Boundary Options for a Research Area within Gray's Reef National Marine Sanctuary

by
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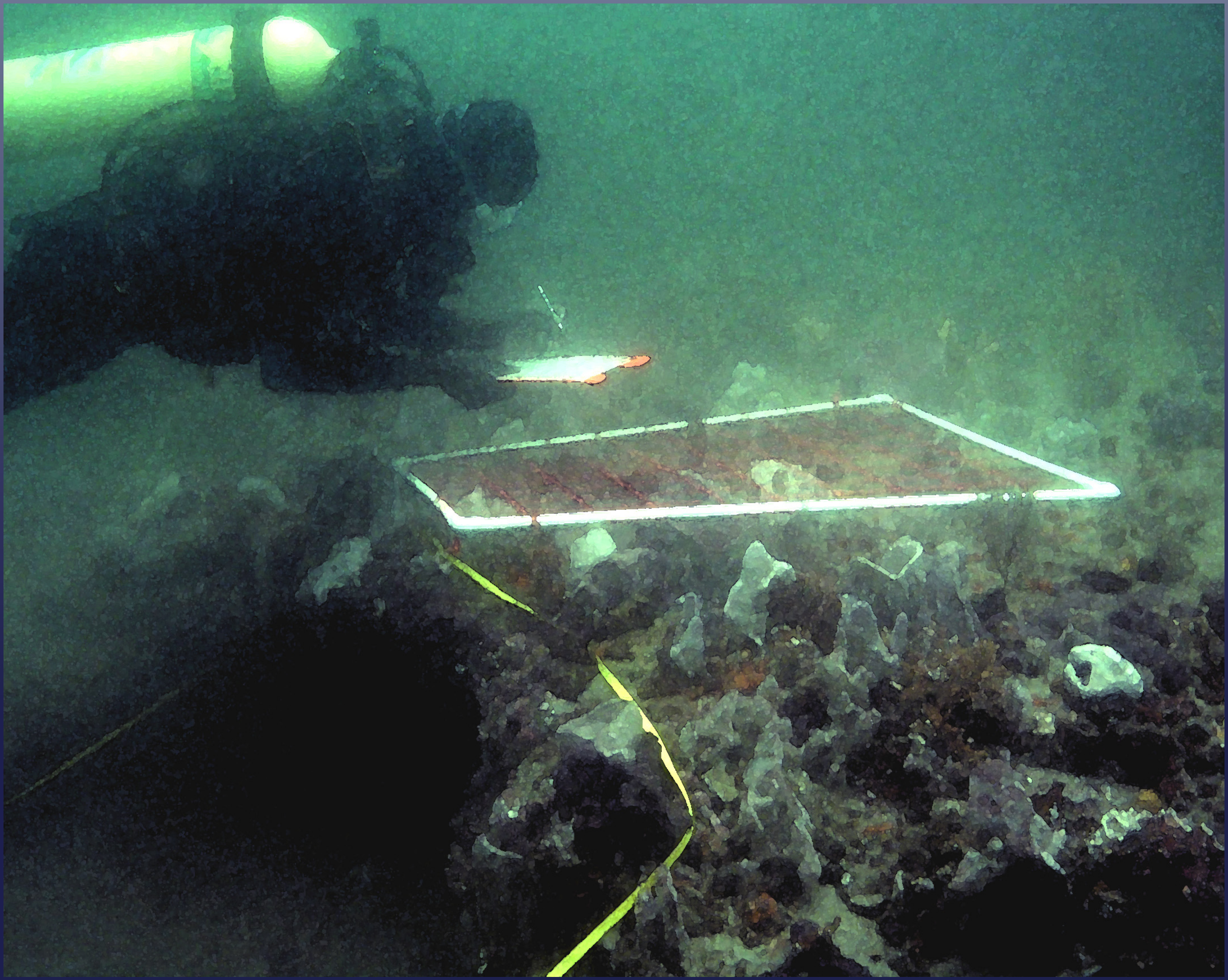
In partnership with Gray's Reef National Marine Sanctuary
and the Research Area Working Group

May 2006



NOAA Technical Memorandum NOS NCCOS 31

Citation:

Kendall, M.S. and K.A. Eschelbach. 2006. Boundary Options for a Research Area within Gray's Reef National Marine Sanctuary. Prepared by National Centers for Coastal Ocean Science (NCCOS) Biogeography Team in cooperation with the National Marine Sanctuary Program. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 31. 51 pp.

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NOAA Technical Memorandum NOS NCCOS 31

May 2006

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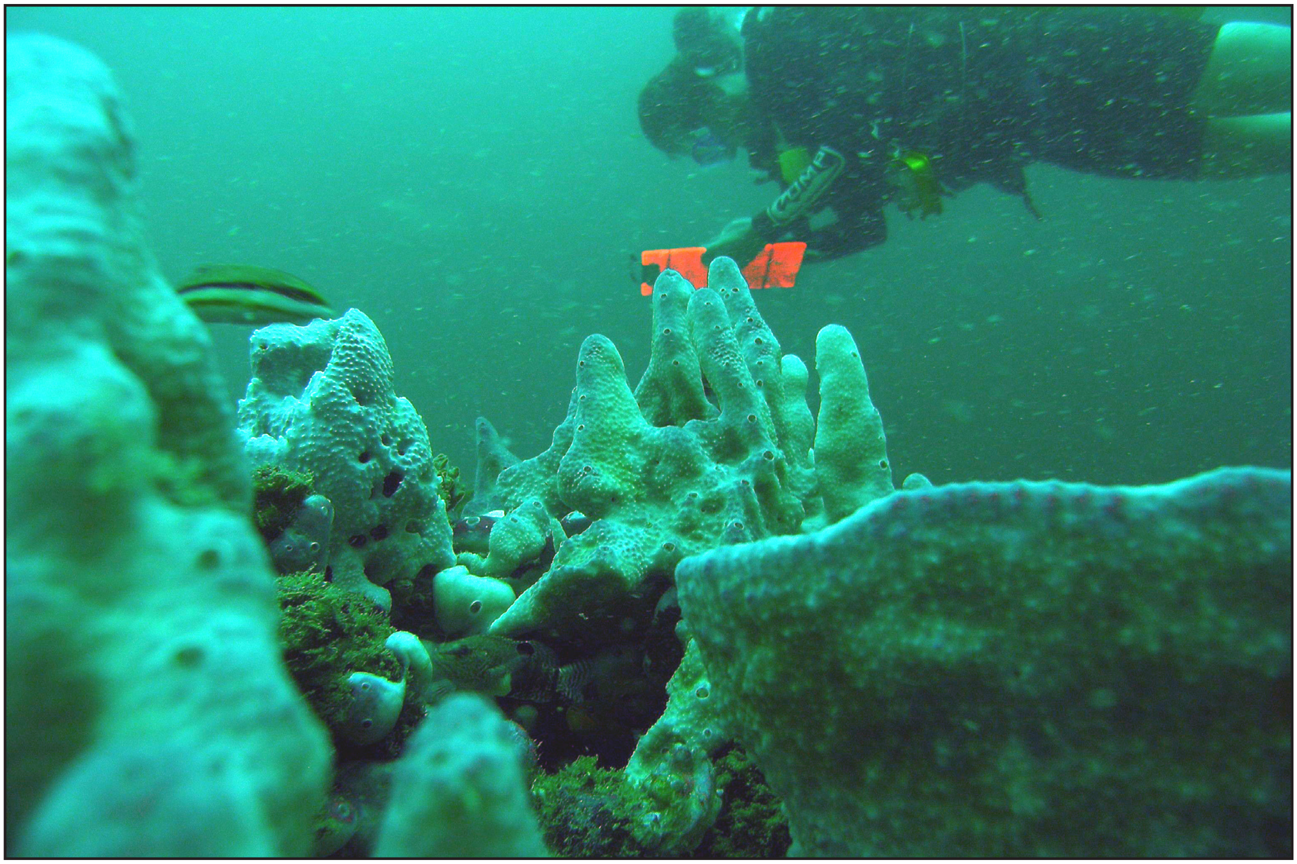


Image 1. Diver conducting research on sponge cover at GRNMS.

ABSTRACT/EXECUTIVE SUMMARY

Gray's Reef National Marine Sanctuary (GRNMS) is exploring the concept of a research area (RA) within its boundaries. The idea of a research area was first suggested in public scoping meetings held prior to the review of the Gray's Reef Management Plan. An RA is a region specifically designed for conducting controlled scientific studies in the absence of confounding factors. As a result, a multidisciplinary group gathered by GRNMS was convened to consider the issue. This Research Area Working Group (RAWG) requested that a suite of analyses be conducted to evaluate the issue quantitatively. To meet this need, a novel selection procedure and geographic information system (GIS) was created to find the optimal location for an RA while balancing the needs of research and existing users. This report and its associated GIS files describe the results of the requested analyses and enable further quantitative investigation of this topic by the RAWG and GRNMS.

To guide the analyses, the RAWG identified several general characteristics needed for an effective and acceptable RA; these are listed below in order of decreasing use value. The RAWG determined that an ideal RA would include:

1) a large number and diversity of ledge types because ledges are the most important bottom type in the sanctuary and the target of most research needs;

2) the full spectrum of other bottom types in the sanctuary besides ledges in order to encompass the full variety of habitats for research;

3) a large number of prior research sites to serve as a baseline for comparison with future studies;

4) as few of the preferred bottom fishing sites as possible (provided that guidelines 1-3 above are not compromised). Bottom fishing should be prohibited within the RA since it could confound research; and

5) a suitable number and area of ledges, other bottom types, and prior research outside the RA to serve as a comparison to sites within the RA.

In addition to these five general guidelines, the RAWG requested that several boundary configurations be considered for a potential RA. These alternatives included squares, rectangles, and hexagons of various sizes including 4, 6, 9, and 16 km^2 . In addition, the squares and rectangles were rotated 30° and 45° counter-clockwise to explore the possibility that this rotation would possibly better align RA boundaries with local geology and hence the desired characteristics of the RA more optimally.

To address these issues, a sliding window approach was used to quantify the diversity of ledges, bottom types, number of prior research sites, and preferred fishing locations inside and outside of each boundary configuration (see Figure 1). This approach systematically considered placement of the various RA boundary configurations throughout the entire sanctuary. A scoring procedure was then applied to enable the exploration of the tradeoffs among boundary size, shape, and orientation and how these choices affect inclusion of target bottom types, prior research, and favored fishing locations. A table of all boundary options and their respective scores for each category of variable was created to facilitate comparisons. Finally, through a step-wise selection process the field of potential RA boundaries was narrowed based on the five general criteria identified by the RAWG.

The best RA options were clustered in the south/central portion of the sanctuary where most ledges and prior research sites were located. The larger sized options were often most desirable because they covered a greater proportion of the sanctuary and therefore encompassed more of the target variables. The largest sizes maximized ledge, bottom type, and prior research within the RA and still allowed sufficient comparable areas outside of it. These also would include the home range for the greatest variety of fish. Rotating boundary shapes improved a small percentage of boundary options. Such options mostly gained ledges along the very edge of their boundaries. Edge effects, fish movement out of the RA, and fishermen concentrating effort along the boundary line may all counter the benefit of a larger number of ledges near a boundary edge.

The consequences of high, moderate, and low stringency or selectivity in applying the siting criteria and choosing acceptable boundary options were demonstrated through three example scenarios respectively. Low selectivity yielded too many options to choose from with widely differing characteristics, many of which did not meet all of the RAWG's preferred siting criteria. The highly selective scenario demonstrated that the ideal RA, one with lots of ledges and prior research but that includes none of the preferred fishing sites and displaces no fishermen, is simply not possible. In contrast, a moderately selective scenario resulted in a reasonable number of options from which an RA could be chosen that generally met the five characteristics requested by the RAWG. A reasonable number of all ledge types were included as well as all other bottom types. Some of nearly all types of prior research were present within each option and the areas with the very highest fishing effort were avoided without compromising the other criteria. All of these options had large amounts of ledges, other bottom types, and prior research sites outside the RA. These options consisted of many alternative shapes, sizes, and rotations and occurred in two clusters located in the east/central and west/central portions of the sanctuary respectively. Ultimately, through the public process and further consideration by the RAWG and GRNMS, this list of possible options could be further narrowed and an acceptable RA chosen.

There are many other issues to be considered in the long term design of a RA not analyzed in this study. No matter what size, shape, or rotation may ultimately be decided upon, the addition of a buffer zone of added protection around the RA should be considered. A buffer zone is simply a border of additional protected space around the area that will serve as the RA. This is especially important in areas where ledges within the RA are near its border. In addition, an RA designated based on the results of this analysis should include some spatial and temporal flexibility. The RA should be periodically remapped and reevaluated or have regulations updated as necessary to accommodate changes in the distribution of bottom features and research needs.

Although avoidance of preferred bottom fishing areas was an important objective of this analysis through the use of boat sighting and marine debris distributions, further care should be taken to minimize displacement of current users. Namely, since bottom fishermen will be the most impacted, they and their representatives should be consulted at public meetings to discuss which among the preferred RA options are most agreeable to them.

Provided that the criteria are met for ledges, other bottom types, and prior research, any of the remaining options most acceptable to bottom fishermen should do equally well in providing an effective RA. Incorporating this group's concerns at every stage in the RA evaluation process has been essential thus far and is expected to improve understanding, acceptance, and ultimately compliance of an RA if implemented.

This document and associated files do not provide a "final answer" to the exact placement of an RA within GRNMS; instead they describe a novel approach and GIS tool to aid in making that decision. Prior to this study, the number of ledges, area of other bottom types, inclusion of prior research, and preferred locations for fishing within the context of the various RA boundary configurations under consideration were simply not understood. The results of this study provide this requisite understanding through a systematic and comprehensive analysis of the boundary options and the resources they encompass. This document and associated files enables the RAWG, GRNMS, and NOAA to further refine their desired parameters and complete the RA selection process. Ultimately, the decision of if and where to implement an RA rests with GRNMS, and NOAA.

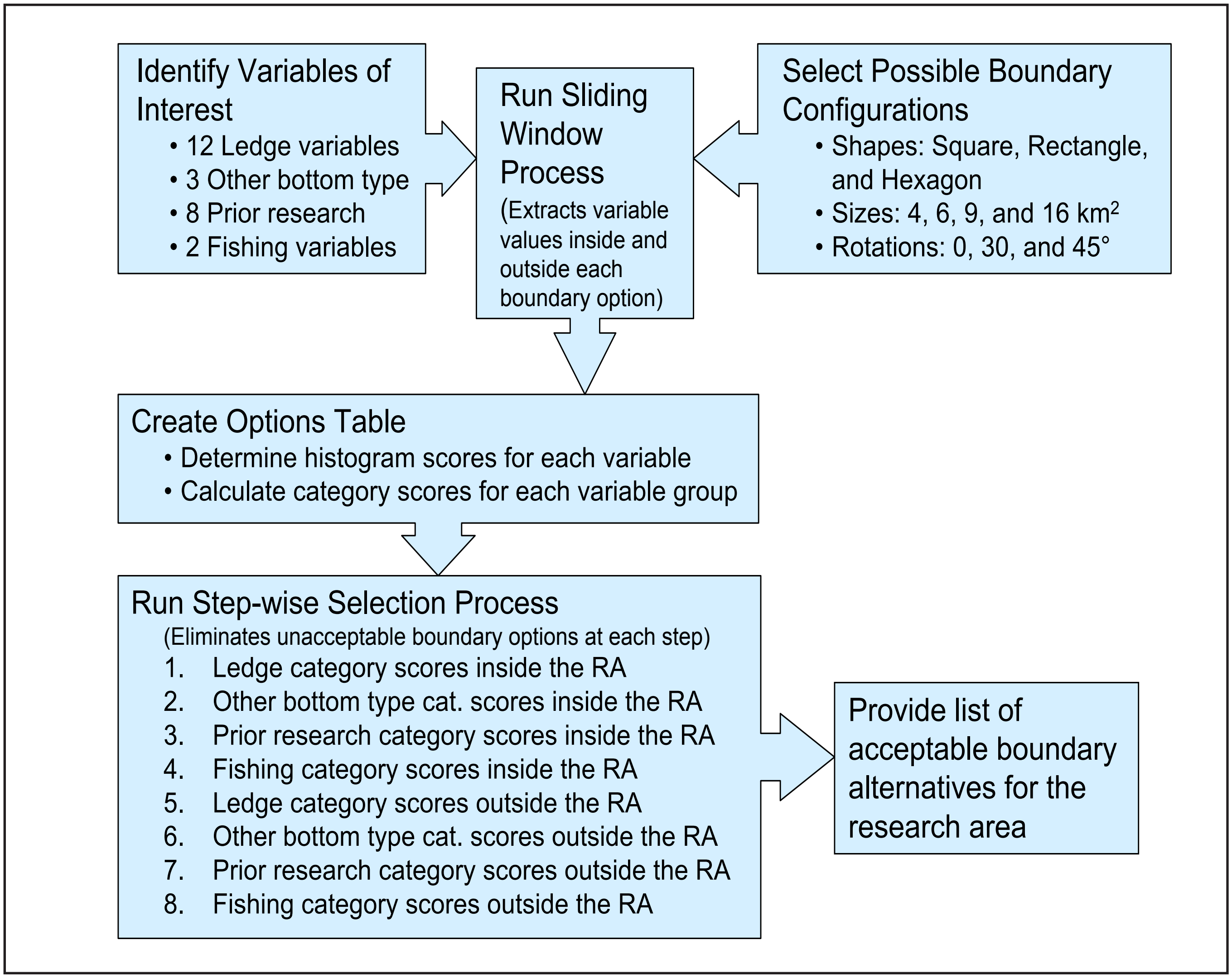


Figure 1. Flowchart of analysis process.

INTRODUCTION

Much attention has recently been given in marine protected area (MPA) literature to recommendations, techniques, and processes for site placement (Ball and Possingham 2000, National Research Council 2001, Leslie et al 2003, Roberts et al 2003a, Roberts et al 2003b, Meester et al 2004, Pattison et al 2004, Dalton 2005, NERRS 2005). The focus has largely been on those MPA's intended for biodiversity conservation (but see NERRS 2005, NPS 2001). Instead the focus of this report is on another specialized type of MPA, those created specifically to support scientific research.

A research area (RA) is a type of MPA in which to conduct controlled scientific studies in the absence of confounding factors. Sites appropriate for conducting manipulative studies with adequate controls are lacking in many marine areas. RAs, like some conservation areas, also offer scientists the opportunity to observe natural ecosystems and their variability thereby enabling discrimination between natural and human induced change (Dayton et al 2000, National Research Council 2001). Unlike conservation areas, RAs have the added potential to serve as sites for conducting controlled manipulations to observe how a natural system would respond to various stressors (e.g. anchoring, trap fishing, hook and line, or spear fishing). Typically, this type of MPA prohibits extractive or destructive activities that may interfere with those studies. As a result, extractive activities may be conducted only under permit for scientific or educational purposes (National Marine Protected Area Center 2005). As with other MPA's that limit use, the location of an RA must be sensitive to displacing current user groups. In addition,

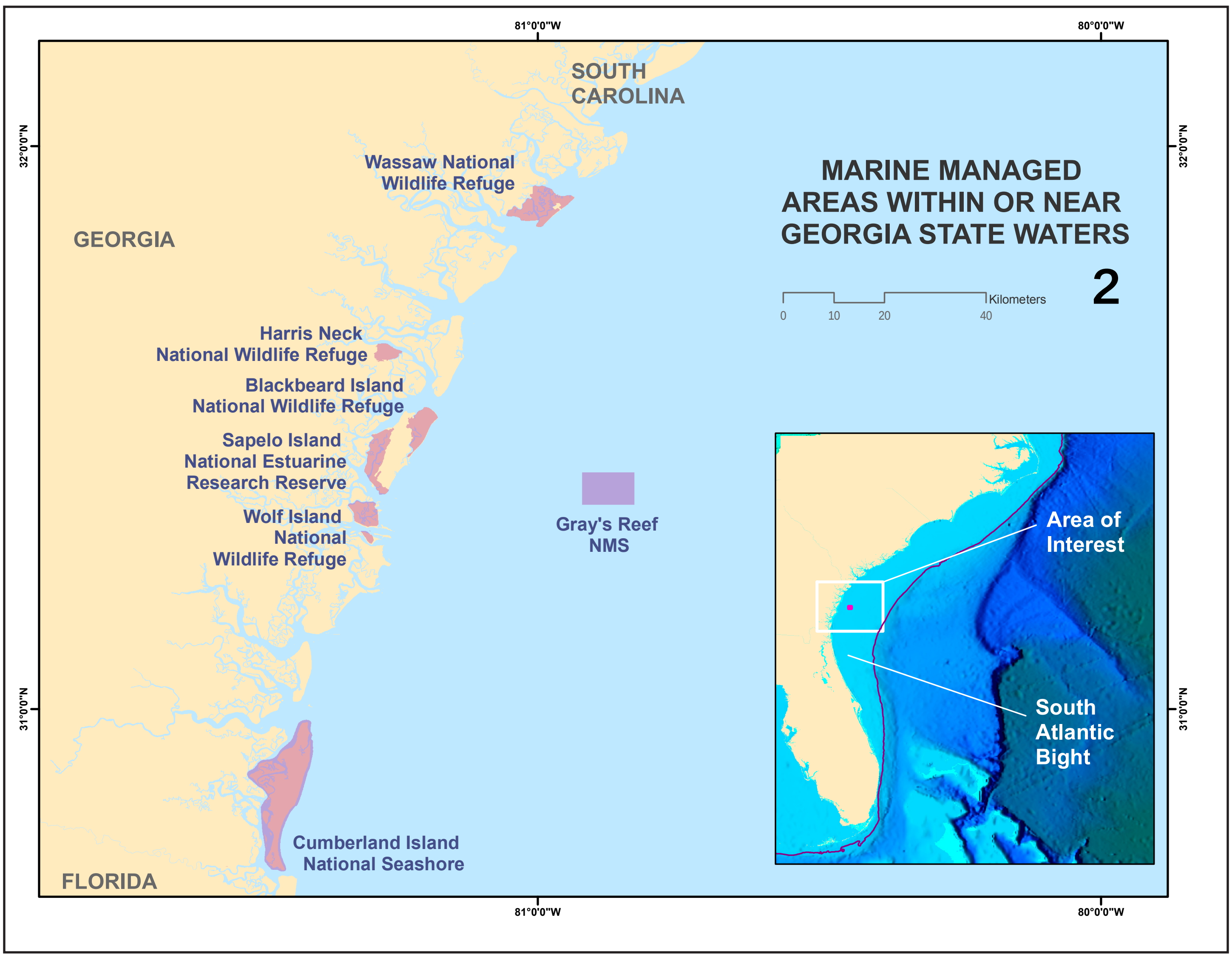


Figure 2. Marine managed areas (including National Estuarine Research Reserve System, National Park Service, National Wildlife Refuge and NMS sites) within or near Georgia state waters as classified by the MMA Inventory.

because long term monitoring and research are primary objectives, a site with a large preexisting body of research is often desirable. An RA is currently under consideration for placement within Gray's Reef National Marine Sanctuary (GRNMS) off the southeastern coast of the United States. Here, a quantitative approach to optimally site an RA within GRNMS given these issues is provided.

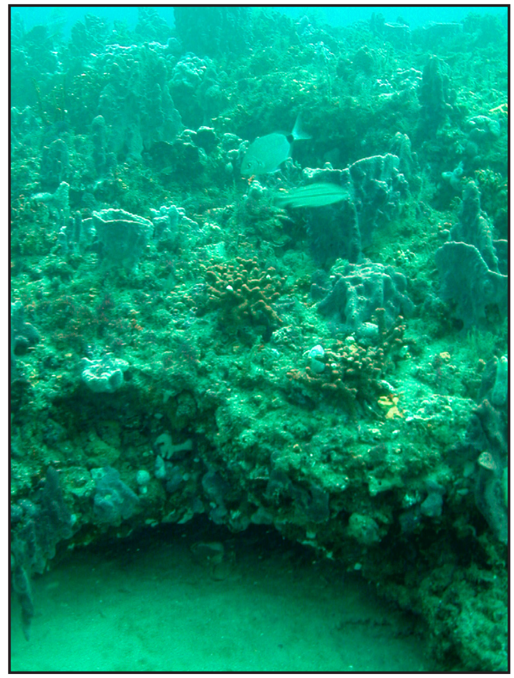


Image 2. Undercut limestone ledge at GRNMS that is densely colonized by sessile invertebrates and fish.

