Northeast Consortium

The University of New Hampshire • Woods Hole Oceanographic Institution
The University of Maine • Massachusetts Institute of Technology

Cooperative Research Project Final Report

Project Title: Intensive Study of the Western Gulf of Maine Closure Area

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Raymond E. Grizzle, Ph.D.

Abstract

This project was an interdisciplinary investigation of the effects of the Western Gulf of Maine (WGOM) closure area. It represented the initial stages of a planned longer-term program to determine various ecosystem-level impacts of the closure. The focus of most of the NEC-funded portion of the project was on seafloor conditions in a 400 km^2 (150 mi^2) study area located along the western boundary of the closure, half inside and half outside. Following an initial multibeam sonar mapping effort that produced a 5-m pixel resolution bathymetric map of the study area, approximately 170 sites were sampled with some combination of box corer, Shipek grab, and towed videography to characterize sediments, infauna, and epifauna. Bottom types ranged from mud sediment in deep water (>100 m) dominated by deposit-feeding infauna to hard bottom (gravel and boulders) in water <80 m dominated by epifaunal organisms. There were significantly ($p<0.05$) higher (up to 2.5x) density, biomass, and taxonomic richness (family level) for epifauna on rocky bottoms inside the closure compared to outside. Infaunal density and taxonomic richness were significantly ($P<0.05$) higher (up to 4x) inside the closure compared to outside, with the most differences in sandy sediments. These "in vs. out"differences in univariate measures were also reflected by differences in community taxonomic composition. Overall, these data indicate that removal of gillnets (mainly used in rocky habitats) and otter trawls (mainly used in soft sediment habitats) has allowed substantial recovery of seafloor invertebrate communities in some areas within the closure.

Introduction

In 1997, the major portion (areas west of 70° W longitude) of the present Western Gulf of Maine (WGOM) closure area was established as part of the overall effort to re-build depleted groundfish stocks. Although some commercial gear types (e.g., lobster traps, shrimp trawls) and recreational fishing are permitted, commercial fishing gear capable of retaining groundfish is prohibited year-round. The entire WGOM closure area, which is approximately 32 km (20 mi) wide (east-west) and 113 km (70 mi) long (north-south), is located off the southern Maine, New Hampshire, and Massachusetts coasts and includes much of Jeffreys Ledge (Fig. 1). It represents one of the largest closures in the United States designed to provide protection for habitat and help in the recovery of over-fished species. The general area has been a primary fishing ground for cod, other gadids, and flatfish for centuries.

No research had been published before the present project on how seafloor habitats may have been affected by the WGOM closure. However, one similar investigation was being conducted concurrently, and two reports are available from this study (Knight 2005; Knight et al. 2006). This NEC-funded research was focused in areas that were mainly affected by bottom trawls. The present project included areas primarily fished by gillnets as well as areas fished mainly by bottom trawls.

There has also been only a meager amount of research on how the closure may have affected fish populations. Recent analyses of commercial trawl data (Murawski et al. 2004) and groundfish tagging studies (Howell & Goethel 2004) suggested no appreciable effect of the closure on stock rebuilding in the region, although there has been substantial recovery of some groundfish stocks since the closure was implemented (Mayo & Terceiro 2005). Based on studies of MPAs in other areas, including New England (e.g., Collie et al. 2005), it seems reasonable to expect that a closure of the magnitude of the WGOM area would have a measurable impact on habitat recovery and fish stock rebounds. Its role in these respects, however, remains to be demonstrated.

The present project was a multifaceted, interdisciplinary study designed as the initial stages of a long-term comprehensive assessment of the WGOM closure. It involved the use of existing data as well as gathering new data, and included the first steps in a social science component. The

ecological mapping components involved obtaining and assessing satellite imagery available on the web, obtaining new multibeam sonar imagery, gathering and assessing new data on bottom characteristics, and producing new maps based on individual and combined datasets. The present report includes all these components but focuses on assessment of seafloor conditions in a 400 km^2 (~150 mi^2) area located along the western boundary of the closure area (Fig. 1).

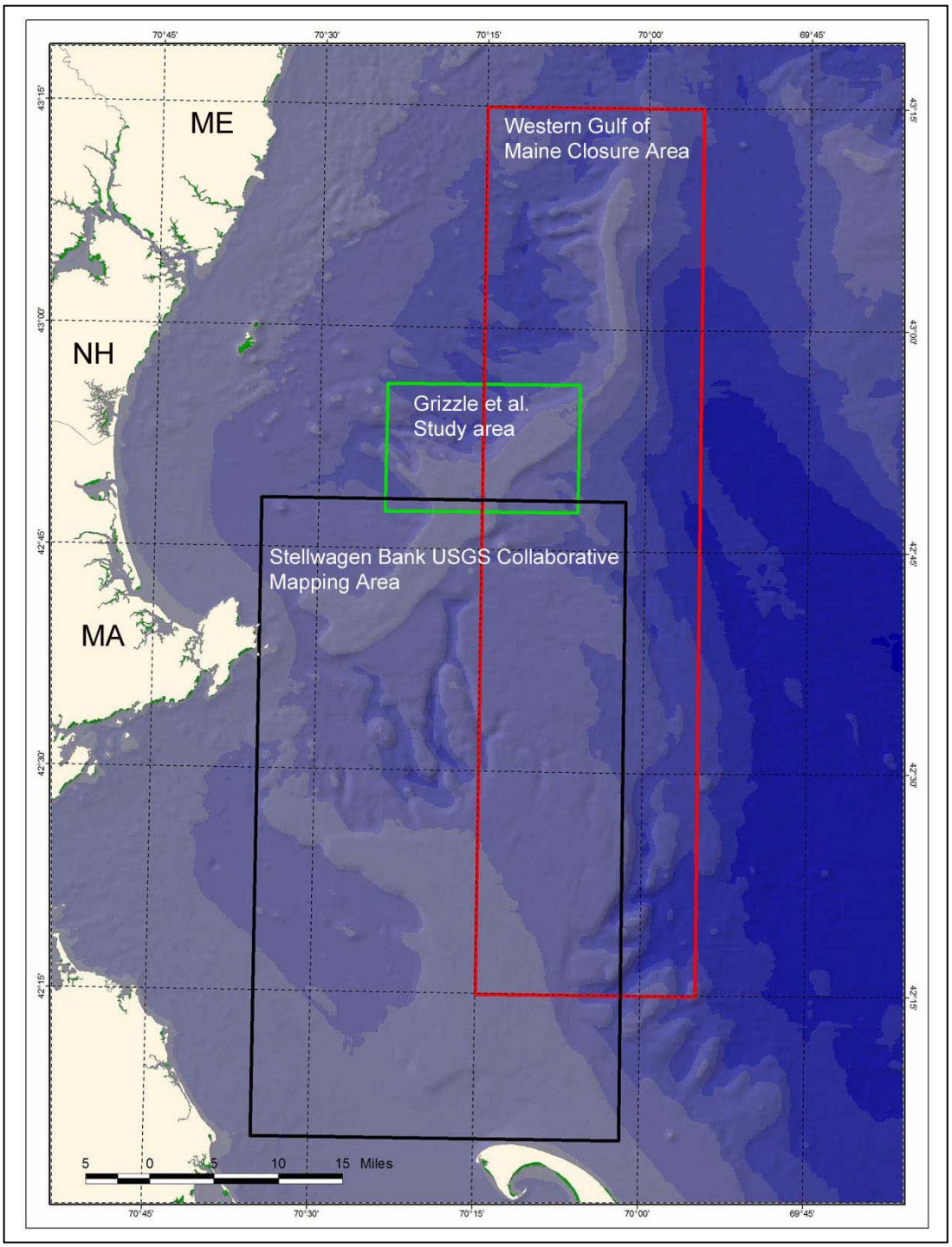

Fig. 1. Location of 400 km^2 (~150 mi^2) study area ("Grizzle et al. Study Area" box) for present project and Stellwagen Bank study area recently surveyed by USGS with high resolution multibeam sonar. Background map is 90-m resolution bathymetry from USGS.

Project objectives

The long-term goal of the overall program (which received funds from NEC and the UNH/NOAA Cooperative Institute of New England Mariculture and Fisheries [CINEMAR; now the Atlantic Marine Aquaculture Center, AMAC]; see Related Projects section below) was to provide an ecosystem-level understanding of the WGOM closure. The present project should be viewed as a first-step in meeting this goal by addressing three major objectives:

Objective 1. Characterize the ecosystem within and adjacent to the Western Gulf of Maine closure area with respect to primary production, sea surface temperature, major bottom habitats, and fine-scale information on seafloor shape and type.
Objective 2. Begin to examine the relationship between groundfish and their habitats.
Objective 3. Initiate a long-term assessment of the effects of the closed area on various ecosystem characteristics and social aspects.

Although not intended to exhaustively address any of these objectives, the present NEC-funded project made substantial progress on Objectives 1 and 3, and these are the focus of this report.

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Methods

Water column

Near-surface chlorophyll *a* concentrations and sea surface temperatures were characterized for the entire Gulf of Maine using data from SeaWiFS (Sea-viewing Wide Field-of-view Sensor) and MODIS (moderate resolution imaging spectrometer) satellite databases available on the web. Temporal datasets from 1997 to 2001 were extracted for selected areas within and outside of the WGOM closure.

Seafloor topography

Most of the 400 km^2 study area (Fig. 1) was surveyed in late December 2002 and early January 2003 using a Reson 8101 MBES (240 kHz) multibeam sonar unit (see Malik & Mayer 2007 for details; also see http://woodshole.er.usgs.gov/projectpages/coastal_mass/html/jeffledge.html). Bathymetric and backscatter data were processed, and a single map based mainly on bathymetric data was produced.

Bottom habitats

Study design

The overall assessment of WGOM closure area impacts on bottom habitats was a Control-Impact (or After-Only) type study using systematic sampling of the seafloor at approximately equal numbers of sites distributed inside and outside of the closed area (Figs. 1 and 4). Target sampling sites were located at 1-min intervals (~1.5 km) of latitude and longitude, yielding a total of 216 potential sampling sites within the overall 400 km^2 study area. A combination of techniques was used at each site, including towed video (for epifauna and general seafloor conditions) and Shipek grab or Wildco box corer (for infauna and sediments), as described below.

Field and laboratory methods

All seafloor sampling occurred from June 2002 through September 2005. However, most sampling occurred during 2002 (~65% of the Shipek grab and box core sampling) and 2004 (~90% of the video sampling, and ~30% of the Shipek grab and box core sampling). Hence, 90-95% of all seafloor sampling occurred during 2002 and 2004. Commercial fishing vessels were used for nearly all field sampling efforts. Methods for infauna and sediments (box corer or Shipek grab), and epifauna (towed video) were as follows.

Bottom sediments were sampled with either a Wildco box corer (Fig. 2) with a design sampling area of 0.0625 m^2, or a Shipek grab with design sampling area of 0.04 m^2. Depth of sediment penetration was measured to the nearest 0.5 cm on each sample, and a subsample of sediment was taken for grain size and organic content analyses (see below). Box core samples were rejected if they did not penetrate 5 cm into the sediment, and Shipek grab samples with less than 2 cm penetration were rejected. The contents of the box corer were subsampled with a 10.4 cm ID (0.0085 m^2) acrylic core tube and washed through a 0.5 mm mesh sieve, fixed in 3% formalin, and preserved in 70% isopropanol. The entire Shipek grab contents were washed on a 0.5 mm mesh sieve and treated as described above. In the laboratory, all invertebrates were removed under 3x magnification, sorted by major taxa, identified (to family level in most cases), counted, and weighed (wet weight of preserved specimens).

Bottom sediments were analyzed for grain size composition (texture) using standard sieve and pipette analytical techniques (Folk 1980). Organic content was determined by loss-on-ignition (LOI) after 4 hours at 450 ^{O}C.

Epifaunal organisms were characterized from bottom videography taken with a camera system (UNH Hubbard Camera; Fig. 3) composed of a video camera mounted on a frame with synchronized strobe lights and an integrated positioning system (GPS). At each station the camera was suspended near the bottom (within 50 cm) and 6 to 10 minutes of downward looking video was recorded along a drift transect of at least 50 m length. For quantitative analyses, the video from each transect was subsampled to isolate the highest quality stills so that a series of non-overlapping images along the length of the transect was produced. Each still image was analyzed for bottom characteristics (sediment type, roughness), visible burrow characteristics (size, density), and epifauna (taxa, density). A trio of laser beams fixed at known distances apart in each scene allowed the total area of each image to be determined.

Fig. 2. Jamie Adams (left) and Craig Mavrikis processing box core sample aboard the *F/V Marion Mae*.

Fig. 3. Hubbard underwater video camera system with some example seabed imagery. Orange spots (15 cm apart) in triangle pattern on each image are lasers used to provide scale for making measurements of underwater features.

Data analysis

The major focus of this part of the project was to determine the impacts of the WGOM closure on seafloor conditions by comparing samples taken inside the closure with samples taken outside. Thus, potential confounding factors (e.g., sediment type, water depth, and sediment organic content) that might affect simple "in vs. out" comparisons were assessed. Also, for the infauna analyses, data from the two sampling devices (box corer and Shipek grab) were analyzed separately to avoid issues with different sample sizes and different selectivity of the gear. Two basic approaches, univariate emphasizing total community characteristics such as density and biomass, and multivariate focusing on taxonomic composition, were used to assess the benthic data.

Infauna (box corer and Shipek grab). For both infauna sampling devices, the role of sediment texture (defined as 3-level unordered categorical variable: sand, mud, and gravel), water depth, sediment organic content, and relative penetration of the sampling device were assessed along with the variable of primary interest: whether the sample was taken from inside or outside the closure. Separate analyses were performed to examine each of the three dependent univariate community variables: (1) density, (2) biomass, and (3) taxonomic richness.

For univariate assessments of the infauna data, all analyses were performed using generalized linear models (GLM, McCullagh & Nelder 1989) in S-PLUS 7.0 (Insightful Corporation). For normally distributed data or data that could be transformed to approximate normality, significance for main effects and interactions were examined using a combination of forward- and backward model selection based on the C_p statistic and sequential F-tests in an analysis of deviance with alpha levels of 0.05 and 0.10, respectively. For non-normally distributed data, significance for main effects and interactions were examined using sequential Chi-square tests in an analysis of deviance with alpha levels of 0.05 and 0.10, respectively. For each model, the inclusion of either Gaussian or exponential spatial correlation was examined using the extended generalized linear modeling capabilities in the S-PLUS correlated data library.

