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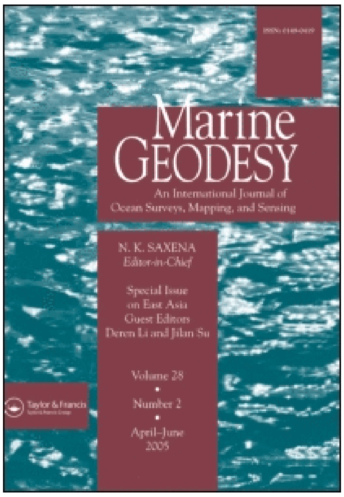

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Benthic Features as a Determinant for Fish Biomass in Gray's Reef National Marine Sanctuary

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A recent focus of the National Oceanic and Atmospheric Administration (NOAA) National Marine Sanctuaries Program is the characterization and assessment of marine resources associated with coral reef and live bottom habitats in protected areas. Detailed bottom maps have been produced making it possible to quantify bottom features within Gray's Reef National Marine Sanctuary, Georgia, USA. Hydroacoustic fisheries surveys were used to estimate fish biomass in the context of underlying features and bottom types by applying spatial techniques and regression analysis. Variables relating bottom features to estimated fish biomass differed based upon depth in the water column. Distance to rock ledges was the best predictor of fish biomass in the bottom 2 m of the water column, whereas the area of two bottom habitat types combined was a reliable predictor of estimated fish biomass in the mid water column.

Keywords Underwater acoustics, Gray's Reef NMS, benthic habitats, GIS

Introduction

Recent efforts to survey marine biological resources and habitats have focused on regions of particular ecological and socio-economic interest (Kendall et al. 2001; Ault 2002; Sheridan and Caldwell 2002; Battista et al. 2007). Often these surveys are centered on coral reef and live bottom habitats in marine protected areas (MPAs) to gain a better understanding of the distribution of habitat types and associated resources. Characteristics of the seafloor and

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associated habitats are presumed to be reflective of fish assemblages found there and vice versa. Live bottom habitats and habitat structure have been correlated with high abundance and diversity of fishes (Bohnsack et al. 1997; Rooker et al. 1997; Friedlander and Parrish 1998).

The management of marine resources has focused increasingly on ecosystem-based strategies (NOAA National Ocean Service, NOAA National Marine Fisheries Service) and assessing ecological function of marine protected areas to aid in the design and management of MPAs (Christensen et al. 2003; Monaco et al. 2007). These approaches rely on assimilating a wide range of information on potential factors that may influence marine resources and require appropriate tools and spatially explicit information. Methods for integrating spatial information into a framework that relates physical and biological characteristics have included the evaluation of bioenergetic advantage using spatially explicit maps of fish distribution and water temperature (Goyke and Brandt 1993; Brandt and Kirsch 1993), applying landscape ecology metrics to examine biological patterns of pelagic fishes in relation to thermal gradients (Kracker 1999), examining the utilization of bottom habitats by reef fishes based on diver surveys (Kendall et al. 2004), and using fisheries acoustic surveys to associate the distribution of small pelagics with salinity and water temperature (Paramo et al. 2003). The underlying premise of all these studies is that heterogeneity, detected at a range of temporal and spatial scales, is an important factor in ecological processes (Huffaker 1958; Horne and Schneider 1995; Mason and Brandt 1999). The ability to detect biological and physical features at an appropriate spatial and temporal scale is dependent on both the capabilities of the survey technology and the level of effort.

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Multibeam bottom mapping and fisheries acoustic surveys are based on the physics of sound in water, measuring the reflectance of a sound wave propagated through the water column by an echosounder. Bottom mapping quantifies seafloor characteristics and results in various data sets produced at a very fine spatial resolution. Fisheries acoustics measures backscatter from objects within a volume of water. Fisheries acoustic surveys can detect individual organisms in the water column, sampling at a temporal rate as fine as milliseconds. For both methods, a typical survey transit speed is approximately five to seven knots, an efficient sampling rate when compared to methods using diver observations or trawling. While there are some differences in how these acoustic data are collected and analyzed, they can be collected simultaneously. To date, the integration of bathymetric backscatter with water column estimates of biomass has been loosely coupled (ICES 2007). Developing new methods for integrating bottom and mid-water surveys will improve our ability to couple biological and physical data and complement the needs presented by ecosystem-based management and resource characterization. The work presented here is one such endeavor aimed at bringing together data on bottom type and fishes in an ecologically meaningful way.