During the public comment phase of the 1999/2000 management plan review process at GRNMS it was requested that sanctuary staff consider designation of an RA within their boundaries. There are several reasons for GRNMS to focus on finding a potential location for such a zone. GRNMS is located within the South Atlantic Bight and at present there are no other federally protected ocean bottom habitats in that region nor have any areas been set aside for research. The six MPA's in Georgia that are intended, at least in part, for research are located on or near the sea islands well inshore (NOAA/DOI 2006) (Figure 2). GRNMS encompasses many key bottom types representative of the South Atlantic Bight's shelf region including flat and rippled sand, flat live bottom sparsely colonized by sessile invertebrates and fish, and high relief rock ledges densely populated with invertebrates and fish (Kenney 1993, Kendall et al 2005). The ledges are the focus of recreational diving and a popular sport fishery for grouper (*Mycteroperca* sp.), sea bass (*Centropristis* sp.), and in the pelagic waters above them, king mackerel (*Scomberomorus cavalla*). The designation document for the sanctuary lists one of its main purposes as promoting scientific understanding of the live bottom ecosystem (NOAA 1983). In addition, a 2003 MPA workshop to identify priority social science questions in marine waters between eastern Florida and Virginia indicated that understanding the influences of human uses, such as fishing, on natural resources is a primary information need for the region (National Marine Protected Area Center 2003). Designating an RA within GRNMS, located mid-shelf in the central part of the South Atlantic Bight, would provide a controlled location at which many key scientific questions, specifically how human activities impact resources, could not otherwise be answered.

To further study the possibility of implementing an RA at GRNMS, the Sanctuary Advisory Council established the Research Area Working Group (RAWG) in January 2004. The RAWG was composed of individuals from science, conservation, recreational and commercial fishing, management, law enforcement, education, and recreational diving (Appendix A). The RAWG used a consensus driven process to address two main issues; first, they identified key research questions and second, determined if an RA would be useful or necessary to address them. The RAWG concluded that there were several research topics that could only or could best be addressed through a research area (RAWG Matrix 2, Appendix B). Specifically, the effect of bottom fishing on bottom fish populations and sessile benthic invertebrates were identified as key research needs that could be addressed through an RA in which bottom fishing would be restricted (RAWG Matrix 4, Appendix C). The RAWG indicated that for such an area to be used to effectively study these issues, bottom fishing and use of any bottom impinging gears or techniques such as deep trolling would be allowed only under permit for scientific research issued by GRNMS. See Appendix C for further justification for considering an RA at GRNMS.

Having established the need for an RA, the RAWG next considered the criteria that should guide its placement within GRNMS. Given that some key research questions were to focus on the influence of bottom fishing on sanctuary resources, the RAWG determined that the RA should include a large amount of ledge habitat, the favored target of bottom fishermen due to its abundance of desirable fish species. Although the main bottom type needed to accomplish the most pressing research objectives is high relief or ledge bottom, the RAWG also indicated a need to include other bottom types such as sand and sparse live bottom. This would achieve full representation of other bottom types in the region, accommodate future studies on those bottom types, and serve to encompass sufficient linkages and interactions between ledges and surrounding habitats to represent a functional ecosystem (Appendix B-C, Sanctuary Advisory Council 2005). Besides including particular types of bottom features, the RAWG also was interested in including a large amount of prior research within the RA. A diversity of research has been conducted within GRNMS for many years which would serve as a valuable reference or baseline for future investigations within an RA. Lastly, because bottom fishing would be restricted within the RA, the RAWG wanted to place it in a location that would minimize the displacement of current fishermen. Placement of the RA with sensitivity to existing users would make regulatory compliance easier and is likely to gain broader public acceptance.

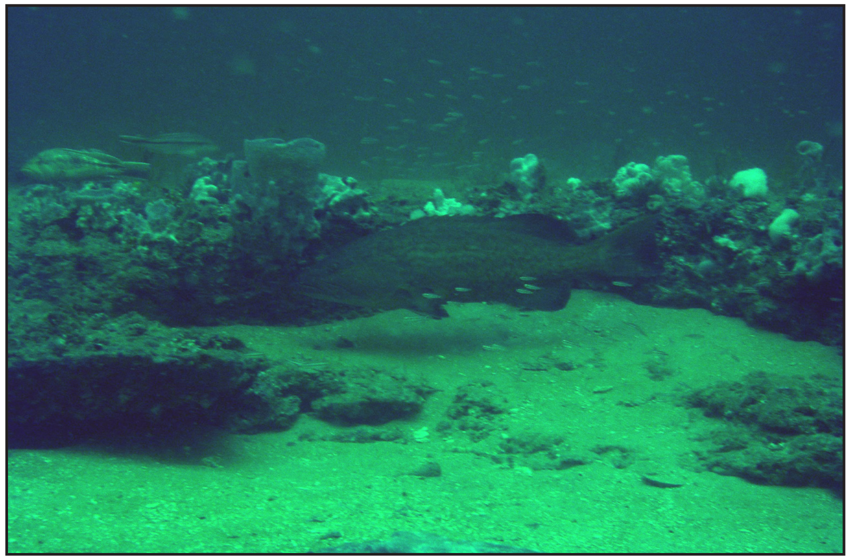


Image 3. Large gag grouper and other fish.

The RAWG also considered various options for the size and shape of the RA according to ease of enforcement, statistical power, and scientific usefulness (RAWG Matrix 5b, Appendix D). Size options ranged from 4 km^2 to 16 km^2. Although a small RA would ease enforcement and acceptance, the larger options would best meet statistical and scientific considerations. A larger RA would likely include more replicate ledges for study, have less area influenced by edge effects (in comparison to its size and smaller areas), and be more likely to include the home range of a greater diversity of bottom fish. However, a sufficient group of reference sites outside the RA, but still within GRNMS, may not be available if the RA is too large. Furthermore, restricting fishing throughout much of the sanctuary as a result of a large RA would also not be acceptable to the public. Different boundary shapes and orientations were considered including squares and rectangles rotated to varying degrees as well as hexagons. Squares or rectangles with edges parallel to latitude and longitude would be easiest to mark, enforce, and comply with; however, rotating such shapes to align with geologic patterns might more efficiently encompass desired bottom features.

Apart from these broad guidelines, quantitative criteria for defining characteristics of an acceptable RA, such as some minimum number or area of ledges to include, were not provided by the RAWG. This was due to a lack of understanding about the spatial distribution of bottom features, prior research, and preferred fishing locations and how these variables might overlay with the boundaries of the various size and shape options under consideration.

To meet this need, a geographic information system (GIS) was developed to systematically analyze the entire sanctuary and determine the optimal placement of an RA given the general characteristics and boundary shapes requested by the RAWG. All relevant bottom data, locations of prior research, and information that could be used to identify preferred fishing locations were incorportated. There are many software tools available to explore the spatial relationships between the target variables and RA boundary options (Pattison et al 2004), however, none met the particular needs of this study. A novel technique was therefore created in which successive RA options were characterized in the GIS using a moving window of the same dimensions as each boundary shape requested by the RAWG. This was chosen over other MPA selection tools because there were a limited number of size and shape options and only a single RA (rather than a network of sites) was needed within GRNMS.

A step-wise approach was used to select viable RA options (Roberts et al 2003a) to ensure that the position of the RA met scientific needs while being sensitive to but not compromised by socioeconomic or other pressures. Any region within GRNMS was considered as a possible RA. RA options were then eliminated that did not include the target bottom types. The RA options that encompassed the large amounts of prior research were then selected from among those options remaining. Finally, among the few RA options that remained a selection was made for those options that minimized displacement of bottom fishermen. In this way it was possible to sure that the RA included the right bottom types above all other considerations but also had adequate amounts of prior research and was sensitive to the displacement of users.

The goals of this analysis were to; 1) compile the datasets that can aid GRNMS staff and the RAWG in selecting a suitable site for the RA, 2) systematically analyze a range of RA boundary sizes and shapes throughout the entire sanctuary, quantifying the bottom types included, prior research, and fishing pressure within and outside of each option, 3) recommend a group of boundary options that all meet the criteria established by the RAWG, and 4) enable an informed approach by which the RAWG can select an RA.

METHODS

STUDY AREA

GRNMS is located 32 km off the coast of Georgia and has typical depths of ~20 m (Figure 2). The rectangular sanctuary is 6.5 km north to south by 9 km east to west and is comprised of 8% flat sand bottom, 67% rippled sand, 25% sparsely colonized live bottom, and <1.0% ledge based on 2001 sonar data (Kendall et al 2005) (Figure 3). Bottom types, prior research areas and fishing activities all have a non-random distribution in the sanctuary. Most sparse live bottom and ledges are located within the central/southern parts of the sanctuary.

INPUT DATA

A total of 25 variables from 11 datasets were identified for the RA selection process based on the general criteria provided by the RAWG. These included four categories of variables that quantified 1) the amount and diversity of ledge habitat, 2) the amount of all other bottom types, 3) the number of research sites, and 4) the amount of bottom fishing effort within the sanctuary. Table 1 lists the variables within these four categories. A description

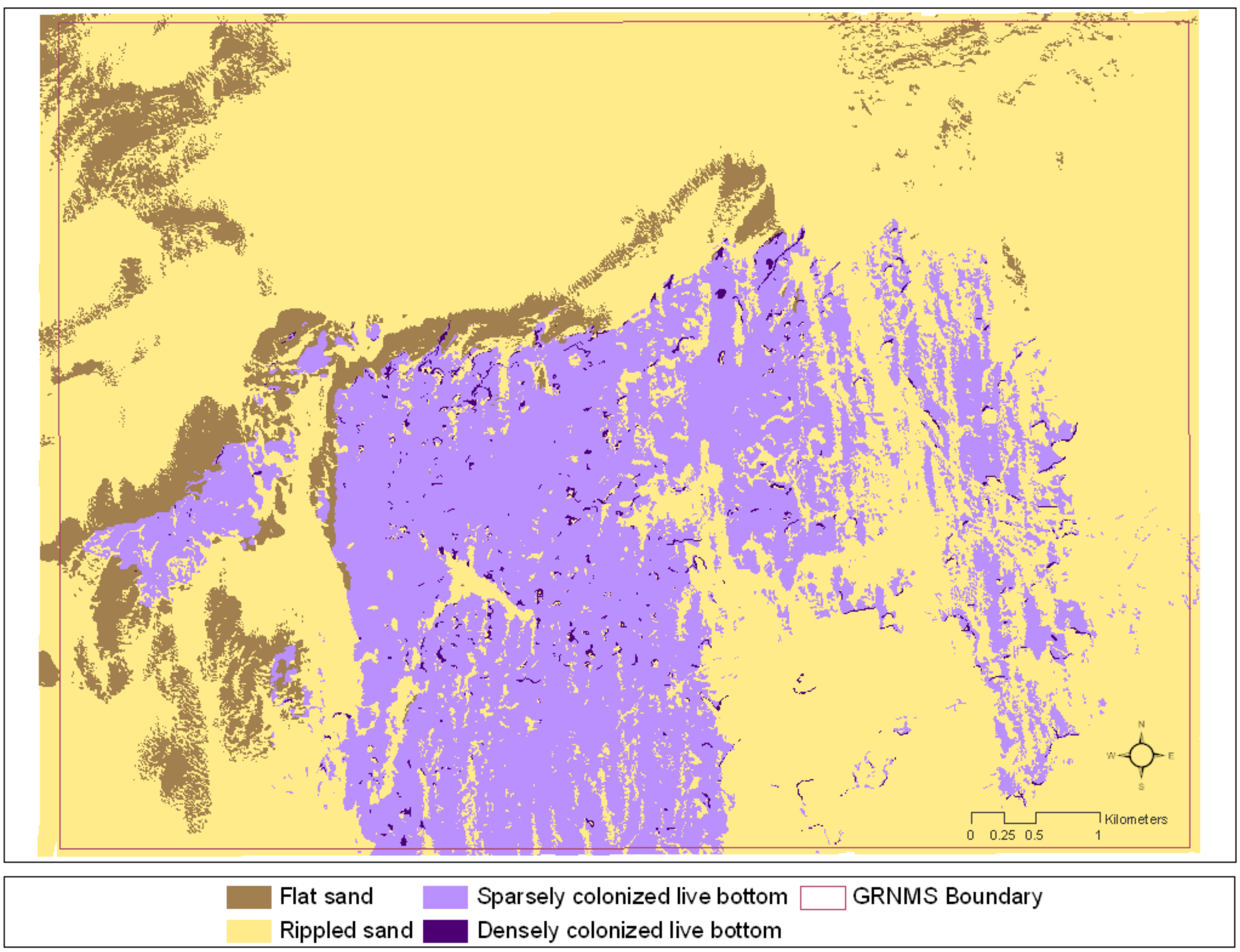


Figure 3. Spatial distribution of GRNMS bottom types classified by Kendall et al (2005).

Table 1. List of variables, a brief description, and sources for each data set.

Category	Name	Description	Source
Ledges	LEG_H_S	Number of short ledges	Modified Kendall et al 2005
(12 variables)	LEG_HSA	Total area of short ledges	Modified Kendall et al 2005
	LEG_H_M	Number of medium height ledges	Modified Kendall et al 2005
	LEG_HMA	Total area of medium height ledges	Modified Kendall et al 2005
	LEG_H_T	Number of tall ledges	Modified Kendall et al 2005
	LEG_HTA	Total area of tall ledges	Modified Kendall et al 2005
	LEG_S_S	Number of small ledges	Modified Kendall et al 2005
	LEG_SSA	Total area of small ledges	Modified Kendall et al 2005
	LEG_S_M	Number of medium size ledges	Modified Kendall et al 2005
	LEG_SMA	Total area of medium size ledges	Modified Kendall et al 2005
	LEG_S_L	Number of large ledges	Modified Kendall et al 2005
	LEG_SLA	Total area of large ledges	Modified Kendall et al 2005
Other Bottom Types	OBT_SCB	Total area of sparsely colonized live bottom	Kendall et al 2005
(3 variables)	OBT_FS	Total area of flat sand	Kendall et al 2005
	OBT_RS	Total area of rippled sand	Kendall et al 2005
Research	RES_ROV	Total bottom time of roving surveys	REEF
(8 variables)	RES_STA	Number of point surveys	REEF
	RES_TAG	Number of tagging sites	MARMAP
	RES_TRP	Number of trap sites	MARMAP
	RES_SED	Number of sediment/contaminant sites	NOAA/CCHBR
	RES_LTR	Number of Long Term Research sites (0 or 1)	NOAA/GRNMS
	RES_TRA	Number of transect surveys	NOAA/Biogeography Team
	RES_BEN	Number of benthic/debris surveys	NOAA/Biogeography Team
Fishing	FIS_BOT	Number of stationary boats	various sources
(2 variables)	FIS_GER	Total gear pieces ÷ number of surveys	NOAA/Biogeography Team

of the variables, their data sources, their relevance to the desired characteristics of an RA as identified by the RAWG, and any processing steps needed to prepare them for analysis are described in subsequent sections. Following the description of processing steps are methods for extracting the data and comparing the suitability of different RA boundary options.

Ledges

The RAWG and Sanctuary Advisory Council indicated that the single most important consideration in selecting an area for the RA was the inclusion of a large number and diversity of ledge types (Sanctuary Advisory Council 2005). The best bottom maps of the sanctuary (Kendall et al 2005) only denote ledges within a single category, even though some are only a few centimeters tall and others are >2 m meters in height. Similarly, some ledges are only a few tens of meters long and cover a small area, but others extend for hundreds of meters. To differentiate among ledges with different height and area characteristics and meet the needs of the RAWG, ledges in the Kendall et al (2005) map were further categorized by height (short, medium, and tall) and by area (small, medium and large).

Using ArcGIS software, ledge polygons were extracted from other bottom types. Ledge height was determined for each polygon through the use of a 2 meter bathymetry grid of the sanctuary. First, all depth values from the bathymetry grid around each polygon were extracted from the bathymetry data. The deepest and shallowest values were subtracted to determine the maximum depth change or height for each ledge. Field work indicated that this was an accurate representation of ledge height since ledges are typically uniform in height for much of their length. Ledges were then categorized as short, medium, or tall by rank-ordering their heights and assigning one-third of the ledges to each category. Area of each ledge was also calculated in ArcGIS and used to categorize ledges as small, medium, or large, again by assigning one-third of the ledges to each category. This allowed us to examine the diversity of ledges based on height and area.

Other bottom types
In addition to maximizing the number and diversity of ledges within an RA, the RAWG indicated that the full complement of other bottom types in the sanctuary should be represented. To meet this need, the total areas of the three other benthic types from the Kendall et al (2005) map, which include sparsely colonized live bottom, flat sand, and rippled sand, were also included in the analysis. These habitat polygons were extracted from the benthic map of the sanctuary into a new shapefile that did not include the ledge polygons.

Prior research sites
Once the bottom type criteria for an RA were met, the RAWG next hoped to identify a location that would also include a significant amount of prior research. Scientific research had taken place within the area prior to the site becoming a National Marine Sanctuary in 1981. In the 1960's the area was studied by biologist Milton B. Gray, after whom the sanctuary was named. More recently, numerous efforts have taken place not only within the sanctuary, but throughout the South Atlantic Bight.

The first step in this part of the selection process was to identify all locations of prior research within GRNMS. Those locations that contributed significantly to understanding the baseline conditions of sanctuary resources were identified and primarily included research that was either long in duration, included many replicates, or was widespread within the sanctuary (Figure 4).

With the exception of the single GRNMS Long Term Monitoring Site (GRNMS 2006), research that was only conducted a few times or at a few sites within the sanctuary was excluded. For example, although it is a source of previous research in the sanctuary, the sites from a 2004 research cruise at GRNMS investigating fish sampling gears were not included in the analysis. This is due to the low number of sites (ranging from 3-32) at which any one gear type was used. Such a low number of sites,

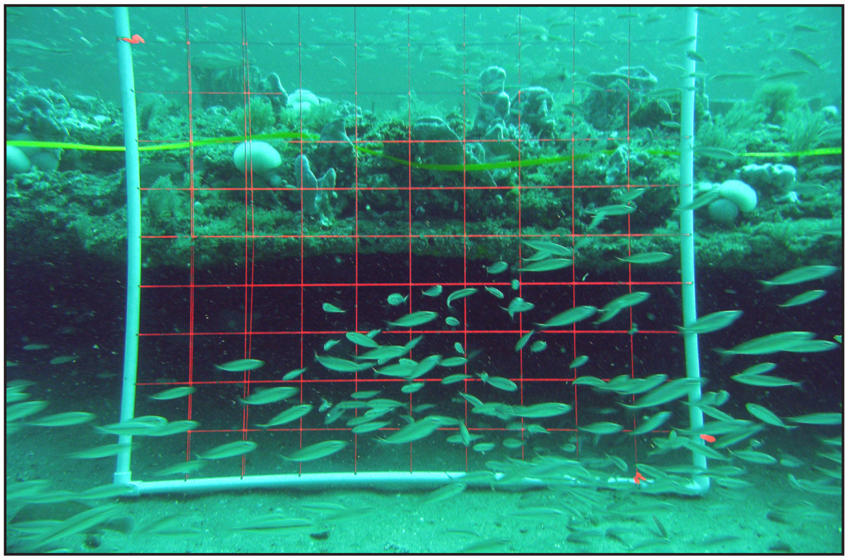


Image 4. Example of a large ledge. A 1x1 m quadrat shown for scale.

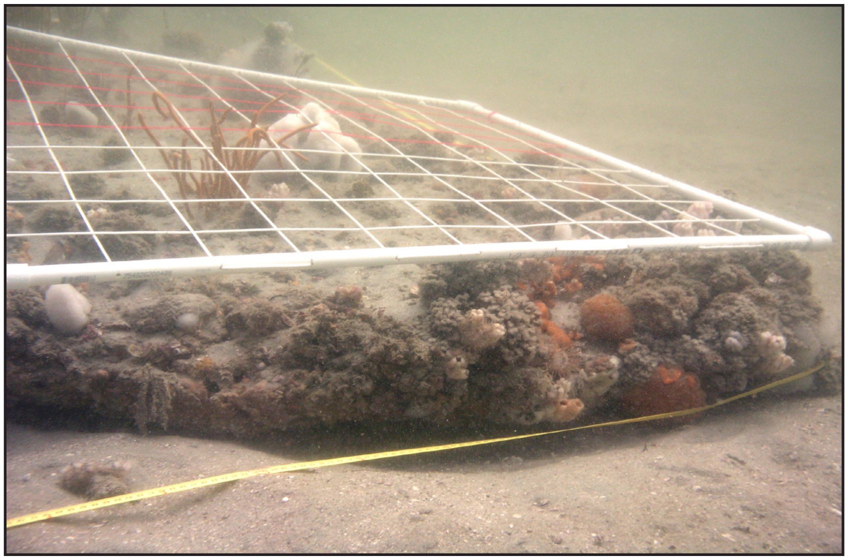


Image 5. Example of a small ledge. A 1x1 m quadrat shown for scale.

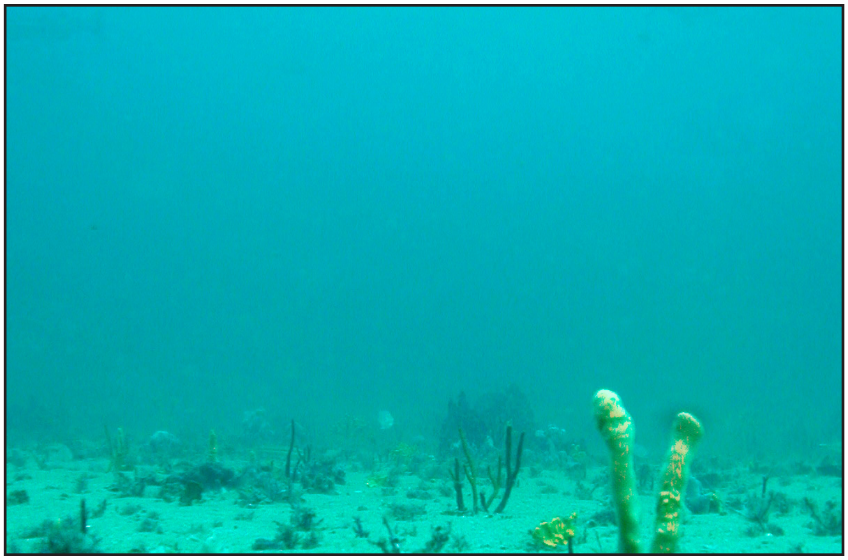


Image 6. Typical sparsely colonized, flat live bottom at GRNMS.