Multivariate assessments of the infauna data at the time of this report (March 2008) have been limited to identification of the dominant taxa associated with each habitat type (see Epifauna

methods below) and how these taxonomic assemblages differ inside compared to outside of the WGOM closure area.

Epifauna (video transects). For univariate assessments, a generalized linear mixed-effects (GLME) model with poisson error and log link was used to analyze the video count data (Breslow & Clayton 1993). The mixed-effects portion of the model was necessary to account for multiple scenes within each transect and the scenes may have been correlated. GLMEs are similar to poisson or log-linear regression, but directly account for the repeated-measures nature of the data and allow for individual transects to differ from one another for reasons unaccounted for by the data. The fixed-effects portion of the model generates coefficients that are applicable beyond the specific transects contained in the data, where as the random-effects portion of the model generates coefficients that describe how each transect in the dataset differs from the area as a whole.

S-PLUS 7.0 for Windows (Insightful Corp., Seattle, Washington, USA, 2005) software and the GLME extension from the S+ Correlated Data library (version 1.0, Release 1) within S-PLUS 7.0 was used for all analyses. The significance of each fixed-effect, both main effects (inside or outside the closure) and interactions, was tested in an ANOVA framework using marginal F-tests (Pinheiro & Bates 2000) based on the (restricted) penalized quasi-likelihood with an alpha-level of 0.05 for main effects and 0.10 for interaction effects (Sokal & Rohlf 1981). In addition to the main variable of interest (in vs. out), water depth, and sediment type were also assessed as potential confounding factors. Offsets were also included in each model to account for the fact that the total surface area observed differed by scene due to variations in the height of the camera. Separate analyses were performed to examine each of the two dependent univariate community variables: (1) total density and (2) taxonomic richness.

Multivariate assessments of the epifauna data at the time of this report (March 2008) have focused on development of a new habitat classification scheme based on the conceptual model in Auster & Langton (1999). The new classification includes eleven different habitat types (compared to eight in Auster & Langton 1999), and incorporates the concept of ecological succession. Five of the eleven habitat types represent an early ecological successional stage for a particular bottom sediment type and six represent a later successional stage (Table 1). The early stages in the new classification are what would be expected for bottom areas that are regularly disturbed by mobile fishing gear that contacts the bottom. For example, pebble-cobble bottoms that are regularly disturbed by bottom trawls would be expected to have minimal densities of attached epifaunal organisms such as sponges and anemones due to their removal by the fishing gear (see reviews by Dorsey & Pederson 1998; Watling & Norse 1998; Auster & Langton 1999; Johnson 2002; NRC 2002; Morgan & Chuenpagdee 2003). In contrast, pebble-cobble bottoms where fishing has ceased and that have not been physically disturbed otherwise (Auster & Langton 1999; DeAlteris et al. 1999; NRC 2002; Kaiser et al. 2006) for several years typically show some amount of recovery as epifauna recolonize the substrate. Our new classification scheme is based on this general model of chronic disturbance (removal of fauna) by fishing gear and recovery of the benthos via the process of ecological succession after disturbance ceases.

The criteria for each habitat type are given in Table 1. The primary criterion was sediment type: M=mud, sM=sandy mud, S=sand, mS=muddy sand, gmS=sand with gravel and mud, gS=sand with gravel, mG=muddy gravel, sG=sandy gravel, msG=gravel with mud and sand, G=gravel. The texture data were obtained from analysis of sediment samples from grab or box corer. Video imagery was used to determine the major component of the "gravel" category, which was either shell accumulations (dead mollusk shells), pebble-cobble, or boulders. Video imagery was also used to determine the relative amounts of infauna based on tubes (probably constructed by polychaetes and/or amphipods) projecting above the bottom and burrows, and of epifauna such as sponges, ascidians, and brachiopods.

Table 1. New bottom habitat classification scheme based on a conceptual model by Auster & Langton (1999) of how mobile fishing gear affects seafloor communities. The "Complexity" scale is taken from Auster & Langton (1999) and applied to the new category designations.

Auster & Langton (1999)	New classification scheme	Category	Complexity
Flat sand and mud (category 1)	Flat mud (minimal burrows, depressions, epifauna) [M or sM; infaunal tubes and burrows, and epifauna rare]	1	1
	Flat sand (minimal burrows, depressions, epifauna) [S, mS, gS, or gmS; infaunal tubes and burrow, and/or epifauna rare]	2	1
Sand waves (category 2)	Sand waves (N/A for our study area)		
Biogenic structure (category 3)	Mud with abundant large infauna and biogenic structure [M or sM; infaunal tubes and burrows, and epifauna common]	3	3
	Sand with abundant large infauna and biogenic structure [S, mS, gS, or gmS; infaunal tubes and burrow, and/or epifauna common]	4	3
	Soft sediment with cerianthid anemones [any sediment class; shell or no shell; cerianthid average density $\geq 1/m^2$]	5	4
Shell aggregates (category 4)	Shell accumulations with no/minimal epifauna [M, sM, S, mS, or gmS; shell accumulations; sponges, brachiopods, other epifauna rare]	6	5
	Shell accumulations with substantial epifauna [M, sM, S, mS, or gmS; shell accumulations; sponges, brachiopods, other epifauna common]	7	7
Pebble-cobble (category 5)	Pebble-cobble with no/minimal epifauna [mG, sG, msG, G; pebble or cobble dominant; sponges, brachiopods, other epifauna rare]	8	6
Pebble-cobble w/ sponges (cat 6)	Pebble-cobble with substantial epifauna [mG, sG, msG, G; pebble or cobble dominant; sponges, brachiopods, other epifauna common]	9	10
Partially buried boulders (cat 7)	Low-relief boulders (not determined for our study area)		
Piled boulders (category 8)	Boulders with no or minimal epifauna [any sediment class with 'boulders' >30% ; sponges, brachiopods, other epifauna rare]	10	12
	Boulders with substantial epifauna [any sediment class with'boulders' >30%; sponges, brachiopods, other epifauna common]	11	15

Social issues

Social issues were only addressed during the first two years of the study. Standard survey methods were used to develop a database on literature dealing with characteristics of the various stakeholders who had an interest in the WGOM closure.

Data

Table 2 summarizes the major datasets that were collected during the project. At the time of this report (March 2008) none of the datasets have been archived into the NEC Fisheries and Oceans Data Management System, but this will occur when the data have been fully processed.

Table 2. Summary of characteristics and status of data collected during the present study.

Topic Area	Major Attributes	Geographic Extent	Dates Covered	Custodian & Location of Data
Water column	Near-surface temp Near-surface chl a	Gulf of Maine	1997-2001	Dr. Michael Lesser, UNH
Bottom topography[1]	5-m resolution multi-beam bathymetry	400 km^2 area	2002-2003	Dr. Larry Mayer, UNH/CCOM
Bottom sediment	Texture, organic content	400 km^2 area	2002-2005	Dr. Larry Ward, UNH
Bottom video	Seafloor geology, Epifauna	400 km^2 area	2002-2005	Dr. Larry Ward, UNH
Benthic infauna	invertebrate taxa	400 km^2 area	2002-2005	Dr. Ray Grizzle, UNH
Social issues	literature database	New England	1970-2002	Dr. Rob Robertson, UNH

[1]The final map produced from this dataset can be found at http://woodshole.er.usgs.gov/project-pages/coastal_mass/html/jeffledge.html.

As mentioned above, the present report (and the major portions of the project funded by NEC) focuses on research on seafloor conditions and how the WGOM closure may have affected bottom habitats. A total of about 190 sites (of the 216 target sites) in the 400 km^2 study area (Fig. 1) were visited during the course of the project and most (~170) were successfully sampled with some combination of video, box core, and/or Shipek grab. Figure 4 shows the status of the 216 target sampling sites with respect to bottom sediment and infauna sampling. It should be noted, however, that a substantial number of grab and corer samples were rejected because of insufficient bottom penetration or other problems, as described in the Methods section; useful infauna and sediment texture data were obtained from approximately 120 sites. Useful video imagery was obtained from these 120 sites plus an additional 50 sites.

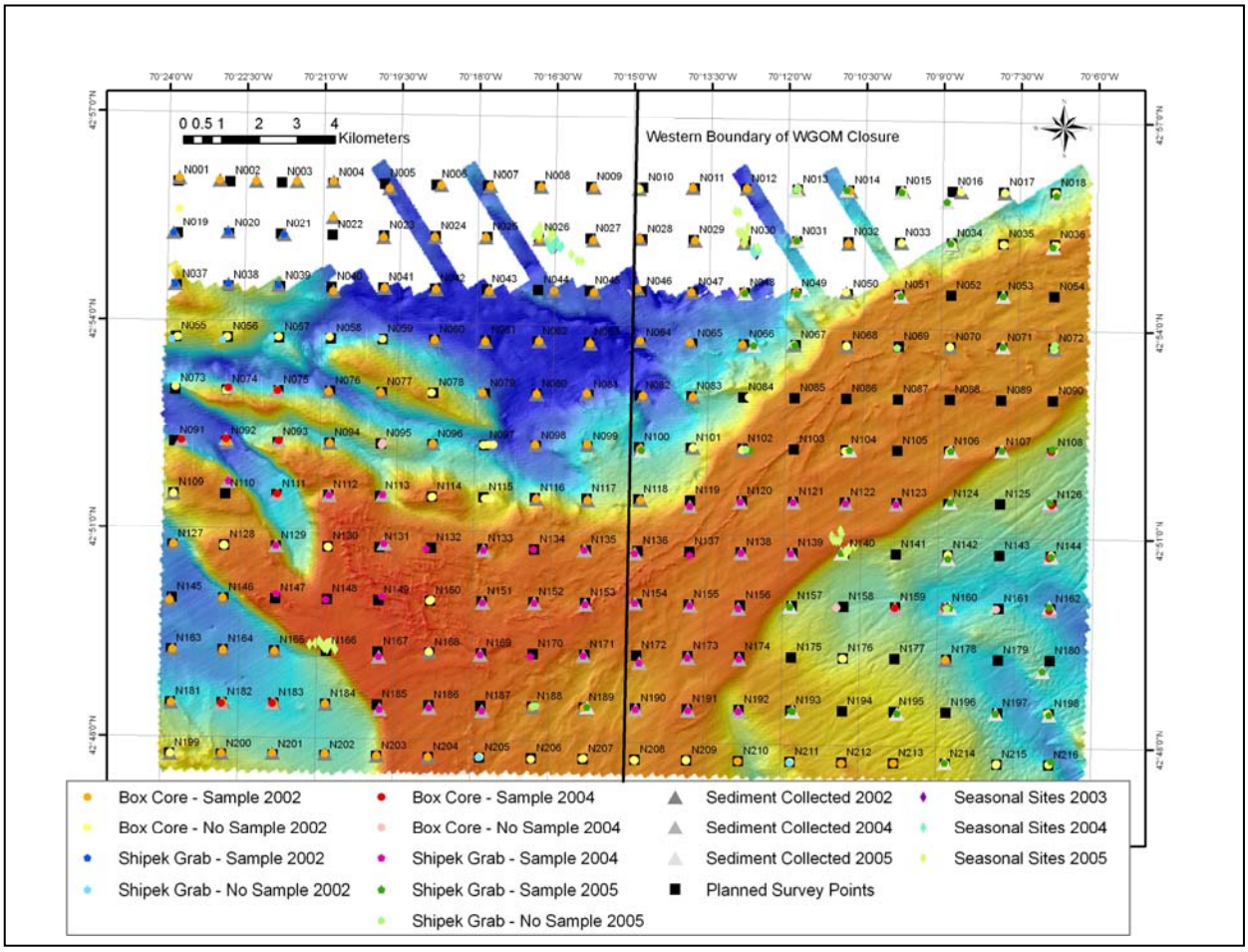

Fig. 4. Status of all seafloor sampling sites visited from June 2002 through September 2005. "No Sample" indicates sites that were visited but no bottom sample was obtained. "Planned Survey Points" were not successfully sampled. Base map is 5-m resolution bathymetric map from present project (see Fig. 6).

Results and conclusions

Objective 1. Characterize the ecosystem within and adjacent to the Western Gulf of Maine closure area with respect to primary production, sea surface temperature, major bottom habitats, and fine-scale information on seafloor shape and type.

The aim of this objective was to provide baseline information on environmental conditions in the general study area, much of which would be needed to meet Objectives 2 and 3. The major findings in each topic area are discussed below.

Water column (NOTE: This portion of the study was only conducted during year 1, 2002-03.)

Datasets based on satellite imagery from 1997 (establishment of the WGOM closure) through 2001 were secured and extraction of various time series was completed. There was a decreasing trend in chlorophyll biomass at four stations (two in and two out of WGOM). This was most pronounced at the landward station where the overall trend over a five year period showed a decrease of 0.6 mg m^{-3} in mean chlorophyll concentration. Perhaps more significantly however, was a persistent decrease over the five-year period of the amplitude of both the spring and fall blooms. Four monthly images for 2001 shown below (Fig. 5) illustrate the seasonal variability in the chlorophyll biomass in the region.