Benthic Habitat Maps of Gray's Reef National Marine Sanctuary

Gray's Reef National Marine Sanctuary (GRNMS) was designated as such in 1981. It is located 27 km off the coast of Georgia, USA, on the continental shelf within the South Atlantic Bight (Figure 1). It encompasses 58 km^2 and is made up of sand flats and submerged limestone with rock outcroppings and ledges up to 3 m high. GRNMS is located at a transition zone between temperate and tropical waters.

Beginning in 2001, Kendall and others initiated a mapping effort to characterize the distribution of benthic habitats of GRNMS for management, research and monitoring

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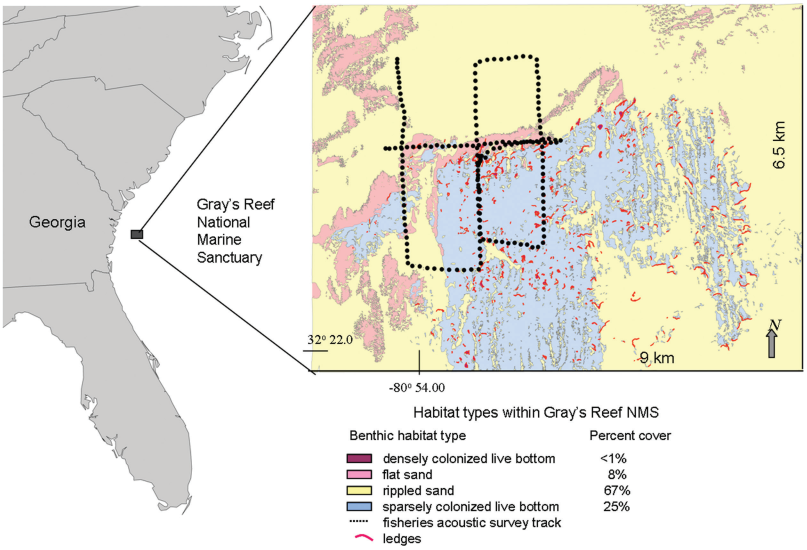

Figure 1. Location of Gray's Reef National Marine Sanctuary. The trackline of a fisheries acoustics survey is shown as a dotted line. Bottom habitats are delineated with percent cover of each habitat type (densely colonized live bottom cannot be depicted at this scale).

purposes (Kendall et al. 2005). Sidescan sonar imagery was acquired from June 26 to July 4, 2001, on the NOAA ship Whiting using ISIS Sonar acquisition software and a Klein 5500 sidescan system with an output resolution of 0.25 m. Multibeam bathymetry data were collected using a Reson Seabat 8101 echosounder with a final output pixel size of 2 m. A combination of scuba dives, towed video, and digital still photos was used to aid in the interpretation of backscatter signal and validate the habitat classification scheme. Habitat classification and delineation of features evident in the sonar imagery were accomplished using the Habitat Digitizer extension for Arcview 3.2 (ESRI Redlands, Calif.). A complete description of the methodology can be found in Kendall et al. (2005), which indicates that a high degree of thematic and positional accuracy in the benthic maps was obtained. Comparison with previous attempts to classify bottom type illustrates the advantages of fine-scale assessments that can be accomplished with advanced sonar technology (Kendall et al. 2005).

The resulting classification map (Figure 1) indicated that GRNMS is composed largely of rippled sand (67%), which is unconsolidated coarse sediment and sand ridges on a flat plain. Flat sand makes up 8% of the sanctuary and is defined as a thin layer of stable sand overlying a flat limestone region. Sparsely colonized hard bottom, where between 1% and 60% of the area is colonized with sessile benthic organisms, comprises 25% of the sanctuary. Densely colonized hard bottom, with 60–100% of the bottom colonized, is found in less than 1% of the sanctuary, typically on ledges or high relief areas. Live bottom areas are composed of sessile benthic organisms such as corals, sponges, and tunicates. In addition, ledges showed high values of species richness, diversity, composition, abundance, and biomass of fish. In particular, total abundance and species richness of fish was positively related to percent cover of sessile organisms and ledge height. Medium (0.58–0.89 m) and high (0.89–2.76 m) ledges had median percentage cover of 75.1% and 97.6%, respectively, and a significantly higher percentage cover of macroalgae, sponges, and other organisms compared to short ledges (0.0–0.58 m) (Kendall et al. 2007). For the purposes of this study, benthic habitats refer to all four bottom types identified by Kendall et al. 2005–flat sand, rippled sand, sparsely colonized live bottom, and densely colonized live bottom, along with associated sessile organisms. In addition, medium and high ledges are of interest in that they support an abundance of invertebrates and fish (Kendall et al. 2007). These designations, derived from the bottom mapping effort, form the basis for examining the link between bottom habitats and biology in the water column.

