

Integrating GIS with Fishery Survey Historical Data: A Possible Tool for Designing Marine Protected Areas

JILL J. ROWE¹ and GEORGE R. SEDBERRY²

¹Applied Science Associates, Inc.

70 Dean Knauss Drive

Narragansett, Rhode Island 02882 USA

²Marine Resources Research Institute

P.O. Box 12559

Charleston, South Carolina 29412 USA

ABSTRACT

Spatial patterns in the abundance, biomass, and diversity of fishes caught on the continental shelf and upper slope off the southeastern United States Atlantic coast were described from a fishery-independent trawl survey conducted from 1973 - 1980. Geographic Information Systems (GIS) analysis revealed that relative abundance and biomass of fishes caught in depths from 11 - 360 m were significantly higher between coastal and shelf break (11-140 m) waters than in deeper off-shelf zones, and fish abundance was significantly higher off the coast of Charleston, South Carolina than farther south off the coast of Georgia and northern Florida. The highest levels of diversity occurred in shelf-edge and upper slope waters (41 - 120 m), and two diversity indices, Shannon Wiener Index and Margalef's species richness, were positively correlated with the presence of hard bottom habitat and reported reef fish spawning locations. The analyses revealed areas of particularly high fish biomass, abundance, and diversity that should be given consideration as marine protected areas for deep reef species that are not effectively managed by traditional means.

KEY WORDS: Diversity, GIS, MPA

Integración de GIS con Datos Históricos de la Pesquería: Un Instrumento Posible para Diseñar Areas Marinas Protegidas

Los patrones espaciales en la abundancia, biomasa, y la diversidad de los peces encontrados en la plataforma continental y la cuesta superior sureste del Atlántico de los Estados Unidos, fueron descritos por una encuesta arrastrada de pesquería independiente conducida desde 1973 hasta 1980. El análisis de los Sistemas de Información Geográfico (GIS) reveló que la abundancia relativa y la biomasa de los peces encontrados en profundidades desde 11 - 360 metros fueron significativamente más altas entre aguas rompientes de plataforma y costeras (11 - 140 metros) que en zonas más profundas fuera de la plataforma, y la abundancia de peces fue significativamente mayor en las afueras de la costa de Charleston, Carolina del Sur que más hacia el sur de la afueras de la costa de Georgia y norte de Florida. Los mayores niveles de diversidad ocurrieron en el borde de plataforma y aguas de cuesta superior (41-

120 metros), y dos índices de diversidad, el Índice de Shannon Wiener y riqueza de especies de Margalef, fueron positivamente correlacionada con la presencia de un hábitat de profundidad duro y reportó localidades de freza (zona de desove) de peces de coral. Los análisis revelaron áreas de particularmente alta de biomasa de peces, abundancia y diversidad, que deben ser dados en consideración como áreas marinas protegidas para especies de corales profundos que no son efectivamente manejados por medios tradicionales.

PALABRAS CLAVES: GIS, áreas marinas protegidas, pesquería

INTRODUCTION

The continental shelf off the southeastern United States from Cape Hatteras to Cape Canaveral out to the edge of the Exclusive Economic Zone (EEZ), also referred to as the South Atlantic Bight in published fisheries research (Govoni and Hare 2001), provides habitat for a highly diverse marine fauna, including many species that are important in recreational and commercial reef fisheries (Coleman et al. 2000). The marine fauna of the region receives contributions from northern waters via intrusions of Labrador Current waters around Cape Hatteras (Briggs 1974), and from the Caribbean via transport of southerly fauna in the Florida Current and Gulf Stream (Schwartz 1989). Rocky outcrops and other reef features also contribute to the diversity of the marine fauna by providing habitat complexity over portions of the sandy continental shelf (Miller and Richards 1980). These rocky reef habitats support a higher abundance, biomass and diversity of fishes and invertebrates than adjacent areas of open, sandy-bottom shelf (Wenner et al. 1983, Sedberry and Van Dolah 1984), and are heavily fished (Coleman et al. 2000).

Struhsaker (1969) divided the continental shelf and upper slope waters between Cape Hatteras, North Carolina and the southern tip of Florida into five bottom habitat types based on species composition of trawl catches:

- i) Coastal areas (0 - 18 m depth) - mostly smooth sandy bottom;
- ii) Open shelf (18 - 55 m) - sandy bottom with relatively stable hydrographic conditions in areas >30m depth due to the influence of the Gulf Stream (Wenner 1983);
- iii) Live bottom (19 - 44 m);
- iv) Shelf edge (45 - 110 m) - smooth to highly broken bottom, and
- v) Lower shelf (110 - 200 m) and upper shelf (>200m) - smooth muddy bottom with some rocky outcrops and mounds.

Oceanographers have divided the open shelf into the middle shelf (21-40m) and outer shelf (41 - 60 m; Barnard et al. 1997), while the shelf edge includes the outer shelf (41 - 60 m) and shelf break (55 - 75 m).

Interest in the distribution of reef habitat has grown due to 1) concerns about the ability of the southeastern U.S. continental shelf to support reef fish populations facing intense fishing pressure (Coleman et al. 2000), and 2) mandates in essential fish habitat (EFH) provisions of the Magnuson-Stevens Fishery Conservation and Management Act that spatial relationships between fishery species and habitats need to be included in fishery management plans

(Rubec et al. 1999). While the definition of habitat quality is difficult to interpret as linkages between fish and their habitats are complex and often dynamic (Able 1999), species distributions based on trawl survey data can be used as proxies for the distribution of seafloor habitats (Auster et al. 2001).

Huntsman and Manooch (1978) reported that no more than 10% (9,064 km²) of the bottom morphology of the southeastern U.S. continental shelf is reef. On the other hand, Parker et al. (1983) estimated the total amount of reef habitat between Cape Hatteras and Cape Canaveral to be 22.8% (57,159 km²) of the total bottom area. The considerable difference between these reported estimates shows the lack of, and uncertainty about, these data. Nonetheless, only a portion of the shelf is available to sustain reef fish populations. A geographic information system (GIS) database has been developed that provides reef habitat locations on the continental shelf and upper slope (to 200m depth) of the southeastern U.S. Atlantic coast (SEAMAP-SA 2001), and supports previous reports of hard bottom habitats being relatively scarce. Over 40% of the records in the SEAMAP database indicate the presence of hard bottom, although effort concentrated on data that could indicate hard bottom (SEAMAP-SA 2001).

In addition to limited habitat availability, reef fishes possess life history characteristics making them particularly susceptible to overfishing (Coleman et al. 2000). As the intensity of fishing pressure has increased off the southeastern U.S., there is greater need for conservation measures such as marine protected areas or MPAs (PDT 1990). MPAs have been defined by The World Conservation Union as “any area of intertidal or subtidal terrain, together with overlying water and associated flora, fauna, historical and cultural features, which have been reserved by law or other effective means to protect part or all of the enclosed environment” (IUCN 1988).

The South Atlantic Fisheries Management Council (SAFMC), which has jurisdiction in the southeastern U.S., is considering two types of MPAs for management of reef fishes: 1) complete no-take areas where no harvest is allowed, and 2) areas where only bottom fishing is prohibited. The purpose of these MPAs would be to restore reef fish stocks, especially those subject to fishing (e.g., snapper and grouper), particularly at depths where traditional management does not work due to release mortality.