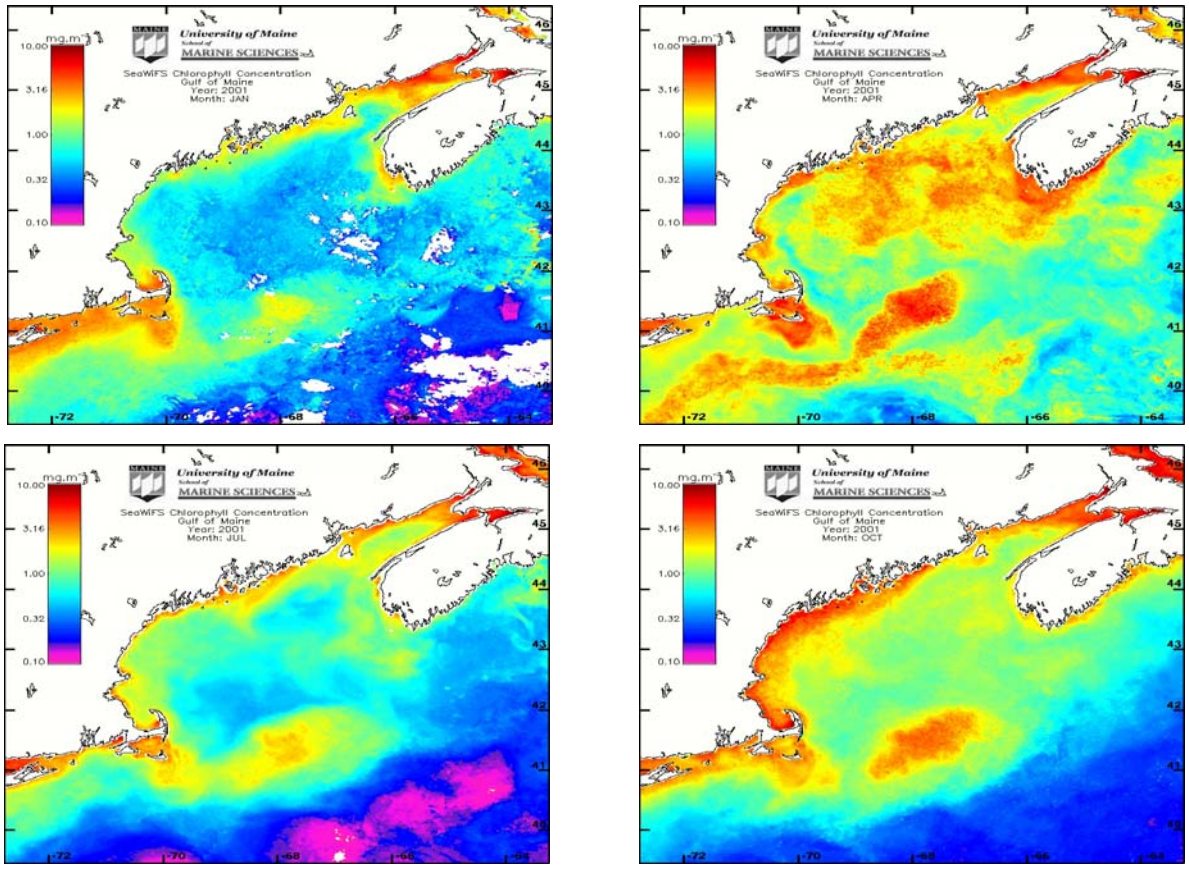

Fig. 5. Example MODIS satellite imagery (1-km resolution) for one day showing temporal variability in the general region that can occur in chlorophyll biomass and sea surface temperature.

This portion of the project yielded interesting and potentially quite useful data on chlorophyll concentrations and temperature variations in the region. Unfortunately, due to departure from UNH of the scientist with primary responsibility for these studies this portion of the project was terminated after the initial data gathering phase.

Seafloor topography

A multibeam survey of approximately 85% of the 400 km^2 study area was completed in December 2002/January 2003, resulting in a high-quality dataset and a bathymetric map at 5-m pixel resolution (Fig. 6). Previously, a 90-m resolution bathymetric map (the base map used in Fig. 1) was the best available for the area. Hence, the present effort resulted in much more information on fine scale seafloor topography and potentially other bottom characteristics.

This new map served as the base map for subsequent sampling of the seafloor and preliminary mapping of bottom habitats, and will also be used in production of the final habitat maps. The wide range of water depths and substantial spatial heterogeneity in the study area reflect the wide range of bottom habitat types (Table 1). Seafloor sampling (video and bottom grabs or cores) indicated that the shallower (<60 m) areas in orange in Figure 6 are hard bottoms, ranging from gravel to large boulder fields. The deeper (>100 m), blue-colored areas are predominantly soft sediments, some with extremely high organic content (~10% loss on ignition) and sparse infaunal densities. Additonal information on the multibeam mapping component of the project can be found on the web at: http://woodshole.er.usgs.gov/project-pages/coastal_mass/html/jeffledge.html.

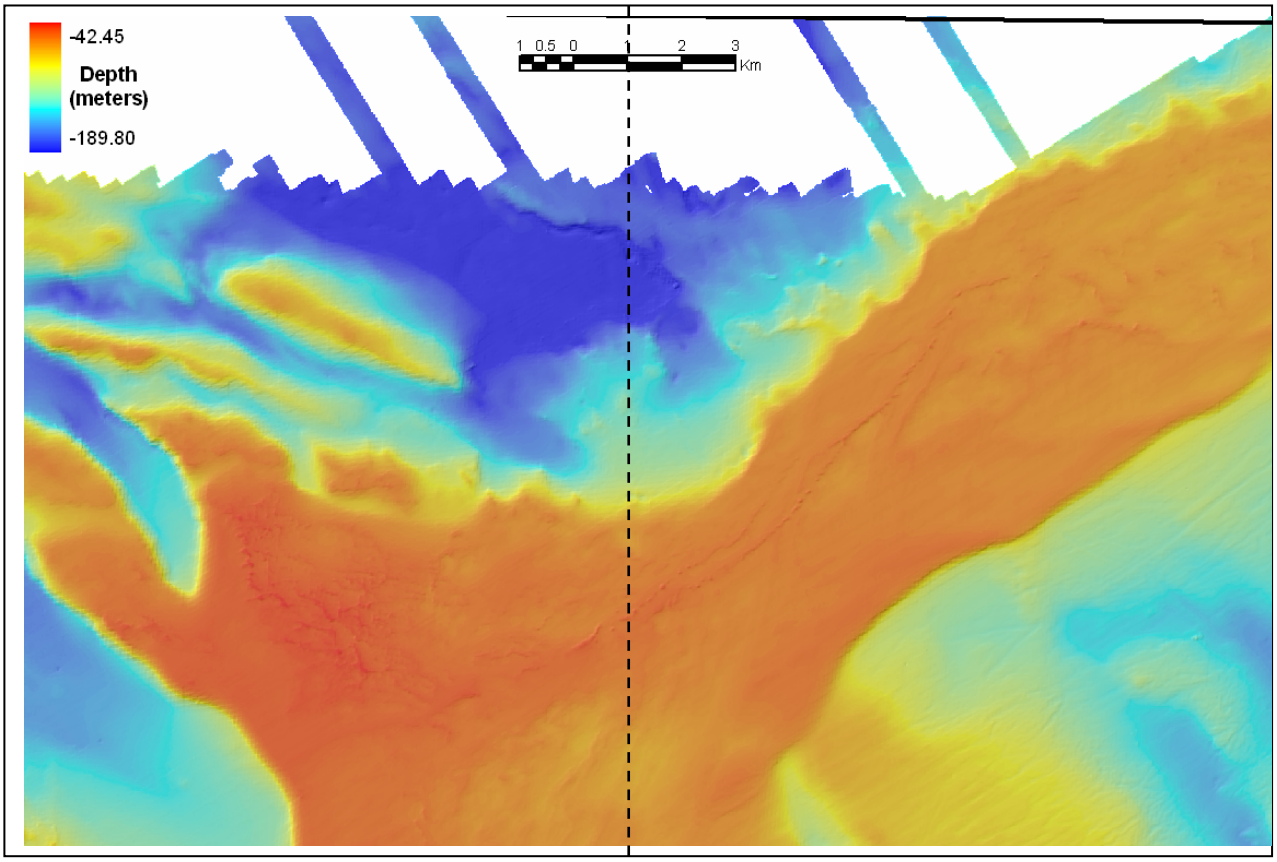

Fig. 6. Bathymetric map at 5-m pixel resolution of the 400 km^2 study area shown in Fig. 1. Vertical dashed line is the western boundary of the WGOM closure area.

In addition to the present project, the new bathymetric map was used in a recently published study comparing high-resolution multibeam sonar, sidescan sonar, and underwater video for detecting and characterizing physical impacts of fishing gear to the seafloor (Malik & Mayer 2007). Briefly, Malik and Mayer supplemented the map above with additional multibeam and sonar data from a small area near the southern boundary that provided <1-m resolution. They were able to extract from the sonar data and then map long, linear furrows thought to be the result of fishing gear contact with the seafloor. Groundtruthing was attempted with video but with inconclusive results. The authors concluded that detailed investigation of gear impacts on the seafloor should be done using combinations of acoustic and video methods as well as appropriate data processing techniques.

Major bottom habitat types

Habitat types ranged from muddy sediments in deep water (>100 m) dominated by deposit-feeding infauna to hard bottom (gravel and boulders) in water <80 m dominated by epifaunal organisms (Figs. 7, 8). Some bottom characteristics and benthic community features correlated strongly with water depth (Fig. 9), indicating that the spatial distribution of major bottom habitat types can be predicted to some extent using only bathymetric data. This relationship also suggests that the new bathymetry map (Fig. 6) can be used to construct much higher resolution maps of bottom habitat types than the ~1.5-km resolution limitation of the actual bottom sampling (Fig. 4). Maps of this type have not yet been produced. However, about 170 of the study sites have been classified using the scheme of eleven different habitat types shown in Table 1 above, and this new assessment has provided important information on how the WGOM closure has allowed some recovery of seafloor communities (see Objective 3 below).

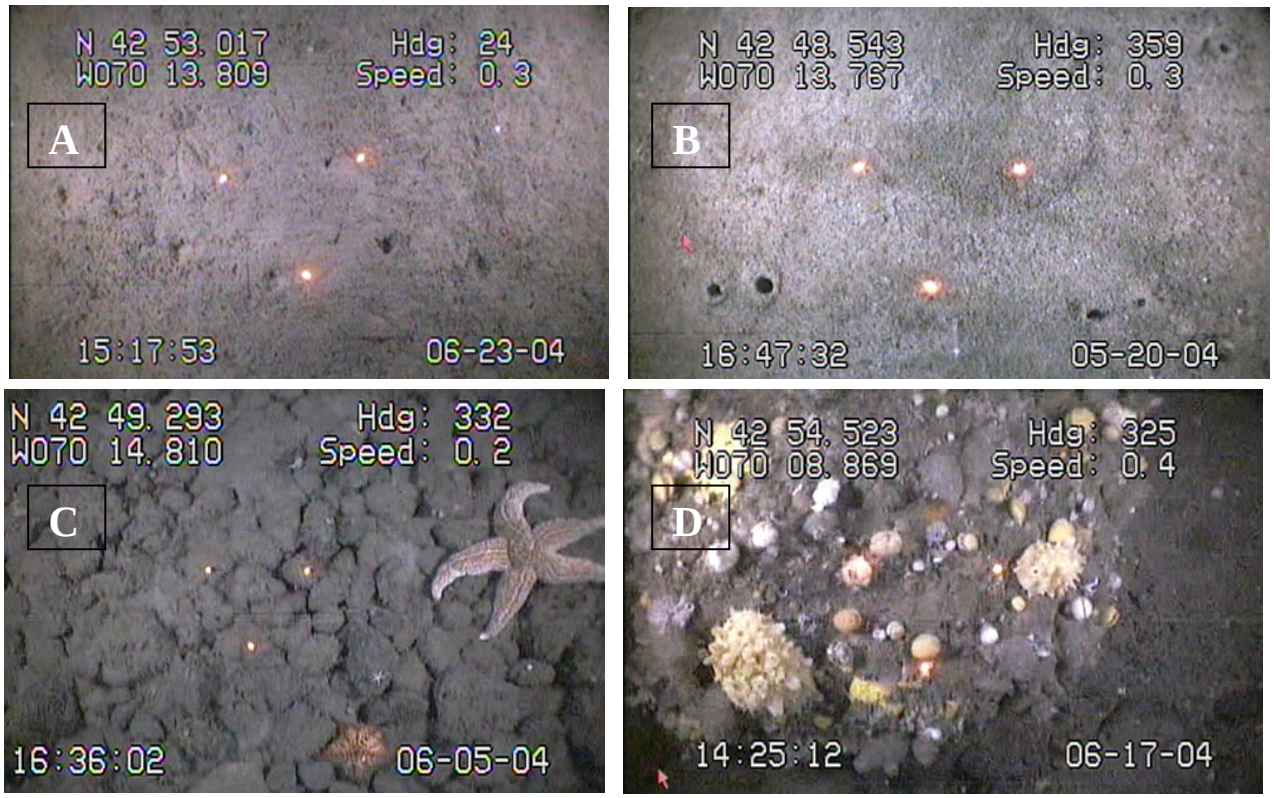

Fig. 7. Video stills showing examples of four major bottom habitats (defined by water depth/bottom type/dominant macrofauna) within the overall study area (Fig. 1.). A) 135 m/muddy sand/deposit-feeding infauna. B) 60 m/sand/infauna. C) 62 m/gravel/epifauna. D) 57 m/boulders/epifauna. These habitat types were expanded to include bottom features relevant to the impacts of fishing gear in Table 1 above.

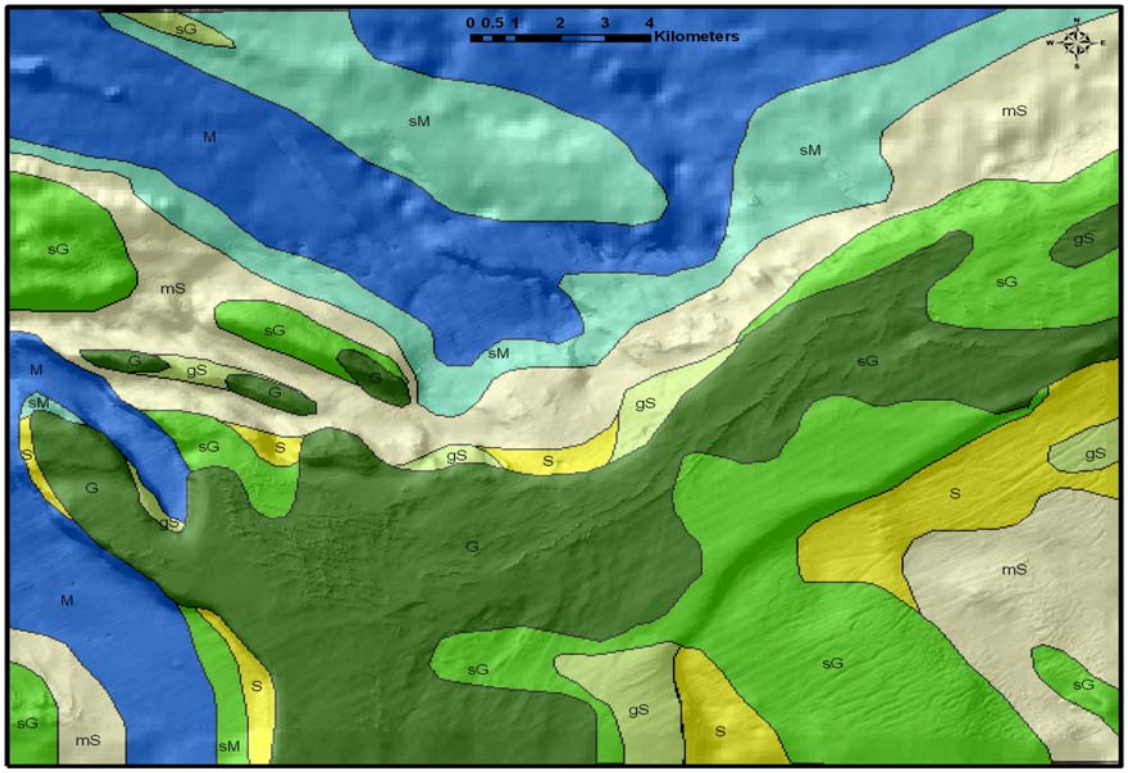

Fig. 8. Seven-class bottom sediment map based on bathymetry, shaded relief, and bottom sediment texture data. M=mud, sM=sandy mud, S=sand, mS=muddy sand, gS=gravelly sand , sG=sandy gravel, G=gravel.

