Assessment of Benthic Recovery in the Western Gulf of Maine Closed Area

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Epifauna in areas of the Western Gulf of Maine Closed Area

Final Report Submitted to
National Marine Fisheries Service, Cooperative Research Partners Program

by

Emily Knight, Graduate Student and Les Watling, Professor of Oceanography
University of Maine, Darling Marine Center

Cameron McLellan, Captain of F/V *Adventurer*

In cooperation with

Laura Taylor Singer, Director of Collaborative Research
Gulf of Maine Research Institute

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I. ABSTRACT

Otter trawling has been shown to disrupt benthic community structure by reducing biodiversity and abundance levels of epifaunal and infaunal species. Such reductions in the abundances of benthic inhabitants has raised concerns in the scientific, management, and fishing communities because many commercially valuable groundfish species depend on benthic habitats of various substrate types for food resources and to avoid predation. However, the long-term ecological consequences of direct disturbance to benthic habitats on ecosystem resilience and function have proven difficult to predict.

Within the last decade, marine protected areas (MPA) have been designated in the Gulf of Maine to address concerns of declining groundfish stocks, with the hope that benthic communities affected by groundfish trawling may also recover in such areas as well. One such MPA, the Western Gulf of Maine Closure (WGOMC), encompasses two regions that, as of 2004, had been closed to groundfish trawling for 6 and 4 years, respectively. In this project, changes in benthic community composition following the cessation of trawling were investigated by comparing community states of sites in the 4 and 6 year regions of the WGOMC to sites in an actively trawled fishing ground known as the Kettle. The epifaunal and infaunal components of benthic communities were surveyed via remotely operated vehicle (ROV) and sediment grab sampling in sites of comparable depth and substrate each August from 2002 through 2004. Multivariate statistics were then used to analyze differences in benthic community composition within and between sites. Finally, family life history information for resident taxa was used to determine possible mechanisms driving observed differences between benthic community composition.

II. EXECUTIVE SUMMARY

The direct effects of mobile fishing gear on continental shelf benthic communities have been documented (Dayton et al. 1995; Auster et al. 1996; Auster and Langton 1999; Jennings and Kaiser 1998; Watling and Norse 1998; Hall 1999; Kaiser and de Groot 2000). Trawling has been shown to reduce biotic habitat structure by removing sensitive organisms, resulting in a loss of biological and structural diversity. That is, mobile gear fisheries were shown to reduce the structural complexity of bottom habitats by direct removal of biological (e.g. sponges, bryozoans, ascidians, etc.) and sedimentary structures (e.g. sand waves, depressions). These structures may provide essential refuge for juvenile fish and invertebrate species. However, the long-term effects biodiversity loss could have on ecosystem function in subtidal coarse bottoms remains largely unknown.

There is considerable debate in both the fishing and scientific communities regarding the magnitude of impacts of mobile-fishing gear on habitat complexity and the ability of fished areas to recover. Prior to the establishment of year-round area closures in the mid-1990's, it was difficult to study recovery of bottom habitats on fishing grounds in the Gulf of Maine because it was not possible to know precisely the last time a certain area of bottom was trawled. On heavily fished bottoms, habitats were rarely, if ever, given a recovery period. While the acute impacts of trawling appear to be a good predictor of the cumulative impacts of chronic trawling (Auster and Langton 1999), there is little data on how impacted communities will change in composition and abundances over time following the cessation of trawling.

Trawling may reduce the structural and biological complexity of subtidal benthic habitats more than any other disturbance, natural or anthropogenic, in areas that are heavily fished and deeper than storm surge (Watling and Norse 1998). In these areas, a disturbance of this frequency and magnitude may jeopardize ecosystem resilience by restricting size, density, and distribution of organisms. Therefore, population abundance must be considered in addition to biodiversity when assessing the ability of these organisms to fulfill their roles in ecosystem function. Even if the species that make up any seafloor community are present, if their populations are beyond the threshold at which they are able to fulfill their ecosystem roles, they can be considered functionally extinct (Thrush and Dayton 2002). Whether or not communities on and within coarse bottoms are anywhere near functional extinction is unknown. In fact, little is known about ecosystem function in these environments prior to trawling, or how community composition may change over time following the cessation of trawling.

In essence, trawling has been shown to reduce habitat structure, and biodiversity has been positively correlated with the presence of habitat structure. In order to detect how communities may change following the cessation of trawling, studies must not only quantify the effects of fishing on habitat structure, but address the connection between habitat structure and diversity over time. The spatial and temporal patterns of recovery in communities after fishing will be variable, depending on the biological and physical characteristics of the environment under study (Auster and Langton 1999). The ecological roles component organisms' play is determined by attributes of the resident species themselves as told by their life histories, interactions between component species and broad-scale and local chemical and physical dynamics, and interactions between different species populations, such as competition for food and space. These community dynamics then make up the provision of ecosystem services available to higher trophic levels such as groundfish, which function in the ecosystem as large predators.

The Western Gulf of Maine Closure (WGOMC), which encompasses regions closed to groundfishing since either 1998 or 2000, provided a unique opportunity to monitor habitat recovery on a gradient of fishing pressure. To investigate the recovery of structural components of benthic biodiversity in the WGOMC, we conducted an observational study where sites in the WGOMC were compared to sites in an actively trawled fishing ground (the Kettle) of similar substrate and depth. Video transects of epifaunal communities were taken in the WGOMC in August 2002 (2 year closed sites) and resampled in August 2004 (4 year closed sites), in the 6 year region of the WGOMC in August 2004 (6 year closed sites), and in the Kettle in August 2003 (Open 2003) and resampled in August 2004 (Open 2004). Samples of infaunal communities were collected in the 4 and 6 year closed sites of the WGOMC in August 2004. Infaunal community samples were taken in Open 2003 and Open 2004 in the Kettle in August 2003 and 2004, respectively.

Multivariate analysis showed significant differences in benthic community composition between the Kettle and the WGOMC which we attributed to the cessation of chronic trawling disturbance. In general, benthic communities in the Kettle were dominated by more disturbance tolerant, opportunistic families, while communities in the WGOMC were dominated by more disturbance intolerant, sessile families. However, it appears that the infaunal and epifaunal components of benthic communities most likely recover at vastly different rates. Infaunal communities of both the 4 and 6 year closed sites were dominated by the sessile tube-building polychaete Sabellidae, while Open 2003 and Open 2004 sites were dominated by the faster reproducing mobile polychaete Spionidae. The 4 and 6 year closed sites of the WGOMC and Open 2004 also had double the number of rarer low abundance families than Open 2003. On the other hand, in the epifaunal communities, very little recovery was observed until the 6 year closed sites. The 6 year closed sites showed higher total abundances of individuals, and higher species richness than the 2 and 4 year closed sites, or Open 2003 and 2004. The 6 year closed sites were dominated by *Mogula sp*. but showed sharp increases in phylum Porifera. The 2 and 4 year closed sites, and Open 2003 and Open 2004 were dominated by *Molgula sp*. and the mobile, opportunistic northern shrimp, *Pandulus borealis*.

The Magnuson-Stevens Fishery Conservation and Management Act (Magnuson), defines essential fish habitat (EFH) as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity”. According to National Marine Fisheries Service, “substrate” includes sediment, hard bottom, structures, and associated biological communities. Groundfish trawling has been shown to significantly reduce biodiversity and abundances of benthic communities of coarse sediments, which may be vital to the life histories of many groundfish (Dayton et al. 1995; Auster et al. 1996; Auster and Langton 1999; Jennings and Kaiser 1998; Watling and Norse 1998; Hall 1999; Kaiser and de Groot 2000). Restrictions to abundances, distribution, and size of resident benthic populations may result in a loss of ecosystem services, such as food resources to higher trophic levels. The 1996 reauthorization of the Magnuson mandates that regional fisheries management councils must designate and conserve EFH (Auster and Langton 1999). However, once the functionally important components of an ecosystem are missing, it is extremely difficult to identify and understand ecological thresholds (Thrush and Dayton 2002). To explain the illusive link between biodiversity and the provision of ecosystem services vital to higher trophic levels such as groundfish, especially in environments that already bear the marks of a long history of fishing disturbance, requires consideration of both its structural and functional components (Thrush and Dayton 2002). With this project, we addressed changes in family diversity and abundances following the cessation of trawling disturbance, one aspect of the structural component of ecosystem function.

III. PURPOSE

Trawling on coarse bottoms, ranging from mixed sediments of gravel, mud, and sand to rock outcrops, began in the late 1970’s with the advent of rock-hopper gear. However, the direct reduction of biodiversity and species abundances on coarse bottoms has only begun to concern scientists in the last decade, meanwhile fisheries management decisions are based largely on direct assessments of fish mortality. The long-term ramifications trawling-induced reductions in biogenic habitat structure may have on ecosystem function, and ultimately groundfish populations, is presently unknown. Given the growing appreciation of the value of marine biodiversity as crucial to the sustainability of commercially valuable grounfish stocks as well as for its own unique heritage (Bengtsson et al. 1997; Costanza et al. 1997; Freckman et al. 1997; Gray 1997; Schlapfer and Schmid 1999), there is now an increasing need to understand and sustain biodiversity as a part of any fisheries management plan.

Biodiversity has been found to be positively associated with habitat complexity (Tokeshi 1999). The presence of structure on coarse bottoms, biotic and abiotic, enhances the biodiversity of the community in a number of ways. Rocks and boulders serve as substrate for sessile epifauna such as Corals, Sponges, Brachiopods, and Bryozoans. These organisms in turn attract symbionts, and create crevices within and between them that draw inquilinous species. Bioturbating infauna regulate the release of ammonium back into the water column, and create resource patchiness by altering chemical gradients within the sediments. Infauna also create three dimensional structure on the surface of mixed sediments by constructing tubes (Auster et al. 1997). Finally, infauna and inquilinous species serve as prey items for adult groundfish, and the presence of structure decreases the vulnerability of 0-year fish to predation (Collie et al. 1997; Lindholm et al. 1999; Lough et al. 1989; Tupper and Boutilier 1995a, b).

The objective of this project was to investigate changes in the biological composition of benthic communities on and within coarse sediments at different time steps following the cessation of trawling in the WGOMC. Changes in benthic community composition from sites in the WGOMC were assessed by comparing current community states in regions of the WGOMC that have been closed to groundfish trawling for different amounts of time to sites of similar substrate and depth in the Kettle, an actively trawled fishing ground. Worth noting is that the WGOMC is currently closed only to groundfish trawling and gill netting, thus mid-water trawls and recreational fishing are still allowed in this area. Because sediment type and depth of sampling sites were comparable and greater than what is affected by storm surge, we anticipated that any differences observed in benthic community composition and abundances could be attributed to release from chronic trawling disturbance.

Meta-analysis conducted on results of 39 published fishing impact studies by Collie et al. (2000) found that the total number of individuals in actively trawled areas were most reduced in more stable biogenic habitat types, namely coarse sediments of gravel, mud, and sand with interspersed stones and boulders. Based on the broad array of fishing impacts research synthesized in Collie et al. (2000) and general knowledge of ecological theory and biology, we generated some predictions regarding the community states of all study sites:

- *Among **infaunal communities**, we did not expect increases in diversity in the 4 and 6 year closed sites as much as shifts in community dominance from more disturbance tolerant mobile opportunistic families in the Kettle to sessile, slower-reproducing families in the WGOMC.*

  Sessile polychaetes and crustaceans stabilize sediments by creating tubes near the sediment-water interface. Not only do these organisms tend to have longer life spans than more mobile families of the same class, they also spend most of their lives in their tubes and reproduce less often, which makes them more vulnerable to direct damage from trawls, and less likely to recover in the interim between frequent trawling disturbances (Jenkins et al. 2001).

- *Among **epifaunal communities** we expected community states in the 6 year closed sites to differ significantly from not only the Kettle, but also the 2 year closed sites, which were sampled again 2 years later when the same region had been closed for 4 years (4 year closed sites).*

  Epifaunal communities of coarse sediment types often support a wide variety of attached sessile groups such as Poriferans, Cnidarians, Bryozoans, Brachiopods, and Tunicates, as well as many mobile groups such as various Crabs, Shrimp, and Sea Stars. Sessile upright epifauna such as Poriferans and Anthozoans, which can be dominant on coarse sediment types, are vulnerable to direct damage from trawls, especially branched growth forms of phylum Porifera (Sainsbury 1993; Wassenberg

2002). Poriferans can sit meters off the bottom and larger specimens can have multitudes of branches that break easily (Sousa 2001). Poriferans also exhibit no escape response, unlike some Anthozoans, such as *Cerianthis*, which can retreat into its tube when disturbed. Life history strategies of Poriferans indicate that communities of these organisms may take years to fully recover. Therefore, we anticipated that the 2, and later the 4 year closed sites would still be more similar in community composition to the Kettle than the 6 year closed sites since it very well may be that 4 years is not enough time for sessile attached epifauna to even begin to show evidence of recovery.

