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Effects of excluding bottom-disturbing mobile fishing gear on abundance and biomass of groundfishes in the Stellwagen Bank National Marine Sanctuary, USA

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Abstract The Stellwagen Bank National Marine Sanctuary (southern Gulf of Maine, northwest Atlantic) is partially overlapped by the Western Gulf of Maine Closure Area (WGMCA). This is a region in which mobile, bottom-disturbing fishing gear has been banned by the New England Fishery Management Council to facilitate the rebuilding of depleted groundfish populations. We assessed the effects and effectiveness of the WGMCA on groundfish assemblages using habitat-stratified (gravel, sand, mixed benthic habitats) sampling by means of a commercial trawler, inside and outside of the WGMCA. Sampling occurred over three month-long sampling periods in 2004-2005, two during the spring seasons and one during the fall season. A total of 18 species were analyzed for protection effects. After controlling for substratum, location and sampling season, eight groundfish species exhibited higher mean proportional abundance inside than outside the WGMCA while two were proportionally more abundant on average outside of the closure. Four species had higher mean proportional biomasses on average inside the closure and three outside. We conclude that the WGMCA may be achieving its goal of rebuilding abundance and biomass for some commercially targeted groundfishes but not all. This study, six to seven years post-closure establishment, reveals fine-scale spatial and taxonomic complexity which will require a very different monitoring protocol than the one currently in place if adaptive management is to be successful in the region [*Current Zoology* 56 (1): 134–143, 2010].

Key words Effects of fishing, Groundfish, Gulf of Maine, Stellwagen Bank National Marine Sanctuary, Trawl closure

New, ecosystem-based approaches to fisheries management are gaining popularity as traditional management approaches continually fail to protect populations of commercial species from overexploitation. Fisheries are collapsing around the world, with decreases in target species and accompanying declines in non-target species as a result of by-catch mortalities (Christensen et al., 2003; Lewison et al., 2004; Mullon et al., 2005; Myers and Worm, 2005). During the second half of the 20th century, almost 25% of global commercial fisheries collapsed (Mullon et al., 2005), including the well publicized collapses of Newfoundland (Canada) in-shore Atlantic cod *Gadus morhua* populations in the early 1990s (Roughgarden and Smith, 1996) and the Peruvian anchovy fishery in the 1970s (Pauly et al., 1998). Losses of localized populations and biodiversity negatively impact the stability of marine systems and decrease their abilities to recover from stochastic events or human activities such as overfishing and pollution (Worm et al., 2006). Close examination of population trends is unsettling. For example, among gadoid fishes in the North Atlantic, including commercially important groundfish species such as haddock and Atlantic cod, more than 50% of the 70 tracked populations showed a decline of over 80% during the last century (Hutchings and Reynolds, 2004).

Current practice is to regulate commercial fishing takes from defined “stocks” through effort controls such as catch limits and days-at-sea allocations (Hughes et al., 2005), using regional MSY (maximum sustainable yield) as the cardinal reference point for management. For example, in the northeastern United States, Atlantic cod are managed under two stocks, Gulf of Maine and Georges Bank and southwards, with separate MSY values set for each stock even though significant movement of individuals between stocks occurs (Fahay et al., 1999). Newer, supplemental management practices are gaining a foothold, though they are not yet widespread. One is the establishment of no-take marine reserves or other limited-take management regimes (in which all extraction, extraction using particular gear, or targeting particular species is restricted) with the aim of fostering

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healthy populations through the protection of the whole ecosystems upon which they depend.

No-take marine reserves, which prohibit all methods of biomass extraction, have been shown to be very effective in rebuilding commercial fish biomass in the Caribbean (Roberts, 1995), the Philippines (Abesamis and Russ, 2005), and the Red Sea (Ashworth and Ormond, 2005). In the Mediterranean, a range of protective measures including no-take areas have been effective at increasing the abundance of commercial fishes (García Charton et al., 2000). Additionally, studies of marine reserves around the world have shown that area management strategies such as no-take reserves can increase stocks of exploited species outside reserve boundaries through spillover effects (Gell and Roberts, 2003). No-take reserves are generally unpopular with commercial fishermen who view such restrictions as infringements on their rights to fish in common areas (Roberts, 1997). In areas where no-take reserves face such opposition, other alternative management methods are needed.