Hydroacoustic Survey Techniques

Traditional methods for fisheries assessments such as diver counts, traps, and trawls often sacrifice animals and are labor intensive. In addition, the spatial and temporal resolution associated with these methods often is not adequate for a deeper understanding of the ecological function of pelagic and reef-related habitats. Consideration of space and time scales influences our understanding of linkages between biological and physical processes such as horizontal migration, vertical diel migration, foraging, growth and predator-prey interactions (Mason and Brandt 1999). Hydroacoustic fisheries surveys can cover a broad spatial extent, provide high-resolution maps of biota in the water column (Brandt 1996; Kracker 2007) and have the potential to capture fine scale processes such as diel vertical migration (Kracker 1999).

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Fisheries assessments using acoustics are conducted along a transect with a shipboard echosounder typically operating at a frequency between 38 and 420 kHz. The echosounder produces beam-forming pressure or sound waves that reflect off objects in the water column (Figure 2). The strength of the return signal or echo is measured at the transducer in decibels (dB) and is equivalent to the size of the object. The time it takes for the echo to return to the transducer indicates the depth of the target. In addition, a differential global positioning system (DGPS) is integrated to locate each ping and map the survey track. Echo returns are visualized in real time on an echogram showing the bottom, individual fish targets, fish aggregations, and position of fish in the water column. Quantitative measures derived from the returned signal include target strength (TS), which is relative to the size of individual fish (Foote 1987; Simmonds and MacLennan 2005). Target strength is the strength of backscattering expressed in decibels. It is the logarithmic measure of the ratio of the measured intensity level of the echo (I_2) to a reference level (I_1) (Simmonds and MacLennan 2005):

$$\mathrm{TS} = 10\ \log(I_2/I_1) \tag{1}$$

As a ratio between the intensity of the actual sound pressure wave and a reference intensity and since the measured echo intensity for fish is always smaller than the reference parameter, dB will always be negative. The TS for fish is generally within the range of −60 dB (small return) to −20 dB (large return), with −60 dB being equivalent, for instance, to a small fish approximately 4 cm in length (Simmonds and MacLennan 2005). When backscattering strength or echo intensity from discrete targets is integrated over a volume, it is indicative of total biomass and is denoted as volume backscatter coefficient (s_v) (Simmonds and MacLennan 2005):

$$s_v = \Sigma\, \sigma_{bs} \big/ V_0 \tag{2}$$

where σ_{bs} is the backscattering cross-section and V_0 is the sampled volume.

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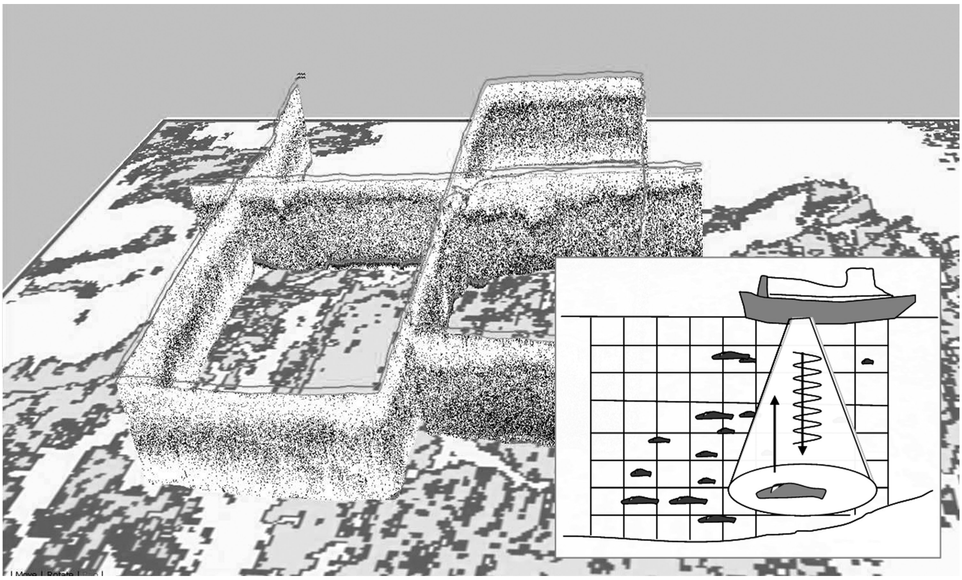

