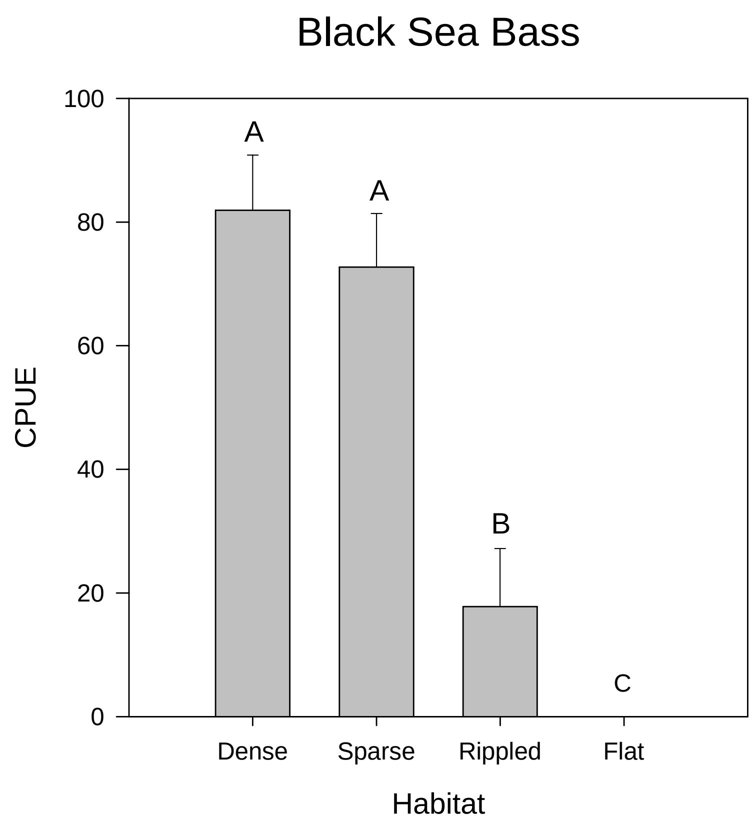

Habitat Type
Dense Live Bottom
Rippled Sand
Sparse Live Bottom
Flat Sand
Trap Collection Habitat Type
Ecotone - Dominated by Rippled Sand
Ecotone - Dominated by Sparse Live Bottom
100% Sparse Live Bottom
100% Rippled Sand
0 0.375 0.75 1.5 Kilometers
Created By: Athan Barkoukis
Projection : NAD 83 UTM Zone 17

Figure 3. Mean CPUE (fish/trap) of black sea bass and scup among habitats. Trap collections during May of 2005 were used in the analyses. The number of trap collections in each habitat were as follows: dense live bottom = 8, sparse live bottom = 7, rippled sand = 6, and flat sand = 8. Means without the same letter are significantly different (Tukey-Kramer, $p<0.05$). Error bars represent standard error.


Black Sea Bass
CPUE
100
80
60
40
20
0
A
A
B
C
Dense
Sparse
Rippled
Flat
Habitat

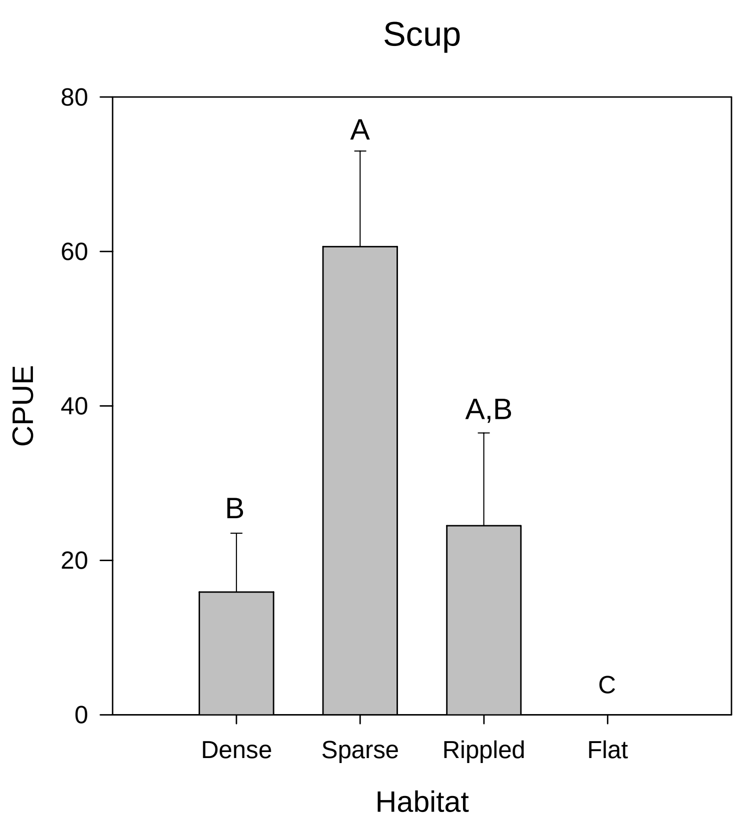

Scup
CPUE
80
60
40
20
0
B
A
A,B
C
Dense
Sparse
Rippled
Flat
Habitat

Figure 4. Mean CPUE (fish/trap) of black sea bass, scup, tomtate, and pinfish collected in traps among sample periods. Traps on sparse live bottom during summer collections between 1993 and 2002 were included in the analyses. The number of traps in each sample period was as follows: 1993-94 = 22, 1995-97 = 24, 1998-99 = 24, 2000-01 = 10, and 2002 = 9. Means without the same letter are significantly different (Tukey-Kramer, $p<0.05$). Error bars represent standard error.