One such alternative management approach is the restriction of bottom-disturbing mobile fishing gear such as trawls and dredges. Trawling in structured habitats has been compared to the devastation of clear-cutting in terrestrial forests (Watling and Norse, 1998). The benthic disturbances of trawling and dredging have been shown to reduce the productivity, density, and diversity of benthic invertebrate communities, consequently affecting groundfishes that prey on them (Collie et al., 1997; Hermsen et al., 2003; Blyth et al., 2004). It is common knowledge that many species of groundfishes have unique habitat preferences, often shifting seasonally and through ontogenetic development as their trophic levels change with growth (Caddy, 2008). For example, young juvenile cod have been shown to prefer gravel substrata (Lindholm et al., 2001) while older juveniles prefer higher-relief substrata such as boulder reefs (Gregory and Anderson, 1997). Adult cod are most commonly found in habitats with rocky ledges (Fahay et al., 1999). Juvenile whiting *Merluccius bilinearis* prefer biogenically structured habitats, specifically areas of high amphipod tube coverage (Auster et al., 1997), while adults are found most commonly over silty (Morse et al., 1999[1]) or sandy substrata (Auster et al., 1991). Thus, groundfish populations rely on structurally diverse and often biogenically generated benthic habitats for protective cover and prey organisms (Caddy, 2008); those preferred habitats are considered very vulnerable to trawling and dredging disturbance (Collie et al., 2000).

Trawling restrictions protect benthic communities from disturbance, leaving essential fish habitats intact and able to fulfill shelter and food requirements for survival. Areas that have been closed to trawl fishing alone can produce large increases in fish biomass. This has been the case in Mediterranean (Pipitone et al., 2000), Alaskan (Witherell et al., 2000) and New Zealand (Barrett et al., 2007) fisheries. Trawl bans can also be an intermediary management tool in areas where full marine reserves are socially and politically opposed. Fisheries of the Gulf of Maine (GOM) in the northwest Atlantic have been particularly resistant to the concept of marine reserves.

Gulf of Maine groundfish populations are at fractions of their historic levels (Holmes, 1994; Mayo and Terceiro, 2005[2]). While presently moving towards an ecosystem-based approach, fisheries managers in the GOM maintain regulatory practices that are species-centric. Commercial groundfish populations are managed with individual species catch limits and days-at-sea allocations and with temporary, rolling closures during the spawning season of Atlantic cod (Pikitch et al., 2004). This type of management regime is based upon the assumptions that groundfish populations are panmictic, not remaining in a given area for extended periods of time. The Western Gulf of Maine Closure Area (WGMCA) is a notable exception. At its inception in 1998, it was hoped that the WGMCA could accelerate the rebuilding of groundfish populations both by reducing mortality in a spatially explicit way and by enhancing recruitment and early survival through habitat protection. The Closure encompasses an area of 2,849 km^2 in the GOM and excludes bottom-disturbing fishing methods, such as trawling and dredging. Commercial fishing for managed groundfish species is prohibited except those taken recreationally. Other types of commercial and recreational fishing are allowed, even in areas that fall within the boundaries of a designated National Marine Sanctuary.

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[1] Morse WW, Johnson DL, Berrien PL, Wilk SJ, 1999. Essential fish habitat source document: Silver hake *Merluccius bilinearis* life history and habitat characteristics. NOAA Tech Memo NMFS NE-135; 42 p.

[2] Mayo RK, Terceiro M, 2005. Assessment of 19 Northeast Groundfish Stocks Through 2004. 2005 Groundfish Assessment Review Meeting (2005 GARM), Northeast Fisheries Science Center, Woods Hole, Massachusetts, 15-19 August 2005. U.S. Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc. 05-13; 499 p.

In order to be effective, marine spatial planning must be matched to the scale of key processes that regulate distribution and abundance in coastal ecosystems. Area management for fisheries has been controversial, particularly in New England. Many fishermen perceive that even though management regimes can be spatially regulated, most fishes are too mobile for the biomass of any species to accumulate within protected areas (Gell and Roberts, 2003). The purpose of this study was to test the null hypothesis of no-effect on fish distribution, abundance, and biomass for a fishery managed area in New England.

The southwestern corner of the WGMCA overlaps with the Stellwagen Bank National Marine Sanctuary (SBNMS), covering approximately one-sixth of the Sanctuary's area (Fig. 1). This overlapping area is called the Sliver. The Sliver serves as an experimental area of sorts within the SBNMS, because throughout the remainder of the Sanctuary, all types of commercial and recreational fishing are currently allowed. This situation allows for a comparison of areas that are disturbed by fishing gear to areas that are in the process of returning to a state largely free of anthropogenic physical disturbance. To exploit this opportunity, we launched a comparative trawl sampling study within the SBNMS, both inside and outside the trawl closure. In accordance with results seen in other similarly protected areas, it was expected that we would find higher abundances and biomasses of commercial species inside the protected area (the Sliver) than outside of it.