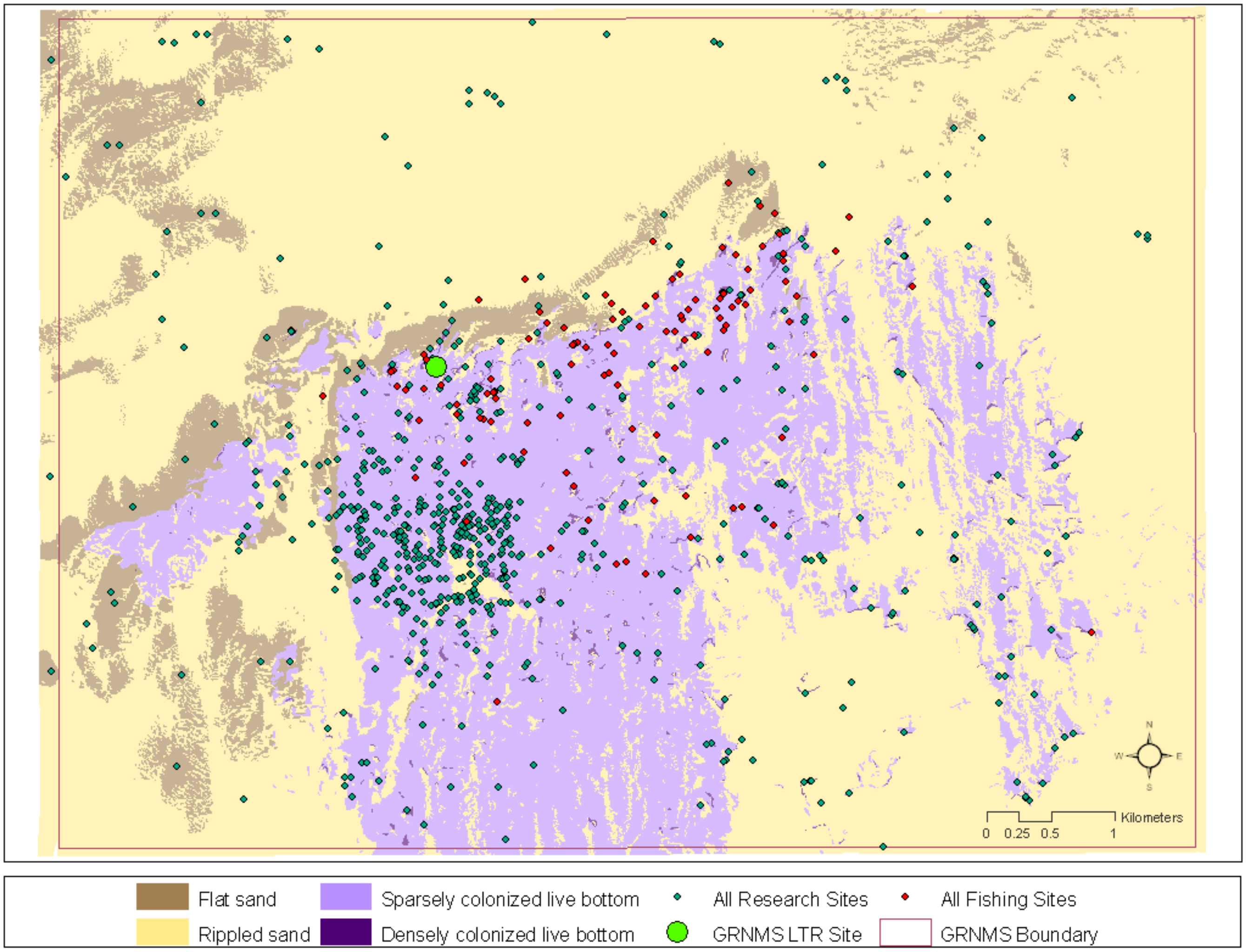


Figure 4. Spatial distribution of category variables used in the analysis.

while suitable for the comparisons intended, do not constitute a large enough body of research to serve as a significant reference dataset, which is the goal of this component of the analysis. A description of each type of prior research included is provided in subsequent sections. The dates range from 1993 to present and include 8 variables, representing a diversity of studies.

The first research site included in the analysis was the GRNMS Long Term Research Site. This site was established in 1995 as an on-going monitoring site for fish populations, benthic invertebrates, oceanographic conditions, sediment transport, and visitor use (GRNMS 2006). A wide variety of yearly ongoing assessments and experiments are conducted at this site, making it important for inclusion in the present analysis despite the fact that it is only a single location. The latitude/longitude of the site was obtained from GRNMS and converted to a point shapefile in ArcGIS.

Five large datasets were identified that assessed fish communities in different ways. Three were based on different types of visual surveys that provide different information about the fish community, two were based on fish traps. One of the visual surveys, completed by the Reef Environmental Education Foundation (REEF), began in 1998 and is ongoing. These timed, roving surveys use volunteer, recreational scuba divers to identify and count fish species and model relative abundance of fish. The locations and bottom time data for the roving survey points were provided by REEF. These survey times were combined according to point location (see Bohnsack and Bannerot 1986 for methods), as several survey points were in the same location, but on different dates (total survey hours = 171). REEF also provided the locations of their stationary fish surveys conducted in 2004 and 2005. The total number of surveys (n=512) were summed for each site. Transect surveys have also been used at

GRNMS to assess the fish community. The NOAA/Biogeography Team used this visual technique in 2004 and 2005 to identify, estimate size, biomass, and abundance of bottom fish (n=177). Fish traps have provided another type of assessment of bottom fish within the sanctuary. The Marine Resources, Assessment, Monitoring, and Prediction (MARMAP) program has been sampling bottom fish since 1993 using baited traps (n=154). In addition, MARMAP has trapped, tagged, and released fish at many locations within the sanctuary as part of a mark recapture study focused on black sea bass, *Centropristis striata* (n=302 sites). The locations of these five activities were obtained from these organizations and converted to point shapefiles in ArcGIS representing the time of roving surveys, number of stationary surveys, number of transect surveys, trap sites, and mark/recapture sites respectively.

Image 7. Tagged black sea bass at GRNMS.

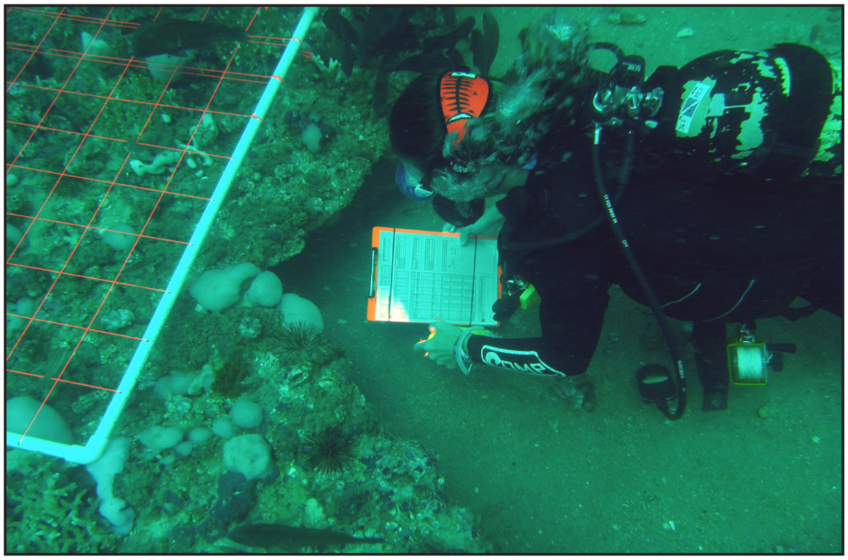


Image 8. Diver collecting data on benthic cover.

Also identified were two datasets that evaluated different aspects of the benthos. A compilation of the research locations visited by the NOAA Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) includes sites from 2000 through 2005 (n=81). A variety of research activities were conducted with a focus on assessing macroinfaunal and sediment/contaminant distributions (Hyland et al 2001, Hyland et al 2006). Another large dataset that focused research on benthic characterization throughout the sanctuary was collected by the NOAA Biogeography Team. The Biogeography Team evaluated type and cover of sessile invertebrates, measured ledge, sand, and sparse live bottom features, and quantified marine debris (n=177). The marine debris data were used further as described in greater detail below. The locations of these two datasets were obtained from these organizations and converted into two point shapefiles respectively.

Fishing effort

Once bottom type and research history goals were met, the RAWG wanted to be sure that RA options minimized impacts to the public. An understanding of the spatial distribution of fishing activity within the sanctuary was essential to identifying potential locations for the RA that minimize displacement of this primary user group. Specifically, since use of bottom impinging fishing gear would be prohibited within the RA, the preferred fishing locations of bottom fishermen should be avoided as potential RA sites.

To determine the spatial distribution of bottom fishing activities two types of information were used, boat counts and the distribution of fishing gear left on the bottom. The boat count data was compiled from multiple sources including national reconnaissance systems. Boat counts within the sanctuary were conducted during daylight hours on 129 dates from September 1998 to October 2004. Counts ranged from 4 to 16 counts in each month (totaled by month for all five years, average 10.75), and were primarily conducted on weekends. Boats were scored as either moving with a wake present or stationary (i.e. drifting with no wake present). Positional accuracy of the data are within 26 m (90% circular error probability; i.e. 90% of the estimated positions are believed to be within 26 m of their true position). These data include all boats, those targeting bottom fish and those likely to be trolling or drift fishing for pelagics, primarily king mackerel, *Scomberomorus cavalla* (Cuvier). A total of 885 boat sightings were made.

It is possible that bottom fishermen will be distributed differently than those targeting pelagics within the sanctuary. To isolate only those boat sightings that were targeting bottom fish, all observations that were likely to be targeting other species or were obviously not actively fishing were eliminated. First, all records from the months of May through October were eliminated since that time of year *S.cavalla* and the fishermen targeting them are most likely to be present in the sanctuary (Trent et al 1987, Sutter et al 1991). Eliminating these months leaves bottom fishing as the main activity for boaters in the sanctuary during the remainder of the year. Next, all records of moving boats were eliminated to prevent boats merely in transit rather than fishing from confounding the analysis. What remained were 87 records of stationary boats observed between the months of November through April (Figure 4). It is recognized that these boats were not necessarily fishing at all times and may have been engaged in another activity such as catching bait (as is commonly done at the data buoy located at 31.40° N, 80.87° W) or diving (although divers also target the same types of ledges as bottom fishermen). Given these acceptably small sources of remaining bias, the boat count data that remain are believed to be a good representation of the spatial distribution of bottom fishing activities in the sanctuary.

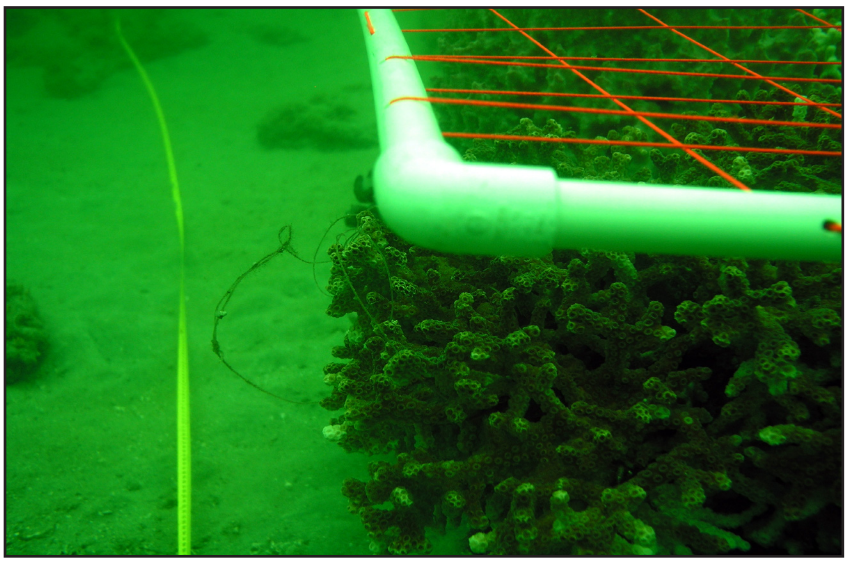


Image 9. Fishing line snagged on coral.

To further identify the spatial distribution of preferred fishing locations, a recently completed survey of marine debris by the NOAA Biogeography Team, quantifying the amount of fishing gear snagged on the bottom, was also analyzed in the context of each of the RA options. The assumption behind using this data to identify fishing patterns is that locations with larger amounts of fishing gear snagged on the bottom receive higher fishing pressure than those with less. Again, locations with more gear are presumed to be the preferred fishing locations within the sanctuary and should be avoided as RA's to minimize displacement of fishermen.

In the marine debris survey, 177 sites were assessed within GRNMS using scuba. A random stratified sampling design was used with bottom type as the strata. The four bottom types, defined and mapped by Kendall et al (2005), were unequally sampled with an emphasis on ledge areas. Specifically, flat sand (18 sites), rippled sand (16), sparse live bottom (42), and ledge/dense live bottom (101) were surveyed. At each site, divers counted and identified all marine debris along a 25 by 4 m transect. A total of 93 pieces of man-made debris were counted and separated into two categories, fishing gear (n=63) and other (30). Only the fishing gear was used in these analyses since they represent direct evidence of fishing activities. Gear included fishing line, leaders, lures, weights, spear gun parts, and other objects associated with fishing (Figure 4). Locations for the boat counts and the marine debris survey were converted into two point shapefiles respectively.

BOUNDARY SHAPES

Due to the relatively small size of the sanctuary, the RAWG recommended considering placement of a single RA. The variety of size, shape, and orientation options for the RA boundary was limited by the RAWG to the 18 given in Table 2. Sizes included 4 km^2, 6 km^2, 9 km^2, and 16 km^2. Shapes included squares, rectangles, and hexagons. Orientations for square and rectangle options included those with edges parallel to latitude/longitude, rotated 45°, and rotated 30° counter clockwise. Smaller or larger options than these were deemed too small to be useful and too large to be publicly acceptable respectively (RAWG Matrix 5b, Appendix D). Squares and rectangles are considered good RA shapes because they can be marked with a minimum of four corner buoys. Squares are preferred since they have a large core area. Hexagons were considered because they nearly approximate a circle and maximize core area among all of the options used in the analysis. Other shape options were discussed but were dismissed as lacking adequate core area or as too difficult for marking, enforcement or compliance purposes. The 30° rotated shapes were considered because they appeared to align well with the local geology and distribution of ledges; this may more optimally encompass the target resources. Similarly, the 45° rotated shapes were considered to determine if they more efficiently encompassed the target characteristics.

The various size, shape, and rotation options were created in ArcGIS. The squares and rectangles were generated by selecting and merging appropriate groups of cells from a 1 km^2 grid. The rotated squares and rectangles were created by copying the original square and rectangle polygons and rotating them 45° or 30° counterclockwise. The hexagons were created using the "Sampling Tools" extension of ArcView.

EXTRACTING DATA FROM EACH OPTION

Because a single RA with a limited number of size and shape options was under consideration, a "sliding window" approach were used to systematically analyze the space within GRNMS and determine where viable RA options could be positioned and what boundary shapes and sizes best encompassed them. In the sliding window approach, a given shape option, a 4x4 km square for example, is first positioned entirely within a corner of the sanctuary (Figure 5). The variables of interest that are encompassed within the square are retained in the first row in an RA options table. Variables of interest (column headers of the options table) reflect the criteria identified by the RAWG such as number of each type of ledge, area of the different bottom types, number of prior research sites of each type, and number of fishing boats. The analysis window is then "slid" a short distance to one side and the variables of interest within the new position of

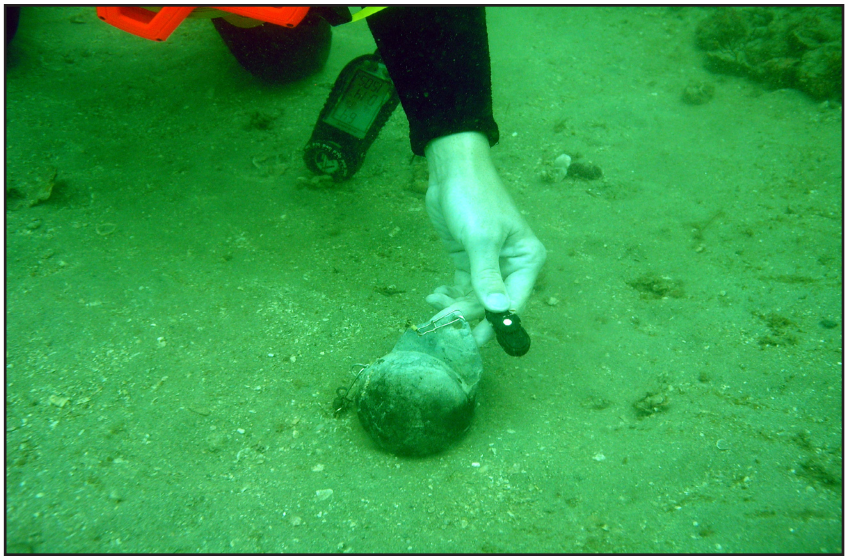


Image 10. Large weight used for fishing.

Table 2. Boundary shapes requested by the RAWG and the corresponding number of placement options within the sanctuary.

Shape	Size (km)	Number of RA options
Square – sides parallel to lat/long	2×2	3060
	3×3	2030
	4×4	1200
Square – rotated 30° (counter clockwise)	2×2	2257
	3×3	1149
	4×4	340
Square – rotated 45°	2×2	2160
	3×3	1012
	4×4	256
Rectangle – sides parallel to lat/long	2×3	2380
	3×2	2610
Rectangle – rotated 30°	2×3	1624
	3×2	1666
Rectangle – rotated 45°	2×3	1537
	3×2	1537
Hexagon	4 km^2	2680
	6 km^2	2108
	9 km^2	1529

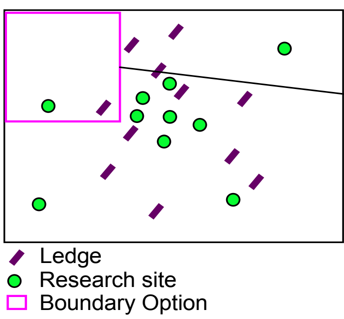
the square are recorded as the second row in the options table. The 4x4 square window is slid the same short distance again and again with the values of target variables being recorded as new RA options each time the window pauses at a new position. The process is continued until the entire sanctuary has been evaluated using the 4x4 square. Each shape and size option went through the same sliding window process and had values added to the RA options table. Only options completely within the sanctuary were considered.

What was the optimal distance to slide the analysis window between consecutive boundary options? To help guide this decision, ledges, the most important variable according to the RAWG were considered in greater depth. Sliding the analysis window too short of a distance would result in no change between consecutive boundary options if no new ledges were encompassed. This would result in an unnecessarily large number of potential RA boundary alternatives, many of which would be virtually identical. Sliding the analysis window too long of a distance between boundary options risks skipping past potentially good RA sites by including multiple changes in the ledges encompassed. Therefore, the distance to slide the window should be just far enough to incorporate roughly one change in ledge inclusion between successive stops of the analysis window. Each time a new ledge is included, a new and viable boundary alternative would be captured.

To define the optimal distance to slide the analysis window between consecutive boundary options, the assumption was used that successive options should each include an entire new ledge rather than merely a small fraction of a new ledge. This is appropriate given that whole, individual ledges will likely serve as the typical experimental units of the RA. The spatial dimensions of the ledges and distances between them were then examined to guide this decision.

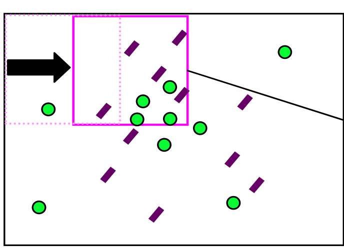
First, the total north to south (y) and east to west (x) dimensions of each ledge were determined since these were the axes that the analysis window would be sliding along. Histograms showed that a majority of ledges are less

Start the window in northwest corner of the sanctuary, this is option 1.



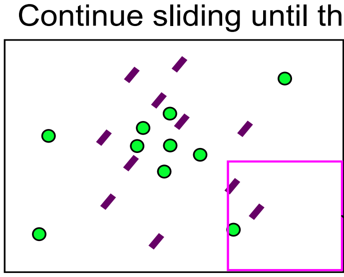
Option	# Ledges Inside	# Research Sites Inside	# Ledges Outside	# Research Sites Outside
1	1	1	9	9
2				
.				
.				
n				

Slide the window east to encompass a new set of variables, this is option 2.



Option	# Ledges Inside	# Research Sites Inside	# Ledges Outside	# Research Sites Outside
1	1	1	9	9
2	5	4	5	6
.				
.				
n				

Continue sliding until the entire sanctuary has been assessed, this is option N.



Option	# Ledges Inside	# Research Sites Inside	# Ledges Outside	# Research Sites Outside
1	1	1	9	9
2	5	4	5	6
.				
.				
n	2	1	8	9

Figure 5. Conceptual diagram of the sliding window approach.

than 100 m long in both dimensions. Next, the nearest neighbor distance between the centers of the ledges were also calculated and summarized in a histogram. The majority of ledges were between 25 and 175 m from their nearest neighbor (center to center). This and the typical dimensions of ledges indicated that sliding the analysis window 100 m between consecutive steps would be sufficient to capture whole new ledges without skipping over too many ledge options.

To automate the process of analyzing the relationship between the boundary options and the preferred siting criteria, a Visual Basic application within an ArcGIS project file was developed. The project file included all of the bottom types, prior research, and fishing effort data described previously as well as the 18 boundary shapes (Table 2). The analysis was run on each of the boundary shapes separately. Beginning with each boundary shape placed within the northwest corner of the sanctuary, the application created a new shapefile to contain the boundary shape copied at 100 m intervals in the x and y dimensions throughout the sanctuary. The initial placement was considered the first boundary option. The application then created a copy of the boundary shape and saved it 100 m to the east of the starting point. This was considered the second boundary option. The boundary shape was then recopied and shifted another 100 m east repeatedly until the shape fell partially outside the eastern edge of the sanctuary. The next copied shape was saved 100 m south from the first boundary option at the western edge of the sanctuary and the process was begun again. This was continued until each boundary shape was recopied and slid 100 m at a time in both the x and y directions within the entire sanctuary. This resulted in a comprehensive set of potential boundary options within the sanctuary for each shape (Table 2).

For each of the variables of interest listed in Table 1, the features falling within each successive boundary option were calculated and stored in the options table. These results were also subtracted from the total value of those variables throughout the entire sanctuary and then stored in the attribute table to provide information about the variables of interest falling outside each boundary option. For the bottom type dataset, another set of calculations was necessary. The modified benthic map was extracted or "clipped", using each boundary option, and the areas of the newly clipped polygons were calculated. The number and area of ledges of each size and height category (section x) that fell within and outside of each boundary option were calculated respectively. The total area of each of the other three bottom types that fell within and outside of each boundary option respectively were calculated as well and then saved in the attribute table in ArcGIS. To identify the relative intensity of fishing activities within each of the RA options, the total number of gear pieces was divided by the total number of surveys within each RA option. This yielded a gear per survey value for each RA option with higher values indicative of greater fishing activity.

COMPARING OPTIONS

The output from the sliding window process provided a wealth of information on all of the boundary options. There were a total of 50 variables described for each option. This included 25 variables that described the ledge, other bottom types, prior research, and fishing effort inside each option and 25 variables that described the same components only in the space outside each option (Table 1). All RA options without at least the full diversity of ledge types inside the boundary option were eliminated. Those were not viable options for the RA given the selection criteria of the RAWG and were therefore removed prior to the next stage of analysis to reduce the number of options.

Sliding the analysis window a small fraction of the total window size (e.g. 100 m for a 3×3 km boundary) allowed a thorough dissection of boundary options within the sanctuary but also had some other consequences. Successive options were very similar. This resulted in a gradient of values between options rather than clearly separated groups. This precluded the use of traditional statistical techniques that rely on independence of samples to identify differences between options. Instead a categorization approach was used to group options along somewhat arbitrary breakpoints. These breakpoints provided an understanding of the relative effectiveness of each option and the range of values for each variable.

SCORING DATA FROM EACH RA OPTION

For each variable, the values from all the RA options were pooled to begin the process of identifying the best locations for an RA. First, the minimum and maximum value of each variable was identified for all options combined (all shapes, sizes, and orientations) (Table 3). Because the RAWG could not predict the experimental design, minimum sample size of ledges, and specific cut-offs of the many variables in the analysis, a more informative approach was chosen to best guide site selection.

The resulting ranges for each variable were split into five classes based on the minimum and maximum values. For example, the range of values for all boundary options for the tall ledges inside the RA (LEG_H_T_I) was from 1 to 102. This means that in every option, there was at least one tall ledge and no more than 102 ledges. When split into 5 categories or 20% increments, the five classes are defined as approximately 1-20, 21-40, 41-60, 61-80, and 81-102. Depending on each boundary option's specific number of tall ledges it was assigned a score from 1 to 5: where the lowest range of 1-20 received a score of 1, the next range of 21-40 received a score of 2 and so on through the range of 81-102, which received a score of 5. A low value denotes an option with few tall ledges and therefore a less favorable site. In contrast, a value of 5 indicates that the boundary option was in the top 20th percentile relative to the range of tall ledge values. The distribution of cutoff values and scores for each variable are provided in histogram format in Appendix E. The range of values was separated into 5 classes to provide some distinction within the range of potential values for each variable and better inform the RAWG on possibilities for the RA.