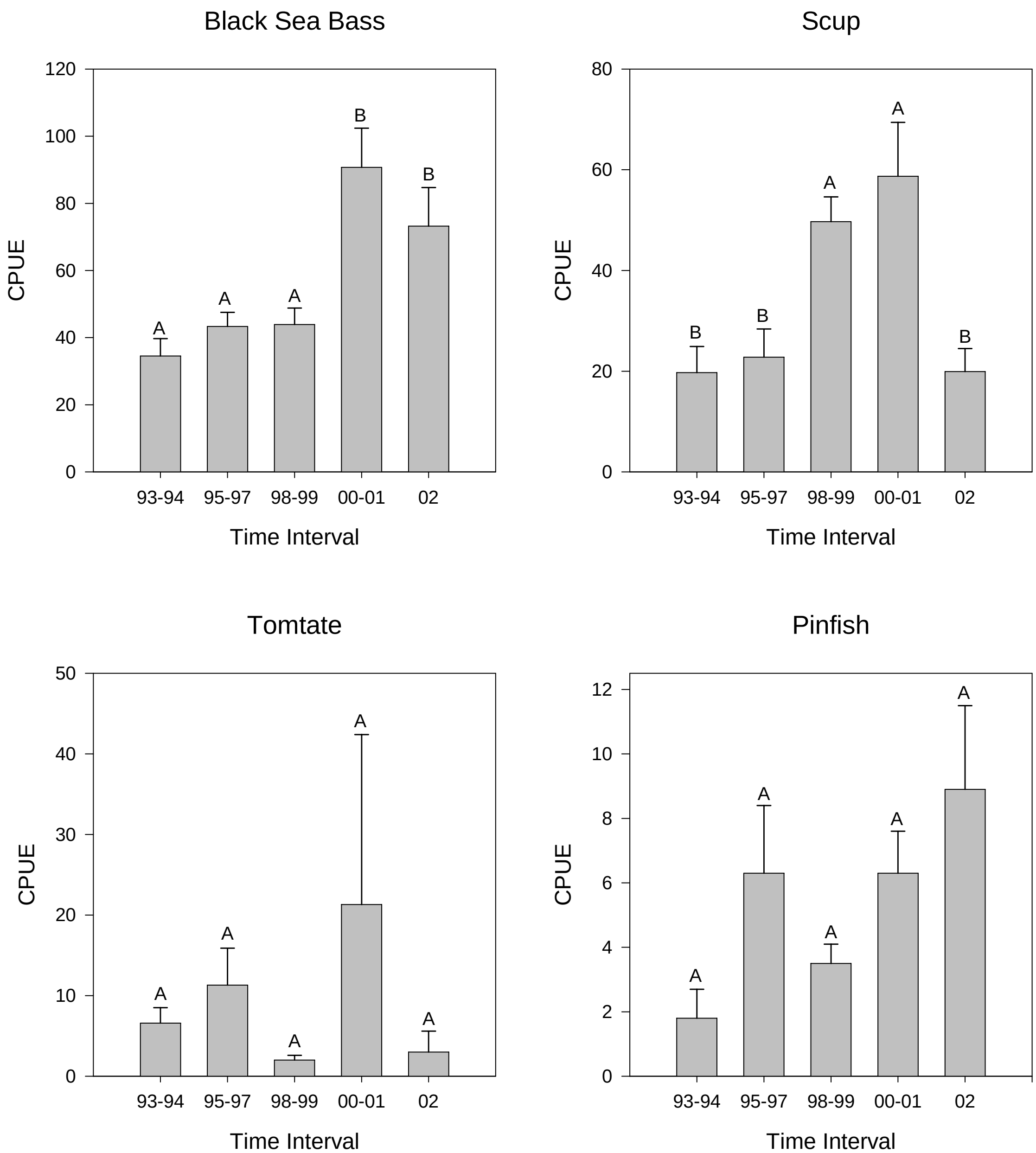
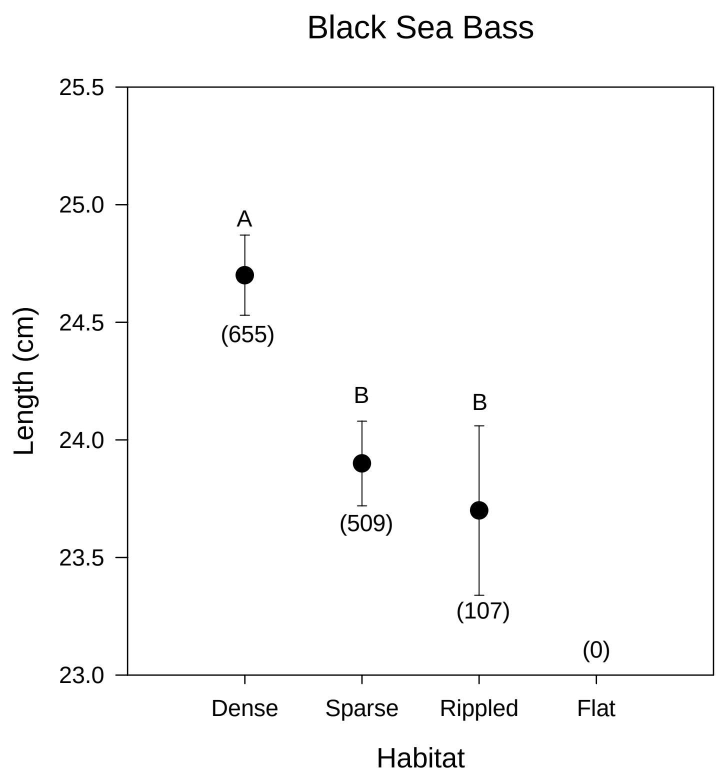

Black Sea Bass
CPUE
0
20
40
60
80
100
120
A
A
A
B
B
93-94
95-97
98-99
00-01
02
Time Interval
Scup
CPUE
0
20
40
60
80
B
B
A
A
B
93-94
95-97
98-99
00-01
02
Time Interval
Tomtate
CPUE
0
10
20
30
40
50
A
A
A
A
A
93-94
95-97
98-99
00-01
02
Time Interval
Pinfish
CPUE
0
2
4
6
8
10
12
A
A
A
A
A
93-94
95-97
98-99
00-01
02
Time Interval

Figure 5. Mean length of black sea bass and scup among habitats. Trap collections during May of 2005 were used in the analysis. The number of trap collections in each habitat were as follows: dense live bottom = 8, sparse live bottom = 7, rippled sand = 6, and flat sand = 8. Sample size indicated in parentheses. Means without the same letter are significantly different (Tukey-Kramer, $p<0.05$). Error bars represent standard error.


Black Sea Bass
Length (cm)
25.5
25.0
24.5
24.0
23.5
23.0
A
(655)
B
(509)
B
(107)
(0)
Dense
Sparse
Rippled
Flat
Habitat

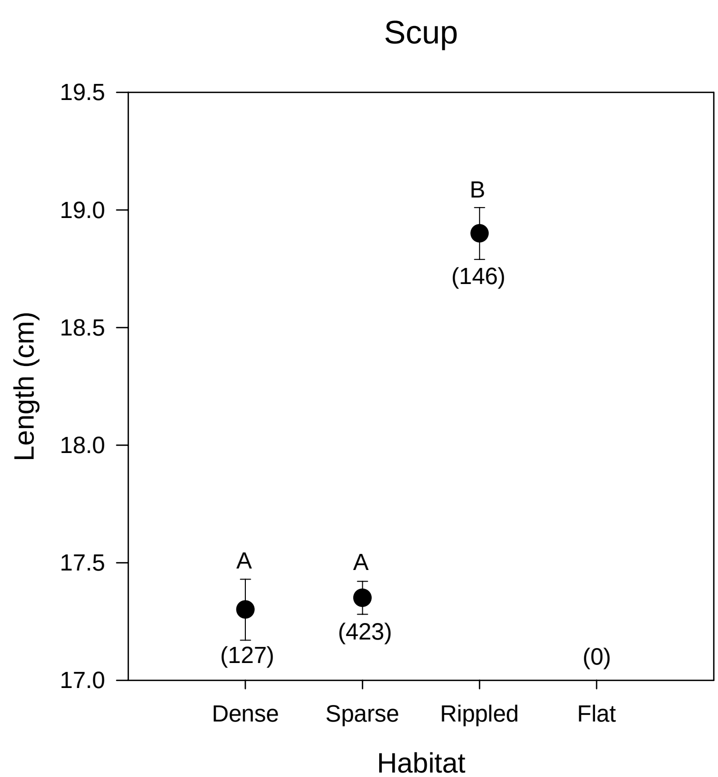
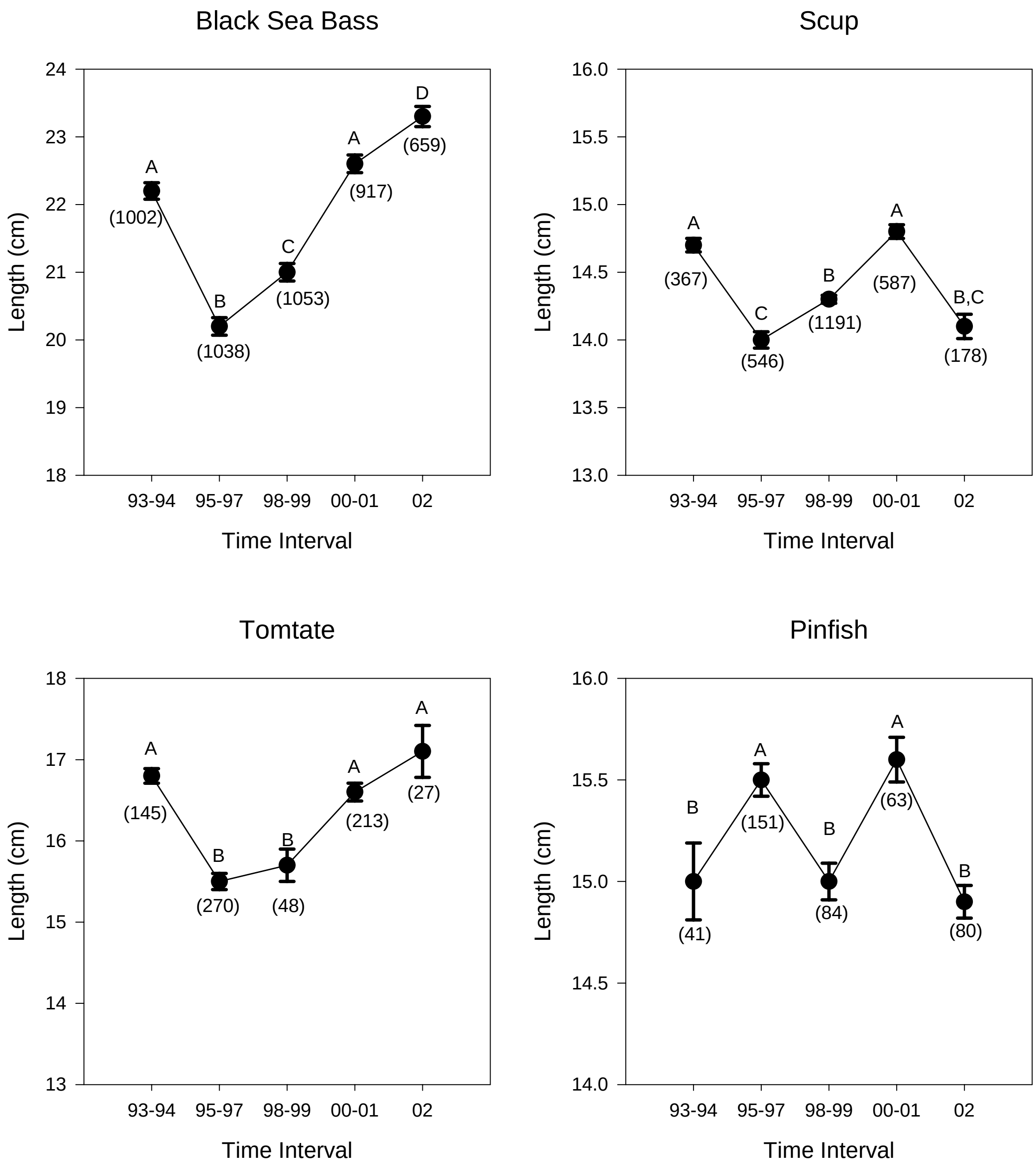
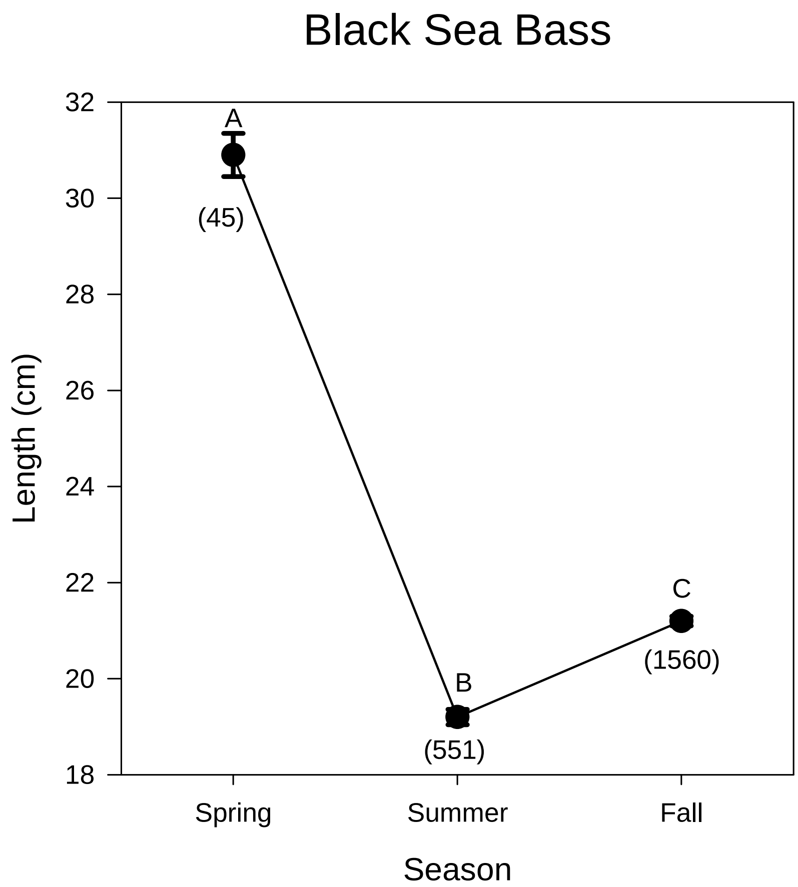