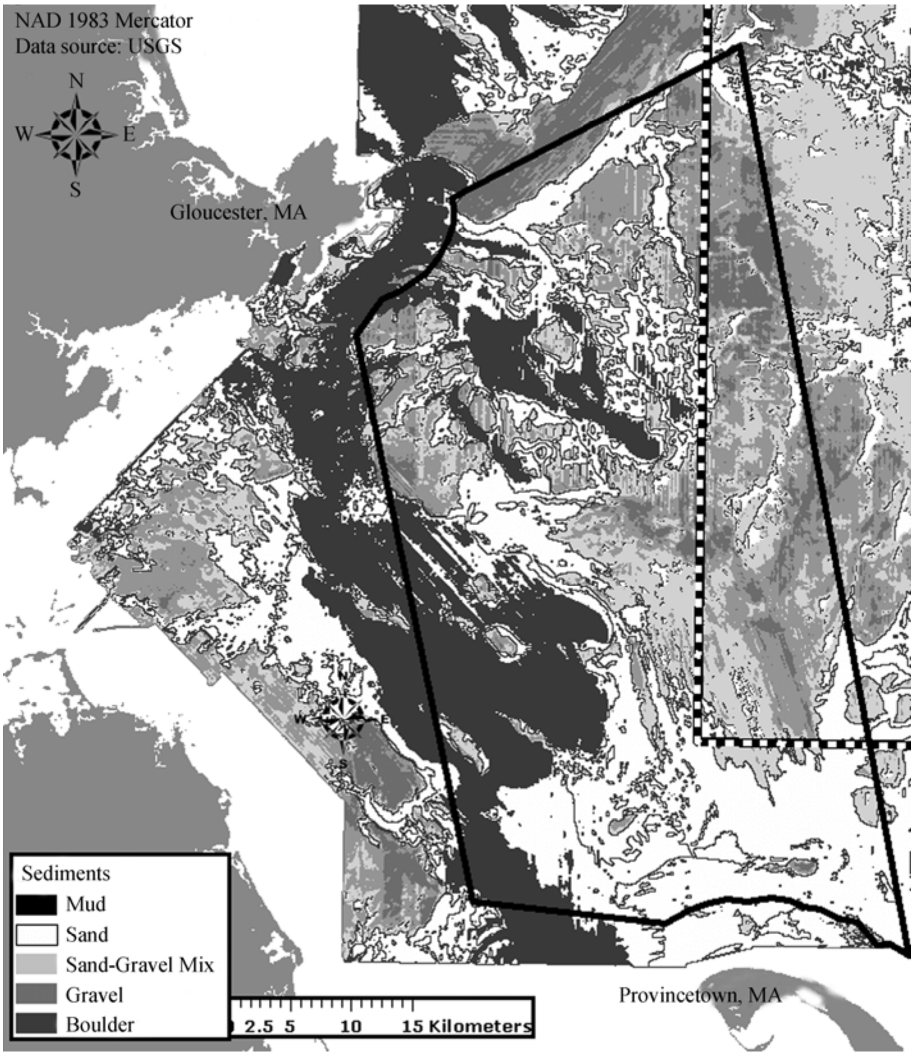

Fig. 1 The Stellwagen Bank National Marine Sanctuary is outlined in black; it is overlapped by the Western Gulf of Maine Closure Area, outlined in white and black checkered pattern

The area of overlap is referred to as the Sliver. Substrata are delineated by shade: mud (black), sand (white), sand-gravel mix (lightest grey), gravel (medium grey), and boulder (darkest grey).

1 Materials and Methods

1.1 Field sampling

We employed a trawl sampling design stratified by benthic habitat (gravel, sand, sand-gravel mix). Sampling was conducted inside and outside of the "Sliver", that area of the Stellwagen Bank National Marine Sanctuary that is overlapped by the WGMCA). Sampling began six years after the WGMCA was established. There were three sampling periods: spring of 2004 (April 17 – May 18), fall of 2004 (September 7 – October 1), and spring of 2005 (April 5 –25). The purpose of this sampling design, incorporating multiple seasons and substrata, was to eliminate seasonal or habitat biases due to the movement patterns and habitat preferences of groundfishes so that protection effects could be isolated. Distribution of sampling trawls by location and substrata are described in Table 1.