It is critical to obtain a better understanding of the distribution of habitat, fishes, fishing effort and ocean circulation patterns, in order to site MPAs and ultimately reach the goal of maintaining sustainable fishery populations (Murray et al. 1999). Siting MPAs in areas of historically low fish biomass is not likely to be effective in conservation of significant fish productivity. Siting MPAs in areas with low historical biodiversity is not likely to include reef habitats that are high in fish diversity and biomass (Sedberry and Van Dolah 1984). Examination of historical fishery survey databases with recently developed analysis tools can help locate areas of traditionally high biomass and diversity for MPA consideration. In this article, we provide an example of such an application by examining a large historical database for patterns in fish abundance, biomass, diversity and distribution using GIS. The purpose of our analysis was to determine sites that are likely to support reef fish populations, as indicated by high diversity of catches. We also looked for areas of high

biomass, abundance or diversity that the SAFMC were not considering as additional potential MPAs.

METHODS

Analyses were based on a groundfish trawl survey conducted by the National Marine Fisheries Service and the South Carolina Department of Natural Resources from 1973 - 1980. Trawl surveys were conducted at least once annually (Table 1). The survey from 1973-winter of 1977 consisted of a stratified random sampling design (see Wenner et al. 1979 for details of trawl sampling) that sampled 738 stations distributed within specified depth (11-366m) and latitudinal zones (Table 1, Figure 1). The Groundfish Survey from summer 1977-1980 consisted of a systematic sampling plan along seven transects, resulting in an additional 282 trawl collections. Transects were spaced fairly equidistant along the coast and perpendicular to the coastline from 11 - 183 m depth. For the Groundfish Survey, tow duration was thirty minutes, and distance varied slightly but was not measured.

Table 1. Summary of all cruises and sampling effort for the MARMAP Groundfish Survey (1973-1980). Effort refers to the number of trawls conducted per cruise. (Survey type: Random = stratified random, Transect = systematic transect sampling; see text for explanation.)

Year	Months	Effort	Survey Type
1973	Oct-Nov	87	Random
1974	Apr-May	116	Random
1974	Aug-Sep	88	Random
1975	Jan-Apr	92	Random
1975	Aug-Sep	87	Random
1976	Jan-Feb	86	Random
1976	Aug-Sep	89	Random
1977	Jan-Mar	93	Random
1977	Aug-Sep	50	Transect
1978	Jan	52	Transect
1978	Sep	60	Transect
1979	Aug	58	Transect
1980	Jul	62	Transect

Total number of trawls (or stations) = 1,020

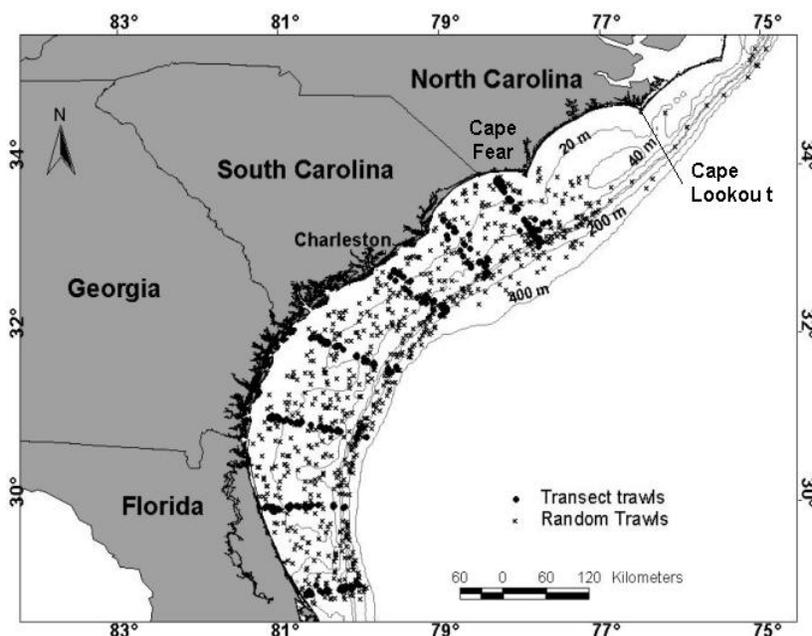


Figure 1. Locations of all trawl stations sampled during fishery surveys from 1973 - 1980. $n = 1,020$.

Analyses were conducted on total fish abundance and biomass using trawl data from summer months (July-September) only, which helped to reduce seasonal effects on catch variability. However, trawls from all seasons were used in diversity analyses to capture seasonal influx of species. Initial analysis of the trawl data showed that the variance in number of individuals and weight per tow far exceeded the mean and approximated a negative binomial distribution. Therefore, all catch per tow data were log-transformed [$\ln(x + 1)$] before statistical analysis to standardize the variance and approximate a normal distribution (Taylor 1953).

GIS (ArcView Version 3.1; ESRI 1998) was utilized for visualization and spatial data analysis and to elucidate geographic patterns in distribution of abundance, biomass, and diversity that were subject to further statistical analyses. For visualization purposes, catch per trawl was mapped and interpolated to a grid surface of 1.5-minute latitude x 1.5-minute longitude cells. These interpolated surfaces were created using the inverse distance weighted (IDW) procedure (ESRI 1998), which converts the point data to grids, and assumes that each input point has a local influence that diminishes with distance. Therefore, points closer to the processing cell are weighted greater than those farther away. Points within a fixed radius of 29.39km were used in these interpolations to create the specified 1.5-minute latitude x 1.5-minute longitude cell size. Further details of the GIS analysis can be found in Jennings (2001).

Following visualization and spatial analysis of the trawl data using GIS,

log-transformed relative abundance and biomass data were statistically compared using nonparametric Kruskal Wallis tests (Sokal and Rohlf 1995). Tukey-Kramer multiple comparison tests (Sokal and Rohlf 1995) were used *a posteriori* to compare among means of unequal sample sizes for specific differences in equally-divided latitudinal regions and depth ranges of 20m increments.

To determine whether a relationship between bottom type, fish abundance and fish biomass existed, bottom type data, compiled from SEAMAP Hard Bottom Mapping Project (Van Dolah et al. 1994), were pooled into 10-minute grids using GIS. For each 10-minute grid, a derived index of bottom type was calculated based on the average score of all collections within that grid. These scores range from 0 (no hard bottom) to 1 (possible hard bottom) to 2 (hard bottom). Pearson correlations (Sokal and Rohlf 1995) were used to compare transformed indices of relative abundance and biomass data of species caught by trawl to derived bottom type scores.

All fishes caught during the groundfish trawl survey were pooled into 10-minute latitude x 10-minute longitude grids (ArcView Spatial Analyst) to calculate three diversity indices: Margalef's (1958) species richness (D), Shannon-Wiener Index (H') (Shannon and Weaver 1949), and Pielou's (1975) Evenness Measure (J'), using a SAS biodiversity program (SAS Institute Inc. 1997). Diversity indices were then mapped and interpolated to a 1.5-minute latitude x 1.5-minute longitude cell surface following the same procedure described previously.

Following visualization and spatial analysis of the trawl data using GIS, the same statistical comparisons were performed on the pooled diversity data as were done with the relative abundance and biomass data. Likewise, applying the same procedure as was used to determine whether relationships existed between bottom type and relative abundance and biomass, Pearson correlations (Sokal and Rohlf 1995) were performed to compare diversity data of species caught by trawl to derived bottom type scores for each 10-minute grid.