IV. APPROACH

Study Site Location and Description

The Western Gulf of Maine Closure (WGOMC) is located in the southwestern region of the Gulf of Maine, running from 43^{o}15' latitude south to 42^{o}15', and west to east from longitude 70^{o}15' to 69^{o}45' (see figure 1). As of May 2004, it had been closed a little over 6 years west of the 70^{o} line, and 4 years east of the 70^{o} line. The 6 year region of the WGOMC was initially established May 1, 1998 with the purpose of conserving depleted commercially valuable groundfish stocks by the New England Fisheries Management Council as part of Framework Adjustment 25 to the Northeast Multi-species Fishery Management Plan. At that time, mobile bottom tending gear and gill netting were banned within the closure, with the exception of shrimp trawls. In May 2000, the 4 year region of the WGOMC was established with the same fishing restrictions as the 6 year region. In May 2004, the entire WGOMC was reclassified as a habitat closure with the expressed purpose of not only conserving groundfish stocks, but also allowing recovery of benthic habitats that may have been affected by past trawling. Currently, all mobile bottom tending gear, including shrimp trawls, and gill netting are banned. Furthermore, as a habitat closure, the WGOMC is now closed to groundfishing indefinitely, rather than until depleted groundfish stocks recover, which is most likely on a much shorter temporal scale than that of benthic habitats. Worth noting, however, is that mid-water trawls and recreational fishing have always been, and are still, permitted in the WGOMC.

The WGOMC was designed to encompass a wide range of habitat types that are representative of the heterogeneity of benthic habitats on the northeastern U.S. continental shelf. Rocky outcrops, gravel pavements, boulder fields, sand, and mud substrates can be found in various locales of the WGOMC. For this project, sampling was focused on a coarse sediment type composed of a mix of gravel, sand, and mud with interspersed stones and boulders often located at the base of rocky outcrops. Such environments often support a diverse assemblage of infaunal and epifaunal species relative to other substrate types due to the availability of attachment space and high quality food resources in the sediments. This makes these areas extremely productive fishing grounds since groundfish will tend to aggregate in more structurally complex habitats to feed or spawn. Fishermen will often fish these areas by trawling the bottom "hard" to drive aggregated fish populations on top of adjacent rocky outcrops where they are easier to catch without damaging trawl gear.

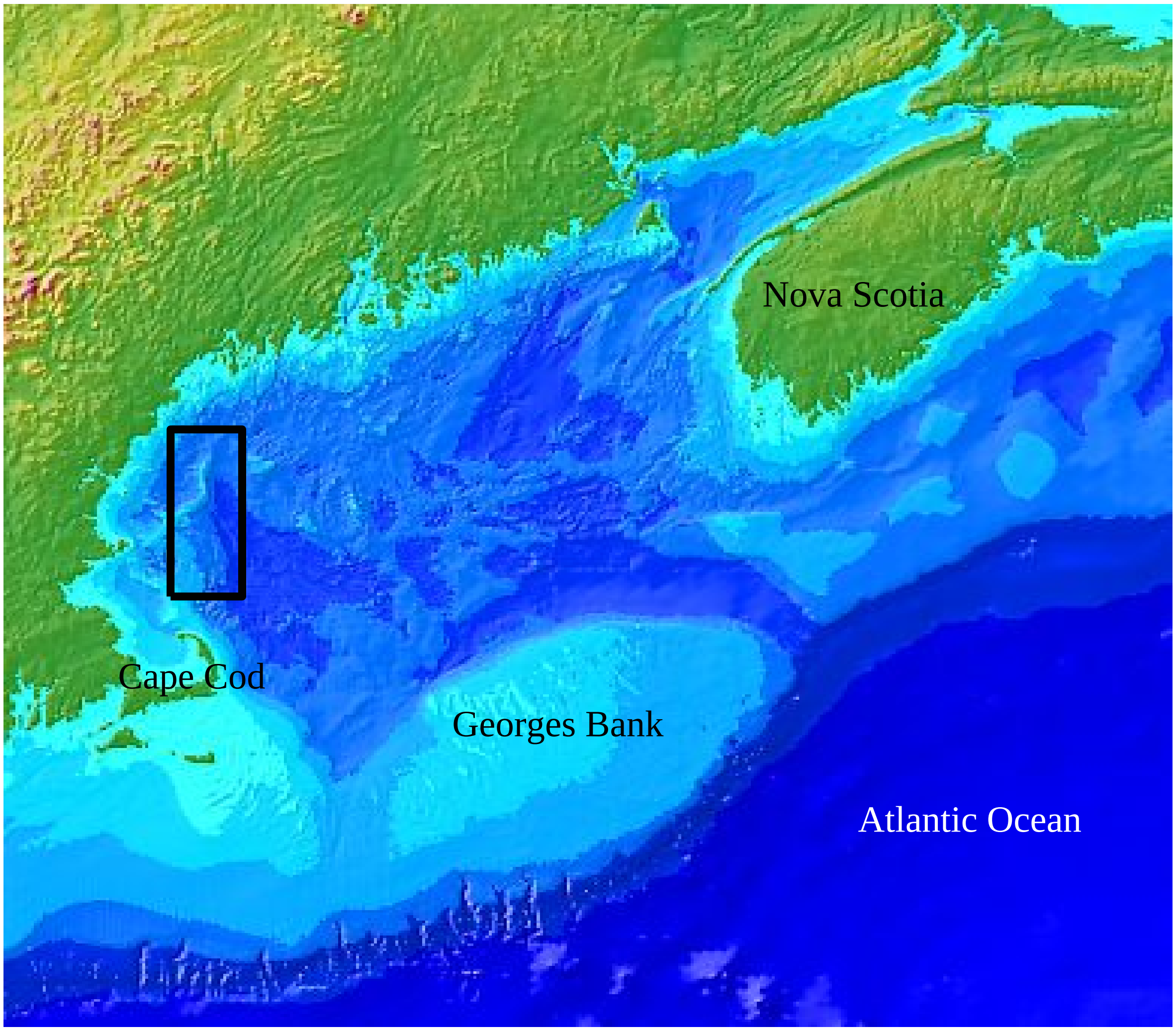

Figure 1: Map of the Gulf of Maine, boxed area represents the Western Gulf of Maine Closure.

Study sites in the WGOMC were located in the northern region of the closure surrounding Jeffrey's Ledge (see figure 2), a rocky outcrop that runs from the northern tip through the mid-region of the WGOMC. Study sites on the eastern side of Jeffrey's Ledge were also east of the 70^{o} line, therefore in the 4 year region of the WGOMC. Study sites on the western side of Jeffrey's Ledge were also west of the 70^{o} line, therefore in the 6 year region of the WGOMC. All actively trawled study sites were located in an historic fishing ground known as the Kettle. Like formerly trawled sites in the WGOMC, sites in the Kettle are also a coarse mix of gravel, sand, and mud with interspersed stones and boulders located at the base of a rocky outcrop. All study sites were between 100 – 130 m depth.

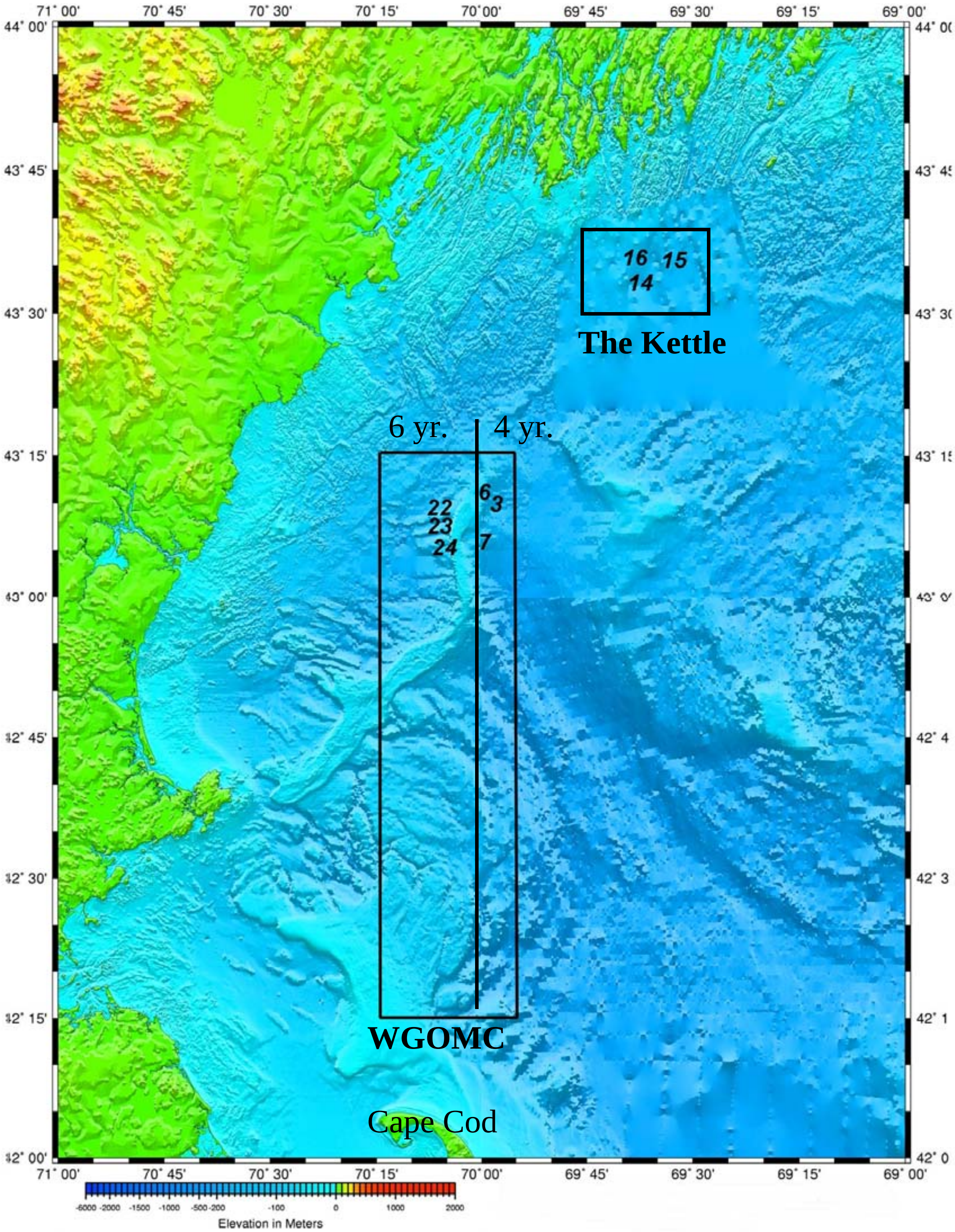

Figure 2: Study sites: WGOMC: sites west of the 70^o line had been closed for 6 years, sites east of the 70^o line had been closed 4 years. The Kettle: sites located roughly 16 nautical miles northeast of sites in the WGOMC.

Study Design

This study was an observational, (as opposed to an experimental), field study conducted using a block design where the treatment variable, the presence of groundfish trawling, was assigned with *a priori* knowledge of fishing activity (Van Dolah et al. 1987; Riemann and Hoffman 1991). Study sites in the Kettle and each region of the WGOMC were chosen based on three criteria: 1. substrate type, 2. depth, and 3. fishing activity. Sediment type sampled was a coarse mix of gravel, mud, and sand with interspersed stones and boulders. To avoid the potentially confounding effects of winter storm surge and temperature changes on results, all study sites were located between 100 – 130 m depth. Study sites in the WGOMC, prior to being closed in May 1998, are within what were productive fishing grounds popular among many fishermen. The Kettle is an historic fishing ground that continues to be fished intensely to this day. Study sites in both the WGOMC and the Kettle specifically were chosen based on recommendations by Cameron McClellan, a fifth generation fishermen and Captain of F/V *Adventurer*, who, along with much of the downeast Maine groundfishing fleet, used to fish study sites in the WGOMC, and currently fishes study sites in the Kettle.