Scup
Length (cm)
19.5
19.0
18.5
18.0
17.5
17.0
B
(146)
A
(127)
A
(423)
(0)
Dense
Sparse
Rippled
Flat
Habitat

Figure 6. Mean length of black sea bass, scup, tomtate, and pinfish among sample periods. Traps on sparse live bottom during summer collections between 1993 and 2002 were included in the analysis. The number of traps in each sample period was as follows: 1993-94 = 22, 1995-97 = 24, 1998-99 = 24, 2000-01 = 10, and 2002 = 9. Sample size indicated in parentheses. Means without the same letter are significantly different (Tukey-Kramer, $p<0.05$). Error bars represent standard error.



Black Sea Bass
Length (cm)
Time Interval
93-94
95-97
98-99
00-01
02
A
(1002)
B
(1038)
C
(1053)
A
(917)
D
(659)
Scup
Length (cm)
Time Interval
A
(367)
C
(546)
B
(1191)
A
(587)
B,C
(178)
Tomtate
Length (cm)
Time Interval
A
(145)
B
(270)
B
(48)
A
(213)
A
(27)
Pinfish
Length (cm)
Time Interval
B
(41)
A
(151)
B
(84)
A
(63)
B
(80)

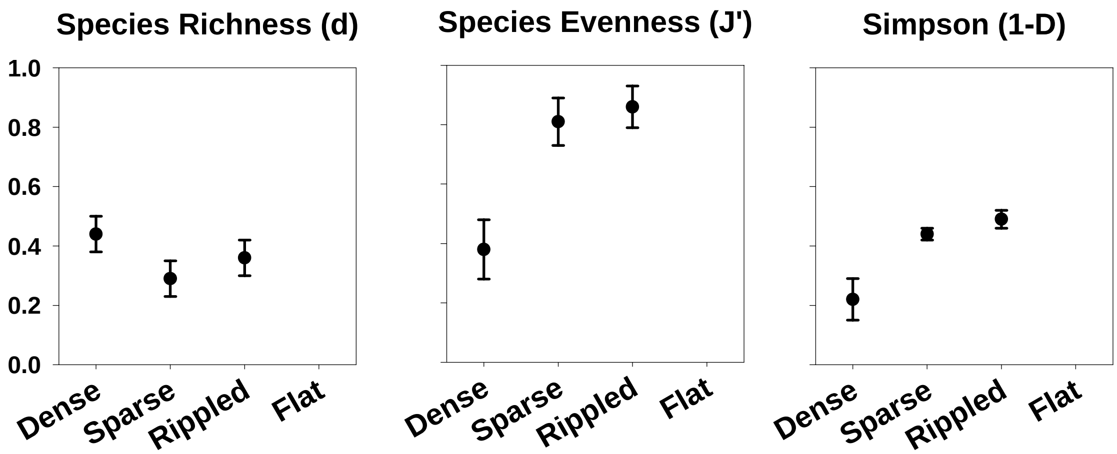
Figure 7. Mean length of black sea bass among seasons. Seasonal data from Annual Assessment and Tag-Recapture surveys on sparse live bottom in 1995 were used in the analyses. The number of traps in each season was as follows: Spring = 7, Summer = 14, and Fall =33. Sample size indicated in parentheses. Means without the same letter are significantly different (Tukey-Kramer, $p<0.05$). Error bars represent standard error.