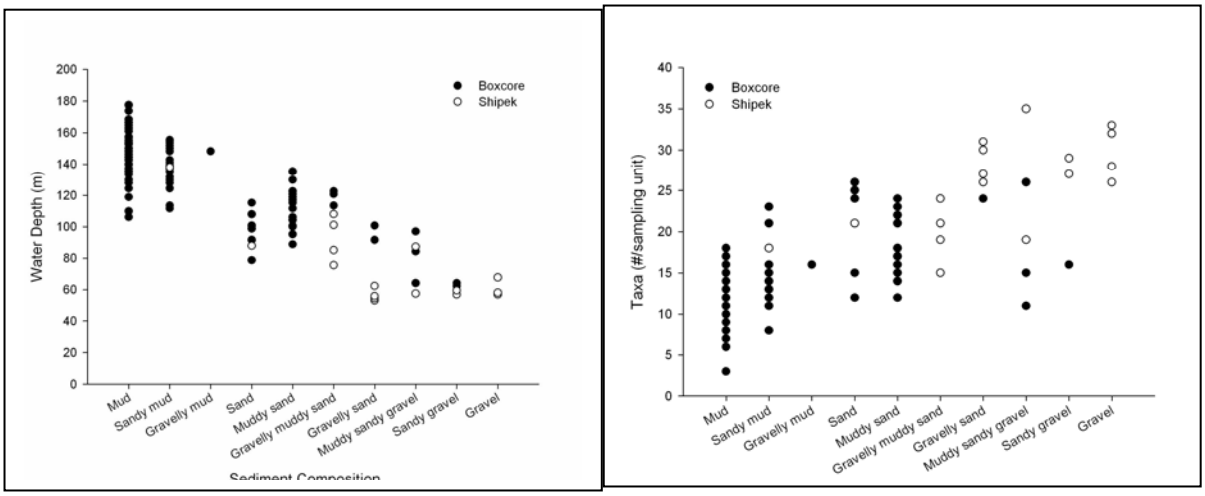

Fig. 9. Sediment type as determined from Shipek grab and box core samples vs. water depth (left), and sediment type vs. infaunal community taxonomic richness (both determined from Shipek grab and box core samples).

<u>Objective 2</u>. Begin to examine the relationship between groundfish and their habitats.

As noted above, this objective was not addressed in the present project using NEC funds. However, funding from NEC and other sources was secured during the course of the present project for research that is providing information on distribution patterns of seafloor habitats and groundfish populations, particularly with respect to potential effects of the WGOM closure (see Grizzle et al. 2007, 2008a).

<u>Objective 3</u>. Initiate a long-term assessment of the effects of the closed area on various ecosystem characteristics and social aspects.

Introduction and general results

This objective was the major focus of the project, with an emphasis on assessing how the WGOM closure may be affecting seafloor invertebrate (infauna and epifauna) communities. The long-term goal for the seafloor research is to understand how the closure affects not only invertebrates but also managed fish species that depend on bottom habitats for their survival. Substantial progress has been made in this respect, including one manuscript in review and two others in preparation. Additional funding has also been secured from NEC to assess fish communities in rocky habitats inside and outside of the WGOM closure (Grizzle et al. 2007, 2008a).

For the present project, a total of ~170 sites in the 400 km^2 study area were sampled and yielded useful information on some combination of data from video, box corer, and/or Shipek grab. No plants were collected in the grab and core samples or observed in the video imagery. Infauna dominated the benthic communities in soft sediments in deeper waters (mainly sampled by box corer), and epifauna dominated the shallower hard bottom areas (mainly sampled by video). However, samples of infauna (from Shipek grab) were also collected from most of the hard bottom sites because most had sufficient amounts of soft sediments to be retained by the Shipek. Hard bottom areas were typically dominated by pebble and cobble. Video counts of epifauna were made from nearly all sites regardless of bottom type.

One of the major initial outputs for Objective 3 was a series of maps of various benthic epifaunal and infaunal characteristics potentially affected by fishing gear and thus related to the WGOM closure. Figures 10 - 13 below are examples. The patterns in invertebrate distributions shown in many of the maps indicated substantial differences in invertebrate population and community-level characteristics between areas within and outside of the closure. These maps caused us to focus initially on univariate benthic community characteristics such as total density, biomass, and taxonomic richness (biodiversity). The result thus far has been one manuscript in review (Grizzle et al. 2008b), from which much of the information below on univariate assessments was taken.

Multivariate assessments of both the geology (Ward et al. in prep.) and ecology (Grizzle et al. in prep.) of the study area and focusing on the effects of the closure are in progress. The major results thus far have been identification and assessment of spatial distribution patterns for eleven different habitat types (as defined in Table 1 above), and as discussed in the multivariate assessments subsection below.

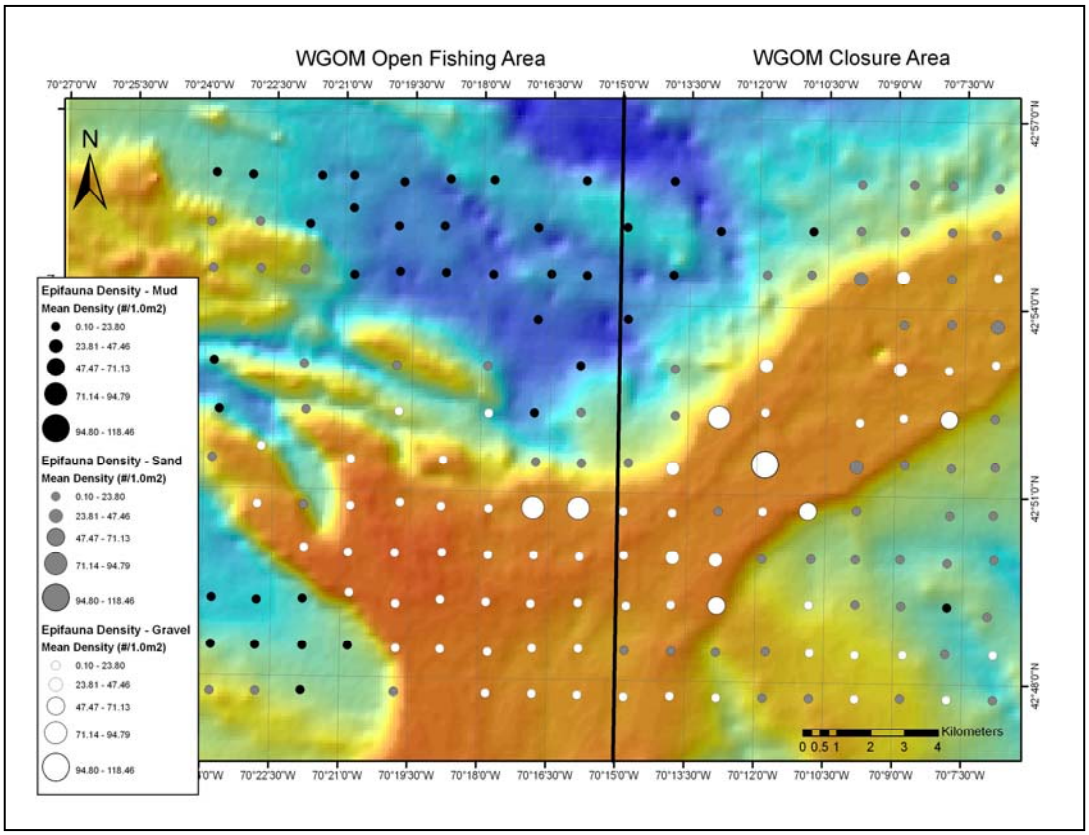

Fig. 10. Total densities (# of organisms/m^2) of epifaunal organisms (e.g., sponges, sea squirts, anemones) from video transects. Vertical solid line is the western boundary of the WGOM closure area.

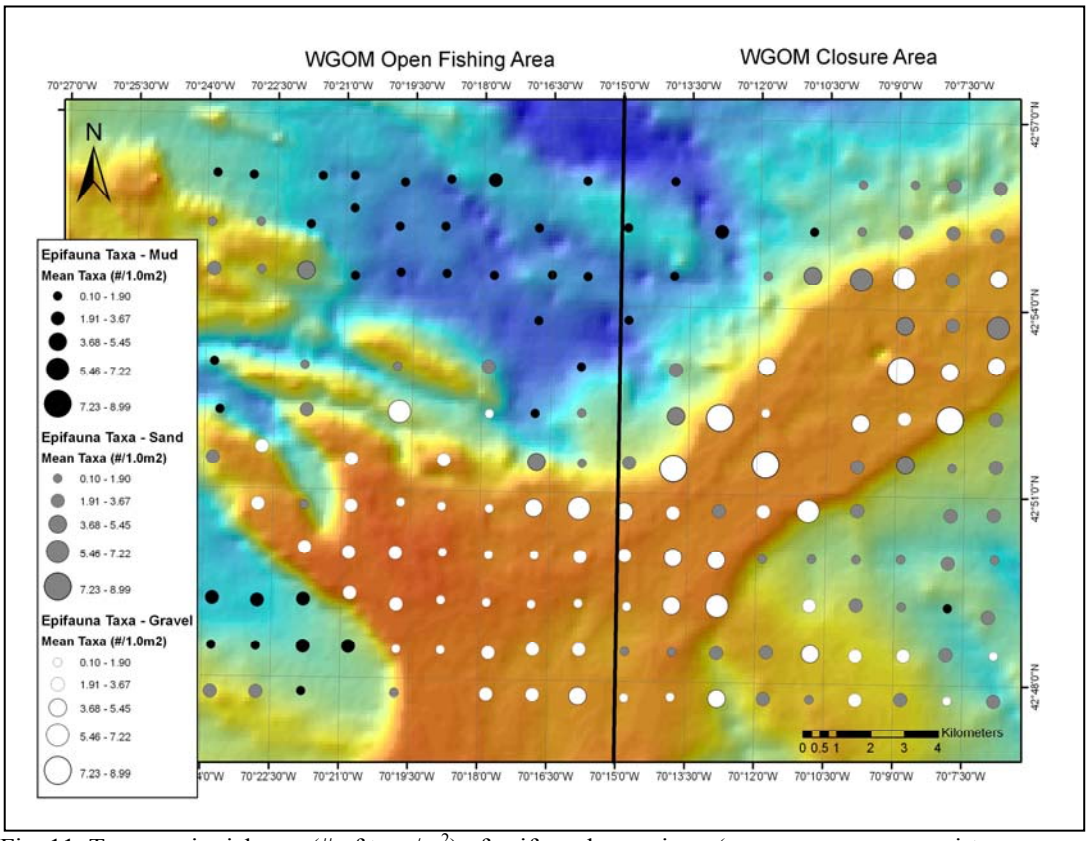

Fig. 11. Taxonomic richness (# of taxa/m^2) of epifaunal organisms (e.g., sponges, sea squirts, anemones) from video transects. Vertical solid line is the western boundary of the WGOM closure.

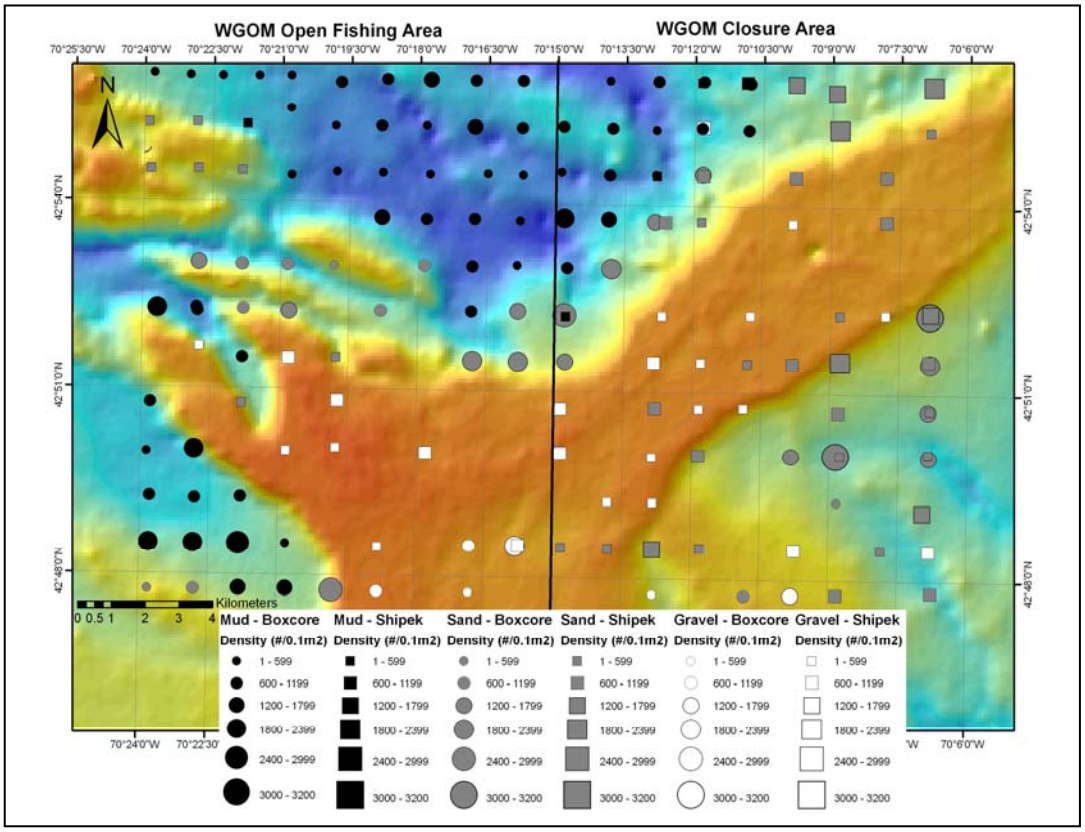

Fig. 12. Total density (# of organisms/m^2) of infaunal organisms (e.g., polychaetes, mollusks) from grab and core samples. Vertical solid line is the western boundary of the WGOM closure.