Table 3. Minimum and maximum values for variables across all boundary options. The "I" or "O" following each variable denotes Inside versus Outside boundary options.

Variable	Min Value	Max Value		Variable	Min Value	Max Value
LEG_H_S_I	1	120		OBT_SCB_O	3766123	14840878
LEG_H_S_O	26	146		OBT_FS_I	0	2546084
LEG_HSA_I	1	38447		OBT_FS_O	2049711	4595795
LEG_HSA_O	8552	46998		OBT_RS_I	0	9998752
LEG_H_M_I	1	110		OBT_RS_O	30012390	40011142
LEG_H_M_O	37	145		RES_ROV_I	0	9532
LEG_HMA_I	12	70374		RES_ROV_O	711	10243
LEG_HMA_O	24077	94439		RES_STA_I	0	382
LEG_H_T_I	1	102		RES_STA_O	130	512
LEG_H_T_O	50	145		RES_TAG_I	0	302
LEG_HTA_I	39	156429		RES_TAG_O	0	302
LEG_HTA_O	61604	217994		RES_TRP_I	0	132
LEG_S_S_I	1	121		RES_TRP_O	22	154
LEG_S_S_O	26	146		RES_SED_I	0	32
LEG_SSA_I	110	24084		RES_SED_O	80	112
LEG_SSA_O	5148	29122		RES_LTR_I	0	1
LEG_S_M_I	1	112		RES_LTR_O	0	1
LEG_S_M_O	35	145		RES_TRA_I	1	109
LEG_SMA_I	15	54850		RES_TRA_O	68	176
LEG_SMA_O	16156	70991		RES_BEN_I	1	109
LEG_S_L_I	1	102		RES_BEN_O	68	176
LEG_S_L_O	47	145		FIS_BOT_I	0	86
LEG_SLA_I	84	189056		FIS_BOT_O	1	87
LEG_SLA_O	70190	259162		FIS_GER_I	0	4.83
OBT_SCB_I	9179	11083934		FIS_GER_O	0	0.50

Since all of the options with a value of zero in the ledge category were eliminated prior to this step, there were no zero scores assigned for that variable. However, there were options without any values in the other bottom types, prior research, and fishing effort categories which were equal to zero. In these cases, a value of zero receives a score of zero rather than 1. For example, because there is only one long term research site, a large number of boundary options had a value of zero for this variable inside the RA.

Once scores were assigned to each option for each individual variable, the 0-5 values were averaged by variable category (ledge, other bottom type, prior research, or fishing effort as in Table 1) with inside and outside scores still kept separately. For example, the category score in the other bottom type category is the sum of the scores for colonized live bottom area, flat sand area, and rippled sand area of a given boundary option divided by three. This value was then rounded up to the nearest whole number value of 0 through 5. Hereafter this will be called a “category score”. The resulting category score for other bottom types for any single boundary option will then only be a single digit on the scale of 1 to 5, with 1 indicating the worst options and 5 being the best. The fishing effort category was the only variable category considered a bit differently. It was the only category where it was possible to have a score of 0 where there were absolutely no occurrences of fishing effort within an option. Additionally, having a large number of fishing occurrences outside, rather than inside, a given boundary option was better according to the siting criteria. Therefore, the category scores of 0 and 1 inside the boundary indicate the best sites due to fewer boats and less occurrence of fishing gear, whereas a score of 5 indicates the worst options as a potentially favored fishing area. The outside fishing effort category score follows the scale of the other categories where the greater number of fishing occurrences outside of the RA are the better options.

EFFECT OF ROTATION

To evaluate the influence of rotating the boundary shapes ledge category scores among the different degrees of rotation were compared. Only ledge category scores were considered because the rotation was done to explore the alignment of boundary rotations relative to local geology and its influence on ledge distribution. The analysis was separated into 5 boundary shapes; 2×2 km, 3×2 km, 2×3 km, 3×3 km, and 4×4 km. Hexagons were not considered. Due to their roughly circular shape, rotation would presumably have little effect. For this analysis, boundary options that shared a common centroid (center point) were compared. First the boundary options were separated into the 5 shapes under consideration. The center points for each boundary option were plotted next. Those options that did not have all three rotation conditions sharing a common centroid were eliminated, including: unrotated (edges parallel to latitude/longitude), 45°, and 30° counter clockwise rotation. For each centroid the ledge category score for the option rotated 30° was subtracted from the category score of the unrotated option. The difference in category scores for these rotations at each centroid could then be plotted. A zero indicated no change in category score as a result of rotation. A positive value indicated a higher category score when the 30° rotation was used relative to unrotated options. A negative value indicated a lower category score. The same procedure was conducted to compare the 45° and unrotated options and 30° and 45° rotated options for each shape size.

EFFECT OF BOUNDARY SIZE

To evaluate the influence of boundary area, category scores among the different option sizes were compared. For this comparison all options (including hexagons) were included and pooled by area; whether they were based on scores inside or outside the option boundary. Pie charts (Figures 10a and 10b) summarized each size and category combination according to the proportion with options of each category score.

STEP-WISE ELIMINATION

The category scores formed the basis of the step-wise elimination process to choose the best boundary options according to the criteria established by the RAWG. First, only the category score for ledges inside the boundary options were considered since this was the most important variable category according to the RAWG. Above all else, the RAWG wanted to ensure that the RA included large amounts of the key bottom type of interest. Based on the category scores and their corresponding number of ledges within each boundary option, the RAWG can identify an appropriate cutoff. For example, if only boundary options with the very highest number and area of ledges are deemed suitable, a category score of five would be chosen and all other boundary options would be eliminated in subsequent selection steps. In contrast, if a lesser number and area of ledges were acceptable, values of 4 (and 5) might be retained. Next, the other bottom type category can be examined within those boundary options remaining after the selection based on ledges has occurred. The desired scores for other bottom types were selected similarly, further narrowing the field of options. This continues for inside boundary values for the prior research category, then the fishing effort category, and iteratively in the same order through the outside categories until a more manageable and meaningful number of boundary options remains.

EXAMPLES

The level of selectivity or “pickiness” in category scores used in the step-wise process dictates the number of options left once all categories are considered. Potential results are demonstrated through three examples: a highly selective, moderately selective, and least selective scenario and their corresponding values for each variable.

RESULTS

A total of 31,135 RA options were examined within the sanctuary boundary. Options without at least one of the complete diversity of ledge types were eliminated. The remaining 30,307 options were the basis for the scoring analysis (Figure 6).

HISTOGRAM DISTRIBUTIONS

The histograms showing the distributions of RA option values for each variable generally follow a consistent pattern (Appendix E). The histograms for RES_TRA_I and RES_TRA_O, the number of NOAA Biogeography Team transect sites inside and outside each option, exemplify this pattern (Figure 7). Histograms for variables inside the RA options typically had lower values relative to those outside. This follows logically since all the option sizes were a small fraction of the total sanctuary area. In addition to generally having lower values, histograms for variables inside the RA options were skewed toward the lower end of their range of values, whereas outside options were skewed toward higher values.

A few of the histograms differed from this typical pattern of variables inside the RA options to have a skewed histogram distribution to the inverse of those outside the RA options. Those histograms with distributions that had irregular patterns were the long term research site, the roving fish survey sites, and the fish tagging sites. Since there was only one long term research site within GRNMS, each of the options had the site either inside or outside, making the count for each variable either zero or one (RES_LTR_I and RES_LTR_O respectively; Figure 8). The roving survey sites had a large spike in the upper and lower ends of the histograms for inside and outside options (RES_ROV_I and RES_ROV_O respectively; Figure 8). This was due to a large number of surveys

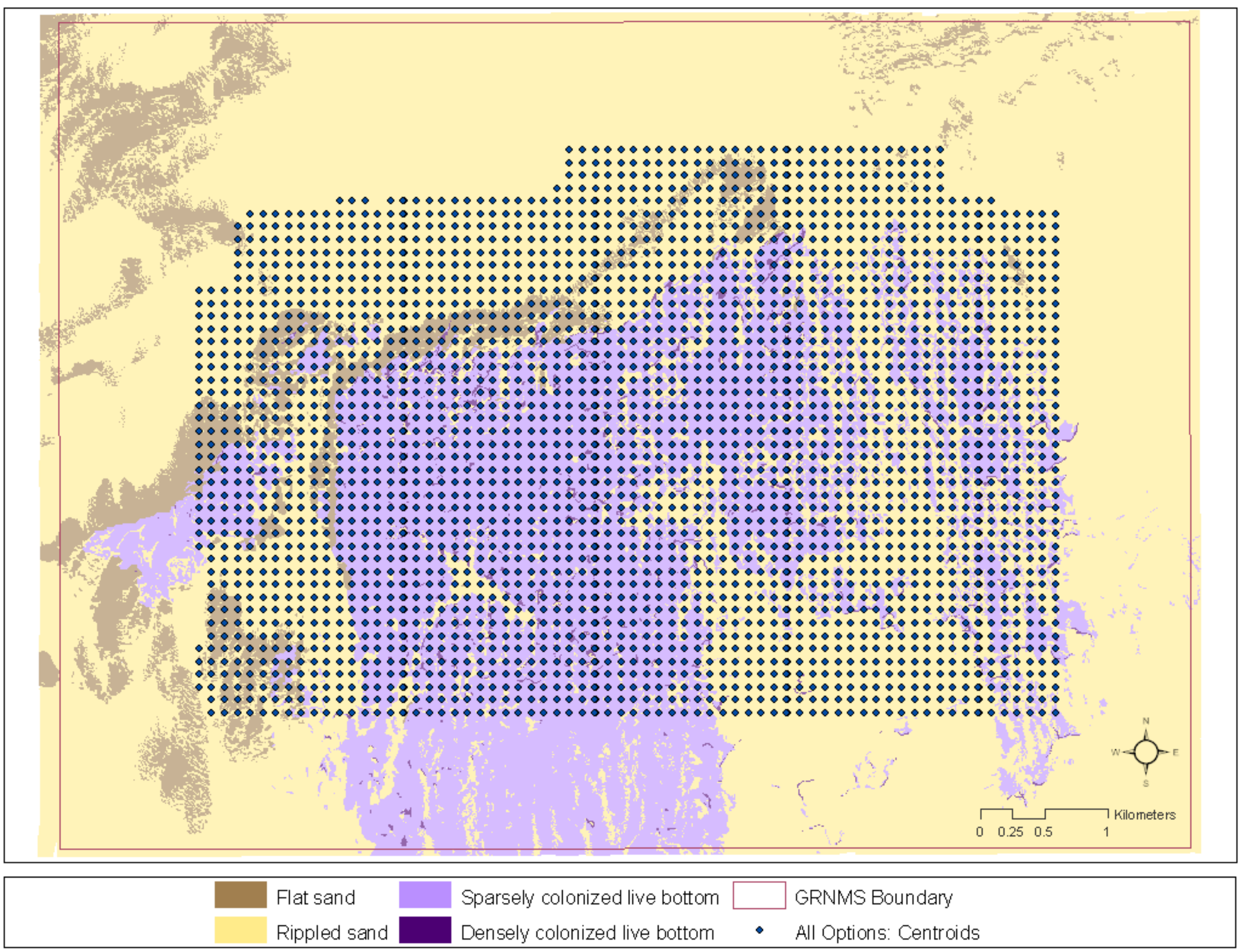


Figure 6. Spatial distribution of centroids for all RA options. Many were overlapping.

focused around the long term research site that were either included or excluded in the sliding window process. Lastly, the fish tagging sites were skewed to the extreme ends of their distributions for inside and outside boundary options (RES_TAG_I and RES_TAG_O respectively; Figure 8). Similar to the roving survey sites, this is due to the majority of tagging sites being spatially clustered in the central/western region of the sanctuary.

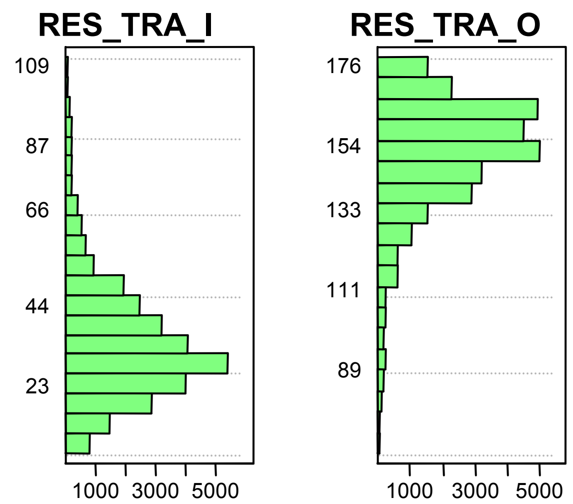


Figure 7. Histograms depicting the number of transect survey sites inside (I) and outside (O) of all the RA options. The solid lines denote the 20% breakpoints for our scoring procedure based on the minimum and maximum values for each variable.

CATEGORY SCORE DISTRIBUTIONS

The patterns of the category scores that resulted from averaging the individual scores from each of the variable groups were evaluated (Figure 9). Due to the averaging process, some category scores did not have the full range of values from 0 to 5. For example, the inside options for the other bottom type category did not have a score of 5. The outside options for the other bottom type category did not have a score of 1. The fishing category did not have a score of 5 for inside options, but did have a score of 0 unlike other options. The rest of the variable categories had options representing the range of category scores from 1 through 5.

RESULTS OF SIZE COMPARISONS

When RA options of each size were pooled and the distribution of category scores were examined, consistent trends were found according to RA size. Results are separated into those inside versus outside the RA. Inside the RA, category scores were positively correlated to option size (Figure 10a). In fact, low inside category scores of 0-2 comprised over 75% of all 4 km^2 RA options, the smallest boundary size considered, and no inside category scores of 5 were found. In contrast, for the largest RA options of 16 km^2, 95-100% of the RA options had category scores of 4 or 5 and no values of 0 or 1 were found. Category scores outside the RA showed the opposite pattern and were inversely related to option size (Figure 10b). Nearly 100% of the 4 km^2 RA options had category scores of 3-5. Many had no values of 0-2. In contrast, areas outside the largest RA option size, 16 km^2, were dominated by lower category scores.

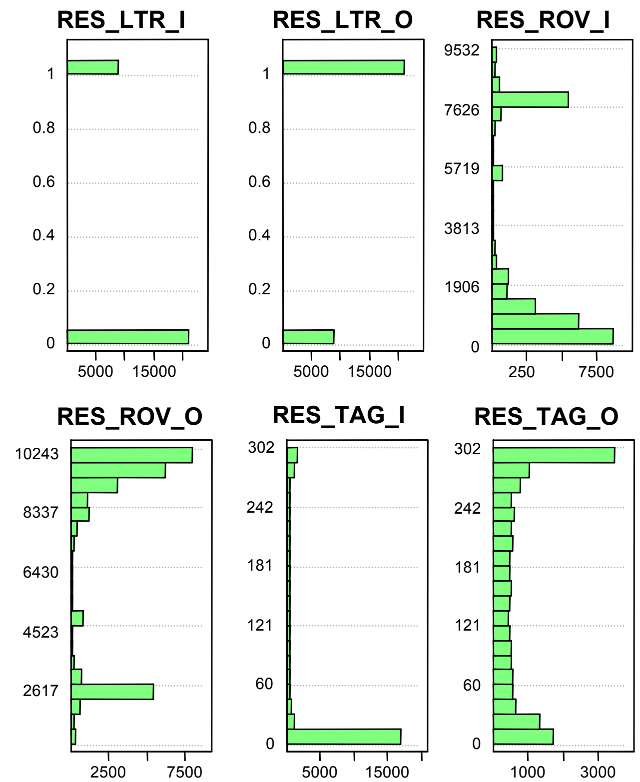


Figure 8. Atypical histogram distributions. Dotted lines denote the 20% breakpoints in our scoring procedure based on the minimum and maximum values for each variable.

RESULTS OF ROTATION COMPARISONS

The majority of ledge category scores (83-94%) did not change whether left unrotated (edges parallel to latitude/longitude), rotated 45°, or 30° counter clockwise (Table 4). For those that did change, rotation never resulted in a change in category score of greater than +/- 1. Rotating boundary shapes 30° almost always resulted in a few more changed category scores than rotating 45°. The boundary shape influenced the most by rotation was the 3×2 km rectangle while that influenced least was the 4×4 km square. The few category scores that did change were not randomly positioned within the sanctuary (Figure 11). Increases and decreases in category score were clustered within or along the edge of the region with the highest density of ledges in the south/central part of the sanctuary. Because many ledges are organized in linear groups according to the geology of some areas, rotating boundary options sometimes resulted in including or excluding such groups of ledges and consequently changed the category score.

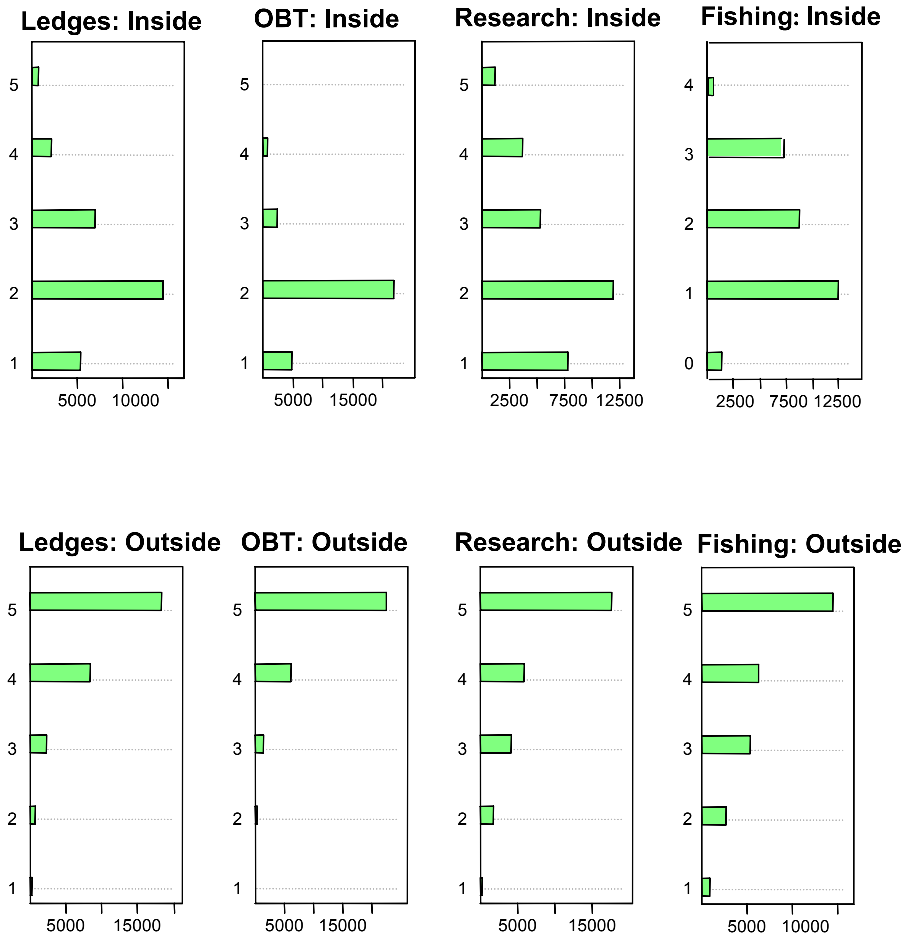


Figure 9. Histograms of category variable scores inside and outside the boundary options. Other bottom types are denoted as OBT.

SPATIAL DISTRIBUTION OF SCORES AND OPTIONS

The category scores of the four groups of variables were distributed in slightly different ways within the sanctuary. The inside scores for each of the categories had lower values around the outer edges of the sanctuary. As the scores increased in value, the options progressively decreased in number, but also became located in tighter clusters in the center of the sanctuary. This was consistent across all variable groups, however, the section of the sanctuary in which the higher scores were centered was slightly different according to category (Figure 12). The other bottom type and research categories with the highest scores were clustered towards the western-central section of the sanctuary, whereas the fishing category options with the highest scores were located toward the north/central area and the highest ledge scores were in the south/central area of the sanctuary. These centrally-located clusters reflect the slightly different locations of the highest number of ledges, other bottom types, research sites, and fishing sites inside possible RA options for the sanctuary.

The results for the outside options were the inverse of this pattern. As the category score increased, the number of options increased and became clustered in the outer edges of the sanctuary. Like the highest scores for the inside options, the lowest scores for the outside options were clustered toward the center of the sanctuary (Figure 13). The lowest ledge and research category scores were clustered towards the south/central area, the other bottom type options with the lowest scores were clustered toward the southwestern/central area, and the fishing options with the lowest scores were located in the central section of the sanctuary.

POSSIBLE SCORE COMBINATIONS

The category scores were designed to make an informed selection of an RA, or group of equally suitable RA options, through step-wise elimination. The level of selectivity in selection of score values, determined the number of possible options remaining at the end of the process. Unacceptable category scores for ledges inside each op-

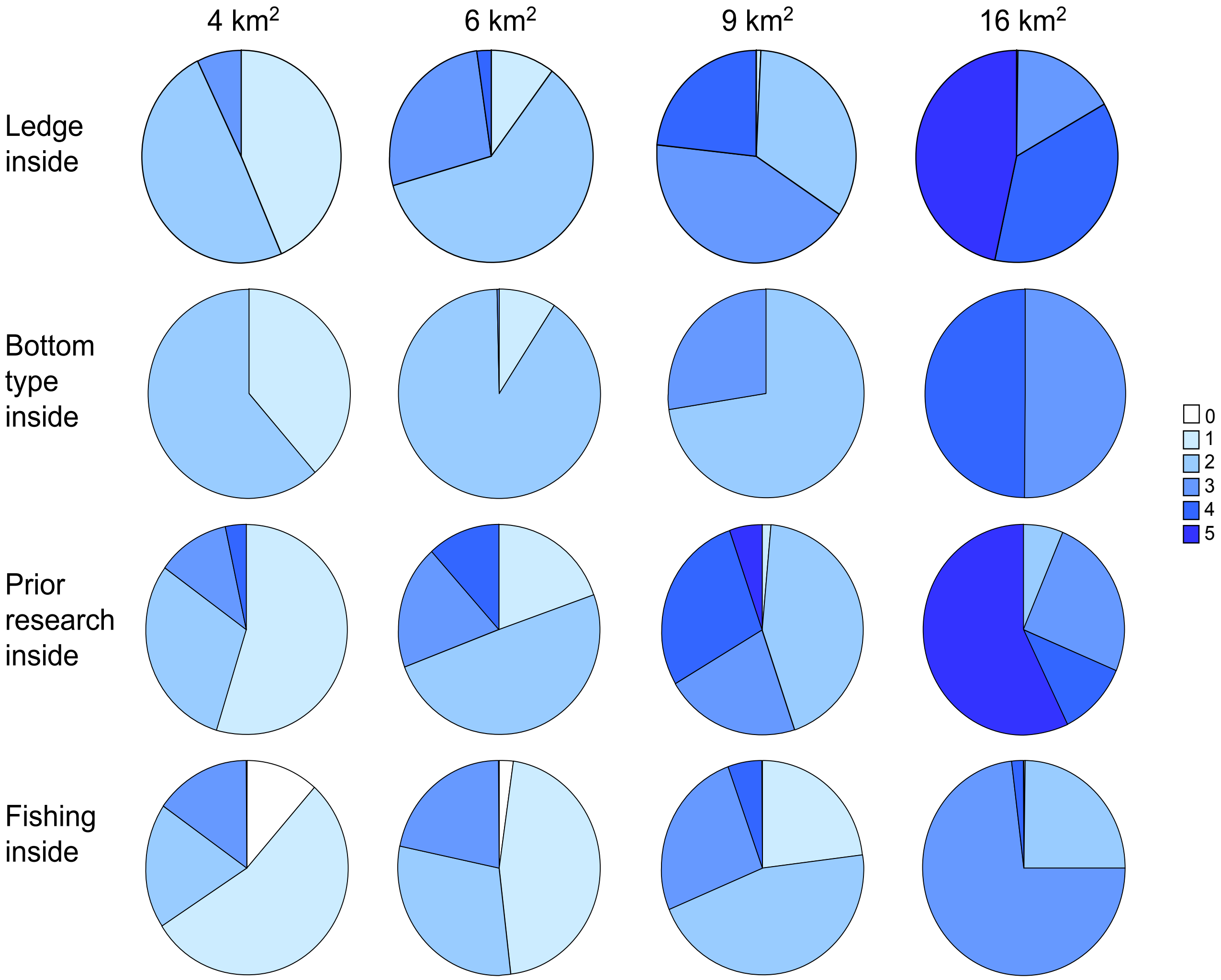


Figure 10a. RA options summarized by each size and variable category. Shapes and rotations are combined according to size. Proportions indicate category scores for inside the RA options.

tion were identified first and eliminated from consideration. Within the remaining options, unacceptable category scores for other bottom type (inside) were eliminated. Then, within these, options with unacceptable research category scores were likewise eliminated through the other category scores in the order of fishing inside, ledge outside, other bottom types outside, research outside, and fishing outside. Depending on the level of selectivity in choosing acceptable category scores at each step in the process, it was possible to have many options left at the end or none at all to represent that combination of category scores. Many combinations of category scores that meet the needs of the sanctuary for all eight categories are possible through this approach.

