Spatial and temporal distributions of pelagic biota using hydroacoustic surveying at Gray's Reef National Marine Sanctuary, Georgia

by

Katherine R. Doyle

(Under the direction of Daniela Di Iorio)

Abstract

The target strength distribution and abundance of pelagic organisms in Gray's Reef National Marine Sanctuary was sampled over the course of three years.

The target strength distributions ranged from −78 to −45 dB for all times of day, at all locations. Diel vertical migration is apparent in the Fall yet muted in the Spring due to a strong thermocline. This parameter does not seem to be influenced by the presence of colonized hard bottom in that the same range of target strengths are sampled throughout the experimental program.

The abundance data found that, there are generally more uniformly distributed fish per cubic meter in the "surface" layers and a patchy distribution in the "bottom" layers. Whether or not habitat affects abundance is inconclusive. Larger numbers of fish were seen over reef habitats, yet corresponding numbers of fish could be found in areas with little or no habitat also.

Index words: diel migration, fish abundance, fisheries acoustics, GIS, Gray's Reef, hydroacoustic, marine sanctuary, pelagic, reef fish, spatial distribution, target strength distribution, temporal distribution

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by

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Chapter 1

Introduction

Gray's Reef National Marine Sanctuary (GRNMS) has been a part of the National Oceanic and Atmospheric Administration's (NOAA) marine sanctuaries program since 1981. The National Marine Sanctuaries (NMS) program is engineered to protect distinctive and ecologically important marine environments, habitats, and ecosystems. One of the reasons that Gray's Reef was designated as a marine sanctuary is because it is one of the largest near shore reefs of the southeastern United States where almost one-third of the habitat can be classified as "live-bottom" (Sedberry et al., 1998). The sanctuary is located 32 kilometers (17.5 nautical miles) off Sapelo Island, Georgia and encompasses 58 square kilometers (about 17 square nautical miles) along the 20 meter isobath (see Figure 1.1).

Gray's Reef's location on the inner-shelf region of the South Atlantic Bight (SAB) allows the sanctuary to function as a transition zone between warm tropical waters in the south and colder, more temperate waters to the north. It is this unique location that results in the sanctuary serving as a geographic limit to several northern and southern species of marine organisms. Tropical, subtropical, and temperate species all co-habitate within Gray's Reef's borders (Gilligan, 1989; McGovern et al., 2002; Sedberry et al., 1998).

Additionally, the reef is along the migratory path of several ocean-going species like the King and Spanish mackerel (*Scomberomorous cavalla* and *S. maculatus*, respectively) (Collins and Stender, 1987; Collins and Wenner, 1988; De Vries and Grimes, 1997), loggerhead sea turtles (*Caretta caretta*) (South Carolina Department of Natural Resources, 2004), and the highly endangered North Atlantic Right Whale (*Eubalaena glacialis*). GRNMS is also within close proximity to known Right Whale calving grounds (Kenney et al., 1995). Further, it

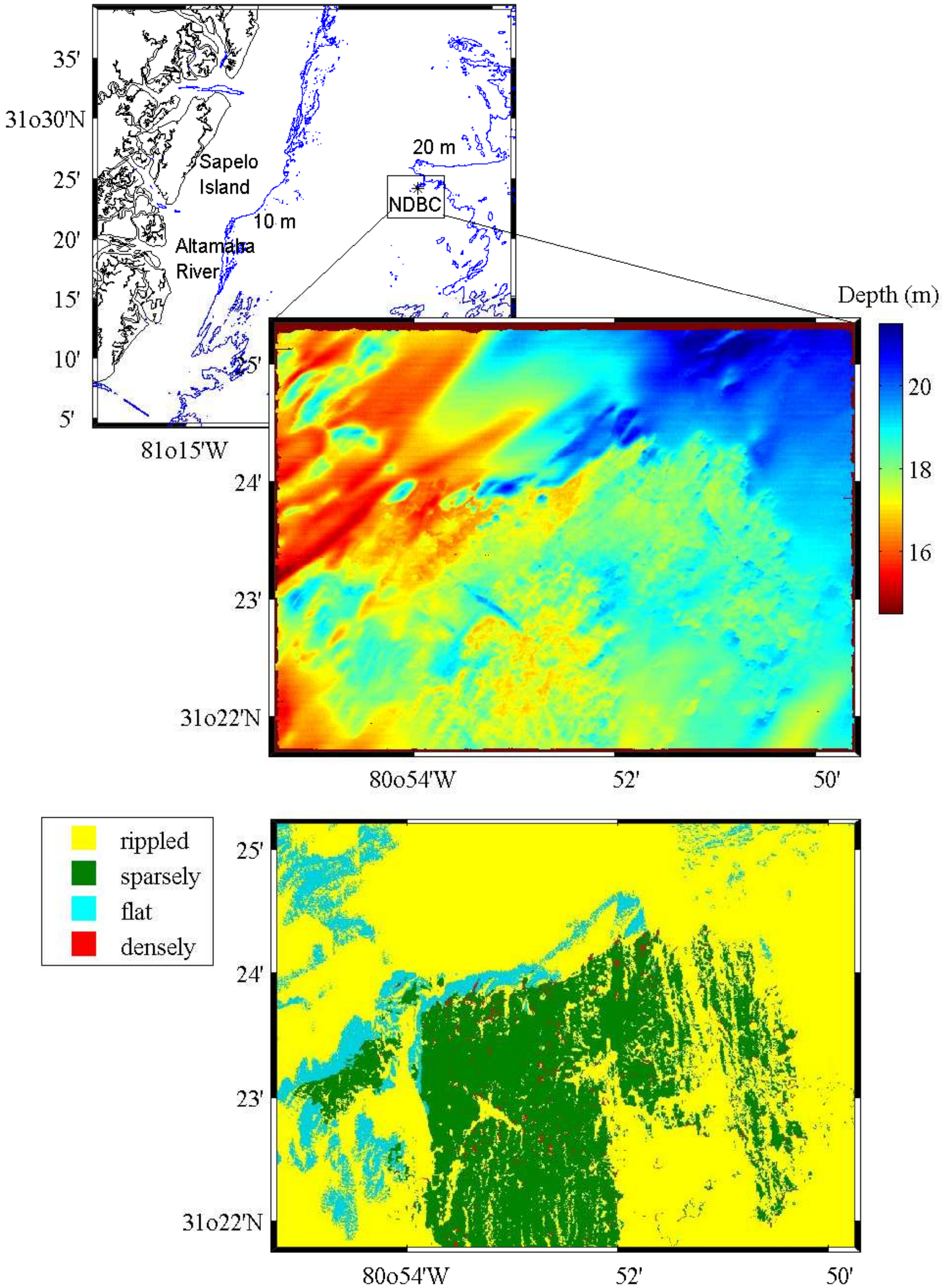

Figure 1.1: The top image is of the Georgia coastal domain showing the location of GRNMS. The asterisk labeled “NDBC” indicates the position of the NOAA National Data Buoy Center Station 41008. The center image shows the bathymetry of the sanctuary with the colorbar on the right indicating depth. The bottom image depicts the minor bottom habitat classifications at GRNMS with the legend on the left illustrating the color labels for each habitat type.

is an area of larval recruitment for several species like the Atlantic menhaden (*Brevoortia tyrannus*) (De Vries et al., 1995; Forward et al., 1996; Stegmann and Yoder, 1996).

This area also attracts a variety of resident benthic organisms [represented by the snapper-grouper complex (Barans and Van Holliday, 1983; Harris, 1995; Manooch et al., 1998)] and pelagic organisms (i.e. Atlantic spadefish, *Chaetodipterus faber* and Atlantic thread herring, *Opisthonema oglinum*). These animals support a federally regulated fishery consisting of some commercial fishing and recreational sport and dive fishing (Gilligan, 1989). Of interest in this study are the resident pelagic organisms, some of whom support the fishery directly and others of whom are the bait or prey fish for these animals. These resident pelagic groups function as a crucial component of the food web for GRNMS and the greater SAB region.

The borders of Gray's Reef are within an area of dynamic oceanographic variability. Atkinson et al. (1983) outline the climatology of the SAB, and their work provides a thorough overview of the physical conditions in the region. They first describe the SAB in terms of the inner-, mid- and outer-shelf with corresponding depths of 1–20 m, 21–40 m, and 41–60 m, respectively. As GRNMS has an average depth of approximately 20 m, it is in a transitional area between the inner- and mid-shelves and would therefore be influenced by the characteristics of both regions. Atkinson et al. (1983) define the mid-shelf as containing flows that are a mixed response to the wind, Gulf Stream, and density forcing. Salinity here tends to be a combination of the Gulf Stream and inner-shelf values with pronounced seasonal stratification depending on river transport. They define the flows of the inner-shelf as being strongly influenced by tidal currents, river runoff, and wind forcing, with river runoff also affecting the salinity of this region. The resulting influx of low salinity waters from runoff events present some amount of year-round stratification that is most evident in the spring when river runoff is at a maximum.

Han et al. (1985) studied the currents specifically within the boundaries of Gray's Reef two years after the Atkinson et al. (1983) study in order to describe the reef energetics and nutrient dynamics representative of the area. This study acknowledges the seasonal influx of freshwater and attributes it to creating pressure gradients that are mostly responsible for the variable currents in this vicinity. Han et al. (1985) found a low correlation between the winds and the currents (measured at the mid-water column and the bottom). Based on this finding, it would seem that Gray's Reef is more like the mid-shelf than the inner-shelf as far as current flow dynamics. Our temperature and salinity data for the area (discussed later) reveals that the sanctuary region has more in common with the inner-shelf than the mid-shelf. Gray's Reef is clearly home to a significant variety of physical parameters that, in turn, influence the chemistry and biology in the region (Mallin et al., 2005; Verity et al., 1993, 2002).

Over the years, GRNMS personnel has provided the scientific community with a vast array of research opportunities through participation in yearly monitoring cruises and by providing the use of ship time. Currently, fish populations at GRNMS are monitored through the use of visual transect swims, video transects (Parker et al., 1994) and random point counts via the Reef Environmental Education Foundation (REEF) program established at GRNMS in 1998 (Hare et al., 2000; Kendall and McFall, 2003). These data supplement the ongoing trapping studies of the Marine Resource Monitoring Assessment and Prediction (MARMAP) Program on the SAB (Barkoukis, 2006; McGovern et al., 2002), which is under the direction of the South Carolina Department of Natural Resources. Much, if not all, of the data collected at Gray's Reef can be used to support the Research and Monitoring Action Plan, RM-4, to maintain and enhance monitoring programs (Gray's Reef National Marine Sanctuary, 2006). In our 2004 and 2005 experimental studies such research opportunities were provided for this project courtesy of Mr. Greg McFall, the Research Coordinator of Gray's Reef NMS. Additionally, these cruises hosted other scientists, representing a variety of disciplines, also taking advantage of this valuable resource.

In 2004, Grant Gilmore, President and Senior Scientist of Estuarine, Coastal and Ocean Science, Inc. (ECOS) deployed Passive Acoustic Monitoring Systems (PAMS) that he developed in the hopes of recording both biological and anthropomorphic sounds within Gray's

Reef. Also in 2004, Mr. Mark Grace, a Research Fisheries Biologist for NOAA National Marine Fisheries Service (NMFS), deployed a video camera array to assess the habitat types and organisms' usage of the habitat at several locations throughout Gray's Reef. In 2004 and 2005 Dr. George Sedberry, who was at the time, the Assistant Director of the South Carolina Department of Natural Resources (DNR) Marine Resources Research Institute (MRRI), organized the deployment of chevron traps around Gray's Reef not only to assess the black sea bass populations, but also to sample the benthic biomass of GRNMS (Barkoukis, 2006).

Additionally, in 2005, we were joined by Dr. Matt Kendall [NOAA/National Ocean Service (NOS)/National Centers for Coastal Ocean Science (NCCOC) Biogeography Team] and his team of scientists whose main goal was to visually characterize the benthic habitat within the sanctuary, the associated fauna, and debris discarded by humans via SCUBA surveys. Later in 2005, Dr. Danny Gleason also made use of ship time provided by GRNMS in order to gather data to add to his interactive web-based guide to the benthic invertebrates and cryptic fishes of Grays Reef and to acquire data to support his study on the dispersal and recruitment of benthic marine invertebrates in the sanctuary. In addition, Gray's Reef is the study site for experiments examining habitat assessment, seabed surveys (Kendall et al., 2005), physical oceanographic studies, loggerhead sea turtle migration (South Carolina Department of Natural Resources, 2004), and paleo-environmental conditions. GRNMS values these studies and collaborations as an integral part of it's overall management plan (Gray's Reef National Marine Sanctuary, 2006).

1.1 Study Site

All surveys described herein were designed to sample the range of habitat types represented by the 2001 GRNMS habitat dataset shown on the bottom image in Figure 1.1 generated by Kendall et al. (2005). This dataset will be referenced throughout the rest of this thesis when illustrating data collection locations, cruise paths, and habitats. These bottom classifications were established from visual assessment of georeferenced video data overlaid onto sonar imagery, which included the backscatter signal strength used to quantify habitat and the bottom bathymetry from sidescan sonar data (Kendall et al., 2003b). Based on scientific and recreational use of the sanctuary prior to the Kendall et al. (2005) study, it was assumed that the densely colonized reef areas totaled as much as 25%. Researchers and sanctuary personnel (G. McFall, 2007 personal communication) were surprised to learn that these densely colonized reef areas actually comprise a very small minority ($\sim$ 1%) of the total habitat. The colors indicated in the bottom image of Figure 1.1 are solely for the identification of the four different minor habitat types: rippled sand, flat sand, sparsely colonized live bottom, and densely colonized live bottom. The bottom topography (the varying heights and changes in elevation) for this same area is shown in the center image in Figure 1.1.

This center image in Figure 1.1, shows that the GRNMS bathymetry ranges from a 15 m to a 21 m depth. Comparing the center, bathymetric image with the bottom, habitat image of Figure 1.1 reveals that the areas on the habitat map that are sparsely colonized appear to correspond to depths between 17–19 meters. For example, the bathymetric data shows an area of higher relief (about 17 m) at about 31° $22.5'$ N latitude and 80° $53'$ W longitude. Transferring these coordinates to the habitat classifications map points to an area of Gray's Reef that is dominated by sparsely colonized habitat with many densely colonized areas scattered throughout. Immediately to the west and northwest of this high relief area are two, small definitive areas in blue (19 m depth) and comparison to the habitat map shows two distinct patches of the rippled sand habitat at these same locations. Additionally, the northwest corner of the sanctuary is defined by a bathymetry that is generally about 16 meters deep with isolated pockets of approximately 19 meters. Examining the habitat classifications map in the same area, shows that those deeper pockets seem to relate to pockets of flat sand within a rippled sand landscape. Finally, the 20 m isobath that cuts through the northeast corner of the sanctuary is definitively shown in Figure 1.1's center bathymetric image.

Kendall et al. (2005) classified the habitats at GRNMS into two major categories that are each further divided into two minor categories. The first major category is "unconsolidated sediment", which umbrellas the minor categories of rippled sand and flat sand. Figure 1.2 depicts an image of the rippled sand habitat which covers approximately 67% of the sanctuary (Hare et al., 2000; Kendall et al., 2003b). Kendall et al. (2005) define this habitat as being "composed of sediment with regular ridges or ripples. The ridges generally run along a north/south axis in this region due to the orientation of waves and tidal currents. These sand ripples are 6–10 cm in height from crest to trough and are 40–60 cm in length from crest to crest. Troughs are often dominated by coarser material such as shell fragments, while crests are composed primarily of sand." Figure 1.3 shows the flat sand habitat which Kendall et al. (2005) define as, "consist[ing] of stable sand deposits in a region with no sudden changes in relief. [And where] grain size appears to be smaller than areas with rippled sand". This habitat comprises about 8% of the total area within the sanctuary boundaries (Hare et al., 2000; Kendall et al., 2003b).

The other major habitat category is "colonized hard bottom", which consists of both sparsely colonized and densely colonized regions. Figure 1.4 is an image of the sparsely colonized live bottom habitat which covers about 24% of Gray's Reef (Hare et al., 2000; Kendall et al., 2003b). According to Kendall et al. (2005) the sparsely colonized habitat "consists of partially exposed limestone substrate that is colonized with a sparse assemblage of sessile benthic organisms". And finally, Figure 1.5 provides an example of the densely colonized live bottom habitat that, surprisingly, covers less than 1% of the benthos within Gray's Reef's boundaries (Hare et al., 2000; Kendall et al., 2003b). The definition of this bottom type according to Kendall et al. (2005) is, "exposed limestone that is colonized with a nearly continuous coverage of sessile benthic organisms such as soft corals, sponges, and tunicates".

Recent dive surveys conducted in May 2005 have shown that the benthic habitat composition in Gray's Reef, as shown in the bottom image in Figure 1.1 and as illustrated by

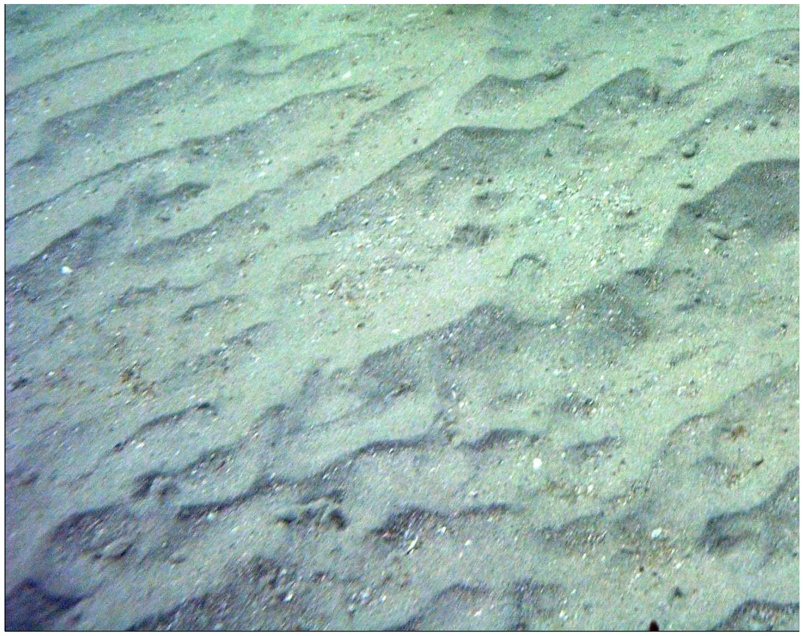

Figure 1.2: Example of the rippled sand habitat at GRNMS. Photo taken in GRNMS, date unknown, by M. Kendall of the NOAA NCCOS BioGeography Team, and provided courtesy of G. McFall of the NOAA GRNMS.

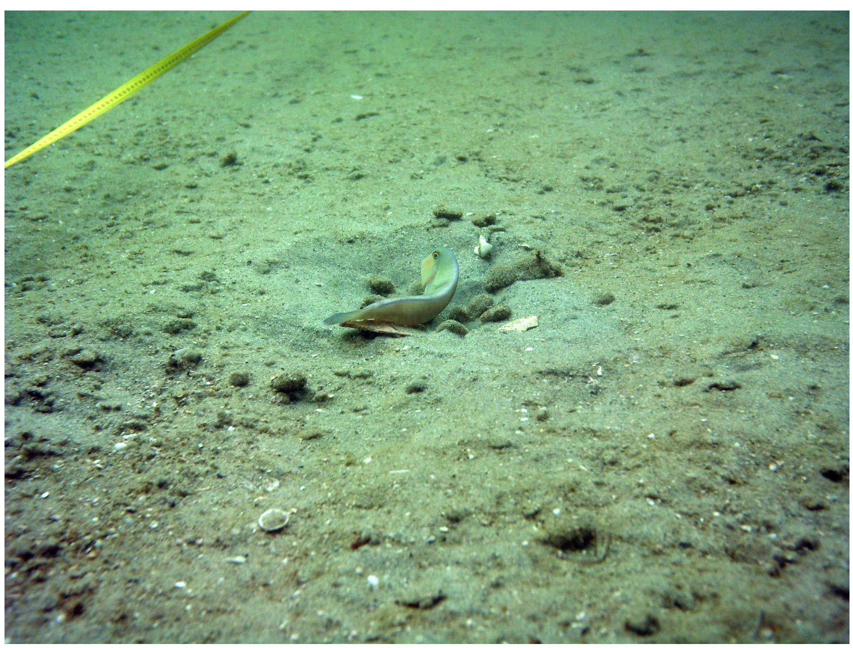

Figure 1.3: Example of the flat sand habitat at GRNMS. (Fish is *Hemipteronotus novacula*. Common name, pearly razorfish.) Photo taken in GRNMS May 2005 by C. Jeffrey, and provided courtesy of M. Kendall, both of the NOAA NCCOS BioGeography Team.

Figure 1.4: Example of the sparsely-colonized habitat at GRNMS. Photo taken in GRNMS May 2005 by R. Clark and provided courtesy of M. Kendall, both of the NOAA NCCOS BioGeography Team.

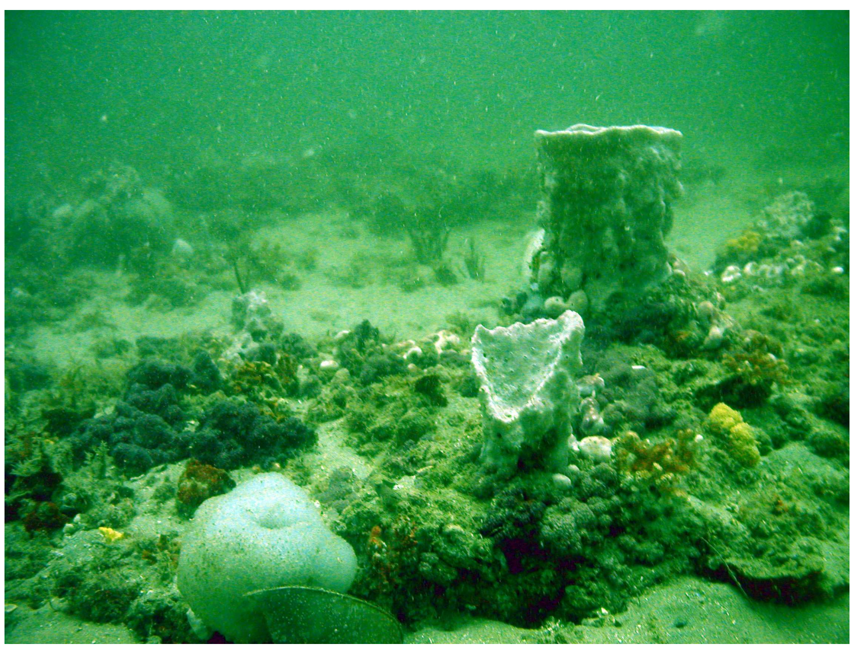

Figure 1.5: Example of the densely-colonized habitat at GRNMS. Photo taken in GRNMS May 2005 by M. Kendall of NOAA NCCOS BioGeography Team—who also provided this photo.

the images in Figures 1.2–1.5, has not changed significantly from the time of data collection in 2001. This conclusion was based on the fact that the observed habitat characteristics at randomly selected SCUBA dive sites were still consistent with the information presented on the habitat map created from this data (M. Kendall, personal communication 2005).

1.2 Motivation

On April 23–25, 2003, Gray's Reef hosted a workshop in Savannah, GA. Among the topics discussed were all of the various methods currently in place at GRNMS for assessing the diversity, abundance, life histories, and morphologies of the resident (and visiting) fish populations in and around the sanctuary area, and how the scientific community can improve upon these methods (D. Di Iorio personal communication). As a result, this workshop served as a springboard for introducing new ways of monitoring the pelagic fisheries using hydroacoustic surveying techniques. Acoustic analyses were seen as a "non-invasive" tool that could be used to supplement other research programs by adding another dimension (the vertical water column) to the current monitoring and management database.

There is currently very little published research that describes pelagic dynamics in and around Gray's Reef NMS. The migration patterns of charismatic megafauna like loggerhead sea turtles (South Carolina Department of Natural Resources, 2004) and right whales (Kenney et al., 1995) have been documented throughout recent years. Also, large schooling and migratory fish that are occasionally found within Gray's Reef and are desirable to commercial and recreational fisherman, are studied in and of themselves (Collins and Stender, 1987; Collins and Wenner, 1988; De Vries and Grimes, 1997; De Vries et al., 1995; Forward et al., 1996; Stegmann and Yoder, 1996). However, information about how these pelagic visitors and their prey utilize the reef environment, while documented for other parts of the ocean, was lacking for Gray's Reef. Moreover, baseline information about the resident population of pelagic fish in the sanctuary had not been established. The concensus was that data on these resident pelagics directly related to the dynamics of both the pelagic and the benthic communities in the area. These conclusions helped to determine the key parameters to be quantified in this thesis: examining whether the size distributions and abundances of the resident pelagic communities change over space and time. Using hydroacoustic analysis will enable us to answer these questions, thereby contributing to the established long term monitoring program at the sanctuary (Gray's Reef National Marine Sanctuary, 2006).

The physical conditions of the ocean medium during the times of our acoustic surveying will be explained as well. When available, concurrent physical oceanographic data will be considered along with the acoustic data to determine if these physical parameters affect any of the acoustic changes observed. If no definitive comparison can be made in this way, this information will serve strictly to provide the background oceanic conditions of the collection site.

1.3 Experimental Purpose and Summary

The goal of this Master's thesis work is to quantify the target strength (TS) distribution and abundance (in terms of number of fish found per cubic meter — FPCM) of pelagic fish within the GRNMS boundaries using a variety of hydroacoustic instrumentation and analyses techniques. The target strength measurements could potentially be related to individual fish length; which can, in turn, be used to determine fish biomass along with abundance measurements, but it is beyond the scope of this thesis to do so. This work focuses on using these data in conjunction with spatial data of the GRNMS habitat. Geographic information systems (GIS) software is employed to determine if target strength distribution and abundance of pelagic fish corresponds to spatial features on the benthic landscape of Gray's Reef. The objectives of this research can be expressed as a series of questions:

1. By investigating the range of target strengths along each transect, using vertical resolutions of approximately 1.4 meters and horizontal resolutions the order of the length of each entire transect track, what is the target strength distribution within the sanctuary?

2. By examining the depth integrated FPCM using a vertical resolution of approximately half of the water column (so as to express the data in terms of the "surface" and the "bottom") and a horizontal resolution averaging 234 meters over each of the individual transect lines, what is the abundance of the pelagic fish that are present within GRNMS?

3. Do temporal relationships, either diel or seasonal, exist for the TS distribution and FPCM data?

4. Are the TS and FPCM data related in some way to the bottom habitat classifications?

5. Does employing different methodologies in each survey have an impact on these results?

The fish measurements were collected via hydroacoustic surveying using three different transducers as will be described in Chapter 2. Hydroacoustic analysis has been a valuable oceanographic tool for decades. It was not until the 1960s that these techniques were first applied to measure the abundance of fish. Since then, the technology has developed rapidly and a wide variety of fisheries acoustics research has taken place (MacLennan and Van Holliday, 1996).

There are several benefits to acoustic sampling. It allows for the collection of a large quantity of data in a relatively short time frame, and a single transducer can be used to obtain simultaneous information on zooplankton and large fish, with high definition at large ranges. Also, acoustic data can be easily collected in conjunction with a myriad of other data. Fisheries acoustics is viewed as a relatively unobtrusive way to sample the wild marine environment with little anthropogenic influence of the data. (Gerlotto and Masse, 2002) Also, acoustic sampling provides the ability to cover areas of low fish abundance (that are usually not commercially or recreationally exploited) in addition to areas of high fish abundance (Maravelias, 1999). However, there is some evidence that ship noise (Brierley et al., 2003; Dylejko et al., 2007; MacLennan and Van Holliday, 1996) and the equipment itself (Kastelein et al., 2005) can have an impact on the organisms being sampled, depending on what they are.

Acoustic studies can utilize either passive or active methods. Passive acoustics is a field that has gained recent attention, and its focus is on listening to fish, and other marine organisms, in an attempt to identify, record, and study underwater animals without visual information (Rountree et al., 2006). In contrast, what has been more extensively studied in the last thirty years is so-called active acoustics where instrumentation is deployed that actively transmits and receives signals detailing the acoustic properties of the organisms in the water column. It is this type of acoustic equipment that was used for the body of this work. In the eighties, improvements in calibration techniques of these machines and the development of split and dual-beam transducers allowed for greater accuracy and the ability to get direct measurements of TS *in situ* (MacLennan and Van Holliday, 1996).

Pioneering work with fish schools has been completed by (Van Holliday, 1972, 1977a,b). In Van Holliday (1972), the author determines that resonance structure in echoes was due to the presence of a swimbladder in the schooling fish. Later, in Van Holliday (1977a) the author successfully applied the Doppler effect to echoes in order to study the internal motions of schooling fish. Finally, Van Holliday (1977b) attempts to examine the resonance of the swimbladder to determine individual fish size within a school, but was only able to make general statements without a means of ground-truth. More recently, (Misund and Coetzee, 2000) has also examined echo integration in schooling fish using multi-beam sonar, another technological advancement for ensonifying the water column. Misund and Coetzee (2000) determined that multi-beam sonar could be used to validate recordings obtained by conventional echo integration and provide more precise mapping and abundance estimates of pelagic fish stocks in schools within 20 m of the surface.