Sampling trawls were recorded using WindPlot II (©P-Sea Software Company), a GPS nautical chartplotter program for commercial fishermen (Fig.2). A greater number of trawls were conducted outside the Sliver than inside due to the greater area outside (approximately 1818 km^2 outside, compared to approximately 364 km^2 inside). Trawling was limited to areas that did not contain boulders, shipwrecks, stationary fishing gear such as gillnets and lobster pots, and known trawl "hang-ups" such as discarded gear and nets on the seafloor. Although sampling trawls were clustered in areas suitable for trawling, repeated trawling over the same coordinates was avoided so as to minimize the long-term effects of the study on the benthic community. Thus, the abundance of obstacles and other commercial fishing activity, overlain on the distribution of available habitat inside and outside of the Sliver, resulted in an unavoidably constrained sample distribution.

The study was carried out in collaboration with Mr. Paul Vitale, Captain and owner of the *FV Angela Rose*, a commercial fishing vessel based out of Gloucester, Massachusetts. The trawl net was a balloon design with ten-inch diameter central rollers and eight- and six-inch diameter rollers at the wings. Ground cables were 30 fathoms and trawl legs were 15 fathoms. The trawl doors were Bison brand number seven (©Edwin Ashworth Marine Ltd.). The cod end mesh size was 1.5 inches; the remainder of the net mesh was six inches. The small mesh size was chosen to adequately assess the impacts of the fishing closure on community size structure, which will be examined in-depth elsewhere. The net was towed at the bottom, into prevailing seas, for 15 minutes for each sampling trawl. This is half of the National Marine Fisheries Service standardized trawl sampling time of 30 min. (Methratta and Link, 2007). The duration of the trawl time was adjusted due to the use of a small mesh size. Towing velocity was adjusted to ambient bottom flow conditions to allow for the mouth of the net to pass over the seafloor at a speed of 2 knots. Numbers of individuals of each species caught were counted and total weights of catch for each species were determined.

1.2 Data analyses

To look at overall differences between the protected area of the Sliver and the remainder of the SBNMS, proportional abundances and biomasses for each species (number of individuals of one species divided by the total number of individuals caught) were calculated for each trawl. Mean proportional abundances and biomasses for individual species were then calculated for each sampling period. Using the mean proportional abundances, species were ranked from most to least common. Rank-abundance plots were then created to describe catch distributions inside and outside the protected area of the Sliver by sampling period.

All statistical analyses were performed using JMP® statistical software (©1989–2004 SAS Institute, Inc.). Protection-level effects were described in a two-step process. To control for confounding factors, three-way analysis of variance (ANOVA) models were run for each species on mean proportional abundance and mean proportional biomass by substrata (gravel, sand, sand-gravel mixed), season, the latitude of the midpoint of each sampling trawl, and the interaction terms for each pair of variables. The effects of protection level (inside or outside of the trawl closure area) were then assessed by running one-way ANOVAs on the residuals with protection level as the sole factor.

Table 1 Distribution of sampling trawls by location and substrata within the Stellwagen Bank National Marine Sanctuary

Sampling period	Inside			Outside		
	Gravel	Sand	Sand-gravel mixed	Gravel	Sand	Sand-gravel mixed
Spring 2004	7	0	2	4	5	3
Fall 2004	6	2	2	4	3	6
Spring 2005	4	3	1	8	5	3

"Inside" refers to the area within the Western Gulf of Maine Closed Area (WGMCA); "outside" refers to the area outside of the WGMCA.

