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Habitat-Dependent Catch Composition and Food Web Dynamics in the Western Gulf of Maine Closure, Stellwagen Bank

INTERIM PROGRAM REPORT
and
FINAL PROJECT REPORT
NOAA Contract EA133F-03-CN-0050

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1. PROJECT SUMMARY

We have launched a research program to investigate the effects of trawling versus trawling exclusion on groundfish assemblages, using the Western Gulf of Maine Closed Area (WGOMCA) as an opportunistic experimental system. Our focus is on the ways that exploited groundfish species function in the food web and how this might be influenced by trawling exclusion. In this first phase of the program, 87 experimental trawls were conducted during three sampling periods, stratified inside versus outside the WGOMCA, and among three benthic habitats: sand, gravel, and mixed sand and gravel. The contents of each trawl were enumerated, resulting in data matrices for catch composition by numbers and weight, weights of livers and ripening ovaries for a subset of the sample, and length-frequency data. Up to five individuals spanning the full size range for each species caught in each tow were sampled for stable isotope analysis, and archival DNA samples were taken from a subset of cod and haddock. The stomachs of these five individuals were also removed for stomach contents analysis on a subset of the samples. Reference isotope samples were taken from invertebrates and algae caught opportunistically in the trawls. In addition, a small sample of cod was jigged from boulder habitats, and two exploratory trawls were made on deep mud, to initiate study of fishes on these bottom types. Follow-on grants are enabling us to continue the work in the deep mud habitat (sampled spring-summer 2006), with work planned for boulder habitat during the 2007 field season with funding from the Pew Institute for Ocean Science.

Analysis-of-Variance (ANOVA) and multivariate analyses were applied to the resulting data to test the hypotheses that inside (as compared to outside) the Western Gulf of Maine Closure fishes were: (1) more numerous, (2) higher in biomass, (3) more diverse, (4) skewed toward larger size classes, (5) longer in food chain length and that (6) any given species or size class was higher in the food web than in comparable habitat outside of the closure. The confounding effects of fish size and habitat were examined, and then extracted statistically as necessary to permit assessment of differences attributable specifically to area management.

Sampling has been completed for this phase of the program, but stomach contents and data analyses are still in progress. In this report, we review the results principally from hypotheses 2, 5 and 6, summed over sampling periods. We found marked, species-specific patterns associated with each of the cardinal variables: habitat, sampling period, and most importantly, area management. Stable isotopic signatures revealed spatial and temporal patterns of variation in the food web, and fishes' position in it. The presence of significant differences in isotopic signature for fishes of the same size and species over such small geographical distances means that abundant species exhibit appreciable site fidelity, remaining within a small area at least long enough for management area effects to appear. Stable isotope analysis has the potential to provide replicable, relevant and useful information in future ecosystem-based management decisions in the Gulf of Maine.

2. PROJECT GOALS AND OBJECTIVES

This project's genesis emerged from observations by fishermen that suggested strong local effects in the distribution, abundance, and behavior of groundfishes in the Stellwagen Bank area. For example, Captain Paul Vitale (our coworker) has observed high densities of skates and/or dogfish in rotating closures immediately following their reopening to fishing. This raises concern about the possibility for area management to alter or be influenced by fish behavior in ways that might run counter to intended conservation outcomes. Indeed, in order for area management to work at all there must be some response to limited area closures despite the high mobility that many fishes are capable of exhibiting. The bottom line is that we need the means to monitor the ecology of areas of seabottom subject to different management regimes, and to know and understand the full suite of ecological effects attributable to these regimes. Without this capability, the effects and efficacy of area management will remain obscure, and neither adaptive management nor ecosystem-based management will be possible.

Despite the oft-noted fact that "fish have tails" and are willing to use them, there is already substantial evidence that large commercial groundfishes in the Gulf of Maine do not simply roam around homogeneously across the region...nor do they always roam very far. Evidence is mounting for stock substructure within the Gulf region. Tagging studies suggest strongly that some portion of the cod population, for example, is highly sedentary (Robichaud and Rose 2004, Lindholm and Auster 2005). Studies of food webs and individual fish feeding habitats offer the potential to appreciate local area effects without actually tracking individual fishes, and so we launched the current study to assess the utility of this approach. In particular we wished to assess the possible advantages of using stable isotope analysis to measure both individual behavior and overall food web dynamics.

We compared catch composition and aspects of the trophobiology (feeding biology) of groundfishes between areas closed versus open to trawling on Stellwagen Bank, inside and outside of the Western Gulf of Maine Closure. ANOVA and multivariate analyses were applied to the resulting data to test the hypotheses that fishes inside versus outside the Western Gulf of Maine Closure were: (1) more numerous, (2) higher in biomass, (3) more diverse, (4) skewed toward larger size classes, (5) longer in food chain length and that (6) any given species or size class was higher in the food web than in comparable habitat outside of the closure. The confounding effects of fish size and habitat were extracted, examined, and removed statistically to permit assessment of differences attributable specifically to area management. Sampling has been completed for this phase of the program, but stomach contents and data analyses are still in progress. In this report, we review the results from hypotheses 2, 5 and 6, summed over sampling periods.

Hypothesis 6 merits explanation. Typically, all mature members of a species of fish are regarded as occupying the same trophic level. In fact, fishes can exhibit great dietary plasticity both among and within individuals, and among habitats and seasons. We postulated that size-matched individuals of the same species will feed differently inside than outside the closure. It is for this hypothesis that we had the greatest statistical power.

At the outset of this study, we also wished to examine the behavior of skates and dogfish around rotating closures, to test Mr. Paul Vitale's hypothesis that when the rotating closure is lifted, these predators swarm in and quickly devour spawn and young of year. The review committee for the grant requested that we drop that objective due to the grant being too ambitious, and so we did. In the course of our sampling, however, we experienced large catches of spurdog (*Squalius acanthius*) on Stellwagen, particularly within the WGOMCA during the fall sampling period of 2004. A seasonal high density of dogfish in the WGOMCA has the potential to impact groundfishes. This is especially so given that dogfish are currently under a strong conservation advisory due to regionally low population levels in a recent FMP assessment.

This study was conducted aboard the fishing vessel "Angela and Rose" out of Gloucester, under the hand of Captain Paul Vitale, and with assistance from his father, Mr. Leo Vitale. Dr. Les Kaufman was project PI and was aboardship for several of the sampling days. Dr. Jason Link of the Northeast Fishery Science Center is a co-investigator, but did not attend sampling missions. Boston University Graduate Student Ms. Elizabeth Soule served as Chief Scientist on most day trips, with assistance from BU grad students Mr. J.F. Betrand, Mr. William Ojwang (now with Kenya Marine and Fisheries Research Institute), and Ms. Briana Brown. Additional assistance on sampling missions was provided by staff of the New England Aquarium, the National Marine Fisheries Service, and the Conservation Law Foundation (Dr. John Crawford of CLF was aboard in his capacity as an Adjunct Professor of Biology at Boston University). Approximately two dozen BU undergraduate students also lent an invaluable hand in all aspects of the work, from sampling at sea to sample processing and analysis. Stable isotope samples were run in the BU Stable Isotope Laboratory under the direction of Dr. Robert Michener.

All aspects of this work were coordinated with the assistance of the Massachusetts Fishermen's Partnership, with whom this was a collaborative project. Mr. David Bergeron served as MFP liaison and grant officer, and Ms. Olivia Free as project coordinator.

3. METHODS

A. Summary of Tows

87 tows were made, distributed among sand, gravel, and mixed sand-gravel bottoms, including also two exploratory tows in deep mud. The original intent was that these would be randomly stratified among habitats inside and outside of the WGOMCA. In practice, though, the area available for sampling is severely constrained by known hangs (known to the fishermen and carefully recorded over lifetimes in precious, richly annotated charts), and by non-mobile gear such as lobster traps that are freely deployed in the WGOMCA. It is probably best to regard the random stratified design as an intent, and the realized sampling design as a necessary but not exactly random compromise.

B. Catch Composition and Tissue Sampling

The contents of each tow were released on deck, sorted by species, and the number and weights of the catch of each species were recorded. Subsets of 25-50 individuals of each of the most numerous species were then measured for length-frequency analysis. Up to five individuals of each species, representing the full size range represented in that tow, were retained for further analysis. Small blocks of tissue were removed from the left epaxial musculature for stable isotope analysis. For some cod and haddock, a second sample was placed in 95% ethanol to be archived for genetic studies in other projects, as were some otoliths. The entire alimentary canal was removed and preserved. Preservation of the guts and their contents varied during the project due to shipboard space and safety constraints. Early on they were frozen, then brought to the lab and maintained at -20° C until thawed for analysis. During the second and third sampling periods guts were bagged, labeled, held at 4° C and then returned to the lab for fixation in Formalternate until analysis. Neither of these methods was as satisfactory as the traditional protocol of placing the guts immediately in formalin aboardship, including injection of larger guts with 10% formalin. However, our methods sufficed for our purposes, increased safety, and conserved space during sampling.

C. Stable Isotope Analyses

All organic samples (fish muscles and plants) were kept fresh in the field using ice in a cooler box and subsequently frozen and maintained at -20°C until prepared for stable isotope analysis. All the frozen samples were dried in the oven at 60° C for 48 hours. The dried material was then ground into fine powder by hand using a mortar and pestle. The mortar and pestle were rinsed clean and dried in between samples to avoid contamination. Organic samples were weighed, approximately 1mg and 2mg of animals and plants respectively and analyzed using an automated continuous-flow isotope mass spectrometry (Preston & Owens, 1983). The combustion gases (N_2 and CO_2) were separated on a GC column, passed through a reference gas box and introduced into the GV Instruments IsoPrime isotope ration mass spectrometer; water was removed using a magnesium perchlorate water trap. Ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ were expressed as the relative per mil (‰) difference between the samples and international standards (NBS 20 Solenhofen Limestone and N_2 in air) where:

$$\square X = (\{R_{sample}/ R_{standard}\}-1) \times 1000 \text{ (‰)}$$
and $X = {}^{13}C$ or ${}^{15}N$; $R = {}^{13}C/{}^{12}C$ or ${}^{15}N/{}^{14}N$

The sample isotope ratio is compared to a secondary gas standard, whose isotope ratio was calibrated to international standards. For $^{13}C_{V\text{-}PDB}$ the gas was calibrated against NBS 20 (Solenhofen Limestone). $^{15}N_{air}$ the gas was calibrated against atmospheric N_2 and IAEA standards N-1, N-2, and N-3 (all are ammonium sulfate standards). All international standards were obtained from the National Bureau of Standards in Gaithersburg, MD. In addition to carbon and nitrogen isotopes from the same sample, continuous flow also reported %C and %N data.