More specific to this thesis Gledhill et al. (1996) developed a method using stationary under water video cameras and acoustic analysis to accurately assess reef fish abundance and species composition. Jech and Horne (2001), found it was difficult to estimate fish density and maintain accurate backscatter frequency distributions. Lawson et al. (2001) was able to correctly distinguish between three fish schools of different species on the South African continental shelf using vertical echosounder equipment and physical oceanographic information. A comparison between split and single beam transducers in Rudstam et al. (1999) concluded that split beam analysis yields a more dynamic range of target strengths providing more detail than a single beam system, yet, comparable results were obtained for targets with strengths over -56 dB between the two systems. Swartzman et al. (1999) developed an acoustic data viewer that has the capability to also analyze environmental and biological data in conjunction with image-processing tools to distinguish between fish schools, plankton patches, and for patch identification. Toresen et al. (1998) used acoustic methods to estimate the abundance of two species of small pelagic fish in the Berents Sea. These are only a few examples of how other scientists have tackled the questions of pelagic fish sizes, and abundance along with their spatio- and temporal relationships.

Since the nature of hydroacoustic sampling is not species specific, species identification from acoustic data alone is not possible. In other words, hydroacoustic analysis does not allow for the identification of which acoustic signal belongs to which fish species. Therefore, some means of concurrent biological sampling should take place in order to get a census of the range of species sampled. Such testing is referred to as "ground truthing" and two common methods include trawling and video recording (McClatchie et al., 2000; Robison, 1993). Trawling provides the advantage of sampling a large volume of the water column, however, some fish are able to avoid the net. Certain fish can see the trawl net and swim out of the way, while it has also been shown that the physical disturbance of the trawl net moving through the water column can alert fish to get out of the way (Misund et al., 1999). A video camera that is mounted on a remotely operated vehicle (ROV) is not subject to the problem of avoidance by organisms in the same way that a ship or a trawl net is because the ROV is towed as the ship is drifting. This effectively results in both the ship and the towed ROV moving along with the current as some organisms themselves do (Robison, 1993).

However, the ROV does have the ability to be maneuvered vertically in the water column using its propulsion system, which could startle fish that it encounters. Another factor that could influence data collected by a ROV-mounted video camera, is the operational lighting which could also attract or repel organisms. While this research includes data from both the trawling method (in 2003) and the video surveying method (in 2004), the task of establishing a definitive ground truthing procedure to correlate with the information collected lies beyond the scope of this thesis.

The physical properties of the water column in terms of stratification, currents, and sea surface state, were collected at the time of all acoustic surveys. This information was attained via either nearby monitoring stations, ship based sampling, or both as will be discussed in Chapter 2. These data provide a means to quantify the sampling conditions in terms of any significant vertical gradients and in terms of sea state and current flows, both of which have an impact on turbidity levels. How the physical oceanographic parameters tended to impact our data will be discussed as well. This area of the SAB is given to a large range of temperature and salinity over the course of a year (Atkinson et al., 1983).

MATLAB numerical processing was implemented to determine if there are significant temporal and spatial variations (in both the horizontal and vertical plains) of the target strength distributions and the fish abundances. Of interest, is whether or not these variations indicate a relationship that exists between the organisms and the time of day (temporal), or, the organisms and the four minor habitat classifications (spatial). GIS technology was used to quantify the bottom bathymetry and habitat classification data as described in Section 1.1. In order to attain the spatial characteristics for comparison, the habitat classification data was “cut” into segments that were equal in size to our acoustic sampling segments. Then, the database of corresponding attributes was imported into MATLAB for analysis with the TS distribution and FPCM data.

Geographic information systems were initially developed during the mid-sixties for analyzing the varying aspects of the terrestrial environment. It was not until about 1987 that scientists began applying these same tools to the marine environment (Valavanis, 2002). No different or new methodology has been developed for ocean applications. Marine geographers employ the same methods and principles as their terrestrial counterparts by asking analogous questions to conventionally land-related queries: "Why is it there?"/"Why does upwelling consistently occur in a particular area?", "What is there?"/"What is the topography of the upwelling area?", etc. (Valavanis (2002), page 14). To date, no one has come up with a universally satisfying way to include the third dimension of depth into marine GIS, which is the key factor that makes the ocean environment very different from, and more complicated than the land environment. Also, the dynamics of marine processes and objects contribute additional levels of complexity to this field. The main benefit of GIS analysis is the ability to link datasets to digital maps. This one feature enables the evaluation of migration patterns for various organisms, how organisms respond to the presence of physical oceanographic fronts or habitats, fisheries dynamics, and marine protected areas for management and conservation purposes (Breman, 2002; Wright, 2002). In addition, marine GIS can be used to "map" the seafloor and water column being studied.

The most frequently researched uses for marine GIS are in the arenas of habitat assessment and fisheries management. As Kendall et al. (2005) did for the benthic mapping of Gray's Reef, so did Cochrane and Lafferty (2002) for the Northern Channel Islands marine sanctuary in California. Diaz et al. (2004) review a multitude of approaches for classifying habitats and evaluating their quality, and ultimately determine that it is a laborious process involving the melding together of disparate methods for mapping the benthos. To do this more efficiently requires the advent of equipment that is capable of producing higher resolution benthic maps. Within the realm of fisheries management, Riolo (2006) developed a custom software component to analyze and visualize the temporal and spatial patterns of the longline tuna fishery in American Samoa's Exclusive Economic Zone (EEZ) by importing hook and catch density statistics from the existing database into a GIS software platform. Also, Close and Hall (2006) focus on a method of interpreting local knowledge of a fishery onto a spatial scale for use with the scientific database. By incorporating a buffer parameter that considers study area, map scale, weather conditions, vessel size, and species harvested they were able to satisfactorily represent this difficult-to-standardize and vital data for practical use in fisheries management. Valavanis et al. (2004) managed to successfully model the essential fish habitat (EFH) of short-finned squid in the Eastern Mediterranean Sea using the GIS environmental model they developed. This species-specific, four-stage, model includes in the stages parameters that describe EFH which are derived from the individual species' life history data (i.e. sea surface temperature, salinity, bathymetry).

There are also studies utilizing GIS to try and analyze the distribution of benthic organisms, or "groundfish", in relation to the varying types of bottom habitat present. By overlaying fish census data onto a habitat map of Buck Island National Monument in St. Croix, U.S. Virgin Islands, Kendall et al. (2003a) were able to determine that there was higher probability of finding juvenile French grunts over hard bottom sites the closer those sites were to soft bottom habitat. Anderson et al. (2005) were able to link distributions of three species of groundfish to existing bathymetry, sediment, and side-scan sonar surveys to show distinctive preference of each species to one of three coarsely defined habitat designations. Although, they acknowledge that "fishes respond to their habitat at a range of spatial scales" that are usually species-specific, so there is a need to develop seafloor maps "with the resolution at which fishes perceive and respond to their habitat" in order to help eliminate the uncertainty that results from performing their analyses at a finer resolution. The present study employs similar methods of comparison to determine any habitat preference of the pelagic population at GRNMS.

1.4 Thesis Outline

Chapter 2 outlines the experimental approach in more detail. This chapter contains explanations of the methodologies, equipment, and software used to address each of the first four research questions posed in the last section. The elements of the method that are unique to each of the three research cruises are highlighted in Section 2.2.

Chapter 3 details the data and results for the acoustic analyses of the target strength distributions for each research cruise. First, the temporal relationships of these data are summarized within each cruise to examine any diel changes. Then this information is compared to the spatial data to determine if there is any pattern or relationship between the habitat type and the target strength distribution of pelagic biota. Finally, there are some comparisons between 2003 and 2005 to estimate of seasonal variability.

In Chapter 4 the hydroacoustic analyses of the FPCM are examined for each of the three research cruises. Vertical and temporal variations are described first in an effort to understand where most of the fish are within the water column and whether any diel and/or seasonal variability exists within the data. In addition, the spatial data is referenced here to see whether or not patterns exist that shows some relationship between the FPCM data and the unique habitat types.

Finally, in Chapter 5 the fifth research question is addressed, comparing the different experimental methods. Recommendations for future studies within GRNMS are put forward based on this comparison. Also, the information presented in Chapters 3 and 4 is considered in order to reveal potential applications for such data, not only within Gray's Reef, but also within any marine environment where the presence of pelagic biota is an integral part of the ecosystem. A study of this nature can play a vital role in the NOAA's NMS program, since certain aspects of this study were designed to cater to the specific needs of Gray's Reef NMS resulting from the monitoring workshop that took place in 2003 (Kendall and McFall, 2003). Additionally, the Gray's Reef Final Management plan (Gray's Reef National Marine Sanctuary, 2006) outlines goals and programs for the sanctuary which offshoots of this research can help to support.

Chapter 2

Experimental Approach

In order to address the research questions posed in Chapter 1, an experimental method was developed that draws on aspects of previous work of Dr. Daniela Di Iorio of the University of Georgia (Tamarach, 2003), Dr. Laura Kracker of the NOAA NOS CCEHBR (Kracker, 1999), and Dr. Doran Mason of the NOAA GLERL (Johnson et al., 2004; Mason et al., 2001, 2005). Using acoustic surveying techniques similar to this study, Tamarach (2003) was able to identify locations in the Altamaha River estuary (Georgia) that act as convergence zones and where fish tend to accumulate. In Lake Ontario (New York), Kracker (1999) implemented assumptions to the hydroacoustic data in order to divide the fish abundance into size classes defined as predators and prey, which enabled the creation of spatially explicit maps of fish densities and predator locations via geostatistical analysis, resulting in the three-dimensional distribution of targets in the water column. Mason et al. (2001) and Johnson et al. (2004) used hydroacoustic data in Western Lake Superior (Michigan) to provide measures of size and abundance (both of which can relate to biomass calculations), and distribution of pelagic biota over a range of spatial scales.

For our investigations, the target strength distributions were measured to gain a perspective on the approximate size of the resident pelagic fish at Gray's Reef. This could provide insight as to how the pelagic population functions within the sanctuary as seen in Kracker (1999). As in, are these organisms more likely to be predators or prey? These measurements are obtained for entire transects at a given time of day. The result is a contour depicting the number of targets that have a given TS and the vertical depth in the water column where they can be located. A vertical bin size of approximately 1.4 meters was chosen so as to give a detailed resolution for observing any diel migration changes or patterns that may occur within this population of targets. In order to assess what these may be, all transect paths repeated within a 24-hour cycle are compared to one another.

The abundance data collected during our sampling programs serve as a measurement of particle density. The FPCM is sampled in horizontal increments averaging 234 meters (logic explained in Subsection 2.1.1) along entire transects at given times of day. This results in a curve describing how many targets are present at particular coordinates along a transect. Again, the vertical bin size was about 1.4 meters, yet here, the information is depth integrated according to the "surface" versus the "bottom" of the water column (explained further in Chapter 4). This integration allows for the examination of diel changes in the FPCM data when comparing data from like transects.

The temporal hypothesis is that there will be an evident diel vertical migration of all targets, regardless of size, as a direct response to how the sun penetrates the water column. While the directionality of this phenomenon is species-specific, generally speaking, organisms move up into the water column as night falls and return to depth during the day (Fabi and Sala, 2002; Orlowski, 2000). There is a possibility that some of these organisms are moving in horizontal migration patterns as well. For example, in Kendall et al. (2003a), French grunts in the U. S. Virgin Islands moved from hard bottom, reef habitats during the day to soft bottom, sediment habitats at night. The existence of this phenomenon within GRNMS is difficult to isolate using the methodology presented here.

The perceived diel events of the TS and FPCM data from October 2003 and May 2005 will also be examined briefly for any evidence of seasonal variability. Seasonal variability of this phenomenon is expected to be directly related to the presence or absence of a well-defined thermocline. While it is still expected that organisms will respond to how the sun penetrates the water column, it is hypothesized that the presence of a strong thermocline, as seen in the Spring (May 2005), will limit this migration (Forward et al., 1999) compared to when the water column is well mixed as seen in the Fall (October 2003). Also, the particle density for the targets is predicted to be less in the Fall (October) than in the Spring (May). This is based on the finding that this region experiences phytoplankton blooms and rapidly developing zooplankton communities in the spring and summer as a result of nutrient-rich intrusions of the North Atlantic Deep Water and increased riverine flux (Verity et al., 1993). Also, it is worth mentioning that some pelagic fish species found in Gray's Reef spawn in the Fall like the Atlantic menhaden, *Brevoortia tyrannus* (Forward et al., 1999), and there are species that spawn in both the Spring and the Fall like the King mackerel, *Scomberomorus cavalla*, (Collins and Stender, 1987). It is anticipated that the seasonal abundance of targets is more a result of primary productivity than spawning events. Similarly, the TS distribution is expected to show decreased numbers of targets of all strengths in the Fall. The actual decibel range of TS is not expected to vary from season to season as the general composition of the pelagic community is assumed to remain relatively constant throughout the year.

The TS distribution and the FPCM of the pelagic fish for each individual transect line are also compared to the habitat map (shown in Figure 1.1) to see if any relationship between the habitat and these data can be quantified. Since the target strength distribution is representative of the entire transect, this data can only be compared to the general habitat composition of that transect as will be explained in Subsection 2.1.2. With the FPCM analysis, points of interest on the data curve can be directly compared to the identical location on the habitat map, and any general statements regarding the abundance trend along a whole transect, like for the target strength distribution, are compared to the general habitat composition percentage calculated for that particular transect. Yet, the habitat information was also georeferenced to the same average horizontal resolution of the FPCM data (234 m) so that the more precise measurement of FPCM per habitat type could be determined along each transect line (detailed in Subsection 2.1.2).

The spatial hypothesis is that the pelagic fish of Gray's Reef will not show any clear preference for a particular habitat type. This is due to the fact that the targets seen in our data are predicted to feed on phyto- and zooplankton and on benthic invertebrates, which live in the water column and the benthos respectively. If any trends between TS distribution and FPCM with the habitat do seem to occur, they are considered a result of the behavior patterns of the targets' prey items. It is well-studied that reef and groundfish show an increased affinity for colonized habitat due to their specific diet or shelter needs (Christensen et al., 2003; Friedlander and Parrish, 1998). Based on these types of studies, the densely colonized areas could potentially impact the data more than the sparsely colonized areas due to the fact that the more reef structure present, the more likely it is that marine organisms will congregate there (Tupper and Boutilier, 1997; Parker et al., 1994) and therefore, the lack of reef structure (unconsolidated sediment areas) implies that the number of organisms could be reduced (Parker et al., 1994). It is therefore, a logical assumption that if the diet and shelter needs of the pelagic targets seen in our experiments are similar to those benthic species, their behavior patterns would be similar. However, that is not believed to be the case, and without knowing the exact species composition of our targets, remains speculation. Finally, habitat composition of the sea floor is not expected to influence the temporal variability of the pelagic targets, in that, the reasons an organism will show an affinity for a certain habitat type are mutually exclusive from the reasons that said organism migrates vertically in the water column.

All objectives were met using data collected on a series of three research expeditions carried out in the fall or spring over three years as summarized by Table 2.1. As shown, each cruise differed slightly in the exact methods that were employed. The significance of this is that the equipment available for use was different at the time of each cruise. The unique procedures for each cruise are described in detail within Section 2.2. Note that the sampling times for all three cruises comprise a 24-hour day. In order to assess any temporal changes of the variables, a naming convention was applied throughout our research as an easy means of dividing a 24-hour day into generally accepted segments of a diel cycle: midnight, dawn, midday, dusk (see Figure 2.1). The midnight time segment has its center at midnight, EDT. Midday is centered around noon, EDT. The segments remaining are assigned dawn

Table 2.1: Summary of research expeditions

Date of cruise	Name of ship	Instrument model	Instrument depth (m)	Transect path direction	Transect length (km)	Transducer IN (date, EDT)	Transducer OUT (date, EDT)	Ground truth method tested
October 2003	R/V Bulldog	120 kHz split-beam	1	east/west	7.25	10/4/2003 21:00	10/5/2003 21:00	trawl[a]
May 2004	NOAA Ship Nancy Foster	120 kHz single beam	3.26	north/south	6.67	5/12/2004 21:30	5/14/2004 01:00	ROV video[b]
May 2005	NOAA Ship Nancy Foster	200 kHz split-beam	3.26	east/west	7.25	5/11/2005 22:00	5/12/2005 23:20	none

[a]outside of sanctuary boundaries
[b]within sanctuary boundaries

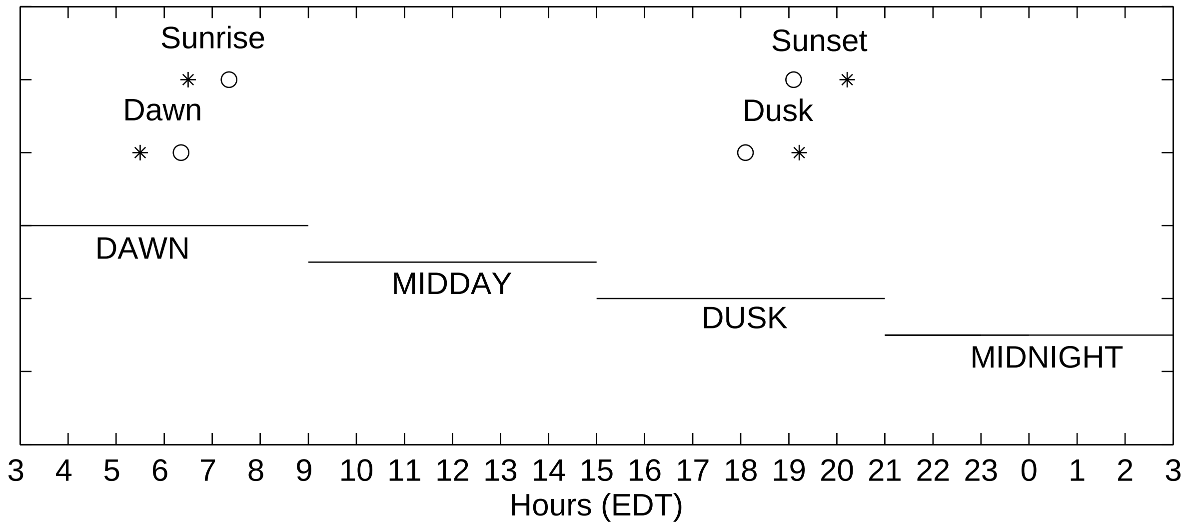

Figure 2.1: Designation of the time segments for a 24-hour cycle. The asterisks represent data from May 2004/2005, while the circles are data from October 2003.

and dusk, where the specific times of "dawn" and "dusk" are defined as an hour preceding local sunrise and sunset times, respectively (Dr. G. Sedberry, Sanctuary Superintendent for GRNMS, personal communication). In Figure 2.1 local sunrise and sunset times for all years are indicated as well as their corresponding "dusk" and "dawn" times. Data for October 2003 are represented by circles and May 2004/2005 are shown by asterisks. Comparing these points indicate that there are two more hours of daylight in May as compared to October.

2.1 Instrumentation and Equipment

2.1.1 Acoustics

In our experiments we used either a 120 kHz split-beam, 120 kHz single beam or a 200 kHz split-beam digital transducer all manufactured by BioSonics, Inc.. These transducers provided the means to sample the target strength distribution and abundance of the pelagic biota within Gray's Reef. All research cruises collected the acoustic profiles in a pattern commonly referred to as "mowing the lawn", with no overlap between neighboring transect lines. By taking these "slices" through the water column at different locations, varying habitat types were sampled. All acoustic surveying occurred within a continuous 24-hour block of time. This was to ensure that any diel changes could be observed.

The difference between the 120 kHz and the 200 kHz frequencies used in these surveys is simply that the higher frequency transducer allows for finer resolution of smaller targets. The target strength calculation depends on the type of transducer used. These experiments made use of two different types of transducers — the split and the single beam. Split beam transducers are designed to directly measure the target strength distribution of the fish, since it can correct the TS measurement by the location of the fish within the acoustic beam. Such a system measures the time delay of the echo between the transducer elements in order to estimate the X and Y angles to the target. Then these angles are used to correct the off-axis amplitude of the echo (contained within the split-beam data) to the actual target strength. By contrast, the single beam transducer can only obtain the target strengths by indirect statistical methods referred to as the Expectation-Maximization-Smoothing (EMS) technique (BioSonics Inc., 2004). The method classifies targets according to their strength in a distribution array which is then combined with a beam pattern matrix which represents the probability of a given target placed within the acoustic beam. This is based on the assumption that fish are distributed with equal probability throughout the sampled volume.

The target strength is defined as the strength of the acoustical reflectivity from a target and is measured in decibels (dB) as,

$$\mathrm{TS} = 10 \log_{10} \frac{I_r}{I_i}, \tag{2.1}$$

where I_r is the intensity reflected from the target and I_i is the intensity incident on the target, all at a reference distance of 1 m from the target and I_r/I_i is equal to $\sigma_{BS}/4\pi r^2$. Here, σ_{BS} is the backscattering cross section from a single target measured at $r = 1$m. Since the reflected signal is always less than the incident signal, TS measurements are negative. If the species of fish is known, these measurements can then be correlated to the size of the fish represented by length, wet weight or dry weight via mathematical equations (Foote et al., 1986; Wiebe et al., 1990). Calibration of the source level (SL) and receiver sensitivity (RL) is essential for all instrumentation in order to obtain absolute measurements of target strength. When *in situ* calibration procedures are not possible (as in May 2004), only relative changes can be observed. This is because the received echo strength (E_S) is dependent upon SL, RL, TS and the two-way transmission losses (2TL) due to spherical spreading and absorption,

$$E_S = SL + RL + TS - 2TL. \tag{2.2}$$

Figure 2.2 is a conceptual depiction of the acoustic beam spreading out from the transducer to the seafloor with an approximate beamwidth of 6 degrees. Over the average 20 meter water depth, the beamwidth corresponds to a circular diameter of approximately 3 meters on the bottom due to the geometrical spreading of the beam. The BioSonics Visual Acquisition software collected all hydroacoustic data according to the parameters listed in Table 2.2. The beam width is the directivity (in degrees) of the under water sound emitted by the transducer. This is illustrated in Figure 2.2 and varied only slightly from one transducer type to another. The transmit frequency is the frequency of the emitted acoustic signal, and as mentioned before these analyses made use of both 120 kHz and 200 kHz devices. The data threshold is a user-defined parameter that instructs the software to ignore any targets whose strengths are less than this number. Different settings for this parameter were used in 2005 so as to capture more planktonic organisms with the higher acoustic frequency. Note that "passes" over transects are numbered and are defined as one journey over a transect (of latitude in 2003 and 2005, or of longitude in 2004) with an alphabetical designation. Also note that in 2005, pass 7 was completed in two parts to make up one whole pass. The squared threshold mode takes into account losses in the acoustic energy due to spherical spreading. The pulse rate is the number of transmissions the transducer emits in one second. The higher rates correspond to more finely sampled transects. The collection range refers to the depth of water sampled from below the face of the transducer to the sea floor. Sampling

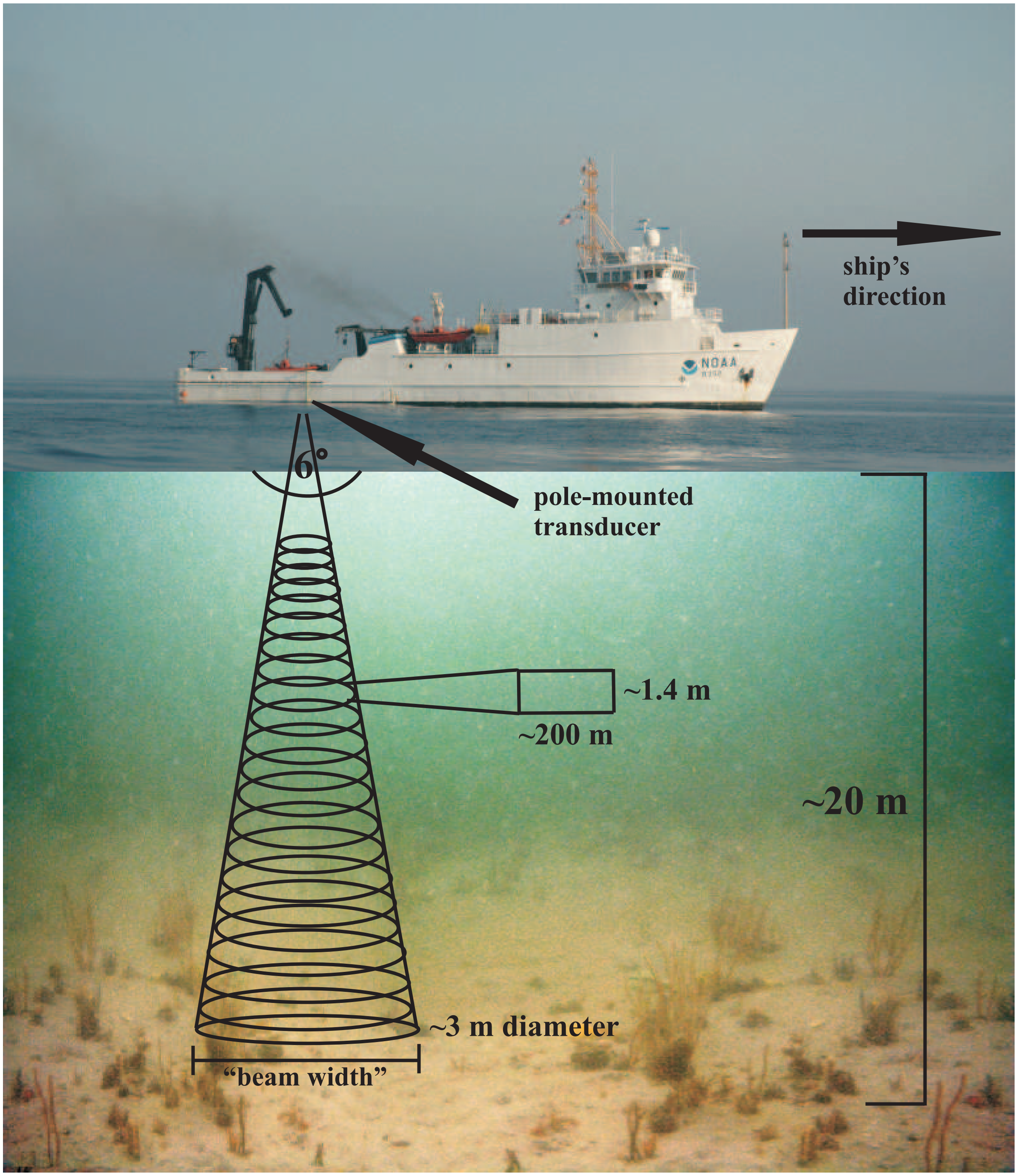

Figure 2.2: A schematic diagram (not to scale) showing the transmitted acoustic signal and the three-dimensional bin resolution (in meters) used in our processing. The signal emitted propagates in a cone shape (as indicated in the figure) as a result of spherical spreading.

Table 2.2: BioSonics Visual Acquisition parameters

	2003	2004	2005
Beam Width (°)	6.2	5.5	6.0
Transmit Frequency (kHz):	129 split-beam	123 single-beam	199 split-beam
Data Threshold (dB)	-100	-100	-110^a -130^b
Threshold Type	squared	squared	squared
Pulse Rate (Hz)	3	4	5
Collection Range (m)	1.99 to 18.35±0.92[c] 0.50 to 18.95±0.96[d]	0.5 to 16.67±1.22	0.98 to 15.92±1.04
Pulse Width (ms)	0.4	0.4	0.4

[a]for passes 1 through 7a
[b]for passes 7b through 14
[c]for passes 1 through 12
[d]for passes 13 through 21

begins at the user-defined blanking distance or "start range". This blanking distance is the depth of water to be masked out immediately below the transducer face. The "start range" typically begins at a distance greater than or equal to the length of the pulse in water (sound speed $*$ pulse width), where pulse width describes the duration of the transmitted pulse, measured in milliseconds. Regardless of the size of the blanking distance, the system will not receive any data until it has finished sending the signal (BioSonics Inc., 2000). The collection range in October 2003 differed between the first twelve passes and the remaining nine passes due to the user-defined blanking distance being changed after the twelfth pass and before the thirteenth pass.

In order to process the hydroacoustic backscatter data, the BioSonics Visual Analyzer 4.1 software was used with user-defined parameters listed in Table 2.3. This table reiterates the types of transducers used for each year. Next, the calibration correction is an offset that is input by the user once that offset is determined by calibration procedures which consist of suspending a tungsten calibration sphere having a known target strength below the transducer at a fixed distance. This number is used to correct the SL + RL term in equation (2.2).This is followed by the bottom threshold which detects the ocean bottom if the received echo strength is greater than or equal to -30 dB. In an area of hard bottom like Gray's Reef, the bottom is a strong reflector and therefore has a high decibel value just as a large object or organism would. To ensure that the bottom is characterized differently from the targets, this value is set higher than the fish targets being studied. It is vital that the bottom be well-tracked in order to prevent error being introduced into the results. For example, if the software neglects to "see" the bottom at any given location and then analyzes the signal of the bottom as targets, the result will be an inordinately high number of targets for that bin. In order to eliminate this, each data file was meticulously studied in order to ensure that the bottom was tracked properly. When the bottom signal was lost (as occurred on a few occasions) the Visual Analyzer software allows the user to correct the bottom trace. Additionally, the bottom blanking distance is another crucial component of

Table 2.3: BioSonics Visual Analyzer parameters

	2003	2004	2005
Transducer	Split-beam	Single-beam	Split-beam
Calibration Correction (dB)	0.4	no data	0
Bottom Threshold (dB)	−30	−30	−30
Maximum Target Strength (dB)	−35	−35	−35
Number of Acoustic Bins	23	23	23
Acoustic Bin Height (dB)	2	2	2
Number of Strata	20[a] 17[b]	15	16
Vertical resolution (m)	1.4	1.4	1.4
Report length (pings)	292	389	486
Average horizontal resolution (m)	243	231	226
Average Salinity (pss-78)	35.12	35.11	33.06
Average Water Temperature (°C)	24.44	23.01	20.17

[a]for passes 1 through 12
[b]for passes 13 through 21

this bottom detection. The bottom blanking distance is set to a constant distance of 0.25 m and is based on the spreading characteristics of the acoustic beam and its reflection off of the ocean floor, interfering with the side lobes that have not yet reflected. This concept is illustrated in Figure 2.3.