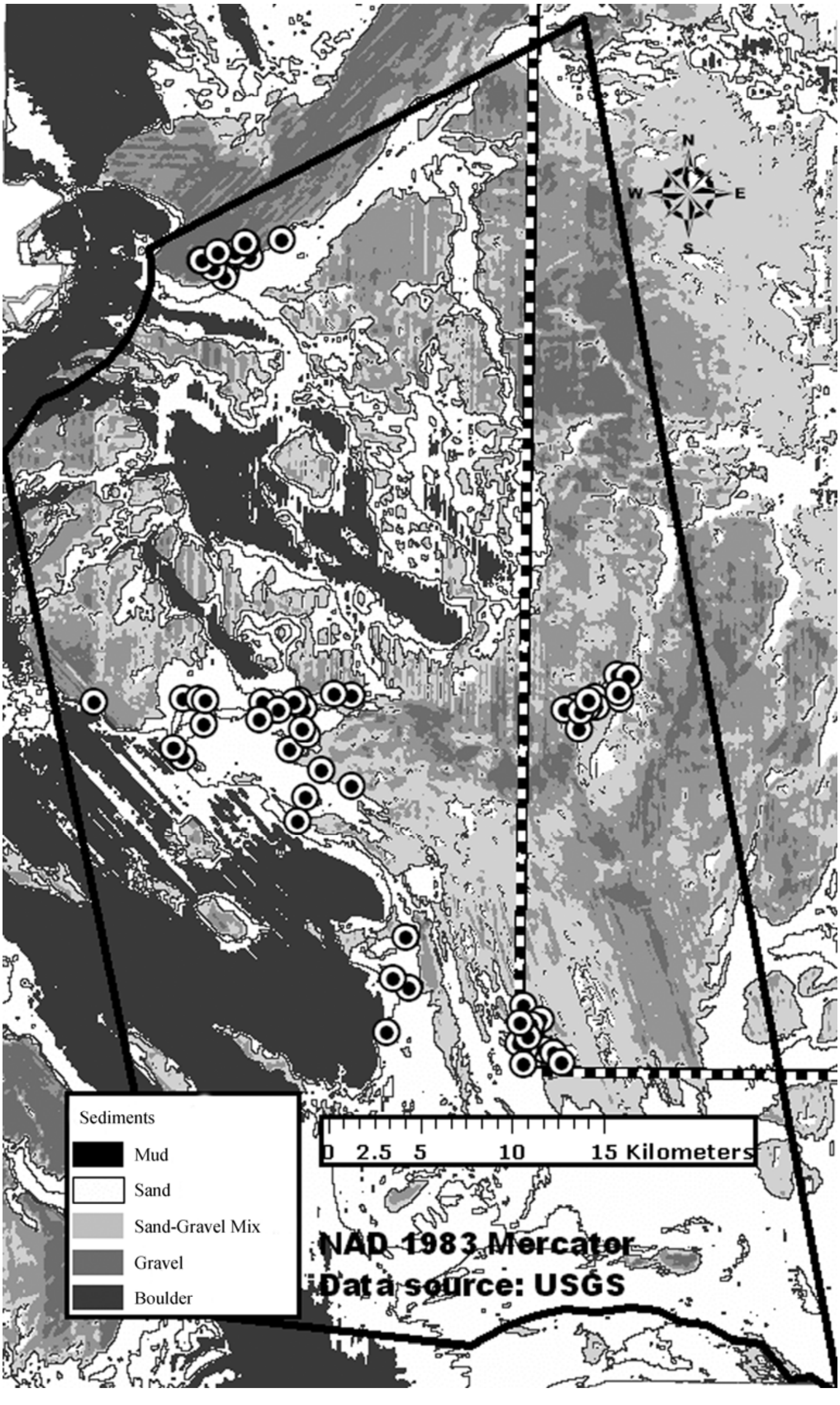

Fig. 2 Mid-points of sampling trawls (black dots outlined in white)

The Stellwagen Bank National Marine Sanctuary is outlined in black; the Western Gulf of Maine Closure Area, outlined in white and black checkered pattern. The area of overlap is the Sliver. Sampling was carried out over sand (white), sand-gravel mix (lightest grey), and gravel (medium grey) substrata.

2 Results

In total, 26 species were caught over all sampling trawls; 18 are reported on (Table 2). The remainder were caught incidentally (one individual) in one or two trawls and therefore were not analyzed for abundance or biomass distribution. Catches were dominated by a few species, as evidenced by low evenness in species rank-abundance plots for each sampling period (Fig. 3).

Table 2 Species of groundfishes caught during the three sampling periods

Common name	Scientific name
American plaice	*Hippoglossoides platessoides*
Atlantic cod	*Gadus morhua*
Haddock	*Melanogrammus aeglefinus*
Little skate	*Leucoraja erinacea*
Longhorn sculpin	*Myoxocephalus octodecemspinosus*
Monkfish	*Lophius americanus*
Ocean pout	*Macrozoarces americanus*
Pollock	*Pollachius virens*
Sea raven	*Hemitripterus americanus*
Smooth skate	*Malacoraja senta*
Spiny dogfish	*Squalus acanthius*
Thorny skate	*Amblyraja radiata*
Windowpane flounder	*Scopthalmus aquosus*
Winter flounder	*Pseudopleuronectes americanus*
Winter skate	*Leocoraja ocellata*
Witch flounder	*Glyptocephalus cynoglossus*
Wolffish	*Anarhichas lupus*
Yellowtail flounder	*Limanda ferruginea*
Species not analyzed	
Acadian redfish	*Sebastes fasciatus*
Butterfish	*Peprilus triacanthus*
Cunner	*Tautogolabrus adspersus*
Halibut	*Hippoglossus hippoglossus*
Lumpfish	*Cyclopterus lumpus*
Red hake	*Urophycis chuss*
Summer flounder	*Paralichthys dentatus*
Whiting	*Merluccius bilinearis*

The first 18 were analyzed; the remaining species were not analyzed due to low frequency of occurrence and resulting low statistical power.