Sampling of study sites began in August of 2002, and continued each August through 2004. In August of 2002 in the WGOMC, west of the 70^o line had been closed for 4 years, and east of the 70^o line had been closed for 2 years. The first 2 summers of the sampling regime were spent attempting to properly survey benthic communities in an attempt to find study sites that would match the above stated sampling criteria in order to have scientifically comparable areas. When sampling to assess diversity, it is desirable to encompass as much variation as possible by taking multiple samples within different sites (Thrush et al. 2001). The goal of this sampling strategy was to obtain grab samples of the infaunal community within video transects documenting the epifaunal community. Within each region, sites were identified where it would be possible to take at least three video transects with one grab sample nested in each transect in order to maximize the variability encompassed within each study site (Table 1). In August of 2002, video transects of the epifaunal component of benthic communities of 3 study sites (sites 6, 3, 7) in the 2 year region of the WGOMC were surveyed. These same sites were resampled in August 2004 for both the epifaunal and infaunal components when the area had then been closed for 4 years. In August of 2003 and subsequently in August 2004, infaunal and epifaunal components of benthic communities of 3 study sites (sites 14, 15, 16) in the Kettle were surveyed. Finally, in addition to resampling all previous study sites in August 2004, the infaunal and epifaunal components of 3 study sites (see figure 2, sites 22, 23, and 24) located in the 6 year region of the WGOMC were sampled.

Table 1: Sampling Scheme.

Sampling Scheme				
Sampling Sites	**Treatment**	**Sampled for:**	**Sites (see figure 2)**	**Year Sampled:**
Open 2003	Trawled	Epifauna/Infauna	14, 15, 16	Aug. 2003
Open 2004	Trawled	Epifauna/Infauna	14, 15, 16	Aug. 2004
2 yr closed sites	Untrawled – 2yrs	Epifauna	6, 3, 7	Aug. 2002
4 yr closed sites	Untrawled – 4 yrs	Epifauna/Infauna	6, 3, 7	Aug. 2004
6 yr closed sites	Untrawled – 6 yrs	Epifauna/Infauna	22,23, 24	Aug. 2004

Each study site of all regions sampled consisted of 3 sampling stations, each station comprising one video transect of the epifaunal community, and one grab sample of the infaunal community taken at the same location of that video transect, with the exception of the 2 year region of the WGOMC. The 2 year region of the WGOMC, sampled in August 2002, was only sampled for the epifaunal component, therefore each study site consisted of 3 video transect stations only.

Sampling of the benthic community

A 0.1-m^2 Smith-McIntyre bottom grab was used to collect sediment samples. Grab samples were sieved into a 500 micron sieve and preserved in 10%, buffered formalin solution. Upon return to the lab all samples were transferred into 70% ethyl alcohol. Infauna were identified to the level of family and enumerated for sample.

The Phantom 300 remotely operated vehicle (ROV: Deep Ocean Engineering, San Leandro, California) was used to conduct all video transects. The ROV was configured to collect video data, which was recorded on to mini-DV tapes aboard the ship. Transects at each sampling station were approximately 10 to 15 minutes in length. In order to get the ROV to the bottom, a drop weight was attached to the tether approximately 100 feet from the ROV itself. Once on the bottom, this left the ROV roughly 50 feet to roam, and the ROV was driven with its skid bars in contact with the bottom as much as possible in a lawn-mower type fashion back and forth over the bottom. Upon return to the lab, organisms were identified to lowest taxonomic level possible and enumerated in all frames where the ROV was on the bottom.

Grain Size Analysis

Grain size analysis will be performed later this fall, prior to final defense and publication.

Multivariate analysis

The multivariate statistical package PRIMER 5.0 (Clarke and Warwick 1994) was used to analyze both infaunal and epifaunal data. Non-metric multidimensional scaling (MDS) using the Bray-Curtis similarity coefficient was applied to fourth-root-transformed infaunal abundance data to indicate patterns in community assemblages. The fourth-root transformation was used to lessen the contribution of a few very abundant taxa and weight more heavily the rarer taxa. No transformation was applied to epifaunal abundances, however numbers were standardized to 50 frames due to unequal number of frames in some transects.

A one-way analysis of similarities (ANOSIM) was performed to test the significance of the effects of the treatment factor on population abundances. The treatment factor levels were determined by fishing history. For infaunal community data, treatment factor levels were (see also Table 1): 1. Open 2003, referring to samples taken from the Kettle in August 2003, 2. Open 2004, referring to sites resampled in the Kettle in August 2004, 3. the 4 year closed sites, referring to sites sampled in the 4 year region of the WGOMC, and 4. the 6 year closed sites, referring to sites sampled in the 6 year region of the WGOMC. For epifaunal community data, treatment factor levels included all above stated study sites as well as the 2 year closed area, referring to sites sampled in the WGOMC in August 2002, when east of the 70^{o} line within the closure had only been restricted for 2 years. When a significant difference ($p < 0.05$) was detected, a similarity percentage breakdown (SIMPER) was conducted to determine which taxa were primarily responsible (make up 90% of the difference between factor levels) for the observed difference.

Research into family life histories of significantly abundant taxa was done to interpret the results of the SIMPER breakdown.

Univariate analysis

The PRIMER function DIVERSE was used to calculate taxonomic richness (s), taxon abundance (*N*), Pielou's evenness (*J'*), and Shannon-Wiener diversity (*H'*(log *e*)) for each sample.

Project Management

1. Principal Investigator: Dr. Les Watling, Darling Marine Center, University of Maine – Dr. Les Watling authored the proposal for this project and provided advice on experimental design, data analysis, and interpretation.
2. Fishing Industry Partner: Captain Cameron McLellan, F/V *Adventurer* – Captain McLellan, a fifth generation groundfisherman, originally proposed the idea to partner with Dr. Watling to investigate the environmental effects of groundfish trawling, which Dr. Watling accepted. Captain McLellan provided insight on locations of popular fishing grounds both in and out of the WGOMC, most of which ultimately became study sites. All sampling was carried out aboard F/V *Adventurer*, under the supervision of Captain McLellan.
3. Project Liaison: Laura Taylor Singer, Gulf of Maine Research Institute – Laura oversaw the dispersal of grant funds to the University of Maine, and edited all final drafts of proposals and progress reports, and made sure all paperwork was completed in a timely manner.
4. Graduate Student: Emily Knight, Darling Marine Center, University of Maine – Emily carried out all sampling aboard F/V *Adventurer*, processed all samples, analyzed and interpreted all data, and authored the final thesis of all work completed over the past 3 years.

V. FINDINGS

Infauna

A total of 41,472 individuals were sampled in all study sites. In Open 2003, 10,261 individuals were sampled, in Open 2004, 10,234 were sampled, in the 4 year closed sites, 9,447 individuals were sampled, and in the 6 year closed sites, 11,530 individuals were sampled. Individuals were identified to the family level (71 families) with the exception of five groups (C: Oligochaetes, O: Caprellid, O: Tanaidacea, C: Sipunculidea, and C: Chaetodermomorpha). All sites were dominated by Annelids, followed by Molluscs in the Closed sites, and Arthropods in the Open sites (Table 2).

Table 2. Infauna: % Composition by Phylum.

	% Composition		
Sampling Sites	**Annelida**	**Arthropoda**	**Mollusca**
Open 2003	69	**13**	8
Open 2004	60	**23**	7
4 yr closed sites	64	11	**13**
6 yr closed sites	60	13	**14**

A 2-D, non-metric, multidimensional scaling (MDS) plot of infaunal familial and group abundance similarities, sorted by treatment, indicated that the communities could be separated according to treatment (figure 3).

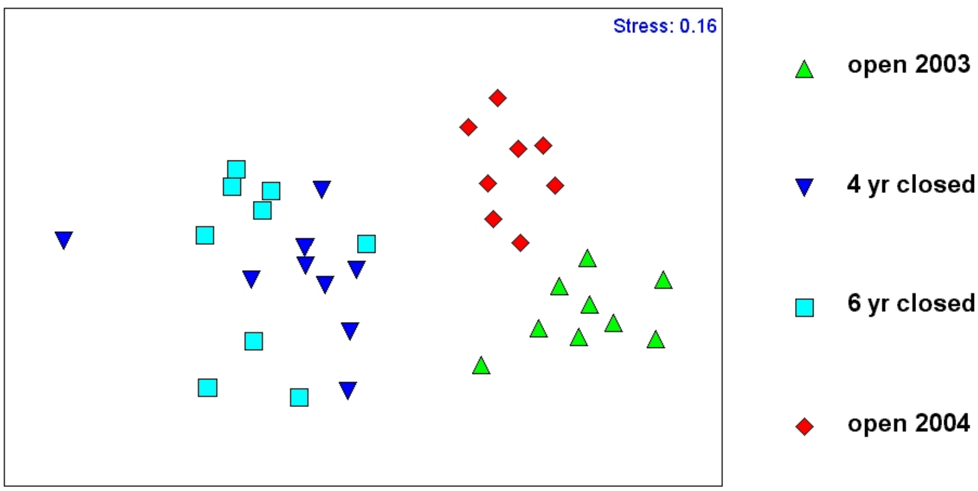

Figure 3: MDS Infauna. Non-metric multidimensional scaling (MDS) ordination for infaunal community assemblages based on Bray-Curtis similarity coefficient of 4th root-transformed abundances.

A one-way ANOSIM indicated the separation based on treatment to be significant (R = .759; p = .001). Pairwise comparisons (Table 3) indicated that while Open 2003 and Open 2004 were significantly different, they were more similar to each other in composition and abundances than they were to either the 4 or 6 year closed sites. Pairwise tests also indicated a significant difference between the 4 and 6 year closed sites, however they were more similar to each other in composition and abundances than they were to either Open 2003 or Open 2004 sites.

Table 3: Pairwise Tests Infauna. One-way ANOSIM for infaunal community

Groups	**Statistic**	**Sign. Level**	**Poss. Permutations**	**Permutations Obs.**
Open 2003 vs. Open 2004	0.636	0.001	24310	999
Open 2003 vs. 4 yr closed	0.916	0.001	24310	999
Open 2004 vs. 4 yr closed	0.839	0.001	24310	999
Open 2003 vs. 6 yr closed	0.961	0.001	24310	999
Open 2004 vs. 6 yr closed	0.951	0.001	24310	999
4 yr closed vs. 6 yr closed	0.252	0.004	24310	999

SIMPER analysis by treatment showed that 20 families, 1 class, and 1 order made up approximately 90% of the similarity between stations in Open 2003 sites. In Open 2004 sites, 23 families, and 2 orders made up approximately 90% of the similarity between stations. In the 4 year closed sites, 26 families, 1 class, and 2 orders made up approximately 90% of the similarity between stations, and in the 6 year closed sites, 27 families, 2 classes, and 2 orders made up approximately 90% of the similarity between stations. Taxa that contributed significantly to the composition of communities in each area were then divided into three categories based on average abundances per station generated by SIMPER. High abundance taxa (community dominants) were those that showed on average > 100 individuals/sample, moderate abundance taxa were those that contributed on average between 10 and 100 individuals/sample, and low abundance taxa were those that showed on average between 1 and 10 individuals/sample. The numbers of taxa making up each group were then enumerated (see figure 4).

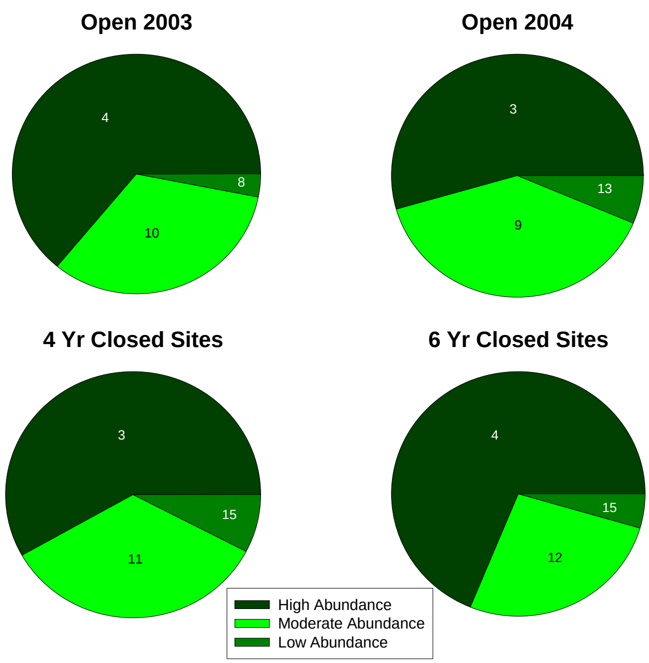

Figure 4: Pie Charts Infauna. Average Abundances generated by SIMPER of significantly contributing taxa to community composition. High abundance group: >100 individuals/sample; Moderate abundance group: 10-100 individuals/sample; Low abundance group: 1-10 individuals/sample. Numbers represent number of taxa making up each group.