4. RESULTS AND THEIR INTERPRETATION

A. Catch Composition

Catch composition may be analyzed in two ways: by weight, and by numbers of individuals. Here we present exemplars of key analyses from both perspectives.

ANOVA was used to screen for significant patterns related to in/out, habitat, and sample period effects for each species, and for the derived quantities "total cods", "total flatfishes", "total skates" and "total biomass". The two mud and one boulder trawl shots excluded so as to compare only sand, mixed sand-gravel, and gravel habitats. Table ____ indicates those cases in which the null hypotheses of samples drawn from populations with the same mean, was rejected at $p<.05$. The reader is cautioned that in this analysis, a Bonferoni correction for multiple tests was not applied due to the high rate of false negatives that it generates when many separate tests are being conducted. Thus the results should be regarded as robust for revealing marked patterns, but not for assigning exact probabilities.

In the table below, one star represents significance at the level of $p < .05$, for two stars $p < .01$, and for three $P < .001$; near-significant levels are indicated by a number greater than but close to .05.

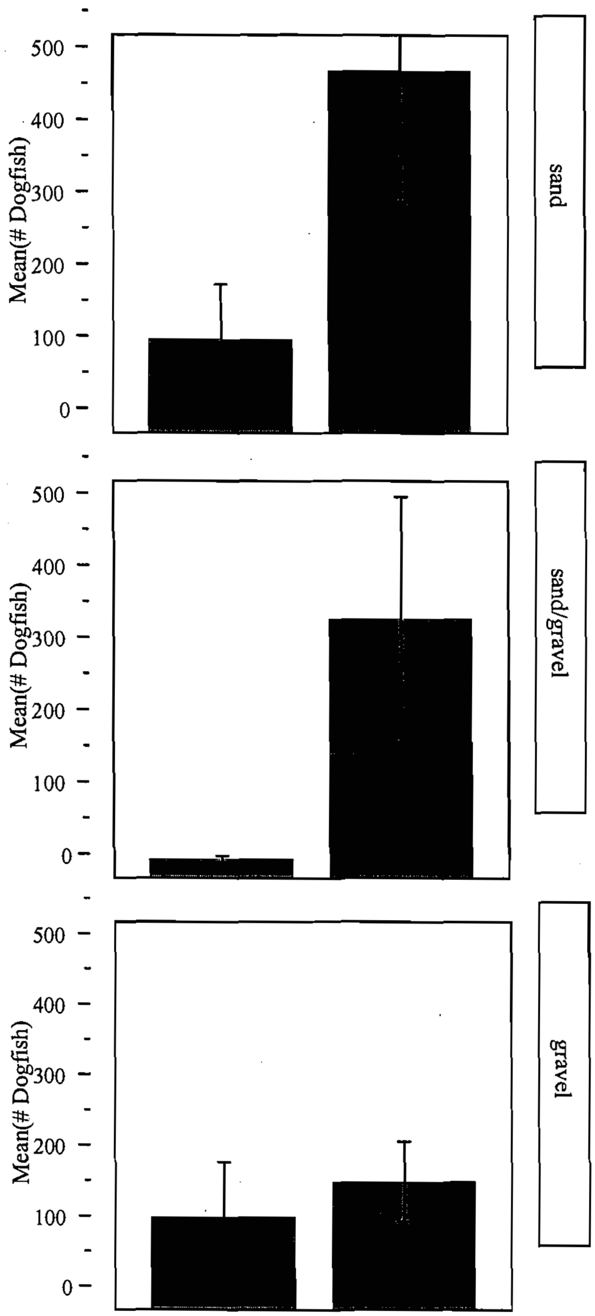
These results point strongly to the existence of significant In/Out and Period effects, and suggest that habitat was not a significant factor in biomass variation among the samples. They also offer a basic description of the major patterns in species distribution and abundance in versus out of the Closure, and across habitats and sampling periods. This is probably a fair indication of where to look for main effects in the data. Furthermore, 24 out of the 102 cells were significant at least the .05 level, a rate nearly five times higher than would be expected by chance. However, it could be argued that the assumptions of species independence and lack of interactions are unreasonable. If so, then the data must be analyzed of a piece to obtain a conservative and correct test of the main hypothesis that fish biomass was greater inside than outside the closure, in all habitats, at all times. Before proceeding, however, it is worth becoming familiar with the basic patterns in the data as revealed in a descriptive sense by the species-by-species analysis.

The following species were present at higher biomass INSIDE the Closure, at levels that were statistically significant or nearly so: dogfish, haddock, witch (grey sole), red hake.

The following species were present at higher biomass OUTSIDE the Closure, at levels that were statistically significant ($p<.05$) or nearly so: longhorn sculpin, yellowtail flounder, sea raven, winter flounder, windowpane flounder.

Species	**In/Out**	**Habitat**	**Period**	**Pattern**

Cod	ns	Ns	***	many caught May 2004
Haddock	.06	Ns	ns	*Possibly* more inside Closure
Longhorn Sculpin	***	Ns	**	more outside Closure
Eelpout	ns	Ns	.06	Low fall, high spring
Yellowtail Flounder	**	Ns	*	More outside Closure
Winter Flounder	*	Ns	ns	More outside closure
Sea Raven	**	Ns	*	More outside, high 2005
Pollack	ns	Ns	ns	
Goosefish	ns	Ns	***	Most fall 2004
Dab	ns	Ns	ns	
Windowpane	ns	Ns	ns	
Herring	ns	Ns	ns	
Wolffish	ns	Ns	ns	
Thorny Skate	ns	*	*	Mostly gravel, mostly May 2004
Winter Skate	ns	Ns	ns	
Smooth Skate	ns	*	*	Mostly gravel, mostly May 2004
Silver Hake	ns	Ns	ns	
Red Hake	**	Ns	ns	Mostly inside Closure
Fourspot Flounder	ns	Ns	.06	Mostly May 2004
Witch Flounder	*	Ns	**	
Dogfish	**	.07	***	More inside, most fall 2004
Other Skate	*	Ns	*	Mostly inside, May 2004
All Flatfishes	***	Ns	*	Mostly outside, April 2005
All Skates	ns	Ns	ns	
All Cod Family	*	Ns	**	Mostly inside, Fall 2004
Total Biomass	*	.06	***	Mostly inside, Fall 2004, sand (dogfish effect)
Alligatorfish	na	Na	na	
Little Skate	ns	Ns	ns	
Redfish	na	Na	na	
Cunner	ns	Ns	ns	
Halibut	ns	Ns	ns	
Lumpfish	ns	Ns	ns	
Butterfish	ns	Ns	ns	
Summer Flounder	ns	Ns	ns	



One thing that is immediately apparent in the data is that there is an overwhelming pattern driven by the occurrence of large catches of dogfish, particularly inside the WGOMCA. Dogfish were very abundant only during fall 2004, and then, were much more abundant inside than outside the Closure. There was a trend for there to be more dogfish inside than outside the closure in all three habitats, but the pattern was forced mostly by dogfish distribution on sand and mixed bottoms.

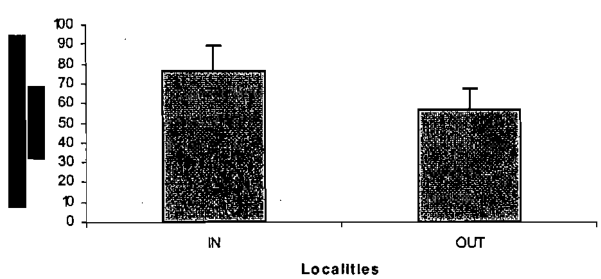
The correlation between total biomass in the samples and dogfish biomass is about 0.998. The catch data support fishermen's observations using normal commercial gear, that dogfish are concentrated on Stellwagen Bank and aggregate there during the late summer and fall, particularly within the Western Gulf of Maine Closed Area.

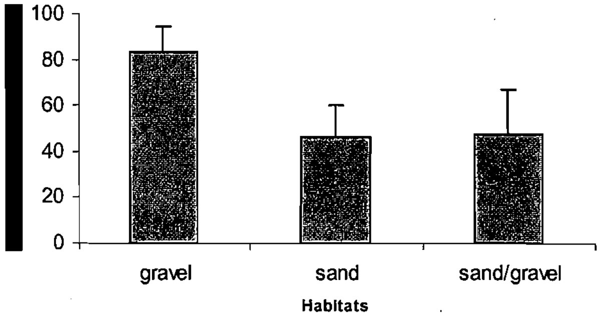
The pattern of dogfish catches is real and interesting, but it is so extreme that it obscures other patterns in the data when they are examined in a multivariate context. To unmask these other patterns in a conservative manner, a factor analysis was performed on the multispecies data (both numbers and biomass for each species in each sample) with dogfish excluded from this particular analysis. Two significant factors were extracted: Factor 1 was related to WGOMC effects (ANOVA $p < .001$ for in/out effect, ns for sampling period or interactions). Factor 2 was related to the interaction between in/out effects and sampling period (ANOVA $p < .005$). Factor 2 described a pattern in which the in/out effect for any particular species was strongest during the sampling period when that species was caught in greatest numbers.

In sum, there is a strong correlation between the Western Gulf of Maine Closed Area and fish catches, both for dogfish specifically, and for the community as a whole. The original hypothesis of higher biomass and fish numbers within the Closure across the board was rejected: some fish species were at higher biomass inside the Closure, others were at higher biomass outside the Closure, and many either showed no effect or could not be assessed with the limited numbers caught during this study.

1. Cod

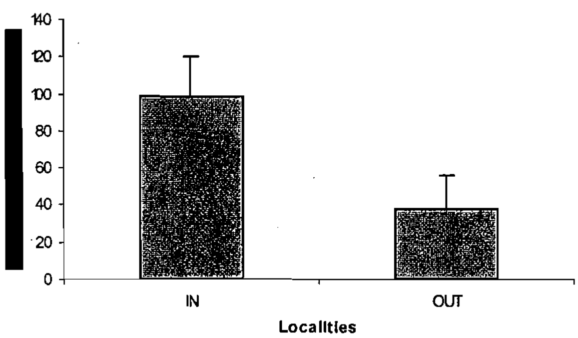
Cod biomass CPUE did not differ significantly inside vs. outside the WGOMC. Catch rates by habitat exhibited a borderline trend, with highest rates on gravel habitat. We suspect that the lack of statistical significance in this case may have been an artifact of high variance among samples, rather than the lack of a real pattern, but the study would have to be repeated over a much longer time period to explore this in a meaningful way (see discussion).