During spring 2004, 21 species were caught inside the Sliver and 22 were caught outside. Longhorn sculpin dominated nearly all catches, with mean proportional abundances (MPAs) of 32% of the total catch inside and 43% outside. Haddock, ocean pout, and Atlantic cod rounded out the dominant species (MPAs of over 10% each) both inside and outside the Sliver and yellowtail and winter flounders were additional dominant species outside the Sliver.

Longhorn sculpin also dominated (MPA of 46%) the catches outside the Sliver during the fall 2004 sampling season, followed by spiny dogfish, Atlantic cod, and yellowtail flounder. Totals of 21 species were caught both inside and outside the Sliver. Spiny dogfish were overwhelmingly dominant inside the Sliver during the fall 2004 season, with a MPA of 53%. No other species had a MPA over 10% during fall 2004 outside of the Sliver.

Twenty species were caught inside the Sliver and 19 outside during the spring 2005 season. Catches inside were topped by ocean pout (MPA of 19%), followed closely by Atlantic cod, longhorn sculpin, and haddock. Yellowtail flounder rounded out the dominant group with a MPA of 10.5%. Outside catches during spring 2005 were dominated by longhorn sculpin and yellowtail flounder, with MPAs of 39% and 30% respectively. None of the other species had MPAs over 10%.

Results of the three-way ANOVAs for MPA and mean proportional biomass (MPB) with substratum, season, and latitude revealed significant heterogeneity for thirteen of the eighteen species analyzed (Table 3). Haddock, little skate monkfish, pollock, spiny dogfish, thorny skate, and winter skate had the highest proportion of variation in their MPAs explained by the three variables, all with R^2 values greater than 0.20. Atlantic cod, haddock, little skate, ocean pout, pollock, spiny dogfish, thorny skate, winter flounder, and winter skate all had

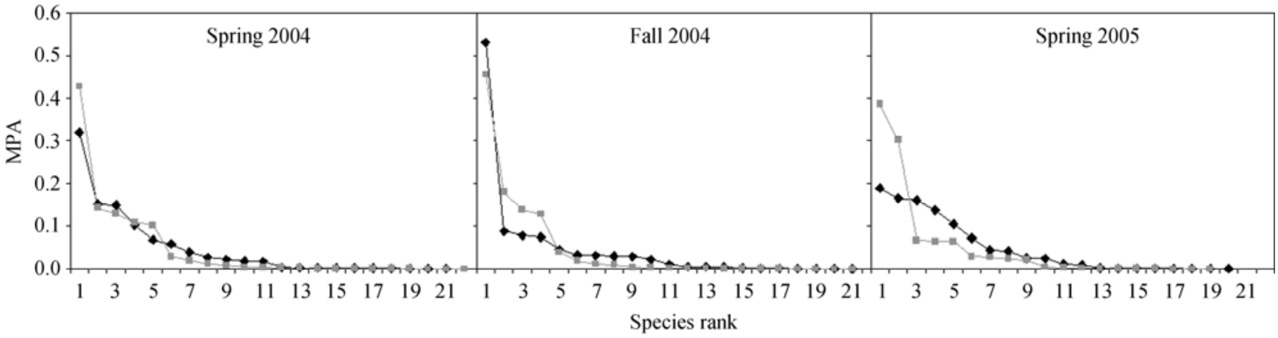

Fig. 3 Rank-abundance plots for each sampling period, separated by sampling locale inside (♦ with black line) or outside (■ with gray line) the Sliver

The y-axis is mean proportional abundance (MPA), the x-axis is species rank, from most (1) to least (21) common.

R^2 values greater than 0.20 for MPB. The remaining species had low R^2 values, suggesting that the benthic habitat, season, and latitude were not primary determinants of their distribution and abundance in the sampling area.