Figure 2. Fisheries acoustic survey track and echogram from May 2006 showing the distribution of targets in the water column overlaid on bottom habitat map. Inset depicts beam forming acoustic detection of targets in the water column.

The equivalent logarithmic measure is (Simmonds and MacLennan 2005):

$$S_v = 10\log(S_v)\ \text{in dB re1 m}^{-1} \tag{3}$$

When S_v is averaged over a volume, it is referred to as S_V_mean or the mean volume backscattering strength (MVBS) (Simmonds and MacLennan 2005). The integrated echo intensity of biomass within a given volume of the water column is used here as a measure of estimated fish biomass. It is used as the dependent variable in the regression models and will be referred to as mean volume backscattering strength (MVBS) or S_V_mean.

The concepts of acoustic backscatter as a function of fish size (TS) and mean volume backscattering strength (MVBS) as a relative measure of fish biomass in the water column have been the mainstay of fisheries acoustics (Love 1971; Foote 1980; Reid 2000; Simmonds and MacLennan 2005). While methods for assessing fish abundance and biomass have evolved over the past few decades (Horne and Clay 1998; Rose 2003; Simmonds and MacLennan 2005), efforts to objectively classify taxa to acoustic backscatter signatures have only recently moved forward (Gauthier and Horne 2004; Jech and Michaels 2006). The backscatter measurement only relays basic information about the reflecting targets, largely determined by the swimbladder (Foote 1980) and does not explicitly contain information about species. Therefore, it is necessary to rely on secondary information to confirm which species are present and the size distribution of fish in the water column. Typically trawls are used to identify the species being insonified and determine the size-frequency distribution. Along with trawl data, empirical models that relate TS to fish length are applied (Love 1977; Nakken and Olsen 1977; Rudstam et al. 2002; Paramo 2003). Since trawling is not possible within GRNMS, this additional step is not practical. Alternatively, expected species composition and size-frequency distributions based on historic data, along with empirical TS-fish length relationships for known species, could be applied in future analyses. For the purposes of this study, however, the measure of mean volume backscattering strength (MVBS) will be used as a measure of estimated fish biomass in the water column (Simmonds and MacLennan 2005). Despite these apparent limitations, fisheries acoustic surveys are automated, cover large areas efficiently, and provide spatially rich data at a fine resolution on abundance of animals in space and time.

Methods

A hydroacoustic survey was completed on May 22, 2006, on board the GRNMS research boat the Sam Gray to quantify the distribution of estimated biomass in the water column over a portion of the sanctuary. The survey was conducted using a Biosonics DT-X 120 kHz split beam acoustic system (beam width = 6.5° at half power point, pulse length = 0.4 ms, pulse rate = 5 pings s^{-1}) towed approximately 1m below the surface of the water. The survey transect was conducted in the evening (19:33 to 22:39 EST) and took 3 hr 6 min to complete. An example echogram showing backscatter in the water column is exaggerated 40 times in the vertical direction and displayed as a curtain overlain on the bottom classification map to visualize the three-dimensional nature of the data (Figure 2).

Data collected from the acoustics survey are best represented visually as an echogram and further analyzed to estimate biomass along the transect (Figure 3). This three-minute portion of the May 2006 transect depicts water depth on the y-axis from 1m below the transducer down to 23 m. The dark band across the bottom of the echogram is the seafloor. Moving from left to right along the echogram is the direction of travel along the transect.