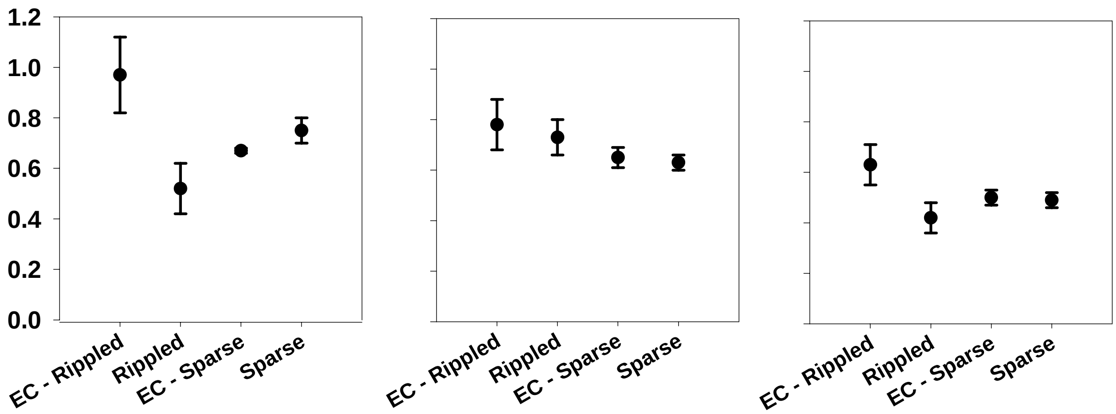
Black Sea Bass
Length (cm)
32
30
28
26
24
22
20
18
A
(45)
B
(551)
C
(1560)
Spring
Summer
Fall
Season

Figure 8. Mean species richness (d), mean species evenness (J’), and mean Simpson’s Index of diversity (1-D) among the habitats in the Point Analysis [A], habitats in the Ecotone Analysis [B] and sample periods [C]. Statistical comparisons could not be made among habitats in the Point and Ecotone Analyses. Trap collections during May of 2005 were used in the Point Analysis. Trap collections in the summer months between 1993 and 1997 were used in the Ecotone Analysis. Traps on sparse live bottom during summer collections between 1993 and 2002 were included in analyses among sample periods. Means without the same letter are significantly different (Tukey-Kramer, $p<0.05$). Error bars represent standard error.

A. Habitat : Point Analysis



B. Habitat : Ecotone Analysis



C. Sample Period

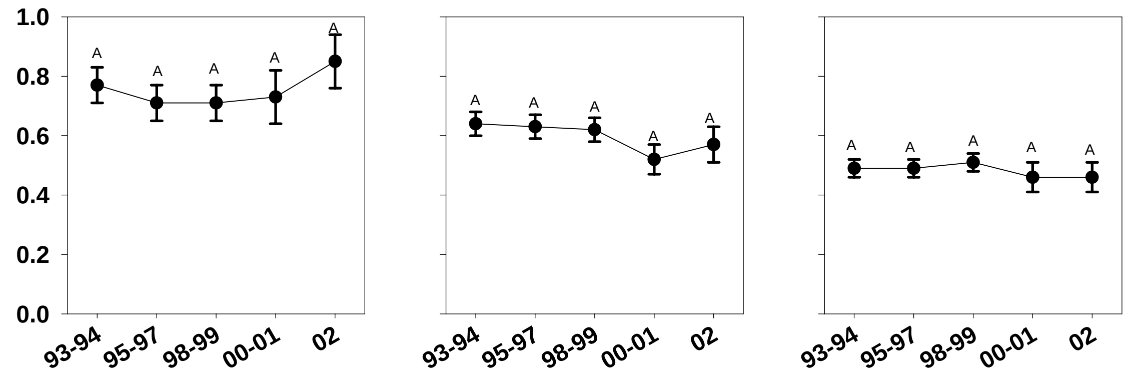


Figure 9. Normal cluster dendrogram of 165 chevron trap collections. Similarity values range from 1.0 (most similar) to 0 (least similar). The first character in the collection designation represents habitat (D = Dense; S = Sparse; R = Rippled; F = Flat). The second character represents time intervals (1 = 1993-1994; 2 = 1995-1997; 3 = 1998-1999; 4 = 2000-2001; 5 = 2002-2004; 6 = 2005). The third character represents seasons (Sum = Summer; Sp = Spring; Fall = Fall).

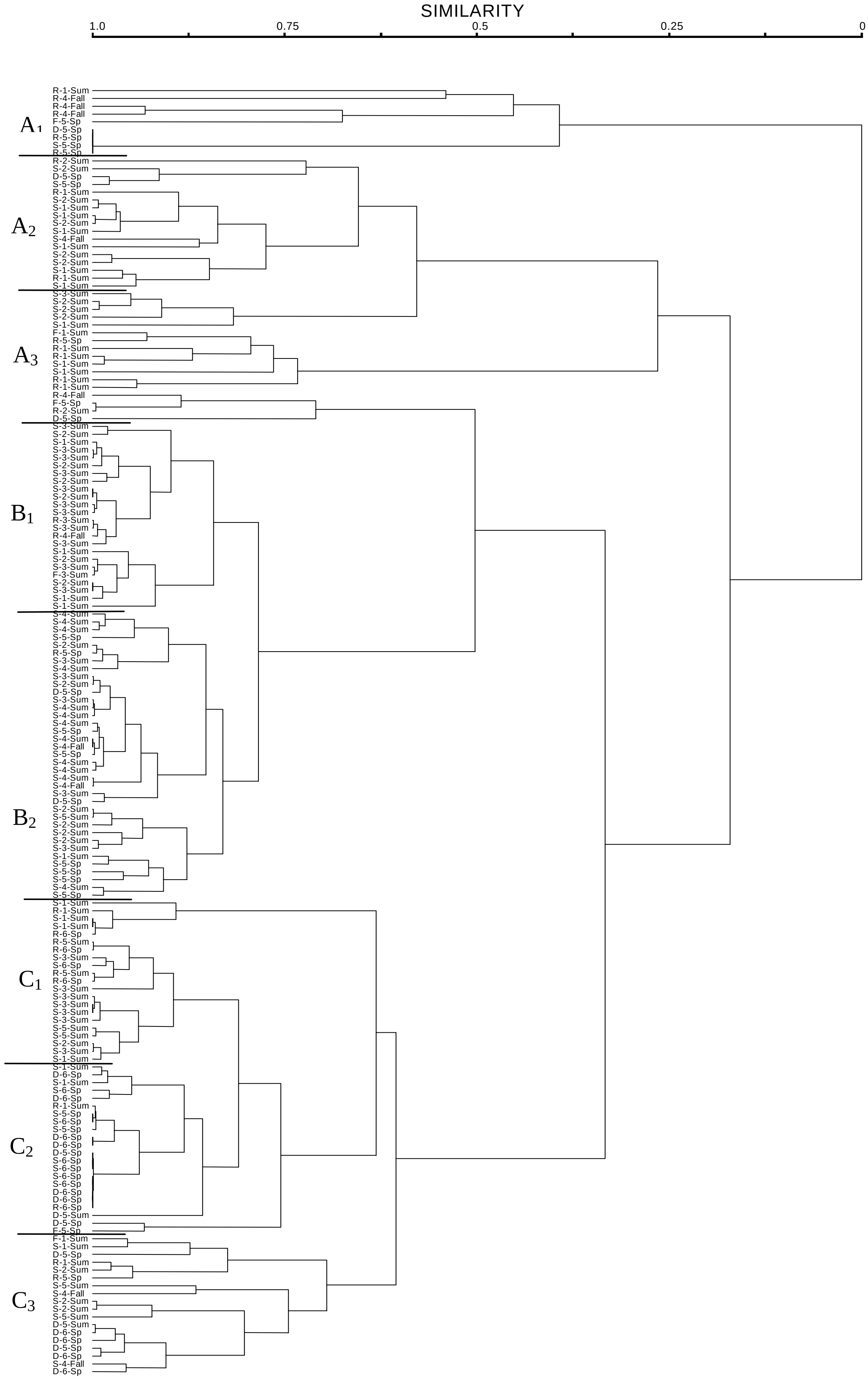

SIMILARITY
1.0
0.75
0.5
0.25
0
A1
A2
A3
B1
B2
C1
C2
C3

Figure 10. Inverse cluster dendrogram of 28 species caught in chevron traps between 1993 and 2005. Similarity values range from 1.0 (most similar) to 0 (least similar).