The maximum target strength of -35 dB listed in Table 2.3 is the upper limit of our TS range and typically corresponds to large fish like the red snapper (*Lutjanus campechanus*) (Foote et al., 1986). The lower threshold used for this study was -78 dB and generally corresponds to the smallest swim bladdered larval or juvenile fish, or small species like the bay anchovy (*Anchoa mitchilli*) (Van Holliday and Pieper, 1980). Target strength values less than -78 dB are considered to be zooplankton (Van Holliday and Pieper, 1980, 1995; Wiebe et al., 1990), and are therefore not included in this experiment. This establishes our target strength range of interest to be from -78 up to -35 dB. Since the desired acoustic resolution for analyzing the TS measurement was 2 dB, 23 acoustic bins were used in order to ensure that the full target strength range of interest was sampled. These parameters remained the same for all three sampling years.

The desired vertical resolution for processing our target strength distribution and abundance data was approximately 1.4 m for each experiment and as such, the number of vertical bins (strata) was determined from,

$$\text{strata}(\#) = \frac{\text{collection range}(m)}{\text{vertical resolution}(m)}. \tag{2.3}$$

The resulting answer was rounded to the nearest whole number and is listed in Table 2.3. For 2003, the different number of strata corresponds to the changed blanking distance after pass twelve. The horizontal averaging for the fish abundances was chosen to be approximately 200 meters. This approximation was established by considering the pulse rate (from Table 2.2), the average speed of the vessel — about 4 knots (or 2.0578 m/s), and the ping range — or total number of pings processed in one pass over a transect. First, it was determined

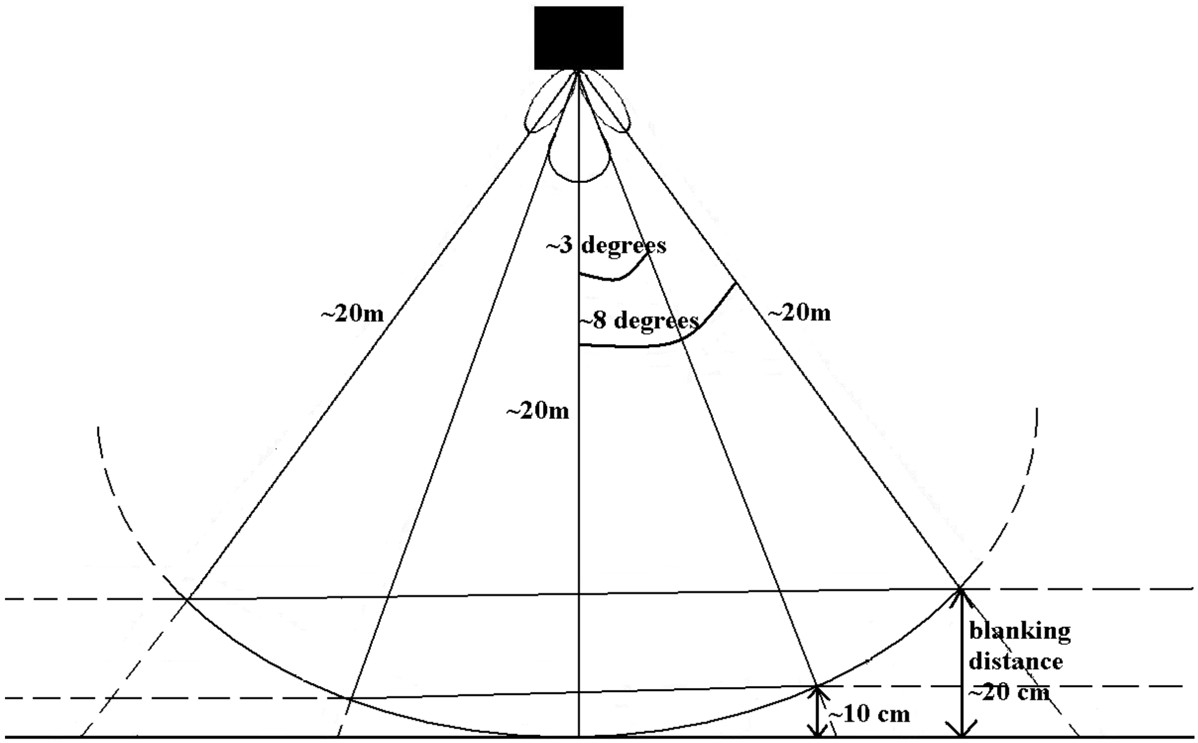

Figure 2.3: A schematic diagram illustrating the logic of blanking distance. The transmitted acoustic signal propagates in three parts, a main lobe and two side lobes. Some of the energy is emitted from the side lobes in addition to the main lobe. Notice that the central part of the main lobe hits the bottom before the side lobes do. If any organisms are ensonified in this area they will not be accurately measured due to the interference of this reflected signal with the side lobes that have not yet reflected.

how many seconds it took to travel a distance of 200 meters,

$$t_{200m}(s) = \frac{200(m)}{v_{\text{boat}}(m/s)}. \tag{2.4}$$

Then the number of pings transmitted during t_{200m} was used to define the report length for each transect according to:

$$\text{report length}(pings) = t_{200m}(s) * \text{pulse rate}(Hz). \tag{2.5}$$

The report length values are also listed in Table 2.3. Differences from year to year correspond to the change in pulse rate from year to year. This process resulted in an actual horizontal resolution that averaged around 234 meters when this data was georeferenced to a Universal Transverse Mercator (UTM) projection of the area (more on this process in Subsection 2.1.2). This is because the actual speed of the vessel varied between 4 and 5 knots. This relatively small horizontal resolution allows for the spatial comparison of abundance to specific types of habitat found in the same locations. Finally, the average temperature and salinity data for each year are listed which are used to calculate the sound speed for depth determination.

Both single and split beam sonar devices are able to obtain a fish density measurement via echo integration techniques over the vertical and horizontal bin size. This abundance, referred to as the target density in terms of fish per cubic meter (FPCM), is calculated from the volume backscattering coefficient (S_v) obtained through echo integration. The particle density (FPCM) together with the backscattering strength from individual particles ($\sigma_{BS}/4\pi$) essentially defines the volume backscattering strength:

$$S_v = FPCM\left(\frac{\sigma_{BS}}{4\pi}\right). \tag{2.6}$$

By dividing the water column into depth and range bins, if the returned echo is within the target strength threshold (of -78 to -35 dB) then the signal strength for the target (P) is squared and added into a running sum for the bin. This sum is divided by the number of samples measured giving an estimate of the average energy contained in the water volume sampled which is approximately rectangular. This energy is then scaled by environmental (sound speed) and transducer (source level, receiver strength, and beam pattern) parameters giving a scaling factor ρ_c which is assumed constant, such that,

$$S_v = \rho_c \left(\frac{\sum P^2}{\sum \text{samples}} \right), \tag{2.7}$$

is the scattering strength of a unit volume. The inherent assumption with this relationship is that there must be no multiple scattering.

Possible limitations of the hydroacoustic method stem from ship avoidance by the organisms. While the hydroacoustic method is non-invasive, species can retreat due to either the noise of the ship's operation or the physical disturbance of the vessel moving through the water. Furthermore, the speed at which the ship must be moving in order to survey acoustically is slow enough that larger species of fish that may be of interest, can swim faster than they can be detected.

2.1.2 Georeferencing

Geographical data was collected during all three cruises in order to provide the basis for the spatial analyses. The latitudes and longitudes were fed into the BioSonics Visual Acquisition software either by time synchronization (in Universal Time Coordinates — UTC) between the ships' navigation systems and the acquisition computer, or by a combination of time synchronization and direct live feed of the ships' Global Positioning System (GPS) to the acquisition computer. In October 2003, GPS information was collected via a serial connection with the RV Georgia Bulldog's National Marine Electronics Association (NMEA) GPS stream directly into the BioSonics Visual Acquisition software. There were occasions when the GPS data stream on the Acquisition software became "hung", causing geographical information to be lost for brief periods. Since we collected the navigation data independently, on another computer, we could then time synchronize the geographical data for those occasions when the GPS was lost on the echosounder data. Then in both May 2004 and 2005, the GPS data was acquired via the Nancy Foster's Scientific Computing Software (SCS). The acquisition computer (and therefore the BioSonics Visual Acquisition software) was time-synchronized to this SCS system so that geographical data could later be determined by the time.

For the spatial analyses, all of the geographical data collected was referenced to the minor habitat classifications map shown in the bottom image of Figure 1.1. Once the acoustic data were assigned latitude and longitude values, they were converted from degrees into meters, on a Universal Transverse Mercator (UTM) projection, which was accomplished using the MATLAB script `deg2utm.m`. The information could then be merged with the minor habitat classifications map (already in UTM).

The area sampled by the transducer was approximated as rectangular polygons derived from the geographic coordinates of the acoustic abundance data. As stated in Subsection 2.1.1, the FPCM data was divided along each transect into "reports" which were approximated to be 200 m in length. Once georeferenced, these "reports" were found to actually average 234 m in length overall, with each individual "report length" being different. The polygons were generated using the centroid values from each "report" together with the total length (variable) and width (3m) of area sampled for each bin. This spreadsheet of centroids, lengths, and widths was then imported into ArcView 3.2 to create polygons of the sampled areas. Using the ArcView tool "intersect", this polygon data was combined with the minor habitat classifications map. The result was hundreds of rectangular "chunks" of the habitat map that were analyzed to determine the percentage of each of the four minor habitat types within each polygon. Then, the percentages of each habitat type of all polygons along a transect were added together in order to determine the habitat composition for the transect as a whole.

It is this whole transect habitat composition percentage that is used to determine any spatial relationships with the TS distribution, since that data is also characterized by entire transects. Only general statements regarding the FPCM trends over whole transects are compared to the general habitat composition percentage calculated for the transects. The nature of these abundance data allows points of interest on the FPCM curves to be directly compared to the identical locations on the habitat map. Also, because the FPCM data was used to generate the polygons used in the spatial analysis, a more detailed, FPCM per habitat type can be determined for each transect line. To do this, the centroid locations of all the unique habitat subpolygons found within each polygon bin were imported from ArcView 3.2 into MATLAB. Then, the acoustic FPCM data was interpolated against this unique habitat subpolygon centroid data using the MATLAB function `interp1`. This resulted in FPCM values being assigned to each unique habitat type in every bin, which enabled analysis of abundance per habitat type.

2.1.3 Physical Oceanographic Data

To assess the physical conditions of the water column at the time of analysis, various environmental data were sampled during each cruise and were obtained from nearby ocean monitoring stations. The sources of the applied oceanographic data were unique for each cruise, and collection methods will be clarified in Section 2.2. In general, conductivity-temperature-depth (CTD) profilers were employed to gain a picture of how the temperature and salinity varied with depth over the vertical water column, in order to determine if any distinct thermo- or halocline existed. This data was also essential in order to quantify the mean temperature and salinity (shown in Table 2.3) so that sound speed is correctly used in the Visual Analyzer software. MicroCAT CTDs provided temperature and salinity information for the surface layer of the water column, and helped to identify the depth of instrumentation, as well as any coastal frontal features. Current flow was monitored by using either an acoustic doppler current profiler (ADCP), towed alongside the echosounder, or from the South Atlantic Bight Synoptic Ocean Observing Network (SABSOON) coastal observatory R2 tower which is approximately 28 km east of the GRNMS NDBC Station 41008. Information on the wind speeds and directions together with the significant wave height, was obtained from the NDBC Station 41008. What impact these data potentially had on our results will be put forward in Chapters 3 and 4 where applicable.

2.2 Research Cruises

2.2.1 October 4–6, 2003

This initial cruise was, fundamentally, a pilot study to assess the feasibility of the research and to collect preliminary data. Using the RV Georgia Bulldog from the Marine Extension Service in Brunswick, acoustic data were collected over a continuous 24-hour period followed by several hours of trawl surveys. The hydroacoustic survey was performed using a BioSonics DT6000 120 kHz split beam echosounder (details in Table 2.2) attached to a towfish, provided courtesy of Doran Mason of the NOAA GLERL. The towfish was deployed at a depth of 1-meter below the surface of the water. Prior to collecting any data, this system was calibrated at the dock in about 4–5 meters of water with a tungsten calibration sphere having a known target strength of −35 dB. The resulting narrow beam offset of 0.4 dB (see Table 2.3), corrected the source level (SL) and receiver sensitivity (RL) sum, $(SL + RL)$, used by the BioSonics Visual Analyzer software.

Note that in Table 2.2 there are two different sampled depth ranges listed for this dataset. This is due to the fact that the user-selected blanking distance was changed mid-collection. The blanking parameter is the distance below the bottom of the transducer where you want to begin sampling. The initial blanking distance used of two meters was determined to be too deep since the towfish and transducer were already suspended one meter below the surface. That is why the depth range for the remainder of the analysis begins at a half meter. This is actually a half meter below the transducer so sampling initiates at approximately 1.5 meters below the surface.

Figure 2.4 shows the east/west ship transects superimposed on the GRNMS habitat classifications map. East/west runs were chosen so as to travel with or against the prevailing wave field in order to limit significant roll on the tow fish. Note also that in Figure 2.4

Table 2.4: October 2003 habitat composition percentages.

Transect	rippled sand	flat sand	sparsely colonized	densely colonized
A	70%	0.5%	29%	0.5%
B	55.25%	8.25%	35%	1.5%
C	40%	7%	52%	1%
D	89%	7%	3%	1%
E	90%	10%	0%	0%

each of the latitudinal transect lines are assigned an alphabetical label (A – E) that will be used to indicate sampling locations. The term, latitudinal, as used here, is analogous to the geographical reference for "zonal" which means along or parallel to lines of latitude.

Figure 2.5 shows the percentage of each transect (A – E) that corresponds to each of the four minor habitat classifications. For ease of reference, Table 2.4 lists the calculated habitat composition for each transect. Of note is that transect C contains the most sparsely colonized reef habitat, where transect D contains the least. Transects A – D all contain slight percentages of the densely colonized reef habitat. Transect E consists of 100% unconsolidated sediment.

Acoustic data were also collected just outside the eastern and southern boundaries of the reef (shown on Figure 2.4) in order to conduct simultaneous mid-water (between 10 and 11 meters) trawls for ground truth analysis. A letter of acknowledgment (LOA) was issued on September 15, 2003, from NOAA's Southeast Regional Office in order to conduct the trawling analyses outside of the sanctuary boundaries. Trawling is not permitted within the sanctuary boundaries according to the GRNMS Regulations expressed in the Federal Register, Vol. 71, No. 197, 15 CFR Part 922, Subpart I 922.92.

The trawl net used had an opening of approximately 13.5 meters with a 4.8 cm stretch mesh that tapered to a 2.3 cm cod end, without turtle exclusion devices (TEDs). Acoustic

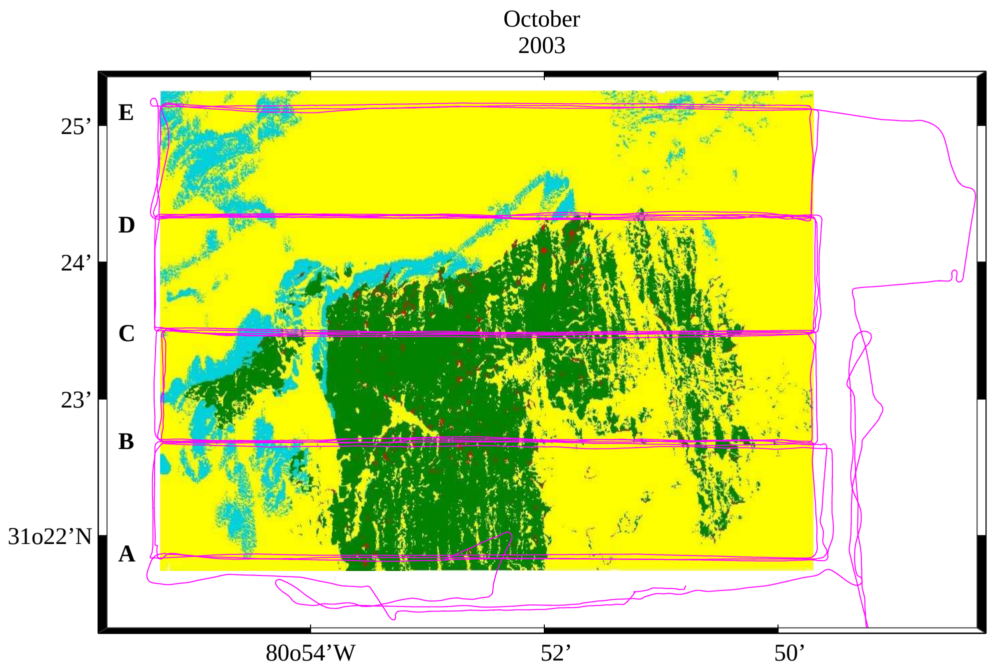

Figure 2.4: Cruise tracks for October 2003 shown in magenta overlaid on the GRNMS habitat map. Note that each latitudinal transect line has been assigned an alphabetical label.

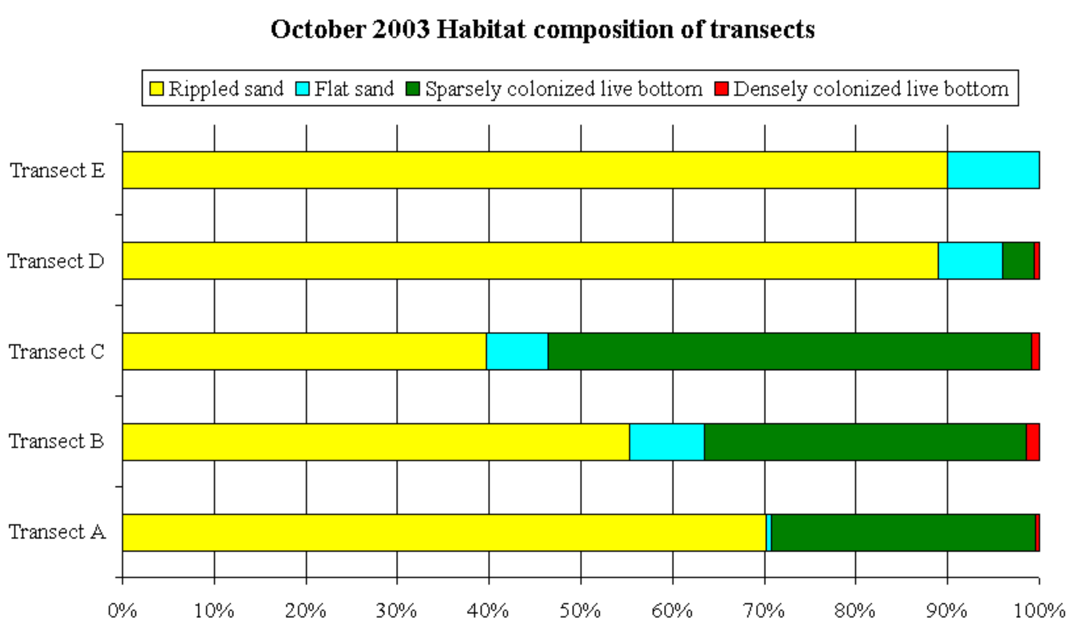

Figure 2.5: The October 2003 transects characterized as percentages of habitat types.

measurements for the trawls were taken from the towed echosounder off the starboard side of the RV Georgia Bulldog as the trawls were deployed off of the rear port quarter. Additionally, a MicroCAT CTD affixed to either the trawl's head rope or within the cod end served to collect pressure measurements in order to establish the depth of the trawl net. This ensured that it was indeed sampling at mid-water column level. There is potential for net avoidance by the organisms (Misund et al., 1999) which introduces errors in the species composition and size distribution.

Table 2.5 illustrates the range of fish species caught in the trawls, and Figure 2.6 shows the size distribution of those catches. The measurement used to create the size distribution for all of the species collected was referred to as the "total length". In regards to fish, this can be defined as the length from the nose of the fish to the tip of the tail fin. For round jellies, this was the diameter. For the bell-shaped jellies and squids, this measurement described the length from the top of the bell to the end of the longest tentacle. It is interesting to note that the two dominant sizes of organisms caught as represented by Figure 2.6, are each characteristic of the two most frequently caught species. The *Anchoa mitchilli* consistently ranged between 4–6 centimeters, while the *Chloroscombrus chrysurus* measured between 18–20 centimeters. And since all organisms caught only ranged in size from a few centimeters to tens of centimeters, this information enables us to focus on the target strength range of -78 to -60 dB which is seen to be the range ideally suited for isolating fish in this size range. It is generally accepted that -78 dB is the limit for detecting swim bladdered organisms (described as physostomous or physoclistous fish depending on their physiology). Target strengths smaller than -78 dB would be from zooplanktonic organisms (Van Holliday and Pieper, 1980, 1995; Wiebe et al., 1990).

During the hydroacoustic assay, cruising was halted at each of the four corners of GRNMS to collect CTD profiles to assess how temperature and salinity varied with depth throughout the survey. Data available from the NDBC Station 41008 provided information on wind speed and direction and significant wave height. Over the entire cruise, water column currents (in

Table 2.5: Summary of species caught during trawling events

Total number caught (kept)	Common name	*Genus species*
13/13	squid	not identified
12/12	moon jelly	*Aurelia aurita*
5/5	sea wasp	*Tamoya haplonema*
1/1	comb jelly	*Mnemiopsis sp.*
2/2	eel/cutlass fish (juvenile)	*Conger sp./Trichiurus lepturus*[a]
4/4	round scad (juvenile)	*Decapterus punctatus*
2/2	permit/butterfish (juvenile)	*Trachinotus falcatus/Peprilus triacanthus*[a]
1/1	lookdown fish (juvenile)	*Selene vomer*
1/1	inshore lizardfish (juvenile)	*Synodus foetens*
3/3	Atlantic thread herring (juvenile)	*Opisthonema oglinum*
4/4	Atlantic thread herring	*Opisthonema oglinum*
79/60	Atlantic bumper	*Chloroscombrus chrysurus*
1717/80	bay anchovies	*Anchoa mitchilli*

[a]Unable to determine the exact Genus and species; both possible common names and classifications are listed.

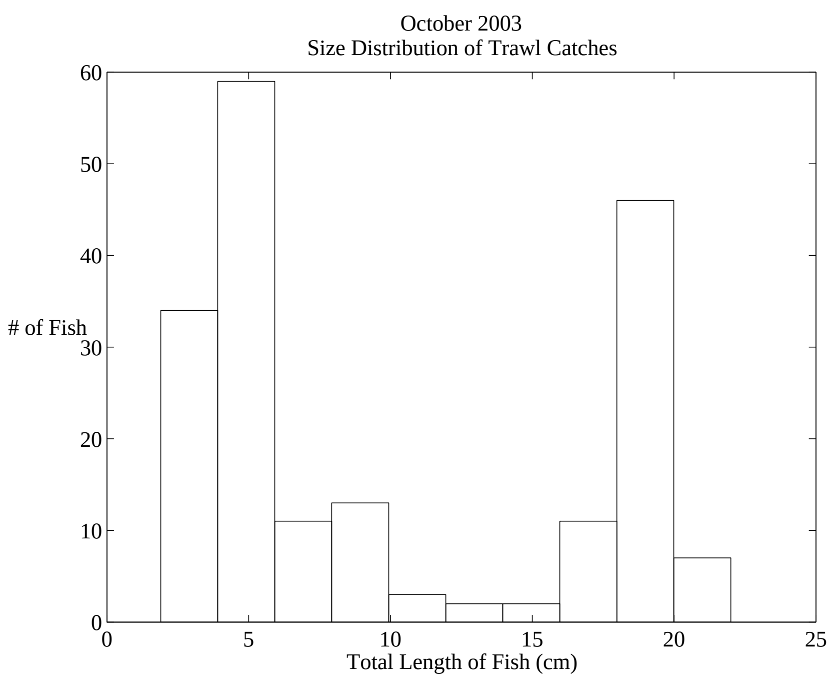

Figure 2.6: The size distribution (in centimeters) of total organisms kept from all trawling events in October 2003.

m/s) were sampled with a 600 kHz ADCP mounted, looking down through the water column, to a rigid mast on the starboard side of the RV Georgia Bulldog. Finally, a MicroCAT CTD was affixed just below the surface of the water to the same mast that secured the ADCP. This was in order to collect the continuous sea surface temperature (SST) and salinity measurements throughout the domain in order to observe any coastal frontal features.

A summary of the physical data obtained is illustrated in Figure 2.7. The top three graphs all share the same x-axis values of year day and time increments are expressed in UTC. Year day of 278 corresponds to October 5, 2003. The graph of wind speed (solid line) versus wind direction (dotted line) indicates that wind speeds remained fairly mild throughout the sampling period — ranging from about 3–5 m/s. The wind direction (expressed as degrees from true North) at the start of the survey originates from the south and rotates clockwise until the wind settles from the east at about noon EDT. The significant wave height (H_s) remains just below 1 meter throughout the 24-hour period, indicative of a consistent gentle swell that did not introduce significant pitch and roll on the tow fish (which would have caused loss of data). The current speed is characteristic of a region having mixed semi-diurnal tides such that the flows in the SAB never really slacken. The color map of the sea surface salinity during transecting alludes to a salinity frontal zone as a result of coastal Georgia rivers, like the Altamaha. The increase in salinity toward the southeast shows the general direction of tidal propagation. Finally, the four salinity and temperature profiles from each corner of the sanctuary indicate small vertical gradients. This is prone to become a highly variable structure since tidal mixing (which is dominant in the sanctuary region) can easily erode such small temperature and salinity gradients.

The acoustic results obtained (as will be discussed) determined that the methods employed are a valid means of conducting this research in the future (Di Iorio, 2003). These deductions helped secure funding from the NOAA GRNMS and the NOAA NURC for additional surveys (May 2004 and May 2005).

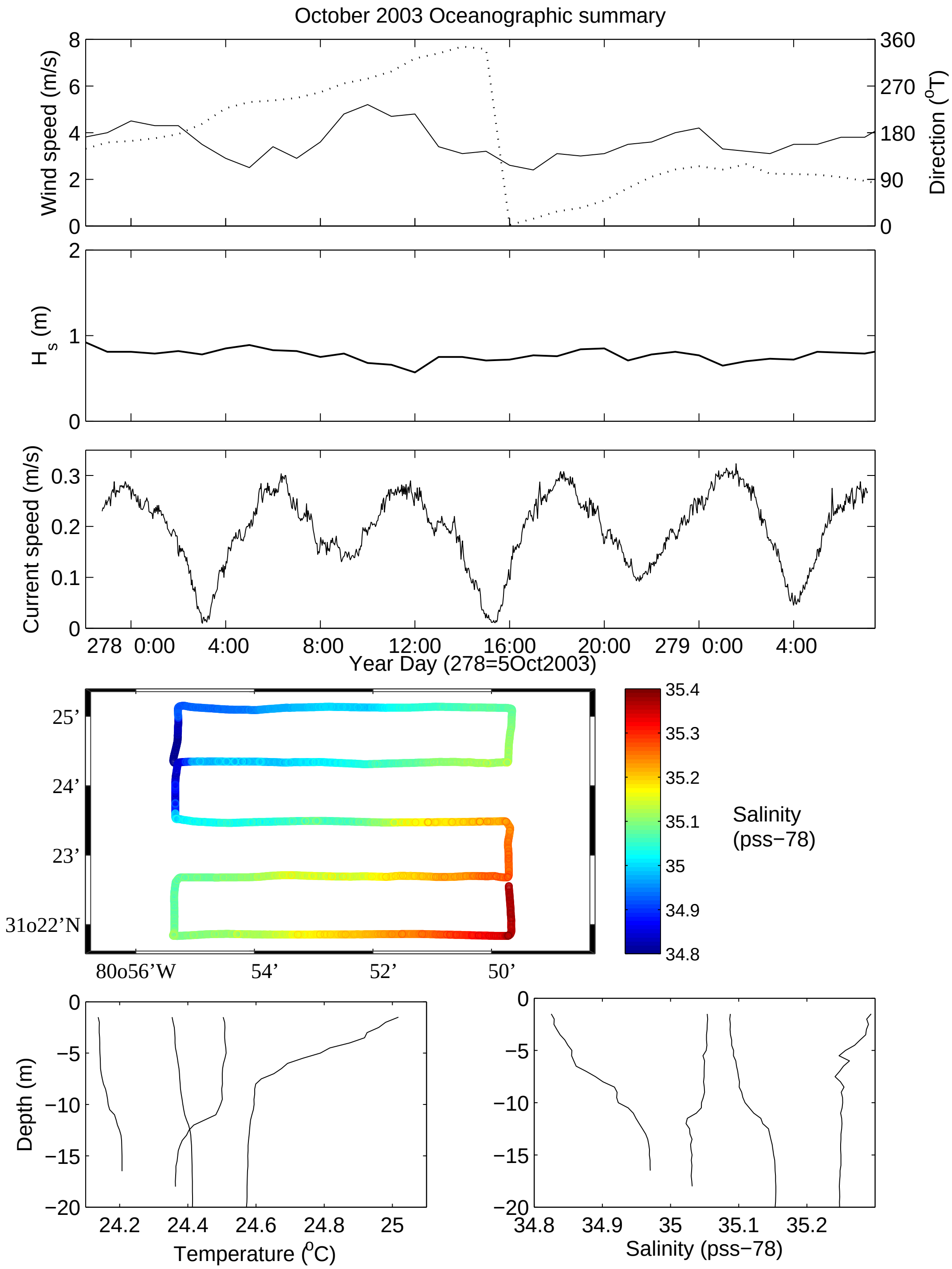

Figure 2.7: October 2003 oceanographic summary

2.2.2 May 12–13, 2004

For the cruise in May 2004, hydroacoustic surveys were performed using a BioSonics DT4000 120 kHz single beam echosounder (details in Table 2.2), attached to a rigid mast on the starboard side of the NOAA SHIP Nancy Foster at a depth of 3.26 meters from the surface. For this dataset, there is no pre- or post- cruise calibration data available to correct the source level (SL) and receiver sensitivity (RL), as it was difficult to suspend a calibration sphere from the NOAA SHIP Nancy Foster. During the attempt, we ended up damaging the transducer which meant no post cruise calibrations were possible either. As a result, the target strength distribution and FPCM measurements are relative as there are unknown offsets that exist within the target strength measurements.