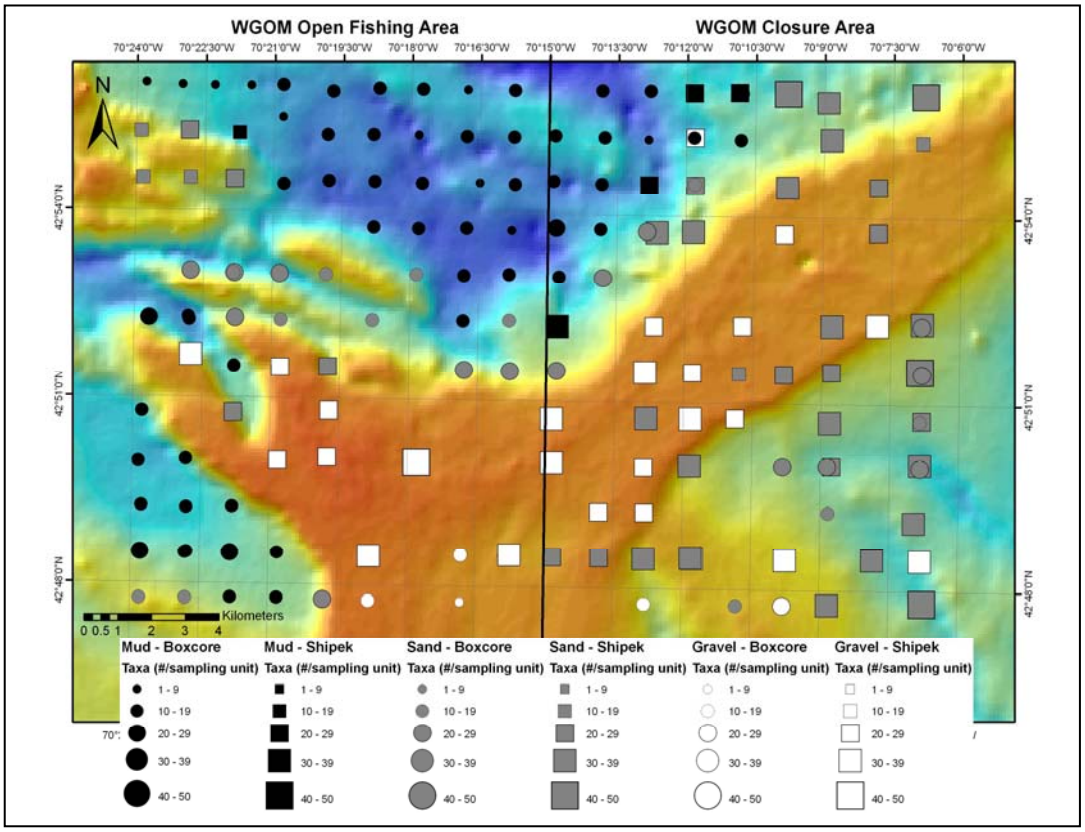

Fig. 13. Taxonomic richness (# of taxa/m^2) of infaunal organisms (e.g., polychaetes, mollusks) from grab and core samples. Vertical solid line is the western boundary of the WGOM closure.

Effects of WGOM closure on univariate benthic community characteristics

There were six significant ($p<0.05$) "in vs. out" comparisons for the infauna (Table 3): overall higher densities (from box corer and Shipek grab data) inside compared to outside the closed area; overall higher taxonomic richness (from box corer data) inside compared to outside; and significant sediment interaction effects for densities, biomass, and taxonomic richness (from Shipek grab data). There were four significant ($p<0.05$) "in vs. out" comparisons for epifauna (Table 3): total community density and taxonomic richness overall, and sediment interactions for both variables. If it is assumed that these in vs. out differences were caused by removal of fishing gear impacts, then these data strongly indicate substantial recovery of both infaunal and epifaunal communities inside the closed area, but not of the same magnitude across all sediment types. Sand (which in many cases also had substantial amounts of gravel) and gravel (which included areas with boulders) particularly reflected this trend. Differences in epifaunal and infaunal communities from mud bottoms showed no significant differences when comparing sites inside the closure with those outside (Table 3).

Table 3. Means (±1 SE) for univariate infauna and epifauna community characteristics comparing sites inside vs. outside the WGOM closure area overall (*i.e.,* data from all sediment types combined) and interaction effects of sediment type (N.S. = P>0.05).

Infauna

Dependent Variable	Sampling Device	In vs. Out Main effect	In vs. Out Sediment interaction	Overall	Mud Only	Sand Only	Gravel Only
Biomass (g 0.1 m^{-2})	Box Corer	NS	NS	Inside: 8.2 (±3.2) (n=30) Outside: 4.6 (±1.3) (n=66)	Inside: 3.0 (±0.4) (n=15) Outside: 3.3 (±1.1) (n=47)	Inside: 13.0 (±7.1) (n=13) Outside: 3.3 (±0.5) (n=15)	Inside: 15.4 (±5.1) (n=2) Outside: 24.1 (±17.4) (n=4)
Density (# 0.1 m^{-2})	Box Corer	p=0.02	NS	Inside: 1298.0 (±139.6) (n=30) Outside: 966.3 (±79.6) (n=66)	Inside: 911.0 (±104.0) (n=15) Outside: 890.3 (±90.9) (n=47)	Inside: 1779.1 (±231.1) (n=13) Outside: 1181.6 (±178.0)(n=15)	Inside: 1073.8 (±708.0) (n=2) Outside: 1053.2 (±368.4) (n=4)
Taxonomic Richness (Taxa per Sampling Unit)	Box Corer	p=0.02	NS	Inside: 18.0 (±1.0) (n=30) Outside: 14.5 (±0.6) (n=66)	Inside: 14.0 (±0.9) (n=15) Outside: 13.2 (±0.6) (n=47)	Inside: 22.2 (±1.3) (n=13) Outside: 18.5 (±1.2) (n=15)	Inside: 20.5 (±4.5) (n=2) Outside: 14.3 (±4.8) (n=4)
Biomass (g 0.1 m^{-2})	Shipek Grab	NS	p=0.04	Inside: 13.1 (±2.5) (n=52) Outside: 10.8 (±4.5) (n=16)	Inside: 10.7 (±8.0) (n=4) Outside: 0.9 (n=1)	Inside: 14.2 (±3.8) (n=31) Outside: 2.8 (±2.2) (n=7)	Inside: 11.6 (±3.1) (n=17) Outside: 19.1 (±7.9) (n=8)
Density (# 0.1 m^{-2})	Shipek Grab	p=0.01	p=0.001	Inside: 770.7 (±66.3) (n=52) Outside: 391.4 (±57.3) (n=16)	Inside: 504.4 (±66.1) (n=4) Outside: 230.0 (n=1)	Inside: 928.2 (±95.8) (n=31) Outside: 217.9 (±42.2) (n=7)	Inside: 546.2 (±65.2) (n=17) Outside: 563.4 (±65.5) (n=8)
Taxonomic Richness (Taxa per Sampling Unit)	Shipek Grab	NS	p<0.0001	Inside: 30.2 (±0.9) (n=52) Outside: 26.1 (±1.8) (n=16)	Inside: 27.3 (±1.4) (n=4) Outside: 18.0 (n=1)	Inside: 31.7 (±1.3) (n=31) Outside: 20.9 (±1.5) (n=7)	Inside: 28.1 (±1.3) (n=17) Outside: 31.8 (±1.8) (n=8)

Epifauna

Dependent Variable	Sampling Device	In vs. Out Main effect	In vs. Out Sediment interaction	Overall	Mud Only	Sand Only	Gravel Only
Density (# m^{-2})	Video	p=0.0001	p=0.02	Inside: 12.0 (±2.1) (n=86) Outside: 4.7 (±1.3) (n=83)	Inside: 1.5 (±0.3) (n=7) Outside: 1.5 (±0.2) (n=33)	Inside: 4.6 (±1.0) (n=38) Outside: 2.9 (±0.5) (n=17)	Inside: 20.7 (±4.0) (n=41) Outside: 8.9 (±3.3) (n=33)
Taxonomic Richness (Taxa m^{-2})	Video	p=0.0004	p=0.07	Inside: 2.9 (±0.2) (n=86) Outside: 1.8 (±0.1) (n=83)	Inside: 1.3 (±0.3) (n=7) Outside: 1.2 (±0.1) (n=33)	Inside: 2.1 (±0.2) (n=38) Outside: 1.9 (±0.2) (n=17)	Inside: 4.0 (±0.3) (n=41) Outside: 2.3 (±0.2) (n=33)

Control-Impact (or After-Only) studies—as was the design for the present study—typically cannot unambiguously separate spatial from temporal effects of the activity of interest because no data are available from before the activity was started. Hence, the findings summarized in Table 3 (and the multivariate analyses below) must be assessed with respect to how factors that may have changed over time relative to the control and impact areas might have contributed to any observed differences. For our study, several lines of evidence suggest it is reasonable to assume that differences between benthic communities inside the WGOM closure compared to those outside were in large measure the result of the removal of fishing gear impacts (trawls and gillnets) inside, as will be discussed below.

First, the overall study area was chosen so the "control" (continued fishing) sites outside the closure were in close proximity to the "treatment" (removal of fishing) sites inside, minimizing potential confounding differences related to distance. Second, the range of habitat types and relative areal coverage by each were similar inside and outside of the closure. Thirdly, information exists on fishing gear use patterns inside and outside of the closed area for pre- and post-closure time periods (see below). Finally, we know of no changes since establishment of the closure, other than fishing gear restrictions, that might have differentially affected sites inside compared to those outside. Therefore, we interpret "in vs. out" differences in our data to mainly be the result of removal of the impacts of otter trawls and gillnets from the closed area. However, spatial distribution patterns for each type of gear use must be considered to fully assess these impacts.

The major factor that determines gear use in the area is bottom type: trawls are restricted to areas with relatively low relief, and gillnets are used mainly on hard bottoms with higher relief. Available data indicate this was the general pattern before and has been after implementation of the WGOM closure (Fig. 14). The maps in Figure 14 are based on fishing vessel trip report (FVTR) data that all federally permitted commercial fishing vessels are required to submit to the US National Marine Fisheries service. For map production, the raw data (submitted at 1-minute intervals) were rounded to 2-minute resolution, and all locations with less than 5 trip records were deleted. This process was done to eliminate potentially spurious data due to rounding errors (particularly when converting from Loran C to latitude/longitude) and other reporting mistakes. The pre- and post-closure plots (Fig. 14) indicate several patterns relevant to our study. First, both pre- and post-closure trip data

confirm the general pattern described above: trawls in soft-bottom areas and gillnets on rocky bottoms. When comparing patterns by gear type, however, the most dramatic difference was for gillnets pre- and post-closure. Areas inside the closure were more heavily fished with gillnets before the closure was implemented compared to adjacent areas outside, while post-closure gillnet intensity overall remained at similar levels but areas outside were more heavily fished. In contrast, the difference between pre- and post-closure trawl activity were not dramatic for most areas. Because water depth was strongly correlated with bottom type (Fig. 9), bathymetry reflects the general patterns for gear use: trawls mainly in waters >50 m along the margins of Jeffreys Ledge (mainly mixed soft sediments and gravel with low vertical relief) extending down into the basins (soft muds), and gillnets in the shallower areas (ranging from gravel to boulders) on the Ledge and in rocky areas to the west. Therefore, we conclude that the overall result of the closure was to remove trawl effects from the deeper, mainly finer sediment texture (mud and sand) areas and gillnets from rocky areas (pebble, cobble, and boulders) along Jeffreys Ledge.

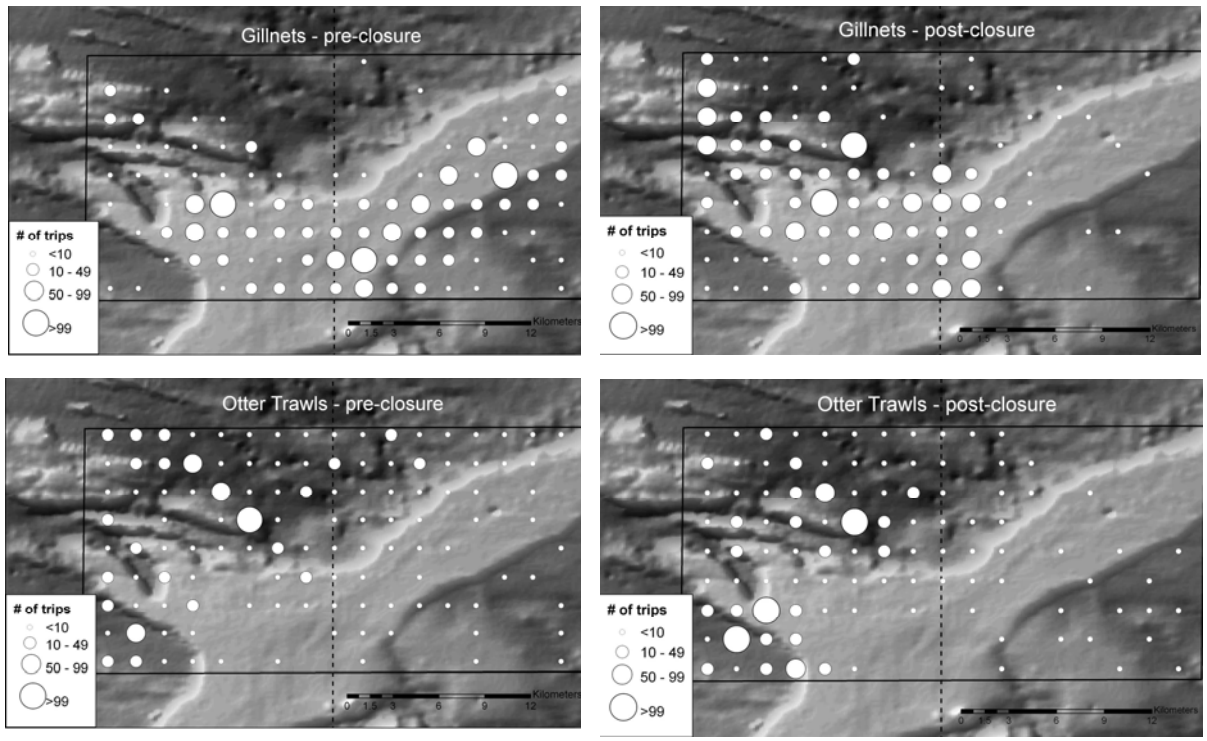

Fig. 14. Major fishing gear activity within the 400 km^2 study area for 4.5 years before the closure was implemented (1994-1998) and 5.5 years after closure implementation (1998-2004) based on Vessel Trip Report (VTR) data from US National Marine Fisheries Service (see text for details).