There were 651 different combinations of the eight category scores. Three examples of possible combinations that exemplify the spectrum of resulting options are discussed including a highly selective, moderately selective, and least selective scenario (Table 5).

Beginning with the highly selective example scenario first any of the options with category scores for ledges inside the RA which were less than the highest possible score of 5 were eliminated. This would eliminate all options from consideration except those few with the very highest number and area of all ledge types. This step resulted in 841 options remaining of the possible 30,307 for further consideration. Within these 841 options, those with category scores for other bottom types which were less than 4 were eliminated. The highest score possible for this category was 4. This further narrowed down the possible options meeting both of these scoring criteria to 474. When the best score for the next category, the research category, was incorporated into the selection process, the number of remaining options became 459. When this set of remaining options was queried for the best fishing category score inside the RA of 1, none of the options met this score combination of 5, 4, 5, then 1. In order to have options remaining and to incorporate the outside category scores, it would be necessary to

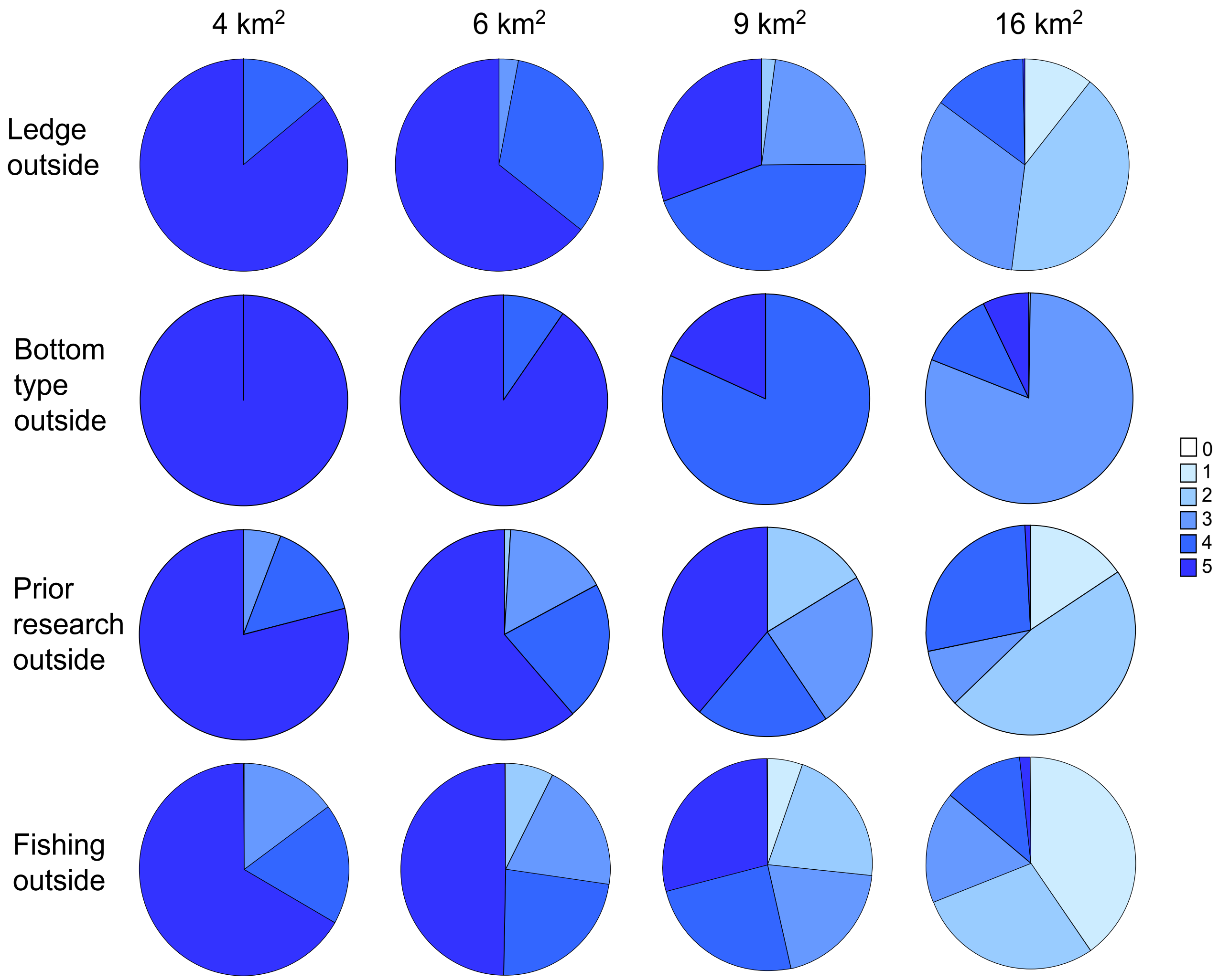


Figure 10b. RA options summarized by each size and variable category. Shapes and rotations are combined according to size. Proportions indicate category scores for outside the RA options.

broaden the score criteria to include lower, less extreme scores earlier in the selection process. For example, it may be acceptable to include category scores for ledges of 5 and 4 in the first step of the process provided that options with a value of 4 still had a sufficient number and diversity of ledges to meet the needs of the RA.

In scenario 2 the consequences of the opposite scenario, not being selective enough, were explored. In this case, category scores of 2 and above were selected for the inside ledge category, other bottom types, and the research categories. The fishing category scores inside the RA were 4 and below to demonstrate the desire to select options that displaced fewer fishermen. All of the outside category scores were also given a value of 2. In this scenario, the sequence of selection criteria resulted in 18,593 options remaining, nearly 2/3 of the original boundary options (Figure 14). Such low selectivity of category scores results in too many choices for the RA, many of which do not meet the goals of the RAWG. They will have too low a diversity of ledges and other bottom types, not enough prior research, displace a significant number of fishermen, and may not have suitable areas outside the RA for comparison.

The final scenario explores one of many moderately selective approaches that are possible between the extremes provided in the previous two examples. Scenario 3 describes a combination of category scores that resulted in a more reasonable number of viable options and still appears to meet the selection criteria of the RAWG. In this scenario all options were selected, in the same step-wise approach, that had category scores of 3 or higher (with the exception of the inside fishing category for which scores of 3 or lower were selected). This provided a moderate number of ledges, other bottom types, prior research, and fishermen displacement while ensuring a large amount of comparable bottom features and prior research outside of the RA. This moderate selectivity of category scores resulted in 551 possible options made up of 9 km^2 and 16 km^2 boundaries including all of the shapes and orientations for these sizes. The spatial distribution of these remaining options was in two distinct clusters located in the west/central and east/central sections of the sanctuary (Figure 15).

Eight of these options in a range of boundary configurations were haphazardly chosen. The actual values for each of the corresponding variables were then examined to determine if they met the needs of the RAWG (Figure 15, Appendix F). In these eight focal examples, no fewer than 24 of each of the ledge types (small, medium, large, short, medium, and tall) were included. There were never fewer than 65 of each ledge type outside of these eight options. All other bottom types were represented both inside and outside these potential RAs. Nearly all types of research were represented inside and outside of these eight options, with the obvious exception of the long term research site since it consisted of a single location. Fishing effort, the last variable in the stepwise process, was compromised the most. The num-

Table 4. Percent of boundary options that changed ledge category scores due to shape rotation. Values are separated by boundary shape (2×2, 2×3, etc.), comparison (0 to 30°, 0 to 45°, or 30° to 45°), and change in category score (-1, 0, or +1).

	0 to 30°			0 to 45°			30° to 45°		
	-1	0	+1	-1	0	+1	-1	0	+1
2×2	6	88	5	8	87	5	3	92	5
2×3	6	89	5	6	87	7	5	92	3
3×2	9	83	8	10	82	8	4	91	5
3×3	3	89	7	3	89	8	4	92	4
4×4	6	91	3	5	89	5	4	94	2

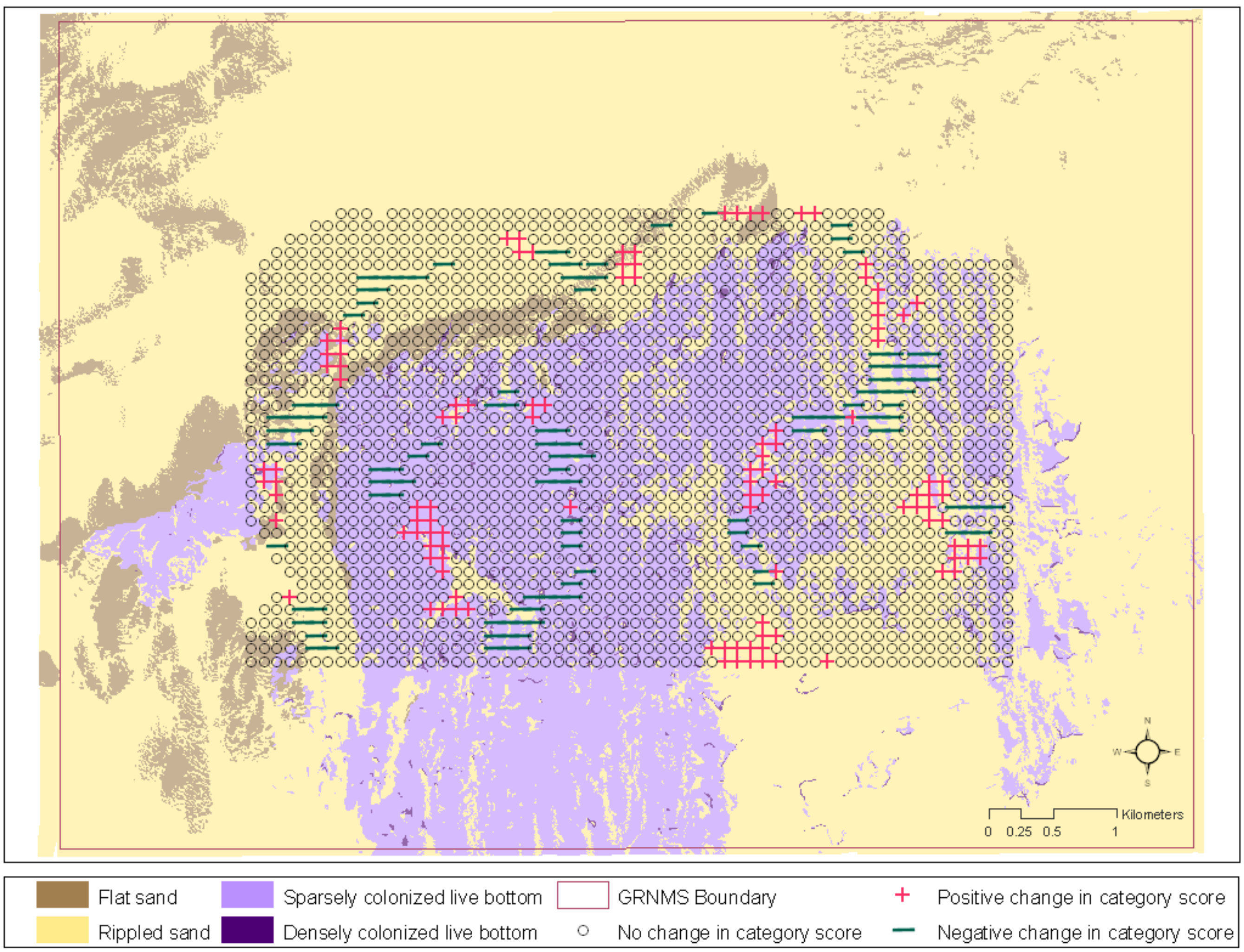


Figure 11. Centroids of 2x2 square options displaying change in ledge category scores between a 0 degree rotation and a 30 degree rotation.

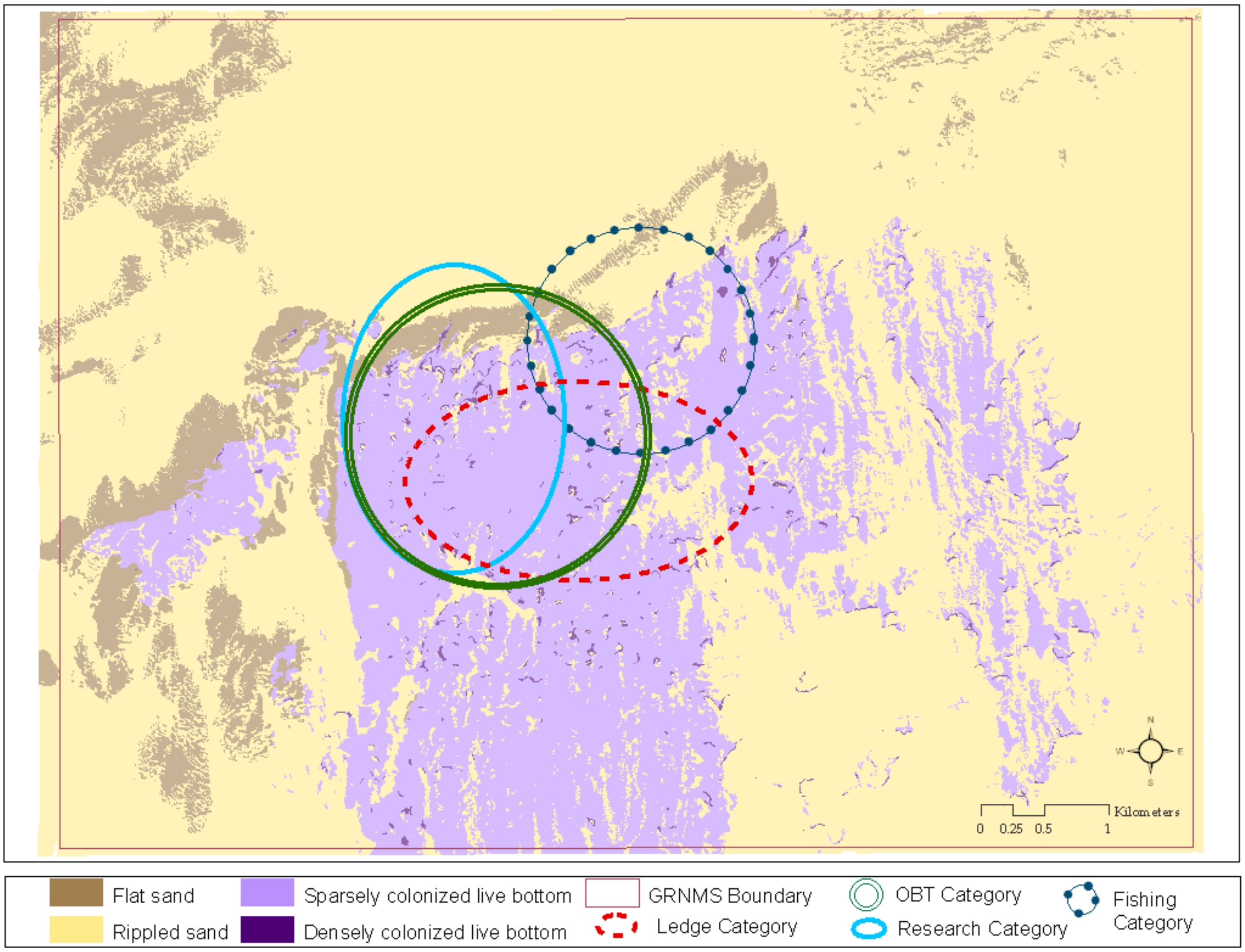


Figure 12. Centroid locations of the highest category scores inside RA options.

ber of boats was higher outside than inside six of the eight focal options. Gear per survey was higher outside than inside in only two of the eight RA options.

The 551 options resulting from the use of moderate category scores provided a reasonable number of choices with suitable characteristics to meet the goals of the RAWG. These options could serve as a group of finalists in the selection process. Through further investigation of specific variable values, public comment, and logistical considerations, a final RA could be chosen.

DISCUSSION

This analysis enables the exploration of the trade-offs among boundary size, shape, and orientation and how these choices affect inclusion of target bottom types, prior research, and favored fishing locations. At first glance, ledges, fishing effort, and prior research appear highly correlated and finding a location with a large amount of ledges and prior research but with lower use by fishermen seemed improbable. This analysis identifies the locations and degree to which such trade-offs can be made.

The centroids of the highest scoring options in this analysis were clustered in the south/central portion of the sanctuary. There were two reasons for this. First, there were simply a large number of ledges and flat live bottom in this area. Due to the historical focus of studying these bottom types, there were also a large number of prior research sites in the area. Additionally, there were simply more high scoring options with centroids near the middle portion of the sanctuary by virtue of the boundary sizes that were used. Because options were required to lie entirely within the sanctuary, the centroids of the 4×4 km options in particular fell closer to the middle of the sanctuary (at least 2 km from the edge of the sanctuary). The larger sized options typically had the highest

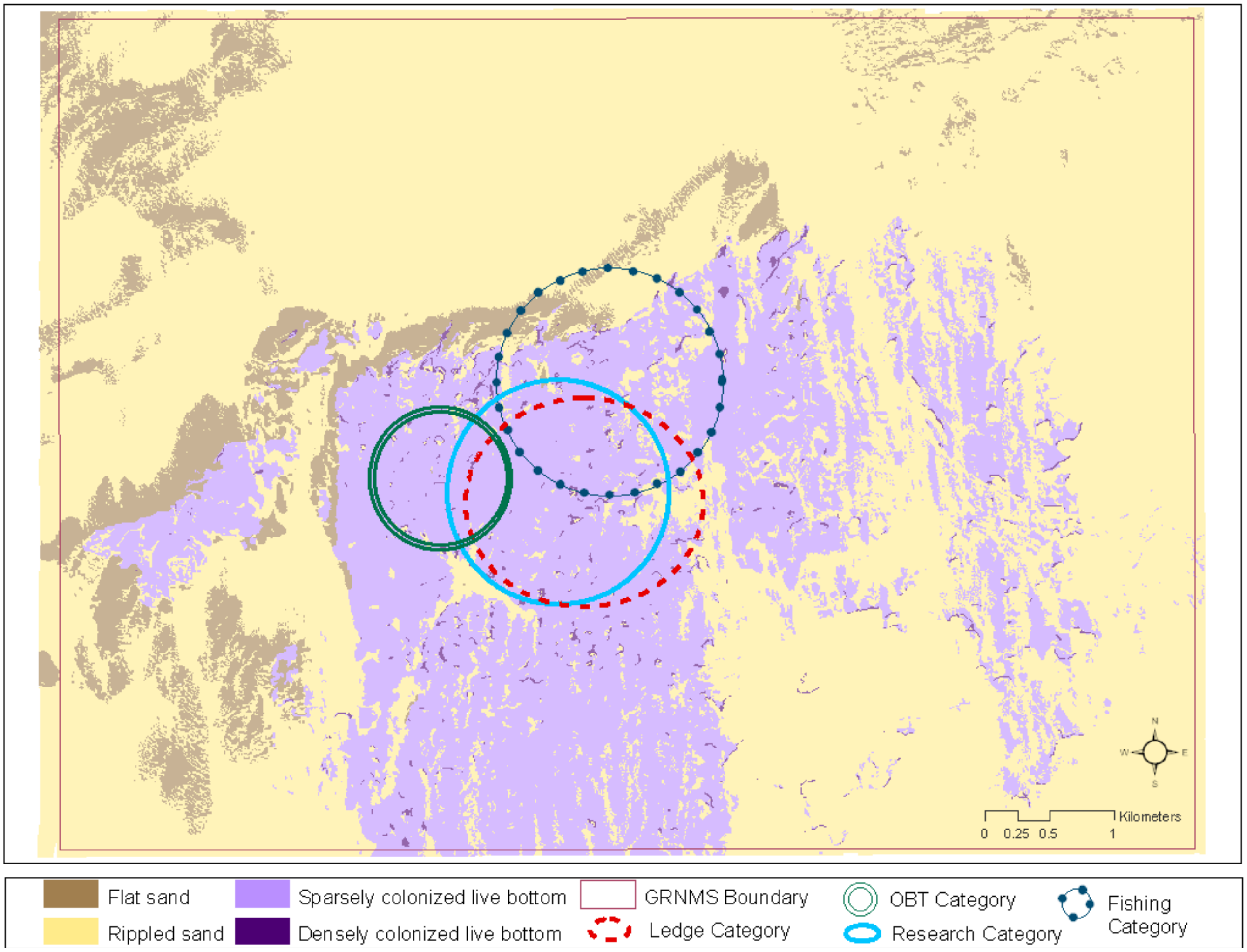


Figure 13. Centroid locations of the lowest category scores outside RA options.

Table 5. Three possible selection scenarios and their category scores.

Scenario	Ledges Inside	OBT Inside	Research Inside	Fishing Inside	Ledges Outside	OBT Outside	Research Outside	Fishing Outside	Options Remaining
1: Most selective	5	4	5	<= 1	-	-	-	-	0
2: Least selective	>= 2	>= 2	>= 2	<= 4	>= 2	>= 2	>= 2	>= 2	18,593
3: Moderately selective	>= 3	>= 3	>= 3	<= 3	>= 3	>= 3	>= 3	>= 3	551

scores because they covered a greater proportion of the sanctuary and so encompassed more of the target variables.

When the distribution of category scores were examined, consistent trends were found according to RA size. Size of options was positively correlated to category scores inside the RA. This was expected because small boundary configurations encompass less space and therefore generally include fewer of the sizing criteria. Conversely, <u>outside</u> the RA an inverse pattern was found with option size being negatively correlated with category scores. This makes sense because small boundary configurations have a larger area outside their boundaries, which would result in high category scores <u>outside</u> the RA.