RESULTS

A total of 785,088 fishes were sampled by trawl from 1973-1980 (Table 2). However, over 70% of the individuals sampled were represented only by 12 species, regardless of seasonality. Mean number of fishes and their biomass per trawl differed significantly among depth ranges (Table 3, Figure 2). Mean number caught per tow was higher in shallow water (11 - 40 m) than elsewhere in the survey area, however, abundance was significantly higher on the continental shelf (11 - 140 m) than upper slope (141 - 340 m) (Table 3, Figure 2). Mean biomass per tow was higher in shallow and outer shelf waters (11 - 80 m) than elsewhere in the survey area, and was significantly higher on the shelf (11 - 40 m and 61 - 80 m) than on the deeper shelf edge and upper slope (81 - 100 m, 121 - 160 m and 241 - 300 m; Table 3, Figure 2). Relative abundance of fish varied by latitude as well as depth. The mean number of individuals per tow was higher in latitude zone 2 off the coast of Charleston, SC than latitude zone 4 off the coast of Georgia and northern Florida (Table 3,

Figure 3). Areas of particularly high fish abundance were noted between Cape Lookout and Cape Fear off North Carolina (Onslow Bay). There was no significant difference in the relative biomass of all fishes caught among latitudinal ranges, but there were scattered areas of high fish biomass throughout the region at mid-shelf depths (Table 3, Figure 2).

Table 2. Most abundant species caught during all months of the groundfish trawl surveys from 1973 to 1980 (n = 1,020 trawls). This reflects the most abundant species living on or near the bottom of the continental shelf and upper slope off the southeastern United States Atlantic coast.

Scientific name	Common name	Total abundance	% of total individuals
<i>Stenotomus chrysops</i>	scup	166,293	21.2
<i>Decapterus punctatus</i>	round scad	70,442	9.0
<i>Anchoa cubana</i>	Cuban anchovy	59,690	7.6
<i>Sardinella aurita</i>	Spanish sardine	51,533	6.6
<i>Etrumeus teres</i>	round herring	49,158	6.3
<i>Anchoa lyolepis</i>	dusky anchovy	40,676	5.2
<i>Peprius tricanthus</i>	butterfish	39,685	5.1
<i>Haemulon aurolineatum</i>	tomtate	21,833	2.8
<i>Monacanthus hispidus</i>	planehead filefish	18,632	2.4
<i>Urophycis regia</i>	spotted hake	12,146	1.6
<i>Chloroscombrus chrysurus</i>	Atlantic bumper	10,877	1.4
<i>Anchoa hepsetus</i>	striped anchovy	10,106	1.3
Sum of above		551,071	
Total of all species caught by trawl		785,088	70.2

Areas of high fish abundance and biomass coincided with concentrations of hard bottom (Table 3, Figure 4), and included the shallow waters just north of Long Bay, NC (< 20 m), the waters just offshore Long Bay (15 - 40 m), and the waters off Charleston, SC (15 - 25 m). When using the derived score in bottom type per grid, there was a significant positive correlation between bottom type and the relative abundance and biomass of fishes (Table 3).

Significant differences were found in the three diversity indices among depth ranges. Mean values of Shannon-Wiener index (H'), which varied from 0.18 - 4.78, were significantly lower in coastal and mid-shelf depths (11 - 40 m) than deeper, off-shelf zones (41 - 120 m, 141 - 160 m and 221 - 280 m; Table 3, Figure 5). Similarly, the coastal and mid-shelf depths (11 - 40 m) had significantly lower mean values of Pielou's species evenness (J'), which varied from 0.05 - 1.0, than deeper zones (41 - 60 m, 81 - 100 m and 261 - 280 m; Table 3, Figure 5). Outer shelf to lower shelf depths (41 - 120 m and 141 - 160 m) had higher means in species richness, which varied from 0.62 - 13.05, than coastal, mid-shelf, deeper lower shelf, and off-shelf depths (11 - 40 m and 181 - 320 m; Table 3, Figure 5). Coastal depths (11 - 20 m) also had significantly

lower species richness than mid-shelf depths (21 - 40 m).

Table 3. Summary of statistical analyses done on the abundance, biomass and diversity of fishes caught per trawl (1973-1980). Statistical comparisons among means for depth and latitudinal ranges were made using Kruskal Wallis tests and Tukey Kramer multiple comparison tests ($p < 0.05$). Pearson correlation analysis was used between the abundance, biomass and diversity of fish and bottom type per 10-minute grid. (NS = no significant difference).

	Depth Range	Latitudinal Range	Correlation with Bottom Type
Biomass	$p < 0.0001$	NS	$r = 0.136$, $p = 0.000$
Abundance	$p < 0.0001$	$p = 0.0222$	$r = 0.134$, $p = 0.000$
<u>Diversity Indices</u>			
Shannon Wiener	$p < 0.0001$	$p = 0.0111$	$r = 0.061$, $p = 0.039$
Species Evenness	$p < 0.0001$	$p = 0.0048$	$r = -0.161$, $p = 0.000$
Species Richness	$p < 0.0001$	$p < 0.0001$	$r = 0.367$, $p = 0.000$

All three diversity indices were significantly different among the six equal latitudinal ranges (Table 3, Figure 6). Significantly higher H' occurred in latitude zone 6 off the coast of Cape Canaveral, FL than in latitude zone 4 off the coast of Georgia and northern Florida. Species evenness was significantly higher off the coast of Cape Canaveral, FL in zone 6 than in latitudinal zone 2 off the coast of Charleston, SC. Significantly higher species richness occurred in latitudinal zones 6 and 2 than in the other survey areas (zones 1, 3, 4 and 5).

GIS and statistical analysis of diversity values indicated localized areas of high fish diversity along the shelf break (40-100 m, Figure 7). High diversity measures correlated with areas of hard bottom (Table 3), particularly along the shelf edge, indicating areas where the presence of hard bottom, deep water and proximity to the Gulf Stream resulted in high reef diversity.