Delineations between high, moderate, and low abundance groups were made based on the magnitude of differences in average abundance separating each group. For example, as well as making the highest % contribution to similarity to each area and at least 20% of overall composition among 3 or 4 taxa, high abundance taxa (>100 individuals/sample) were separated from the highest moderate abundance taxa by at least 30 individuals/sample. A large number of taxa contributed significantly to the composition of communities in each area, the purpose of dividing taxa according to average abundances were to better organize organisms into generalized groups that might give the reader some kind of context in which to place taxa when named throughout the paper.

The high abundance group was dominated by 3 or 4 families of polychaetes in each area, however, different families dominated based on treatment (Table 4). Open 2003 and Open 2004 were largely dominated by the polychaete family Spionidae, while the 4 and 6 year closed sites were largely dominated by the polychaete family Sabellidae.

Table 4: Infauna. High Abundance Group >100 individuals/sample.

Open 2003		Open 2004		4 yr closed		6 yr closed	
Taxa	**Ave. Ab.**	**Taxa**	**Ave. Ab.**	**Taxa**	**Ave. Ab.**	**Taxa**	**Ave. Ab.**
Spionidae	297.89	Spionidae	247.5	Sabellidae	260.33	Sabellidae	351.11
Ampharetidae	197	Ampharetidae	192.13	Syllidae	181.56	Cirratulidae	177.67
Paraonidae	111.11	Cirratulidae	146.88	Ampharetidae	155.22	Ampharetidae	163.22
Cirratulidae	106.11					Syllidae	161.89

High contributers worth noting to the moderate abundance group of Open 2003 and Open 2004 were represented by the polychaetes Syllidae, which was in the high abundance group of both the 4 and 6 year closed sites, Lumbrineridae, and the crustacean Halacaridae. High contributers worth in the moderate abundance group in the 6 and 4 year closed sites was the polychaete Maldanidae, and the bivalve Astartidae (Table 5).

Table 5: Infauna. Highest contributers to Moderate Abundance Group 10-100 individuals/sample.

Open 2003		Open 2004		4 yr closed		6 yr closed	
Taxa	**Ave. Ab.**	**Taxa**	**Ave. Ab.**	**Taxa**	**Ave. Ab.**	**Taxa**	**Ave. Ab.**
Sabellidae	82.33	Halacaridae	92.75	Cirratulidae	74.89	Maldanidae	54
Syllidae	73.11	Sabellidae	64.5	Spionidae	70.33	Paraonidae	54.67
Lumbrineridae	43.78	Syllidae	57.63	Paraonidae	48.44	Astartidae	46.89
Halacaridae	42.89	Paraonidae	55	Maldanidae	43.67		
		Lumbrineridae	49.13	Astartidae	22.89		

There was roughly double the number of low abundance taxa in the 4 and 6 year closed sites and Open 2004, as there was in Open 2003 (Table 6). Families significantly present in the low abundance group of Open 2004 and not in either closed area were the crustaceans Isaeidae, Munnidae, and Stenothoidae. Families significantly present in the low abundance group of the 4 and 6 year closed sites and not in Open 2004 were the polychaetes Terebellidae, Goniadidae, Opheliidae, and Flabelligeridae. Additionally in the 6 year closed sites was the mollusc Arcidae, and the crustaceans Janiridae and Ampleliscidae.

Table 6: Infauna. Contributers to Low Abundance Group (1-10 individuals/sample).

Open 2004		4 yr closed		6 yr closed	
Taxa	**Ave. Ab.**	**Taxa**	**Ave. Ab.**	**Taxa**	**Ave. Ab.**
Isaeidae	6.25	Opheliidae	9.44	Terebellidae	4.89
Munnidae	5	Terebellidae	8.33	Opheliidae	3.67
Stenothoidae	2.25	Goniadidae	2.78	Arcidae	3
		Flabelligeridae	1.11	Ampeliscidae	2.89
				Goniadidae	2.78
				Flabelligeridae	2.56
				Janiridae	1.89

* Taxa listed represent differences between Open 2004 and both Closed sites, and were not significantly present in Open 2003.

Taxa were divided into functional feeding groups based on past literature and general knowledge of the biological capabilities of all taxa present (Bousfield 1973; Fauchald and Jumars 1979; Ruppert, Fox, and Barnes 2004). Generalized definitions of feeding groups are listed in Table 8. When plotted by functional feeding groups, the 2-D non-metric MDS also showed a separation of treatment groups (figure 5), indicated to be significant by ANOSIM (R = .578; p = .001).

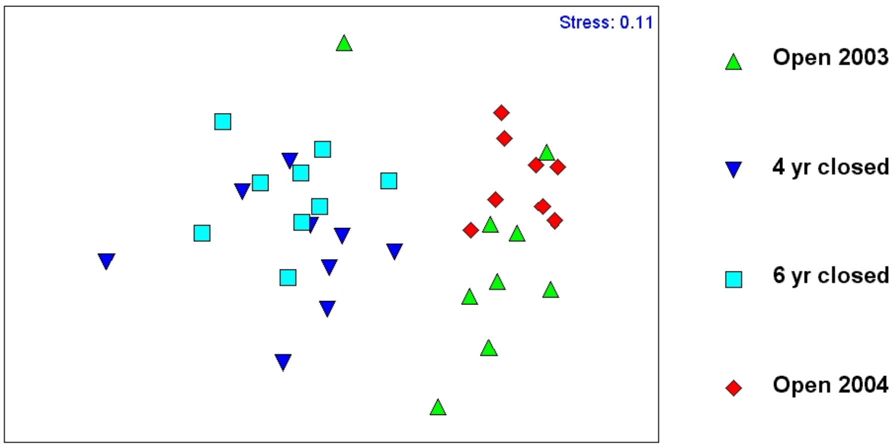

Figure 5: MDS FFG. Non-metric multidimensional scaling (MDS) ordination for infaunal functional feeding group assesmblages in open and closed sites (based on Bray-Curtis similarity coefficient of 4^{th} root-transformed abundances).

Pairwise testing among treatment groups indicated significant differences between all groups along the lines of separation shown previously based on taxa identifications (figure 3; Table 3), however divisions between sites based on feeding groups were weaker between Open 2003 and Open 2004, and between the 4 and 6 year closed sites (Table 7).

Table 7: Pairwise Test FFG Infauna. One-way ANOSIM for infaunal functional feeding groups.

Groups	Statistic	Sign. Level	Poss. Permutations	Permutations Obs.
Open 2003 vs. Open 2004	0.173	0.026	24310	999
4 yr closed vs. Open 2003	0.601	0.001	24310	999
4 yr closed vs. Open 2004	0.875	0.001	24310	999
6 yr closed vs. Open 2003	0.751	0.001	24310	999
6 yr closed vs. Open 2004	0.937	0.001	24310	999
4 yr closed vs. 6 yr closed	0.123	0.065	24310	999

SIMPER analysis of similarity between stations within all sites showed that Open 2003 and Open 2004 were largely dominated by non-selective deposit feeders and carnivores (approximately 60% cum.), followed by suspension feeders and selective deposit feeders. The 4 and 6 year closed sites were largely dominated by non-selective deposit feeders and suspension feeders (approximately 60% cum.), followed by carnivores and selective deposit feeders.

Table 8: Infaunal Functional Feeding Groups: Generalized Definitions.

Non-selective deposit feeders	consume sediment in bulk; most annelids collected
Selective deposit feeders	consume sediment but not in bulk; most crustaceans collected
Carnivores	predators/scavengers of animal material; some annelids/crustaceans
Suspension feeders	feed on suspended particles; some annelids/crustaceans, bivalves

Observed differences between Open 2003 and Open 2004

Univariate diversity indices indicated that Open 2004 showed higher average taxonomic richness, dominance, evenness, and diversity, while Open 2003 showed higher average abundance. SIMPER analysis of dissimilarity demonstrated that 39 families, 1 phylum, 2 classes, and 1 order made up approximately 90% of observed differences between Open 2003 and Open 2004. No one group contributed more than 6% to observed differences. The largest contributions to differences between the two areas were made by moderate and low abundance taxa. In the low abundance group, the crustaceans Isaeidae and Caprellid showed the highest percent differences by being consistently present in Open 2004, and completely absent from Open 2003. The crustaceans Diastylidae and Munnidae, and the polychaete Scalibregmatidae were consistently present in Open 2004, and not significantly present in Open 2003. In the moderate abundance group, the crustacean Halacaridae showed higher abundances in Open 2004, while the polychaete Owenidae showed higher abundances in Open 2003. Among the high abundance group, the polychaete Paraonidae showed higher abundances in Open 2003, while the polychaete Cirratulidae showed higher abundances in Open 2004.

Observed differences between Open 2003 and 4 Year Closed Sites

Univariate diversity indices indicated that the 4 year closed sites showed higher average taxonomic richness, and diversity. Open 2003 sites showed higher average abundance, evenness, and dominance. SIMPER analysis of dissimilarity showed that 42 families, 3 classes, and 2 orders made up approximately 90% of observed differences between communities in Open 2003 sites and the 4 year closed sites. A diversity of groups contributed to the differences between areas, with no one family contributing more than 5% to observed differences. For the most part, differences were made up by groups showing higher average abundances in the 4 year closed sites, as indicated by the higher taxonomic richness there. Families in the high abundance group (>100 individuals/sample) that contributed significantly to observed differences were the polychaetes Sabellidae and Syllidae, which showed higher abundances in the 4 year closed sites, and Spionidae and Paraonidae, which showed higher abundances in the Open 2003. Among the moderate abundance group (10-100 individuals/sample), Open 2003 sites showed higher abundances of the polychaete Lumbrineridae and the crustacean Halacaridae, while the 4 year closed sites showed higher abundances of the crustacean Tanaidacea and the bivalve Yoldiidae. Among the low abundance group (1-10 individuals/sample), a number of families contributed significantly to observed differences because they were consistently present in the 4 year closed sites and not present, or not significantly present, in Open 2003 sites. Families consistently present at low abundances in the 4 year closed sites and completely absent from Open 2003 were the bivalves Mesodesmatidae and Cuspidariidae. Families consistently present at low abundances in the 4 year closed sites and not significantly present in Open 2003 were the polychaete families Terebellidae, Goniadidae, Scalibregmatidae, Dorvilleidae, and Sigalionidae, and the bivalve Cardiidae.

Observed differences between Open 2004 and 4 Year Closed Sites

Univariate diversity indices indicated that the 4 year closed sites showed higher average taxonomic richness and dominance, while Open 2004 showed higher average taxonomic abundance, and evenness. Diversity was approximately the same between both areas. SIMPER analysis of dissimilarity indicated that 42 families, 1 phylum, 2 classes, and 1 order made up approximately 90% of differences between communities in Open 2004 and the 4 year closed sites. A diversity of taxa made up the differences between communities with no one family contributing more than 5% to observed differences. Among the high and moderate abundance groups, families of higher average abundances in Open 2004 were the crustacean Halacaridae, and the polychaetes Spionidae, Cirratulidae, and Lumbrineridae. In the 4 year closed sites, the polychaetes Sabellidae and Syllidae showed higher average abundances. In the low abundance group, unlike differences between Open 2003 and the 4 year closed sites, certain groups were significantly present in Open 2004 and not in the 4 year closed sites and vice versa. The crustaceans Leuconidae, Isaeidae, and Munnidae, and the polychaetes Capitellidae and Nephtyidae, were consistently present in Open 2004 and not significantly present in the 4 year closed sites. The polychaetes Terebellidae, Goniadidae, Opheliidae, and Flabelligeridae, and the bivalves Mesodesmatidae and Cardiidae, were consistently present in the low abundance group in the 4 year closed sites and not in Open 2004.