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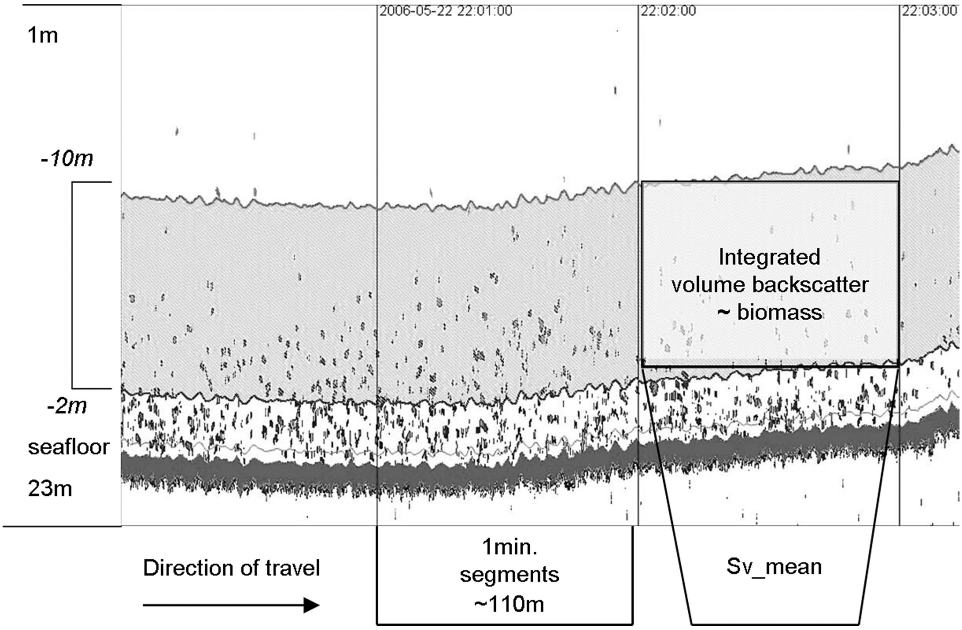

Figure 3. Echogram from a portion of the May 2006 acoustic survey. The dark band along the bottom represents the seafloor. The entire transect was divided into one-minute segments. Estimates of fish biomass (Sv_mean) were calculated for two regions of the water column: near-bottom (from the seafloor to 2 m above the seafloor) and mid-water (from 2 m above the seafloor to 10 m above the seafloor).

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The reflectance values are typically scaled across a color scale (not shown) to indicate the strength of the returned signal in dB.

For this study, the water column was divided into two sections to examine estimated fish biomass in relation to benthic features in both the near-bottom region and the mid-water region. A bottom detection algorithm was applied using maximum Sv, with a backstep range of −0.5 m to define the seafloor (SonarData 2006). To examine fish biomass close to the reef structure, a near bottom region was defined as the region from the seafloor to 2 m from the seafloor. The mid-water region is defined as 2 m off the bottom to 10 m off the bottom. This demarcation is based on the assumptions that reef-related fishes are typically found within 2 m from the bottom and that the biological distribution of scatterers likely exhibit uniformity within these horizontal depth strata (Figure 3). To eliminate noise and turbulence from wave action and movement of the ship in the upper water column, data from 10 m off the bottom to the surface were not included in the analyses. The volume of water sampled within the acoustic beam changes with depth, such that an 8 m depth range in the mid-water region results in a sampling domain that is roughly twice that of the near-bottom volume of water.