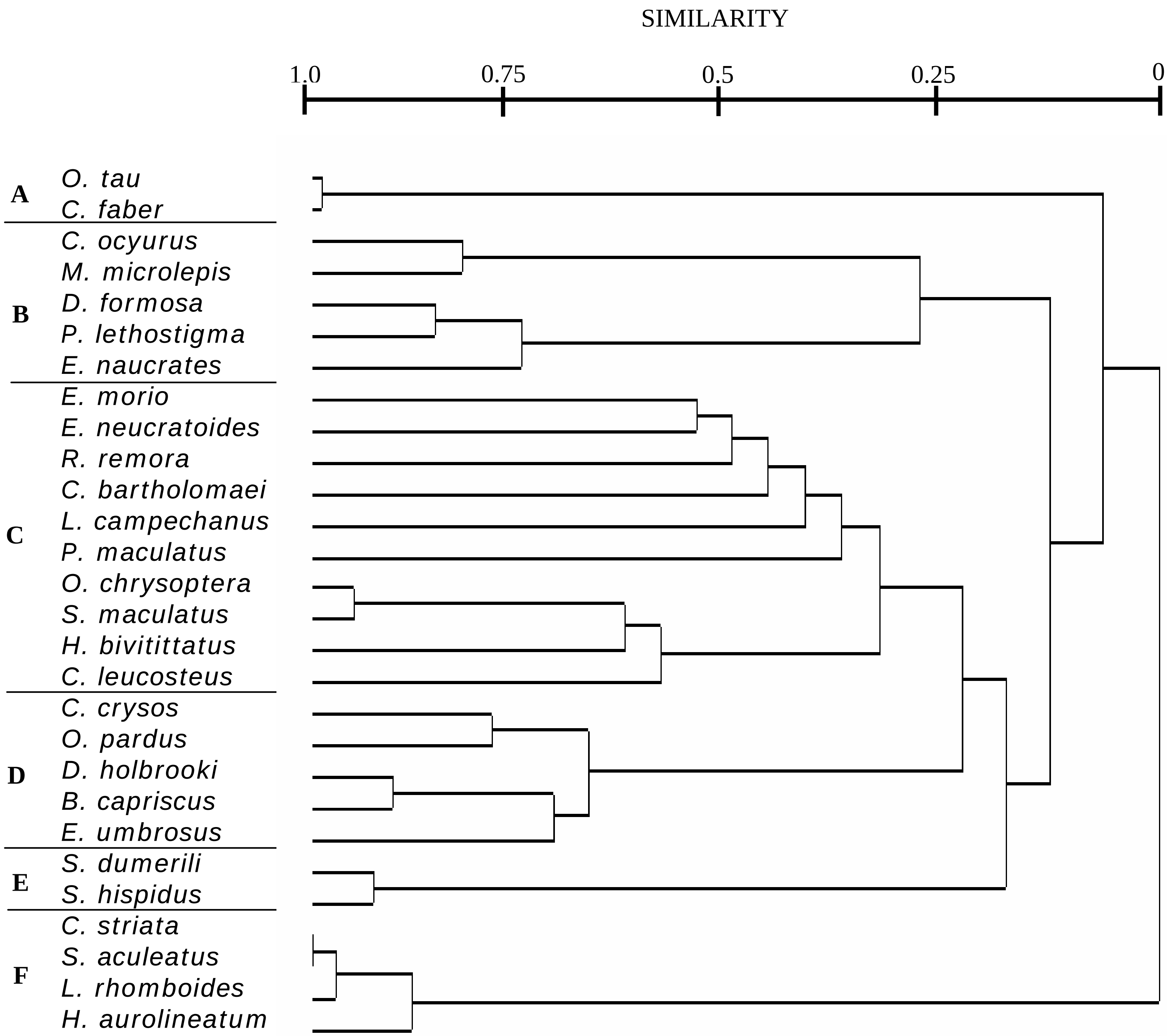

SIMILARITY
1.0
0.75
0.5
0.25
0
A
O. tau
C. faber
B
C. ocyurus
M. microlepis
D. formosa
P. lethostigma
E. naucrates
C
E. morio
E. neucratoides
R. remora
C. bartholomaei
L. campechanus
P. maculatus
O. chrysoptera
S. maculatus
H. bivitittatus
C. leucosteus
D
C. crysos
O. pardus
D. holbrooki
B. capriscus
E. umbrosus
E
S. dumerili
S. hispidus
F
C. striata
S. aculeatus
L. rhomboides
H. aurolineatum

Figure 11. The GRNMS Benthic Habitat Map and location of 10 black sea bass recaptured more than two times within the sanctuary. Similar colors indicate the same black sea bass. Different symbols indicate the recapture number. Habitats represented by different map colors are the same as those in Fig. 1.

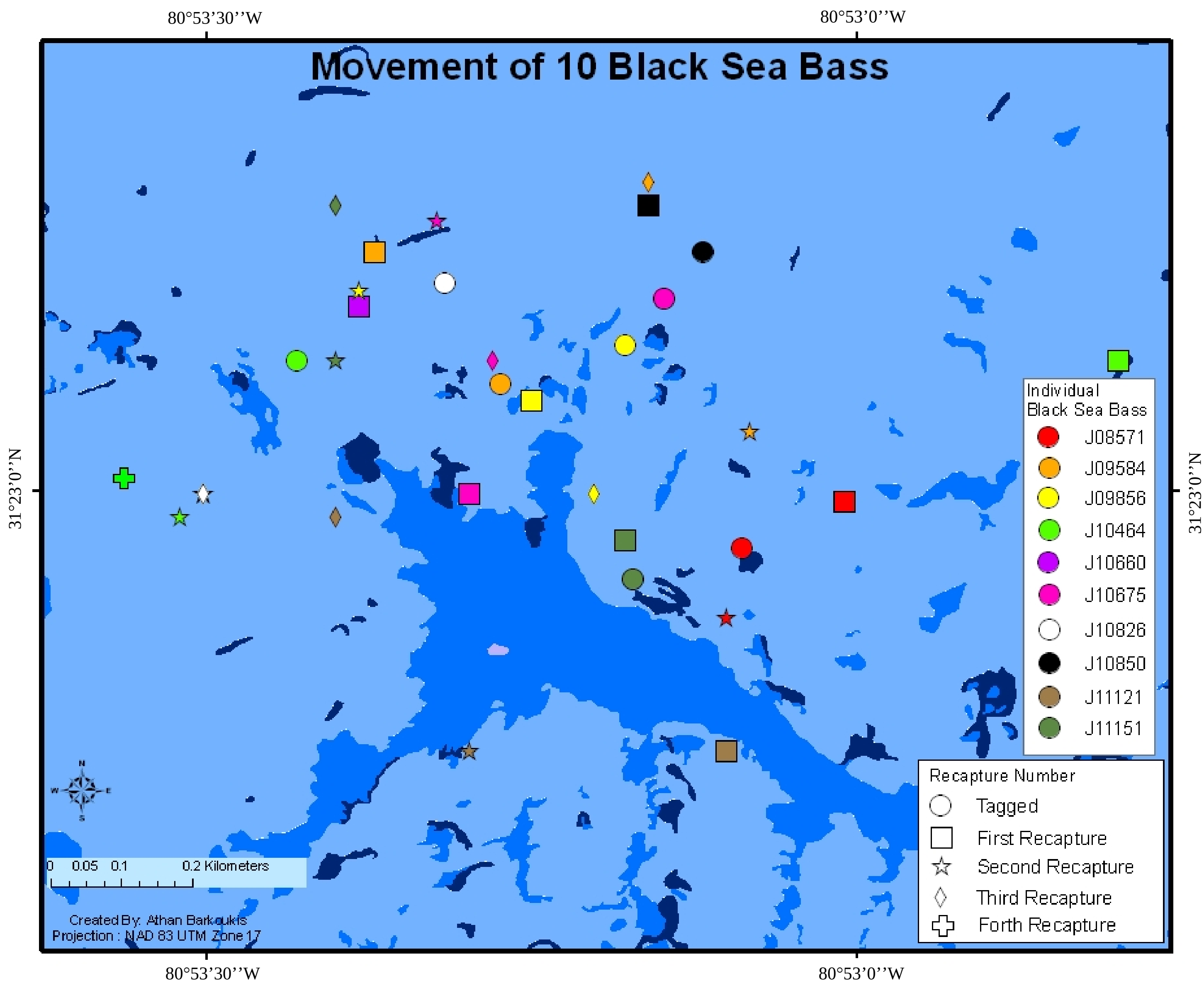
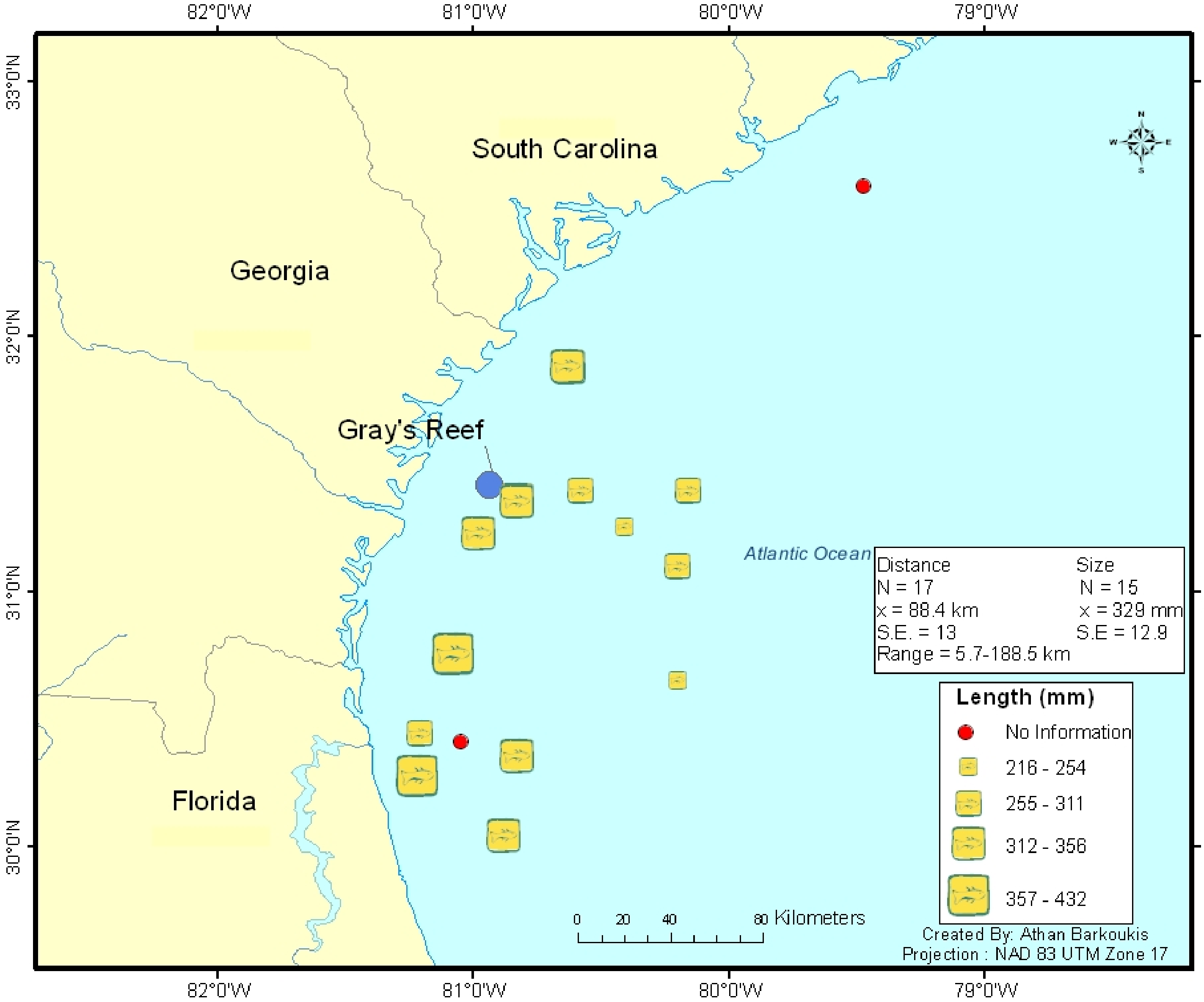