Observed differences between Open 2003 and 6 Year Closed Sites

Univariate diversity indices indicated that the 6 year closed sites showed higher average taxonomic richness, abundance, dominance, and diversity, while Open 2003 showed higher evenness. SIMPER analysis of dissimilarity showed that 44 families, 1 phylum, 2 orders, and 1 class made up approximately 90% of differences between communities in the 6 year closed sites and Open 2003. No one family contributed more than 5% to observed differences between the two areas. Unlike the 4 year closed sites vs. Open 2003 where the two highest contributers to community differences were low abundance groups, high abundance taxa contributed the highest percentages to community differences between the 6 year closed sites and Open 2003. In the 6 year closed sites, the polychaete family Sabellidae showed higher average abundances, while the polychaete family Spionidae showed higher average abundances in Open 2003. Other high abundance taxa that contributed significantly to observed differences were the polychaetes Syllidae, Cirratulidae, which both showed higher abundances in the 6 year closed sites, and Paraonidae, which showed higher abundances in Open 2003. In the moderate abundance group, the crustacean Halacaridae and the polychaete Lumbrineridae showed higher abundances in Open 2003, while the bivalves Yoldiidae and Cardiidae, and the crustacean Tanaidacea showed higher abundances in the 6 year closed sites. In the low abundance group, differences were largely made up by groups that were consistently present in the 6 year closed sites, and not significantly present in Open 2003. The polychaetes Terebellidae, Goniadidae, Flabelligeridae, and Scalibregmatidae, the phylum Sipuncula, the crustaceans Ampeliscidae, Ischyroceridae, and Janiridae, the bivalve Cardiidae, and the ophiuroid Ophiactidae were all consistently present in the 6 year closed sites and not significantly present in Open 2003. Furthermore, the bivalve Mesodesmatidae was consistently present in low abundances in the 6 year closed sites and not present at all in Open 2003. The only low abundance group present in Open 2003 and not significantly present in the 6 year closed sites was the crustacean Leuconidae.

Observed differences between Open 2004 and 6 Year Closed Sites

Univariate diversity indices indicated that the 6 year closed sites showed higher average taxonomic richness, abundance, and dominance, while Open 2004 showed higher evenness. Diversity was, on average, approximately the same between communities in both areas. SIMPER analysis of dissimilarity showed that 44 families, 1 phylum, 2 classes, and 1 order made up approximately 90% of observed differences between the 6 year closed sites and Open 2004. No one taxa contributed more than 5% to observed differences between communities. The highest contributers to community differences between the two areas were much like the 4 year closed sites vs. Open 2004. Sabellidae showed higher average abundances in the 6 year closed sites, while Spionidae showed higher average abundances in Open 2004. Other high abundance families that contributed significantly to community differences were the polychaetes Syllidae and Cirratulidae, which both showed higher abundances in the 6 year closed sites. In the moderate abundance group, the crustacean Halacaridae and the polychaete Lumbrineridae showed higher abundances in Open 2004, while the bivalve Cardiidae and the crustacean Tanaidacea each showed higher abundances in the 6 year closed sites. In the low abundance group, much like the 4 year closed sites vs. Open 2004, certain groups were significantly present in each area and not in the other. Taxa consistently present in Open 2004 and not in the 6 year closed sites were the crustaceans Isaeidae, Leuconidae, Diastylidae, Stenothoidae, and Munnidae, and the polychaetes Sigalionidae and Nephtyidae. Taxa consistently present in the 6 year closed sites and not in Open 2004 were the polychaetes Terebellidae, Goniadidae, Opheliidae, and Flabelligeridae, the crustacean Ischyroceridae and Ampeliscidae, the bivalves Cardiidae and Arcidae, the phylum Sipuncula, and the opiuroid Ophiactidae.

Observed differences between 4 Year Closed Sites and 6 Year Closed Sites

Univariate diversity indices indicated that the 6 year closed sites showed higher average taxonomic richness, abundance, and dominance, while the 4 year closed sites showed higher average evenness. Diversity between the two areas was approximately the same. SIMPER analysis of dissimilarity between the 4 and 6 year closed sites showed that 47 families, 1 phylum, 2 classes, and 1 order made up approximately 90% of observed differences. No one taxa contributed more than 4% to observed differences. Almost all significant differences between the 4 and 6 year closed sites were due to taxa showing higher abundances in the 6 year closed sites. In the high abundance group, the polychaetes Sabellidae and Cirratulidae showed higher abundances in the 6 year closed sites. Among the moderate abundance group, the bivalves Astartidae and Cardiidae, and the polychaete Cossuridae all showed higher abundances in the 6 year closed sites. In the low abundance group, the crustacean Ampeliscidae was consistently present in the 6 year closed sites and not in the 4 year closed sites. The only family that was consistently present in the 4 year closed sites and not the 6 year closed sites was the bivalve Cuspidariidae.

Summary: Infauna

Results indicated that there have been changes in the composition of infaunal community assemblages in the WGOMC following the release of chronic trawling disturbance. In general, rather than observing presence/absence between most taxa, the data demonstrated shifts in community dominance that reflected the interaction of fishing disturbance with the life history strategies of resident organisms. This was corroborated by dividing taxa into functional feeding groups, where differences in the presence and abundances of groups with certain feeding strategies were all significant.

One of the most striking differences between all Closed and Open sites were the shifts from the dominance of the polychaete Spionidae in the Open sites to Sabellidae in the Closed sites. From Open 2003 and 2004 to the 4 and finally the 6 year closed sites, not only did dominance shift from Spionidae to Sabellidae, but the average abundances of these families appeared to continue changing over time. Spionidae decreased from an average abundance per sample of approximately 297 and 247 in Open 2003 and 2004, respectively, to an average abundance of 70 individuals/sample in the 4 year closed sites, down to roughly 35 individuals/sample in the 6 year closed sites. Sabellidae, on the other appeared to increase over time from roughly 82 and 65 individuals/sample in Open 2003 and 2004, respectively, to roughly 260 individuals/sample in the 4 year closed sites, and 351 individuals/sample in the 6 year closed sites. This result strongly suggested a transition in community composition over time, and was further corroborated by analysis of dissimilarity between study sites, which showed an increase in the dissimilarity between the abundances of these families over time. Thus, the % contribution of differences in Sabellidae and Spionidae abundances between the Open and Closed sites to community-wide differences increased from Open 2003 and 2004 to the 4 year closed sites to the 6 year closed sites (figure 6).

Figure 6a

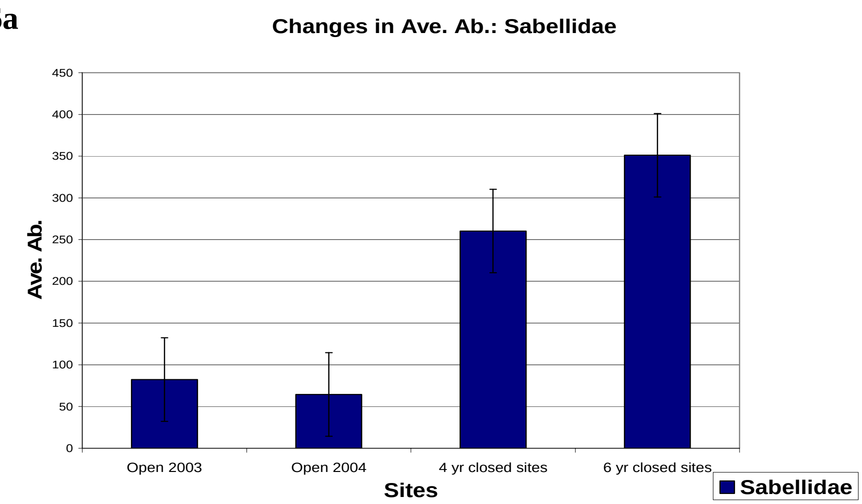

Figure 6b

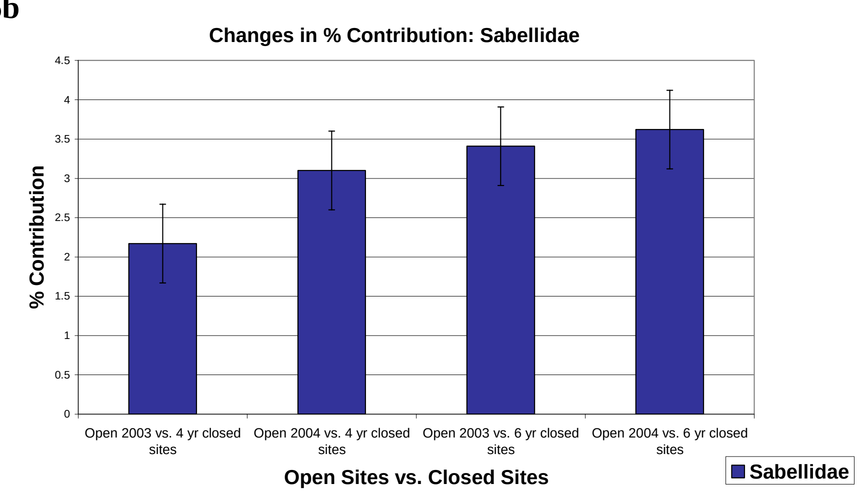

Figure 6c

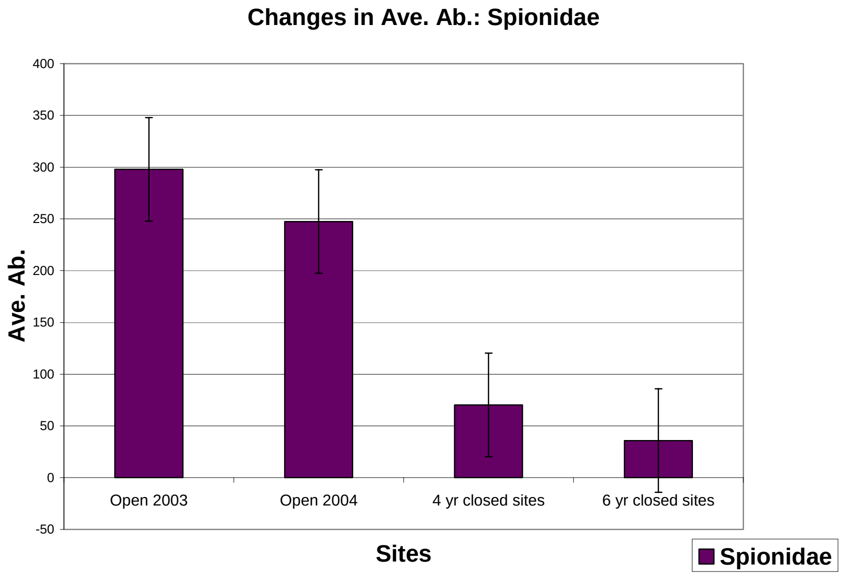

Figure 6d

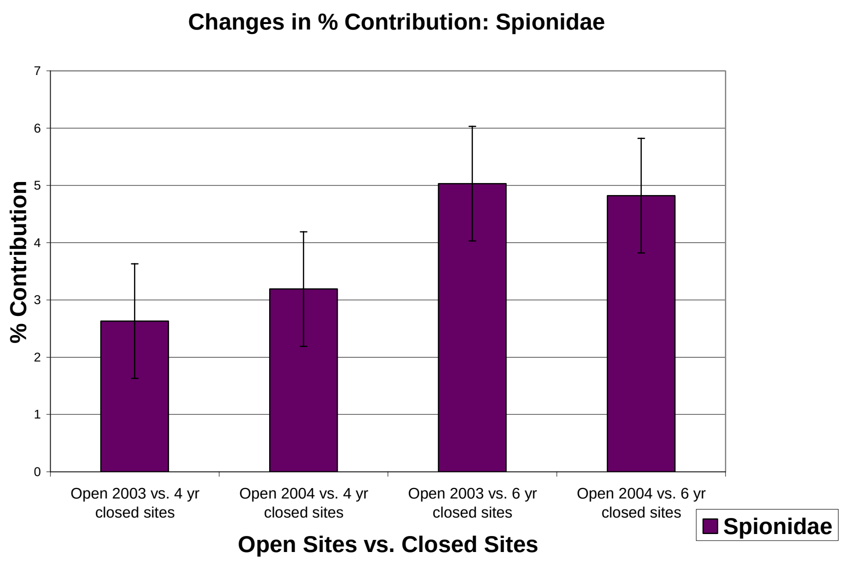

Figure 6: Shifts in Dominance, Sabellidae and Spionidae. *6a:* shifts in average abundances of Sabellidae over time. *6b:* shifts in % contribution of differences in Sabellidae abundances between Open and Closed sites over time. *6c:* shifts in average abundances of Spionidae over time. *6d:* shifts in % contribution of differences in Spionidae abundances between Open and Closed sites over time.

SIMPER analysis of similarity between stations within sites also indicated shifts over time in the polychaete family Maldanidae. In Open 2003 and 2004, average abundances of Maldanidae stood around 27 and 33, respectively, but increased in the 4 and 6 year closed sites to 43 and 54 individuals/sample. At corresponding abundances in the moderate abundance group, the crustacean Halacaridae and the polychaete Lumbrineridae ranged between 43 and 92 individuals/sample in Open 2003 and 2004. The 4 and 6 year closed sites also showed an increase in the influence of bivalves on community structure, particularly in the low abundance group. Between Open 2003 and the 4 year closed sites, for example, Mesodesmatidae, which was not found in Open 2003, contributed the highest % difference to community composition.