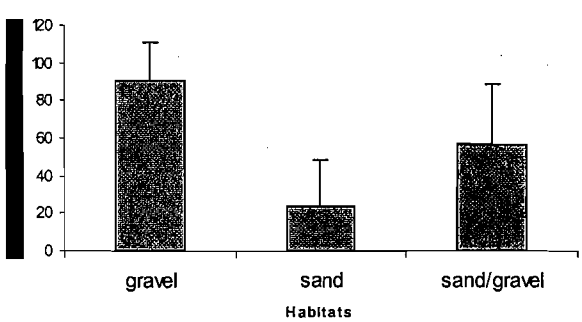




2. Haddock

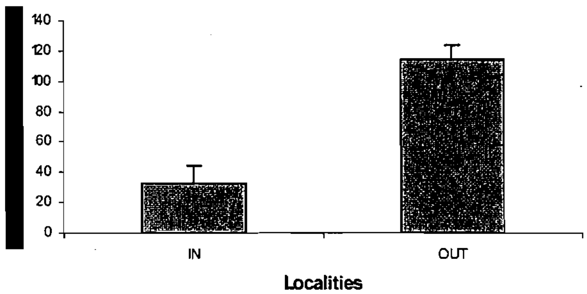
Taken across the three trawled habitat types, haddock were higher in biomass inside than outside the WGOMC, but this difference was not quite significant statistically (p=.06). Catch rates did not vary significantly across the habitats sand, gravel, and mixed sand and gravel. There is an apparent tendency for higher haddock catches to be associated with gravel or at least some admixture of gravel in the environment but greater statistical power would be required to assess this definitively.

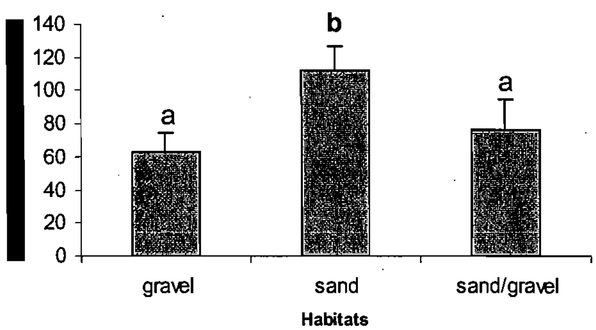




3. Longhorn

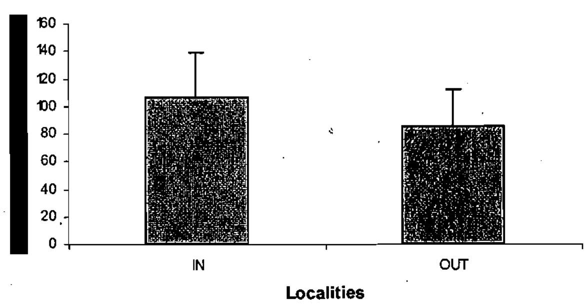
Longhorn sculpin catches were much higher outside than inside the closure (p<<.001). Longhorn were most abundant on sand, lower on mixed sand and gravel, and lowest on gravel, with the difference between gravel and sand statistically significant (p=.034).

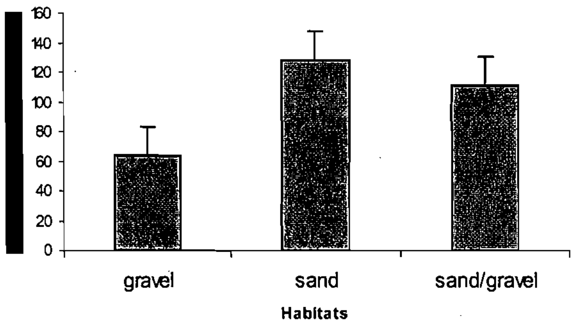




4. Eelpout
All habitats (in & out) NS p=0.61

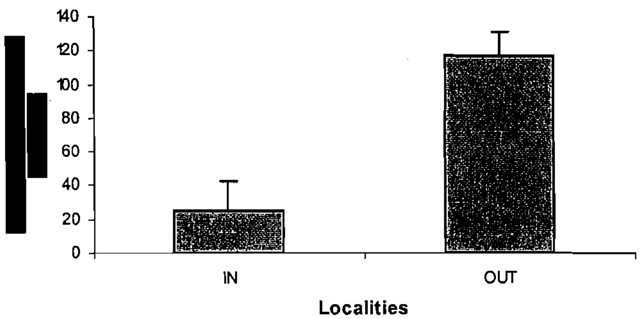
Catches per unit effort for eelpout were statistically indistinguishable inside versus outside the WOMGC, or across the three trawled habitats.

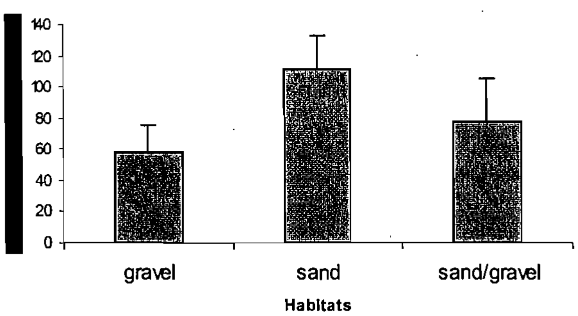




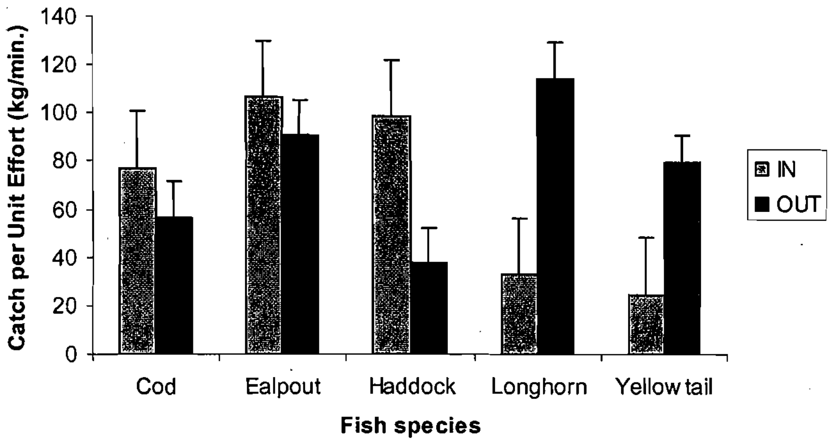
5. Yellowtail

Yellowtail flounder were much more abundant outside than inside the WGOMC. Though they appeared to be more strongly associated with sand than with gravel habitats, this trend was not significant.





Biomass of All the five fish species (IN & OUT)



B. Preliminary Analysis of Stable Istotopic Values for Cod, Haddock, Eelpout and Longhorn Sculpin.

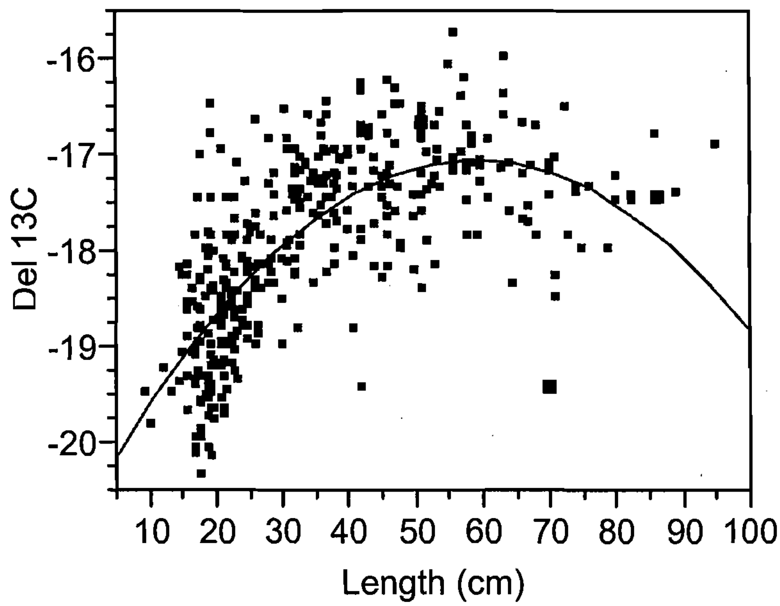
Hypotheses 4 and 5 are being tested in two ways- first, by using stomach contents analysis to determine instantaneous trophic level from the observed prey, and second, by testing for significant differences between stations (within species and size class) in the degree of enrichment by stable heavy nitrogen (delN^{15}) in the tissues of predatory fishes. Heavy nitrogen is enriched moving up the food chain, reflecting an average trophic level exhibited by an organism during the previous four to six weeks (the time required for tissue turnover).

In each case, we first tested the hypothesis that isotopic enrichment (delC and delN) increased with fish size. If the null was rejected, subsequent analyses (to test for habitat and management area effects) were conducted on the residuals after the effects of length were removed.

1. Cod

Del C vs length

The relationship between fish length and delC13 in Cod was strongly curvilinear. This suggests that young cod, up to ca. 30cm in length, fed principally on prey whose tissues were dominated by the light isotope of stable carbon, C12. In the environment where we were working, this is probably indicative of feeding on prey closely tied to the pelagic food chain phytoplankton as primary producers. Larger specimens exhibited higher enrichment by C13, and hence higher delC values, most likely reflecting an ontogenetic switch from midwater to benthic prey. At very large sizes, some cod exhibited light delC values. This would be expected if they had switched to feeding largely on herring, pollack, sand lance, or other chiefly zooplanktivorous fishes.



Summary of Fit

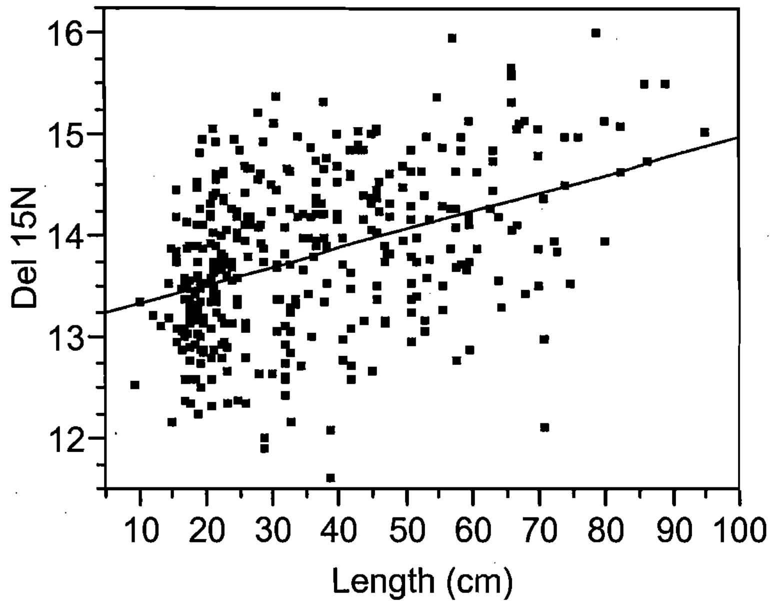
RSquare	0.524953
RSquare Adj	0.522393
Root Mean Square Error	0.645874
Mean of Response	-17.956
Observations (or Sum Wgts)	374

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	171.02279	85.5114	204.9881
Error	371	154.76379	0.4172	**Prob > F**
C. Total	373	325.78658		**<.0001**

Analysis of Del N vs Length

Cod exhibited a size/age-dependent enrichment in heavy nitrogen as they grow larger, but with a great deal of scatter about the common line indicating substantial variation due to factors other than size. We removed the effect of size to explore factors bearing on the residual variance.