Effects of WGOM closure on multivariate benthic community characteristics

As already noted, our multivariate assessments are still in progress. Here we present an initial assessment based on classification of ~170 of the sampling sites (Fig. 4) into eleven habitat types, as defined in Table 1. In soft sediments predominately of mud or sand, the dominant macrofauna in the region typically consist of polychaete worms, crustaceans, and bivalve mollusks, all living predominantly within the sediments; i.e., infaunal (Sherman et al. 1988; Watling 1998; Theroux & Wigley 1983, 1998). Many infauna construct burrows that open to the surface or tubes that project above the sediment into the overlying water column. On bottoms dominated by shell, pebble, cobble or boulders, the dominate invertebrates are epifauna that live attached to the hard substrate, and in our study area include sponges, ascidians (sea squirts), and brachiopods.

The eleven habitat types are related to one another in an ecological successional perspective that describes how each habitat "recovers" over time after disturbance has ceased, as illustrated in Table 4 below. A substantial literature exists on the effects of bottom trawls on seafloor habitats (see general reviews by Dorsey & Pederson 1998; Watling & Norse 1998; Auster & Langton 1999; Johnson 2002; NRC 2002; also see Knight 2005, and Knight et al. 2006 for seafloor studies dealing with the WGOM closure area), and our findings discussed above that indicate gillnets can have similar negative impacts on hard bottom habitats. Both kinds of fishing gear contact the bottom, physically disturbing the seafloor to some extent and dislodging or damaging benthic organisms. When the physical disturbance ceases, the benthic communities recover via ecological succession, which typically means increases in density and taxonomic richness over time. Thus, in our classification the "later" successional stages essentially differ from the "early" stages by having greater densities and diversity of infauna and/or epifauna.

In our new classification, five of the eleven habitat types represent early successional stages that typically dominate areas regularly affected by physical disturbances caused by mobile fishing gear or wind-generated waves (Auster & Langton 1999, DeAlteris et al. 1999, NRC 2002, Kaiser et al. 2006). The remaining seven habitat types represent later successional stages, which are dominated by many of the same taxa as in the early stage communities, but in greater abundances and often including larger, longer-lived species. It should also be noted that the basic characteristic of each of the five successional series shown in Table 4 is sediment type. In other words, a successional sequence consisting of early and later stages was defined for five major bottom sediment types: mud, sand, shell, pebble/cobble, and boulders.

Table 4. Conceptual model of the relationship between early and later ecological successional stages for the eleven bottom habitat types defined in Table 1. Arrows represent time.

Early stages		Later stages		
1 (mud w/ minimal large infauna)	→	3 (mud w/ abundant large infauna)	→	5 (mud w/ cerianthid anemones)
2 (sand w/ minimal large infauna)	→	4 (sand w/ abundant large infauna)	→	5 (sand w/ cerianthid anemones)
6 (shell with minimal epifauna)	→	7 (shell with abundant epifauna)		
8 (pebble/cobble with minimal epifauna)	→	9 (pebble/cobble with abundant epifauna)		
10 (boulders with minimal epifauna)	→	11 (boulders with abundant epifauna)		

We predicted that bottom habitats outside of the closure (and heavily fished; Fig. 14) would be dominated by early successional stages (habitat types 1, 2, 6, 8 and 10; Table 4), and conversely that habitats within the WGOM closure would be dominated by benthic communities representing later successional stages (habitat types 3, 4, 5, 7, 9 and 11; Table 4). To test this prediction, we determined the number of sites representing each habitat type inside the closure and the number outside (Table 5). To standardize for differences in numbers inside compared to oustside, each was also expressed as a percentage of the total for the basic (defined by sediment type) habitat type. For example, all bottoms defined as "shell" were classified into one of two habitat categories: 6 (shell with no or minimal epifauna), and 7 (shell with abundant epifauna). The number of sites

representing the basic habitat type was determined by summing the numbers for the two successional stages. For sites inside the closure, there was a total of 10 "shell" habitats, but only 1 site was classified as "shell with epifauna" thus representing 10% of the "shell" sites. This same process was followed for all three hard bottom types: shell, pebble/cobble, and boulders.

For soft sediments (mud and sand), the situation was more complicated because the overall successional sequence consisted of three possible stages (Table 4). The early stages for mud and sand had only minimal numbers of large infauna, the first later stage had abundant large infauna, and the second later stage had abundant cerianthid anemones (*Cerianthis borealis* in our area). Cerianthids are large (up to ~50 cm in length) probably long-lived (~50 years; Watling 1998) organisms that live in mud/sand sediments in tubes that extend deep into the sediment as well as several centimeters above it (Wigley 1968; Watling 1998). The establishment of abundant cerianthid anemones would therefore probably take longer than most other infaunal taxa after disturbance (e.g., mobile fishing gear impacts) ceases.

The process for determining the relative amounts (percentages) of the soft sediment habitat types consisted of comparing each habitat type to the sum of itself and the category (or categories) earlier in the successional sequence. For example, the percentage of "mud w/ abundant large infauna" was determined by comparing it to the total for itself plus "mud w/ minimal large infauna." For habitats defined by abundant cerianthid anemones (category 5), all types of "mud" and "sand" sites (categories 1, 2, 3 and 4) were potential "basic" habitats, so all five soft sediment categories were summed and used to determine the percentage.

Table 5. Summary data on numbers and percentages for each of eleven bottom habitat types (defined in Table 1) at ~170 study sites. The larger of each "in vs. out" comparison by habitat type is shown in bold.

		Inside WGOMCA			Outside WGOMCA		
Habitat Type	**Habitat Category**	**Number of sites**	**Totals for basic habitat type**	**% of basic habitat type**	**Number of sites**	**Totals for basic habitat type**	**% of basic habitat type**
Mud w/ minimal large infauna	1	3 (of 6 total)		50.0	22 (of 31 total)		**70.1**
Sand w/ minimal large infauna	2	7 (of 11 total)		63.6	4 (of 5 total)		**80.0**
Mud w/ abundant large infauna	**3**	3 (of 6 total)	6 (cat. 1 & 3)	**50.0**	9 (of 31 total)	31 (cat. 1 & 3)	29.0
Sand w/ abundant large infauna	**4**	4 (of 11 total)	11 (cat. 2 & 4)	**36.4**	1 (of 5 total)	5 (cat. 2 & 4)	20.0
Sand or mud w/ cerianthids	**5**	20 (of 37 total)	37 (cat. 1-5)	**54.1**	15 (of 51 total)	51 (cat. 1-5)	29.4
Shell	6	9 (of 10 total)		90.0	2 (of 2 total)		**100.0**
Shell w/ epifauna	**7**	1 (of 10 total)	10 (cat. 6 & 7)	**10.0**	0 (of 2 total)	2 (cat. 6 & 7)	0.0
Pebble-cobble	8	4 (of 20 total)		20.0	16 (of 18 total)		**88.8**
Peb-cob w/ epifauna	**9**	16 (of 20 total)	16 (cat. 8 & 9)	**80.0**	2 (of 18 total)	18 (cat. 8 & 9)	11.2
Boulders	10	15 (of 17 total)		88.2	11 (of 11 total)		**100.0**
Boulders w/epifauna	**11**	2 (of 17 total)	17 (cat. 10 & 11)	**11.8**	0 (of 11 total)	11 (cat. 10 & 11)	0.0

All six later successional stages (Habitat Categories 3, 4, 5, 7, 9 and 11) were more common inside the WGOM closure than outside (Table 5). Conversely, all five early successional stages were more common outside the closure. This provides another (in addition to our univariate data) indication that both soft bottom and hard bottom habitats have experienced substantial recovery since implementation of the closure, as predicted based on our assessment of the univariate data.

The taxonomic (to family level in most cases) composition for each of the eleven habitat types was also determined using a rank-sum process. The top ten macrofaunal taxa (infauna and epifauna) were determined by summing the numbers of individual organisms for each taxon collected from all sites in each of the eleven habitat types, then converting the raw numbers to percentages of the total number of organisms collected. This resulted in dominant macrofaunal community composition lists for each habitat type (Table 6 and 7).

Table 6. Rankings by Habitat Class (Tables 1, 4 and 5) of dominant infaunal taxa (Family level in most cases) by percent of total organisms collected. Classes are arranged in successional sequences shown in Table 4, as indicated by arrows.

Organism	Habitat Class 1
F. Ampharetidae	28.3%
F. Maldanidae	16.9%
F. Capitellidae	13.4%
F. Cirratulidae	5.6%
F. Arabellidae/Lumb	4.1%
F. Thyasiridae	4.1%
F. Spionidae	3.9%
F. Cossuridae	3.7%
F. Paraonidae	2.8%
F. Ampeliscidae	2.0%
F. Tellinidae	2.0%
F. Phoxocepalidae	1.8%
F. Terebellidae	1.6%
F. Oweniidae	1.3%
F. Nuculidae	1.1%
F. Nephtyidae	1.0%
F. Nereidae	0.9%
F. Sabellidae	0.7%
F. Syllidae	0.7%

→

Organism	Habitat Class 3
F. Maldanidae	22.6%
F. Ampharetidae	19.2%
F. Capitellidae	14.6%
F. Cirratulidae	6.2%
F. Cossuridae	5.1%
F. Thyasiridae	4.9%
F. Arabellidae/Lumb	4.5%
F. Paraonidae	3.4%
F. Tellinidae	2.4%
F. Spionidae	2.0%
F. Nereidae	1.8%
P. Rhynchocoela	1.5%
F. Phoxocepalidae	1.2%
F. Terebellidae	1.0%
F. Goniadidae	0.9%
F. Oweniidae	0.8%
F. Syllidae	0.7%
F. Astartidae	0.7%
F. Nuculidae	0.7%

→

Organism	Habitat Class 5
F. Sabellidae	27.6%
F. Spionidae	13.7%
F. Ampharetidae	8.2%
F. Syllidae	6.3%
F. Maldanidae	6.3%
F. Paraonidae	3.1%
F. Astartidae	3.0%
F. Cirratulidae	2.5%
P. Nematoda	2.2%
F. Cardiidae	1.5%
P. Sipunculoidea	1.5%
F. Capitellidae	1.5%
C. Ophiuroidea	1.3%
F. Thyasiridae	1.3%
F. Mytilidae	1.2%
F. Phoxocepalidae	1.2%
F. Tellinidae	1.1%
F. Pleustidae	1.1%
F. Nuculidae	1.0%

Organism	Habitat Class 2
F. Ampharetidae	21.8%
F. Sabellidae	13.0%
F. Maldanidae	11.6%
F. Spionidae	7.1%
F. Capitellidae	5.2%
P. Nematoda	4.8%
F. Syllidae	4.7%
F. Cirratulidae	3.4%
F. Thyasiridae	3.1%
F. Cossuridae	2.7%
F. Paraonidae	2.2%
F. Nuculidae	2.0%
P. Sipunculoidea	1.9%
F. Astartidae	1.8%
F. Arabellidae/Lumb	1.6%
F. Tellinidae	1.5%
F. Phoxocepalidae	1.1%
P. Rhynchocoela	1.0%
F. Scalibregmidae	0.9%

→

Organism	Habitat Class 4
F. Ampharetidae	21.0%
F. Maldanidae	17.5%
F. Capitellidae	11.7%
F. Sabellidae	9.4%
F. Thyasiridae	7.9%
F. Spionidae	5.3%
F. Syllidae	4.4%
F. Astartidae	2.7%
F. Cirratulidae	2.7%
P. Nematoda	2.7%
F. Cossuridae	2.1%
F. Phoxocepalidae	1.9%
F. Tellinidae	1.7%
F. Nuculidae	1.3%
F. Paraonidae	1.0%
F. Ampeliscidae	0.8%
Unidentified Annelid	0.8%
P. Rhynchocoela	0.6%
O. Cumacea	0.5%

→

Organism	Habitat Class 5
F. Sabellidae	27.6%
F. Spionidae	13.7%
F. Ampharetidae	8.2%
F. Syllidae	6.3%
F. Maldanidae	6.3%
F. Paraonidae	3.1%
F. Astartidae	3.0%
F. Cirratulidae	2.5%
P. Nematoda	2.2%
F. Cardiidae	1.5%
P. Sipunculoidea	1.5%
F. Capitellidae	1.5%
C. Ophiuroidea	1.3%
F. Thyasiridae	1.3%
F. Mytilidae	1.2%
F. Phoxocepalidae	1.2%
F. Tellinidae	1.1%
F. Pleustidae	1.1%
F. Nuculidae	1.0%

Organism	Habitat Class 6
F. Spionidae	24.5%
F. Sabellidae	17.6%
F. Ampharetidae	13.2%
F. Syllidae	9.0%
P. Nematoda	3.6%
F. Paraonidae	2.7%
F. Nuculidae	2.4%
F. Cardiidae	2.3%
P. Rhynchocoela	2.0%
F. Astartidae	1.9%
F. Photidae	1.8%
F. Maldanidae	1.6%
F. Nereidae	1.5%
C. Ophiuroidea	1.2%
F. Oweniidae	1.1%
F. Nuculanidae	1.1%
P. Sipunculoidea	1.1%
O. Cumacea	1.0%
F. Tellinidae	1.0%

(cont.)

(Table 6 cont.)