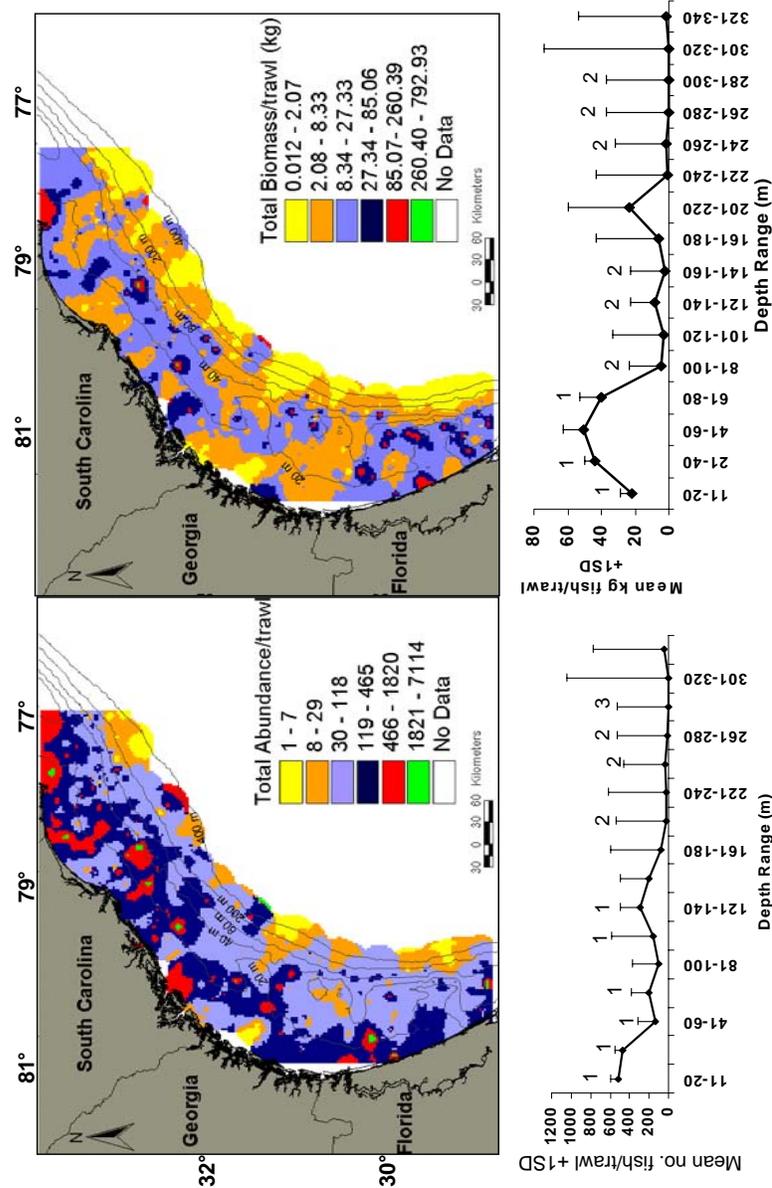


Figure 2. Mean number of individuals per tow and mean biomass per tow of all fishes caught by trawl ($n = 487$) during the summer months of the groundfish survey (1974-1980) statistically compared between 20 m depth ranges (Kruskal Wallis, $p < 0.0001$ for each). The graphs illustrate Tukey-Kramer test results, with significantly different ($p < 0.05$) means indicated by different numbers. Means with the same number are not significantly different from each other.

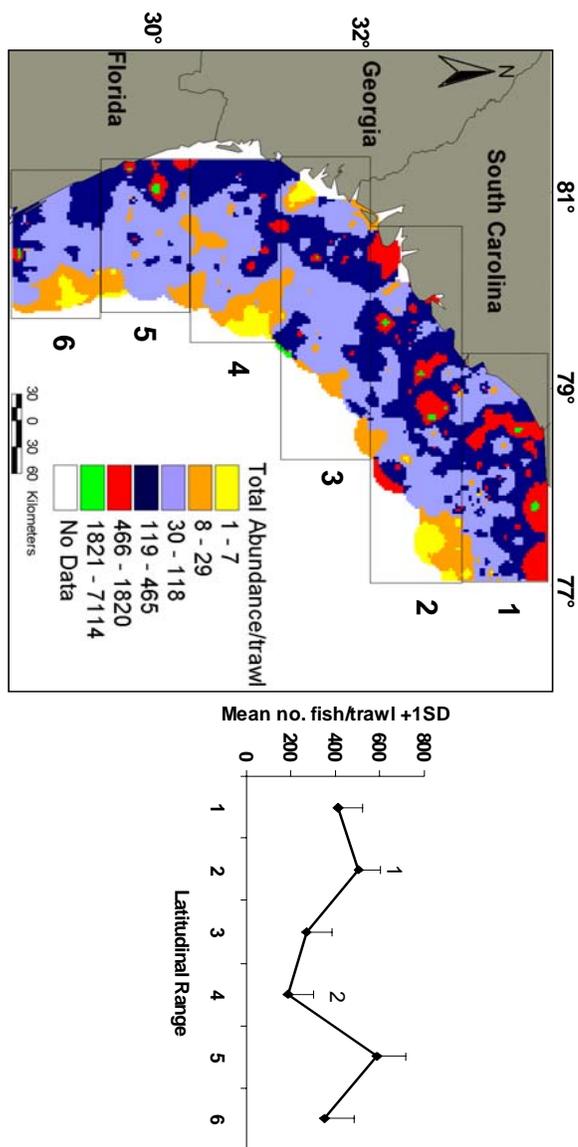


Figure 3. Mean number of individuals per tow for all fishes caught by trawl (n = 487) during the summer months of the groundfish survey (1974-1980) statistically compared between six equal latitudinal ranges (Kruskal Wallis, $p = 0.0222$). The graphs illustrate Tukey-Kramer test results, with significantly different ($p < 0.05$) means indicated by different numbers. Means with the same number are not significantly different from each other.

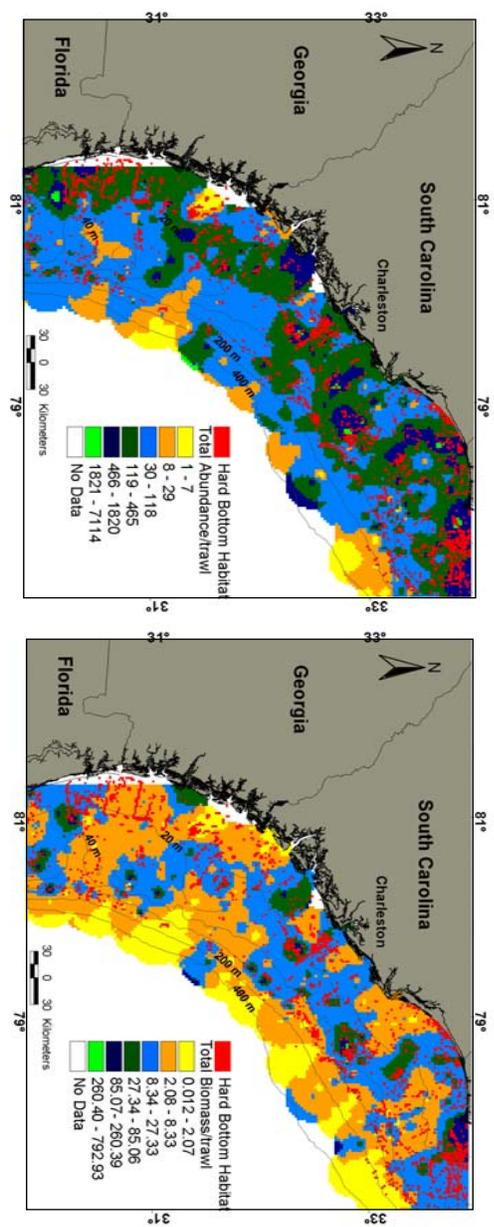


Figure 4. SEAMAP hard bottom grids (one minute *one minute) mapped on the interpolated surface of fish abundance and biomass from summer trawls (n = 487) during the groundfish survey (1974-1980).