Figure 2.8 shows this cruise grid superimposed onto the GRNMS habitat classifications map. The north/south transect pattern was selected in order to attempt to specifically observe any changes in the number of fish as the vessel approached the distinct "ledge" of live-bottom habitat in the northern part of the sanctuary located at the approximate latitude of $31^\circ\ 24'$ N. In addition, this pattern was chosen to deliberately concentrate efforts over the areas of GRNMS known to contain more reef structure according to the GRNMS habitat classifications map. These longitudinal transects were also assigned an alphabetical label (A – E) that will be used to indicate sampling locations for 2004. Here the term, longitudinal, is analogous to the geographical reference for "meridonal" which means along or parallel to lines of longitude.

Figure 2.9 shows the percentage of each transect (A – E) that corresponds to each of the four minor habitat classifications. For ease of reference, Table 2.6 lists the calculated habitat composition for each transect. Note that all five transects contain the sparsely colonized reef habitat, with transect C containing the most. Further, only transect A does not contain any densely colonized habitat. The remaining transects, while all contain densely colonized habitat, it is only in small percentages.

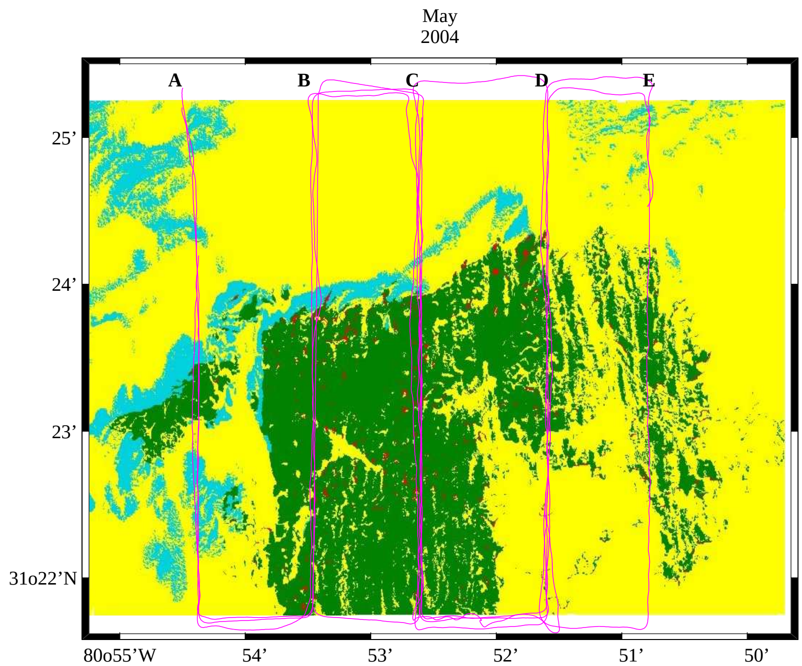

Figure 2.8: Cruise tracks for May 2004 shown in magenta overlaid on the GRNMS habitat map. Note that each longitudinal transect line has been assigned an alphabetical label.

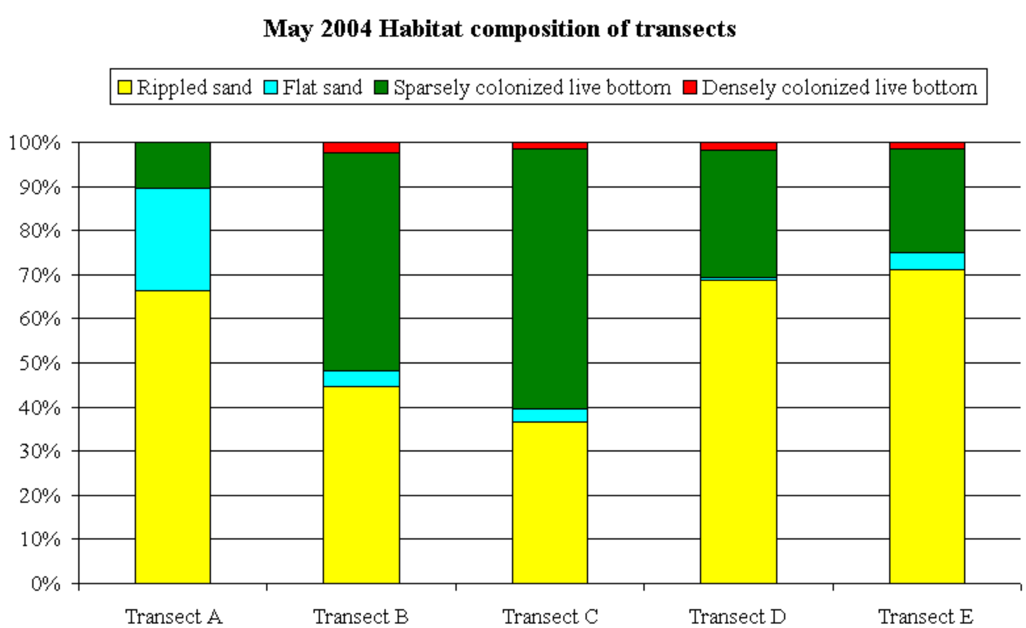

Figure 2.9: The May 2004 transects characterized as percentages of habitat types.

Table 2.6: May 2004 habitat composition percentages.

Transect	rippled sand	flat sand	sparsely colonized	densely colonized
A	67%	23%	10%	0%
B	45%	4%	49%	2%
C	36.5%	3%	59%	1.5%
D	68.5%	0.5%	29%	2%
E	71%	4%	23.5%	1.5%

In 2004, experimental ground truthing observations were made with a digital video recorder mounted to the remotely operated vehicle (ROV), "Phantom S2". In order to conduct these ROV-mounted video surveys, hydroacoustic transecting was interrupted for two-hour periods so that the NOAA SHIP Nancy Foster could drift with the ROV in tow. These two hour drift periods were centered around midnight, dawn, midday, and dusk. When the drifting periods began, the boat was positioned within the reef boundaries so that it would drift in such a way as to always be "leading" with the transducer. As mentioned, the transducer was on the starboard side, so the ROV was deployed off of the port side. This set-up allowed the ROV operator (Mr. G. Taylor, NOAA NURC) time to position the ROV vertically in the water column so as to videotape any targets that were first seen on the acoustic output produced by the echosounder.

The tracks of the ship's path during the periods while drifting with the ROV can be seen on Figure 2.10. This Figure indicates that our drift was consistently to the northwest, which can be attributed to the prevailing southeast winds that day (as evidenced in Figure 2.11 and discussed in more detail later on in this Chapter).

ROV-mounted video footage can be biased in that organisms will be either drawn to — or repelled from — the operational lights of the ROV. These biases can be negated by placing various filters or gels over the lights. For our experiments, a red filter was intermittently

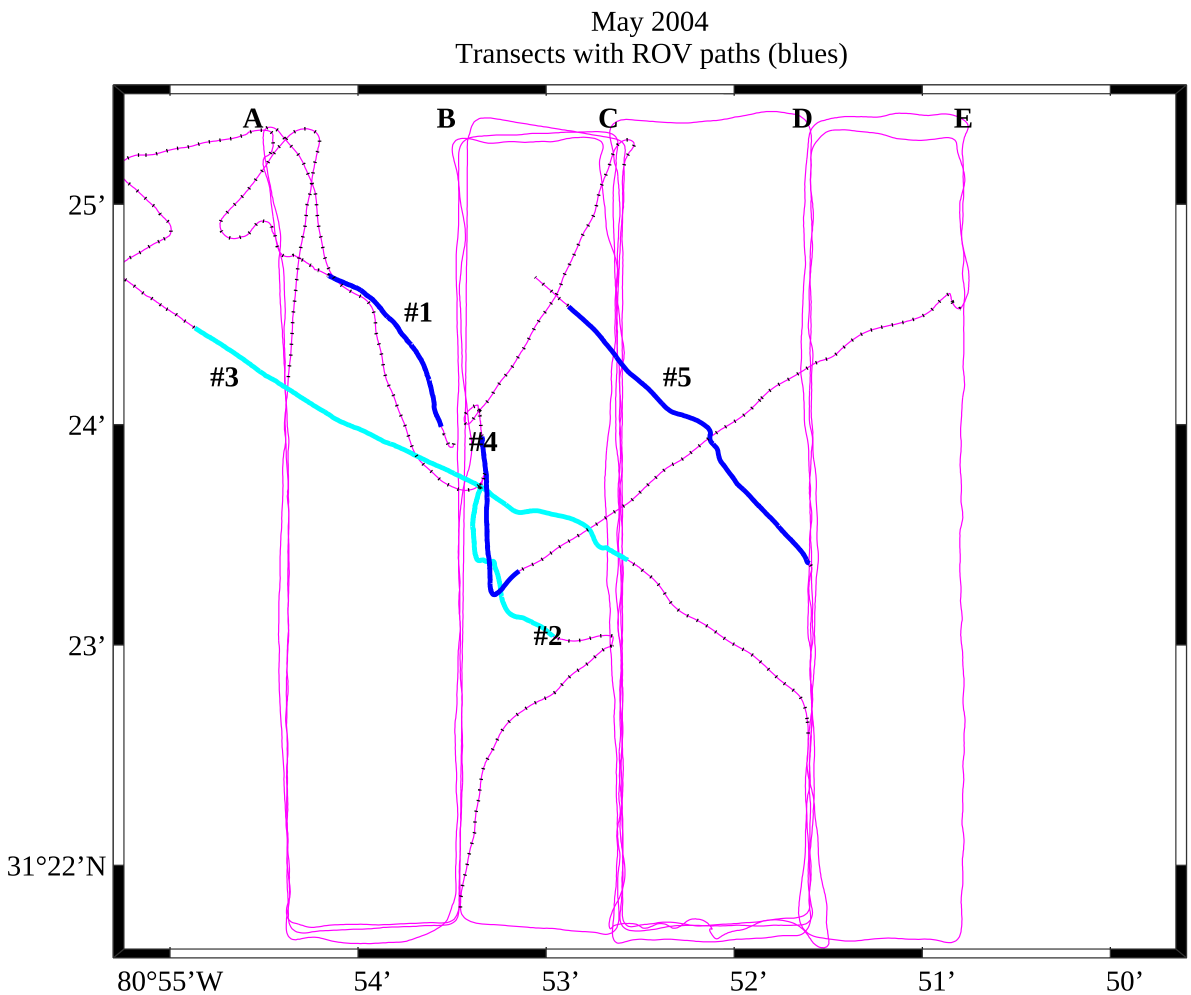

Figure 2.10: May 2004 cruise tracks in magenta with tracks during ROV use in blue. Dark blue depicts evening/night sampling and light blue depicts morning/day sampling. The black dotted tracks represent the times which the NOAA SHIP Nancy Foster was travelling from, or back to, the hydroacoustic cruise tracks preceding, or subsequent to, ROV sampling times. The numbers indicate the chronological labeling of the ROV dives.

activated over the ROV lights to determine if the biota being seen would react either way, yet there was no discernable change in the behavior of the organisms on screen. Also, because drifting speeds were relatively fast (see Figure 2.11), it was difficult to identify species of fish in the video coverage. However, selected footage was used to confirm that the majority of pelagic biota at GRNMS was less than or equal to the same 25 cm size range isolated in 2003, and hence would have low associated target strengths. The video footage predominantly consisted of marine snow, or flocculation, in our mid-water column sample at all times of day. There was no noticeable change in the characteristics of this turbidity from one time of day to another. This phenomenon is easy to detect while viewing the video data. However, capturing still, representative, images from these videos proves to be fruitless. The relative speed of the drift caused the resolution of the still images to be insufficient for picking out any distinguishing characteristics of the flocculation or fish in the frame.

The oceanographic data collected in 2004 consisted of a single CTD profile collected upon completion of the hydroacoustic analysis in order to determine if any significant thermocline existed. An acrobat undulating CTD profiler towed during a couple of transects (not shown) confirmed that the water column remained essentially well-mixed throughout the experiment. Additional environmental data available from the NDBC Station 41008 provided information on wind speed and direction and significant wave height. As no current measurements were collected from the NOAA SHIP Nancy Foster, we made use of the SABSOON R2 ocean observatory and its bottom mounted ADCP.

A summary of these physical data is shown in Figure 2.11. The top three graphs all have the same x-axis values expressed in UTC where 133 is the year day that represents May 12, 2004. The wind speed (solid line, top graph) varies throughout the day with gusts up to 7 m/s prevailing steadily out of the southeast all day (dotted line, top graph). The significant wave height (H_s) shows a general trend of just below 1 meter with certain segments during the day marking above 1 meter. As the significant wave heights were small, pitch and roll on the transducer were also small hence, data loss was minimized. Also, any turbidity that

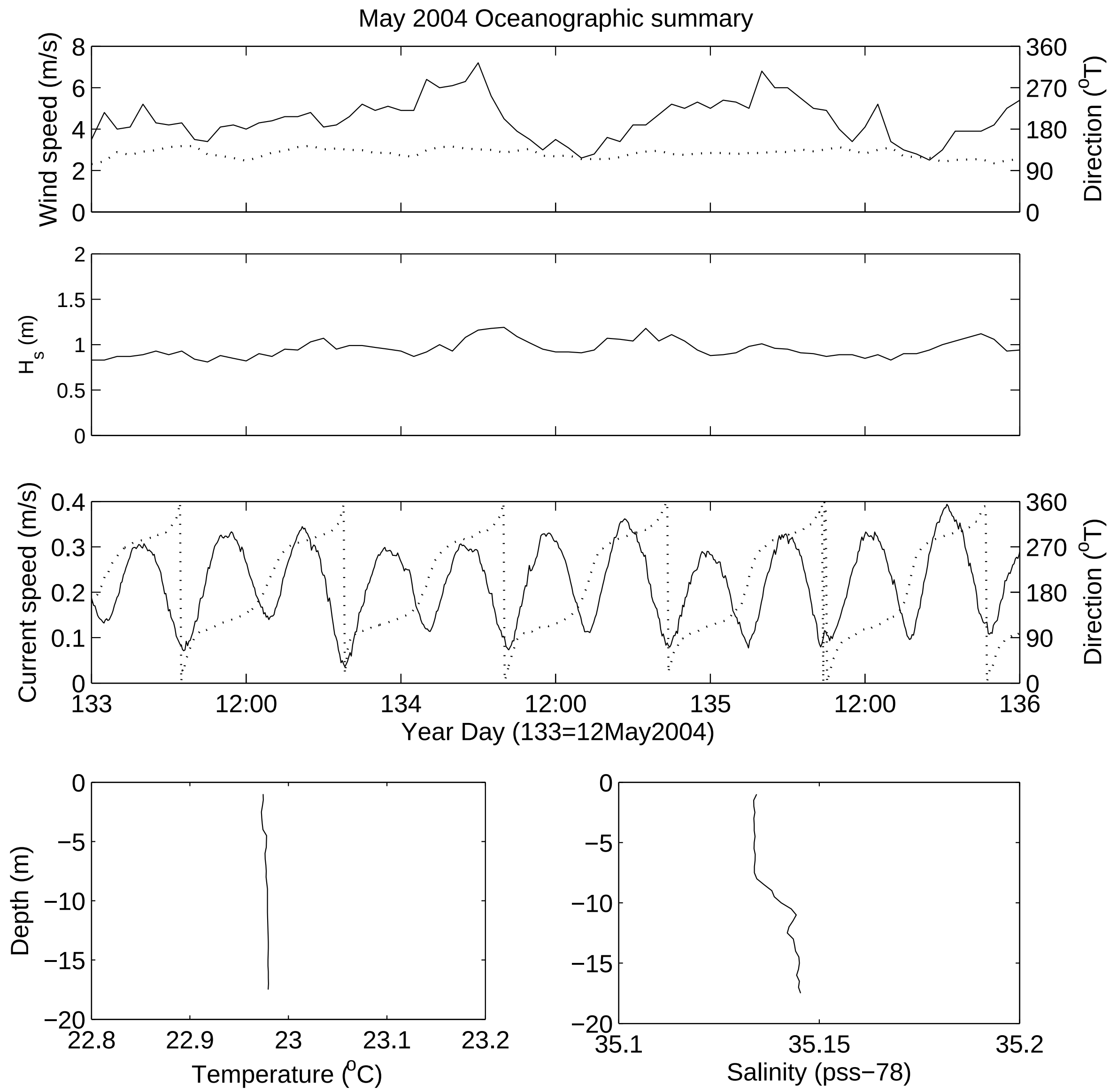

Figure 2.11: May 2004 oceanographic summary

might exist due to wave stress acting on the ocean bottom suspending particulates was also small. Examination of the current speed (solid line) versus current direction (dotted line) graph illustrates a definitive mixed semi-diurnal tidal cycle, as is characteristic of the Georgia bite region (Atkinson et al., 1983). Lastly, the salinity and temperature profiles show the well-mixed conditions in the water column as no apparent thermocline or significant halocline exists.

2.2.3 May 11–12, 2005

The hydroacoustic analysis in 2005 was taken with a BioSonics DTX 200 kHz split beam echosounder (details in Table 2.2), attached to the same rigid mast as in 2004, and again deployed off of the starboard side of the NOAA SHIP Nancy Foster at a depth of 3.26 meters below the surface. This transducer was calibrated in a controlled tank environment at the manufacturer's facility prior to the cruise, so the target source level (SL) and the receiver sensitivity (RL) were known prior to its operation at sea. Therefore, no correction was made to $(SL + RL)$. Also, midway through the data collection, the user-defined data threshold was decreased from -110 to -130 decibels in order to ensonify planktonic scales which allow visualization of the water column like the presence or absence of a thermocline since these organisms tend to accumulate at the base of the thermocline.

The cruise track for 2005 also followed an east/west grid pattern similar to the October 2003 survey (see Figure 2.12). It was decided for this experiment to run the transects latitudinally so that the transect paths would coincide more closely with randomly selected densely colonized reef areas that were distributed more latitudinally than longitudinally. These areas were chosen by the NOAA's BioGeography team, also conducting research on board the NOAA SHIP Nancy Foster at this time. The NOAA BioGeography team conducted SCUBA dives to perform analyses on the randomly selected densely colonized reef sites and to visually assess each location. Although no biotic ground truth analysis accompanied the hydroacoustic surveying for this year, anecdotal information provided by the NOAA

Table 2.7: May 2005 habitat composition percentages.

Transect	rippled sand	flat sand	sparsely colonized	densely colonized
A	64%	2%	33%	1%
B	52%	1%	46%	1%
C	56%	17%	26%	1%
D	87%	13%	0%	0%

BioGeography team served as an informal means of determining the conditions in the water column: an apparent thermocline and good visibility (i.e. low levels of turbidity in the water column). Divers also described seeing several schools of Atlantic spadefish, *Chaetodipterus faber*, at several dive locations. Other notable fish congregations were in and around reef structure on or near the bottom within the blanking distance of 0.25m so that information is not considered. These latitudinal transects were given alphabetical labels (A – D) that will be used to identify sampling locations.

Figure 2.13 shows the percentage of each transect (A – D) that corresponds to each of the four minor habitat classifications. For ease of reference, Table 2.7 lists the calculated habitat composition for each transect. Transect D consists of entirely unconsolidated sediment (both the rippled sand and flat sand classifications). The three remaining transects are characterized by containing at least one-fourth hard bottom habitat (from a combination of both the sparsely colonized and densely colonized habitat types).

Periodic physical oceanographic data was collected via CTD profiles each time the ship arrived at the southernmost easterly and westerly boundaries of the sanctuary. An average of these sea temperature (in degrees Celsius) and salinity values were applied to the hydroacoustic survey data (shown in Table 2.3). Meteorological data was acquired from NDBC Station 41008 and currents were obtained from the SABSOON R2 tower bottom mounted ADCP.

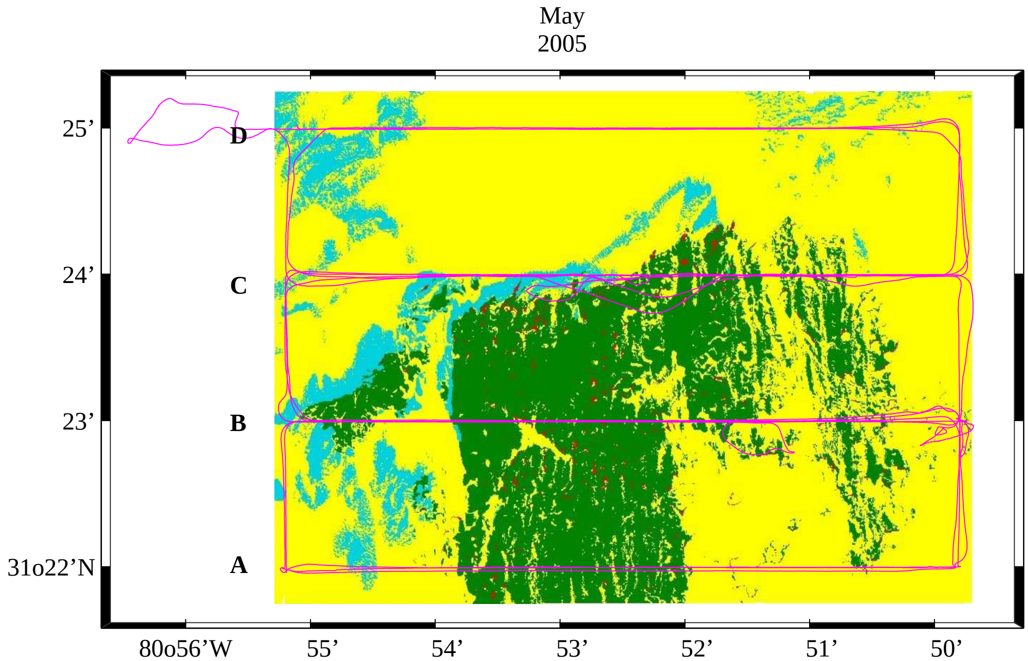

Figure 2.12: Cruise tracks for May 2005 shown in magenta overlaid on the GRNMS habitat map. Note that each latitudinal transect line has been assigned an alphabetical label.

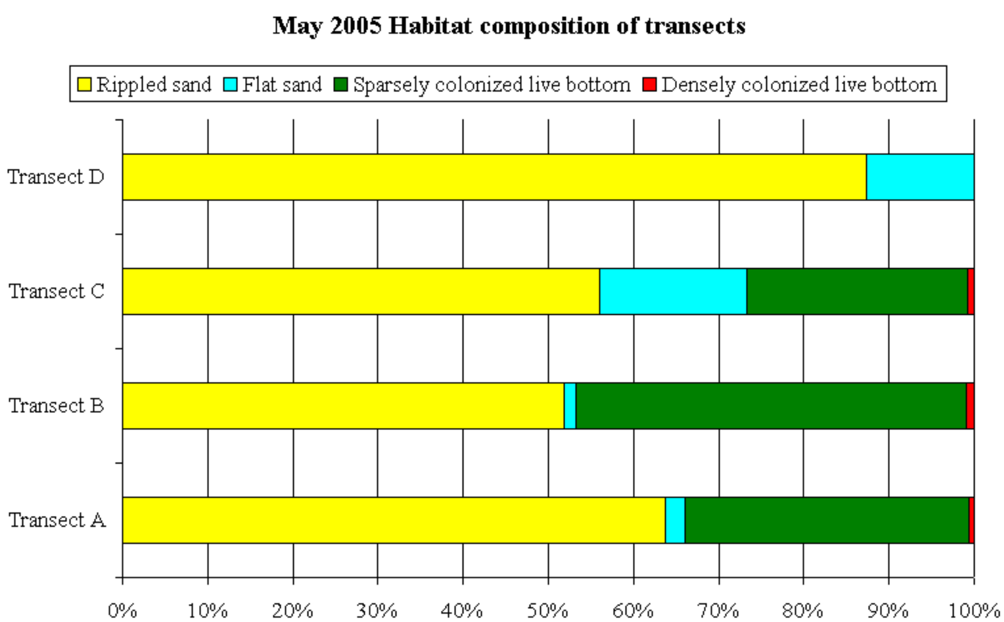

Figure 2.13: The May 2005 transects characterized as percentages of habitat types.

The physical oceanographic summary for 2005 is in Figure 2.14. The top three graphs all share the same x-axis, date and time of day expressed in year day and UTC (with 131 being equal to May 11, 2005). The wind speed (solid line) and direction (dotted line) graphs show that both were highly variable throughout the 24-hour sampling period. Wind speeds ranged from 0 – 6 m/s, and rotated through all directions. The significant wave heights begin with a maximum value of about 0.8 meters and continue to gradually decrease throughout the sampling period indicating very calm conditions at sea. As expected, the graph illustrating the current speed (solid line) and direction (dotted line) is typical of the mixed semi-diurnal tides found in this region of the SAB. Finally, examination of the CTD profiles show a strong thermo- and halocline as a result of significant freshwater discharge from the Altamaha River during this time (see Figure 2.15). Notice that there is a huge surge of freshwater from the Altamaha in March/April of 2005 as a result of significant rainfall early in the year. By the time of our sampling, in May, the coastal frontal zone had extended out to the coordinates of GRNMS (Blanton and Atkinson, 1983), contributing to the distinct temperature and salinity profiles collected. This figure also marks the times of our October 2003 and May 2004 experimental programs for comparison. Examining the Altamaha River volume transport at these times provides further evidence supporting the well mixed temperature and salinity profiles for each of those years. Neither 2003 or 2004 data exhibited a strong thermocline or any remarkable water column gradients because the river volume transport was relatively small at these times.