80°53'30''W
80°53'0''W
Movement of 10 Black Sea Bass
31°23'0''N
31°23'0''N
Individual Black Sea Bass
J08571
J09584
J09856
J10464
J10660
J10675
J10826
J10850
J11121
J11151
Recapture Number
Tagged
First Recapture
Second Recapture
Third Recapture
Forth Recapture
0 0.05 0.1 0.2 Kilometers
Created By: Athan Barkoukis
Projection : NAD 83 UTM Zone 17
80°53'30''W
80°53'0''W

Figure 12. The GRNMS Benthic Habitat Map and location of black sea bass (n=17) recaptured outside the sanctuary. Length data was not available for points in red. Some points overlap.



82°0'W
81°0'W
80°0'W
79°0'W
33°0'N
32°0'N
31°0'N
30°0'N
South Carolina
Georgia
Gray's Reef
Florida
Atlantic Ocean
Distance
N = 17
x = 88.4 km
S.E. = 13
Range = 5.7-188.5 km
Size
N = 15
x = 329 mm
S.E = 12.9
Length (mm)
No Information
216 - 254
255 - 311
312 - 356
357 - 432
0 20 40 80 Kilometers
Created By: Athan Barkoukis
Projection : NAD 83 UTM Zone 17

Table 1. The number of trap collections (in parentheses) in Annual Assessment (A), Tag-Recapture (T) and Ground Truth (G) surveys by habitat, sample period and season. There was no sampling conducted in 1996 or 2003.

	Spring		Summer		Fall	
Flat Sand			1993-1994 (3) -	A,T	1993-1994 (1) -	T
			1995-1997 (1) -	A		
			1998-1999 (1) -	A		
	2002-2004 (2) -	A				
	2005 (8) -	G				
Rippled Sand			1993-1994 (19)	A,T	1993-1994 (4) -	T
	1995-1997 (1) -	T	1995-1997 (2) -	A	1995-1997 (3) -	T
			1998-1999 (1) -	A	1998-1999 (6) -	T
			2000-2001 (2) -	A	2000-2001 (5) -	A,T
	2002-2004 (12) -	A			2002-2004 (8) -	T
	2005 (6) -	G				
Sparse Live Bottom			1993-1994 (33) -	A,T	1993-1994 (34) -	T
	1995-1997 (7) -	T	1995-1997 (24) -	A	1995-1997 (33) -	T
			1998-1999 (24) -	A	1998-1999 (15) -	T
			2000-2001 (14) -	A,T	2000-2001 (47) -	A,T
	2002-2004 (6) -	A	2002-2004 (9) -	A	2002-2004 (42) -	T
	2005 (7)	G				
Dense Live Bottom					1995-1997 (3) -	T
					2000-2001 (1) -	T
	2002-2004 (11) -	A				
	2005 (8) -	G				

Table 2. List of species (alphabetical), total abundance, and percent of total abundance per sample period (in parentheses) in Annual Assessment surveys between 1993 and 2004. There was no sampling conducted in 1996 or 2003.

Scientific Name	Common Name	1993-1994	1995-1997	1998-1999	2000-2001	2002-2004	Total
Balistes capriscus	gray triggerfish	5 (0.3)	7 (0.3)	2 (<0.1)	11 (0.3)	22 (0.8)	47 (0.4)
Calamus leucosteus	whitebone porgy	2 (0.1)					2 (<0.1)
Carangoides bartholomaei	yellow jack		1 (<0.1)				1 (<0.1)
Caranx crysos	blue runner				8 (0.2)	3 (0.1)	11 (<0.1)
Centropristis ocyurus	bank sea bass	1 (<0.1)	1 (<0.1)		6 (0.2)	7 (0.3)	15 (0.1)
Centropristis striata	black sea bass	897 (53.5)	1042 (48.9)	1146 (43.6)	1861 (55.4)	1731 (63.1)	6677 (53.2)
Chaetodipterus faber	atlantic spadefish					1 (<0.1)	1 (<0.1)
Diplectrum formosum	sand perch		1 (<0.1)	1 (<0.1)	5 (0.2)	1 (<0.1)	8 (<0.1)
Diplodus holbrookii	spottail pinfish	126 (7.5)	26 (1.2)	16 (0.6)	3 (<0.1)	26 (1.0)	197 (1.6)
Echeneis naucrates	sharksucker					19 (0.7)	19 (0.2)
Echeneis neucratoides	whitefin sharksucker					1 (<0.1)	1 (<0.1)
Equetus umbrosus	cubbyu	1 (<0.1)	25 (1.2)				26 (0.2)
Haemulon aurolineatum	tomtate	165 (9.8)	281 (13.2)	61 (2.3)	214 (6.4)	48 (1.75)	769 (6.1)
Halichoeres bivittatus	slippery dick	1 (<0.1)					1 (<0.1)
Lagodon rhomboides	pinfish	41 (2.4)	152 (7.1)	99 (3.8)	110 (3.3)	117 (4.3)	519 (4.1)
Lutjanus campechanus	red snapper					1 (<0.1)	1 (<0.1)
Mycteroperca microlepis	gag					1 (<0.1)	1 (<0.1)
Opsanus pardus	leopard toadfish	17 (1.0)	7 (0.3)	5 (0.2)	2 (<0.1)	1 (<0.1)	32 (0.3)
Opsanus tau	oyster toadfish					1 (<0.1)	1 (<0.1)
Orthopristis chrysoptera	pigfish			6 (0.2)	3 (<0.1)	1 (<0.1)	10 (<0.1)
Paralichthys lethostigma	southern flounder	1 (<0.1)				1 (<0.1)	2 (<0.1)
Psenes maculatus	silver driftfish	1 (<0.1)					1 (<0.1)
Remora remora	remora			1 (<0.1)			1 (<0.1)
Seriola dumerili	greater amberjack		1 (<0.1)	2 (<0.1)	1 (<0.1)	1 (<0.1)	5 (<0.1)
Sphoeroides maculatus	northern puffer	7 (0.42)		4 (0.2)	4 (0.1)	2 (<0.1)	17 (0.1)
Stenotomus chrysops	scup	410 (24.5)	585 (27.5)	1286 (48.9)	1130 (33.6)	754 (27.5)	4165 (33.2)
Stephanolepis hispidus	planehead filefish	2 (0.1)	1 (<0.1)	1 (<0.1)	2 (<0.1)	4 (0.2)	10 (<0.1)
Total		1,677	2,130	2,630	3,360	2,743	12,540