Summary of Fit

RSquare	0.169271
RSquare Adj	0.167038
Root Mean Square Error	0.718517
Mean of Response	13.81396
Observations (or Sum Wgts)	374

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	39.13273	39.1327	75.7994
Error	372	192.05142	0.5163	Prob > F
C. Total	373	231.18414		<.0001

With Cod Length normalized (analysis of residuals)

All habitats In & Out
Del C

ANOVA on delC residuals with removal of size revealed significant differences in mean delC among cod caught in different habitats. Cod of any given size caught on sand had lower delC values than those of similar size caught over boulder, gravel, or mixed sand/gravel seabottom.

Summary of Fit

Rsquare	0.033948
Adj Rsquare	0.025942
Root Mean Square Error	0.639086
Mean of Response	-0.0007
Observations (or Sum Wgts)	366

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	**Prob > F**
Habitat	3	5.19560	1.73187	4.2403	**0.0058**
Error	362	147.85193	0.40843		
C. Total	365	153.04753			

Each pair t-test

Level	- Level	p-Value
boulder	sand	**0.0021893**
sand/gravel	sand	**0.0071780**
boulder	gravel	**0.0325075**
sand/gravel	gravel	0.1092921
gravel	sand	0.0865119
boulder	sand/gravel	0.5112546

Del N

DelN15 also differed significantly among cod of any given size caught over different bottom types. The most obvious component of this pattern was that cod in boulders exhibited higher delN than in any other habitat.

Summary of Fit

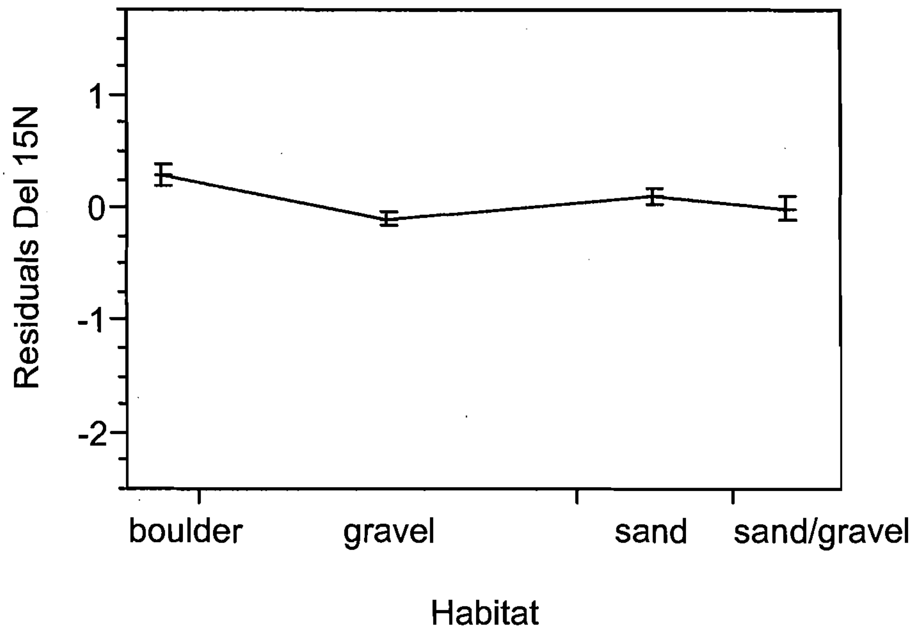
Rsquare	0.032627
Adj Rsquare	0.02461
Root Mean Square Error	0.707846
Mean of Response	0.001724
Observations (or Sum Wgts)	366

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	**Prob > F**
Habitat	3	6.11738	2.03913	4.0697	**0.0073**
Error	362	181.37868	0.50105		
C. Total	365	187.49607			

Each pair t-test

Level	- Level	p-Value
boulder	gravel	**0.0021696**
boulder	sand/gravel	**0.0497182**
sand	gravel	**0.0242233**
boulder	sand	0.2034709
sand	sand/gravel	0.3457898
sand/gravel	gravel	0.3762365



IN VS OUT

There was a strong effect attributable to the WGOMC, and the suggestion of an interaction between habitat and WGOMC effects.

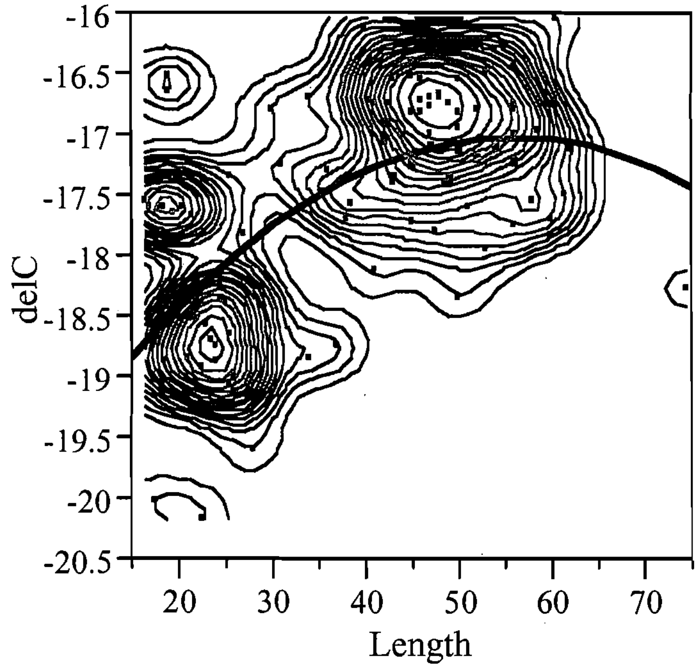
Habitat	N	P Values WGOMC In/Out	Season	Pattern
Sand	**80**	**ns**	**.0001*****	**2005 > 2004**
Sand/Gravel	**52**	**ns**	**.0031****	**2005 > 2004**
Gravel	**195**	**.0263 ***	**.0001*****	**higher INSIDE (2005>2004)**
Boulder	**36**	**.0114 ***	**ns**	**higher INSIDE**

The general impression was that there was a strong hard-bottom WGOMC in/out effect, plus a year effect reflecting higher fish densities and biomass on soft bottoms during the spring 2005 sampling than during the two 2004 periods.

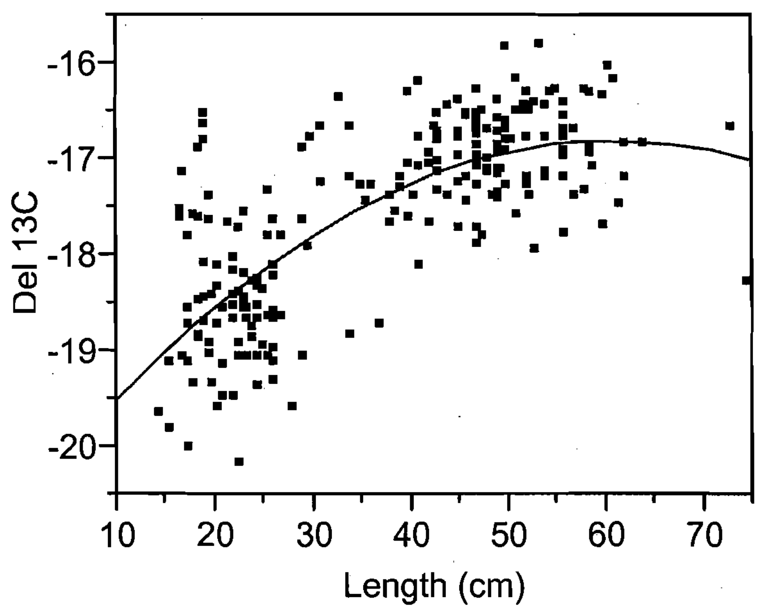
2. Haddock

Del C vs length

As indicated in the density topography of the data in the first graph below, our haddock catches were bimodally distributed toward the small and large end of the size spectrum.



However, the range in sizes was sufficiently filled out to examine length-dependent relationships in stable isotope signatures. The relationship between length and delC was curvilinear, roughly as in cod, with a light signature in the smallest haddock, becoming heavier quickly with size and leveling out among larger individuals.



Summary of Fit

RSquare	0.54659
RSquare Adj	0.542411
Root Mean Square Error	0.655623
Mean of Response	-17.587
Observations (or Sum Wgts)	220

Analysis of Variance

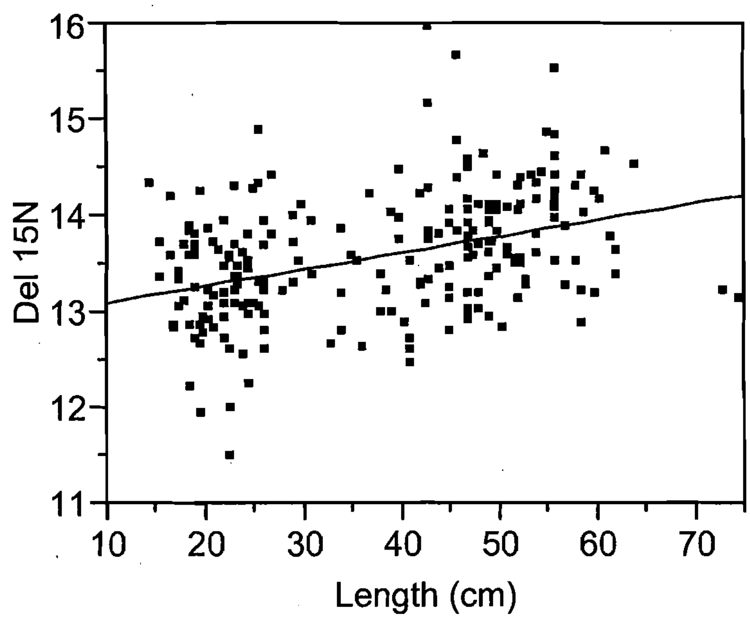
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	112.44467	56.2223	130.7977
Error	217	93.27571	0.4298	Prob > F
C. Total	219	205.72038		<.0001

Haddock Length Normalized

Once the effects of size were removed, there was no detectable difference in delC of haddock across habitats.