The acoustic transect was further divided vertically into one-minute segments. The volume of water sampled along the transect is a function of beam width, ping rate, and boat speed (ave. = 3.7 kts). While boat speed was somewhat variable, sampling rate and beam width are consistent over time. Therefore, a temporal sampling unit (one minute transects at 5 pings s^{-1}) was chosen as opposed to distance traveled. As a result, the sample size is standardized to number of pings. The average distance travelled in one minute was 110 m and the acoustic swath covers an area of the bottom approximately 2 m wide. Within each one-minute segment the return echo was integrated as described earlier to derive a mean volume backscatter for each depth region (SonarData 2006) as an estimate of fish biomass. A minimum target strength threshold was applied in post-processing to remove echoes that may be from background noise, large invertebrates, and very small larval fish. While −60 dB is commonly used as a minimum threshold in fisheries acoustics (Simmonds and MacLennan 2005), various thresholds are applied depending on the species under investigation or other factors. Jech and Michaels (2006) used a threshold of −66 dB with multiple frequencies to target Atlantic menhaden. Rudstam et al. (2002) found that reliable estimates of fish as small as 15 mm can be detected using a threshold of −64 dB. For this study, targets smaller than −65 dB were eliminated from the analysis of mean volume backscattering (S_V_mean) to include as wide a range of fish sizes as possible while minimizing inclusion of large invertebrates. To dampen the effects of temporal and spatial autocorrelation within the acoustic data, 60% of the original one minute segments were randomly selected and used for analysis. Overlapping buffers (due to transect crossings or variable transit speed) were removed, leaving 62 segments for analysis. An estimate of fish biomass (Sv_mean) was calculated for each one-minute segment for both the near-bottom region and the mid-water region (Figure 3).

To define the area of bottom habitat types associated with each acoustic transect, a 50 m radius buffer (7854 m^{-2}) centered on the midpoint of each one minute acoustic segment was created in ArcGIS (ESRI Redlands, Calif.). Within this 50 m radius, the area of each of the four bottom types was calculated (m^2). This scale of observation is expected to capture a mixture of bottom habitat types for more complex areas and a single habitat type where the bottom type is homogeneous over a larger area. Likewise, the volume of water sampled by the acoustic beam in one minute (110 m by 2 m at the seafloor) sets the scale at which estimated fish biomass is observed. Finally, medium (0.58–0.89 m) and high (0.89–2.76 m)

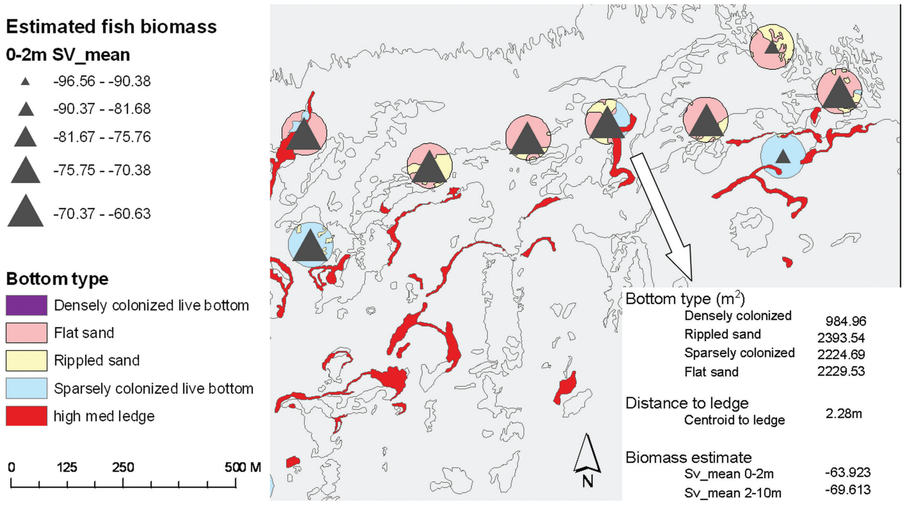

Figure 4. Analysis of area of bottom habitats, distance to ledge, and biomass estimates within a portion of GRNMS. These components provide input into the regression model. Inset table shows the value for each variable at one location.

relief ledges were identified from the bathymetric data (Kendall et al. 2005). Distance (m) from the midpoint of each acoustic segment to the nearest medium or high ledge was determined using the NEAR function in ArcGIS (ESRI Redlands, Calif.) and assigned to each of the 62 segments (Figure 4).

To examine the link between bottom habitats and estimated fish biomass two regression models were developed—one for the near-bottom region (0–2 m) and one for the mid-water region (2–10 m). A linear regression analysis (backward method, SPSS 13.0) was performed. Input into the regression models included the area (m^2) of each habitat type (flat sand, rippled sand, sparsely colonized live bottom, and densely colonized live bottom) within the buffered area and distance (m) to the nearest medium or high ledge as independent variables. The dependent variable was an estimate of fish biomass, Sv_mean for the near-bottom model, as well as Sv_mean for the mid-water model.