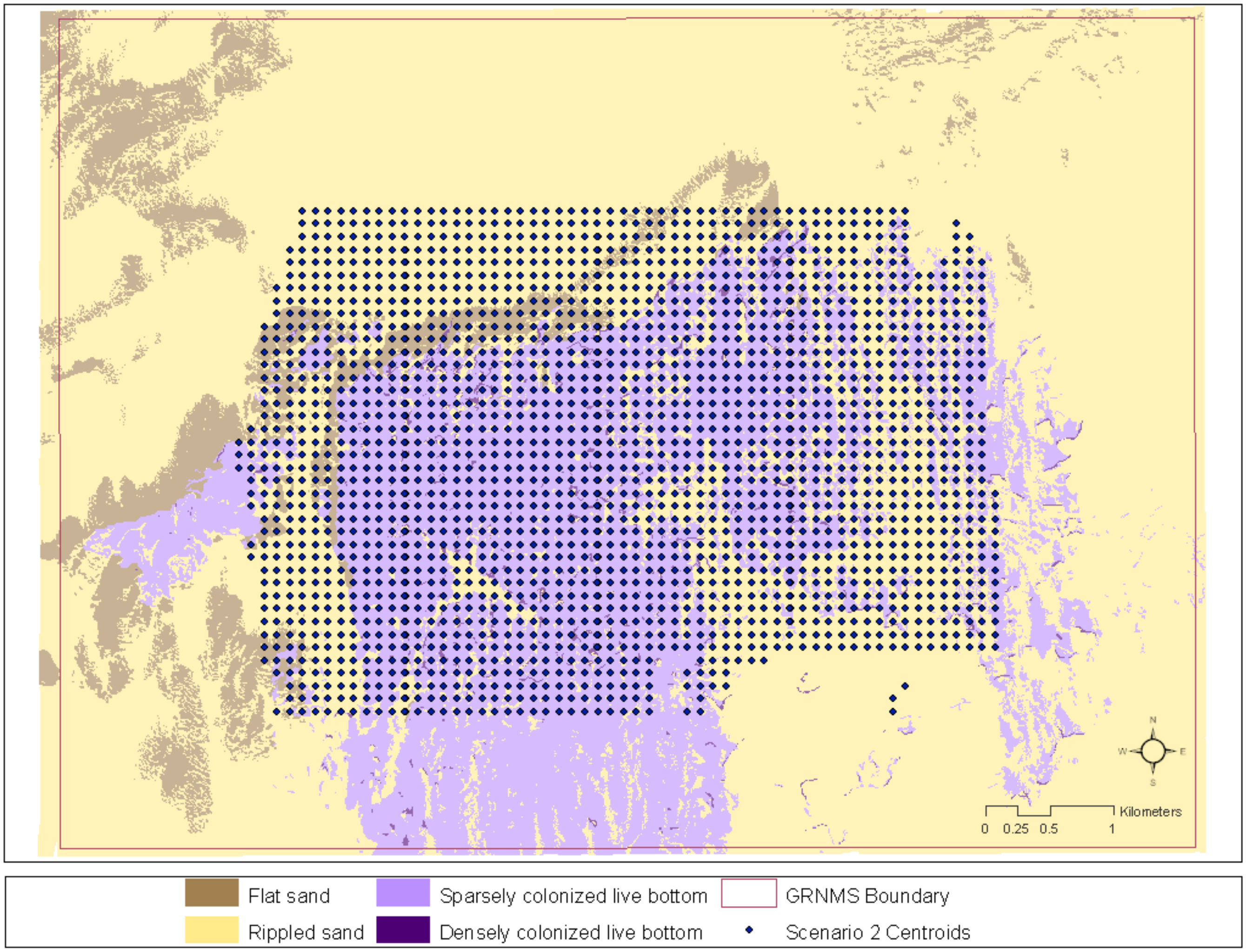


Figure 14. Centroids for the 18,593 acceptable options according to scenario 2. Note that many are overlapping.

That larger RA options include more of the target characteristics was no surprise. Larger options would offer more experimental units (i.e. ledges) and space for research opportunities. There are, however, additional issues to consider that could not be addressed by this analysis. For example, are "home range" size data available on bottom fish at GRNMS to help define the proper size of a research area? Given that studying bottom fish in the absence of fishing pressure is a major rationale for considering an RA, available home range size information should be used to guide site selection. A few studies have examined home range size for one species of interest, black sea bass, *Centropristis striata*. During a 15 month tag-recapture study in a New Jersey estuary, juveniles (3-10 cm TL) were almost always recaptured within a mere 30 m of the release site (Able and Hales 1997). Of more relevance to fish farther offshore at GRNMS, is a 6 month tag-recapture study of larger, legal sized fish (>20 cm) movement among artificial reef and hard bottom sites on the South Carolina shelf (Low and Waltz 1991). The study was conducted in similar water depths to those at GRNMS. A large majority of fish recaptured in that study were observed to not only have remained close to their release points but were often at the same site indicating very little movement (e.g. <100 m). Another tag-recapture study of a live bottom off Beaufort, NC in 30 m of water that spanned two years also supports the notion that black sea bass has high site fidelity with only 1 out of 100 recaptures located away from the release site (Parker 1990). Most notably, the tag-recapture study at GRNMS conducted by MARMAP indicates that the vast majority (>90%) of legal sized fish stay primarily within a 1-2 km area for as much as 2 to 3 years. A much smaller proportion of individuals (<10%) appear to undertake longer distance movements of 3 to nearly 200 km (G. Sedberry and A. Barkoukis pers. comm.).

Data that may be used to determine home ranges for other species of interest is much less thorough. The scamp, *Mycteroperca phenax*, for example was recaptured a few times in the Parker (1990) tagging study, all within 3 km of the release site and a particular gag grouper, *M. microlepis*, was seen by divers repeatedly at the same site off Beaufort, NC for over a year. A more recent tag-recapture of gag along the shelf of the southeastern US

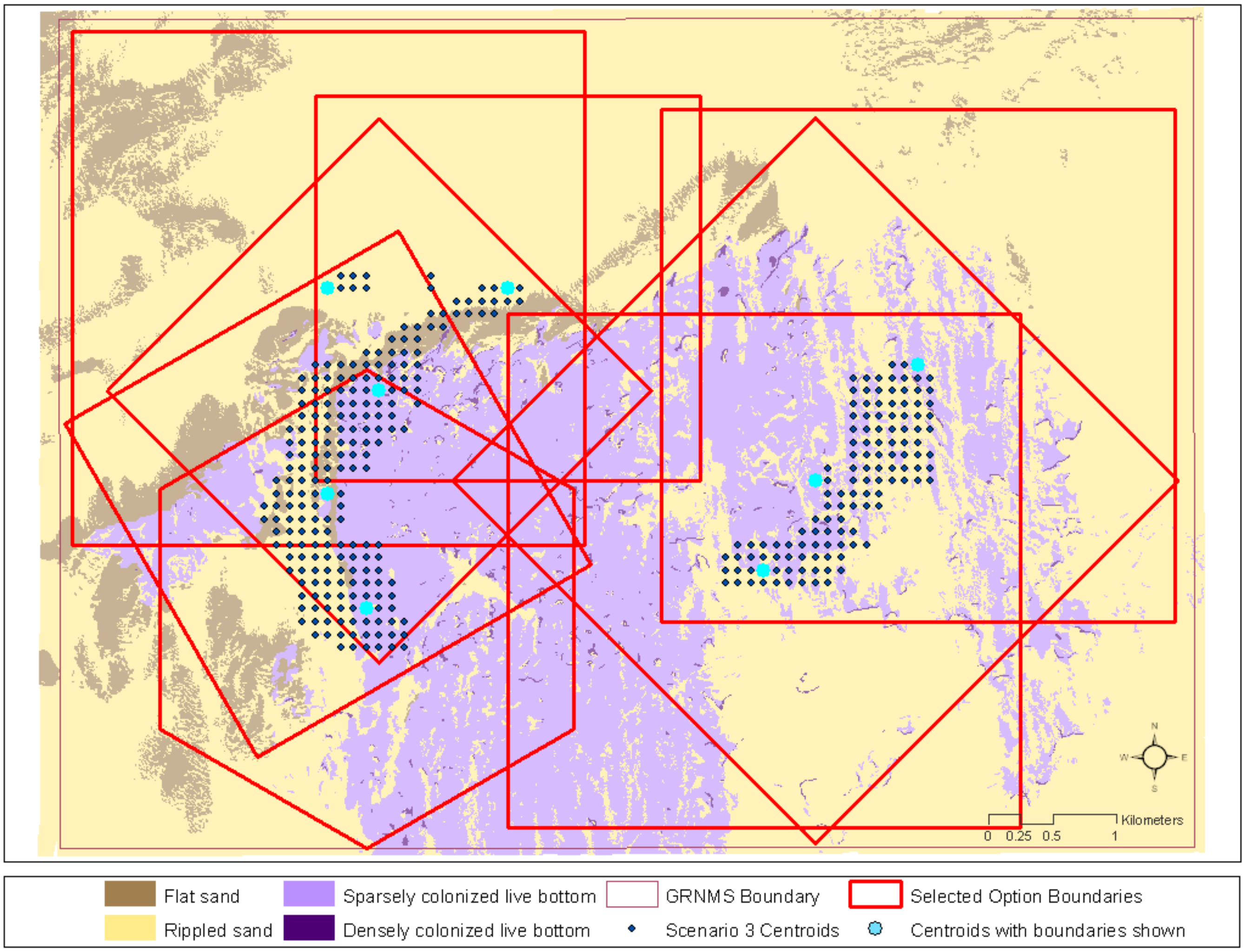


Figure 15. Centroids for the 551 acceptable options according to scenario 3. Eight options are highlighted to show the diversity of boundary configurations represented in this scenario.

from 1995 to 1999 documented movement patterns at broader scales (McGovern et al 2005). Thirty-six percent of recaptures did move <2 km, however, a considerable number (23%) moved >185 km. Fish tagged in the depth range of GRNMS showed the greatest tendency for movement whereas fish in deeper waters were more sedentary. Also of note, fish tagged in Georgia tended to be recaptured at roughly the same latitude, whereas fish tagged in the Carolinas were often recaptured farther south in Georgia and Florida latitudes. These findings indicate that long term movements of gag, especially in consideration of potential spawning migrations to shelf edge sites, routinely take many gag well beyond the spatial scope of GRNMS and certainly beyond any research area within it. Shorter term and daily movement patterns of this species are less understood.

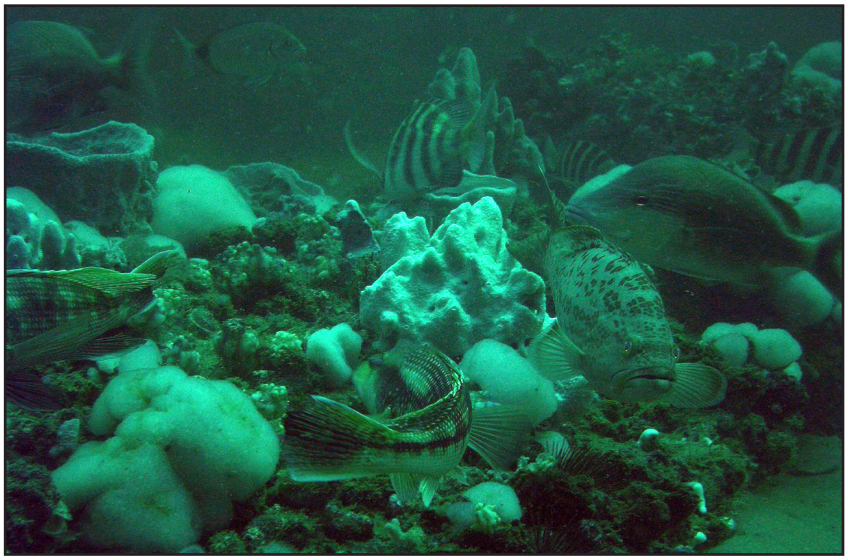


Image 11. Various species of fish at GRNMS.

A trawl and video study of the cross-shelf and seasonal distribution patterns of demersal fish communities in the South Atlantic Bight suggests that the scale and timing of seasonal movements and ontogenetic habitat shifts of many bottom fish are generally well beyond the confines of GRNMS (Sedberry and Van Dolah 1984). One site in the study was actually within the sanctuary. Most community metrics at the site were much higher in the Summer than in the Winter. Species richness increased from 22 to 48, number of fish/hectare increased from 81 to 1132, and biomass increased from 8.9 to 38.7 kg/ha. These substantial seasonal changes in community structure were evident for even black sea bass which were over 7 times more abundant during the Summer, an increase most likely due to the seasonal recruitment or ontogenetic habitat shifts of juveniles (Sedberry pers. comm.).

None of the studies mentioned above provided a comprehensive understanding of the daily scale of movements of bottom fish. This is perhaps best done through additional studies such as sonic tagging and intensive monitoring of the daily activities of individual fishes. The broad-scale ontogenetic habitat shifts and spawning migrations of many species of interest to GRNMS continue to be the subject of further study but appear to be well beyond the scale of the sanctuary and certainly an RA within it no matter how large.

Studies from other systems, especially those on coral reef ecosystems around islands provide further insight into home range sizes of bottom fish. For example, a compilation of home range size data for many species of Caribbean reef fish identified the following relationship with fish size: $\log_{10}y = -3.75+2.35\log_{10}x$, where y is mean home range length (m) and x is mean fork length (mm) ($n = 24$, $r^2 = 0.85$, $p < 0.0001$) (Kramer and Chapman 1999). For example, a 25 cm long fish would have a home range length of ~45 m whereas a 50 cm fish has a home range length of ~390 m. Despite the relative abundance of such studies on island coral reefs that could be drawn upon to identify home range sizes for similar species, it is questionable how well such patterns may translate to a continental shelf, live bottom ecosystem, different species, and sub-tropical/temperate climate at GRNMS. Indeed, even the studies of home range size for the same species at different Caribbean islands and reef types have revealed considerable plasticity in territory size, migratory behaviors, and the spatial scales of daily activity patterns (e.g. bluehead wrasse, *Thalassoma bifasciatum*; Warner et al 1995, Tecumseh et al 1990, Warner and Hoffman 1980).

The available information leaves many unanswered questions regarding the spatial scale of habitat use for bottom fish at GRNMS and does little to support recommendation of a particular size of an RA within the sanctuary. Even the information for black sea bass is somewhat conflicting. Furthermore, the recommendation should not rest on the scale of habitat use of a single species since the RA will be used to investigate a wide variety of organisms and topics. Instead, other considerations are likely to be of greater importance to guide the identification of an appropriately sized RA. The simple principle should be considered that a large RA is more likely to accommodate the daily spatial scales of habitat use for the widest possible assemblage of bottom fishes and insulate them from edge effects. This must of course be balanced with ensuring a suitable area for comparison within the sanctuary. Contrary to earlier speculation (Appendix D), this analysis indicates that suitable areas for outside comparison exist even for a 4×4 km RA (e.g. Scenario 3: category score of greater than or equal to 3 inside and outside), the largest size that was considered.

Rotating boundary options 30° or 45° improved 3-8% of the category scores by 1 relative to no rotation. This low number of affected options and small change in category score may seem trivial; however, this higher category score may translate into a large difference in actual number or area of the different ledge types depending on the specific options involved. For example, a histogram score of 3 includes options with as few as 41 tall ledges, whereas a score of 4 may have up to 82 tall ledges. The few options with the gain in category score due to rotation at first seem quite appealing since they more optimally capture ledge variables, however, this must be considered in tandem with several other factors. Recall the reason that category scores were higher for some options. The region's geology resulted in some ledges occurring together in linear groups. When the edge of a rotated option boundary included or excluded these groups, the category score changed. This means that rotated options with higher category scores mostly gained ledges along the very edge of their boundary. Edge effects, fish movement out of the RA, and fishermen concentrating effort along the boundary line may all counter the benefit of a larger number of ledges. In addition, there may be logistical problems associated with boundaries not aligned to latitude and longitude. Given the increasing use of hand-held Global Positioning Systems (GPS) by recreational fishermen to position themselves in open water, aligning a square or rectangular RA boundary to latitude and longitude would make compliance much easier. For example, a fisherman could be certain that going south of latitude X would place his/her boat inside the RA boundary. Alternatively, if the primary means of compliance were through line-of-sight between buoys marking the boundaries or the use of GPS integrated digital nautical charts including RA boundaries, rotated shapes or even hexagons which maximize core area may be the preferred boundary configurations.

No matter what size, shape, or rotation may ultimately be decided upon, the addition of a buffer zone of added protection should be considered. A buffer zone is simply a border of added protected space around the area that will serve as the boundary for the RA. The buffer provides a measure of insulation against fish traveling out of the RA as well as fishermen intensively targeting its borders. Buffers need not be equal width around all sides of the RA, rather it should only be included where needed. For example, a wide buffer along one side may be particularly appropriate for preserving the advantages of high scoring rotated options because they have a large number of ledges near one edge.

The example scenarios demonstrated the consequences of high, moderate, and low selectivity in choosing category scores. Low selectivity yields too many options to choose from with widely differing characteristics, many of which may not even be suitable for the RA. Being too selective demonstrates that the ideal RA, one with lots of ledges and prior research but that displaces zero fishermen, is simply unattainable. In contrast, the moderately selective scenario resulted in a reasonable group of options from which an RA could be chosen. Examining the actual values for these eight options revealed that they generally met the siting characteristics requested by the RAWG. A reasonable number of all ledges types were included in the RA options (24 to 87), which would serve as experimental units for the most pressing research questions. All other bottom types were represented in some quantity to provide areas for studies in different habitats. Some of nearly all types of prior research were located within each option to provide baseline values for future comparisons. The areas with the very highest fishing effort can be avoided without compromising the other criteria for the RA. All options had large amounts of ledges, other bottom types, and prior research sites outside the RA to serve as comparison sites. Including the Long Term Research site within the RA, which seems prudent, further limits the potential choices to only some of those in the western cluster of this example (Figure 16).

A recent search of the Marine Managed Area Inventory Database (NOAA/DOI 2006) revealed 185 sites in the United States that at least partly identify research as a purpose of their site (accessed January 17, 2006). Apart from the National Estuarine Research Reserve System (NERRS) and Dry Tortugas National Park, little information on methods for site placement for research areas is available. Dry Tortugas National Park analyzed five alternative boundaries for a research area within the Park that would exclude all fishing activity (NPS 2001). It is similar to the process conducted here in that the criteria included habitat characteristics, prior research, minimization of fishermen displacement, and ease of enforcement. However, the Dry Tortugas were less quantitative in their investigation of variations in size, shape and orientation compared to this process for GRNMS due to their emphasis on reducing the number of boundary lines necessary. A main driver of the Dry Tortugas site selection process was to include as many of the present park boundaries as possible in the boundary for their RA. The NERRS process, which is also less quantitative, had many similarities to that conducted here as well. NERRS bases site selection on criteria within four groups: 1) environmental representativeness, 2) value of the site for research, monitoring, and resource protection, 3) suitability of the site for education and interpretation, and 4) acquisition and management considerations (NERRS 2005). The selection process assigns points on a scale from 0 to 3 to sites based on several measures within each group, some quantitative and some subjective. Higher values are given for “better” sites. Similar goals between the NERRS selection process and the process conducted here include targeting representative habitats, high habitat diversity, key habitat, complete ecosystems, a long history of prior research, sites that can serve as a baseline, both control areas and experimental areas, sites appropriate for investigating coastal issues, and minimizing conflicts with historical and current use patterns. Values for these and other NERRS criteria are then either simply averaged or discussed in a consensus based process by a selection committee. A key difference in the NERRS process is that it is a network of sites that are being continually added to, and this influences the choice of each successive new site. In contrast, there are no marine research areas currently within the South Atlantic Bight.

Although avoidance of preferred bottom fishing areas was an important objective of this analysis through the use of boat sighting and marine debris distributions, further care should be taken to minimize displacement of current users. Namely, since bottom fishermen will be the most impacted, they and their representatives should be consulted at public meetings regarding which among the preferred RA options least displace them. Provided

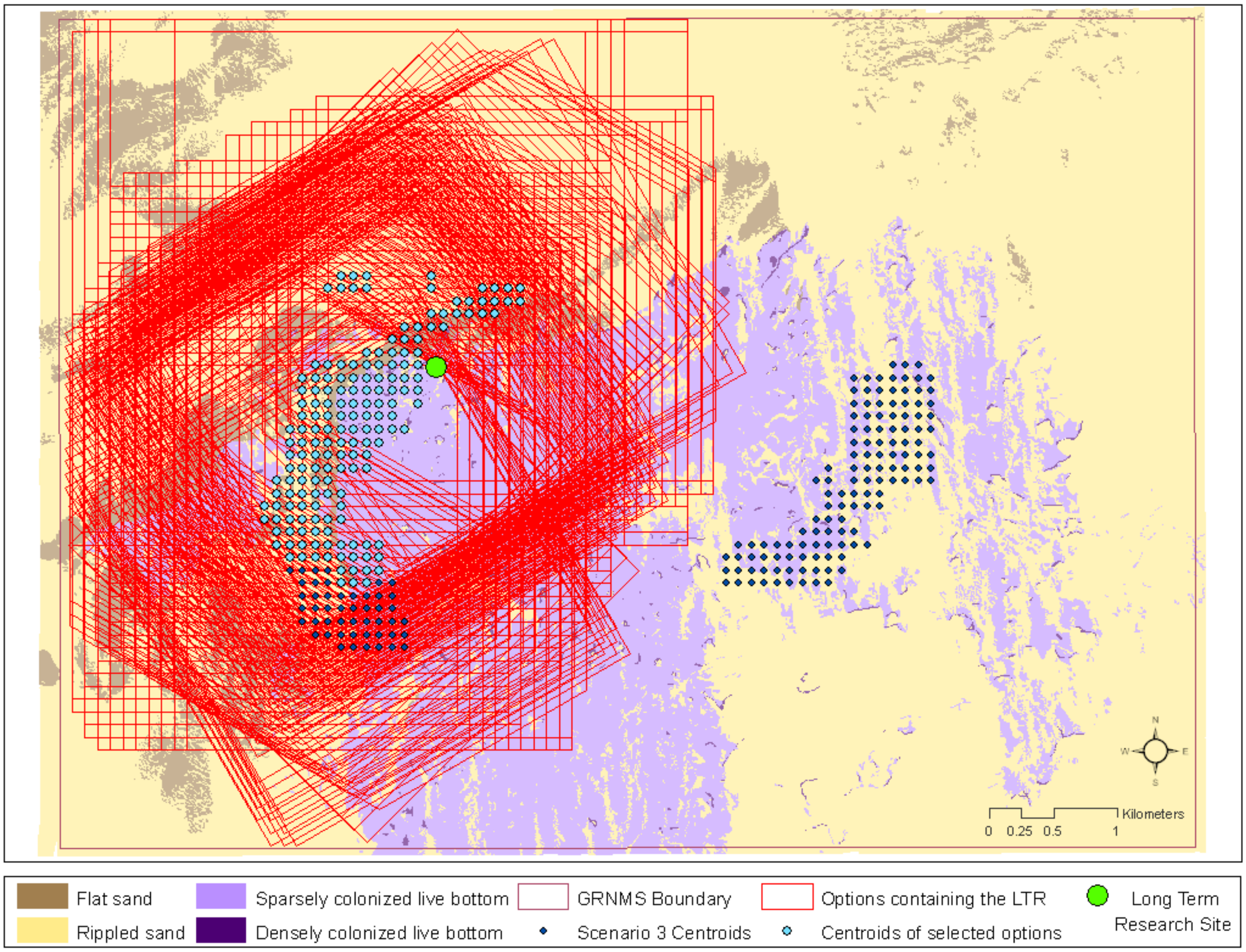


Figure 16. Scenario 3 options with centroids and boundaries that contain the Long Term Research Site.

that the criteria are met for ledges, other bottom types, and prior research, any of the remaining options most acceptable to bottom fishermen should do equally well. Incorporating this group's concerns at every stage in the RA evaluation process has been essential and is expected to improve understanding, acceptance, and ultimately compliance of an RA if implemented.

Ideally, the RAWG would have been able to select minimum cut-off values for each of the variables in the analysis from the start. This would have eliminated the need for the scoring process that was devised. Option selection could have proceeded directly to eliminating those that did not meet the cut-off value for each variable. This was not possible with the information available to the RAWG prior to this study. The number of ledges, area of other bottom types, inclusion of prior research, and preferred locations for fishing within the context of the various RA boundary configurations under consideration were simply not understood. The results provide this requisite understanding through a systematic and comprehensive analysis of the boundary options and the resources they encompass. Ultimately, the RAWG still needs to decide acceptable cutoffs for each variable. This can be done through the use of category scores and the corresponding values for each variable as was done here. Alternatively, the present study has provided a greater understanding of the range of values and the trade-offs among the variables associated with the boundary configurations under consideration. As a result, informed selection of specific minimum cutoffs for each variable can be achieved and the selection process run on the raw data for each option (rather than the category scores used here).

This technique provides an effective way to comprehensively evaluate a discrete number of alternative boundary shapes within a region of interest. The approach may be especially effective in the design of zoning within existing MPA's. Often MPA's have a considerable body of prior research and characterization available to serve as data inputs. Siting criteria based on these data can either be general, as was in this case, or more quantitative such as through the use of minimum acceptable cut-off values. The sub-zoning process that was used recommends the following steps: choosing sub-zone selection criteria, selecting possible boundary configurations, determining the optimal distance to slide the analysis window between options, tallying the variables of interest within each option, organizing the variables into a meaningful step-wise order, categorizing or selecting cut-offs for each, and obtaining a list of equally suitable options for which to select a specialized zone. The limited space within existing MPA's and tendency to establish single specialized sub-zones within them also make this an attractive approach.