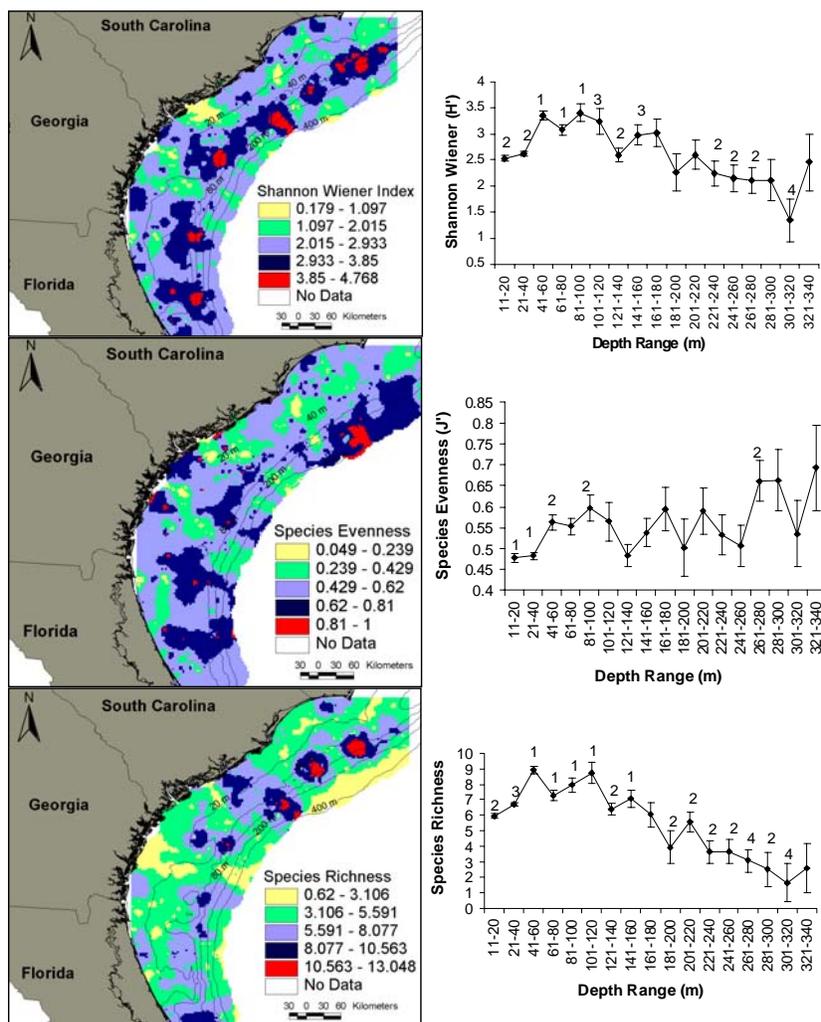


Figure 5. Statistical comparisons between 20-m depth ranges and Shannon-Wiener diversity index (H'), species evenness, and Margalef's species richness based on pooled samples of all species caught by trawl ($n = 1,020$) during all months of the groundfish survey (1973-1980). The graphs illustrate Tukey-Kramer test results, with significantly different ($p < 0.05$) means indicated by different numbers. Means with the same number are not significantly different from each other.

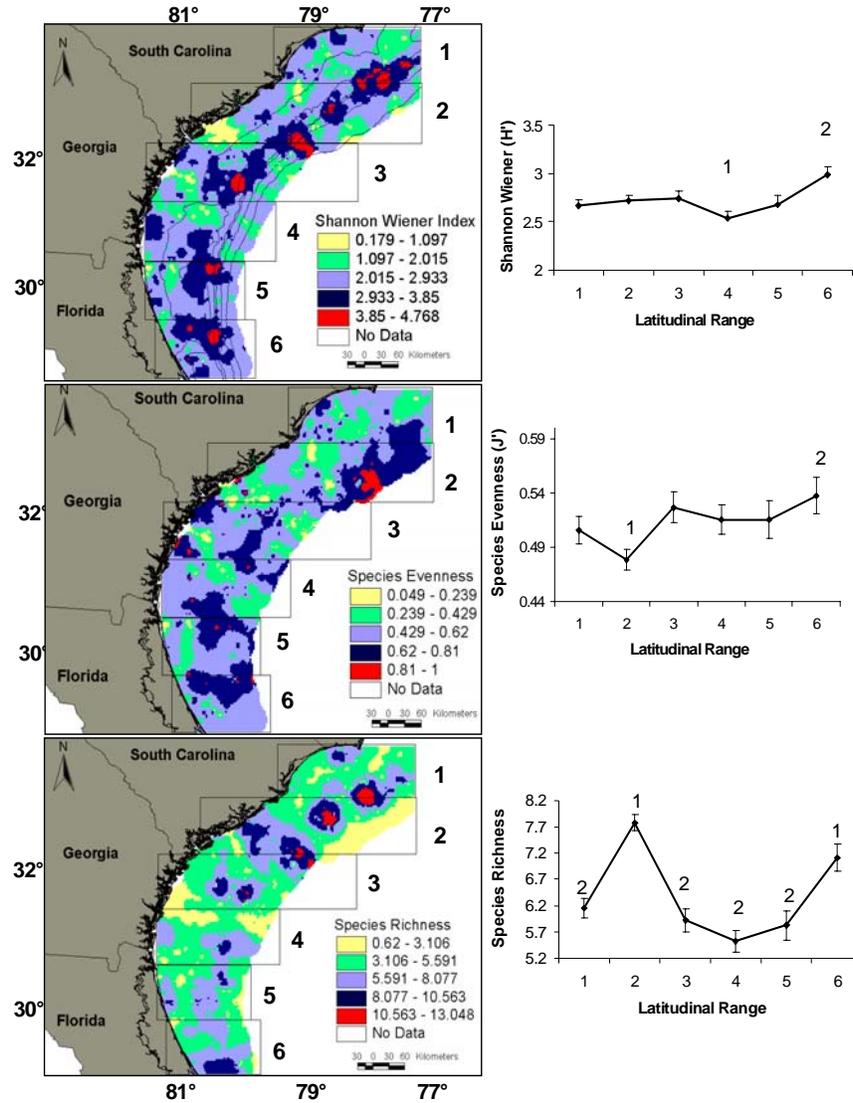


Figure 6. Statistical comparisons between six equal latitudinal ranges and Shannon-Wiener diversity index (H'), species evenness, and Margalef's species richness based on pooled samples of all species caught by trawl ($n = 1,020$) during all months of the groundfish survey (1973-1980). The graphs illustrate Tukey-Kramer test results, with significantly different ($p < 0.05$) means indicated by different numbers. Means with the same number are not significantly different from each other.

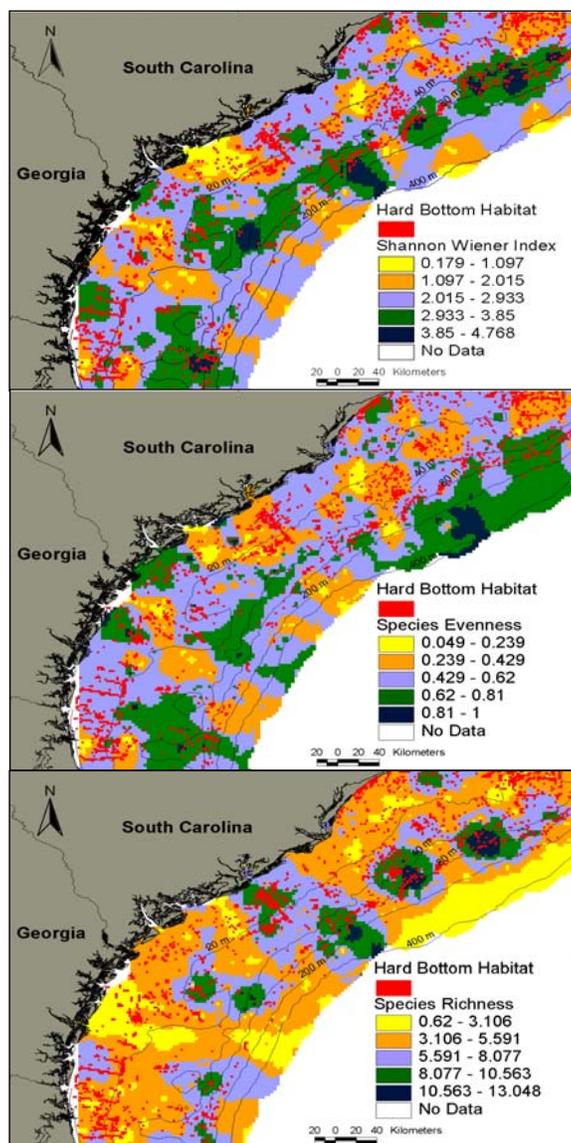


Figure 7. SEAMAP hard bottom grids (one minute *one minute) mapped on the interpolated surface of Shannon Wiener index (H'), species evenness and Margalef's species richness from all trawls (n = 1,020) during the groundfish survey (1973-1980).