Table 3. List of species (alphabetical), total abundance, and percent of total abundance per habitat (in parentheses) in the Point Analysis of habitat from the Ground Truth survey (May 2005), and the Ecotone Analysis (trap collections during summer months between 1993 and 1997 from Annual Assessment surveys).

		Ground Truth Survey - 2005 - Point Analysis				Annual Assessment Surveys - 1993 to 1997 - Ecotone Analysis			
Scientific Name	Common Name	Dense	Sparse	Rippled	Flat	Ecotone-Sparse	Sparse	Ecotone-Rippled	Rippled
Balistes capriscus	gray triggerfish					4 (0.3)	3 (0.3)		
Centropristis ocyurus	bank sea bass			1 (<0.1)		1 (<0.1)	1 (<0.1)		
Centropristis striata	black sea bass	655 (82.7)	509 (54.4)	107 (42.1)		540 (41.5)	431 (38.3)	46 (30.7)	115 (58.1)
Diplectrum formosum	sand perch					1 (<0.1)			
Diplodus holbrookii	spottail pinfish		1 (0.1)				149 (13.2)		
Epinephelus morio	red grouper	1 (<0.1)							
Equetus umbrosus	cubbyu					25 (1.9)	1 (<0.1)		1 (0.5)
Haemulon aurolineatum	tomtate	5 (<0.1)	1 (0.1)			207 (15.9)	198 (17.6)	16 (10.7)	7 (3.5)
Lagodon rhomboides	pinfish					36 (2.8)	34 (3.0)	5 (3.3)	
Lutjanus campechanus	red snapper	1 (<0.1)							
Mycteroperca microlepis	gag	1 (<0.1)							
Opsanus pardus	leopard toadfish					3 (0.2)	3 (0.3)	2 (1.3)	1 (0.5)
Opsanus tau	oyster toadfish	1 (<0.1)	1 (0.1)						
Orthopristis chrysoptera	pigfish	1 (<0.1)						1 (0.7)	
Seriola dumerili	greater amberjack					1 (<0.1)			
Sphoeroides maculatus	northern puffer					2 (0.2)	2 (0.2)		
Stenotomus chrysops	scup	127 (16.0)	423 (45.2)	146 (57.5)		479 (36.8)	302 (26.8)	79 (52.7)	74 (37.4)
Stephanolepis hispidus	planehead filefish					2 (0.2)	2 (0.2)	1 (0.7)	
Total		792	935	254	0	1,301	1,126	150	198

Table 4. List of species (alphabetical), total abundance and percent of total fish caught per sample period (in parentheses) in traps during the summer on sparse live bottom in the Annual Assessment surveys between 1993 and 2002.

Scientific Name	Common Name	1993-1994	1995-1997	1998-1999	2000-2001	2002	Total
Balistes capriscus	gray triggerfish	5 (0.3)	7 (0.3)	1 (<0.1)	8 (0.5)	19 (1.9)	40 (0.46)
Calamus leucosteus	whitebone porgy	2 (0.1)					2 (<0.1)
Carangoides bartholomaei	yellow jack		1 (<0.1)				1 (<0.1)
Caranx crysos	blue runner				5 (0.3)		5 (<0.1)
Centropristis ocyurus	bank sea bass		1 (<0.1)	1 (<0.1)			2 (<0.1)
Centropristis striata	black sea bass	758 (51.6)	1039 (50.0)	1053 (43.6)	907 (50.7)	659 (67.2)	4416 (50.6)
Diplectrum formosum	sand perch		1 (<0.1)				1 (<0.1)
Diplodus holbrookii	spottail pinfish	126 (8.6)	26 (1.3)	16 (0.6)	3 (0.2)	9 (0.9)	180 (2.1)
Equetus umbrosus	cubbyu		25 (1.2)				25 (0.3)
Haemulon aurolineatum	tomtate	145 (9.9)	270 (13.0)	48 (2.0)	213 (11.9)	27 (2.8)	703 (8.1)
Halichoeres bivittatus	slippery dick	1 (<0.1)					1 (<0.1)
Lagodon rhomboides	pinfish	40 (2.7)	152 (7.3)	84 (3.5)	63 (3.5)	80 (8.2)	419 (4.8)
Opsanus pardus	leopard toadfish	14 (1.0)	7 (0.3)	5 (0.2)	2 (0.1)	1 (0.1)	29 (0.3)
Orthopristis chrysoptera	pigfish			5 (0.2)		1 (0.1)	6 (<0.1)
Paralichthys lethostigma	southern flounder	1 (<0.1)					1 (<0.1)
Psenes maculatus	silver driftfish	1 (<0.1)					1 (<0.1)
Remora remora	remora			1 (<0.1)			1 (<0.1)
Seriola dumerili	greater amberjack		1 (<0.1)	2 (<0.1)		1 (0.1)	4 (<0.1)
Sphoeroides maculatus	northern puffer	7 (0.5)		4 (0.2)	2 (0.1)		13 (0.2)
Stenotomus chrysops	scup	367 (25)	546 (26.3)	1191 (49.4)	587 (32.8)	179 (18.3)	2870 (32.9)
Stephanolepis hispidus	planehead filefish	2 (0.1)	1 (<0.1)			4 (0.4)	7 (<0.1)
Total		1,469	2,077	2,411	1,790	980	8,727

Appendix 1. Metadata for Figure 1, which depicted the GRNMS Benthic Habitat Map and location of all chevron traps deployed between 1993 and 2005

Originator: MARMAP and Athan Barkoukis

Publication Date: 2006

Title: Location of all chevron traps deployed between 1993 and 2005 at GRNMS

Geospatial Data Presentation Form: Map

Abstract: Sampling at Gray's Reef National Marine Sanctuary was conducted through three survey types that utilized chevron fish traps. 1) trap set used as part of a region-wide annual monitoring program in the South Atlantic which included traps set at GRNMS (Annual Assessment). 2) trap sets that were verified by divers to determine placement of traps with respect to specific habitat types (Ground Truth). 3) trap sets used to collect black sea bass for tag-recapture studies (Tag-Recapture).

Purpose: To elucidate spatial and temporal variations in fish assemblages at Gray's Reef National Marine Sanctuary using chevron trap data collected between 1993-2005.

Overview Description: Trap collections during Annual Assessment and Tag-Recapture sampling were assigned habitats using the Intersect Tool, which linked the latitude and longitude coordinates of the traps to the habitats within the Benthic Habitat Map shapefile created by NOAA in conjunction with GRNMS. If the diver's habitat assessment differened from the Benthic Habitat Map during the Ground Truth survey, traps were assigned to the diver observed habitat.

Calendar Date: 2006

Currentness Reference: Data collected between 1993-2005 and published in 2006.