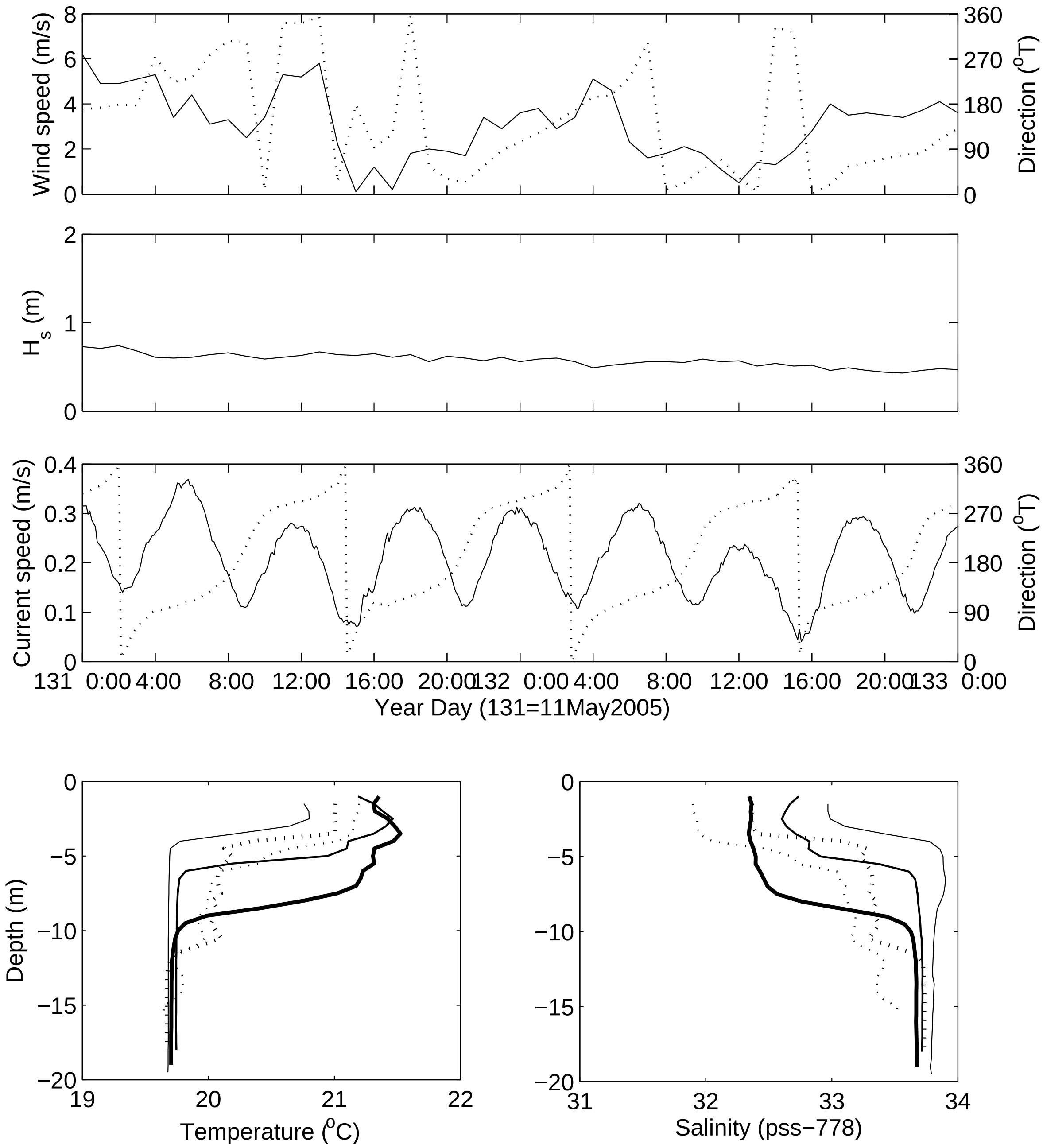

Figure 2.14: May 2005 oceanographic summary

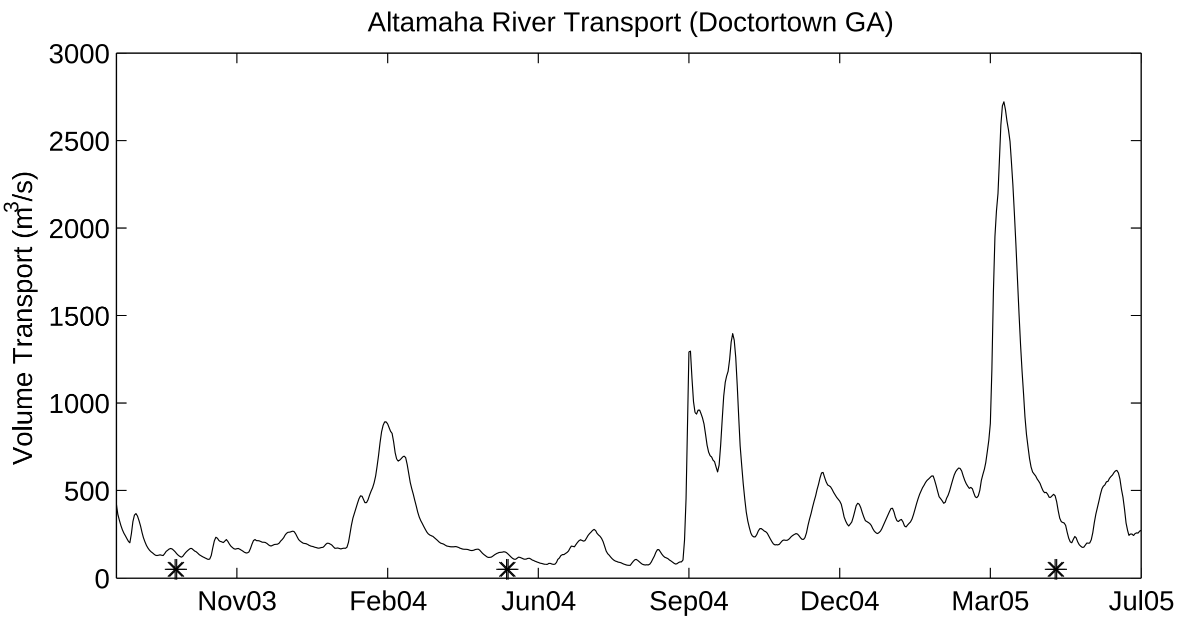

Figure 2.15: Altamaha River volume transport from October 2003 to July 2005 at the U.S. Geological Survey gauging station in Doctortown, GA. The asterisks indicate our three sampling programs.

Chapter 3

Size Distribution

D. Van Holliday describes, in detail, the varying uses and importance of target strength distribution measurements in Foerster (1989). These measurements can be used to determine the spatial distribution of fish in a geographical region, water column mass, or in relation to each other. It can be used to estimate a variety of properties regarding fish schools, i.e. the number of individuals in and the dynamics of the school. (Petitgas and Levenez, 1996) used TS distributions to study the morphology of entire fish schools in Senegal and found that the shape of the school related to depth in the water column and the stages of the diel cycle. Also, TS distributions can be correlated to the sizes of individual fish and used to estimate the range of sizes of fish within schools, and then these estimates can related to biomass values. Additionally, TS distributions are also used to measure rates of ascent or descent in vertically migrating species, profile swimming speeds, and assess certain behavioral patterns such as swimbladder inflation/deflation at particular times of day. These types of analyses are important components for discovering how fish and fish schools vary with species, season, behavior, food supply, and physical and chemical oceanographic properties, all of which could provide ecological insight to the regions in which these targets are found.

While there are several studies aimed at isolating the target strength to fish size ratio of particular species (Bertrand and Josse, 2000; Foote et al., 1986; Foote, 1987; Hartman and Nagy, 2005), this study uses TS as an attempt to quantify a group of fish for a certain area, in this case, the pelagic population within the boundaries of Gray's Reef NMS. A similar study is that of Gauthier and Horne (2004), who used TS to determine the sizes of forage fish in Gulf of Alaska and the Bering Sea.

The target strength distributions were measured to try and gain a perspective on the approximate size of the resident pelagic fish community at Gray's Reef. It is hoped that this measurement will provide any predator/prey size separations of the pelagic population as seen in Kracker (1999). Since there are two distinct groupings of targets as seen in the data, we assign the term "predators" to fish with target strengths of -60 to -45 dB and "prey" to those targets with strengths of -78 to -60 dB. These terms, as they apply here, are merely to differentiate between the two groups of targets that will be discussed in this Chapter, noting that food web dynamics indicate that all of these organisms are both predators and prey at some level of the hierarchy.

Target strength distribution measurements are obtained for entire transects at a given time of day. In order to isolate the size distribution along each transect, the BioSonics Digital Analyzer software separated the targets into acoustical and depth bins according to the parameters listed in Table 2.3. The result is a contour depiction of the number of targets that have a given TS and the vertical depth in the water column where they can be located over the length of a whole transect.

By examining these contours, a picture of the TS distribution within the sanctuary can be created. Also, the temporal attributes of the data are investigated. The depth bin resolution was set to approximately 1.4 meters so as to observe any diel migration changes or patterns, which can be assessed by comparing all transect paths repeated within a 24-hour cycle. Any seasonal relationships are defined by a comparison of the data from October 2003 (Fall) to May 2005 (Spring). Finally, the TS data is analyzed with respect to the bottom habitat classifications to identify any spatial relationships that may exist.

3.1 October 4–6, 2003

Target strength distributions as a function of depth for October 2003 are shown in Figure 3.1. Each column corresponds to the time of day and each row corresponds to a different transect, or latitude. The target strengths are plotted along the x-axis with the lower numbers

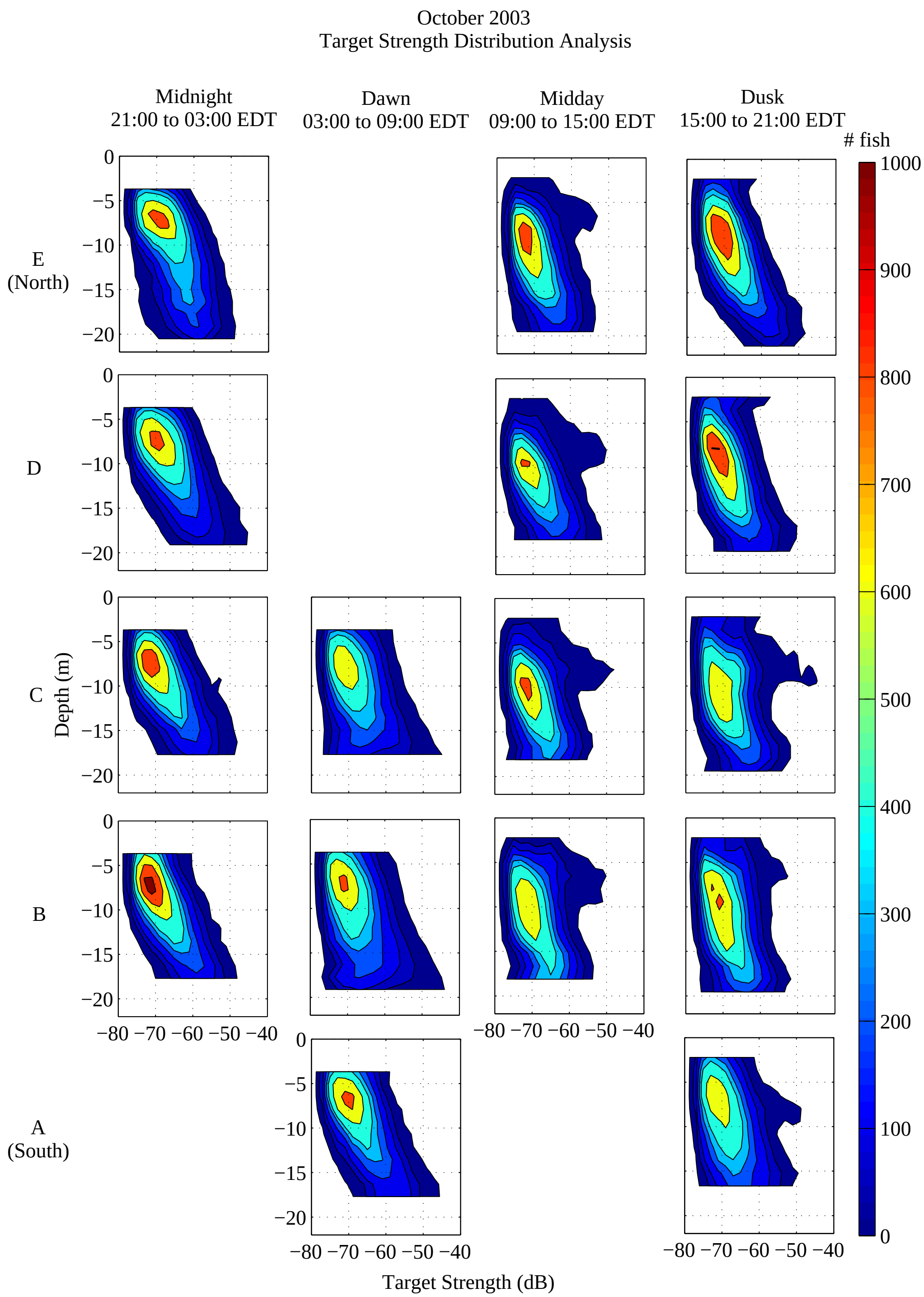

Figure 3.1: Latitudinal and temporal variations in the October 2003 target strength data plotted as a function of depth. Zero ("0") represents the surface of the water column.

on the left representing the smaller organisms and depth is along the y-axis. The 0 m depth corresponds to the ocean surface. The color contours correspond to the number of fish having a particular target strength at a particular depth and the intervals are [10, 50, 100, 200, 300, 400, 600, 800, and 1000] fish. The 600-count contour is the highest density contour common to all of the graphs, and is represented by yellow. First, each transect will be evaluated for how it changes throughout a 24-hour diel cycle. Next, the general characteristics of the 600-count contour are extracted for further temporal analysis. Then, all of this information is visually compared to the habitat data to determine any spatial trends.

The southernmost transect, A, which according to Figure 2.5 is dominated by rippled sand (70%) and sparsely colonized live bottom (29%), shows that there are more of the smaller fish present at dawn as compared to dusk by virtue of the existence of the 800-count contour in orange. Examination of the 600-count and smaller contours reveal that these fish are more concentrated in the upper water column at dawn than they are at dusk where the fish become more spread out through the water column. The dawn graph for transect A additionally shows some larger-sized fish (-60 to -50 dB target strengths) deeper in the water column than at dusk where it is more spread vertically.

Moving north to transect B, which is composed of 55.25% rippled sand, 35% sparsely colonized, 8.25% flat sand, and 1.5% densely colonized habitat, we have the advantage of having captured an entire diel cycle for this transect. Looking strictly at the 600-count contour (yellow), this data appears more concentrated in the upper water column during the midnight/dawn times and more spread out and lower in the water column during the midday/dusk times. Since there are higher-count contours present at midnight and dawn, there are therefore more fish in the upper water column at these times. In general, larger fish are deeper in the water column with smaller fish in the upper water column except at midday and dusk when larger fish (up to -50 dB) are between 5–10 meters.

Transect C is right in the middle of Gray's Reef, with 52% sparsely colonized, 40% rippled sand, 7% flat sand, and 1% densely colonized habitat, and was also sampled during all four segments of our diel cycle. Here again, the 600-count contour is more concentrated in the upper water column at midnight/dawn than it is at midday/dusk. More larger fish can be seen higher in the water column (5–10 meter depth) at midday and dusk and lower in the water column at midnight/dawn, as was also seen at transect B. Here, it is interesting to see that the numbers of fish present in the water column are higher at midnight and midday than at dawn and dusk.

Heading northward to transect D where it is dominated by rippled sand (89%) and only contains 7% flat sand, 3% sparsely colonized, and 1% densely colonized habitat, it is clear that the 600-count contour is once again concentrated in the upper water column at midnight and spreads out vertically as the day progresses. The −60 to −50 dB fish are seen below 10 meters at midnight and dusk, and they are evident above 10 meters only at midday. Along transect D, the numbers of fish actually fluctuate throughout the day — decreasing from midnight to midday and then increasing again during dusk (based on the presence and size of the higher level contours).

Finally, the northernmost transect, E , with 90% rippled sand and 10% flat sand, also shows the pattern of the 600-count contour being concentrated in the upper water column at midnight and spreading throughout the water column as midday and dusk approaches. The larger fish congregating in the mid-water column at midday are here as well, just as in the other three previous transects for which there is midday data. By dusk and then midnight, these large targets seem more associated with the bottom, a trend that can be picked out from transects B – D as well.

Examining this data as a whole, it can be said that regardless of habitat type, the larger fish presumably move up into the water column at midday and by dusk some of these fish have presumably moved back down. The smaller targets tend to congregate nearer the surface for midnight and dawn. At midday these targets have moved down into the mid-water column, and they are the most vertically distributed at dusk. Also, the large quantity of smaller sized targets that tend to be present from midnight to dawn in transects A – C, decrease during the afternoon and evening, but for transects D and E the numbers of fish don't seem to vary.

To further examine the changes in the 600-count contour for 2003's target strength distribution, the center of mass for each 600-count contour was calculated as a mean of the target strengths (x-axis) and a mean of the depths (y-axis) for each time. The resulting coordinates give a centroid for the 600-count contour at all time and locations. The vertical changes of these centroids are shown in the top graph of Figure 3.2, and the corresponding target strengths for these centroids are shown in the bottom graph.

In the top graph, a fairly representative pattern of diel vertical migration can be seen in the depth changes of these centroids. For each transect, follow the data markers in time from midnight (the asterisks) through to dusk (the triangles). The pattern begins at a depth of about 7–8 meters at midnight and dawn (where available). Then at midday the organisms have moved down to about a ten meter depth, and dusk finds them creeping back up into the water column, indicated by a vertical separation of 2–3m. An anomaly in this pattern exists for transect A. In transect A, there is only data available at dawn and dusk, and the 600-count centroids are located at approximately the same depth. During midnight and dawn we would expect organisms to be nearer the surface, as seen. However, the information for dusk here is not consistent with the dusk values of the other four transects. This could be due to the fact that the dusk time segment for transect A was derived from an average of two passes. The first pass occurred between 20:19 and 21:17 EDT, where the second pass occurred from 15:31 to 16:30 EDT the following day. Both of these passes were defined as belonging to the dusk time segment, although the first pass slightly overlaps midnight by our definition. The target strength distribution graphs of each of these passes shows that the first pass looks more similar to the dusk graphs for transects D and E and the second pass more closely resembles the images at midday for transects B – E.

The bottom graph of Figure 3.2, shows the centroid target strength as a function of transect. This describes the target strength values for the greatest number of fish present

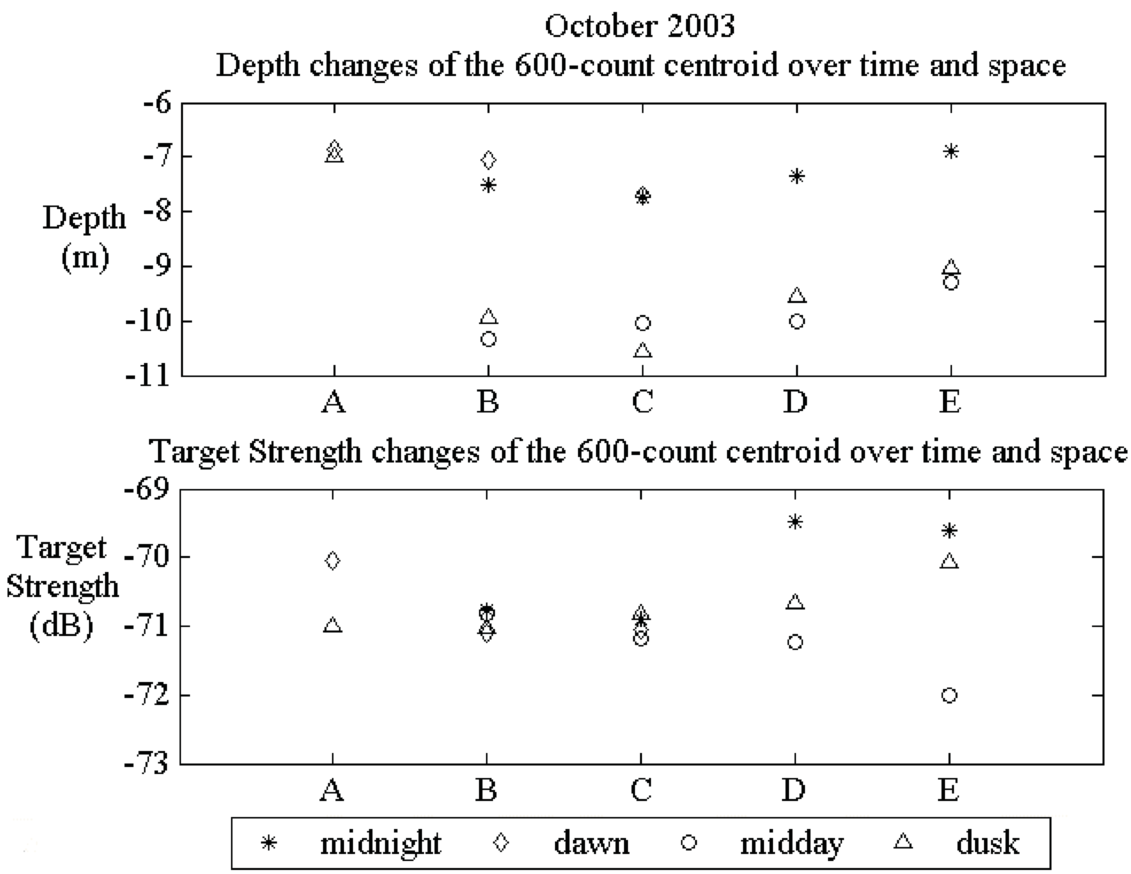

Figure 3.2: Markers indicate the depth and target strength for the centroid of the 600-count contour as a function of transect for October 2003. The 600-count centroid was the highest count contour that is common throughout the dataset.

in the water column (represented by the 600-count contour). All of these targets have TS values between -72 and -69 dB, a small variation, with the majority of fish having target strengths of -71 dB. Note that regardless of transect or time of day, this target strength remained representative of the greatest number of fish found in the water column.

To consider the spatial analysis of these data, all of the above information was compared against the associated habitat composition. Refer back to Figure 2.5 and Table 2.4 for the percentages of habitat for each of these transects. If we examine the dusk time point for all transects in Figure 3.1, it can be seen that the larger fish are higher up into the water column in areas where there is reef structure present (as in transects A – C). Transect C, however, contains the most larger fish, highest in the water column during this time, and it happens to be the transect with the highest percentage of hard bottom habitats. The type of habitat on the ocean floor does not seem to effect the target strength distribution found above it. For example, transect E does not contain any reef structure, while transect D contains the least amount of reef structure out of the four remaining transects, meaning that those larger fish seen near the bottom here are more over sand habitats at all times than the larger fish seen in the remaining transects. Note also that there are generally more fish overall in the day at these two transects than at any of the other three.

To summarize, the reef structure does not appear to influence the diel migration patterns as discussed previously. The same trend of vertical separation in the water column can be seen at transect E as can at the other four. This is reinforced by the data shown in the upper graph of Figure 3.2 in that there is a general pattern of diel migration within the 600-count centroids among all transects. Interestingly, by examining these 600-count centroids further, there is a tendency in all of the data points at transect C to be about 1 m lower in the water column than the data points in the other four transects. This could be a result of habitat influence in that transect C has the highest percentage of reef out of the transects A – D and E contains no reef structure. This phenomenon could indicate the feeding habits of these targets. Fish that consume reef-associated invertebrates would need to remain closer to the reef structure below. Likewise, fish that feed primarily on pelagic phyto- and zooplankton would venture further up into the water column in search of their prey.

3.2 May 12–13, 2004

The target strength distribution as a function of depth for May 2004 is shown in Figure 3.3 where color represents the number of fish and the contour intervals are [10, 50, 100, 200, 300, 400, 600, 800, and 1000] fish. For this dataset all TS measurements are relative as no calibration data is available that can correct the transducer source (SL) and receiver (RL) levels. As a result, absolute TS values are meaningless and only relative changes are of significance. For 2004, the transects ran longitudinally as a function of time. Each column corresponds to a time segment and each row corresponds to a different transect, or longitude. The x-axes are all relative target strength, and all y-axes indicate depth. In all graphs, the 0 m depth is the surface of the water column. The color contours give the relative number of fish for the different target strength ranges. The 1000-count contour is the highest density contour common to all of the graphs, and is represented by red. Each transect will be first evaluated individually for how it changes throughout a 24-hour diel cycle, listed from the most western (A) to the most eastern (E). Next, the general characteristics of the 1000-count contour are extracted for further temporal analysis. Then, all of this information is compared to the habitat data to determine any spatial trends.

The westernmost transect, A, according to Figure 2.9, contains 67% rippled sand, 23% flat sand, and 10% sparsely colonized habitat. It was sampled during dawn and midday. There is indication of larger fish at midday near the bottom. Examining the 1000-count contour (in red) shows that it could be more elongated at midday than at dawn, indicating organisms spread more throughout the water column at this time.

Transect B is almost evenly divided between the unconsolidated sediment (45% rippled sand/4% flat sand) and colonized habitat (49% sparsely colonized/2% densely colonized). There are more larger targets present at midnight in the mid water column than at dusk,

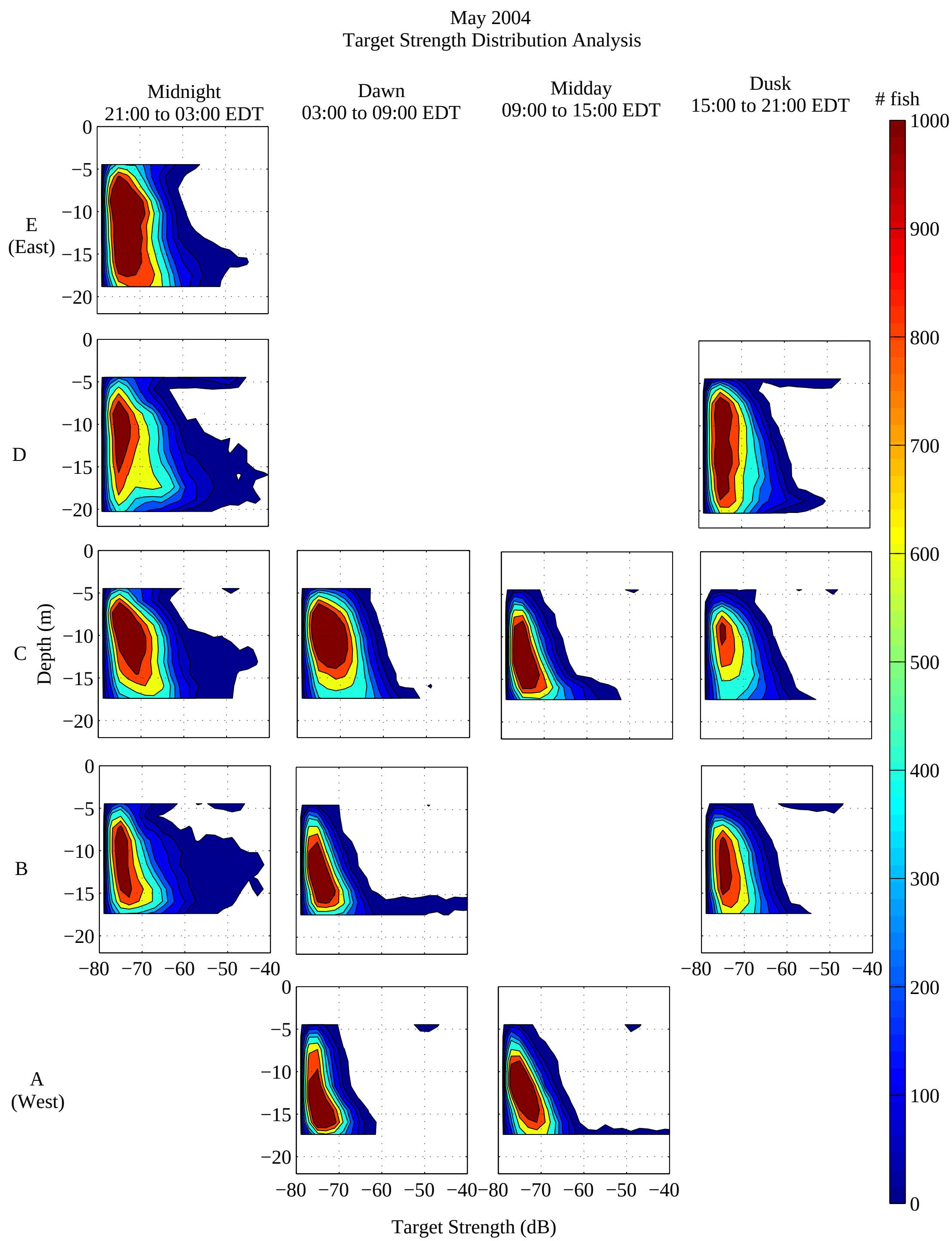

Figure 3.3: Longitudinal and temporal variations in the May 2004 target strength data plotted as a function of depth. Zero ("0") represents the surface of the water column.

with fish becoming more concentrated in the lower water column as midnight becomes dawn. The smaller targets seem to decrease in numbers between dawn and dusk.

Transect C is a slice right through the middle of the sanctuary, and has 59% sparsely colonized, 36.5% rippled sand, 3% densely colonized, and 1.5% flat sand habitat. Transect C is the only location this year where all four time intervals were sampled. Again, there seems to be more of the larger fish present at midnight than at other times of day concentrated below the ten meter (mid-water) depth. Examination of the 1000-count contour indicates that the small fish seem to be more concentrated together at dusk than they are at any other time. Also, the size of this contour tends to decrease from midnight through to dusk.

The next transect, D, consists of 68.5% rippled sand, 29% sparsely colonized, 2% densely colonized, and 0.5% of the flat sand habitat. Transect D also shows larger fish during midnight in the lower water column. By dusk, these larger targets occur lower in the water column. The smaller fish are both more numerous and more spread out at dusk than they are at midnight.

Finally, transect E, the easternmost transect, is mainly composed of rippled sand (71%). The sparsely colonized habitat makes up 23.5%, while flat sand is 4%, and the densely colonized habitat measures 1.5%. This transect was only sampled during the midnight time-frame so any diel changes occurring over a 24-hour period cannot be discussed. However, comparing this information to the other three transects sampled at midnight, this data appears consistent in that there are larger targets present, in the lower half of the water column.

In several of these graphs, and in particular along transect D, there are signals of, what appear to be, a group of a few larger sized fish at depths directly beneath the transducer. This information will ultimately be ignored due to the fact that it may not be representative of fish at all, but rather interference from bubbles created by wave action and the thrusters of the NOAA Ship Nancy Foster.

Looking at all of the target strength distribution data, it can be said that the larger fish (from −60 to −40 dB) tend to range from the lower to the mid water column at midnight and are restricted to the lower water column at other times of the day. The smaller sized targets tend to generally remain well distributed vertically with equal numbers, the only obvious exception being in transect C at dusk. This phenomenon could be attributed to well-mixed water column conditions (see Figure 2.11). Recall that the EMS technique of determining target strengths assumes that the fish are uniformly distributed in the sample volume but in practice this is not always so and can introduce errors in the absolute TS values.