DISCUSSION

The highest relative abundance and biomass occurred on the shelf (11 - 140 m) versus off the upper slope (> 140 m). Higher fish abundance and biomass in coastal and mid-shelf depths than in deeper areas probably resulted from factors such as more stable temperatures and the presence of moderate relief hard bottom at these depths (Sedberry and Van Dolah 1984). High abundance and biomass of fishes was also noted on the outer shelf off North Carolina, between Cape Fear and Cape Lookout (Figure 2). The shelf edge between these capes is an area of cross-shelf transport of nutrients upwelled at the shelf edge, and of increased productivity (Lee et al. 1991). The localized, yet persistent, oceanographic phenomena that cause this productivity support very localized high abundance and biomass of fishes. Such systems, in which productive oceanographic conditions coincide with suitable bottom habitat for fishery species (i.e. hard bottom reef), are relatively rare on the southeastern continental shelf, and may warrant special protection as producers and possible exporters of fish biomass in the region.

Although there have been reports of higher estimates of fish biomass from specific hard bottom areas of the South Atlantic Bight compared to nearby sandy bottoms (Wenner 1983), this phenomenon could not be easily examined in the current analysis, since bottom type was not confirmed visually as in Wenner (1983). Nonetheless, the abundance and biomass of fishes collected during the groundfish survey showed positive correlations with the derived bottom-type scores from the SEAMAP-SA (2001) hard bottom mapping project. It is apparent from fishery landings and fishery-independent surveys that hard bottom reefs support the greatest fish biomass and constitute the primary bottom fishery habitats off the southeast coast (Wenner 1983).

A latitudinal variation in the amount of hard bottom could explain the higher abundance in trawl catches off Charleston, SC than farther south, off Georgia and northern Florida. The SEAMAP bottom type analysis is supported by previous geological surveys showing the greatest amount of high relief habitat at the shelf edge off the Carolinas and in a small area off northern Florida (Barans and Henry 1984). The combination of increased hard bottom composition and oceanographic features on the continental shelf off North Carolina and northern South Carolina results in higher fish abundance relative to the shelf off Georgia and northern Florida.

Sedberry and Van Dolah (1984) found diversity (H') values ranging from 0.80 - 3.21 in hard bottom areas of the South Atlantic Bight, while in the current study the H' values from trawl collections pooled by cell ranged from 0.18 - 4.78, with the elevated values similar to those found in some tropical systems (Sedberry et al. 1999). It has been suggested the normal scale for H' results spans from 1.50 - 3.50, and rarely surpasses 4.50 (Magurran 1988). Species evenness (J') estimates in this study were within the range reported previously for the continental shelf of the southeastern U.S. and tropical areas (Sedberry and Van Dolah 1984; Sedberry and Carter 1993). The range of species richness estimates in this analysis, however, far exceeded those reported previously for this region. The occasional high species richness value helps to explain higher than normal H' estimates (Magurran 1988). Species

richness values for this study ranged from 0.62 - 13.05, while ranging from either 3.54 - 5.51 on mid-shelf, live bottom reefs of the southeastern shelf (Sedberry and Van Dolah 1984) or 2.5 - 5.5 in Belize (Sedberry and Carter 1993). High species richness estimates resulted from a much broader range of depths, latitude and seasonal temperature variation than that covered in other trawl surveys.

Levels of diversity in this study were significantly higher between the outer shelf (41 - 60 m) and lower shelf (110 - 120 m and 141 - 160 m), as compared to shallower and deeper areas. Small areas of high H' diversity and species richness were positively correlated with hard bottom habitat. These pockets of high diversity were discontinuous, apparently coinciding with rocky outcrops at the shelf edge (Grimes et al. 1982). While discontinuous, these features are connected by the Gulf Stream flow, which may disperse pelagic eggs and larvae of tropical and subtropical fishes and other marine organisms, from one patch of outcrop to the next (Olney and Sedberry 1983). Such influx of larvae from tropical and subtropical locations upstream helps maintain a high diversity in fishes and invertebrates.

While high H' diversity and species richness coincided with shelf edge reefs, species evenness was negatively correlated with the presence of hard bottom. Low evenness appears to be associated with hard bottom on the shelf, which could indicate low evenness with high niche diversity. This low species evenness may be caused by the capture of large schools of pelagic schooling forage fishes, such as round scad. Dominance of the catch by one species makes for low evenness. Schools of scad are more abundant on reefs than on sand (Hales 1987), therefore lowering evenness in reef trawls, as round scad are such a dominant species.

Shelf-edge reefs, along the western edge of the Gulf Stream, were areas of particularly high diversity, connected by persistent warm-water currents. Protecting a series of these shelf edge reefs could help conserve high biodiversity of organisms along the shelf edge and replenish reef areas downstream in the Gulf Stream flow. An MPA network, along the shelf edge, could ultimately protect larval sources (Dayton et al. 2000), nurseries for targeted fish species (Sala et al. 2002), and may ensure the connectivity and persistence of reef fish populations through protection of sources of larvae and their settlement habitats (Palumbi 2001).

A trend towards increasing H' diversity and species richness was apparent with decreasing latitude. Some of the highest fish diversity in the trawl dataset occurred in the waters off northern Florida. These results are similar to previous observations showing higher diversity in the lower latitudes, which are more thermally stable than higher latitudes (Sala et al. 2002).

Spatial analysis of historical fishery survey data elucidated areas where high relative abundance, biomass, and diversity of fishes have occurred based on data collected prior to rapid expansion of the reef fish fishery in the southeastern U.S. in the late 1970s (Huntsman and Manooch 1978). Such historical databases are invaluable in locating areas where high fish production and diversity may have existed prior to heavy fishing pressure. For example, high fish abundance, biomass and diversity existed in mid-shelf (21 - 40 m), shelf edge (55 - 75 m), and upper slope (> 200 m) collections east of Long

Bay, NC (approximately 33°18'N-32°29.4'N). Historically, there have also been high levels of diversity in the shelf edge areas off the entire coast of South Carolina, off the border of Georgia and Florida, and slightly north of Cape Canaveral, FL. Such sites deserve special consideration for protection, as they have unique conditions that support concentrations or diverse assemblages of fishes. Because of recent overfishing of fish stocks off the southeastern U.S. and worldwide, examination of historical databases might be one way to determine areas that possess combinations of oceanographic and habitat conditions that are conducive to high fish abundance, biomass and diversity. Examination of such databases should be an essential part of MPA design and placement.

A chain of MPAs along the shelf edge reef of the southeastern U.S., in addition to protecting diverse fish assemblages, may help in protecting stocks of valuable reef fishes such as gag (*Mycteroperca microlepis*) that spawn at shelf edge reefs (McGovern et al. 1998). Such an MPA network should include all known spawning aggregations of vulnerable reef fishes (Sala et al. 2002). Protection afforded by a reserve network that targets spawning areas of commercial species will also ensure sufficient larval production for diverse assemblages of non-threatened species (Sala et al. 2002). An added benefit of setting aside some shelf edge reefs as MPAs is the protection of deep reef species that do not survive traditional management measures such as minimum sizes and bag limits. Survival of reef fishes released at shelf edge depths is significantly lower than fishes released at shallower depths (Collins et al. 1999).

The results of this GIS analysis were compared to potential MPA sites (no bottom fishing) being considered by the South Atlantic Fishery Management Council (SAFMC) for management and restoration of overfished stocks of hard-bottom reef fishes. The SAFMC criteria for MPA establishment included overfished status and emphasis on deep reef species that have very high release mortality. The SAFMC approach has been toward establishment of no-take MPAs for bottom fish that encompass habitat, but which are directed at specific fishery species. In this sense, the MPA criteria under which the SAFMC is operating are not much different than individual species management plans. A more desirable approach might be to take an ecosystem perspective and protect areas that have high fish abundance and biomass, or which support diverse assemblages of reef fishes.