Organism	Habitat Class 8	Organism	Habitat Class 9
F. Sabellidae	16.2%	F. Sabellidae	30.9%
F. Photidae	11.9%	F. Syllidae	13.8%
F. Syllidae	8.3%	F. Spionidae	4.8%
F. Spionidae	7.9%	C. Ophiuroidea	4.4%
C. Ophiuroidea	6.8%	F. Paraonidae	3.6%
F. Maldanidae	4.7%	F. Maldanidae	3.2%
F. Phyllodocidae	3.9%	P. Sipunculoidea	2.8%
F. Astartidae	3.5%	F. Cardiidae	2.8%
O. Tanaidacea	3.1%	F. Cirratulidae	2.7%
P. Sipunculoidea	3.0%	P. Nematoda	2.6%
F. Mytilidae	2.7%	F. Glyceridae	2.4%
F. Cirratulidae	2.6%	F. Phyllodocidae	2.1%
F. Paraonidae	2.2%	F. Astartidae	2.0%
F. Cardiidae	2.0%	F. Mytilidae	2.0%
O. Cumacea	1.6%	F. Terebellidae	2.0%
F. Pleustidae	1.5%	C. Anthozoa	2.0%
C. Oligochaeta	1.5%	C. Oligochaeta	1.6%
F. Glyceridae	1.5%	F. Oweniidae	1.4%
F. Oweniidae	1.3%	F. Ampharetidae	1.1%

Organism	Habitat Class 10	Organism	Habitat Class 11
F. Sabellidae	17.9%	F. Ampharetidae	27.0%
F. Spionidae	12.6%	F. Maldanidae	20.5%
F. Cirratulidae	6.7%	F. Capitellidae	12.3%
F. Syllidae	6.7%	F. Tellinidae	5.7%
C. Ophiuroidea	5.4%	F. Sabellidae	4.9%
F. Paraonidae	4.7%	F. Spionidae	4.1%
F. Oweniidae	4.2%	F. Cossuridae	3.3%
O. Tanaidacea	3.8%	F. Sternaspidae	3.3%
F. Astartidae	3.7%	F. Syllidae	3.3%
F. Maldanidae	3.4%	F. Ampeliscidae	2.5%
F. Mytilidae	3.3%	F. Thyasiridae	2.5%
P. Sipunculoidea	2.9%	F. Cirratulidae	1.6%
F. Phyllodocidae	2.4%	F. Veneridae	1.6%
P. Rhynchocoela	2.0%	F. Arabellidae/Lumb	0.8%
F. Muricidae	1.6%	F. Goniadidae	0.8%
F. Cardiidae	1.4%	F. Nephtyidae	0.8%
F. Glyceridae	1.2%	F. Opheliidae	0.8%
C. Oligochaeta	1.2%	F. Paraonidae	0.8%
C. Ascidiacea	1.1%	F. Scalibregmidae	0.8%

Table 7. Rankings by Habitat Class (Tables 1, 4 and 5) of dominant epifaunal taxa by percent of total organisms collected. Classes are arranged in successional sequences shown in Table 4, as indicated by arrows.

Habitat Type 1		Habitat Type 3		Habitat Type 5	
Edwardsia elegans	50.2%	Cerianthus borealis	51.8%	Phylum Porifera (encrusting)	45.6%
Phylum Porifera	25.5%	Porania sp.	22.0%	Cerianthus borealis	34.2%
Cerianthus borealis	16.3% →	Edwardsia elegans	15.9% →	Phylum Porifera	7.3%
Class Ascidiacea (colonial)	8.0%	Class Ascidiacea (colonial)	10.4%	F. Cancellothyrididae	3.3%
	100.0%		100.0%	Asterias vulgaris	3.2%
				Henricia sanguinolenta	2.3%
				Edwardsia elegans	2.3%
				Class Ascidiacea (colonial)	1.0%
				Hippasteria phrygiani	0.2%
				Placopecten magellanicus	0.2%
				Class Ascidiacea (stalked)	0.2%
				Crossaster papposus	0.2%
				Porania sp.	0.1%
				Urticina felina	0.1%
					100.0%

Habitat Type 2		Habitat Type 4		Habitat Type 5	
Cerianthus borealis	41.0%	Cerianthus borealis	39.4%	Phylum Porifera (encrusting)	45.6%
Asterias vulgaris	17.0%	Edwardsia elegans	21.2%	Cerianthus borealis	34.2%
Edwardsia elegans	15.9%	Phylum Porifera	19.4%	Phylum Porifera	7.3%
Henricia sanguinolenta	8.8% →	Henricia sanguinolenta	11.6%	F. Cancellothyrididae	3.3%
Phylum Porifera (encrusting)	7.9%	Asterias vulgaris	3.5% →	Asterias vulgaris	3.2%
Phylum Porifera	6.8%	Class Ascidiacea (stalked)	1.8%	Henricia sanguinolenta	2.3%
Hippasteria phrygiani	1.8%	Phylum Porifera (encrusting)	1.8%	Edwardsia elegans	2.3%
Crossaster papposus	0.5%	Hippasteria phrygiani	1.4%	Class Ascidiacea (colonial)	1.0%
Class Ascidiacea (colonial)	0.2%		100.0%	Hippasteria phrygiani	0.2%
	100.0%			Placopecten magellanicus	0.2%
				Class Ascidiacea (stalked)	0.2%
				Crossaster papposus	0.2%
				Porania sp.	0.1%
				Urticina felina	0.1%
					100.0%

Habitat Type 6		Habitat Type 7
Phylum Porifera (encrusting)	23.8%	Phylum Porifera (encrusting) 43.2%
Cerianthus borealis	17.2%	F. Cancellothyrididae 37.4%
F. Cancellothyrididae	16.6%	Phylum Porifera 8.3%
Henricia sanguinolenta	15.6%	Class Ascidiacea (colonial) 5.8%
Asterias vulgaris	13.5%	Cerianthus borealis 2.4%
Phylum Porifera	4.6% →	Asterias vulgaris 1.0%
Class Ascidiacea (colonial)	3.4%	Henricia sanguinolenta 1.0%
Edwardsia elegans	1.8%	Urticina felina 0.5%
Porania sp.	1.2%	Leptasterias polaris 0.5%
Placopecten magellanicus	1.1%	100.0%
Crossaster papposus	0.9%	
Hippasteria phrygiani	0.3%	
	100.0%	

Habitat Type 8		Habitat Type 9
Phylum Porifera (encrusting)	57.3%	Phylum Porifera (encrusting) 84.1%
Henricia sanguinolenta	10.7%	F. Cancellothyrididae 10.2%
Asterias vulgaris	7.2%	Phylum Porifera 2.2%
Class Ascidiacea (colonial)	6.8%	Class Ascidiacea (colonial) 1.3%
Cerianthus borealis	6.8%	Cerianthus borealis 0.8%
F. Cancellothyrididae	3.8%	Asterias vulgaris 0.4%
Phylum Porifera	2.2% →	Henricia sanguinolenta 0.3%
Porania sp.	1.3%	Edwardsia elegans 0.2%
Crossaster papposus	1.1%	Placopecten magellanicus 0.1%
Edwardsia elegans	0.8%	Crossaster papposus 0.1%
Class Ascidiacea (stalked)	0.8%	Hippasteria phrygiani 0.1%
Hippasteria phrygiani	0.5%	Porania sp. 0.05%
Urticina felina	0.4%	Class Ascidiacea (stalked) 0.04%
Placopecten magellanicus	0.4%	Urticina felina 0.04%
	100.0%	100.0%

Habitat Type 10		Habitat Type 11
Phylum Porifera (encrusting)	53.0%	F. Cancellothyrididae 37.0%
Phylum Porifera	14.6%	Phylum Porifera (encrusting) 29.6%
Porania sp.	9.4%	Phylum Porifera 28.7%
Asterias vulgaris	7.0%	Cerianthus borealis 1.4%
F. Cancellothyrididae	5.6% →	Asterias vulgaris 1.3%
Henricia sanguinolenta	3.6%	Class Ascidiacea (colonial) 1.0%
Class Ascidiacea (colonial)	2.9%	Henricia sanguinolenta 0.4%
Cerianthus borealis	2.0%	Hippasteria phrygiani 0.3%

Discussion of major findings

Results relative to goals of the Northeast Consortium. The present project touched upon all four major objectives of the Northeast Consortium: Develop partnerships between commercial fishermen and scientists, educators, and coastal managers; Enable commercial fishermen and commercial fishing vessels to participate in cooperative research and the development of selective gear technologies; Help bring fishermen's information, experience, and expertise into the scientific framework needed for fisheries management; and Equip and utilize commercial fishing vessels as research and monitoring platforms. All four objectives were met in the context of assessing the impacts of a major fisheries closure on seafloor habitats.

Existing knowledge of gear impacts. The impacts of fishing gears on seafloor habitats have been summarized in several recent reviews (Dorsey & Pederson 1998; Watling & Norse 1998; Johnson 2002; NRC 2002; Morgan & Chuenpagdee 2003; Kaiser et al. 2006), and general theoretical relationships have been proposed (Auster & Langton 1999; NRC 2002). Here we consider our findings for both univariate and multivariate assessments in light of the developing theory, and we offer refinements to the theory.

All ten cases of significant differences for univariate faunal community characteristics related to position inside or outside the closure showed higher values inside compared to outside (Table 3). Three of the six for infauna showed overall in vs. out differences, and three were for interaction effects between location and sediment type. The greatest differences in all cases were in "sand" (which in many cases was a mixed sediment containing gravel and/or mud) mainly along the edges of Jeffreys Ledge. Hence, these data suggest that the removal of otter trawls has allowed some recovery of the infaunal communities, particularly in the mixed sandy sediments along the margins of the Ledge. Personal communications (by REG) with fishermen indicate that trawl efforts are often concentrated between the 30-fa (~60 m) and 50-fa (~96 m) isolines; the "30-fa edge" in many areas represents the boundary between trawled areas and rocky bottom where gillnets are the predominant gear type (Fig. 14). All seven later successional stage habitat types (i.e., those with abundant larger infauna or abundant epifauna; Table 5) were more common inside the closed area compared to outside. This also suggests that the overall frequency and/or intensity of disturbance has been lessened sufficiently inside the closure to allow recovery of both soft sediment and rocky bottom habitats.

The Auster & Langton (1999; see their Fig. 2) conceptual model relates habitat structural complexity to level of fishing effort by mobile gears such as trawls and dredges; note that this does not include gillnets (see discussion below). The general relationship is twofold: as level of fishing effort increases habitat complexity is reduced, and as habitat complexity increases the magnitude of the effect increases. The relative impacts on complexity also reflect the relative impacts on benthic communities. In our study area, mobile gears (mainly otter trawls) are largely restricted to sand and mud bottom areas (Fig. 14). Hence, the most impact on infauna would have been predicted in the sandy sediments with gravel because these areas have the most structural complexity. The least impact would have been expected on mud bottoms with low structural complexity in the basins. This is the general pattern that was observed for both univariate (Table 3) and multivariate (Table 5) assessments.

Our findings for mud bottoms also compare well with most previous research in other areas, including study areas in the western Gulf of Maine. For example, Sparks-McConkey & Watling (2001) reported recovery to ambient levels for the infauna on muddy bottoms within 3.5 months after experimental trawling disturbance. Simpson & Watling (2006) found only short-term (<3 months) effects on mud-bottom infaunal communities regularly fished by bottom trawls with rock hopper gear compared to an adjacent unfished area. Studies in other areas on the effects of trawls

and dredges on muddy bottoms typically show no measurable effect on faunal communities, or recovery times of less than 2 years (Collie *et al.* 2000; Johnson 2002; Kaiser *et al.* 2006). Since our study was conducted 4 to 6 years after the closure was implemented no differences would have been expected on the muddy bottoms when comparing sites inside with those outside of the closure. A recent study on the Pacific US coast, however, indicates that benthic communities in mud sediments with taxa that protrude well above the bottom (e.g., sea pens) may be severely impacted by bottom trawls and have long recovery times (Hixon & Tissot 2007).

The impact of mobile gears on macrofaunal communities in sand and gravel depends on structural complexity as well as frequency of natural disturbances such as wind waves and/or tidal currents (Auster & Langton 1999; DeAlteris et al. 1999; NRC 2002; Kaiser et al. 2006). Areas that are frequently disturbed by storms or tidal currents tend to have communities adapted to physical disturbance and are able to quickly recover from physical disturbances in general. For example, two recent studies on nearby Georges Bank found little measurable effects of two large fishing closures (Closed Areas I and II) on benthic fauna. Link et al. (2005) reported no significant differences in a variety of measures of benthic communities based on video and grab samples when comparing sites fished mainly by scallop dredges outside with those inside the closures 4.5 years post-closure. They attributed these findings to the naturally dynamic nature of the seafloor that is frequently affected by storms and strong tidal currents. Stokesbury & Harris (2006) reported similar findings for a video study of epifauna in the same general study areas. However, a longer-term study on gravel bottoms inside and outside Closed Area II on Georges Bank showed substantial recovery of benthic epifauna (megafauna) inside the closure, but the most dramatic differences did not occur until 4 to 6 years post-closure (Collie et al. 2005).

In contrast to mobile gears such as dredges and trawls which have been studied across various habitat types and in many different geographic areas, the impact of gillnets on seafloor habitats has received very little attention. The major conservation issues for gillnets have been bycatch and entanglement of non-target species (He 2006). Our data, however, suggest that gillnets may have been responsible for substantial reductions in epifauna on Jeffreys Ledge.

Although Malik & Mayer (2007) reported seafloor marks on top of the ledge which may point towards evidence of use of other bottom fishing gear in this area, available fishing activity data on pre- and post-closure gear use in the study area indicate that gillnets are the major gear type used on rocky bottoms in the area. If these data accurately reflect the distribution of potential impacts by gear type, then the substantial and significant differences between epifauna densities and taxonomic richness inside compared to outside of the closure suggest that macrofaunal communities on gravel bottoms were damaged by gillnets and are recovering from these impacts. The dominant taxa in these hard-bottom communities were sponges and encrusting bryozoans. These kinds of colonial animals might be easily dislodged by a gillnet, but other than the present research we are aware of no studies on how gillnets might impact seafloor macrofauna.

Recovery rates for benthic communities. As already mentioned, our data may be interpreted to provide an assessment of the recovery process for 4 to 6 years post-disturbance (after establishment of the closure). We inferred that fishing activities were the major cause of reductions in infaunal community density, biomass, and taxanomic richness, and taxonomic composition as well as epifaunal density and taxonomic richness in areas outside the WGOM closure. After 4 to 6 years, infaunal community density, biomass, and taxonomic richness inside the closure were substantially higher, particularly in sand substrates, with maximum increases of 4.2x for density, 3.9x for biomass, and 50% for taxonomic richness (Table 3). Epifaunal community density and taxonomic richness inside the closure after 6 years were up to 2.3x and 1.7x higher, respectively (Table 3).