Image 12. Marine debris associated with human use which was gathered from the bottom at GRNMS.

An RA designated based on the results of this analysis should include some spatial and temporal flexibility. The bottom data on which much of this analysis was based were from sonar surveys conducted in 2001 (Kendall et al 2005). The dynamics of shifting sands in the South Atlantic Bight and frequency with which ledges and other live bottom features are exposed or covered over are not well understood. Flat sand may become rippled or vice versa as bioturbation, currents, and waves reshape the benthos. Field work in 2005 indicates that features remain much the same as depicted in the map (Figure 3) but the long term persistence of mapped features is unknown. The RA should be periodically remapped and possibly moved as necessary to accommodate such changes. Also, as research is completed, new hypotheses are devised, and experimental designs are modified to meet the changing science needs of the sanctuary, the size (larger or smaller), location, and regulations within the RA should be flexible enough to accommodate them. Furthermore, this analysis, like any GIS analysis is intended to be used as a tool by the RAWG to aide in the selection of available options. Ultimately, the decision of if and when to implement an RA rests with GRNMS and NOAA.

FINAL RECOMMENDATIONS

- A set of equally suitable options should be presented to the SAC/GRNMS, not just one option.
- The RAWG needs to select acceptable cutoffs. This can be based on the category scores or the histograms for each variable.
- 4x4 km options maximize ledge, bottom type, and prior research within the RA and still allow sufficient comparable areas outside of it.
- Selecting moderate category scores (e.g. scenario 3) appears to meet the needs of the RAWG when the actual values of each option are considered.
- There are two clusters of options that appear to meet all of the criteria of the RAWG located in the east/central and west/central portions of the sanctuary.
- A small fraction of rotated shapes improved option characteristics. These should be considered individually for relative advantages.
- Buffers should be placed around final selection as appropriate to insulate the RA from edge effects (especially rotated options).
- The long term research site should be included in the final set of boundary options to be recommended to

the SAC. Many suitable options support this choice (Figure 16).

- The fishing variables included here should be heavily considered in this decision; however public input on preferred fishing locations is essential.
- The largest options will include the home range for the greatest variety of fish.
- The final boundary should remain flexible to encompass changes in bottom type or research needs over time.
- The analysis should include sonic fish tagging data to greater enhance the sanctuary's understanding of the relationships between fish and their habitats and the spatial scales of their movements.

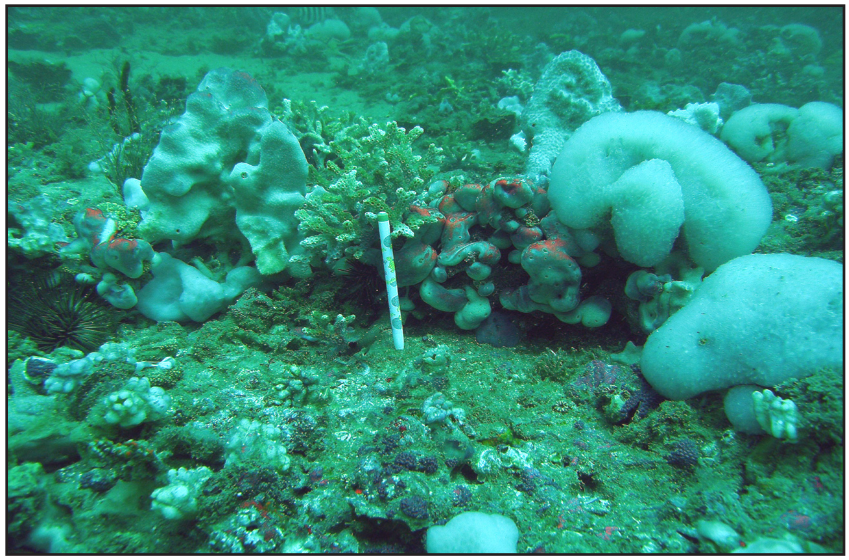


Image 13. Encrusting organisms at GRNMS. The pencil in the image denotes the scale.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance of many individuals who made this work possible. Ken Buja tenaciously automated the extraction of values within the thousands of boundary options. Lad Akins, Athan Barkoukis, Cindy Cooksey, Sarah Davidson-Hile, Erik Hund, Jeff Hyland, Greg McFall, George Sedberry, Christy Semmens, and others generously provided the locations of their many excellent research activities that have been conducted within GRNMS. Sarah Davidson-Hile also organized the underwater photographs for Gray's Reef. Our deepest gratitude to Kevin McMahon and Pam Rubin for imparting their editorial wisdom. Christine Harvey contributed to preliminary versions of the analysis approach. Thanks to the many staff of the Biogeography Team who allowed us to highjack their computers to run all of the analysis options. Thanks to Laurie Bauer, Chris Caldow, Charles Menza, Mark Monaco, and Simon Pittman whose comments provided helpful guidance. Greg McFall, Cathy Sakas, Becky Shortland, and Jim Sullivan also contributed helpful comments for the improvement of this report, which is greatly appreciated. Randy Clark and Jamie Higgins did an excellent job formatting and organizing the final version of the report. A special thanks to all the members of the GRNMS/RAWG whose creative discussions and suggestions improved the analysis.

GLOSSARY

Boundary configuration: A specific combination of boundary size, shape, and rotation.

Boundary option: A specific boundary configuration placed within the sanctuary using the sliding window process.

Category score: The average of all histogram scores within a variable category, rounded up to the nearest whole number.

Histogram score: Values for each variable from 1 to 5 that correspond to 20% quantiles for all RA options.

RA: An RA or Research Area is a region specifically set aside for conducting scientific research in the absence of confounding factors.

Selection variable: Any of the 25 variables used in the analysis.

Siting criteria: General qualities of the RA as requested by the RAWG. For example, a large number for ledges and prior research sites were identified as important characteristics for an RA.

Variable category: Any of the 4 groups of variables used in the selection process including ledges, other bottom types, prior research, and fishing effort.

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APPENDIX B: RAWG MATRIX 2, CONSIDERATIONS FOR THE VALUE OF A RESEARCH AREA

Research questions to support management priorities	Could a Research Area provide significant information to address Management concerns?	Is a Research Area necessary?	Why would or why wouldn't the research area address the concerns?	What should be the characteristics of the area? (e.g. physical properties, activities)	What are the issues of concern? (e.g. user concerns, cons, costs, scientific process)	What are some additional information needs or requirements prior to establishment of area?
PRODUCTION / RIPPLED SAND	Yes	probably not or unknown	*Provide an area of minimum disturbance to understand natural dynamics *Place scientific gear with less loss *Place for inventory of natural biological community present in RS *Pattern of distribution relative to other habitats	Representative *Phys- proximity to adjacent, protected hard bottom Rep of range of hab types at GR (avg, range) Halo effect included (physical/biological processes) *Activities-Limited human disturbance Minimize removal of organisms of interest/or substrate or sand No other human activities restricted << natural variability	*Concerns: Restricting current and historical activities -Rec fishing, comm fishing, diving, bottom fishing *Costs: Reqs surveillance	*Determine representative area -Halo -grain distribution (avg, range) *Recommended or probable sci sensors and equip to understand impact *Understand hydrodynamics/ storm events (surface water surrogate)
SESSILE INV/ BOTTOM FISHING **fishing gear effects**	Yes	Yes because traditional studies such as caging would not be adequate	*Provide a control site	*Representative/ matched to treatment area *Eliminate bottom fishing gear effects *Could be a small area *Should not exclude other activities *Replication is necessary *Identifiable to public	*Enforcement/ Physical Marking *Cost and Commitment *Public Acceptance and Compliance *Displacement of Bottom Fishing *Education *Identification of the area *Size of area selection *Requires long-term study *Regional Oceanography/ Climatology	*Size options **a priori* distribution of fished area *Bottom type *composition of invert species *Literature review *Experimental design *Usage data/ overflights *Info on removals at GR
SESSILE INV/ BOTTOM FISHING **recovery rates**	Yes	Yes because traditional studies such as caging would not be adequate	*Provide a control site	*Representative/ matched to treatment area *Eliminate bottom fishing gear effects *Could be a small area *Should not exclude other activities *Replication is necessary *Identifiable to public	*Enforcement/ Physical Marking *Cost and Commitment *Public Acceptance and Compliance *Displacement of Bottom Fishing *Education *Identification of the area *Size of area selection *Requires long-term study *Regional Oceanography/ Climatology	*Size options **a priori* distribution of fished area *Bottom type *composition of invert species *Literature review *Experimental design *Usage data/ overflights *Info on removals at GR *Biology and growth rates of spp of concern

APPENDIX B: CONTINUED

Research questions to support management priorities	Could a Research Area provide significant information to address Management concerns?	Is a Research Area necessary?	Why would or why wouldn't the research area address the concerns?	What should be the characteristics of the area? (e.g. physical properties, activities)	What are the issues of concern? (e.g. user concerns, cons, costs, scientific process)	What are some additional information needs or requirements prior to establishment of area?
SESSILE INV/BOTTOM indirect effects	Yes	Yes because traditional studies such as caging would not be adequate	*Provide a control site	*Representative/ matched to treatment area *Eliminate bottom fishing gear effects *Could be a small area *Should not exclude other activities *Replication is necessary *Identifiable to public *Possibly a larger area is required to capture indirect effects	*Enforcement/ Physical Marking *Cost and Commitment *Public Acceptance and Compliance *Displacement of Bottom Fishing *Education *Identification of the area *Size of area selection *Requires long-term study *Regional Oceanography/ Climatology *Additional studies are required to investigate the details of indirect effects	*Size options **a priori* distribution of fished area *Bottom type *composition of invert species *Literature review *Experimental design *Usage data/ overflights *Info on removals at GR
BOTTOM FISH/ BOTTOM FISHING direct effects	Yes	Yes	*Provide a control site	*Representative/ matched to treatment area *Eliminate bottom fishing gear effects *Could be a small area *Should not exclude other activities *Replication is necessary *Identifiable to public *Intermediate size *Non-destructive sampling *Long-tem measured in generation time of spp of concern *Requires comparative site within GR	*Enforcement/ Physical Marking *Cost and Commitment *Public Acceptance and Compliance *Displacement of Bottom Fishing *Education *Identification of the area *Size of area selection *Requires long-term study *Regional Oceanography/ Climatology *Size to capture edge/halo effect	*Fish movement *Need regional population estimate supplemented by estimates of removal rates at GR
SESSILE INV/ BOTTOM FISHING recovery rates	Yes	Yes because traditional studies such as caging would not be adequate	*Provide a control site	*Representative/ matched to treatment area *Eliminate bottom fishing gear effects *Could be a small area *Should not exclude other activities *Replication is necessary *Identifiable to public	*Enforcement/ Physical Marking *Cost and Commitment *Public Acceptance and Compliance *Displacement of Bottom Fishing *Education *Identification of the area *Size of area selection *Requires long-term study *Regional Oceanography/ Climatology	*Size options **a priori* distribution of fished area *Bottom type *composition of invert species *Literature review *Experimental design *Usage data/ overflights *Info on removals at GR *Biology and growth rates of spp of concern

APPENDIX B: CONTINUED

Research questions to support management priorities	Could a Research Area provide significant information to address Management concerns?	Is a Research Area necessary?	Why would or why wouldn't the research area address the concerns?	What should be the characteristics of the area? (e.g. physical properties, activities)	What are the issues of concern? (e.g. user concerns, cons, costs, scientific process)	What are some additional information needs or requirements prior to establishment of area?
BOTTOM FISH/ BOTTOM FISHING recovery rates	Yes	Yes	*Provide a control site	*Representative/ matched to treatment area *Eliminate bottom fishing gear effects *Could be a small area *Should not exclude other activities *Replication is necessary *Identifiable to public *Intermediate size *Non-destructive sampling *Long-tem measured in generation time of spp of concern *Requires comparative site within GR	*Enforcement/ Physical Marking *Cost and Commitment *Public Acceptance and Compliance *Displacement of Bottom Fishing *Education *Identification of the area *Size of area selection *Requires long-term study *Regional Oceanography/ Climatology *Size to capture edge/halo effect *More frequent sampling *Recruitment rates *Fish growth rates *Mortality rates *Life history *Production (secondary)	*Size options **a priori* distribution of fished area *Bottom type *composition of invert species *Literature review *Experimental design *Usage data/ overflights *Info on removals at GR *Fish movement *Need regional population estimate supplemented by estimates of removal rates at GR *Baseline fish population data
BOTTOM FISH/ BOTTOM FISHING spearfishing effects on fish behavior	Yes	Yes	*Provide a control site	*Representative/ matched to treatment area *Eliminate bottom fishing gear effects *Could be a small area *Should not exclude other activities *Replication is necessary *Identifiable to public *Intermediate size *Non-destructive sampling *Requires comparative site within GR	*Difficult to distinguish behavior vs take (i.e. why aren't fish there) *Behavior of fish could affect other studies	
SESSILE INV/ BOTTOM FISHING recovery rates	Yes	Yes because traditional studies such as caging would not be adequate	*Provide a control site	*Representative/ matched to treatment area *Eliminate bottom fishing gear effects *Could be a small area *Should not exclude other activities *Replication is necessary *Identifiable to public	*Enforcement/ Physical Marking *Cost and Commitment *Public Acceptance and Compliance *Displacement of Bottom Fishing *Education *Identification of the area *Size of area selection *Requires long-term study *Regional Oceanography/ Climatology	*Size options **a priori* distribution of fished area *Bottom type *composition of invert species *Literature review *Experimental design *Usage data/ overflights *Info on removals at GR *Biology and growth rates of spp of concern

APPENDIX B: CONTINUED

Research questions to support management priorities	Could a Research Area provide significant information to address Management concerns?	Is a Research Area necessary?	Why would or why wouldn't the research area address the concerns?	What should be the characteristics of the area? (e.g. physical properties, activities)	What are the issues of concern? (e.g. user concerns, cons, costs, scientific process)	What are some additional information needs or requirements prior to establishment of area?
BAIT FISH / PELAGIC FISHING **effect of pelagic take on bait pops and reef structure**	No	No				
BAIT FISH **% of bait fish activity outside GR vs inside GR**	No	No				
PELAGIC FISH/ PELAGIC FISHING **direct effects (e.g. structure, pops.)**	Unknown	No				*Need regional population estimate supplemented by estimates of removal rates at GR
PELAGIC FISH/ PELAGIC FISHING **Effects on migratory behavior**	No	No				

APPENDIX C: RAWG MATRIX 4, SUMMARY OF PROPOSED STUDIES WITHIN THE RESEARCH AREA.

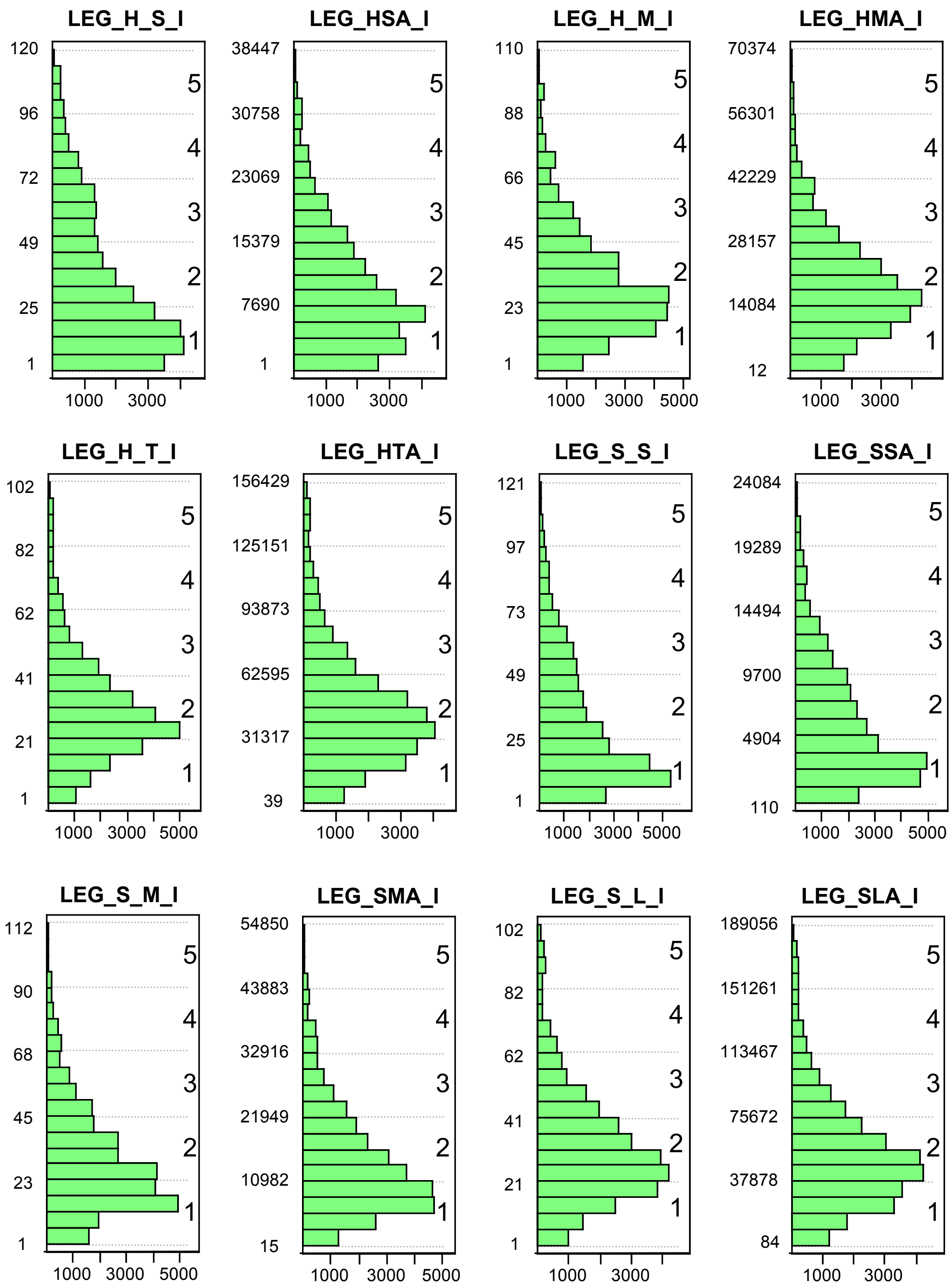
Gray's Reef National Marine Sanctuary Sanctuary Advisory Council Research Area Concept Working Group Workshop II October, 2004	**Proposed Studies to be conducted in a Research Area at GRNMS**							
	Sessile Invertebrates/Bottom Fishing			**Mobile Invertebrates/ Bottom Fishing**	**Bottom Fish/Bottom Fishing**			
Requirements	**Fishing Gear Effects**	**Recovery Rates**	**Indirect Effects**	**Effect of Predators**	**Direct Effects**	**Recovery Rates**	**Spearfishing v angling**	**Spearfishing effects on fish behavior**
Objective	Evaluate the impacts of bottom fishing gear on benthic invertebrate populations (priority organisms include sponges and corals). Can be expanded to look outside.	Determine the rate of recovery of populations of sessile inverts following various levels of disturbance by bottom fishing gear	Determine the nature and extent of indirect effects (e.g., changes in benthic food webs) caused by changes in benthic communities due to bottom fishing	Characterize the mobile invert communities in the absence of fishing	Determine the level to which benthic fish populations are reduced by bottom fishing effort	Determine the rate of recovery for species targeted by bottom fishing	Ascertain differences in the level of impact on benthic fish populations caused by spearfishing and angling	Determine what aspects of fish behavior (e.g., schooling, feeding, mating, predation, symbioses) are affected, the extent of effects (temporary or long-term), and impacts of changes caused by spearfishing
Research/ Sampling Requirements	Document incidences of injury only (simple counts) vs. more detailed benthic characterizations including injuries	Lower end - follow recovery of documented injury in Fishing Gear Effects study - Compare recruitment, abundance, condition and growth in closed vs reference areas or manipulative experiment	High end - trophic structure studies (i.e. gut contents, predator-prey, energy flow models)	Low end - 1)Predator exclusion/ inclusion experiment w/cages, 2)Predator and prey censuses before and after closure	Low end - 1) Benthic fish censuses before and after closure	Low end - 1) Benthic fish censuses before and after closure		
Habitat Type/ Specific Place	Densely and Sparsely colonized Live Bottom			All habitats			Live Bottom with target species of both activities (e.g. black sea bass are bottom-fished, not spearfished)	Live Bottom with high density of target species
Size	VS			S, M, L	M-L		VS - M	VS - M
Number of Research Areas	3 VS or 1 M-L (to accommodate plots)			3S or 1 M-L (to accommodate plots)	3M or 1 L (to accommodate plots)		2 to 12	2 to 12
Design Option	A or B (C or BC if outside)						All but D	All but D
Duration	2 - 5 years	5 -10 years	3 - 10 years	5-7 years		10-15 years	4 - 10 years	18 months - many years (up to 20yrs)
Marking	Yes, buoys for closed area						Yes, buoys for closed area (would be challenging)	Yes, buoys for closed area
Enforcement	Yes,Onsite and/or remote - requires outreach and education						from random inspections to onsite and/or remote (would be challenging)	from random inspections to onsite and/or remote
Outreach	Yes to tell what, why and for how long - seminars, flyers, print, news, web, visualization techniques, media, marking on charts, buoy labeling, notices to mariners, etc.						Yes, from announcements to results published to "why, how, who" (need would be greater presumably due to complicated nature of study)	Yes, from announcements to results published to "why, how, who"
Displacement/ Prohibited Activities	Bottom Fishing, Spearfishing, Bottom-impinging trolling,						From No Entry to no take to no bottom fishing to no bottom or spearfishing to no spearfishing	From No Entry to no take to no bottom fishing to no bottom or spearfishing
Ancillary Data Requirements	Fishing Effort by gear type, compliance, Physical measurements including episodic events	Fishing Effort by gear type, compliance, Physical measurements including episodic events, Lit Review (e.g., growth rates)	Fishing Effort by gear type, compliance, Physical measurements including episodic events, Lit Review (e.g., population and community ecology)	Predator and Prey home ranges, Gut content studies, compliance, Physical measurements including episodic events, Lit Review	Benthic fish home ranges, compliance, Physical measurements including episodic events, Lit Review, fishing effort by gear type	Benthic fish home ranges, compliance, Physical measurements including episodic events, Lit Review, fishing effort by gear type	Effort for all activities, Boat Counts, Physical measurements, Extensive Lit Review (info on life histories, ecosystem, regional oceanography/ climatology, edge effect, movement, regional estimate of population size, growth rates, mortality rates, life history, recruitment rates)	Need to know number and behavior of spearfishermen, Boat Counts, Physical measurements, Lit Review (info on life histories, movement)
Research Costs	$15K to $200K/yr above and beyond GRNMS logistical support (would include grant funds)		>$300K	$50K - $100K/yr			For this project - "Minimal" to $500K total For all projects - $350K to $1M/year	For this project - "Minimal" to $150K total For all projects - $350K to $1M/year
Notes	Assuming no anchoring, unclear about the effects of bottom-impinging trolling, also practicality of enforcement might be easier to close the area to all fishing, if GRNMS staff had time to participate the research costs would be substantially reduced, more buoys = increased cost and more hassle, assume minimum 3 year baseline data prior to implementation of research area, concern for the potential impact of non-permitted/ recreational divers on experiments.	assume minimum 3 year baseline data prior to implementation of research area,concern for the potential impact of non-permitted/recreational divers on experiments.	Formulation of specific questions and feasibility of study depend on results from fishing gear effects and recovery rate studies. assume minimum 3 year baseline data prior to implementation of research area, concern for the potential impact of non-permitted/recreational divers on experiments.		Alternative to measuring removal of target species can be done through census of fishing effort by gear type. Should the spearfishing ban not be adopted at GRNMS, it could be included in this study			

APPENDIX D: RAWG MATRIX 5B, RAWG CONSENSUS ON POTENTIAL BOUNDARY SIZES PRIOR TO THE PRESENT ANALYSIS.