Spatial analysis of potential MPA sites off South Carolina, Georgia and northern Florida indicate that two of the MPAs under consideration by the SAFMC (North Florida option 1 and South Carolina B option 2) coincide with areas of high fish diversity, however, lower fish abundance (Figure 8). The South Carolina A, option 3 proposed site is the only one that historically has had high H' diversity and fish abundance. Fish abundance is lower at deeper shelf edge reefs than on the continental shelf (Sedberry and Van Dolah 1984), so it is not too surprising that the trawl survey indicates lower fish abundance at shelf-edge reefs. However, the high diversity of these areas indicate this is reef habitat and should support populations of large reef fishes that are not as vulnerable to trawls as are smaller reef fish (Wenner 1983). Such sites contain a high diversity of reef fishes, such as snappers and groupers, that do not

survive release under traditional management methods, and these areas are good candidates for no-take protected areas.

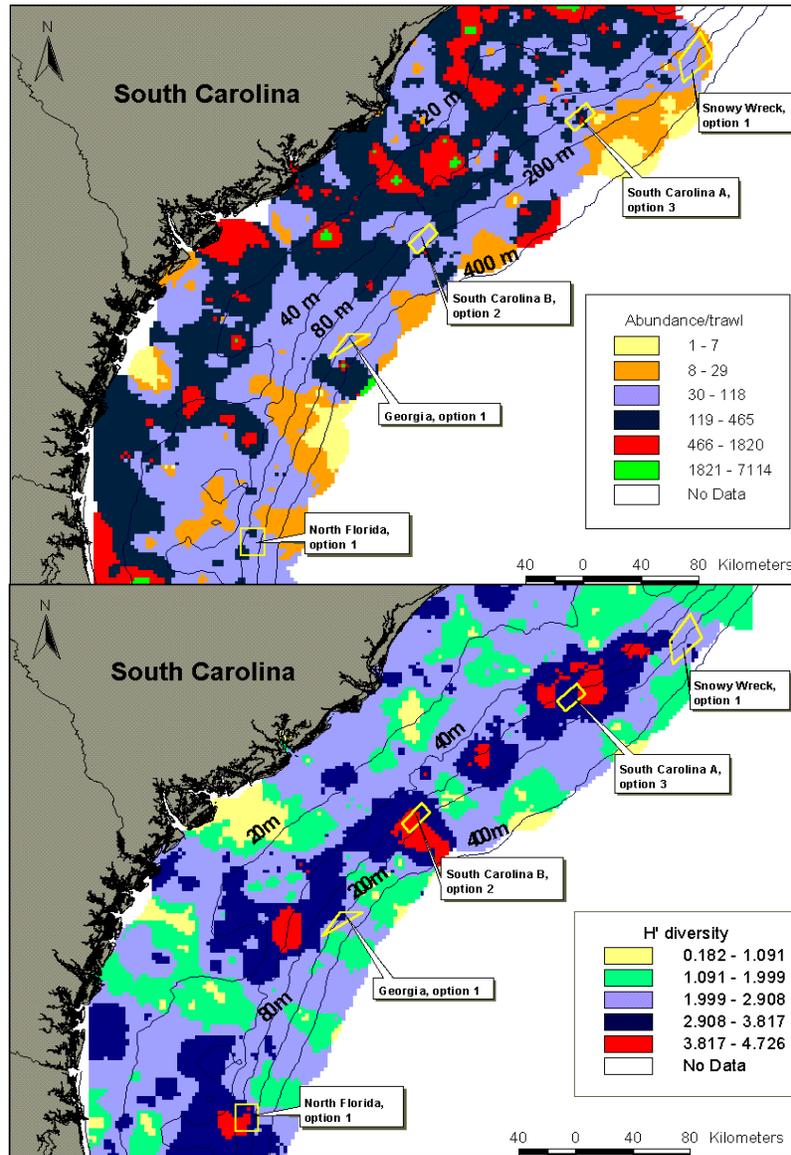


Figure 8. Sites being considered by the SAFMC in January 2002 as MPAs to protect stocks of deepwater reef fishes, in relation to the mean catch per tow from the summer trawls ($n = 487$) of the groundfish survey (1974 - 1980) and diversity (H') of fishes caught during all trawls ($n = 1,020$) of the groundfish survey (1973-1980).

Our analyses demonstrated that, although existing databases are useful in evaluating MPA sites selected using other criteria besides evaluation of fishery surveys, the data and analyses can, and should, be used prior to site selection, to look at areas that are particularly productive. At the least, the analysis points out areas of particularly high fish abundance, biomass and diversity that warrant additional research and consideration as MPAs. The method can also point out where additional analyses or surveys are needed to detect locations and habitats important to particular life history stages, such as juvenile nursery habitats and spawning locations for adults. Preliminary work has mapped locations that are important spawning grounds for some species (e.g., Burgos 2001).

More recent community studies of the fish in the South Atlantic Bight are needed in order to determine whether shallow and mid-shelf areas are still areas of high fish abundance after years of overfishing of key predator species, and thus might be candidates for further protection. This could be completed by performing another trawl survey or through non-removal visual census, to compare historic and current conditions. More detailed study in these areas will increase the value of the historical dataset, and provide further valuable insight into the condition of all fish populations in the continental shelf waters of the southeastern United States.

ACKNOWLEDGMENTS

We thank C.A. Barans, L.M. Kracker and C.J. Plante for their review of early drafts of this manuscript. T. Snoots (SCDNR) and L. Balthis (NOAA) provided assistance with data processing. This work was supported by MARMAP Grant 50-WCNF-0-06002 from the National Marine Fisheries Service to the SCDNR (J.C. McGovern and G.R. Sedberry, principal investigators). This is Contribution Number 552 from the South Carolina Marine Resources Center, and Contribution Number 266 of the Grice Marine Laboratory, College of Charleston (South Carolina).

LITERATURE CITED

- Able, K.W. 1999. Measures of juvenile fish habitat quality: examples from a national estuarine research reserve. *American Fisheries Society Symposium* **22**:134-197.
- Auster, P.J., K. Joy, and P.C. Valentine. 2001. Fish species and community distributions as proxies for seafloor habitat distributions: the Stellwagen Bank National Marine Sanctuary example (NW Atlantic, Gulf of Maine). *Environmental Biology of Fishes* **60**:331-346.
- Barans, C.A., and V.J. Henry, Jr. 1984. A description of the shelf edge groundfish habitat along the southeastern United States. *Northeast Gulf Science* **7**:77-96.
- Barnard, A.H., P.M. Stegmann, and J.A. Yoder. 1997. Seasonal surface ocean variability in the South Atlantic Bight derived from CZCS and AVHRR imagery. *Continental Shelf Research* **17**:1181-1206.