Another significant contributer to community differences was Yoldiide, whose abundances increased between all Open and Closed sites. Bivalves also consistently contributed to differences between the low abundance groups in all Open and Closed sites. Mesodesmatidae and Cardiidae, which were consistently present in low abundances in both the 4 and 6 year closed sites and not present in Open 2003, were not significantly present in Open 2004 either.

Open 2004, the 4 year closed sites, and 6 year closed sites all had double the number of low abundance taxa consistently contributing to community differences than Open 2003. In Open 2004, low abundance taxa were dominated by the mobile crustaceans Munnidae, Stenothoidae, and the burrowing polychaetes Sigalionidae, and Nephtyidae. Low abundance taxa in the Closed sites, however, were largely dominated by tube-building organisms such as Terebellidae and Ampeliscidae, bivalves, and interface dwellers such as Flabelligeridae and Janiridae, and the predatory polychaete Goniadidae.

Overall changes in community composition between the Open and Closed sites were diverse and exhaustive, however, the general trend was a shift from less stable, more mobile taxa in the Open sites towards more stable, sessile taxa dominating the Closed sites. Chronic trawling disturbance has been shown to select for species with more vulnerable life history characteristics (Collie et al. 2000). Many of the families identified in this study agreed with such a conclusion. Community dominants in the Closed sites were consistently found to be the sessile tube-builder Sabellidae. Members of this family build tubes just below the sediment-water interface, where their feather-like radiolar crowns can protrude into the water column and feed on suspended particles. This makes Sabellidae vulnerable to mortality from trawls, and if disturbance is frequent enough, difficult for them to recover fully before the next disturbance. Spionidae, on the other hand, are more likely to be able to recover between frequent trawling disturbances. Spionids reproduce more often than Sabellidae, and are mobile. Spionids also build tubes, however they do not necessarily spend their entire lives in them as most Sabellids do, therefore Spionids often expend less energy on tube construction.

Shifts in community composition towards more stable taxa were not just among dominant families, but appeared to be community-wide as well. Lumbrinerids and Halacarids were also consistent contributers to community composition in both Open 2003 and 2004, while being significantly reduced in the 4 and 6 year closed sites. Both families may actually benefit from trawling disturbance. Lumbrinerids are mobile carnivores, and Halacarids are mobile surface detritivores. Firstly, both are less vulnerable to direct damage from trawls. Lumbrinerids are burrowers, and Halacarids are tiny highly mobile mites that live on the sediment surface attaching themselves to aggregated sediments and fluff at the sediment-water interface. Secondly, the food resources of both these families may be enhanced by trawling. Lumbrinerids are carnivores and carrion-feeders that may feed on other organisms damaged by trawls. Halacarids feed on plant and animal debris on the sediment surface, and frequent trawling disturbances often maintains a thick resuspended fluff layer at the sediment-water interface (which was observed on ROV videos). At corresponding abundances in the Closed sites were an increase in the deposit feeding polychaete Maldanidae. Due to its life style as a sessile tube-builder, Maldanidae is particularly vulnerable to trawling disturbance.

Shifts in the Closed sites towards the consistent presence of a diversity of bivalves, particularly in the low abundance group, echoed trends seen among high and moderate abundance taxa. The bivalves present were all sessile suspension feeders that live in the top 2 cm of the sediment with their siphons protruding into the water column. Clearly, such taxa would be vulnerable to frequent trawl damage. Other vulnerable low abundance taxa present in the Closed sites and not the Open sites were such delicate sediment-water interface dwellers as Flabelligeridae, and Janiridae in the 6 year closed sites.

Trends in analysis of functional feeding groups reflected the shift in community composition. SIMPER analysis of similarities between stations within sites showed that the Open sites were dominated by non-selective deposit feeders, while the Closed sites showed a distinct decrease in non-selective deposit feeders with a simultaneous increase in suspension feeders (see figure 7). Many of the more stable sessile families such as Sabellidae, some crustaceans such as Ampeliscidae, and all the bivalve families that contributed significantly to the composition of the Closed sites and to differences from the Open sites, were all suspension feeders. Furthermore, according to SIMPER analysis of dissimilarities, over time the % contribution of suspension feeders to community differences increased from approximately 39% and 32% between 4 year closed sites and Open 2003 and 2004, respectively, to approximately 50% of differences between the 6 year closed sites and Open 2003, and 48% between the 6 year closed sites and Open 2004.

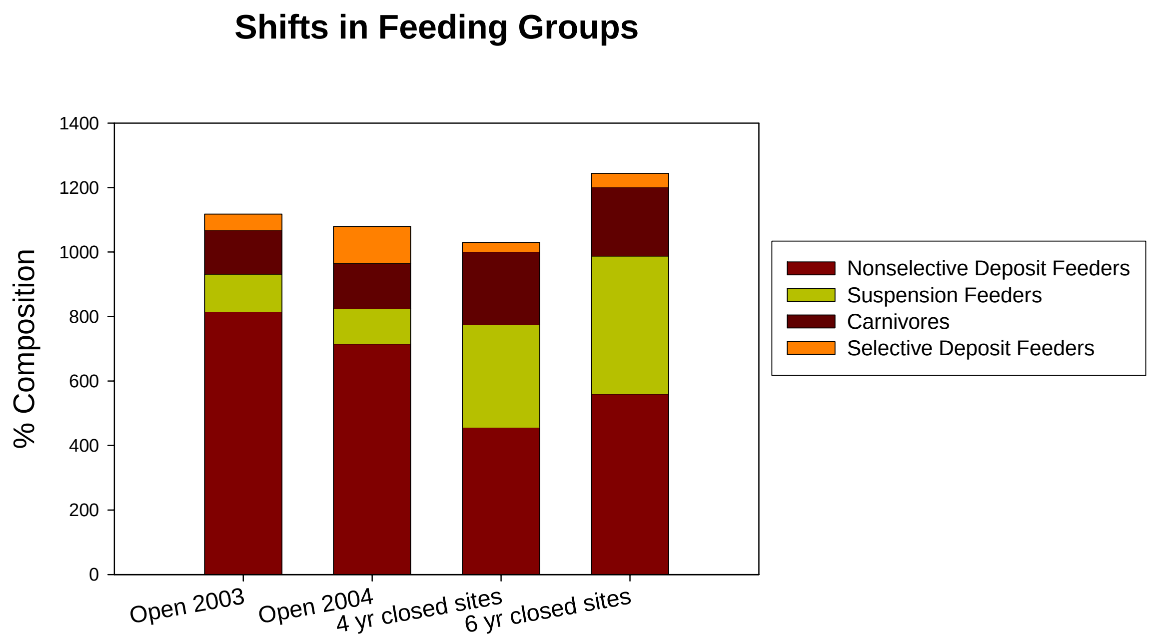

Figure 7: Shifts in Infaunal FFG. Shifts in feeding group dominance in infaunal community assemblages.

Epifauna

A total of 25,987 individual organisms were identified in all ROV video transects. Analysis of all transects were performed on identifications to the lowest taxonomic level possible that could be consistently identified in all videos. In the 2 year closed sites, 2,006 individual organisms were idenitified, in Open 2003, 2,068 individual organisms were identified, in Open 2004 (a resampling of Open 2003), 3,186 individuals were identified, in the 4 year closed sites (a resampling of the 2 year closed sites), 3,973 individuals were identified, and in the 6 year closed sites, 14,754 individuals were identified. All counts were standardized to 50 frames for analysis due to unequal length of transects. All sites were dominated by the ascidian *Molgula sp.* (2 yr closed: 74%; Open 2003: 46%; Open 2004: 46%; 4 yr closed: 77%; 6 yr closed: 65%).

Following *Molgula sp*., the 2 year closed sites, Open 2003, and Open 2004 were dominated by the northern shrimp *Pandulus borealis* (2 yr closed: 13%; Open 2003: 41%; Open 2004: 34%), while the Cnidarian *Cerianthis borealis* followed in the 4 year closed sites (8%), and phylum Porifera in the 6 year closed sites (26%). A 2-D, non-metric, multidimensional scaling (MDS) plot of epifaunal group abundance similarities, sorted by treatment, indicated that the communities could be separated based on treatment group (figure 8).

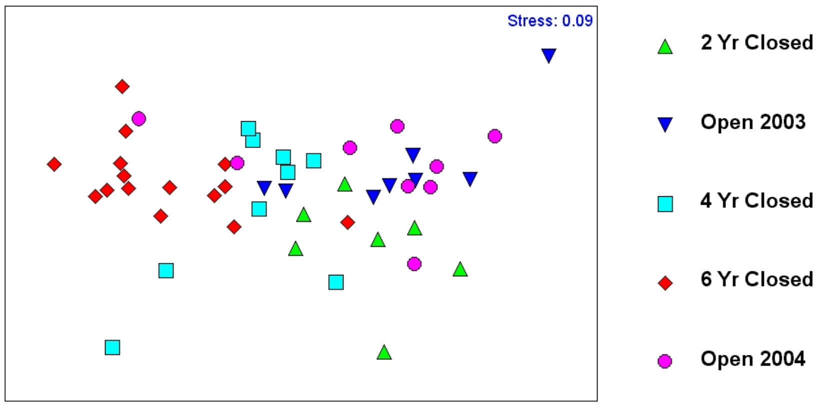

Figure 8: MDS Epifauna. Non-metric multidimensional scaling (MDS) ordination for epifaunal community assemblages based on Bray-Curtis similarity coefficient of standardized untransformed abundances.

A one-way ANOSIM indicated the separation based on treatment to be significant (R = .412; p = .001). Pairwise tests (Table 9) indicated that comparisons between Open 2003 and Open 2004, the 2 year closed sites and Open 2003, the 2 year closed sites and Open 2004, and the 2 year closed sites and the 4 year closed sites were not significantly different. There appeared to be weakly significant differences indicated between the 4 year closed sites and Open 2003, and Open 2004. The 6 year closed sites showed significant differences from all areas sampled, however were more similar to the 4 year closed sites than any other area sampled.

Table 9: Pairwise Tests Epifauna. One-way ANOSIM for epifaunal community

Observed differences between Open 2003 and Open 2004

Groups	Statistic	Sign. Level	Poss. Permutations	Permutations Obs.
Open 2003 vs. Open 2004	-0.05	0.757	24310	999
2 yr closed vs. Open 2003	0.126	0.113	6435	999
2 yr closed vs. Open 2004	0.213	0.026	11440	999
4 yr closed vs. Open 2003	0.229	0.009	24310	999
4 yr closed vs. Open 2004	0.288	0.004	24310	999
6 yr closed vs. Open 2003	0.7	0.001	490314	999
6 yr closed vs. Open 2004	0.61	0.001	1307504	999
2 yr closed vs. 6 yr closed	0.754	0.001	170544	999
2 yr closed vs. 4 yr closed	0.236	0.021	11440	999
4 yr closed vs. 6 yr closed	0.323	0.002	1307504	999

Image: Open 2003

Univariate diversity indices indicated that Open 2004 showed on average higher taxonomic richness, abundance, dominance, and diversity than Open 2003. There was no appreciable difference in evenness. However, pairwise tests indicated no significant differences between Open 2003 and Open 2004, which was corroborated by SIMPER analysis of dissimilarity. The same taxa dominated both areas, and while SIMPER-generated average abundances were higher in Open 2004 (corroborated by higher univariate taxonomic abundance), the dissimilarity coefficient to standard deviation ratio was extremely low, indicating that abundance differences may have been due to random variability inherent in benthic systems rather than treatment or, in this case, year effects.

Observed differences between Open 2003 and 2 Year Closed Sites

Univariate diversity indices indicated that the 2 year closed sites showed higher average taxonomic richness and dominance, while Open 2003 showed higher average abundance and evenness. Average diversity in these areas was approximately the same. However, pairwise tests indicated no significant differences between the 2 year closed sites and Open 2003. While average abundances were generally higher in Open 2003, the dissimilarity coefficient to standard deviation ratio was very low, indicating that abundance differences may have been due to random variability rather than treatment.