Size of Research Area (km)	Total Score	Ease of Enforcement			Statistical Power			Scientific usefulness		
		pros	cons	score (1-10)	pros	cons	score (1-10)	pros	cons	score (1-10)
1X1	13	* Buoy cost is lowest * More acceptable, better compliance		10	* more reference area available	* # of samples too low * sample independence	1	* Addresses invertebrate issues and some reef fish issues	* Edge effect too large * Unlikely to encompass home range * Possibly displaces fishing pressure on reference area	2
2X2	22		* Buoy costs are higher. Need 8 buoys (assuming 1 buoy per km)	9	* Better than 1X1 * Leaves adequate reference area		6	* May encompass close to 50% of high relief hardbottom * May be situated to reduce edge effect * Potential to examine 4 different treatments (2in, 2out)	* Edge effect potentially large * Hard to locate away from reference * Possibly displaces more fishing pressure on reference area	7
3X3	23		* Increasing buoy costs	8	* Better than 2X2 depending on reference area left	* May not leave adequate reference	7	* Reduced edge effect * More likely to include home range of target organisms	* Possibly displaces more fishing pressure on reference area	8
4X4	20		* Increasing buoy costs	7	* More sites for sampling * Greater sample independence	* Fewer options for reference	5	* Least edge effect * Most likely to include home range of target organisms * Include greater number of species	* Possibly displaces more fishing pressure on reference area	8

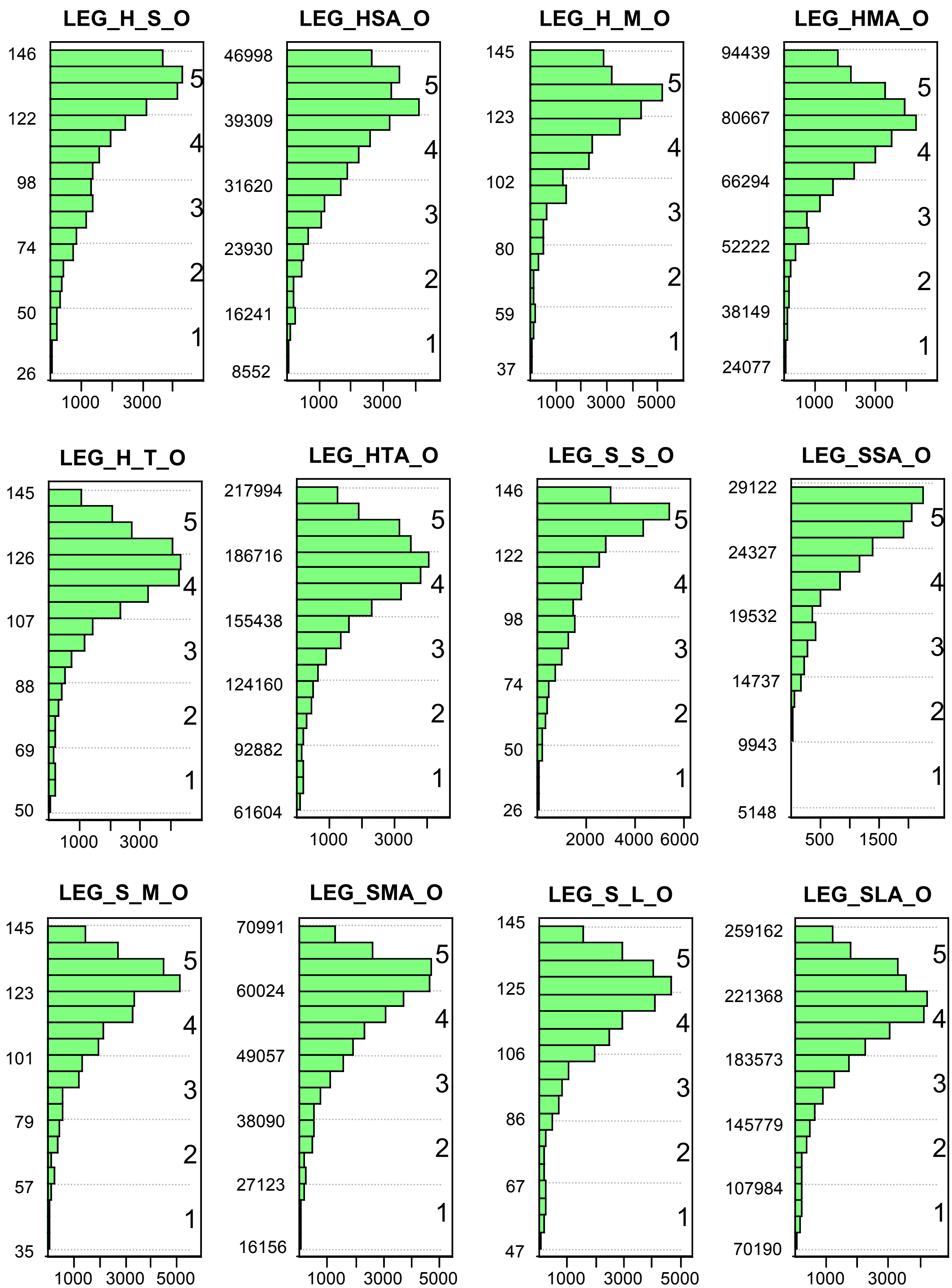
APPENDIX E: DISTRIBUTION OF VALUES AND SCORES FOR EACH VARIABLE.

Histograms of ledge variables inside the boundary options. The dotted lines denote the 20% breakpoints based on minimum and maximum values for each variable.



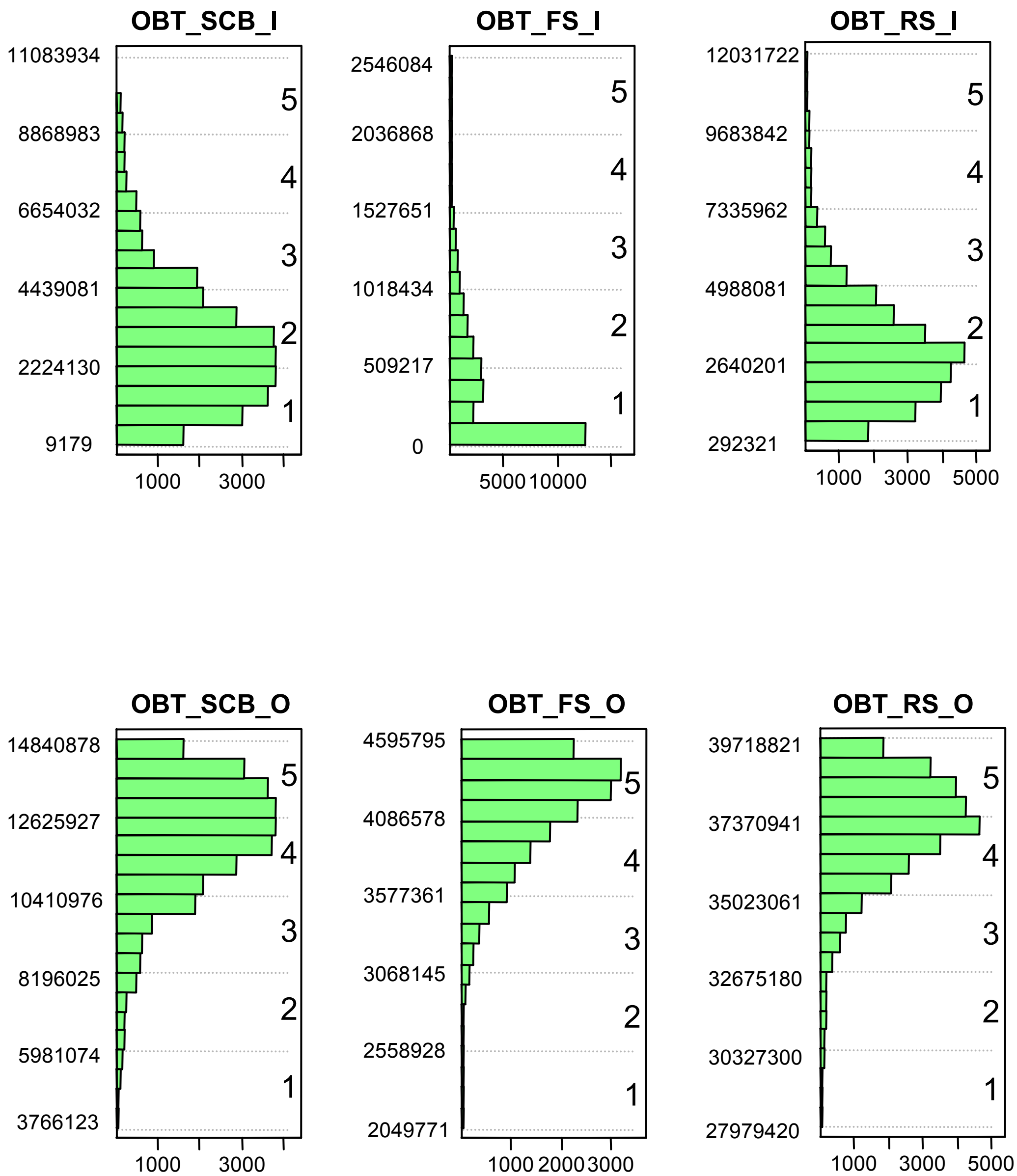
APPENDIX E: CONTINUED

Histograms of ledge variables outside the boundary options. The dotted lines denote the 20% breakpoints based on minimum and maximum values for each variable.



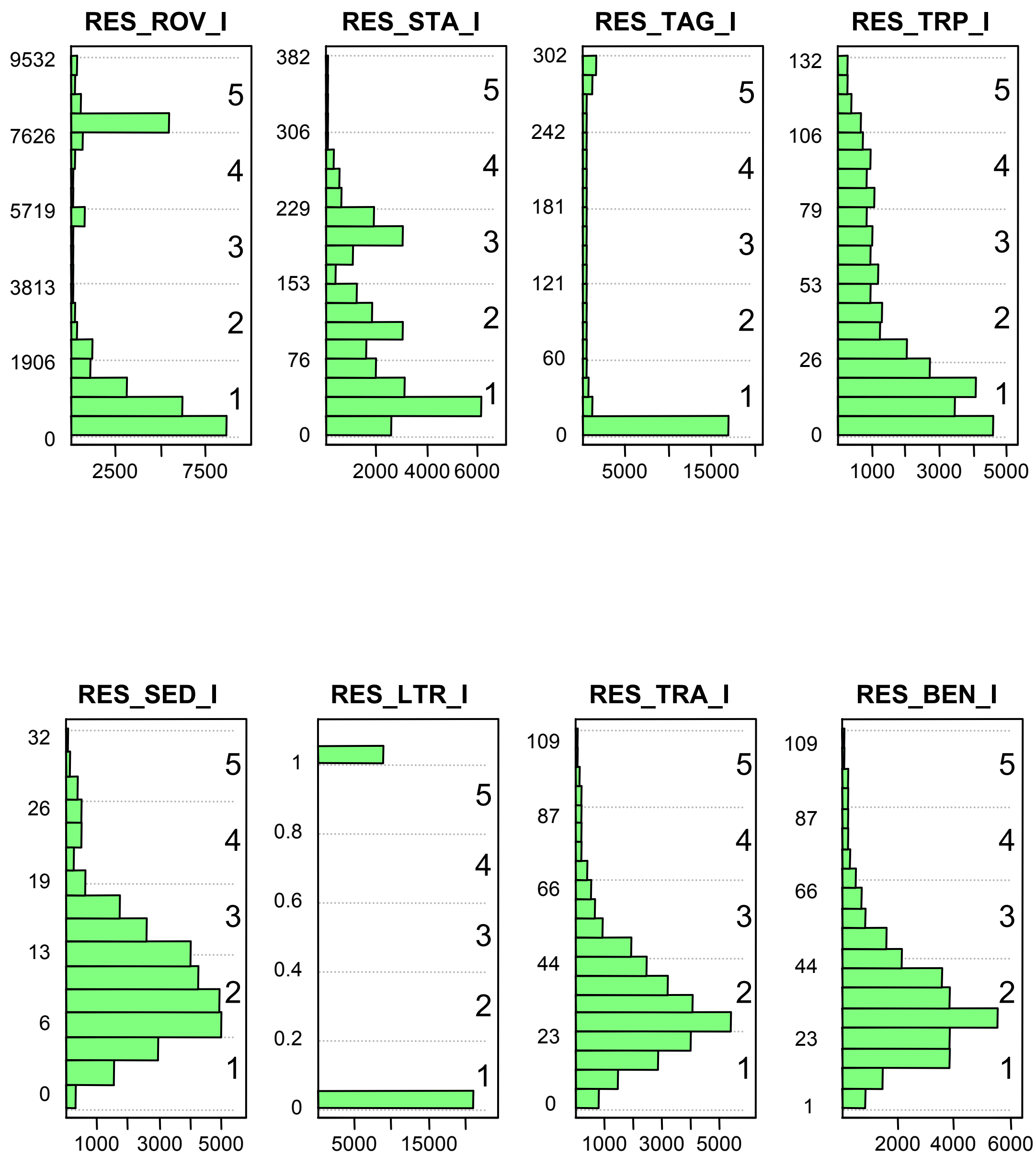
APPENDIX E: CONTINUED

Histograms of bottom type variables inside and outside the boundary options. The dotted lines denote the 20% breakpoints based on minimum and maximum values for each variable.



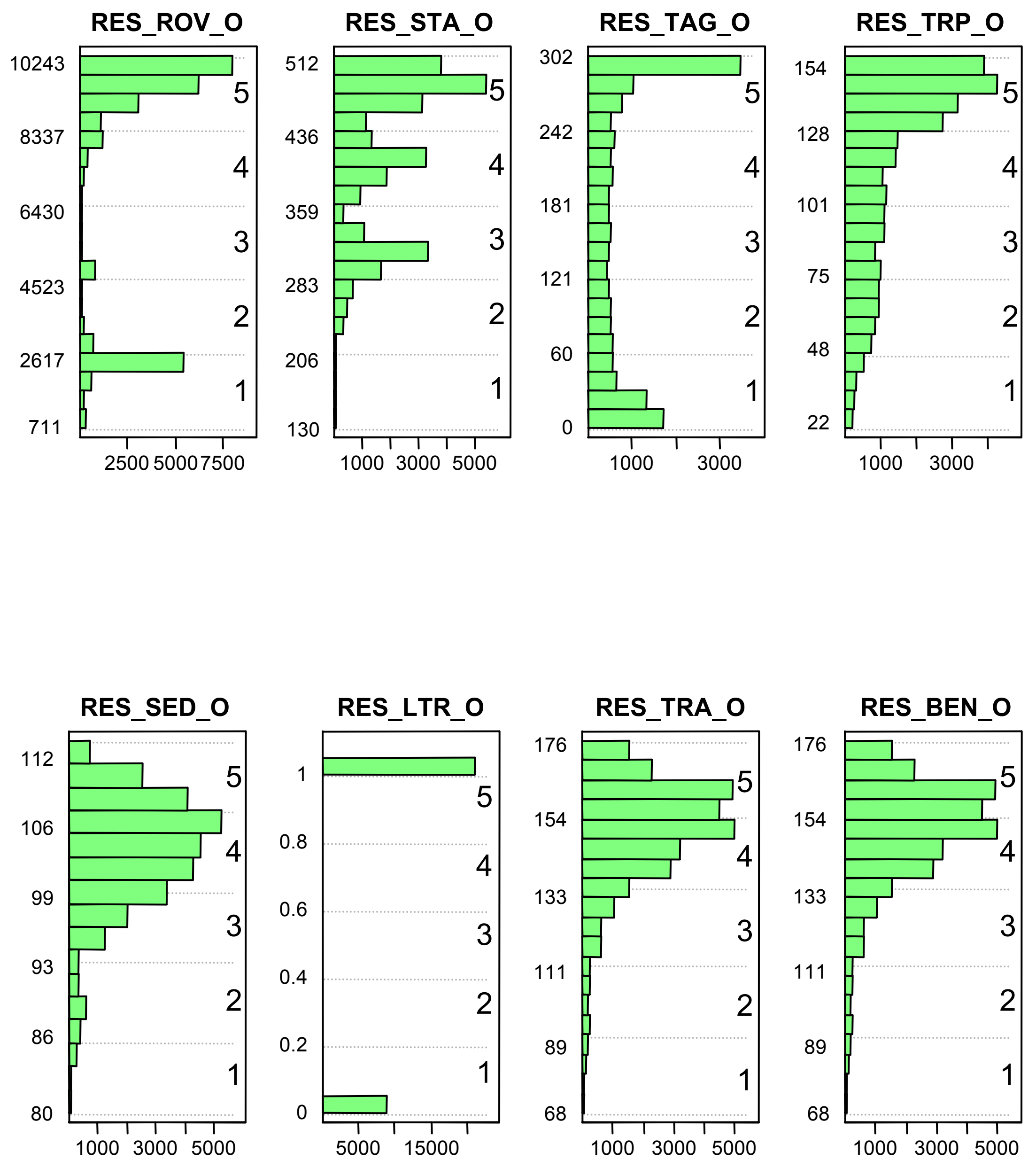
APPENDIX E: CONTINUED

Histograms of prior research variables inside the boundary options. The dotted lines denote the 20% break-points based on minimum and maximum values for each variable.



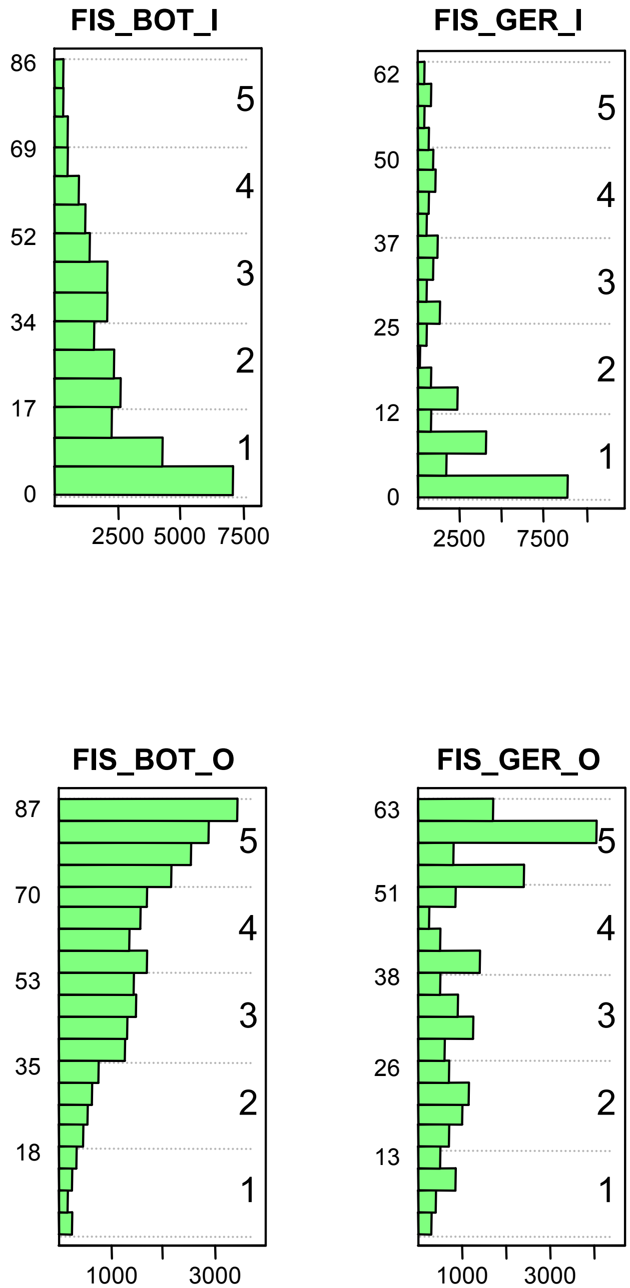
APPENDIX E: CONTINUED

Histograms of prior research variables outside the boundary options. The dotted lines denote the 20% break-points based on minimum and maximum values for each variable.



APPENDIX E: CONTINUED

Histograms of fishing effort variables inside and outside the boundary options. The dotted lines denote the 20% breakpoints based on minimum and maximum values for each variable.



APPENDIX F: VARIABLE VALUES OF THE EIGHT OPTIONS SHOWN IN FIGURE 14.

	Square 3x3 km, 0°	Square 3x3 km, 30°	Square 3x3 km, 45°	Hexagon 9 km²	Square 4x4 km, 0°	Square 4x4 km, 0°	Square 4x4 km, 0°	Square 4x4 km, 45°
LEG_H_S_I	35	72	62	72	63	59	25	60
LEG_H_S_O	111	75	84	76	84	87	121	89
LEG_HSA_I	11392	18494	17435	19439	24561	15234	9153	21909
LEG_HSA_O	35607	28505	29564	27560	22438	31765	37846	25090
LEG_H_M_I	24	36	28	59	76	28	41	71
LEG_H_M_O	122	110	119	90	71	118	106	76
LEG_HMA_I	15391	20893	17276	29900	47481	14778	28575	51340
LEG_HMA_O	79060	73558	77175	64551	46970	79673	65876	43111
LEG_H_T_I	33	29	34	32	74	28	53	80
LEG_H_T_O	112	124	114	116	77	118	95	70
LEG_HTA_I	63111	44522	57786	39894	105415	54712	77434	113595
LEG_HTA_O	154922	173511	160247	178139	112618	163321	140599	104438
LEG_S_S_I	29	66	56	71	56	55	28	56
LEG_S_S_O	117	81	90	75	91	91	118	92
LEG_SSA_I	5489	11048	9556	13083	12119	9265	6380	12019
LEG_SSA_O	23743	18184	19676	16149	17113	19967	22852	17213
LEG_S_M_I	33	41	36	57	79	34	36	68
LEG_S_M_O	113	106	111	92	70	111	111	78
LEG_SMA_I	16540	19277	17254	26978	38293	16546	16782	32637
LEG_SMA_O	54466	51729	53752	44028	32713	54460	54224	38369
LEG_S_L_I	30	30	32	35	78	26	55	87
LEG_S_L_O	115	122	116	115	71	121	93	65
LEG_SLA_I	67864	53583	65687	49172	127045	58913	92000	142189
LEG_SLA_O	191382	205663	193559	210074	132201	200333	167246	117057
OBT_SCB_I	2747445	3755571	3563823	5035382	8355137	3262932	4348286	6948580
OBT_SCB_O	12102611	11094485	11286233	9814670	6494920	11587124	10501770	7901477
OBT_FS_I	686925	1482325	1129570	860855	99889	2546084	282640	113019
OBT_FS_O	3908870	3113470	3466225	3734940	4495906	2049711	4313155	4482776
OBT_RS_I	5475736	3678196	4214111	3014475	7367518	10106258	11253913	8751558
OBT_RS_O	34535406	36332946	35797031	36996700	32643624	29904884	28757229	31259584
RES_ROV_I	7628	7510	7710	255	1197	7710	1728	2061
RES_ROV_O	2615	2733	2533	9988	9046	2533	8515	8182
RES_STA_I	204	183	225	35	115	225	158	167
RES_STA_O	308	329	287	477	397	287	354	345
RES_TAG_I	17	295	235	294	15	154	0	22
RES_TAG_O	285	7	67	8	287	148	302	280
RES_TRP_I	63	87	90	69	45	87	29	57
RES_TRP_O	91	67	64	85	109	67	125	97
RES_SED_I	11	14	15	18	24	24	27	26
RES_SED_O	101	98	97	94	88	88	85	86
RES_LTR_I	1	1	1	0	0	1	0	0
RES_LTR_O	0	0	0	1	1	0	1	1
RES_TRA_I	38	45	44	51	68	48	46	72
RES_TRA_O	139	132	133	126	109	129	131	105
RES_BEN_I	38	45	44	51	68	48	46	72
RES_BEN_O	139	132	133	126	109	129	131	105
FIS_BOT_I	50	18	32	7	39	29	39	56
FIS_BOT_O	37	69	55	80	48	58	48	31
FIS_GER_I	1.13	0.13	0.59	0	0.43	0.44	0.41	0.54
FIS_GER_O	0.14	0.43	0.28	0.5	0.31	0.33	0.34	0.23

United States Department of Commerce

Carlos M. Gutierrez
Secretary

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