Further analysis of the 1000-count contour for 2004 is shown in Figure 3.4. The center of mass for each 1000-count contour was calculated from the mean depths and target strengths for each time segment and transect. The top graph plots these centroids as a function of depth and transect (longitude) for each time of day. The bottom graph represents the corresponding target strengths for these centroids of the 1000-count contour.

The top graph shows a pattern of diel vertical migration that can be picked out from the 1000-count centroid changes with depth, although it is not as apparent as in the data from 2003. Transects B to E corroborate the expected diel pattern, in that at midnight the fish are 2–3 meters closer to the surface than at midday and dusk. In transects A and B however, the dawn values are lower in the water column than the mean midnight values, and lower than dawn during transect C. Also the data shows that for transects A and B midday and dusk values are higher than dawn values. For transect C, while we would expect the dusk value to be higher than the midday value, it is odd that it is also higher than the midnight and dawn values.

The centroid target strength as a function of transect graph (bottom), represents the target strength values for the greatest number of fish present in the water column, which are represented by the 1000-count contour in 2004. All of these targets have TS values between −75 and −72 dB. Target strength variations of about 3 dB are consistent with the October 2003 observations and the mean offset in May 2004 corresponds to the lack of calibration

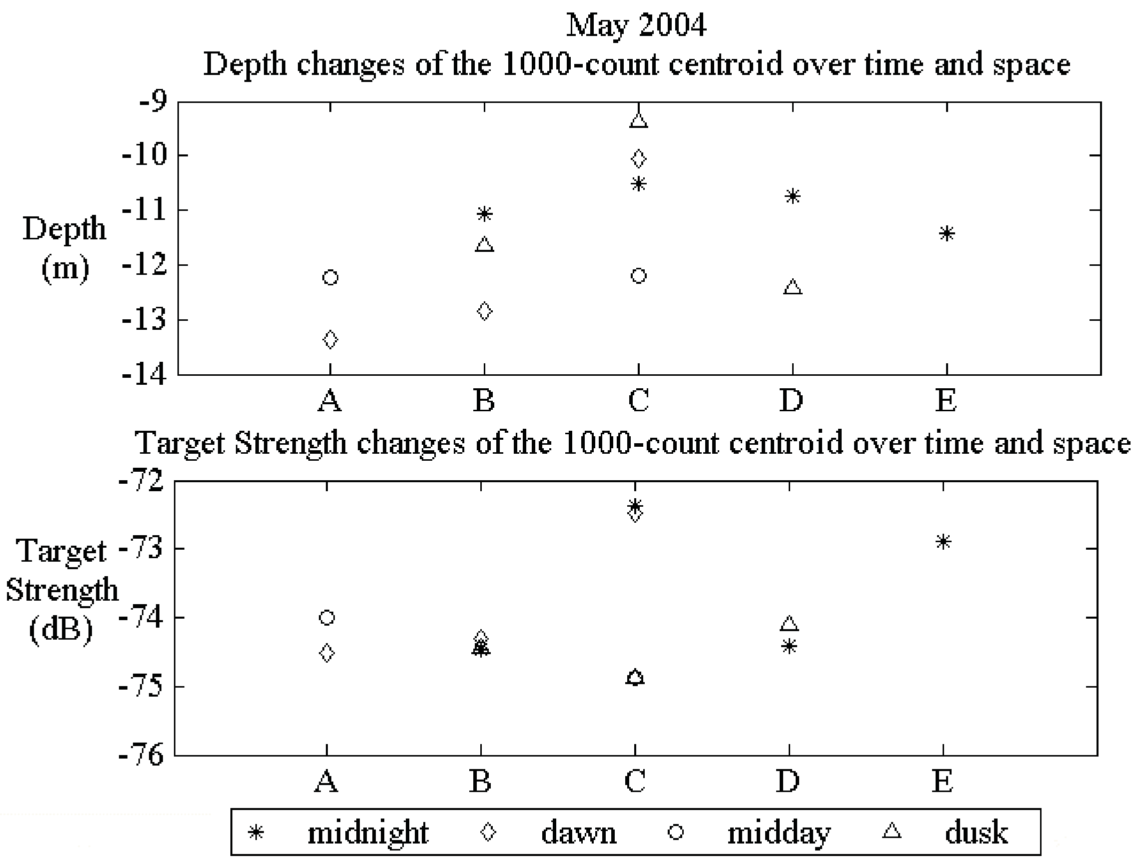

Figure 3.4: Markers indicate the depth and target strength for the centroid of the 1000-count contour as a function of transect for May 2004. The 1000-count centroid was the highest count contour that is common throughout the dataset.

data for this year. Once again, regardless of transect or time of day, this small target strength range remained representative of the greatest number of fish found in the water column.

Recall the habitat composition for each transect in Figure 2.9 and Table 2.6. All these transects contain the sparsely colonized reef habitat, and all transects — except A — contain some fraction of the densely colonized reef habitat. There appears to be more of a presence (higher numbers) of larger size fish that are consistent over transects B, C, and D throughout the lower water column at midnight. The same observation can be made in relation to the overall size distributions, in that there are more fish of more sizes over transects B, C, and D while transect A has the smallest size distribution in that the contour lines span a smaller range of target strengths. This smaller size distribution could be due to the lack of the densely colonized habitat in this transect.

In summary, during the entire experimental program, the larger targets tend to remain lower in the water column, venturing into shallower waters only at midnight. For the population of smaller targets, represented by the 1000-count centroids, these are generally more spread throughout the water column at all times of day within those transects that contain some presence of densely colonized reef structure (B through D) as compared to their counterparts within transect A which has no densely colonized habitat. This suggests that the larger organisms measured here have a stronger association to the bottom habitat than smaller organisms do.

3.3 May 11–12, 2005

Figure 3.5 outlines the target strength distribution data during May 2005 as a function of depth and time taken along latitudinal transects. Each column corresponds to a time period within the 24-hour diel cycle and each row corresponds to a different transect, or latitude. The x-axes are all target strength, with lower numbers on the left representing the smaller organisms. The y-axes indicate depth. For these graphs, the 0 m depth is the ocean's surface. The color contours give the number of fish having a given target strength at a given

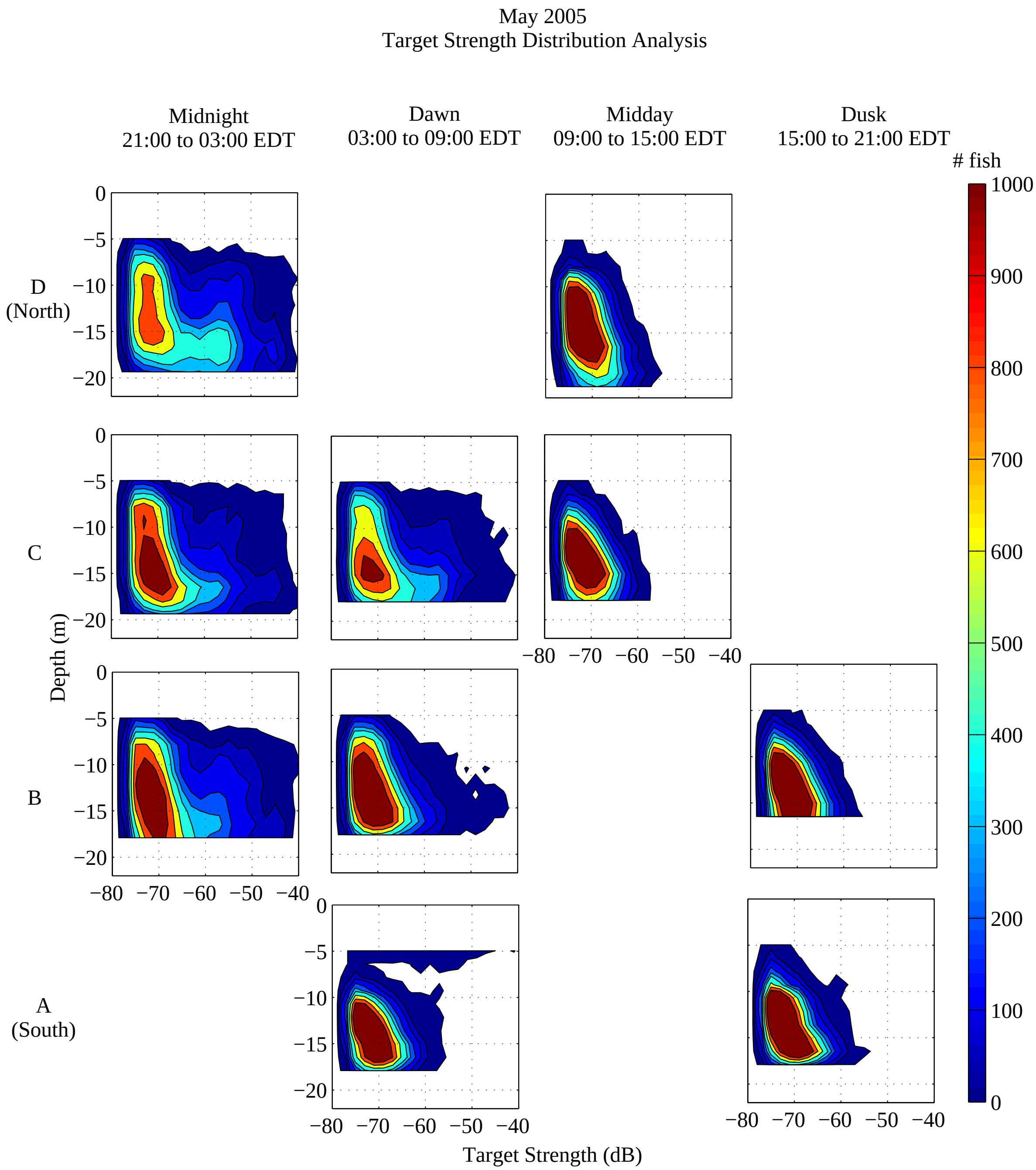

Figure 3.5: Latitudinal and temporal variations in the May 2005 target strength data plotted as a function of depth. Zero (“0”) represents the surface of the water column.

depth where the contour intervals are [10, 50, 100, 200, 300, 400, 600, 800, and 1000] fish. The 800-count contour is the highest density contour common to all of the graphs, and is represented by orange. Each of these transects will be independently discussed for how it changes throughout a 24-hour diel cycle. Then, the general characteristics of the 800-count contour are extracted for further temporal analysis. Lastly, all of this information is compared to the habitat data to determine any spatial trends.

This year, transect A was again the southernmost transect, with 64% rippled sand, 33% sparsely colonized, 2% flat sand, and 1% densely colonized habitat. Only dawn and dusk are represented. Here, the size distribution and the number of targets are very similar with the majority of fish having sizes from -78 to -60 dB. Also during dawn, the graph indicates a few larger sized fish spread along the upper limit of the water column but we neglect them as they could be related to indirect ship effects.

For transect B, there is 52% rippled sand, 46% sparsely colonized, and 1% of both the flat sand and densely colonized habitats. At midnight and dawn, the TS distributions appear very similar to one another in that they detect larger fish (-60 to -40 dB) throughout the sampled water column. Those larger fish disappear from the distribution later in the day at dusk. The smaller sized fish (-78 to -60 dB) are greater in numbers and are generally more concentrated in the lower water column.

At an approximate latitude of $31^\circ\ 24'$ N, transect C cuts right through what GRNMS personnel refer to as the “highly populated ledge” area of the sanctuary. Ship-based and aerial surveys of recreational fishermen in Gray’s Reef show an astonishing concentration of efforts along this latitude (G. McFall, personal communication 2007), which was one reason why this area was chosen for our survey. The habitat here consists of 56% rippled sand, 26% sparsely colonized, 17% flat sand, and 1% densely colonized habitat. Again, midnight and dawn show similar target strength distributions with all sizes of fish concentrated nearer the bottom. The difference between them is that the small fish become more concentrated into the lower water column at dawn compared to midnight. Moving through to midday shows an increase in the number of smaller targets (larger 1000-count contour, red), and a complete absence of the larger targets that were present at the other times of day.

Finally, the northernmost transect for 2005 is D, containing just unconsolidated sediment (87% rippled sand and 13% flat sand). Only midnight and midday were sampled here. More large fish are present and spread throughout the water column at midnight than at midday and the smaller sized targets increase in numbers at midday.

Overall, the 800-count contours are fairly elongated (as seen in 2004 as well), indicating a concentration of smaller targets that are spread vertically in the lower water column (except transect C at dawn). Of note is that all of the distributions tend to be concentrated to the lower portion of the water column. A fact that is likely a result of the strong thermocline present during data collection (refer back to Figure 2.14). This is more apparent upon closer examination of the changes in the 800-count centroid with depth.

Figure 3.6 shows the calculated centers of mass for each 800-count contour plotted as a function of transect (latitude) for depth and target strength. The top graph shows the vertical distribution of these centroids in the water column, while the bottom graph illustrates the corresponding target strengths of these points.

Upon examination of the top graph, the changes in depth for these 800-count centroids is very small (on the order of 1 m) and thus no vertical migration is detected. Also, note that there are no points shallower than 12 m possibly due to the established thermocline at 9 m depth (Figure 2.14).

In the bottom graph, the target strength values for the greatest number of fish range between -72 and -70 dB. The variation of less than 2 dB are of the same order as the variations from 2003 and 2004. However, it is clear that the data is much tighter in 2005, a fact that could be contributed to the higher transmit frequency and controlled environment calibration of the equipment used this year. The average target strength of -71 dB is consistent with the data collected in October 2003. Once again, regardless of location or time

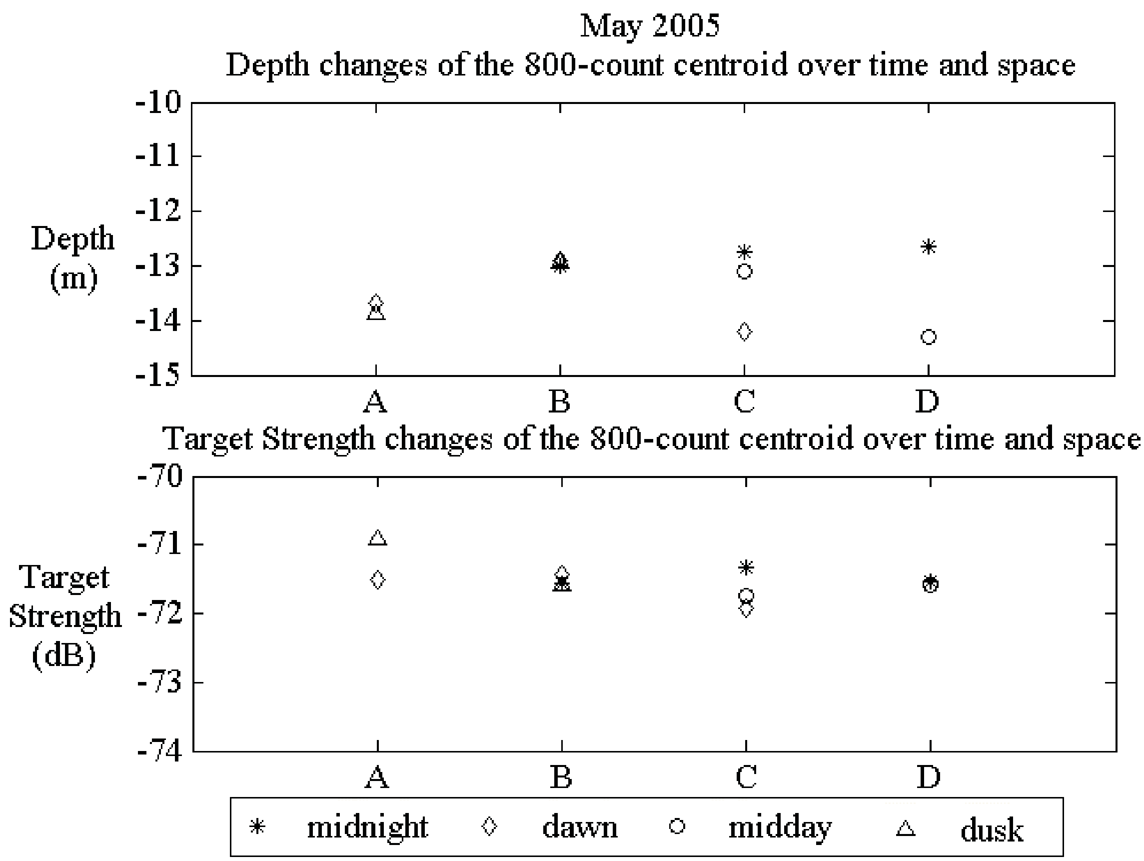

Figure 3.6: Markers indicate the depth and target strength for the centroid of the 800-count contour as a function of transect for May 2005. The 800-count centroid was the highest count contour that is common throughout the dataset.

of day, this target strength value remained representative of the greatest number of fish in the water column.

For the spatial comparison, recall that Figure 2.13 shows the habitat composition of each of these transects and Table 2.7 lists the composition percentages. It would seem that the presence of colonized reef habitat does not affect the numbers of targets or their size distribution. Transect D contains no colonized reef habitat and it's trends are similar to the other three transects that do. Of these transects that contain colonized reef habitat, all three contain about 1% of the densely colonized habitat, yet varying percentages of the sparsely colonized habitat. Transects A and B have larger percentages of sparsely colonized reef than C. Interestingly, these two transects also generally have larger 1000-count contours than C.

3.4 Seasonal Variations

Comparing the TS distribution data from 2003 and 2005 provides an interpretation of seasonal changes. In 2003, there appear to be more numbers of targets of all sizes in the upper layers of the water column at all times of day in every transect, whereas for 2005, there are more in the lower layer. This is thought to be due to the distinct thermocline seen in 2005 as evidenced by the data in Figure 2.14.

The highest number of targets overall (represented by the 600-count contour in 2003 and the 800-count contour in 2005) always corresponded to target strengths between -72 to -69 dB. Further, the fact that the highest-count contour in 2003 was 600, and in 2005 it was 800, indicates that there were more of these fish present overall in the Spring as compared to the Fall. These highest-count contours also provided evidence of obvious diel migration in October 2003 compared to none in May 2005. This again, is seen to be attributable to the thermocline in 2005 at an approximate 9 m depth.

By examining the larger pelagic fish, represented by the TS range of -65 to -45 dB, this same pattern can be seen. There are fewer of these -65 to -45 dB fish in the Fall than in the Spring across all times and locations. Also, both the smaller targets (-75 to -65 dB) and the larger targets (-65 to -45 dB) are more vertically compressed in the water column during the Fall. In Spring, both size groups of fish are widely spread vertically throughout the water column, limited only by the presence of the thermocline at about 9 m. It is worth noting that although the results from May 2004 are not comparable in the sense that the instrumentation was not calibrated, the same general pattern of wide vertical distribution was seen in this year as well.

Also, note that Figure 2.1 shows that there is approximately two more hours of daylight in May versus October. This fact could seemingly affect TS distribution in that those organisms that spend the daylight hours at depth, would be near the surface of the water for a shorter period of time in May as compared to October. However, any such influence is undetectable within this dataset since the dawn and dusk time segments comprise a six-hour block of time where sunrise and sunset for both the Fall and the Spring fall in the middle of the segment. To determine if the longer period of daylight does affect the TS distribution, the data could be re-grouped according to daylight hours versus non-daylight hours and re-processed, a task that is beyond the scope of this thesis to do so.

Evidence of spatial relationships is inconclusive. In 2003, a tendency seen in the 600-count centroid data points could suggest a habitat influence, which in turn, could indicate the feeding habits of these targets. However, in 2005, all 800-count centroid data points are within the 13–15 m depth, so if any habitat influence does exist, it was muted this year by the presence of the thermocline.

It seems likely that the presence of colonized reef habitat does not affect the numbers of these pelagic targets or their size distribution. As seen in both years, the TS range encompassed the same dB levels. What is more likely affecting the amount of targets present in the water column is the physical oceanographic parameters that define the seasons and time of day. What influence habitat may have would only extend to vertical proximity between the habitat and the pelagic fish above it, and again that would only affect those fish species that associate with the reef structure for particular lifestyle benefits.

Chapter 4

Fish Abundance

Measurements of abundance provide information on how many organisms exist within a given geographical or volumetric location. This, in turn, can be used in conjunction with TS measurements to assess the biomass of populations of targets (Mason et al., 2005), which is of vital importance to fisheries and ecosystem management protocols. Also, abundance measurements can be used to examine the life histories [i.e. larval recruitment (Collins and Stender, 1987; Forward et al., 1999) or mortality rates (Toresen et al., 1998)] of certain economically important species of fish. In addition, these data can help to flesh out potential predator-prey dynamics (Mason et al., 2005).

The abundance data collected during all sampling programs function as a measurement of particle density in order to attempt to distinguish both temporal and spatial patterns for the pelagic fish in GRNMS. Similar analysis was performed by Ornellas and Coutinho (1998) in Brazil by determining local tropical fish preference for particular habitat via abundance measurements.

The FPCM, defined by equation 2.6, is sampled along entire transects in horizontal increments averaging 234 meters for given times of day. BioSonics Digital Analyzer software separated the targets into horizontal and depth bins according to the parameters listed in Table 2.3. Again, the vertical bin size was about 1.4 meters, yet for the abundance measurements, the information is depth integrated according to the "surface" versus the "bottom" of the water column. The result is a series of curves describing the particle fish density present at particular coordinates along a transect for each time of day at both the "surface" and the "bottom" water column depths.

These curves generate an image of the density of fish throughout Gray's Reef and where within the reef they are located. The diel attributes are investigated by utilizing the depth-integrated data of the "surface" versus the "bottom" to determine diel changes in the FPCM when comparing data from like transects. Seasonal trends, if they exist, are defined by a comparison of the FPCM data from October 2003 (Fall) to May 2005 (Spring). Finally, the abundance data is compared to the bottom habitat classifications to identify any spatial relationships that may exist.

4.1 October 4–6, 2003

Figure 4.1 shows the FPCM plotted on a logarithmic scale and separated into "surface" (left column) and "bottom" (right column) layers for October 2003 all as a function of longitude (x-axis), latitude (transects A – E), and time of day (midnight, dawn, midday, dusk). As the blanking distance was 1.99m (for 12 passes) and 0.5m (for 9 passes), corresponding to starting depths of 2.99m and 1.5m respectively, we defined the surface layer starting at an average depth of 2.35m with a standard deviation of 0.76m. The FPCM for the top five strata having a size of approximately 1.4m were summed to give the abundance for the surface layer that extends to an average depth of 9.44±0.65m. The lower layer encompassed from six to nine strata depending on the bottom topography and as such the lower layer ranged from an average depth of 9.44±0.65m to 19.60±0.96m. (An approximately 10m thickness versus a 7m thickness for the surface.) This layering was chosen to separate the extent of the diel migration observed in the TS distribution discussed in Chapter 3. Each time segment is compared for horizontal and vertical variations. It is the general trend of the baseline, where a uniform distribution can be seen, that is considered first in order to determine where the majority of the fish are located (at the "surface" versus the "bottom"). The obvious peaks that occur are location specific and will be discussed afterwards. Then the results presented below will be compared to the associated habitat classifications to determine if any spatial relationships exist.

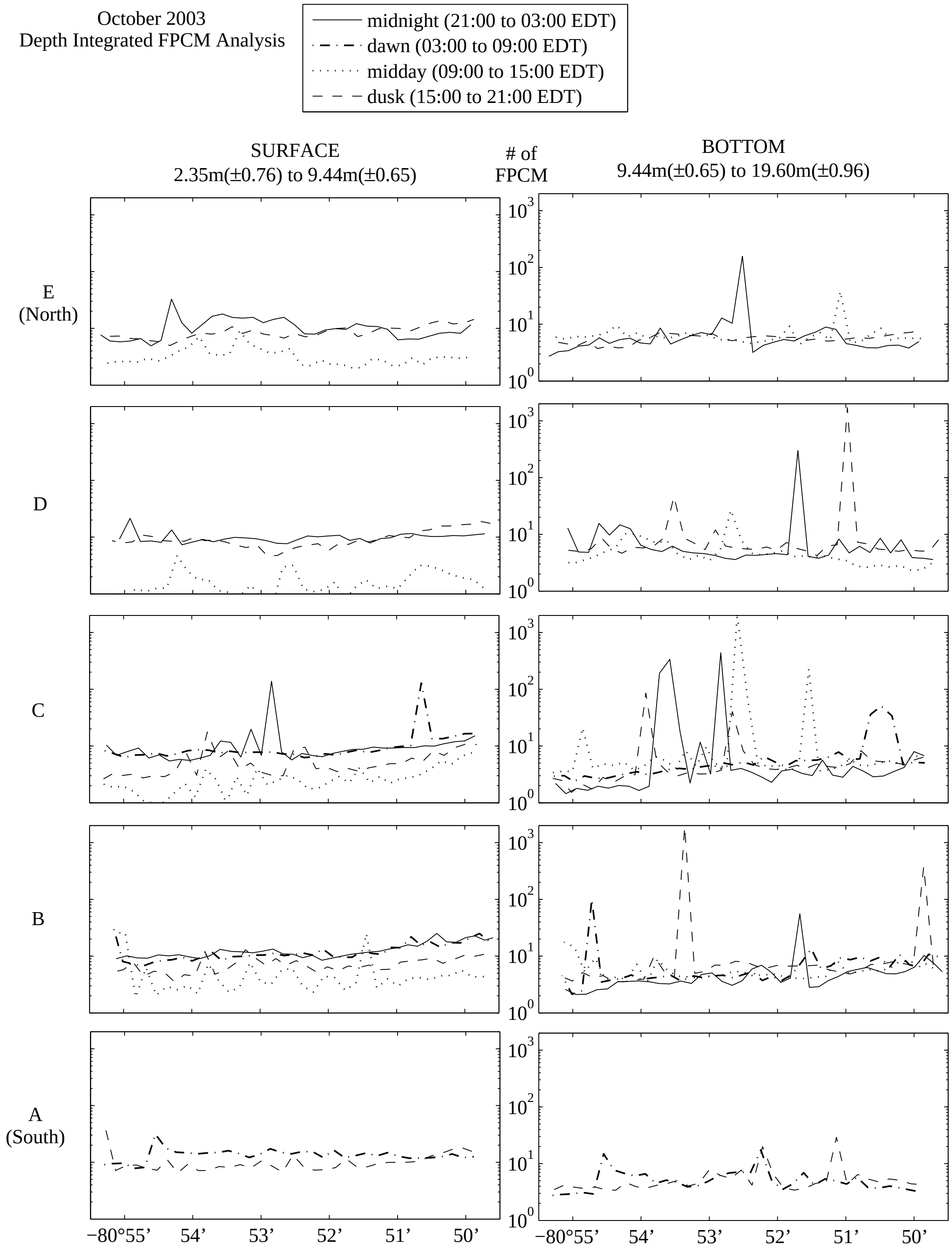

Figure 4.1: FPCM data separated into surface (left) and bottom (right) layers all as a function of longitude, latitude, and time of day during October 2003.

In transect A, only dawn and dusk are examined. In both time intervals, the FPCM have the same order of magnitude, but there are more fish in the surface layer than there are in the bottom layer. Transects B and C were both sampled at all four time segments. At midnight, dawn and dusk in both B and C, there are more uniformly distributed fish present in the "surface" than in the "bottom". At midday, both transects B and C show about the same, or slightly less, fish present in the "surface" than in the "bottom". For transects D and E, the midnight, midday and dusk time segments were sampled. For midnight and dusk, there are more fish in the upper layer of the water column than in the lower layer. For midday, in both transects, there are more fish present in the lower layer than in the upper layer. By examining only the surface layer data (left column) a clear increase in FPCM can be seen going from midday to midnight within all transects where these two time intervals are sampled. This provides further evidence of a diel cycle that is consistent with the target strength distribution.

In general, there are more spatially uniformly distributed fish per cubic meter at the "surface" than at the "bottom" except for all transects sampled at midday. Compare this information to what we see in the target strength distribution graphs in Figure 3.1. Drawing a line across all of these graphs at the point at which we differentiated between the "surface" and the "bottom" (9.44 ± 0.65m) shown in Figure 4.1, results in there being more fish present in the upper layer of the water column than in the lower layer at all times of day except midday where the trend is reversed.

Finally, there are several obvious peaks in the FPCM data within every transect, with the majority occurring in the "bottom" half of the water column. It is important to reiterate that all of the data files were meticulously scrutinized to ensure that the bottom was "seen" along the entire transect. This fact provides confidence that the peaks seen in the lower water column are genuinely due to the presence of higher numbers of fish, and not echo integration through the bottom. Thus, this seems to indicate that fish are more concentrated together in patches in the lower water column than in the upper water column. Of these occurrences, the most profound peaks are in transects B and C which also happen to contain the most sparsely colonized and densely colonized reef habitat (refer back to Figure 2.5 for the habitat composition of each of these transects). Also of interest is that transect D has higher fish per cubic meter peaks during dusk than transect A at the same time interval. Transect A has more sparsely colonized reef habitat while D has more densely colonized reef habitat albeit by only 0.5%. By examining where these peaks fall out along the transects, and comparing those longitudes to that of the habitat map (Figure 2.4), it is not necessarily so that these areas of high fish counts per cubic meter are associated with reef structure. For example, only one of the peaks present in transect A is over an area of sparsely colonized habitat. Also, transect E displays a few notable peaks and there is no colonized habitat present at this latitude. However, the largest peaks in transects C and D are at longitudes associated with sparsely colonized habitat and within the area GRNMS personnel refer to as the "highly populated ledge" of the sanctuary.