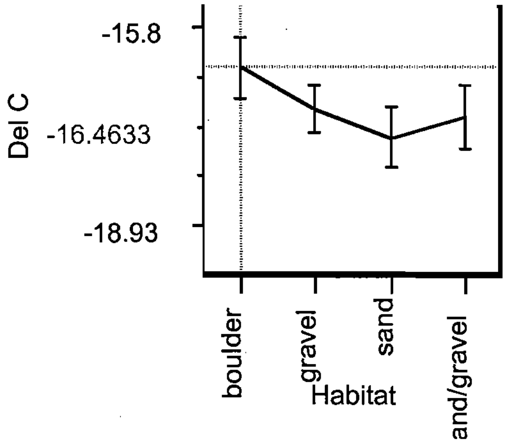
Del N vs length

DelN increased linearly with length in haddock, as in cod, but the amount of increase is smaller than that seen in cod.



Habitat-Dependent Feeding Behavior From DelC

On boulders, haddock tissues were enriched in heavy carbon (high delC13), indicating that they fed more on prey that eat benthos. On other habitats the delC13 values for haddock of any given size were lower (lighter), indicating a forage base that was itself feeding on plankton.



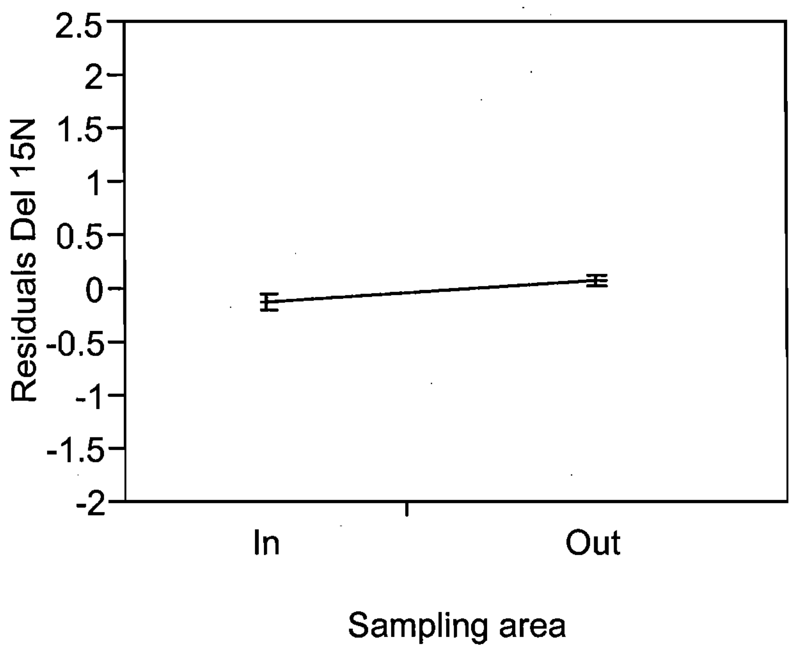
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Habitat	3	3	5.6394731	3.7796	0.0184

In vs Out

No management effect was detectable for delC; however, delN was significantly higher in haddock of any given size outside than inside the WGOMC.

Del C: ANOVA-Not significant p=0.8

Del N: ANOVA (significant)



Summary of Fit

Rsquare	0.025723
Adj Rsquare	0.021084
Root Mean Square Error	0.59919
Mean of Response	-0.00072

Observations (or Sum Wgts)	212

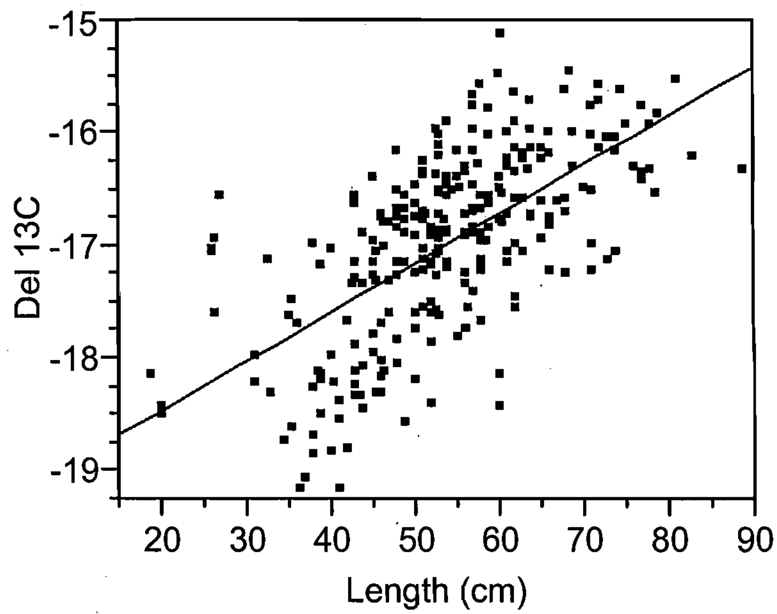
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
In & Out	1	1.990615	1.99061	5.5444	0.0195
Error	210	75.396081	0.35903		
C. Total	211	77.386696			

3. Eelpout

Del C vs length

Eelpout exhibited a strong linear relationship between size and delC, though with substantial scatter above and below the line. Interestingly, there was no relationship between size and delN. Following correction for size, there were no habitat effects. However, size-corrected values for both delC and delN in eelpout were markedly and significantly higher outside than inside the WGOMC.



Summary of Fit

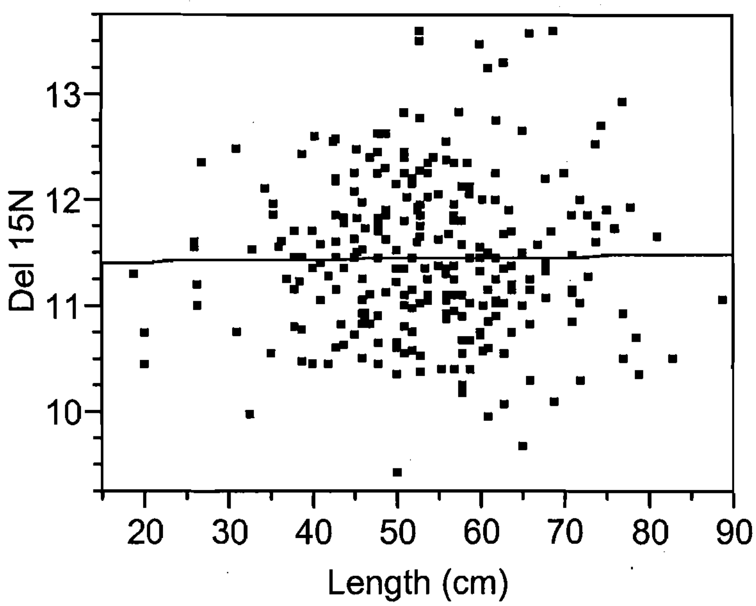
RSquare	0.409497
RSquare Adj	0.407243
Root Mean Square Error	0.627915
Mean of Response	-16.9858
Observations (or Sum Wgts)	264

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	71.63593	71.6359	181.6894
Error	262	103.30052	0.3943	Prob > F

Source	DF	Sum of Squares	Mean Square	F Ratio
C. Total	263	174.93645		<.0001

Del N vs length



Summary of Fit

RSquare	0.000254
RSquare Adj	-0.00356
Root Mean Square Error	0.741613
Mean of Response	11.45598
Observations (or Sum Wgts)	264

Analysis of Variance

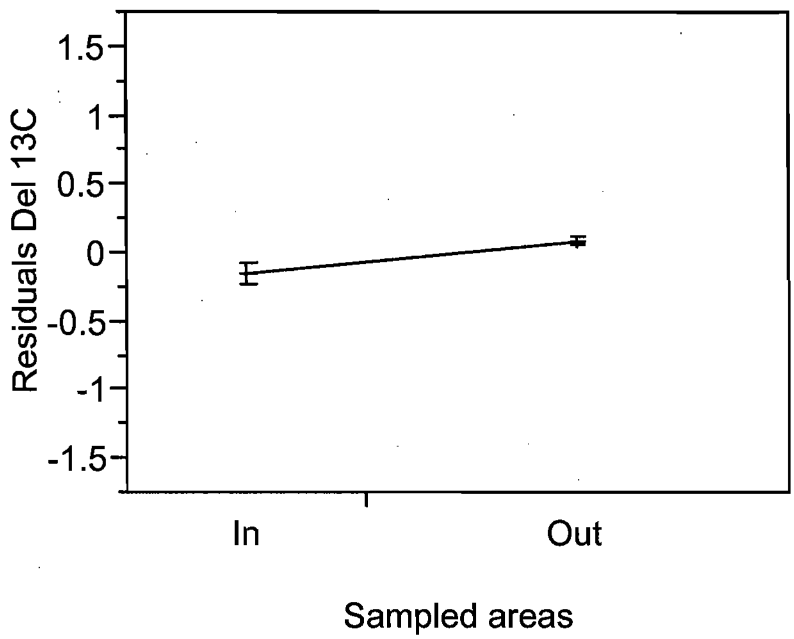
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.03662	0.036619	0.0666
Error	262	144.09752	0.549991	Prob > F
C. Total	263	144.13414		0.7966

Del N (All habitats) not significant p=0.3

Del C-Length Normalized (All habitats) Not significant p=0.12

In vs Out

Del C (length normalized): ANOVA: significantly different $p<0.004$ $n=263$

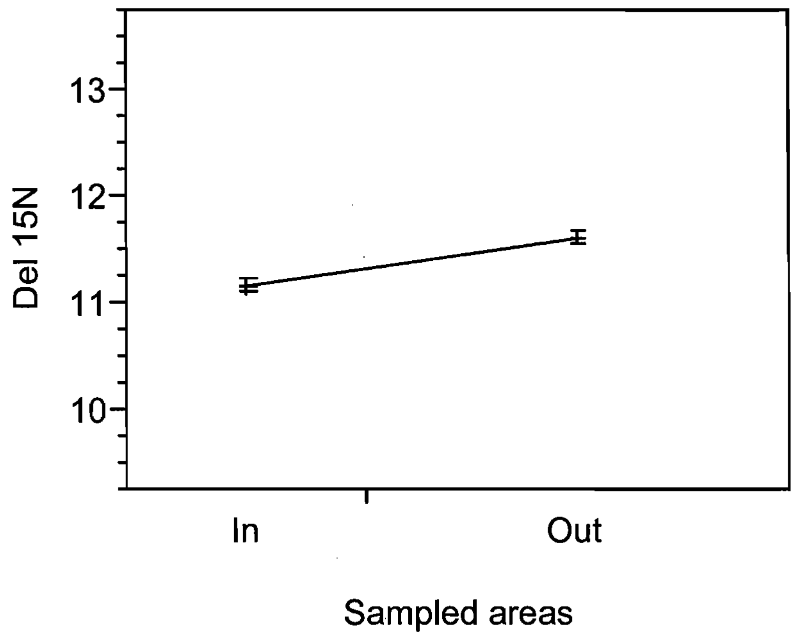


Summary of Fit

Rsquare	0.031269
Adj Rsquare	0.027557
Root Mean Square Error	0.619016
Mean of Response	0.000948
Observations (or Sum Wgts)	263