- Briggs, J.C. 1974. *Marine Zoogeography*. McGraw-Hill Book Company, New York, New York USA. 475 pp.
- Burgos, J.M. 2001. Life history of the red grouper (*Epinephelus morio*) off the North Carolina and South Carolina coast. M.S. Thesis, University of Charleston, Charleston, South Carolina USA.
- Coleman, F.C., C.C. Koenig, G.R. Huntsman, J.A. Musick, A.M. Eklund, J.C. McGovern, R.W. Chapman, G.R. Sedberry, and C.B. Grimes. 2000. Long-lived reef fishes: The grouper-snapper complex. *Fisheries* **25**(3):14-21.
- Collins, M.R., J.C. McGovern, G.R. Sedberry, H.S. Meister, and R. Pardick. 1999. Removing gas from the distended bladder of reef fish: does it really increase post-release survival? *North American Journal of Fisheries Management* **19**:828-832.
- Dayton, P.K., E. Sala, M.J. Tegner, and S. Thrush. 2000. Marine reserves: parks, baselines, and fishery enhancement. *Bulletin of Marine Science* **66**:617-634.
- ESRI (Environmental Systems Research Institute, Inc.). 1998. *Getting to Know ArcView GIS*. ESRI, Redlands, California USA.
- Govoni, J.J. and J.A. Hare. 2001. The Charleston Gyre as a spawning and larval nursery habitat for fishes. Pages 123-136 in: G.R. Sedberry (ed.). *Island in the stream: oceanography and fisheries of the Charleston Bump*. *American Fisheries Society Symposium* **25**, Bethesda, Maryland USA.
- Grimes, C.B., C.S. Manooch, and G.R. Huntsman. 1982. Reef and rock outcropping fishes of the outer continental shelf of North Carolina and South Carolina, and ecological notes on the red porgy and vermilion snapper. *Bulletin of Marine Science* **32**:277-289.
- Hales, L.S., Jr. 1987. Distribution, abundance, reproduction, food habits, age, and growth of round scad, *Decapterus punctatus*, in the South Atlantic Bight. *Fisheries Bulletin* **85**:251-268.
- Huntsman, G.R., and C.S. Manooch III. 1978. Coastal pelagic and reef fishes in the South Atlantic Bight. Pages 97-106 in: H. Clepper (ed.). *Proceedings of the Second Annual Marine Recreational Fisheries Symposium*. Sport Fishing Institute, Washington, D.C. USA.
- IUCN (The World Conservation Union). 1988. *Resolution 17.38 of the 17th General Assembly of the IUCN*. Gland, Switzerland and Cambridge, UK.
- Jennings, J.A. 2001. Distribution, diversity and habitats of fishes on the continental shelf and upper slope of the southeastern Atlantic coast of the U.S. M.S. Thesis, University of Charleston, Charleston, South Carolina USA.
- Lee, T.N., J.A. Yoder, and L.P. Atkinson. 1991. Gulf Stream frontal eddy influence on productivity of the southeast U.S. continental shelf. *Journal of Geophysical Res* **96**:22191-22205.
- Magurran, A.E. 1988. *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton, New Jersey USA.
- Margalef, D.R. 1958. Information theory in ecology. *General Systems* **3**:36-71.
- McGovern, J.C., D.M. Wyanski, O. Pashuk, C.S. Manooch II, and G.R. Sedberry. 1998. Changes in the sex ratio and size at maturity of gag, *Mycteroperca microlepis*, from the Atlantic coast of the southeastern

- United States during 1976-1995. *Fisheries Bulletin* **96**:797-807.
- Miller, G.C. and W.J. Richards. 1980. Reef fish habitat, faunal assemblages and factors determining distributions in the South Atlantic Bight. *Proceedings of the Gulf and Caribbean Fisheries Institute* **32**:114-130.
- Murray, S.N., and 18 co-authors. 1999. No-take reserve networks: sustaining fishery populations and marine ecosystems. *Fisheries* **24**:11-25.
- Olney, J.E., and G.R. Sedberry. 1983. Dragonet larvae (Teleostei, Callionymidae) in continental shelf waters off the eastern United States. *Biological Oceanography* **3**:103-122.
- Palumbi, S.R. 2001. The ecology of marine protected areas. Pages 509-530 in: M.D. Bertness, S.M. Gaines, and M.E. Hixon (eds.). *Marine Community Ecology*. Sinauer Associates, Sunderland, Massachusetts USA .
- Parker, R.O., Jr., D.R. Colby, and T.D. Willis. 1983. Estimated amount of reef habitat on U.S. South Atlantic and Gulf of Mexico continental shelf. *Bulletin of Marine Science* **33**:935-940.
- PDT (Plan Development Team). 1990. The potential of marine fishery reserves for reef fish management in the U.S. southern Atlantic. *NOAA Tech. Mem. NMFS-SEFC-216*.
- Pielou, E.C. 1975. *Ecological Diversity*. John Wiley & Sons, New York, New York USA..
- Rubec, P.J., J.C. Bexley, H. Norris, M.S. Coyne, M.E. Monaco, S.G. Smith, and J.S. Ault. 1999. Suitability modeling to delineate habitat essential to sustainable fisheries. Pages 108-133 in: L.R. Benaka, (ed.). *Fish Habitat: Essential Fish Habitat and Rehabilitation*. American Fisheries Society Symposium **22**, Bethesda, Maryland USA.
- Sala, E., O. Aburto-Oropeza, G. Paredes, I. Parra, J.C. Barrera, and P.K. Dayton. 2002. A general model for designing networks of marine reserves. *Science* **298**:1991-1993.
- SAS Institute Inc. 1997. *Statistical Analysis System*. Cary, North Carolina USA.
- Schwartz, F.J. 1989. Zoogeography and ecology of fishes inhabiting North Carolina's marine waters to depths of 600 m. Pages 335-374 in: R.Y. George and A.W. Hulbert (eds.). *Carolina Coastal Oceanography. National Undersea Research Program Research Report 89*. NOAA NURP, Silver Spring, Maryland USA.
- Sedberry, G.R. and J. Carter. 1993. The fish community of a shallow tropical lagoon in Belize, Central America. *Estuaries* **16**:198-215.
- Sedberry, G.R., J. Carter, and P.A. Barrick. 1999. A comparison of fish communities between protected and unprotected areas of the Belize reef ecosystem: implications for conservation and management. *Proceedings of the Gulf and Caribbean Fisheries Institute* **45**:95-127.
- Sedberry, G.R. and R.F. Van Dolah. 1984. Demersal fish assemblages associated with hard bottom habitat in the South Atlantic Bight of the USA. *Environmental Biology of Fishes* **11**:241-258.
- Shannon, C.E. and W. Weaver. 1949. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, Illinois USA.
- Sokal, R.R., and F.J. Rohlf. 1995. *Biometry. Third Edition*. W.H. Freeman, San Francisco, California USA.

-
- Southeast Area Monitoring and Assessment Program–South Atlantic (SEAMAP-SA). 2001. Distribution of bottom habitats on the continental shelf from North Carolina through the Florida Keys. *Southeast Area Monitoring and Assessment Program–South Atlantic Bottom Mapping Workgroup*, Atlantic States Marine Fisheries Commission, Washington D.C. USA.
- Struhsaker, P. 1969. Demersal fish resources: composition, distribution and commercial potential of the continental shelf stocks off the south-eastern United States. *Fisheries Industry Research* **4**:261-300.
- Taylor, C.C. 1953. Nature of variability in trawl catches. *Fisheries Bulletin* **54**:145-166.
- Van Dolah, R.F., P.P. Maier, G.R. Sedberry, C.A. Barans, F.M. Idris, and V.J. Henry. 1994. Distribution of bottom habitats on the continental shelf off South Carolina and Georgia. *Final Report to SEAMAP South Atlantic Committee, NOAA Award NA27FS0050*.
- Wenner, C.A. 1983. Species associations and day-night variability of trawl-caught fishes from the inshore sponge-coral habitat, South Atlantic Bight. *Fisheries Bulletin* **81**:537-552.
- Wenner, C.A., C.A. Barans, B.W. Stender, and F.H. Berry. 1979. Results of MARMAP otter trawl investigations in the South Atlantic Bight I: Fall 1973. *Technical Report No. 33*, South Carolina Marine Resources Center, Charleston, South Carolina USA.
- Wenner, E.L., D.M. Knott, R.F. Van Dolah, and V.G. Burrell, Jr. 1983. Invertebrate communities associated with hard bottom habitats in the South Atlantic Bight. *East Coast Shelf Science* **17**:143-158.