To examine possible spatial autocorrelation, a Moran's I value was computed and semivariance analysis conducted. Spatial autocorrelation refers to the situation where nearer neighbors are more similar in value than distant neighbors, depending on the spatial behavior of the variable of interest. Semivariance analysis and Moran's I statistics are useful tools in defining spatial autocorrelation (Bailey and Gatrell 1995; Issaks and Srivastava 1989). A global Moran's I statistic was calculated for Sv_mean in both the near bottom and mid-water regions. A semivariogram is used to model the degree of similarity at a range of separation distance between points. Semivariance analyses were conducted for estimated fish biomass from the 62 acoustic segments for both the near-bottom and mid-water regions. Semivariograms were constructed in ArcGIS (ESRI Redlands, Calif.) and the best fitting models were determined based on mean prediction error, root mean square, and root mean square standardized results.

Given the influence of neighboring values and to better account for the effect of autocorrelation, spatial lag regression models were developed in GeoDa (Anselin 1996; Anselin et al. 2006), which may lead to improved predictive power of the regression models. This approach may be appropriate when considering phenomena such as schooling

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behavior or the distribution of animals responding to underlying environmental factors that may themselves be spatially autocorrelated. The inputs to the spatial lag regression models were the significant independent variables from the linear regression and S_V_mean as the dependent variable. The spatial weights matrices were created in GeoDa to define which neighbors to include in the spatial lag regression ranging from 1 to 12 neighbors (Anselin et al. 2006).

Results and Discussion

The regression analysis for the near-bottom (0–2 m) region ($R^2 = 0.404$, $F(1, 60) = 40.74$ $p < 0.001$) indicates that distance to ledge is a significant predictor of estimated fish biomass (Table 1) and is negatively correlated. As distance to ledge increases, Sv_mean (−dB) decreases indicating less biomass at further distances from ledge features. This suggests that fish biomass is closely associated with medium and high ledge features in the 0–2 m region. In this near-bottom region, bottom habitat types were not a reliable predictor of estimated fish biomass.

Within the mid-water region (2–10 m), results of the regression model ($R^2 = 0.420$, $F(2, 59) = 21.35, p < 0.001$) indicate that the amount of sparsely colonized live bottom and flat sand are good predictors of estimated fish biomass within the water column (Table 1). As the combined amount of sparsely colonized live bottom and flat sand increases, estimated fish biomass increases. Distance to ledge was not a significant predictor of biomass in the mid-water model at the .05 level. Overall, the linear regression model is slightly better at

Table 1
Regression model results for the near-bottom and mid-water regions

Near bottom model	Unstandardized coefficients	Standardized coefficients			
Dep. Var. Sv_mean 0–2 m $R^2 = .404$ F (1, 60) = 40.74 $p < .001$	B	Std. Error	Beta	t	Sig.
(Constant)	−73.010	1.067		−68.426	0.000
Distance to ledge	−0.011	0.002	−0.636	−6.383	0.000

Mid-water model	Unstandardized Coefficients	Standardized Coefficients			
Dep. Var. Sv_mean 2–10 m $R^2 = .420$ F (2, 59) = 21.35 $p < .001$	B	Std. Error	Beta	t	Sig.
(Constant)	−85.872	1.091		−78.732	0.000
Sparsely colonized live bottom	0.001	0.000	0.601	5.630	0.000
Flat sand	0.002	0.000	0.552	5.169	0.000

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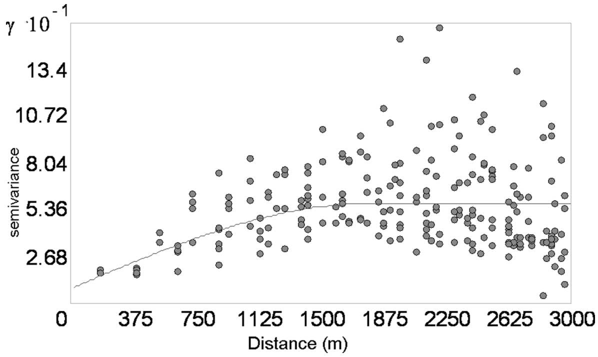

Figure 5. Semivariogram analysis of Sv_mean for the mid-water region (2–10 m). Spherical model, range = 1783 m, lag size = 250, number of lags = 12, nugget = 8.6

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predicting estimated fish biomass in the 2–10 m range ($R^2 = 0.420$) than in the near-bottom range ($R^2 = 0.404$).