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
In & Out	1	3.22814	3.22814	8.4246	0.0040
Error	261	100.01004	0.38318		
C. Total	262	103.23818			

Del N: ANOVA: significantly different p<0.001 n=263



Summary of Fit

Rsquare	0.090489
Adj Rsquare	0.087004
Root Mean Square Error	0.706166
Mean of Response	11.45213
Observations (or Sum Wgts)	263

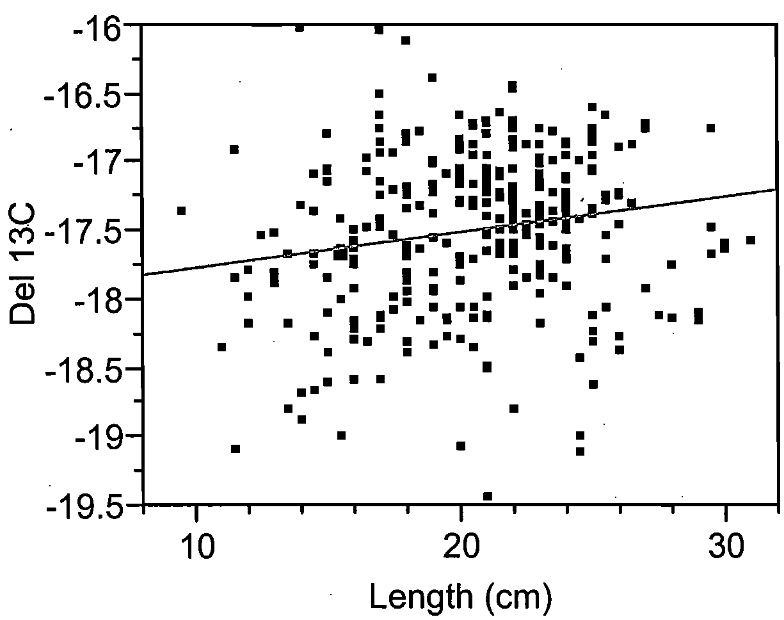
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
In & Out	1	12.94910	12.9491	25.9673	<.0001
Error	261	130.15290	0.4987		
C. Total	262	143.10201			

4. Longhorn

Longhorn sculpin exhibited a significant and approximately linear enrichment in both delC and delN with size, with substantial scatter.

Del C vs length



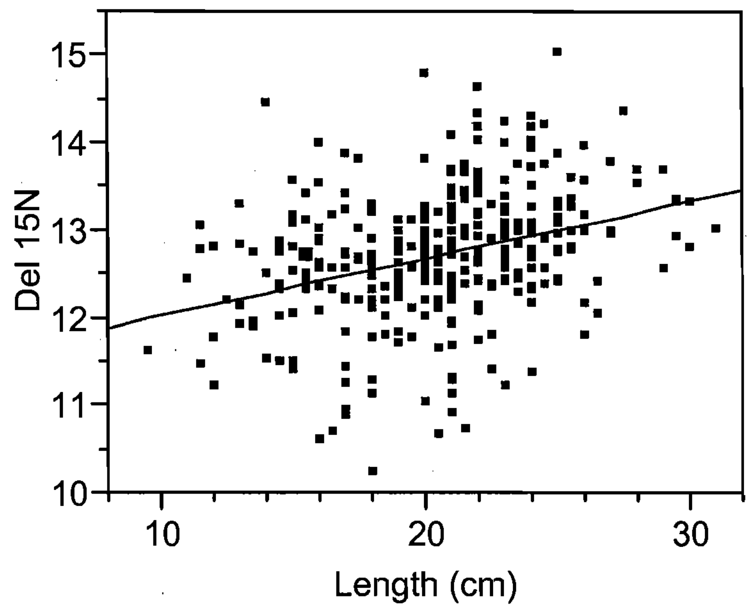
Summary of Fit

RSquare	0.032193
RSquare Adj	0.029187
Root Mean Square Error	0.56368
Mean of Response	-17.5002
Observations (or Sum Wgts)	324

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3.40322	3.40322	10.7109
Error	322	102.31056	0.31773	Prob > F
C. Total	323	105.71378		0.0012

Del N vs length



Summary of Fit

RSquare	0.116306
RSquare Adj	0.113561
Root Mean Square Error	0.720173
Mean of Response	12.71068
Observations (or Sum Wgts)	324

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	21.98005	21.9801	42.3794
Error	322	167.00520	0.5186	Prob > F
C. Total	323	188.98525		<.0001

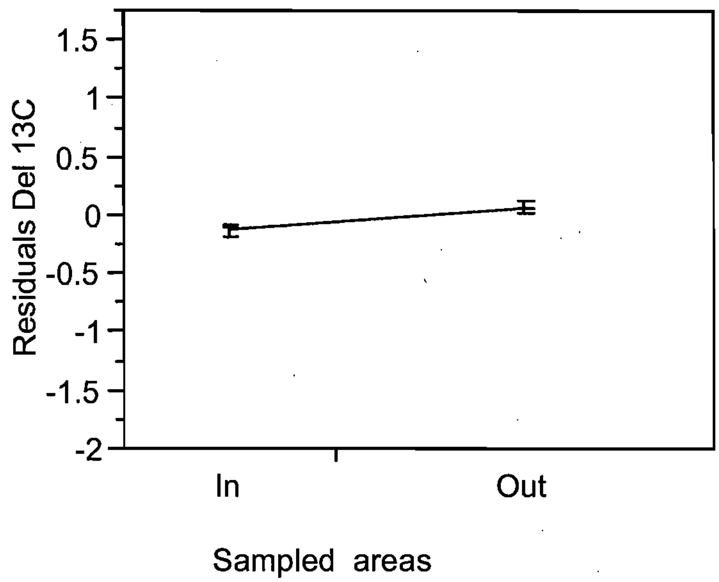
Longhorn (Length normalized)

Size-corrected values for delC and delN did not differ significantly across habitats. With the effects of size removed, longhorn sculpin delC was significantly higher outside than inside the WGOMC. delN in longhorn sculpin did not differ in any way attributable to a management (closure) effect.

All habitats (ANOVA) Not significant

Del C p=0.7
Del N p=0.7

In vs Out
Del C (Significantly different)



Summary of Fit

Rsquare	0.027333
Adj Rsquare	0.024215
Root Mean Square Error	0.561116
Mean of Response	0.002367
Observations (or Sum Wgts)	314

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
In & Out	1	2.76043	2.76043	8.7674	0.0033
Error	312	98.23340	0.31485		
C. Total	313	100.99383			

Del N (not significant) p=0.3

Rec'd 5/10/07

Habitat-Dependent Catch Composition and Food Web Dynamics in the Western Gulf of Maine Closure, Stellwagen Bank

INTERIM PROGRAM REPORT
and
FINAL PROJECT REPORT
NOAA Contract EA133F-03-CN-0050

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Co-Principal Investigators:
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Paul Vitale, Captain, Gloucester commercial fishing vessel "Angela and Rose"
Jason Link, Senior Scientist, Northeast Fisheries Science Center

Senior Research Associates:
William Ojwang, Boston University and Kenya Marine and Fisheries Research Institute (KMFRI)
Briana Brown , Boston University
Jean-Francois Bertrand, Boston University

1. PROJECT SUMMARY

We have launched a research program to investigate the effects of trawling versus trawling exclusion on groundfish assemblages, using the Western Gulf of Maine Closed Area (WGOMCA) as an opportunistic experimental system. Our focus is on the ways that exploited groundfish species function in the food web and how this might be influenced by trawling exclusion. In this first phase of the program, 87 experimental trawls were conducted during three sampling periods, stratified inside versus outside the WGOMCA, and among three benthic habitats: sand, gravel, and mixed sand and gravel. The contents of each trawl were enumerated, resulting in data matrices for catch composition by numbers and weight, weights of livers and ripening ovaries for a subset of the sample, and length-frequency data. Up to five individuals spanning the full size range for each species caught in each tow were sampled for stable isotope analysis, and archival DNA samples were taken from a subset of cod and haddock. The stomachs of these five individuals were also removed for stomach contents analysis on a subset of the samples. Reference isotope samples were taken from invertebrates and algae caught opportunistically in the trawls. In addition, a small sample of cod was jigged from boulder habitats, and two exploratory trawls were made on deep mud, to initiate study of fishes on these bottom types. Follow-on grants are enabling us to continue the work in the deep mud habitat (sampled spring-summer 2006), with work planned for boulder habitat during the 2007 field season with funding from the Pew Institute for Ocean Science.

Analysis-of-Variance (ANOVA) and multivariate analyses were applied to the resulting data to test the hypotheses that inside (as compared to outside) the Western Gulf of Maine Closure fishes were: (1) more numerous, (2) higher in biomass, (3) more diverse, (4) skewed toward larger size classes, (5) longer in food chain length and that (6) any given species or size class was higher in the food web than in comparable habitat outside of the closure. The confounding effects of fish size and habitat were examined, and then extracted statistically as necessary to permit assessment of differences attributable specifically to area management.

Sampling has been completed for this phase of the program, but stomach contents and data analyses are still in progress. In this report, we review the results principally from hypotheses 2, 5 and 6, summed over sampling periods. We found marked, species-specific patterns associated with each of the cardinal variables: habitat, sampling period, and most importantly, area management. Stable isotopic signatures revealed spatial and temporal patterns of variation in the food web, and fishes' position in it. The presence of significant differences in isotopic signature for fishes of the same size and species over such small geographical distances means that abundant species exhibit appreciable site fidelity, remaining within a small area at least long enough for management area effects to appear. Stable isotope analysis has the potential to provide replicable, relevant and useful information in future ecosystem-based management decisions in the Gulf of Maine.

2. PROJECT GOALS AND OBJECTIVES

This project's genesis emerged from observations by fishermen that suggested strong local effects in the distribution, abundance, and behavior of groundfishes in the Stellwagen Bank area. For example, Captain Paul Vitale (our coworker) has observed high densities of skates and/or dogfish in rotating closures immediately following their reopening to fishing. This raises concern about the possibility for area management to alter or be influenced by fish behavior in ways that might run counter to intended conservation outcomes. Indeed, in order for area management to work at all there must be some response to limited area closures despite the high mobility that many fishes are capable of exhibiting. The bottom line is that we need the means to monitor the ecology of areas of seabottom subject to different management regimes, and to know and understand the full suite of ecological effects attributable to these regimes. Without this capability, the effects and efficacy of area management will remain obscure, and neither adaptive management nor ecosystem-based management will be possible.