The trawl closure was associated with a higher abundance and biomass for some but not all groundfish species within the protected area of the Sliver. Controlling for the covariant, non-target factors of substratum, season, and latitude, ten species showed significant differences in either abundance or biomass (or both) between the protected and unprotected areas (Table 4). Eight species (haddock, ocean pout, smooth skate, spiny dogfish, thorny skate, winter skate, witch flounder, and wolffish) were significantly more abundant inside the Sliver and two species were significantly more abundant outside (longhorn sculpin and yellowtail flounder; longhorn sculpin is not commercially exploited). Four species had significantly higher biomasses inside the Sliver (haddock, smooth skate, spiny dogfish, and thorny skate) while three species had higher biomasses outside (longhorn sculpin, winter skate, and yellowtail flounder). Winter skate was more abundant inside the Sliver but had higher biomass outside the Sliver, suggesting that the Sliver may harbor more winter skate juveniles than the unprotected area.

Table 3 ANOVA table results of multiple linear regressions predicting mean proportional abundance and mean proportional biomass by substrate (gravel, sand, or sand-gravel mix), season (fall or spring), and latitude (sampling trawl mid-point)

Species	Relative abundance			Relative biomass		
	R^2	F	p>F	R^2	F	p>F
American plaice	0.15	2.91	*	0.18	3.55	*
Atlantic cod	0.15	2.91	*	0.22	4.56	**
Haddock	0.29	6.54	***	0.25	5.35	***
Little skate	0.21	4.32	**	0.21	4.39	**
Longhorn sculpin	0.18	3.69	*	0.19	3.72	**
Monkfish	0.38	10.09	***	0.20	4.18	**
Ocean pout	0.19	3.85	**	0.31	7.31	***
Pollock	0.22	4.57	**	0.23	4.86	**
Sea raven	0.09	1.71	NS	0.20	4.05	**
Smooth skate	0.07	1.28	NS	0.08	1.33	NS
Spiny dogfish	0.48	14.89	***	0.76	50.27	***
Thorny skate	0.31	7.25	***	0.29	6.68	***
Windowpane flounder	0.19	3.85	**	0.12	2.16	NS
Winter flounder	0.09	1.67	NS	0.33	8.15	***
Winter skate	0.35	9.11	***	0.31	7.39	***
Witch flounder	0.07	1.30	NS	0.07	1.15	NS
Wolffish	0.10	1.72	NS	0.07	1.30	NS
Yellowtail flounder	0.18	3.64	*	0.17	3.35	*

* $P<0.05$, ** $P<0.01$, *** $P<0.001$

Table 4 Results of ANOVAs predicting residual variation for mean proportional abundance and mean proportional biomass by protection level (inside the WGMCA versus outside the WGMCA)

Species	Relative abundance			Relative biomass		
	F	P>F	Relationship	F	P>F	Relationship
Haddock	13.49	***	I > O	7.59	**	I > O
Longhorn sculpin	11.63	**	O > I	10.45	**	O > I
Ocean pout	9.11	**	I > O			
Smooth skate	9.93	**	I > O	5.16	*	I > O
Spiny dogfish	13.99	***	I > O	8.30	**	I > O
Thorny skate	10.59	**	I > O	8.82	**	I > O
Winter skate	13.16	***	I > O	4.15	*	O > I
Witch flounder	4.30	*	I > O			
Wolffish	4.11	*	I > O			
Yellowtail flounder	12.98	***	O > I	18.99	***	O > I

* $P<0.05$, ** $P<0.01$, *** $P<0.001$. Empty boxes indicate that the overall model was not statistically significant.

3 Discussion

Evidently, area management in the Gulf of Maine, even on a small scale, can be expected to contribute to stock rebuilding despite the presumed high mobility of the species concerned. Six years following the exclusion of bottom-disturbing gear, the closure was associated with increased abundances of at least eight (haddock, ocean pout, smooth, thorny, and winter skates, spiny dogfish, witch flounder, and wolfish) and biomasses (haddock, smooth and thorny skates, and spiny dogfish) of at least four groundfish species. Although not all commercial groundfish species appear to be benefitting from the closure, the results of this study generally support our hypothesis that the protected area of the Sanctuary, the Sliver, would harbor higher abundances and biomass of commercial groundfish species than the unprotected area.