Observed differences between Open 2004 and 2 Year Closed Sites

Univariate diversity indices indicated that the 2 year closed sites showed higher average dominance, while Open 2004 showed higher average taxonomic abundance, evenness, and diversity. There was no appreciable difference between taxonomic richness in the two areas. Pairwise tests indicated no significant differences between the 2 year closed sites and Open 2004, however it appeared the 2 year closed sites were more similar to Open 2003 than Open 2004. SIMPER analysis of dissimilarity indicated this may have been due to the appreciably higher average abundances in Open 2004 than both Open 2003 and the 2 year closed sites. However, while greater differences in average abundances generated higher dissimilarity between the two areas, the dissimilarity coefficient to standard deviation ratio remained low, indicating random variation as a possibility rather than treatment effects.

Observed differences between 2 Year Closed Sites and 4 Year Closed Sites

Image: 2 Year Closed Sites

Univariate diversity indices indicated that the 4 year closed sites showed higher average taxonomic abundance, while the 2 year closed sites showed higher average taxonomic richness, dominance, evenness, and diversity. Pairwise tests, however, indicated that the 2 and 4 year closed sites were not significantly different. SIMPER analysis of dissimilarity revealed that the 4 year closed sites showed higher average abundances of

4 groups that contributed significantly to the composition of both areas. The greatest abundance differences were observed between *Molgula sp*. and phylum Porifera. However, the dissimilarity coefficient to standard deviation ratio was low even though abundance differences were great.

Observed differences between Open 2003 and 4 Year Closed Sites

Univariate diversity indices indicated that the 4 year closed sites showed higher average taxonomic richness, abundance, and dominance, while Open 2003 showed higher average evenness and diversity. Pairwise tests indicated weakly significant differences between the 4 year closed sites and Open 2003. SIMPER analysis of dissimilarity indicated that this may have been due to higher average abundances of *Molgula sp.* in Open 2003, and phylum Porifera in the 4 year closed sites (contributed cumulatively to 77% of differences). While the average abundance differences between these taxa were high, thus generating high dissimilarity, however, the dissimilarity coefficient to standard deviation ratio was low.

Observed differences between Open 2004 and 4 Year Closed Sites


Image: 4 Year Closed Sites

Univariate diversity indices indicated that the 4 year closed sites showed higher average taxonomic abundance, while Open 2004 showed higher average taxonomic richness, dominance, evenness, and diversity. Pairwise tests indicated weakly significant differences between the 4 year closed sites and Open 2004. SIMPER analysis of dissimilarity indicated that these differences were largely accounted for by generally higher average abundances of taxa in the 4 year closed sites, especially *Molgula sp.* and phylum Porifera, which made up approximately 74% of the differences between the two areas. Dissimilarity coefficients between these two taxa were high, however the dissimilarity coefficient to standard deviation ratios were low.

Observed differences between 4 Year Closed Sites and 6 Year Closed Sites

Univariate diversity indices indicated that the 6 year closed sites showed higher average taxonomic richness, abundance, dominance, evenness, and diversity. SIMPER analysis of dissimilarity demonstrated 4 groups made up approximately 90% of community differences between the two areas. All except one species showed higher average abundances in the 6 year closed sites. Appoximately 85% of differences were accounted for by higher abundances of *Molgula sp*. and phylum Porifera, correspondingly, in the 6 year closed sites. The only species to have higher average abundances in the 4 year closed sites was the northern shrimp *Pandulus borealis*, which contributed roughly 5% to community differences. Finally, the Cnidarian *Cerianthis borealis* contributed roughly another 5% to differences, and was in higher average abundances in the 6 year closed sites.

Observed differences between Open 2003 and 6 Year Closed Sites

Image: 6 Year Closed Sites

Univariate diversity indices indicated that the 6 year closed sites showed higher average taxonomic richness, abundance, dominance, and diversity, while Open 2003 showed higher average evenness. SIMPER analysis of dissimilarity showed that 3 groups made up approximately 90% of the differences between the 6 year closed sites and Open 2003. Approximately 54% of the differences were accounted for by *Mogula sp.*, and another 30% of the differences were accounted for by phylum Porifera. Higher average abundances of both these groups were found in the 6 year closed sites. The third species to contribute signficantly to dissimilarity between the two regions was also the only species to have higher average abundances in Open 2003, the northern shrimp *Pandulus borealis* contributed approximately 5% to observed community differences.

Observed differences between Open 2004 and 6 Year Closed Sites

Univariate diversity indices indicated that the 6 year closed sites showed higher average taxonomic richness, abundance, and dominance, while Open 2004 showed higher average evenness. Average diversity was not appreciably different between the two areas. SIMPER analysis of dissimilarity revealed that 4 groups accounted for approximately 90% of differences between the 6 year closed sites and Open 2004. Of the 4 groups, *Molgula sp*. and phylum Porifera, both of which showed higher average abundances in the 6 year closed sites, accounted for roughly 83% of observed community differences. The northern shrimp *Pandulus borealis*, much like differences between the 6 year closed sites and Open 2003, contributed roughly 6% to differences and was the only species in higher average abundances in Open 2004. The fourth and final species to contribute to differences was the Cnidarian *Cerianthis borealis,* which showed higher average abundances in the 6 year closed sites.

Observed differences between 2 Year Closed Sites and 6 Year Closed Sites

Univariate diversity indices indicated that the 6 year closed sites showed higher average taxonomic richness, abundance, and diversity, while the 2 year closed sites showed slightly higher average dominance and evenness. SIMPER analysis of dissimilarity showed that 3 groups accounted for roughly 90% of differences between the 6 year closed sites and 2 year closed sites. All groups showed higher average abundances in the 6 year closed sites. Approximately 87% of the differences were collectively contributed by *Molgula sp*. and phylum Porifera, and roughly another 3% by the Cnidarian *Cerianthis borealis*.

All taxa indentified and enumerated from video transects were then classified as mobile or sessile, and analyzed as such to detect for possible treatment differences in the number of mobile predators and attached suspension feeders present in study sites. Taxa comprising either group are listed in Table 11. A 2-D, non-metric, multidimensional scaling plot was created of epifaunal group abundances sorted into sessile and mobile categories (see figure 7). A one-way ANOSIM indicated that differences based on treatment were significant ($R = .411$; $p = .001$).

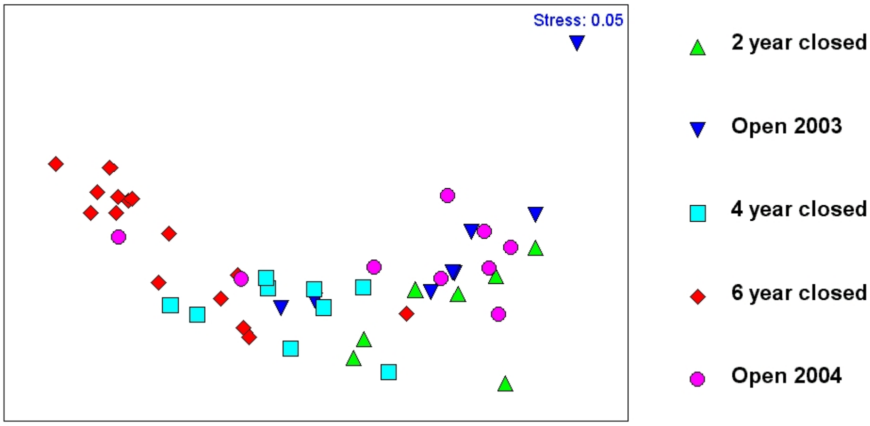

Figure 7: MDS Epifaunal Mobility. Non-metric multidimensional scaling ordination for epifaunal community assemblages sorted into sessile and mobile categories based on Bray-Curtis similarity coefficient of standardized untransformed abundances.

Pairwise tests generated by a one-way ANOSIM intensified similarities and differences observed previously in analysis based on taxa identifications (see Table 10). The 2 year closed sites did not differ significantly from Open 2003 or Open 2004. However, the 2 year closed sites now differed significantly from the 4 year closed sites. The 4 year closed sites differed more strongly from Open 2003 and Open 2004 than was previously observed. Finally, the 6 year closed sites differed significantly from all sites, however were more similar to the 4 year closed sites than anywhere else.

Table 10: Pairwise Tests Epifaunal Mobility. One-way ANOSIM for epifaunal community assemblages.

Groups	Statistic	Sign. Level	Poss. Permutations	Permutations Obs.
Open 2003 vs. Open 2004	-0.062	0.876	24310	999
2 yr closed vs. Open 2003	-0.027	0.556	6435	999
2 yr closed vs. Open 2004	0.005	0.377	11440	999
4 yr closed vs. Open 2003	0.343	0.006	24310	999
4 yr closed vs. Open 2004	0.394	0.002	24310	999
6 yr closed vs. Open 2003	0.696	0.001	490314	999
6 yr closed vs. Open 2004	0.569	0.001	1307504	999
2 yr closed vs. 6 yr closed	0.777	0.001	170544	999
2 yr closed vs. 4 yr closed	0.519	0.001	11440	999
4 yr closed vs. 6 yr closed	0.341	0.004	1307504	999

Table 11: Mobility Classifications of Epifauna

Phylum	Taxa	Mobility
Cnidaria	Cerianthis borealis	Sessile
Porifera	Porifera	Sessile
Chordata	Molgula sp.	Sessile
Cnidaria	Bolocera tuediae	Sessile
Porifera	Polymastia sp.	Sessile
Lophophorata	Terebratulina septentrionalis	Sessile
Chordata	Boltenia ovifera	Sessile
Cnidaria	Urticina feline	Sessile
Porifera	Haliclona sp.	Sessile
Cnidaria	Umbellula	Sessile
Porifera	St. Sponge	Sessile
Arthropoda	Pandulus borealis	Mobile
Echinodermata	Porania insignis	Mobile
Echinodermata	Henricia sanguinolenta	Mobile
Arthropoda	Cancridae	Mobile
Arthropoda	Pagarus sp.	Mobile
Arthropoda	Majidae	Mobile
Arthropoda	Pycnogonid	Mobile

Summary: Epifauna

Analyses indicated a possible directionality in community differences between Open and Closed sites. Open 2003 and 2004 did not differ significantly from each other, however the Closed sites appeared to show a more complex relationship. The 2 and 4 year closed sites did not differ significantly from the Open sites, however the 4 year closed sites were not as similar to the Open sites as the 2 year closed sites. This result was later magnified in multivariate analyses of mobility classifications, where the significance levels increased between the 4 year closed sites and Open sites, and between the 4 and 2 year closed sites. The 6 year closed sites differed significantly from all sites, however the 4 and 6 year closed sites were more similar than the 6 year closed sites and anywhere else.

When actual taxonomic differences were analyzed, it appeared that community differences reflected the process of recovery over time that may be ongoing in the WGOMC. From the Open and 2 year closed sites to the 4 year closed sites to the 6 year closed sites, there was a rise in the influence of sessile suspension feeders, particularly phylum Porifera . Not only did the abundances of Porifera continually increase from the Open sites and 2 year closed sites to the 4 year closed sites to the 6 year closed sites, but the % contribution of Porifera to community differences increased as well (see figure 8).