Preliminary multivariate assessments showed early successional stages characteristic of areas affected by chronic seafloor disturbance were dominant outside the closure, and later successional

stages characteristic of areas not affected by physical disturbances dominated most areas sampled inside the closure (Table 5). There were also substantial differences in taxonomic composition of among the habitat classes. For example, the polychaete family Sabellidae was the dominant (27.6% of the total community; Table 6) infaunal taxon in Habitat Class 5 (later successional stage for soft sediments and more common inside the closure), whereas it was absent or rare in the two earlier stages (Classes 1 and 2) that were more common outside of the closure. Sabellids are tube builders that extend a feather-like crown of tentacles into the water column to feed, and are thus perhaps more vulnerable to mobile gear impacts (Hall-Spencer et al. 1999; Collie et al. 2000). Class 5 was characterized by the large infaunal anemone, *Cerianthus borealis*, that would be similarly vulnerable to mobile gear (Watling 1998; Hall-Spencer et al. 1999). The same kinds of trends were observed for epifaunal communities (Table 7). For example, the epifauna on hard bottoms inside the closure had more species and were dominated by taxa such as sponges and brachiopods that would also be more likely to be damaged by fishing gear. In sum, this preliminary assessment of our multivariate data on community taxonomic composition of both infauana and epifauna strongly indicate substantial recovery of seafloor invertebrate communities inside the WGOM closure.

To our knowledge, only one previous study of how the WGOM closure has affected seafloor habitats has been completed (Knight 2005; Knight et al. 2006). This NEC-funded research focused on areas north of our study area that were mainly (only?) affected by bottom trawls, and it was also an "in vs. out" approach. Their field sampling occurred from 2002 through 2004, covering nearly the same time interval as our project, but also included areas in the eastern-most portion of the WGOM closure that was not implemented until 1999 (2 years after the initial closure area was implemented). These differences aside, they reported similar findings to ours: much higher abundances for some infaunal and epifaunal taxa inside the closure compared to outside; and a shift in taxonomic composition of infaunal (e.g., increases in sabellid polychaetes inside the closure) and epifauna towards taxa less tolerant of physical disturbances had occurred at sites inside the closure.

Our understanding of the recovery process for seafloor habitats disturbed by fishing gears is in the early stages, in large measure because of the number of factors involved (e.g., gear type, frequency and intensity of disturbances, bottom type). Recent meta-analyses of gear impacts reveal widely variable recovery times, with no consistent trends for many combinations of gear and bottom types (Collie et al. 2000; Kaiser et al. 2006). For example, for otter trawls (one of the two major gear types used in soft-bottom areas in the present study; Fig. 14), Kaiser et al. (2006) reported no data on recovery times for seafloor communities on sand and gravel bottoms, which were the major bottom types showing impacts in the present study. However, the study by Collie et al. (2005) noted above showed substantial recovery of benthic epifauna (megafauna) on gravel bottoms inside Closed Area II on Georges Bank in the western Gulf of Maine. But differences did not occur until 2.5 years post-closure, and increases in biomass and abundance of some taxa were still occurring after 5 years. They suggested that recovery times for faunal communities on gravel bottoms in their study area is on the order of 10 years. Although our study was designed only to provide a single measurement in time of the overall recovery process, the data in Collie et al. (2005) and Knight (2005) and Knight et al. (2006) suggest that recovery of bottom communities in the WGOM closure is still occurring. Further studies are needed to characterize the recovery process as it proceeds.

Conclusions - implications for ecosystem-level management policy

The major overall finding of our study was that the WGOM closure area is achieving a very important management goal: protection and enhancement of seafloor habitats. How might these changes in seafloor habitats be related to ongoing recoveries of some fish populations and what are the management implications?

The overall management goal of the closure is stock re-building via "depleted stock protection" (Wooninck & Bertrand 2004), which can include a variety of ecological functions affecting all life stages of the managed species. Although a variety of fishing gears (e.g., lobster traps, mid-water trawls) are still permitted in the area, all fishing gears capable of retaining groundfish are prohibited. Hence, a major goal is reduction in mortality by prohibiting harvest but also protection of habitat from the potentially damaging effects of mobile bottom gear. Stocks of several managed species in the region have shown consistent upward trends over the past several years, suggesting that various management measures, including the WGOM closure, are working. However, there has been little rigorous assessment of how the WGOM closure may be contributing to the stock re-bounds.

Recent research on "spillover" effects (Murawski et al. 2004) and groundfish movement patterns (Howell & Goethel 2004) that involved the WGOM closure has indicated little if any effect of the closure on movements of adult groundfish in the general area. Howell and Goethel (2004) concluded with regards to cod: "Cod show no preference for movement into the closed area [WGOM], i.e. the area does not appear to be a sink. There is also no evidence of wholesale movement out of the closed area, i.e. the area does not appear to be a particularly important source of adults. The area may be a source of eggs, larvae, and juveniles, and may be an important nursery area, but such functions need to be verified."

Much of the WGOM closure area encompasses Jeffreys Ledge which consists largely of rocky bottom with substantial vertical relief in some areas. This kind of bottom typically functions as nursery habitat for groundfish species such as cod (Collette & Klein-MacPhee 2002), and can be severely damaged by mobile gear (Dorsey & Pederson 1998; Watling & Norse 1998; Auster & Langton 1999; Johnson 2002; NRC 2002). For Atlantic cod in particular, Fahay et al. (1999) listed as a research need "…the importance of certain bottom habitat types for the survival of young-of-the-year." There is a need to better characterize the role of rocky bottoms as groundfish nursery habitat and the effectiveness of marine closures such as the WGOM in protecting such habitat.

Some of our findings are directly relevant to these issues and represent potentially important information for managers. For example, the fact that there were substantially greater abundance and diversity of infaunal and epifaunal benthos inside the closure compared to outside strongly suggests that the closure is working (as also concluded by Knight 2005 and Knight et al. 2006). If it is assumed that these changes are mainly the result of the removal of the impacts of fishing activities, as we think it is reasonable to do, then dramatic recovery of the bottom communities has occurred over the 6 years since the closure was established and the recovery is continuing. Therefore, the WGOM closure has indeed served to protect/rebuild habitat. The relationship of these changes in habitat, however, to protection of Essential Fish Habitat (EFH) for managed species or other goals related to re-building groundfish stocks remain to be elucidated.

Closed area management measures are expected to have two separate effects on productivity and sustainability of fisheries (Stefansson & Rosenberg 2005). First, if the closure is properly designed, it may reduce fishing mortality rates on some stocks by shifting limited effort away from areas where catchability is high to areas where it is lower. Effort control is essential to ensure that effort increases don't compensate for reduced catchability. Reduced fishing mortality rates on overfished stocks should increase productivity through stock and recruitment effects.

Secondly, closed areas that protect habitat may increase productivity of stocks by increasing growth, reproduction, and/or survival rates. This effect of closed areas is much harder to quantify or demonstrate with respect to recovery of the fish stocks. But, one important aspect of inferred habitat quality is the abundance of food resources, which includes both infauna and epifauna for many managed fish species (Collette & Klein-MacPhee 2002).

The management implications of this study are also two-fold. The observed differences in infauna and epifauna indicate that the closed area has been an effective measure for protecting

habitat and potentially aiding stock recovery, though the latter has yet to be quantified. This conclusion is important in evaluating the efficacy of management. Closed area effects on reducing fishing mortality in New England have been generally accepted, but habitat protection benefits are still controversial.

A final important implication of this study is in the design (or modification) of closed areas. Clearly, the results presented here indicate that certain bottom types benefit more from protection than others and that fixed gear (gillnets) as well as mobile gear can have important habitat impacts. As closed area management is modified in the future, these results will help clarify design criteria and refine the closures. Coupled with the improved ability to accurately monitor the position of vessels during fishing operations, these data may enable managers to more finely tailor management measures for different gear types to very specific bottom types and areas. Higher resolution controls have the potential to improve the effectiveness of management measures while reducing the restrictions on fishing operations to only those areas whose protection can most benefit the resource.

Social issues

The final component of the present project was aimed at development of a database on the literature dealing with various stakeholder groups/agencies (Table 1). As noted above, however, this component of the project was only preliminarily addressed during the first two years of the study. Nonetheless, the resulting database represents the initial stages of a more comprehensive socioeconomic assessment of the WGOM closure area that is being designed.

Partnerships

The present project resulted in many opportunities for collaborative research and other activities involving fishermen and researchers. The collection of new sediment and benthic data for the seafloor mapping was done from fishing vessels, and was a collaborative effort between fishermen and scientists. Deployment of some gear (e.g., Hubbard camera) required modifications to the fishing vessels, but for much of the work existing configurations were adequate. Overall, the present project involved collaboration between eight scientists and three fishermen.

The project also resulted in collaboration with non-NEC funded research on predator-prey relationships in the 400 km^2 study area involving Dr. Jeb Byers and a graduate student, John Meyer, from UNH. This study provided information on differences in predation rates on major groundfish food organisms (e.g., crabs, brittle stars) at areas within and outside of the WGOM closure, and also used fishing vessels for some components.

Several new collaborative research projects also resulted from the fishermen/scientist relationships that were established during the present project. An NEC development project that led to a full research project on how the WGOM closure is affecting fish populations in rocky habitats was funded and is ongoing. This project led to another proposal that has been submitted for research on how dogfish are affecting cod populations in the region.

In sum, we feel that the partnerships resulting from the present project have been extraordinarily productive. Our findings have important management implications and the partnerships formed have been ongoing in the form of new proposals as well as funded research.

Impacts and applications

The present project had important impacts and applications in two major ways. First, during the course of the project, two very well-attended public meetings were held to explore the effects of the WGOM closure on various ecosystem processes. The first, held at the Brown Center at UNH on 30 October 2003, was attended by over 40 investigators, including fishermen, research scientists,

government managers, and students. The meeting included presentations and workshops, and resulted in a proceedings volume focusing on major research needs and themes (see NEC 2004 below). The second meeting was also held at UNH on 26 March 2007, and focused on what is known about the impacts of the WGOM closure in the context of regulatory issues. It was organized around invited presentations by fishermen, scientists, and government managers, and also resulted in a proceedings volume (see UNH 2007 below). This meeting provided a unique opportunity for fishermen and researchers to interact with representatives of the New England Fishery Management Council and the National Marine Fisheries Service.

The second major impact of the present project was the research itself. Together with a concurrent NEC-funded project conducted by Les Watling, Emily Knight and colleagues (discussed above), some important effects of the WGOM closure area have been demonstrated. The closure has resulted in significant recovery of bottom habitats, including soft bottom areas affected by otter trawls and rocky areas primarily fished before the closure by gillnets. The effect of these changes in bottom habitat conditions on associated fish populations, however, has not been assessed. The present project led to an ongoing NEC-funded project investigating fish populations in rocky habitats, which should contribute to a broader ecosystem-level understanding of the closure.

Related projects

The present project was possible largely because of additional funds from the NOAA/UNH Cooperative Institute for New England Marine Fisheries and Aquaculture (CINEMAR; now the Atlantic Marine Aquaculture Center, AMAC). These funds provided salary and other support for most of the scientists on the project. In many cases, the present structure of NEC funding that requires 75% of the money to go to fishermen greatly restricts the participation by scientists unless additional funds are secured. The support by CINEMAR/AMAC was also used to fund the related project on predation rates on benthic invertebrates in the study area by Dr. Jeb Byers and his student John Meyer at UNH (see “Partnerships” section). We greatly appreciate the support of AMAC.

Two major outreach projects, the UNH meetings discussed in the “Impacts and Applications” section, were funded by NEC, AMAC, New Hampshire Sea Grant, New Hampshire Cooperative Extension, and the UNH Marine Program.

Presentations

Grizzle, R.E. 2007. Recovery of seafloor habitats inside the WGOMCA and some potential impacts on groundfish populations. Western Gulf of Maine Closure Area 2007 Symposium, March 26, 2007, University of New Hampshire

Grizzle, R.E., L.G. Ward, L.A. Mayer, A.B. Cooper, A.A. Rosenberg, M. Brodeur, J.K. Greene, H. Abeels, and M. Malik. Effects of the Western Gulf of Maine closure area on seafloor habitats: GIS-based assessments. Geographic information systems and ocean mapping in support of fisheries research and management. MIT Sea Grant symposium, Cambridge, MA, April 2006.

Grizzle, R.E. Effects of the Western Gulf of Maine closure area on benthic habitats. Maine Fishermen's Forum, Rockport, ME, March 2006.

Grizzle, R.E. Ecosystem level studies of the Western Gulf of Maine closure area. Northeast Regional Sea Grant Meeting, Roger Williams University School of Law, RI. January 2006.

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Grizzle, R.E. (and 9 others). Intensive study of the Western Gulf of Maine Closure Area. Fifth Annual Project Participants' Meeting, Northeast Consortium, 27 October 2005, Portsmouth, NH.

Grizzle, R.E. Seabed mapping using acoustics and underwater videography. UNH Zoology Department Seminar Series, November 2003, Durham, NH.

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Student participation

UNH undergraduate students: Krystin Ward, Kaitlin Graiff, Ryan McDonnell, Ben Winslow, Michelle Graffam, Molly Garitta, Amber Perkins, Sarah Mikulak, Katy Johnson, Janet Kleiner

UNH graduate students: Jennifer Greene, Edward Merchant, Mark Capone, Randy Cutter, Mashkoor Malik

High School Students (Upward Bound, Newmarket High School, NH): Julianne Morin, Alicia June, Blake Bowick, Eric Dugre, Jessica Pearson, Sarah Morrison

Technical reports, theses, and published papers

Grizzle, R.E., L.G. Ward, H. Abeels, J.K. Greene, M. Brodeur, M. Malik. Recovery of bottom habitats in a large fishing closure in the western Gulf of Maine, USA. (in prep.)

Ward, L.G., M. Brodeur, M. Malik. Seafloor geology of a large fishing closure in the western Gulf of Maine, USA. (in prep.)

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Future research

This project strongly indicates that further work should be done on various ecological aspects of the WGOM closure. The finding that substantial recovery of seafloor habitats had occurred after 4 to 6 years in some areas needs to be followed by research on the trajectory of the recovery process as well as how managed fish populations may be affected. This will give a more complete picture of how the closure is functioning overall with respect to its management goal of stock re-building. An ongoing NEC-funded project using multi-mesh gillnets to determine how fish communities in rocky bottom habitats are being affected by the closure has been designed to provide data in this respect and to complement existing data from the NMFS trawl surveys.

Research is also needed on ecological interactions among species inside the closure. The work of Byers and Meyer mentioned above (see "Partnerships" section) found different predation rates on invertebrate prey species important to managed fish species inside the closure compared to outside. The same might be true for fish species that are food items. There is also ongoing research as well as proposed research that would shed light on how the greatly increased population of spiny dogfish in the region may be affecting groundfish recoveries and the potential role of fishery closures. These are controversial areas of research and potentially quite important because they might yield data indicating that one (or more) managed species is inhibiting the recovery of another. Such findings would be squarely in the arena of "ecosystem-based management" and could lead to management strategies that are not even possible under current species-based management policy.

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