In the area covered by this transect, flat sand is fairly well interspersed with other habitats. It is not as dominant a feature as the areas of rippled sand, for instance. Likewise, sparsely colonized live bottom is interspersed with other bottom types. Overall, a mixture of habitats seems to be an important determinant of biomass in the mid-water portion of the water column, while distance to nearest ledge was an important determinant of biomass in the near-bottom region.

The global Moran's I statistic, which provides a measure of second-order variation by examining the correlation between values at a range of separation distances (Bailey and Gatrell 1995), was significant, indicating spatial dependence of biomass values in both regions. Semivariogram models further described spatial dependence in estimates of fish biomass over a range of separation distances in the near bottom and mid-water regions (Figure 5, mid-water). The result of the semivariance analysis indicates that biomass estimates of the acoustic segments up to 1783 m apart can be considered spatially autocorrelated for the mid-water region and up to 1873 m apart for the near-bottom region.

The application of a spatial lag regression model involves building spatial weights matrices to identify near neighbors to include in the regression (GeoDa 2004). For this analysis several matrices were built ranging from 1 to 12 neighbors. The results of the spatial lag regression model indicate that both the near-bottom and mid-water models improved by including near neighbors, with six neighbors resulting in the best fit based on R^2. Beyond six neighbors, R^2 decreased for both spatial lag models. For the near-bottom model, R^2 increased from 0.404 to 0.492 with the spatial lag model based on six neighbors. For the mid-water model, R^2 increased from 0.420 to 0.637 with the spatial lag model based on six neighbors. The average distance between points in this study that is inclusive of six neighbors is 705 m.

While the near-bottom regression model only showed slight improvement with the inclusion of neighboring points, the mid-water model improved considerably. Ledges were a good predictor of estimated fish biomass near the seafloor. However, the distribution of fish biomass in the mid-water region is better explained by a mix of flat sand and sparsely colonized live bottom habitats, in particular, at a scale of approximately 700 m. This may represent an ecologically significant spatial scale at which to consider the distribution of pelagic fish biomass at GRNMS. While fish biomass near the bottom exhibits an association with ledge features, the distribution of fish biomass in the mid-water region may be indicative of sparsely colonized live bottom mixed with flat sand as an important landscape feature.

Conclusions

This study has focused on the spatial association between bottom features and the distribution of fish biomass. Fishes that occupy the pelagic zone associated with the rocky outcrops of GRNMS are likely an important link to the reef itself and to higher trophic level fishes in the South Atlantic Bight (Gilligan 1988). Using fisheries acoustics as a rapid method of quantifying fish distribution makes it possible to capture variation in the distribution of animals over space and in relation to bottom features. The integration of fisheries acoustic surveys and bathymetric mapping, along with spatial techniques and regression analysis, was applied to test the association between benthic habitats and estimated fish biomass. Our findings show that:

1. distance to ledge is a significant predictor of estimated fish biomass in the near-bottom region;
2. the amount of sparsely colonized live bottom and flat sand bottom types are reliable predictors of estimated fish biomass in the mid-water region;
3. spatial lag models improve the ability to predict estimated fish biomass in the mid-water region;
4. near-bottom and mid-water regions should be modeled differently to predict biomass; and
5. 700 m may be a relevant spatial scale at which to examine the distribution of fish biomass in the mid-water column at GRNMS.

These results support the premise that variation within the marine seascape can be quantified at a fine spatial (meters) and temporal (minutes) resolution using underwater acoustic technology. Data from bottom mapping and hydroacoustic surveys of the water column can be successfully integrated to quantify biomass in relation to benthic habitats and provide an effective, non-intrusive approach for assessing spatial patterns in the marine environment. This work adds to the current effort to better understand the distribution of resources within marine protected areas, including the pelagic zone. Relationships between biomass and benthic habitats have been examined and a specific spatial scale regarding the distribution of fish biomass in the water column has been suggested. These methods can be developed further to include the validation of fish species at GRNMS. In addition, applying this approach to other ecosystems and protected areas will test the potential for integrating biological and physical data for resource characterization and as a management strategy within the National Marine Sanctuary system.

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