Despite the oft-noted fact that "fish have tails" and are willing to use them, there is already substantial evidence that large commercial groundfishes in the Gulf of Maine do not simply roam around homogeneously across the region…nor do they always roam very far. Evidence is mounting for stock substructure within the Gulf region. Tagging studies suggest strongly that some portion of the cod population, for example, is highly sedentary (Robichaud and Rose 2004, Lindholm and Auster 2005). Studies of food webs and individual fish feeding habitats offer the potential to appreciate local area effects without actually tracking individual fishes, and so we launched the current study to assess the utility of this approach. In particular we wished to assess the possible advantages of using stable isotope analysis to measure both individual behavior and overall food web dynamics.

We compared catch composition and aspects of the trophobiology (feeding biology) of groundfishes between areas closed versus open to trawling on Stellwagen Bank, inside and outside of the Western Gulf of Maine Closure. ANOVA and multivariate analyses were applied to the resulting data to test the hypotheses that fishes inside versus outside the Western Gulf of Maine Closure were: (1) more numerous, (2) higher in biomass, (3) more diverse, (4) skewed toward larger size classes, (5) longer in food chain length and that (6) any given species or size class was higher in the food web than in comparable habitat outside of the closure. The confounding effects of fish size and habitat were extracted, examined, and removed statistically to permit assessment of differences attributable specifically to area management. Sampling has been completed for this phase of the program, but stomach contents and data analyses are still in progress. In this report, we review the results from hypotheses 2, 5 and 6, summed over sampling periods.

Hypothesis 6 merits explanation. Typically, all mature members of a species of fish are regarded as occupying the same trophic level. In fact, fishes can exhibit great dietary plasticity both among and within individuals, and among habitats and seasons. We postulated that size-matched individuals of the same species will feed differently inside than outside the closure. It is for this hypothesis that we had the greatest statistical power.

At the outset of this study, we also wished to examine the behavior of skates and dogfish around rotating closures, to test Mr. Paul Vitale's hypothesis that when the rotating closure is lifted, these predators swarm in and quickly devour spawn and young of year. The review committee for the grant requested that we drop that objective due to the grant being too ambitious, and so we did. In the course of our sampling, however, we experienced large catches of spurdog (*Squalius acanthius*) on Stellwagen, particularly within the WGOMCA during the fall sampling period of 2004. A seasonal high density of dogfish in the WGOMCA has the potential to impact groundfishes. This is especially so given that dogfish are currently under a strong conservation advisory due to regionally low population levels in a recent FMP assessment.

This study was conducted aboard the fishing vessel "Angela and Rose" out of Gloucester, under the hand of Captain Paul Vitale, and with assistance from his father, Mr. Leo Vitale. Dr. Les Kaufman was project PI and was aboardship for several of the sampling days. Dr. Jason Link of the Northeast Fishery Science Center is a co-investigator, but did not attend sampling missions. Boston University Graduate Student Ms. Elizabeth Soule served as Chief Scientist on most day trips, with assistance from BU grad students Mr. J.F. Betrand, Mr. William Ojwang (now with Kenya Marine and Fisheries Research Institute), and Ms. Briana Brown. Additional assistance on sampling missions was provided by staff of the New England Aquarium, the National Marine Fisheries Service, and the Conservation Law Foundation (Dr. John Crawford of CLF was aboard in his capacity as an Adjunct Professor of Biology at Boston University). Approximately two dozen BU undergraduate students also lent an invaluable hand in all aspects of the work, from sampling at sea to sample processing and analysis. Stable isotope samples were run in the BU Stable Isotope Laboratory under the direction of Dr. Robert Michener.

All aspects of this work were coordinated with the assistance of the Massachusetts Fishermen's Partnership, with whom this was a collaborative project. Mr. David Bergeron served as MFP liaison and grant officer, and Ms. Olivia Free as project coordinator.

3. METHODS

A. Summary of Tows

87 tows were made, distributed among sand, gravel, and mixed sand-gravel bottoms, including also two exploratory tows in deep mud. The original intent was that these would be randomly stratified among habitats inside and outside of the WGOMCA. In practice, though, the area available for sampling is severely constrained by known hangs (known to the fishermen and carefully recorded over lifetimes in precious, richly annotated charts), and by non-mobile gear such as lobster traps that are freely deployed in the WGOMCA. It is probably best to regard the random stratified design as an intent, and the realized sampling design as a necessary but not exactly random compromise.

B. Catch Composition and Tissue Sampling

The contents of each tow were released on deck, sorted by species, and the number and weights of the catch of each species were recorded. Subsets of 25-50 individuals of each of the most numerous species were then measured for length-frequency analysis. Up to five individuals of each species, representing the full size range represented in that tow, were retained for further analysis. Small blocks of tissue were removed from the left epaxial musculature for stable isotope analysis. For some cod and haddock, a second sample was placed in 95% ethanol to be archived for genetic studies in other projects, as were some otoliths. The entire alimentary canal was removed and preserved. Preservation of the guts and their contents varied during the project due to shipboard space and safety constraints. Early on they were frozen, then brought to the lab and maintained at -20° C until thawed for analysis. During the second and third sampling periods guts were bagged, labeled, held at 4° C and then returned to the lab for fixation in Formalternate until analysis. Neither of these methods was as satisfactory as the traditional protocol of placing the guts immediately in formalin aboardship, including injection of larger guts with 10% formalin. However, our methods sufficed for our purposes, increased safety, and conserved space during sampling.

C. Stable Isotope Analyses

All organic samples (fish muscles and plants) were kept fresh in the field using ice in a cooler box and subsequently frozen and maintained at -20°C until prepared for stable isotope analysis. All the frozen samples were dried in the oven at 60° C for 48 hours. The dried material was then ground into fine powder by hand using a mortar and pestle. The mortar and pestle were rinsed clean and dried in between samples to avoid contamination. Organic samples were weighed, approximately 1mg and 2mg of animals and plants respectively and analyzed using an automated continuous-flow isotope mass spectrometry (Preston & Owens, 1983). The combustion gases (N_2 and CO_2) were separated on a GC column, passed through a reference gas box and introduced into the GV Instruments IsoPrime isotope ration mass spectrometer; water was removed using a magnesium perchlorate water trap. Ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ were expressed as the relative per mil (‰) difference between the samples and international standards (NBS 20 Solenhofen Limestone and N_2 in air) where:

$$\square X = (\{R_{sample} / R_{standard}\} - 1) \times 1000 \ (‰)$$
$$\text{and } X = {}^{13}C \text{ or } {}^{15}N; \ R = {}^{13}C/{}^{12}C \text{ or } {}^{15}N/{}^{14}N$$

The sample isotope ratio is compared to a secondary gas standard, whose isotope ratio was calibrated to international standards. For $^{13}C_{V\text{-}PDB}$ the gas was calibrated against NBS 20 (Solenhofen Limestone). $^{15}N_{air}$ the gas was calibrated against atmospheric N_2 and IAEA standards N-1, N-2, and N-3 (all are ammonium sulfate standards). All international standards were obtained from the National Bureau of Standards in Gaithersburg, MD. In addition to carbon and nitrogen isotopes from the same sample, continuous flow also reported %C and %N data.

4. RESULTS AND THEIR INTERPRETATION

A. Catch Composition

Catch composition may be analyzed in two ways: by weight, and by numbers of individuals. Here we present exemplars of key analyses from both perspectives.

ANOVA was used to screen for significant patterns related to in/out, habitat, and sample period effects for each species, and for the derived quantities "total cods", "total flatfishes", "total skates" and "total biomass". The two mud and one boulder trawl shots excluded so as to compare only sand, mixed sand-gravel, and gravel habitats. Table ____ indicates those cases in which the null hypotheses of samples drawn from populations with the same mean, was rejected at $p<.05$. The reader is cautioned that in this analysis, a Bonferoni correction for multiple tests was not applied due to the high rate of false negatives that it generates when many separate tests are being conducted. Thus the results should be regarded as robust for revealing marked patterns, but not for assigning exact probabilities.

In the table below, one star represents significance at the level of $p < .05$, for two stars $p < .01$, and for three $P < .001$; near-significant levels are indicated by a number greater than but close to .05.

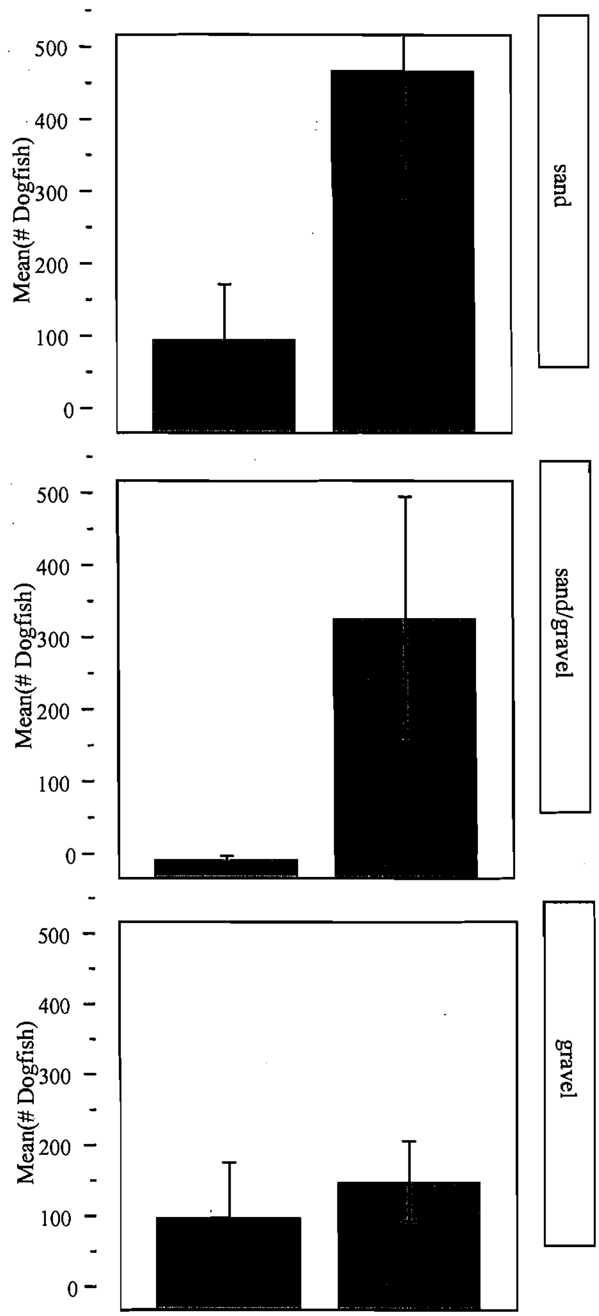
These results point strongly to the existence of significant In/Out and Period effects, and suggest that habitat was not a significant factor in biomass variation among the samples. They also offer a basic description of the major patterns in species distribution and abundance in versus out of the Closure, and across habitats and sampling periods. This is probably a fair indication of where to look for main effects in the data. Furthermore, 24 out of the 102 cells were significant at least the .05 level, a rate nearly five times higher than would be expected by chance. However, it could be argued that the assumptions of species independence and lack of interactions are unreasonable. If so, then the data must be analyzed of a piece to obtain a conservative and correct test of the main hypothesis that fish biomass was greater inside than outside the closure, in all habitats, at all times. Before proceeding, however, it is worth becoming familiar with the basic patterns in the data as revealed in a descriptive sense by the species-by-species analysis.