Figure 4.2 shows a version of the abundance data that is plotted as the base 10 logarithm of FPCM as a function of habitat type for the surface layer (2.35 to 9.44$\pm$0.65m) of the water column. The log 10 transformation was performed on the y-axis simply to allow all data to be represented aesthetically. The bars represent the median FPCM value measured at each habitat type at each time of day. These were calculated so as to get a representation of what the most commonly observed numbers of targets are. The open circles are the mean FPCM values and while the mean is not necessarily representative of the data in this case, it does allow for the inclusion of exceedingly high, "outlier" values that could provide evidence of an association between the abundance and the habitat type. Finally, the vertical lines indicate the standard deviations for those means. Time of day is represented by the columns and the rows indicate transect location (latitude).

Based on these graphs, presence of hard bottom habitat has little to do with the abundance of fish in the water column above it. Transect C, which contains the most hard bottom habitat, does not display median or mean FPCM values that are greater than any of the

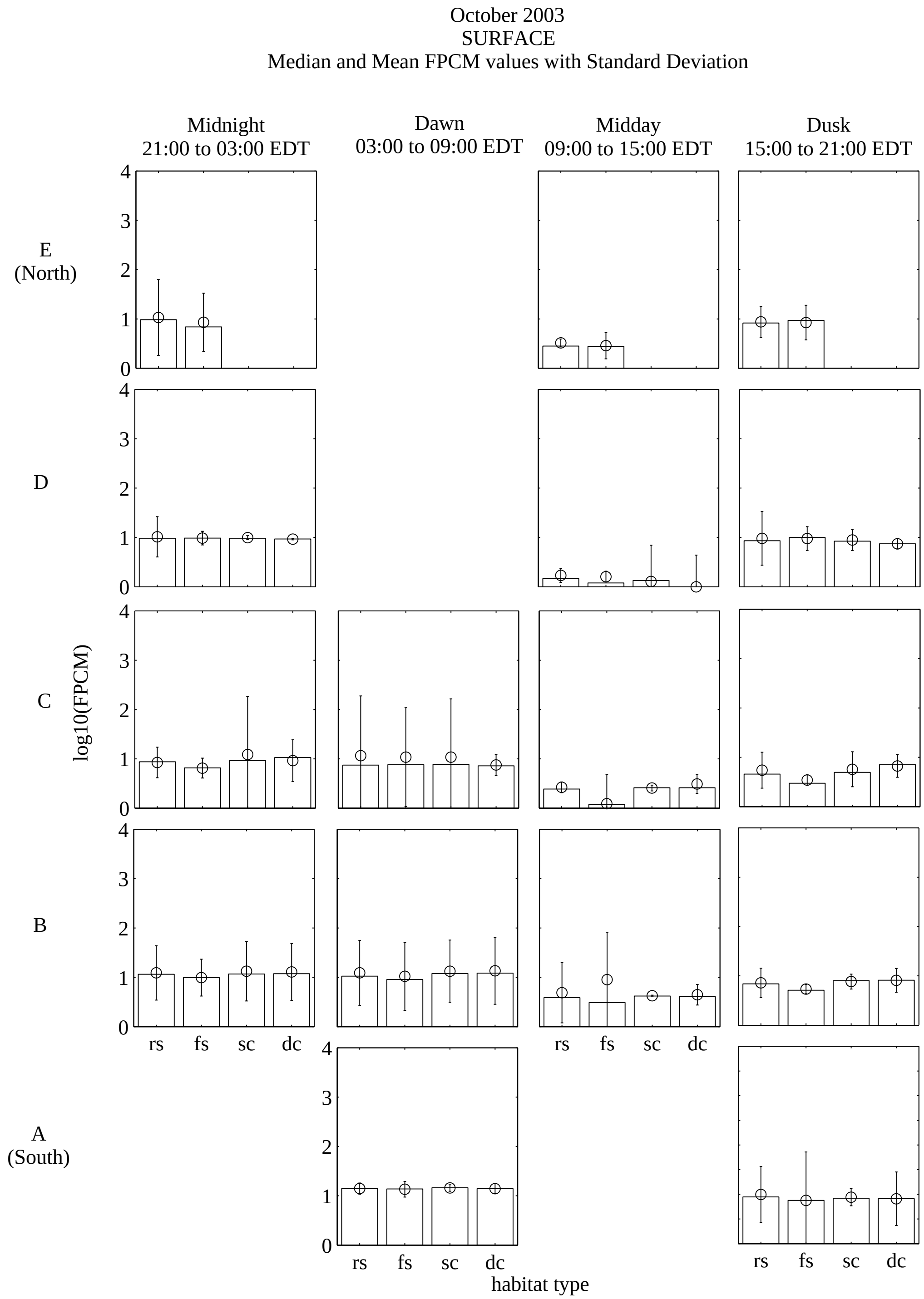

Figure 4.2: The log10 transformation of the FPCM data plotted versus habitat type for the surface layer of the water column during October 2003 all as a function of time and latitude. Habitat type abbreviations are: rs—rippled sand, fs—flat sand, sc—sparsely colonized, and dc—densely colonized.

other transects. If the FPCM values were to be multiplied by their corresponding volume of water that is over any of the flat sand, rippled sand, or sparsely colonized habitats, the answer would yield a greater number of fish for each of those habitats as compared to the FPCM multiplied by the volume over densely colonized habitat. Further, transect E which contains no reef structure at all, has comparable median and mean values to the other transects at all times of day. The only noteworthy item is that at midday all habitat types show less fish.

Figure 4.3 shows the base 10 logarithm of the FPCM data for bottom layer of the water column as a function of habitat type. The bars are the median FPCM values, the open circles are the means, and the vertical lines are the standard deviations for those means. Time of day is along the columns and the rows represent transect location (latitude).

While the median values remain largely unchanged, there are drastic variations in the means and standard deviations in transects that contain the largest amount of colonized hard bottom (B – D). This suggests that at depth, pelagic organisms are more associated with the type of benthic habitat below them, or, are more distributed in patches, than their counterparts near the surface. However, examining the results presented for transects A and E dispute that conclusion. Transect A contains approximately 26% hard bottom habitat while transect E contains none and the magnitudes of the medians, means, and standard deviations at all times of day are similar. Or, this can be evidence that it is the densely colonized reef habitat that instills more of an influence on the organisms over the sparsely colonized habitat. Transects B – D all contain more of the densely colonized reef than transect A, and the higher means and standard deviations could be a reflection of this influence.

4.2 May 12–13, 2004

The FPCM analyses for May 2004 is shown in Figure 4.4 plotted on a logarithmic scale and separated into "surface" (upper row) and "bottom" (lower row) layers all as a function of latitude (y-axis), longitude (transects A – E), and time of day (midnight, dawn, midday,

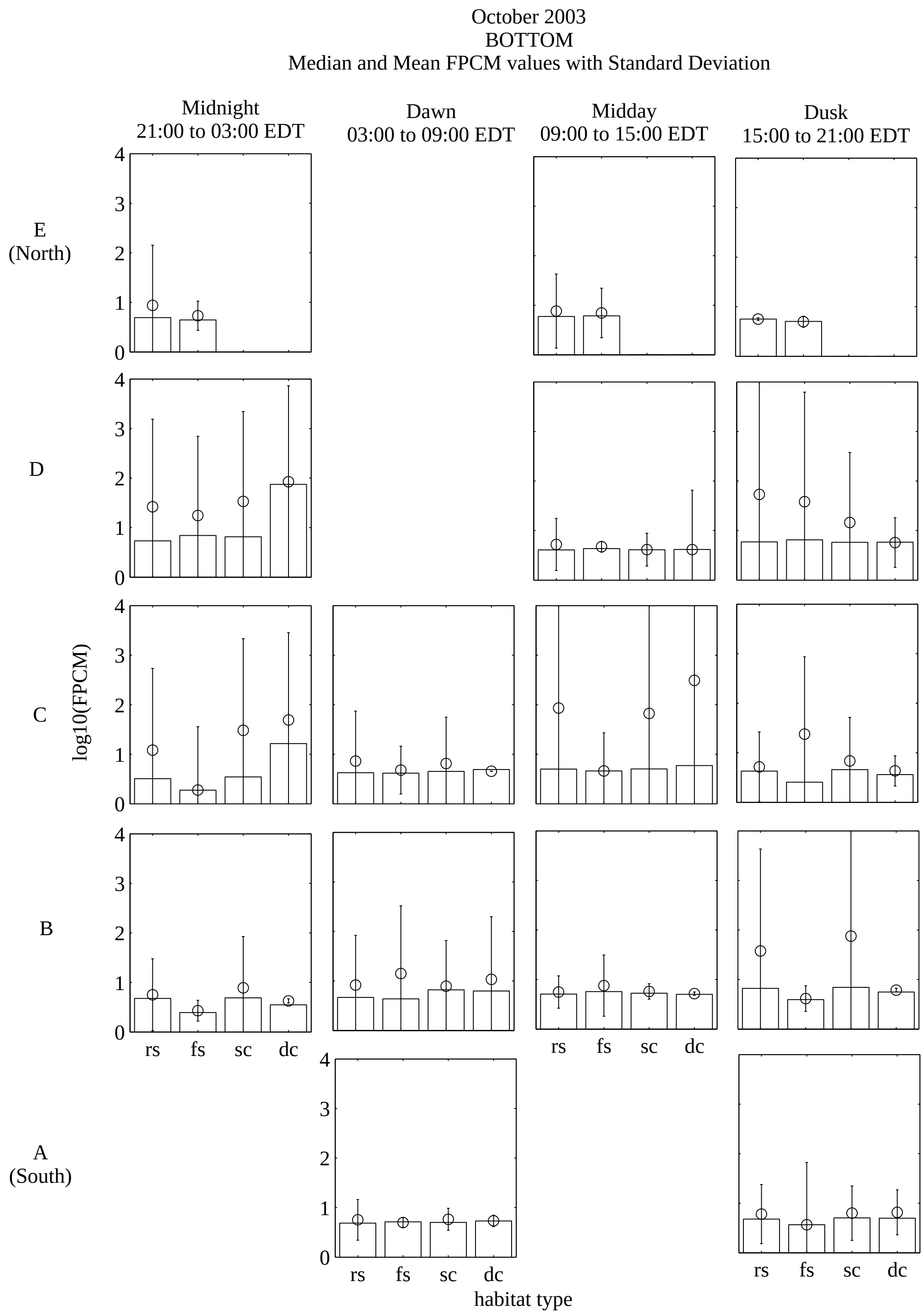

Figure 4.3: The log10 transformation of FPCM data plotted versus habitat type for the bottom layer (9.44±0.65m to 19.60±0.96m) of the water column during October 2003 all as a function of time and latitude. Habitat type abbreviations are: rs—rippled sand, fs—flat sand, sc—sparsely colonized, and dc—densely colonized.

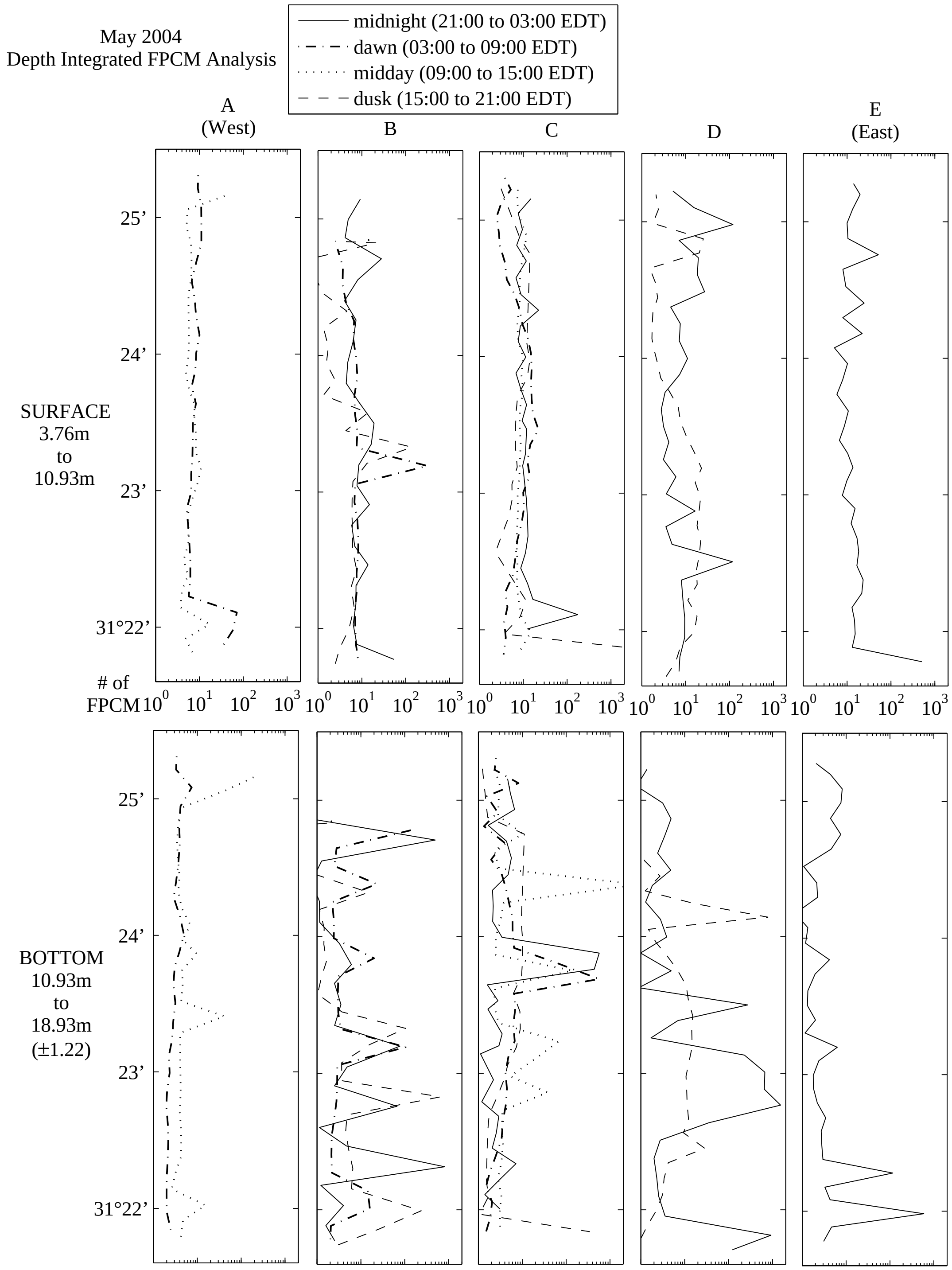

Figure 4.4: FPCM data separated into surface (upper) and bottom (lower) layers all as a function of latitude, longitude, and time of day during May 2004.

dusk). This year, our blanking distance remained constant at 0.5m throughout the survey resulting in a uniform starting distance of 3.76m below the ocean surface. The surface layer consisted of the first five strata each with a size of approximately 1.4m and thus extending to a depth of 10.93m. The FPCM in these strata were summed to give the total abundance for the surface layer. The lower layer encompassed from five to seven strata depending on the bottom topography and as such the lower layer ranged from 10.93m to an average depth of 18.93±1.22m. Note that these measurements are relative as the backscattering cross section (σ_{BS}) obtained by the target strength calculations, and used in equation (2.6), is not absolute. For these graphs, each time segment is first compared for horizontal and vertical variations relative to a uniform baseline. Then the peak events that deviate from the uniform distribution will be discussed. Finally, these results will be compared to the habitat classification data for the spatial analyses.

At dawn, the westernmost transect, A, had more fish per cubic meter in the “surface” than in the “bottom”, while at midday the number of fish in both layers are approximately the same. For dusk, transect B also shows similar numbers of fish in both layers, yet for midnight and dawn the fish are more uniformly distributed along this transect in the “surface” than in the “bottom”. In 2004, transect C was the only slice through the sanctuary that was sampled at all four time segments. For all times relatively more fish were present in the “surface” than in the “bottom”. For midday at transect C, the general baseline in both the “surface” and the “bottom” of the sample volume are of the same order of magnitude. However, at the “surface”, the fish are uniformly distributed whereas the “bottom”, shows isolated peaks of FPCM alluding to schooling or patchiness. At both midnight and dusk in transect D, we again see the lower baseline trend in the “bottom” and more enhanced numbers of fish in isolated locations. Transect E was only sampled once during the midnight time frame. In this graph we again see fewer targets unevenly distributed in the lower layer of the water column and evenly distributed in the upper water column. Overall, more fish congregate in the upper layer with a somewhat uniform distribution compared to in the lower water column at all times of day.

Comparing this information to the target strength distribution data presented in Figure 3.3 suggests that these results are inconsistent with what is shown there. Seventy-five percent of the target strength distribution graphs indicate more numbers of fish in the "bottom" layer when a line is drawn across each graph at the point where the "surface" is differentiated from the "bottom". However, while the FPCM data presented in this chapter shows a higher baseline number in the upper layer of the water column, the distribution of these fish is more uniform when compared to the patchy distribution of fish in the "bottom" layer. These patches contain significant numbers of fish which sheds light on the fact that the target strength distribution data indicates more fish in the "bottom".

Recall that transects in this sample year ran longitudinally (Figure 2.8) with all five of these transects containing some percentage of the sparsely colonized reef habitat (refer to the habitat composition of Figure 2.9). In Figure 4.4 all transects contain peaks at various latitudes that are more robust in the "bottom" layer of our sampled volume suggesting a stronger association with the bottom type present. Upon examination of the latitudes at which these peaks occur, it is shown that not all of these correspond to locations where there is colonized reef below. Some of the increases in fish per cubic meter occur over areas of sand, like in transect A at $31^\circ\ 22'$ N and $31^\circ\ 25'$ N. Also transect D shows peaks in the surface layer over sandy bottom at $31^\circ\ 25'$ N. All other peaks are at latitudes where the sparsely colonized reef habitat is present on the substrate below. Of interest is the latitude $31^\circ\ 24'$ N for transects C and D where a well-defined ledge occurs transitioning between sandy to colonized habitat. This area is within a "highly populated"/"well fished" ledge that sanctuary personnel are most interested in. In these two transects there are marked peaks at most times of day in the vicinity of this latitude. This would seem to further support anecdotal evidence that this region of Gray's Reef fosters a greater abundance of marine life.

Figure 4.5 shows the log10 transformation of FPCM plotted as a function habitat type for the surface layer (3.76 to 10.93m) of the water column. The log 10 transformation was performed on the y-axis simply to allow all data to be represented aesthetically. The bars represent the median FPCM measured at each habitat type at each time of day. The open circles are the mean FPCM values and the vertical lines indicate the standard deviations for the means. Each time segment of the day is represented by a column and each row is a longitudinal transect.

There appears to be no consistent association between the abundance of fish in the surface layer of the water column and the habitat below. All transects contain some percentage of hard bottom habitat, with transect C having the most. However, it is worth noting that the largest variation in standard deviation occurs within the sparsely colonized habitat of transect C at dusk, which could be relevant due to the fact that transect C is the most colonized transect and dusk is one of two more active times of day (the other being dawn) due to feeding activities (Orlowski, 2000; Thomson and Allen, 2000).

Figure 4.6 shows the base 10 logarithm of the abundance data that is also plotted as a function of habitat type for the bottom layer (10.93 to 18.93±1.22m) of the water column. The median FPCM values are represented by the bars, the open circles are the means, and the vertical lines indicate the standard deviations. Time of day is represented by the columns and the rows indicate transect location (longitude).

Here the changes in the median values across transect and all times of day appear insignificant. The variations in the means and standard deviations are such that no concrete conclusions can be drawn in regards to the influence of habitat type. However, it is interesting to note that transect A contains no densely colonized reef habitat and the variations seen here are smaller than the other transects at the same times of day.

4.3 May 11–12, 2005

Finally, the May 2005 FPCM analyses is outlined in Figure 4.7. FPCM is plotted on a loga-

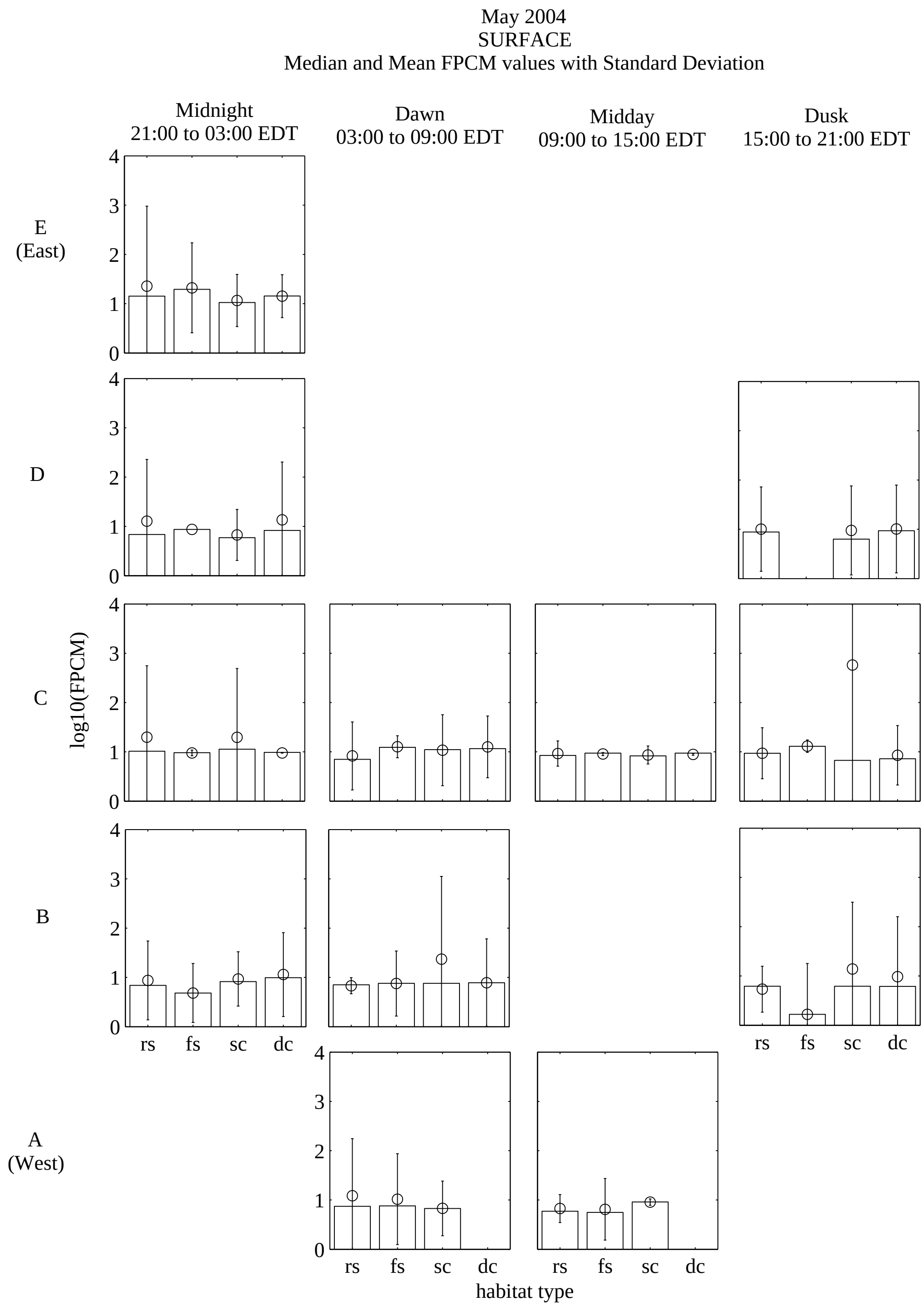

Figure 4.5: The log10 transformation of FPCM data plotted versus habitat type for the surface layer of the water column during May 2004 all as a function of time and longitude. Habitat type abbreviations are: rs—rippled sand, fs—flat sand, sc—sparsely colonized, and dc—densely colonized.

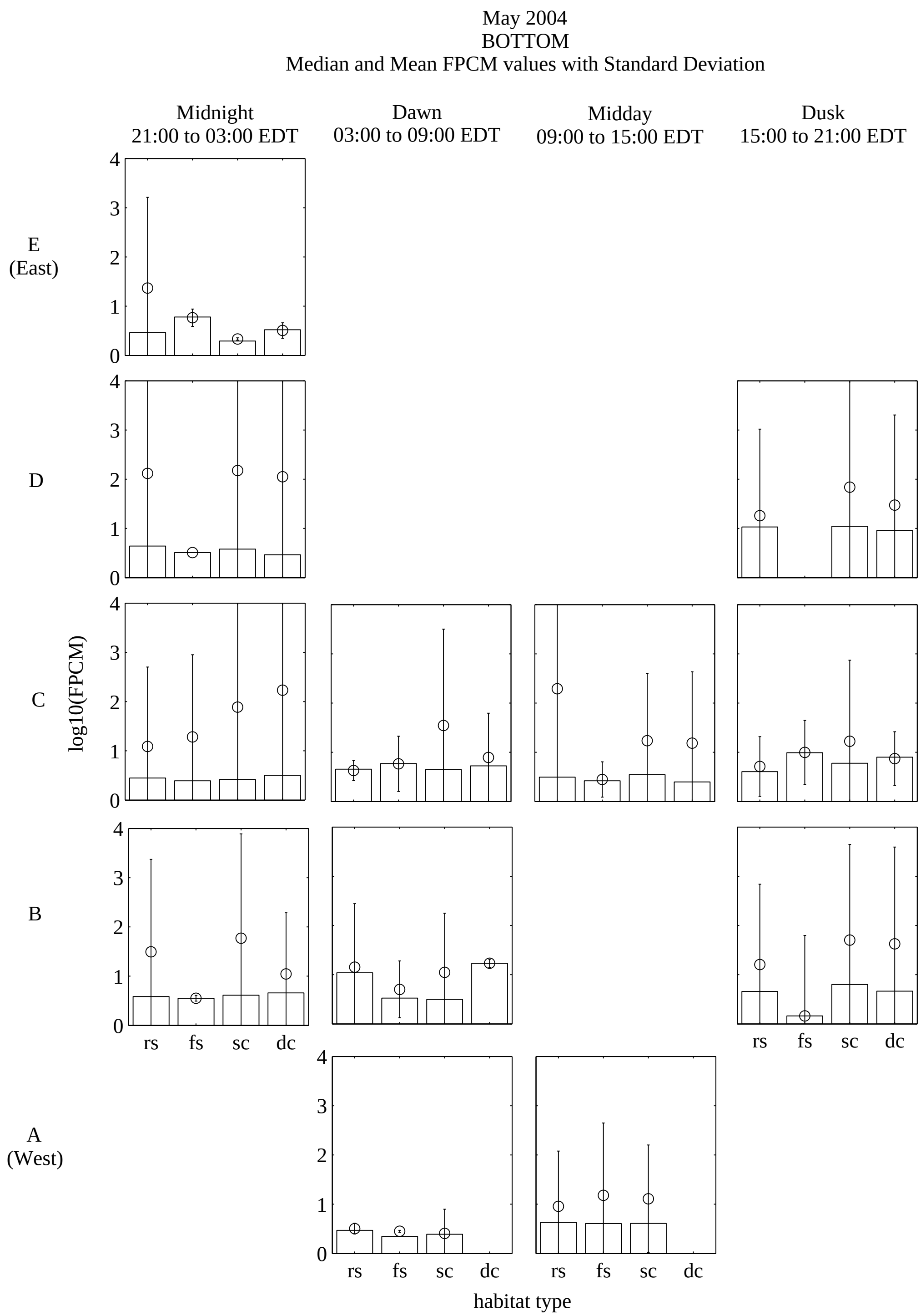

Figure 4.6: The log10 transformation of FPCM data plotted versus habitat type for the bottom layer of the water column during May 2004 all as a function of time and longitude. Habitat type abbreviations are: rs—rippled sand, fs—flat sand, sc—sparsely colonized, and dc—densely colonized.