Figure 8a

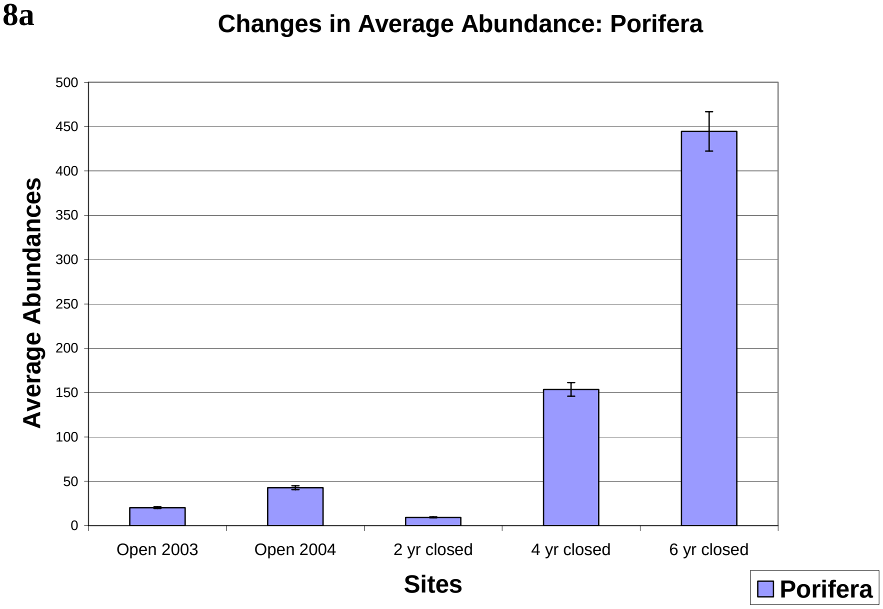

Figure 8b

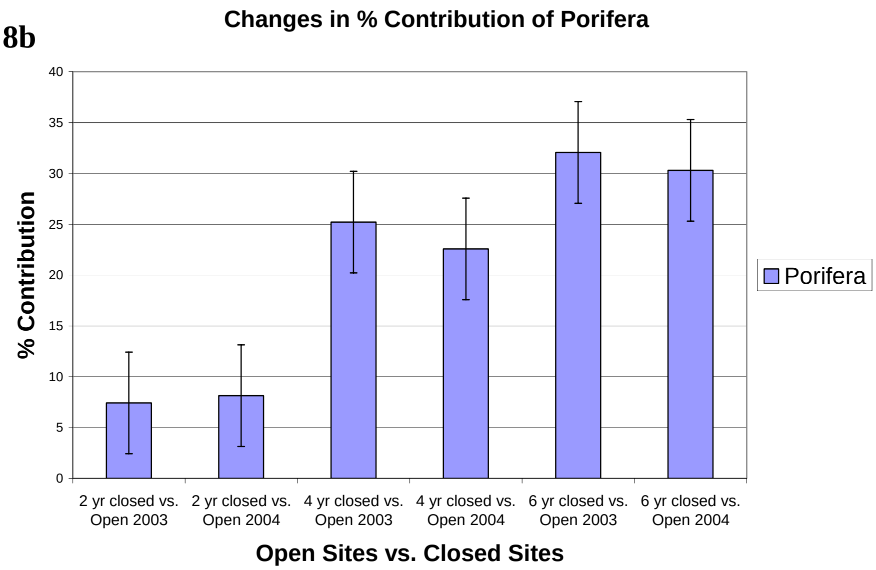

Figure 8: Shifts in Dominance, Porifera. *8a*: Shifts in average abundance of Porifera over time. *8b*: Shifts in % contribution of Porifera to community differences over time.

Much past research has shown that Porifera is highly vulnerable to disturbance, particularly branched, bushy growth forms (Sainsbury 1993; Sousa 2001; Wassenberg 2002). When possible, sponges were identified to lower taxonomic levels and counted separately, those counted under the Porifera label were most likely all the same species, however the quality of the video made this level of discrimination impossible. The growth form of this group was highly branched springing out of multiple bases, which most likely made them quite fragile and vulnerable to at least breakage under disturbance. Recovery of such animals is most likely on the order of years due to slow reproductive and growth processes of many Poriferans, which was also suggested by these data, as abundances do not seem to increase until after at least 4 years.

Image: 6 Year Closed Sites: Poriferans

The increases in the 6 year closed sites appeared dramatic, but really the most significant is that of increases in the 4 year closed sites because they were a resampling of the 2 year closed sites, thus the only direct measure of changes occurring over time.

Abundance-wise *Molgula sp*. was the dominant organism of all sites, and accounted for the greatest amount of difference between each area. While abundances increased over time (the 6 year closed sites saw the highest abundances of *Molgula sp*.), the % contribution of *Molgula sp.* to community differences, however, stayed the same, at approximately 50%. This may have been in part due to the increasing % contribution of Porifera to community differences over time. Colonial forms such as *Molgula sp.* can often be fragmented by trawling disturbances, rather than cleared completely. It would have been difficult for another organism to invade cleared patches enclosed by *Molgula sp.*. The recovery of *Molgula sp.* was most likely related to infilling these open patches, because they already had a reproductive advantage being in such close proximity to newly available space.

Image: 2 Year Closed Sites: *Molgula sp.*

A consistent contributer to similarity between stations within Open sites, and to community differences between Open and Closed sites was that of the northern shrimp *Pandulus borealis*. From the Open sites and 2 year closed sites to the 4 and 6 year closed sites, the abundances and % contribution of *Pandulus borealis* to community differences went down. Environmental conditions in the Open sites may have been more ideal for these animals as they are mobile predators and scavengers. Firstly, their quick mobility may have made them less vulnerable to direct mortality from groundfish trawling. Secondly, trawling may have enhanced the food sources of these shrimp in intensely and chronically trawled fishing grounds. *Pandulus borealis* may feed on other organisms damaged by trawls. Upright attached epifauna may also sustain damage from trawls, possibly reducing cover for potential prey, giving these shrimp and other predators a visual advantage. Furthermore, such a community state is most likely maintained in chronically trawled fishing grounds as well because vulnerable organisms may not be able to recover between disturbances.

VI. EVALUATION

This project was a continuation of work that began in 2002 under a grant from the Northeast Consortium. The goal of this project was to conduct a comparative study where differences in community states in Open sites (trawled) and sites in the WGOMC (untrawled) at different time steps were analyzed. In order to achieve this, benthic communities inside the WGOMC and outside in actively trawled sites had to be characterized to the fullest extent possible. Initially, we had intended to begin with a side scan sonar survey of potential study sites both inside and outside the WGOMC in order to help choose sampling sites based on fishing history and substrate type. We then planned to conduct a survey in all chosen study sites of resident organisms living both on and within the sediments using ROV video transects, and benthic grab sampling. Finally, benthic community states in all study sites would be assessed and compared to look at the response of communities in the WGOMC to the cessation of trawling.

ROV video transects and benthic grab sampling, and analyses and interpretation of these data, was all successfully completed. The NMFS/CRPP grant, enabled us to expand the scope of the project by re-sampling the open and closed sites two years after the original sampling season. This allowed for a long-term comparison of trawled and untrawled sites. In total, 41,472 infaunal organisms were collected and identified via benthic grab sampling and 25,987 epifaunal organisms were identified via ROV. This was a considerable endeavor and formed the basis for a graduate student thesis at the University of Maine.

Multivariate analysis showed significant differences in benthic community composition between the Kettle (open sites) and the WGOMC. Because of the lack of pre-closure samples these differences cannot be conclusively attributable to one specific cause. However, these differences are most likely attributable to the cessation of trawling in the WGOMC. In general, benthic communities in the Kettle were dominated by more disturbance tolerant, opportunistic families, while communities in the WGOMC were dominated by more disturbance intolerant, sessile families. However, it appears that the infaunal and epifaunal components of benthic communities most likely recover at vastly different rates. Infaunal communities of both the 4 and 6 year closed sites were dominated by the sessile tube-building polychaete Sabellidae, while Open 2003 and Open 2004 sites were dominated by the faster reproducing mobile polychaete Spionidae. The 4 and 6 year closed sites of the WGOMC and Open 2004 also had double the number of rarer low abundance families than Open 2003. On the other hand, in the epifaunal communities, very little recovery was observed until the 6 year closed sites. The 6 year closed sites showed higher total abundances of individuals, and higher species richness than the 2 and 4 year closed sites, or Open 2003 and 2004. The 6 year closed sites were dominated by *Mogula sp*. but showed sharp increases in phylum Porifera. The 2 and 4 year closed sites, and Open 2003 and Open 2004 were dominated by *Molgula sp*. and the mobile, opportunistic northern shrimp, *Pandulus borealis*.

Unfortunately, due to a number of reasons, we concluded in September 2004 that it would be impossible to collect the side scan sonar images needed in order to characterize the geological aspects of these habitats. While this is regrettable, a number of unanticipated issues surfaced regarding the logistics and cost of the work that made it unrealistic to complete. All of our sampling sites for this project are located between 100 and 130 m. When we were preparing to begin sampling in the summer of 2004, the geologists involved in the project realized that we needed to rent a steel cable and depressor for side scan work of greater than 100m. Because we did not anticipate this at the time we submitted our proposal to NMFS in the fall of 2003, we did not include any room in the budget to cover such costs. We researched the cost and availability of renting this additional equipment and concluded that the time and funds that were to go to completing the side scan survey would not be adequate. There were a number of legitimate logistical reasons to exclude the side scan survey, however the loss of side scan did not compromise the conclusions rendered from the data in any way.

Sampling sites were chosen based on fishing history under the recommendations of Cameron McLellan, a fifth generation fisherman and partner on the project, then surveyed via ROV to find comparable substrate. This method worked very well. We feel extremely confident that areas identified by Captain McLellan as fished and unfished areas were classified correctly. His experience as well as communications with other fishermen allowed us to focus on areas within the WGOMC that were not only void of groundfish trawling but were not shimp trawling areas and not currently being trawled by other research projects (such as the cod tagging program). Sampling sites of comparable substrate in both regions of the WGOMC that had been heavily fished, and a region the Kettle, a currently trawled fishing ground, were identified. All sampling sites were also located between 100 and 130 m, an ideal depth range because it was deeper than storm surge, which may have confounded attributing results to the effects of trawling.

Side scan would have proved useful to characterize habitat heterogeneity around all previously sampled sites. However, the side scan images that would have been possible with the limited funds would not have provided a more “regional” context within which to assess the community impacts of trawling. The preferred analysis would be to quantify the ratio of seafloor disturbed to seafloor undisturbed, which would give us the ability to predict reasonable recovery rates and where the pool of recruits would be coming from. The scope of side scan we proposed was not comprehensive enough to address this question. While side scan is a highly useful tool in many benthic surveys, it would not have yielded any more quantifiable information about the response of benthic communities to the cessation of trawling under the circumstances of this project.

While we felt that canceling the side scan portion of the project was regrettable, it was necessary to successfully complete the biological portion of the project to its fullest potential. The overall aim of the project was to investigate current community states in the Western Gulf of Maine Closure through characterization of community composition. Therefore, the first priority of the project was to characterize the biological composition of these habitats through an analysis of population abundances, and species’ life histories. That portion of the project was completed thoroughly. First, we surveyed more stations (not sites) than proposed. Rather than occupy 20 sites, we included three ROV and grab stations per site, so though we had less sites we sampled more stations (three replicates). We selected this sampling strategy based on a review of the literature which has criticized studies that do benthic sampling without enough replicates within sites. There is a lot of variability within benthic communities within a small amount of space, so one sample at each site does not provide enough confidence to say this sample is representative of the community. While we only occupied 12 sites, there were 36 stations. Second, we added grain size analysis to Open 2004 sites and 6 yr closed sites in order to attribute for the loss of side scan imaging. Many different infaunal communities are separated pretty distinctly by grain size. Grain size analysis will reveal what fraction of the sediments are gravel, sand, silt and clay, and will be a quantifiable measure that assures that the substrates were indeed comparable. Also, percent clay is an indication of food deeper in the sediments; an increase in burrowing deposit feeders (worms deep in the sediment that eat organic matter) often times correlates to an increase in the clay fraction of the sediment.

The overall objective of the project was to directly compare changes in community states following the cessation of trawling. The loss of side scan did not compromise that objective. The significance of our results stated earlier demonstrates this. The side scan work would have been support work to look at habitat heterogeneity around our sampling sites to get an idea of how communities may change over a larger spatial scale than what ROV's are able to cover. Such information is certainly worthwhile and important; however the costs of conducting such an operation outweighed its worth in our particular situation.

This project was an excellent example of collaboration between the fishing community and the scientific community. A professor and research scientist at the University of Maine's Darling Marine Center, Dr. Les Watling has been studying benthic habitats (sea bottom) for nearly 30 years. Typically outspoken in his concerns about the influence of dragging on marine biodiversity, he cites four main reasons for agreeing to participate in a research project with a commercial groundfish fisherman: the very real need to know more about whether the benthic habitats can recover from trawling and how long it might take; McLellan's genuine interest in the outcome of the research; the suitability of the F/V Adventurer for the project; and the potential funding for a graduate student. A fifth generation trawler, Cameron McLellan knows the fishing community has important expertise to contribute to habitat discussions. Determined to better understand the issues he may confront as habitat management strategies evolve, he decided to find out what happens to the sea floor when mobile fishing gear is prohibited from certain areas. McLellan identified Dr. Les Watling as a leading marine scientist in this field and approached GMRI to facilitate the partnership and assist him with a proposal for funding to study an area that has been relatively free from fishing disturbance since 1998. At sea, he worked directly with Watling's graduate student, Emily Knight, to collect sediment samples and underwater video to quantify remaining evidence of bottom disturbance and compare the diversity and abundance of the benthic fauna in the Closed Area to other sites.

This project has served as the basis for a Master's thesis by Emily Knight at the University of Maine. The thesis is under review and will be defended in November 2005. Following the completion of the thesis and defense, the complete project results will be disseminated to project partners and made available to the National Marine Fisheries Service and Northeast Consortium. Result will also be made available in electronic format. In late 2005/early 2006 manuscripts will be prepared for submission to scientific journals.

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