Progress: Completed

Maintenance and Update Frequency: No updates

Bounding Coordinates:

West Bounding Coordinate: 507328.048273 m

East Bounding Coordinate: 516427.648657 m

North Bounding Coordinate: 3476177.276464 m

South Bounding Coordinate: 3469554.182852 m

Keywords: Gray's Reef National Marine Sanctuary, Benthic Habitat Map, Fish.

Access Constraints: Contact MARMAP at the SCNDR

Use Constraints: Contact MARMAP at the SCDNR

Native Data Set Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.0.0.535

Citation Information - Title: A Temporal and Spatial Analysis of Chevron Traps at Gray's Reef National Marine Sanctuary.

Metadata Date: 20060409

Metadata Contact Person: Athan Barkoukis

Contact Organization: College of Charleston

Contact Position: Graduate Student

Contact Address: Brecksville, OH 44141 USA

Contact Electronic Mail Address: athan02@hotmail.com

Metadata Standard Name: FGDC Content Standards for Digital Geospatial Metadata

Metadata Standard Version: FGDC-STD-001-1998

Appendix 2. Metadata for Figure 2, which depicted the GRNMS Benthic Habitat and location of traps used in the Ecotone Analysis.

Originator: MARMAP and Athan Barkoukis

Publication Date: 2006

Title: Location of 65 traps used in the Ecotone Analysis

Geospatial Data Presentation Form: Map

Abstract: Three aspects of the project provided a degree of spatial uncertainty when assigning traps to habitat types. These aspects included Benthic Habitat Map inaccuracy, ambiguity in knowing the precise location of traps deployed on the seafloor, and a lack of information on the area fished by a chevron trap. Therefore, a GIS application was used to create a 20-m radius circle (1257 m^2) around each trap, which provided more information on habitats associated with each catch.

Purpose: To determine differences in diversity of traps associated with multiple habitats to those surrounded by only one habitat type.

Overview Descriptions: Three aspects of the project provided a degree of spatial uncertainty when assigning traps to habitat types. These aspects included Benthic Habitat Map inaccuracy, ambiguity in knowing the precise location of traps deployed on the seafloor, and a lack of information on the effective area fished by a chevron trap. To address spatial uncertainty in trap placement with respect to habitat, additional analyses were conducted on the traps. Traps were classified to a habitat based on the area surrounding a trap rather than only using the specific point (Point Analysis) at which a trap landed. To do this, a Personal Geodatabase was created in a Geographic Information System (GIS) using ArcGIS version 9.0 (Murad-al-shaikh *et al*., 2003) for all traps deployed in the Annual Assessment surveys. A GIS application was used to create a 20-

m radius circle (1257-m^2) around each trap, which provided more information on habitats associated with each catch. Once the circles were created around each trap, the ‘Intersect, Dissolve and Compute Statistics’ tools in ArcToolbox were used to determine the area of all habitats within the 20-m circle. Habitats were assigned to a trap if they consisted of five percent or more of the total area within the circle. Traps that contained more than one habitat were assigned as an “ecotone” trap of multiple habitats.

Calendar Date: 2006

Currentness Reference: Data collected between 1993 and 2005 and published in 2006.

Progress: Completed

Maintenance and Update Frequency: No updates

Bounding Coordinates:

West Bounding Coordinate: 507328.048273 m

East Bounding Coordinate: 516427.648657 m

North Bounding Coordinate: 3476177.276464 m

South Bounding Coordinate: 3469554.182852 m

Keywords: Gray’s Reef National Marine Sanctuary, Benthic Habitat Map, Ecotone, Fish.

Access Constraints: MARMAP; SCDNR

Use Constraints: MARMAP; SCDNR

Native Data Set Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.0.0.535

Citation Information -Title: A Temporal and Spatial Analysis of Chevron Traps at Gray's Reef National Marine Sanctuary.

Metadata Date: 20060409

Metadata Contact Person: Athan Barkoukis

Contact Organization: College of Charleston

Contact Position: Graduate Student

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Metadata Standard Name: FGDC Content Standards for Digital Geospatial Metadata

Metadata Standard Version: FGDC-STD-001-1998

Appendix 3. Metadata for Figure 11, depicting 10 black sea bass recaptured more than two times at GRNMS.

Originator: MARMAP and Athan Barkoukis

Publication Date: 2006

Title: Movement of 10 Black Sea Bass

Geospatial Data Presentation Form: Map

Abstract: Understanding movement of the dominant fishes in GRNMS is important to their continued protection. Not only does movement influence patterns in abundance and community structure, but grasping the extent and area of fish movement offers a tool for managers seeking to potentially close a section of GRNMS from fishing activities for conservation and research purposes. These data depict high site fidelity by 10 black sea bass within GRNMS.

Purpose: To show the high site fidelity observed by black sea bass at GRNMS.

Overview Description: GIS was used to determine the linear distance movement from tag to recapture locations for black sea bass. The distance was calculated with an ArcGIS extension code and tool, 'Points to Lines V.2,' which converted the DBF of XY values between tag and recapture coordinates to a polyline shapefile.

Calendar Date: 2006

Currentness Reference: Data collected between 1993 and 2005 and published in 2006.

Progress: Completed

Maintenance and Update Frequency: Not updated

Bounding Coordinates:

West Bounding Coordinate: 507328.048273 m

East Bounding Coordinate: 516427.648657 m

North Bounding Coordinate: 3476177.276464 m

South Bounding Coordinate: 3469554.182852 m

Keywords: Gray's Reef National Marine Santuary, black sea bass, site fidelity, movement

Access Constraints: MARMAP, SCDNR

Use Constraints: MARMAP, SCDNR

Native Data Set Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.0.0.535

Citation Information - Title: A Temporal and Spatial Analysis of Chevron Traps at Gray's Reef National Marine Sanctuary.

Metadata Date: 20060409

Contact Person: Athan Barkoukis

Contact Organization: College of Charlesotn

Contact Position: Graduate Student

Contact Address: Brecksville, OH 44141 USA

Contact Electronic Mail Address: athan02@hotmail.com

Metadata Standard Name: FGDC Content Standards for Digital Geospatial Metadata

Metadata Standard Version: FGDC-STD-001-1998

Appendix 4. Metadata for Figure 12, depicting the location of black sea bass recaptured outside of GRNMS.

Originator: MARMAP and Athan Barkoukis

Publication Date: 2006

Title: Location of all black sea bass (n=17) recaptured outside of GRNMS

Geospatial Data Presentation Form: Map

Abstract: Understanding movement of the dominant fishes in GRNMS is important to their continued protection. Not only does movement influence patterns in abundance and community structure, but grasping the extent and area of fish movement offers a tool for managers seeking to potentially close a section of GRNMS from fishing activities for conservation and research purposes. Increases in linear movement of fishes are often positively correlated to their size, and fishes that utilize more than one habitat often have larger home ranges.

Purpose: To determine the movement of black sea bass tagged at GRNMS.

Overview Description: GIS was used to determine the linear distance movement from tag to recapture locations for black sea bass. The distance was calculated with an ArcGIS extension code and tool, ‘Points to Lines V.2,’ which converted the DBF of XY values between tag and recapture coordinates to a polyline shapefile.

Calendar Date: 2006

Currentness Reference: Data collected between 1993 and 2005 and published in 2006.

Progress: Completed

Maintenance and Update Frequency: No updates

Bounding Coordinates:

West Bounding Coordinate: 507328.048273 m

East Bounding Coordinate: 516427.648657 m

North Bounding Coordinate: 3476177.276464 m

South Bounding Coordinate: 3469554.182852 m

Keywords: Gray's Reef National Marine Sanctuary. black sea bass, Tagging, Movement

Access_Constraints: MARMAP; SCDNR

Use_Constraints: MARMAP; SCDNR

Native Data Set Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.0.0.535

Citation Information - Title: A Temporal and Spatial Analysis of Chevron Traps at Gray's Reef National Marine Sanctuary.

Metadata Date: 20060409

Contact Person: Athan Barkoukis

Contact Organization: College of Charleston

Contact Position: Graduate Student

Contact Address: Brecksville, OH 44141 USA

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Metadata Standard Name: FGDC Content Standards for Digital Geospatial Metadata

Metadata Standard Version: FGDC-STD-001-1998

Metadata Time Convention: local time

Profile Name: ESRI Metadata Profile