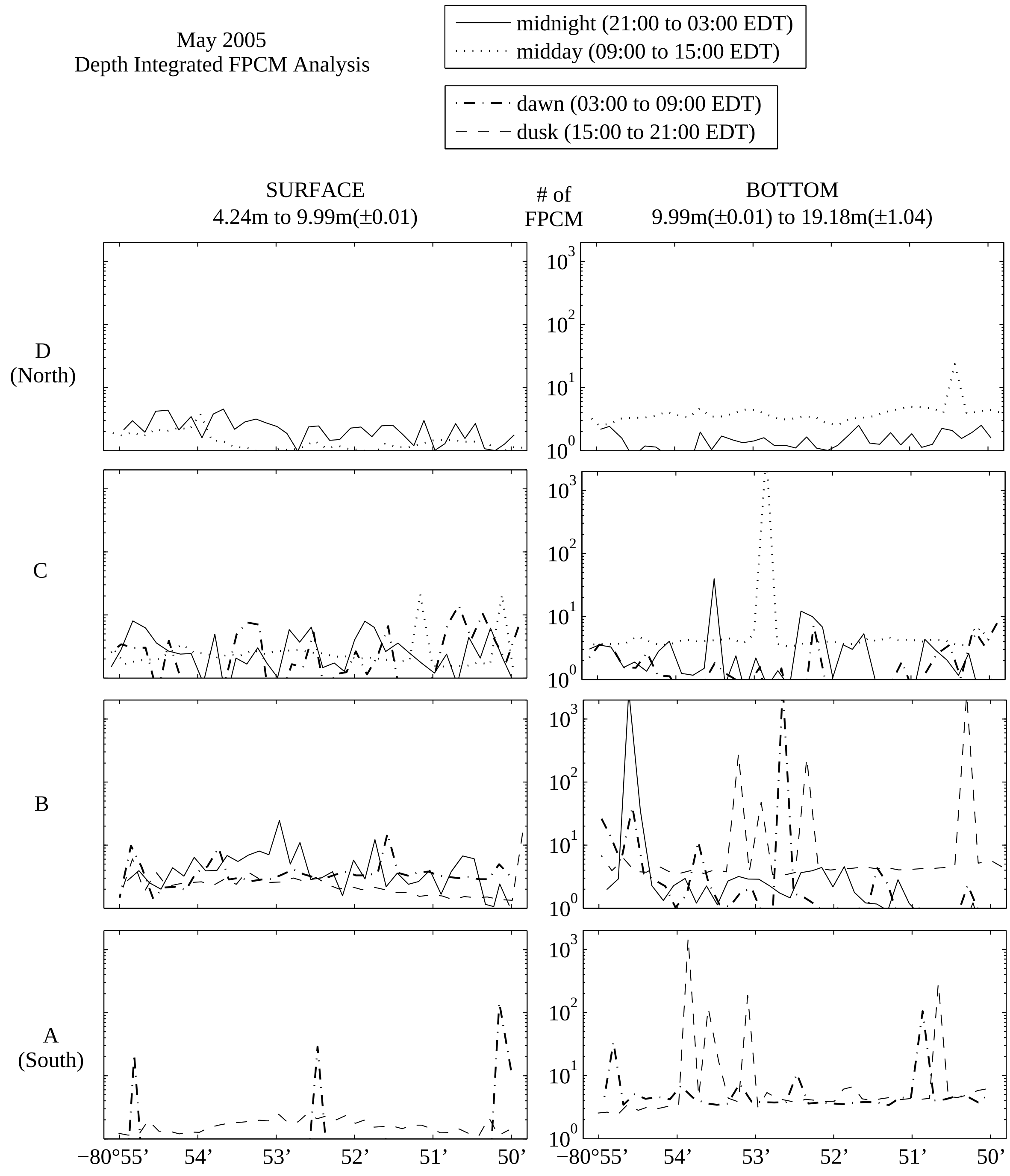

Figure 4.7: FPCM data separated into surface (left) and bottom (right) layers all as a function of longitude, latitude, and time of day during May 2005.

rithmic scale as a function of depth ("surface", left column versus "bottom", right column), longitude (x-axis), latitude (transects A – D), and time of day (midnight, dawn, midday, dusk). For this survey the blanking distance remained constant at 0.98m resulting in a uniform starting distance of 4.24m below the surface. The surface layer consisted of the first five strata each with a size of approximately 1.4m (thus extending to an average depth of 11.43m) where the FPCM were summed to give the total abundance for this layer. The lower layer encompassed from four to seven strata depending on the bottom topography and as such the lower layer ranged from 11.43m to an average depth of 19.18±1.04m. The general trends of both "surface" and "bottom" baseline data at each time of day for each transect will be compared to isolate the part of the water column that the fish occupy, and then peak events will be discussed. The spatial characteristics of these data will conclude this section.

Beginning at transect A, there are more fish uniformly distributed in the "bottom" of the water column than in the "surface" at dawn. Some of the peaks in the "surface" at dawn may be related to the increase in TS distribution directly beneath the transducer that may be associated with ship effects rather than the presence of fish (refer back to Figure 3.5). In transect B during midnight and dawn there are also a greater number of fish per cubic meter at the "surface". At dusk, these baselines appear roughly the same with the possibility that there are more organisms present at the "bottom" because of increased numbers at isolated locations. For transect C, which cuts right through the "highly populated ledge" region of the sanctuary, all time intervals show a generally uniform distribution in both layers of our sampled volume. At midnight and dawn there are less fish in the lower layer, while the midday time segment shows approximately the same number of fish in this layer as in the "surface" layer at this time. At midnight, the greater number of FPCM in transect D are more concentrated to the "surface" of the water column sample, and are well distributed along the entire transect throughout the water column. At midday, these numbers again are very similar to one another. It could be said that there are slightly more fish present in the lower layer as compared to the surface, but the difference is subtle.

On the whole, this data also shows that there are greater numbers of fish near the surface at midnight, and by midday, the majority of organisms occupy the lower portion of the water column, as seen in previous years' abundance data. Yet referring back to the target strength distribution graphs in Figure 3.5, and drawing a line at the separation of the "surface" and the "bottom" layers, it is clear that greater numbers of fish can be found in the lower water column which apparently contradicts the FPCM data presented above. However, if the obvious patchiness (in the form of the several large peaks in the bottom layer) is considered, the FPCM data can be seen to more accurately coincide with what the TS distribution graphs show. It is also worth mentioning here that the presence of a distinct thermocline in 2005 (see Figure 2.14) is a likely contributor to few targets being found shallower than the 10 meter depth.

To extract the spatial correlations of this data, refer back to Figure 2.13 for the habitat composition of each of these transects. Next re-examine Figure 4.7 to pick out the peaks of higher FPCM. Note that all four transects contain significant peaks in the lower layer. It is worth pointing out that the northernmost transect, D, consists of only unconsolidated sediment (just as in 2003) and the midday data shows an increase in the number of fish near the eastern boundary of GRNMS. The other three transects all contain some percentage of colonized habitat and the peaks are visibly more frequent in these areas. In particular, transects A and B have several very robust peaks in the lower layer that all occur at locations where the sparsely colonized reef habitat is below. Also, transect C, which was of great interest by virtue of its location, has markedly less clusters of fish (peaks) than transects A and B. Although, those peaks that are present in the "bottom" water column layer are, indeed, occurring in areas where sparsely colonized reef habitat is present.

Figure 4.8 shows a version of the FPCM data that is the base 10 logarithm plotted as a function of habitat type for the surface layer (4.24 to 11.43m) of the water column. The log 10 transformation was performed on the y-axis simply to allow all data to be represented aesthetically. The bars represent the median FPCM measured for each habitat type at each

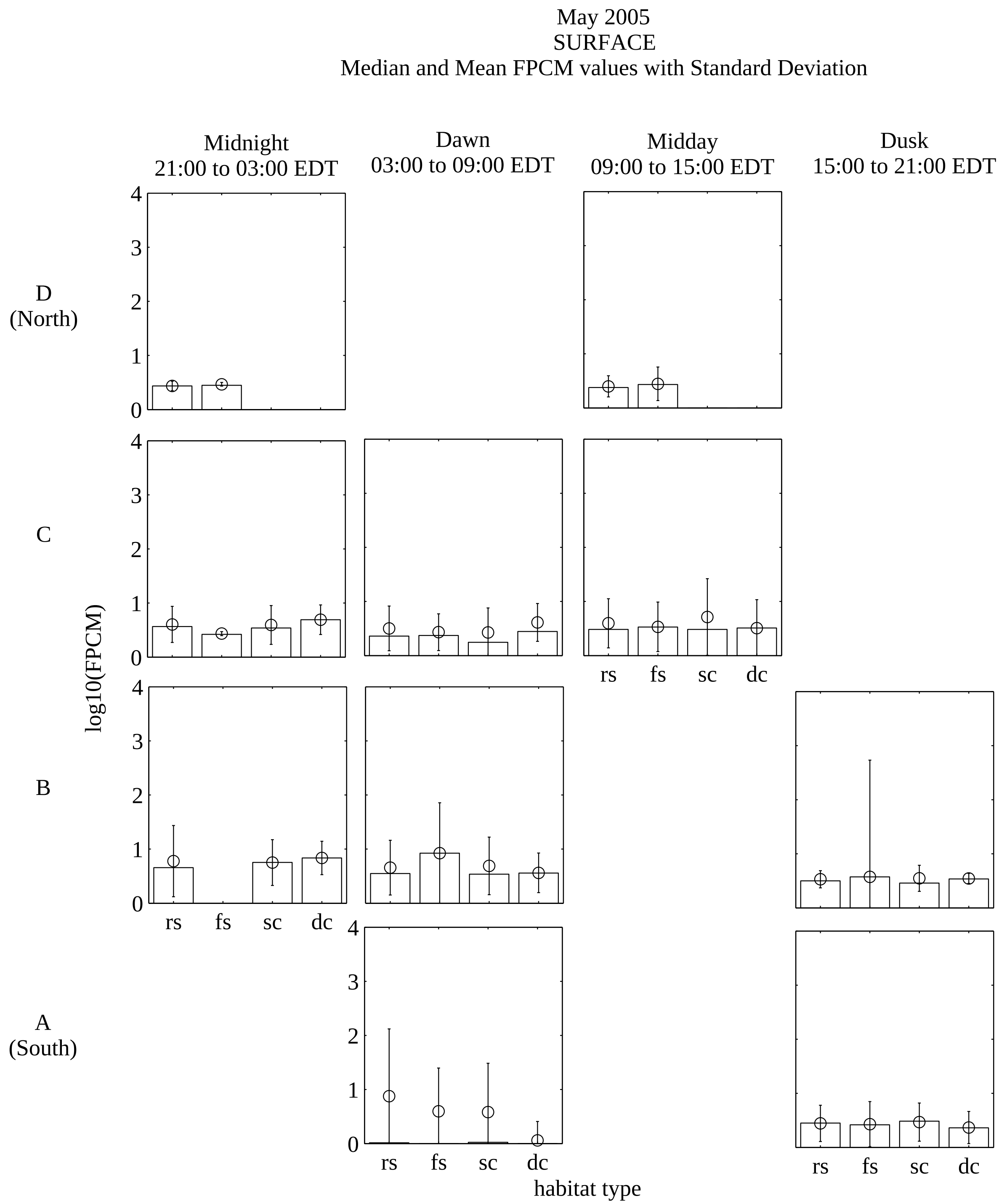

Figure 4.8: The log10 transformation of FPCM data plotted versus habitat type for the surface layer of the water column during May 2005 all as a function of time and latitude. Habitat type abbreviations are: rs—rippled sand, fs—flat sand, sc—sparsely colonized, and dc—densely colonized.

time of day. The mean FPCM values are shown as open circles, and the standard deviations for those means are the vertical lines. Time of day is represented by the columns and the rows indicate transect location (latitude).

This figure illustrates that there is no clear relationship between habitat type and fish abundance in the surface layer of the water column. Where there are means that differ greatly from the median (transect A at dawn and transect B at dusk), most of this data represents the unconsolidated sediment habitat types. This may be related to feeding behaviors on benthic organisms, particularly since these trends occur at dawn and dusk, the two most conventionally active times of the day for most organisms (Orlowski, 2000; Thomson and Allen, 2000). However, these are the only two isolated occurrences of such a trend.

Figure 4.9 shows the log10 transformation of the abundance data that is plotted as a function of habitat type for the bottom layer (11.43 to 19.18$\pm$1.04m) of the water column. Median FPCM measured at each habitat type at each time of day is shown by the bars. The open circles represent the mean FPCM values, and the vertical lines indicate the standard deviations for those the means. Time of day is represented by the columns and the rows indicate transect location (latitude).

There is more association with the hard bottom habitat among those pelagic organisms found in the bottom layer of the water column as seen here particularly in transects A – C. This is indicated by the fact that there is a great amount of variability in the mean and standard deviation values for these transects when compared to transect D, which is 100% unconsolidated sediment.

4.4 Seasonal Variations

Seasonal changes of the FPCM data will again be determined via comparison of the data between Fall (October 2003) and Spring (May 2005). Both years show an increased number of data peaks in the "bottom" layer when compared to the "surface", yet there are visibly

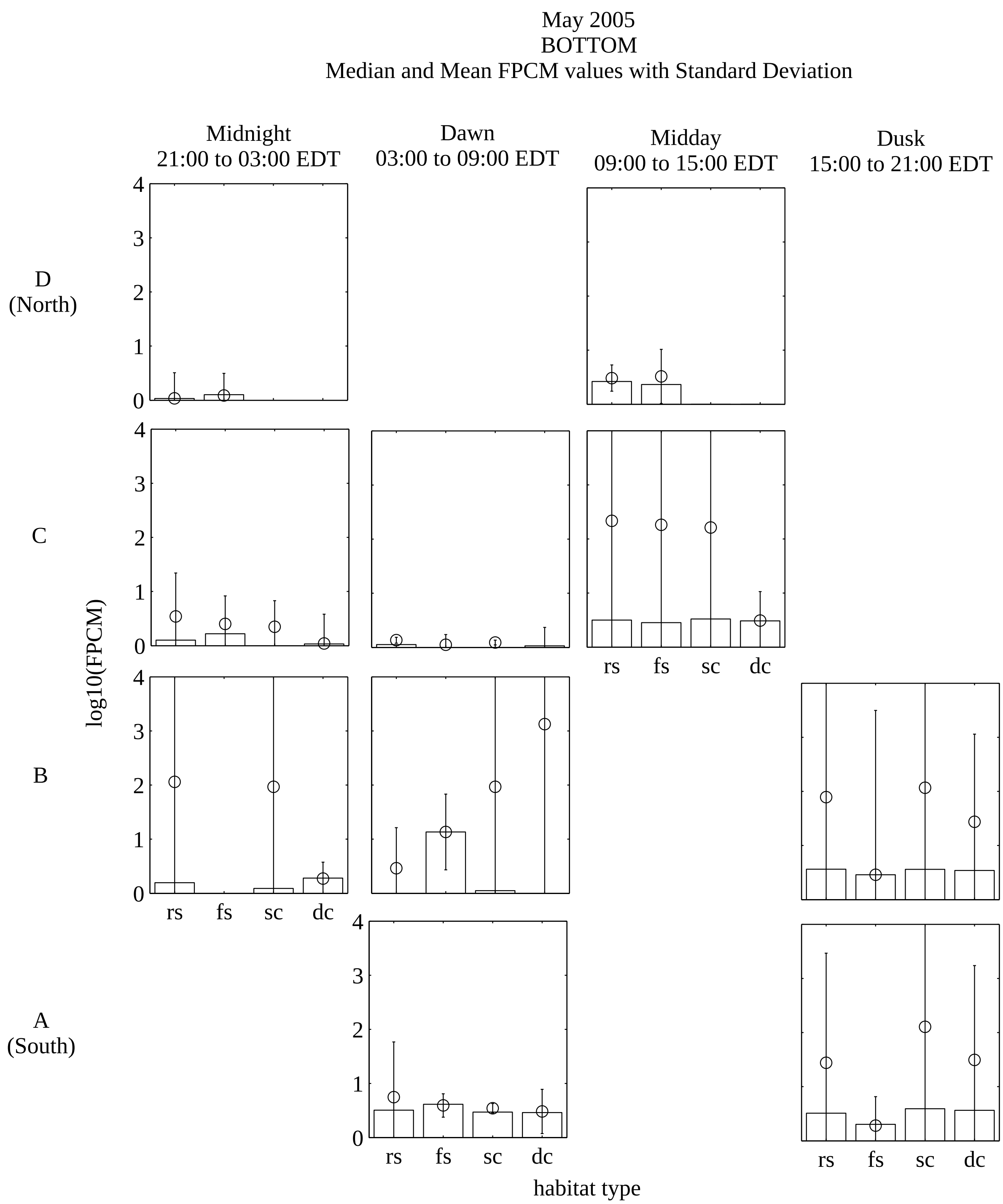

Figure 4.9: The log10 transformation of FPCM data plotted versus habitat type for the bottom layer of the water column during May 2005 all as a function of time and latitude. Habitat type abbreviations are: rs—rippled sand, fs—flat sand, sc—sparsely colonized, and dc—densely colonized.

more of these in the Spring. There are peaks in both years that correspond to colonized habitat and unconsolidated sediment.

There is evidence of diel vertical migration in that there are more fish uniformly distributed in the "surface" layers at midnight, dawn, and dusk than there are at midday. This trend is evident in 2005 yet muted, perhaps due to the thermocline.

At a glance, 2003 seems to have more fish overall which contradicts the hypothesis that there would be less organisms present in the Fall. Yet, 2005 contains several more large peaks overall than the 2003 data does. If these are taken into account to estimate the total FPCM between seasons, it can be said that there are more fish present in the Spring.

Again, recall that Figure 2.1 shows that there is approximately two more hours of daylight in May versus October. This fact could seemingly affect FPCM in that those organisms that spend the daylight hours at depth, would be near the surface of the water for a shorter period of time in May as compared to October, thereby showing fewer fish in the "surface" layer particularly at dawn and dusk. Yet, this potential influence is undetectable for this dataset since the dawn and dusk time segments are centered around the sunrise and sunset times for both seasons. To determine if the longer period of daylight does affect FPCM, the data could be re-grouped according to daylight hours versus non-daylight hours and re-processed, a task that is beyond the scope of this thesis.

Chapter 5

Conclusions and Suggestions for Future Work

5.1 Target Strength Distribution

Recall that the first objective was to investigate the range of target strengths along each transect, using vertical resolutions of approximately 1.4 meters and horizontal resolutions the order of the length of each entire transect track, to determine the target strength distribution within the sanctuary. Based on all of our analyses, the range of target strengths for the highest count contours extend from -75 to -65 dB. This is not attributable to a significant change in the size of the organism since these target strengths can represent fish ranging in size from a few centimeters to 10cm. In fact, according to (Kinacigol and Sawada, 2001) the target strength-length relationship for an anchovy is,

$$TS = 20 \log 10(L) - 77.5, \tag{5.1}$$

which gives a target strength range of -68 to -60 dB for fish lengths L=3cm to 8cm. For fish lengths of 15cm to 30cm target strength-length equations for our observed species are not available. However, a general equation put forth by Foote (1987) for clupeoids is,

$$TS = 20 \log L - 71.9. \tag{5.2}$$

This gives target strengths of -51.9 to -43 dB for fish lengths of 10cm to 30cm respectively. It is clear that detailed target strength relationships are needed for the variety of prey fish sizes that exist at GRNMS which dominate the acoustic scattering. In general, the results of all three experimental programs yielded total target strength distributions that ranged within -78 to -45 dB for all times of day, at all locations in the sanctuary which represents a wide range of fish sizes and comprises many diverse species of pelagic biota.

5.2 Abundance

The second objective states, "By examining the depth integrated FPCM using a vertical resolution of approximately half of the water column (so as to express the data in terms of the "surface" and the "bottom") and a horizontal resolution averaging 234 meters over each of the individual transect lines, what is the abundance of the pelagic fish that are present within GRNMS?" For 2003, by examining the baseline trends of the abundance data, in general, there are more fish per cubic meter at the "surface" than at the "bottom" except for all of those transects that were sampled during midday (which is expected). Comparison of this information to the target strength distribution graphs reinforces this fact. Figure 3.1 shows that more fish are present in the upper layer of the water column than in the lower layer at all times of day except midday where the trend is reversed. In 2004, again using the baseline FPCM, more fish appear to congregate in the upper layer when compared to the lower water column at all times of day. This is inconsistent with what is shown in the target strength distributions for this year. Figure 3.3 indicates more numbers of fish in the "bottom" layer. The significance of this lies with the fact that there is a more uniform distribution of fish in the upper layer of the water column than in the lower layer, which contains significant numbers of fish dispersed in patches. Similarly, the FPCM data for 2005 shows a general trend of more fish at the surface than at the bottom (except at midday). This is an apparent anomaly compared to the 2005 target strength distributions. However, once the peak events in the "bottom" are taken into consideration this is no longer the case and the results emphasize what is illustrated in Figure 3.5 as these target strength measurements are based on the entire transect length.

5.3 Temporal Relationships

Do temporal relationships, either diel or seasonal, exist for the TS distribution and FPCM data? Both the target strength distribution and abundance data supported the fact that diel vertical migration affects the pelagic biota of Gray's Reef. Our target strength distribution data presented strong evidence in October 2003 and more moderate evidence in May 2004 of diel migration. However, it appears that when well-mixed conditions occur during those times of the year with more daylight (the Spring), as in 2004, and when a pronounced thermocline exists, as in 2005, this trend is muted. Additionally, these data revealed generalized diel biological activity in that fish present during the day time are fairly well distributed throughout the water column, and fish present at night are distributed more in patches (Fabi and Sala, 2002; Guillard, 1998; Orlowski, 2000).

The abundance data for all three experimental programs clearly showed more fish in the "surface" layer during the midnight time segment when compared to midday, which showed more fish in the "bottom" of the water column, as we would expect. Again, due to the thermocline, there are many fewer fish found in the "surface" layer in 2005 when compared to 2003. Even those fish seen in the "bottom" in 2005 are generally (according to the baseline data) lower than those in the "bottom" in 2003. Seasonal migration of organisms in/out of the sanctuary can be deduced from the fact that in the target strength distributions as a whole, there are indeed fewer targets present in the water column overall in October 2003 versus May 2005 as indicated by the absence of the 1000-count contour in 2003 (with the two exceptions as noted in Chapter 3). Additionally, by examining Figures 4.1 and 4.7 it is clear that there are many more peak events in 2005 versus 2003. All of which supports the hypothesis of fewer organisms being present in the sanctuary during October 2003 (Fall), as suggested by the increased productivity this region experiences in the spring and summer (Verity et al., 1993).

5.4 Spatial Relationships

Are the TS and FPCM data related in some way to the bottom habitat classifications? The evidence for the influence of habitat type on our data is mixed. For 2003 and 2005, it would seem that the presence of colonized reef habitat does not effect the target strength distribution of the organisms in that similar numbers of fish of all sizes are found within all transects. Yet in 2005, the argument can be made that the larger 1000-count contours seen in transects A and B, when compared to transect C, are the result of transects A and B having higher percentages of sparsely colonized reef habitat than transect C. Nor does habitat type appear to influence the diel migration pattern seen in 2003. One possible effect of habitat type may be that fish are generally one meter higher in the water column within those transects that contain little or no reef structure than within their counterparts containing colonized habitat, based on the highest count contour analysis for October 2003. This could indicate a potential need for organisms to remain closer to the reef structure below if it is present and a need to venture further up into the water column if it is not as a result of species-specific diet and shelter requirements (Christensen et al., 2003; Friedlander and Parrish, 1998). There does not appear to be any distinct seasonal patterns in the target strength distribution as it relates to habitat, since seasonality is seen to be mutually exclusive from affinity for a certain bottom type.

In 2004, the presence of colonized reef habitat did appear to affect the target strength distribution of the organisms in that more fish of more sizes were generally found within transects that contained reef structure over those that do not. In addition, during the entire experimental program this year, the "predator" targets tended to remain lower in the water column, venturing into shallower waters only at midnight while the population of "prey" targets, represented by the 1000-count centroids, were generally more spread throughout the water column at all times of day within those transects that contain some presence of densely colonized reef structure (B through D) than their counterparts within transect A which has no densely colonized habitat which suggests that the "predator" group of organisms has a stronger association to the bottom habitat than the "prey" group does.

The abundance data presented some patterns of FPCM as it relates to habitat type. A majority of significant peaks occur in the "bottom" layers of all years, suggesting a stronger association to habitat among fish in the "bottom" layer. Interestingly, it is not necessarily so that all of these areas of high fish counts per cubic meter are associated with reef structure. Some peaks in all years can be georeferenced back to sand habitat. However, all of the most robust "bottom" peaks in all years are associated with sparsely colonized habitat. Also, peaks are visibly more frequent within transects that contain a higher percentage of reef structure. Indicating that at depth, pelagic organisms are more associated with the type of benthic habitat below them than their counterparts near the surface are. Seasonal patterns, again, are not evident since the time of year appears not to effect an organism's affinity for a particular bottom type.

It is important to emphasize that the method of quantifying the habitat for the spatial analysis resulted in a description that represented a very small portion of the sanctuary as a whole, and was discovered to be too coarse a resolution for finer-scale analysis. Biological interactions with habitat are known to occur on a multitude of scales (Christensen et al., 2003; Mora et al., 2003). While a survey such as this may be adequate for determining meso- or mega-scale interactions, a more comprehensive analysis of the habitat types would be required for micro-scale comparisons. Additionally, there is the phenomenon of "edge effect" to consider where there is greater species diversity and biological density in a region that borders adjacent ecological communities of differing composition (Friedlander and Parrish, 1998). Gray's Reef can be described as containing hundreds, or even thousands, of these "edges", and the current method of quantifying the habitat is not capable of isolating these from the landscape.

5.5 Methodological Impact

Does employing different methodologies in each survey have an impact on these results? Data collection for each of the three research cruises employed a similar general methodology with variations particular to the transducer type used and direction of travel. These variations did not appear to affect the quality or nature of the results in any way although it is generally accepted that transducers that directly measure the target strength are better suited for measuring size distribution characteristics (Rudstam et al., 1999). What was affected by the split- versus single-beam transducer types, was the manner in which we talk about the data. Only relative observations could be made for the data in 2004 because of the lack of calibration data, while absolute measurements could be extracted from the data in 2003 and 2005. Further, each of the two split-beam transducers operated on a unique frequency, 120 kHz and 200 kHz respectively. For target strength-length relationships the acoustic frequency must be taken into account as the equation will be different for a 120 kHz versus a 200 kHz transducer. In practice, the higher frequency devices allow for finer resolution of smaller targets generally associated with planktonic organisms with TS less than −78 dB. Since we are only interested in the −78 to −40 dB range, this resource was not exploited.

Of all of the methods employed in these studies, the split beam transducer type is thought to be better than the single beam because it can measure target strength directly without any assumption of how fish are distributed in the sample volume. Our 200 kHz transducer included the added convenience of being calibrated at the manufacturer in a controlled setting prior to our measurements, thus eliminating the need for *in situ* calibration. Integrated GPS data collection is best in that it is the most convenient. Georeferencing with the time data is doable but considerably more time consuming.

5.6 Potential Future Applications

Calculating the FPCM for −78 to −60 dB and then again for −60 to −45 dB would be an interesting determination for estimating potential predator/prey relationships within this dataset. Analysis of this kind could determine if these pelagic organisms are interacting in a predator/prey capacity with one another, or with other organisms, not represented by these datasets. Furthermore, biomass estimates could be determined from this information (as explained later) in order to extrapolate this potential dynamic even more.

Ideally, if these experiments were to be repeated, the 200 kHz split-beam transducer (as used in 2005) would be used but the transect paths would be narrower or overlapping. Or, a grid pattern that covers both horizontal directions (east/west and north/south) could be used to attempt to better assess the three-dimensional aspect of the data as in Kracker (1999). More sampling days would be required since the increased number of passes over the sanctuary probably would not allow for multiple passes over the same transects within 24 hours. Multiple passes over transects are necessary for replication of the data and results. Software has been developed (Jech and Luo, 2000) that would enable spatially explicit analysis of the target distributions ensonified by these techniques, and present the data in such a way as to preserve the spatial and temporal integrity.

Alternatively, because our observations showed very few schools present in the water column, it would be advantageous to use a high frequency multi-beam swath in order to get at a more three-dimensional image of the water column. A multi-beam transducer can ensonify up to 180° in the athwartships direction for the entire water column, a feature that would greatly increase the odds of encountering and isolating schools of fish. This method would not require as many transects over the sanctuary as the split-beam method, due to the capability of sampling an exponentially larger volume of water with each swath. Also, the data recovered from multi-beam transducers more easily lends itself to three-dimensional applications (Mayer et al., 2002).

The management at Gray's Reef is interested in further understanding the dynamics of the fisheries that the sanctuary supports (Gray's Reef National Marine Sanctuary, 2006). In order to do this, the biomass statistics must be extracted for each of the components of the fishery. The pelagic organisms isolated in this study are seen to represent the bottom to the middle of the food chain for GRNMS. Biomass figures can be determined via a target strength versus mass relationship equation, however, doing so lies beyond the scope of this thesis, yet would be an interesting extension of this work. Further, schooling, fast-moving fish (like the bay anchovies, *Anchoa mitchilli*, captured in our October 2003 trawl data or Atlantic menhaden, *Brevoortia tyrannus*, which represent the next trophic level) tend to have the same "aerodynamic shape" which inherently has physical and physiological constraints that can also be expressed as an equation to determine biomass. Several additional years of data collection could begin to determine whether or not these -78 to -65 dB fish are increasing or decreasing in biomass, which has ramifications both up and down the food chain, giving indications of overfishing (or abundance) of their predators. Three-dimensional acoustic analysis could help to determine the dimensions of any fish schools that may be encountered providing further analysis of these organisms' spatial relationships within the water column.

There are also potential applications for this data to be used within any marine environment where the presence of pelagic biota is an integral part of the ecosystem. Similar studies have been done in estuarine environments (Ornellas and Coutinho, 1998; Petitgas et al., 2003). A study of this nature can play a vital role in the NOAA's NMS program, since several of the sanctuaries express in their management plans, a desire and need to better understand the ecosystems that are being protected. Also, in recent years, there has been an increasing push toward "whole ecosystem" preservation and management (Anderson et al., 2005), and the present study is seen as a stepping stone toward achieving that goal.

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