The increased abundances and biomasses of some commercial groundfish species in the protected area of the Sanctuary are consistent with results reported in other studies, including those examining fishery closures and no-take marine reserves. A study of the groundfish closed area covering Georges Bank (southeast of the GOM) found that biomasses of Atlantic cod, haddock, and yellowtail flounder were higher inside the closed area than in surrounding, unprotected areas (Murawksi et al., 2000). Similarly, a trawl closure in the Gulf of Castellammare (Mediterranean Sea) recorded increases in biomass inside a trawl closure for nine commercial fish species, four years after the trawl ban was enacted (Pipitone et al., 2000). A longer-term study in the western Mediterranean, conducted eight and 16 years post-establishment, found that there were higher abundances and biomass of multiple commercial fish species but not all, inside marine protected areas (Stobart et al., 2009). In an Australian marine sanctuary, the abundance of a heavily exploited species was 10 times greater and the biomass five times greater inside the protected area than outside (Kleczkowski et al., 2008). Similar to the results shown in this study, an investigation of five no-take reserves in southern California found that biomass of commercially targeted fishes was significantly higher inside the reserves than outside, while the biomass of non-targeted fishes was significantly higher outside the reserves than inside (Tetreault and Ambrose, 2007). Long-term monitoring of Tasmanian marine reserves documented variable increases in abundance and biomass of some commercial fish species after ten years of protection (Barrett et al., 2007), indicating that a long recovery period may be necessary to see the full benefits of closing an area to commercial fishing activities.

The results of this study, showing increased abundance and biomass of some commercial groundfish species, and others suggest that fine-scale management of temperate marine fishes can be effective in increasing populations of overexploited species, often presumed to be too mobile to benefit from small-scale protection measures such as the WGMCA. The simplest explanation is that they are not quite as mobile as historically believed. In addition to this study, one of the most intensive fine-scale sampling efforts undertaken in the region, there is a growing body of diverse evidence supporting the hypothesis that groundfishes are more sedentary than traditionally believed in the Gulf of Maine. Atlantic cod, the quintessential New England groundfish, serves as the model species for this emerging body of work. Rather than comprising a single panmictic population throughout the Gulf of Maine, Atlantic cod exhibits a surprisingly high degree of population structure, with some discrete, more or less sedentary populations (Lindholm and Auster, 2003; Robichaud and Rose, 2004). Genetic studies have shown that subpopulations of Atlantic cod are maintained in the northwest Atlantic and over the entire geographic range of the species, suggesting low adult dispersal (Pogson et al., 2001; Imsland and Jónsdóttir, 2003; Knutsen et al., 2003). There is variability within species: while some cod do wander considerable distances, a large fraction of the cod population exhibits a highly sedentary behavior (Robichaud and Rose, 2004). This growing bank of data, collected using a variety of methods and on multiple scales, demonstrates that area management is a feasible approach to fisheries management and conservation.

Despite design limitations, our study did find spatial variation in biomass and abundance that can be attributed to the trawling ban in the WGMCA. To a limited extent, the results may also be attributable to a spatial confound. Due to its glacial geomorphology, the area of Stellwagen Bank that lies within the Sliver includes much coarse gravel and hard bottom, while our comparison area has a greater representation of sand and mud (Fig. 1). Even though we controlled for this difference through stratified sampling, it is quite possible that similar substrata serve as distinctly different habitats inside and outside of the Sliver. For example, sand patches surrounded by gravel and boulder reefs (inside the Sliver) may harbor a different fish community than sand surrounded by more sand (outside the Sliver). The greater abundance of longhorn sculpin and yellowtail flounder outside of the Sliver in unprotected areas of Stellwagen Bank could simply reflect that these species prefer large contiguous stretches of sandy habitat.

Our results offer only a brief snapshot in time of possible management area effects, and one with limited statistical power at that. In theory, a good design for a long-term study would be an expansion of the approach taken here; for example, a time series of the habitat-stratified samples inside and outside of a protected area, or, more generally, across all types of management regimes within a marine spatial planning domain. However, this is not practical. Monitoring of benthic fish assemblages at a fine spatial scale is a challenging exercise, and doing so with a trawl a somewhat self-defeating one as well, due to the damage that trawling inflicts on benthic communities. Trawl samples can be highly variable (Curley et al., 2002), so a large number of replicates are required. A small marine protected area is likely to be destroyed by any trawling program adequate enough to achieve the statistical power necessary to confidently measure spatial management effects. Our experience shows that it is even more difficult in a multi-use area where the “protection” may involve only one of many gear types and activities. The gear that is not excluded from the zone of interest greatly limits the area available for sampling. On-going monitoring of the WGMCA is needed for assessment of its effectiveness in rebuilding populations of overexploited groundfishes. Given the limitations of trawl sampling, there is an urgent need to develop reliable monitoring protocol for non-destructive sampling methods such as acoustic sounding, video transects, or motion-detector camera stations.

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