The following species were present at higher biomass INSIDE the Closure, at levels that were statistically significant or nearly so: dogfish, haddock, witch (grey sole), red hake.

The following species were present at higher biomass OUTSIDE the Closure, at levels that were statistically significant ($p<.05$) or nearly so: longhorn sculpin, yellowtail flounder, sea raven, winter flounder, windowpane flounder.

Species	**In/Out**	**Habitat**	**Period**	**Pattern**

Cod	ns	Ns	***	many caught May 2004
Haddock	.06	Ns	ns	*Possibly* more inside Closure
Longhorn Sculpin	***	Ns	**	more outside Closure
Eelpout	ns	Ns	.06	Low fall, high spring
Yellowtail Flounder	**	Ns	*	More outside Closure
Winter Flounder	*	Ns	ns	More outside closure
Sea Raven	**	Ns	*	More outside, high 2005
Pollack	ns	Ns	ns	
Goosefish	ns	Ns	***	Most fall 2004
Dab	ns	Ns	ns	
Windowpane	ns	Ns	ns	
Herring	ns	Ns	ns	
Wolffish	ns	Ns	ns	
Thorny Skate	ns	*	*	Mostly gravel, mostly May 2004
Winter Skate	ns	Ns	ns	
Smooth Skate	ns	*	*	Mostly gravel, mostly May 2004
Silver Hake	ns	Ns	ns	
Red Hake	**	Ns	ns	Mostly inside Closure
Fourspot Flounder	ns	Ns	.06	Mostly May 2004
Witch Flounder	*	Ns	**	
Dogfish	**	.07	***	More inside, most fall 2004
Other Skate	*	Ns	*	Mostly inside, May 2004
All Flatfishes	***	Ns	*	Mostly outside, April 2005
All Skates	ns	Ns	ns	
All Cod Family	*	Ns	**	Mostly inside, Fall 2004
Total Biomass	*	.06	***	Mostly inside, Fall 2004, sand (dogfish effect)
Alligatorfish	na	Na	na	
Little Skate	ns	Ns	ns	
Redfish	na	Na	na	
Cunner	ns	Ns	ns	
Halibut	ns	Ns	ns	
Lumpfish	ns	Ns	ns	
Butterfish	ns	Ns	ns	
Summer Flounder	ns	Ns	ns	



One thing that is immediately apparent in the data is that there is an overwhelming pattern driven by the occurrence of large catches of dogfish, particularly inside the WGOMCA. Dogfish were very abundant only during fall 2004, and then, were much more abundant inside than outside the Closure. There was a trend for there to be more dogfish inside than outside the closure in all three habitats, but the pattern was forced mostly by dogfish distribution on sand and mixed bottoms.

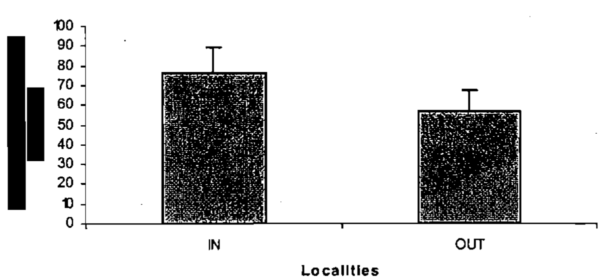
The correlation between total biomass in the samples and dogfish biomass is about 0.998. The catch data support fishermen's observations using normal commercial gear, that dogfish are concentrated on Stellwagen Bank and aggregate there during the late summer and fall, particularly within the Western Gulf of Maine Closed Area.

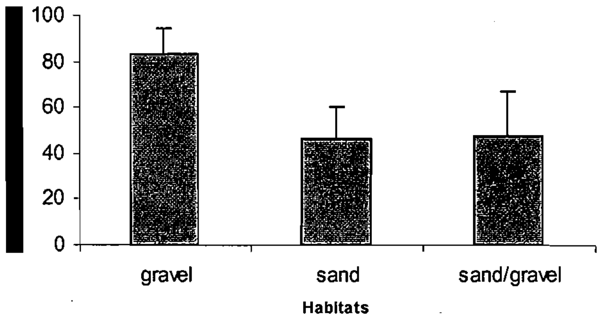
The pattern of dogfish catches is real and interesting, but it is so extreme that it obscures other patterns in the data when they are examined in a multivariate context. To unmask these other patterns in a conservative manner, a factor analysis was performed on the multispecies data (both numbers and biomass for each species in each sample) with dogfish excluded from this particular analysis. Two significant factors were extracted: Factor 1 was related to WGOMC effects (ANOVA $p < .001$ for in/out effect, ns for sampling period or interactions). Factor 2 was related to the interaction between in/out effects and sampling period (ANOVA $p < .005$). Factor 2 described a pattern in which the in/out effect for any particular species was strongest during the sampling period when that species was caught in greatest numbers.

In sum, there is a strong correlation between the Western Gulf of Maine Closed Area and fish catches, both for dogfish specifically, and for the community as a whole. The original hypothesis of higher biomass and fish numbers within the Closure across the board was rejected: some fish species were at higher biomass inside the Closure, others were at higher biomass outside the Closure, and many either showed no effect or could not be assessed with the limited numbers caught during this study.

1. Cod

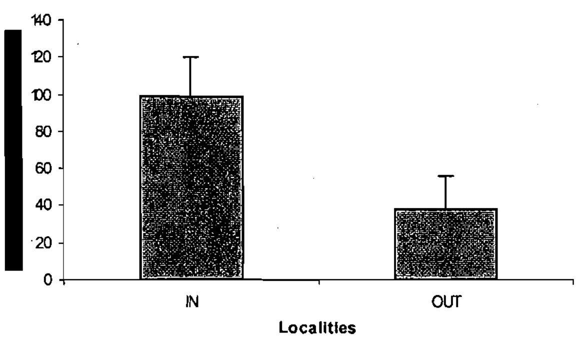
Cod biomass CPUE did not differ significantly inside vs. outside the WGOMC. Catch rates by habitat exhibited a borderline trend, with highest rates on gravel habitat. We suspect that the lack of statistical significance in this case may have been an artifact of high variance among samples, rather than the lack of a real pattern, but the study would have to be repeated over a much longer time period to explore this in a meaningful way (see discussion).

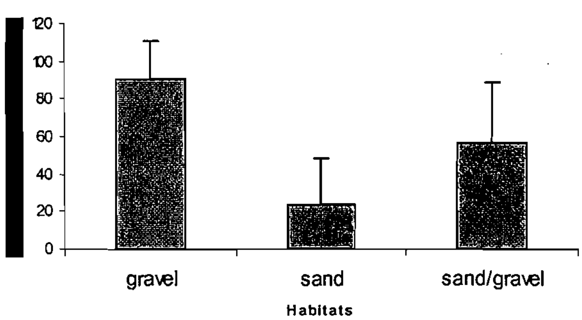




2. Haddock

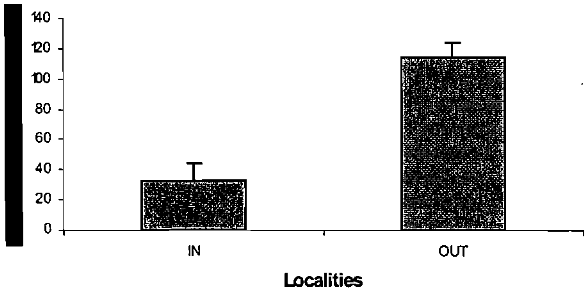
Taken across the three trawled habitat types, haddock were higher in biomass inside than outside the WGOMC, but this difference was not quite significant statistically (p=.06). Catch rates did not vary significantly across the habitats sand, gravel, and mixed sand and gravel. There is an apparent tendency for higher haddock catches to be associated with gravel or at least some admixture of gravel in the environment but greater statistical power would be required to assess this definitively.

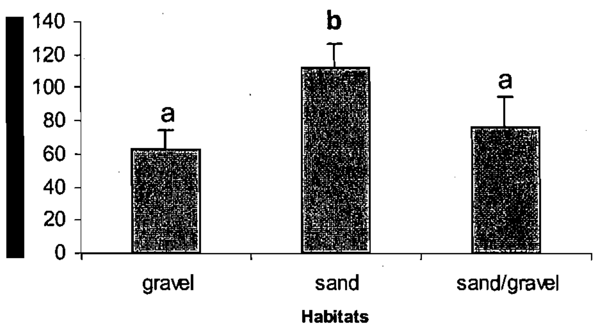




3. Longhorn

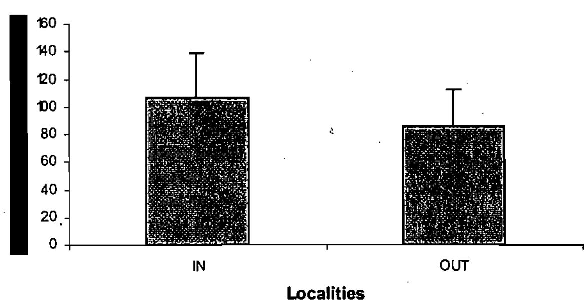
Longhorn sculpin catches were much higher outside than inside the closure ($p<<.001$). Longhorn were most abundant on sand, lower on mixed sand and gravel, and lowest on gravel, with the difference between gravel and sand statistically significant ($p=.034$).

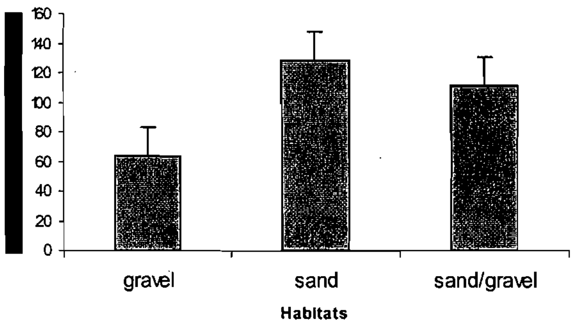




4. Eelpout
All habitats (in & out) NS p=0.61

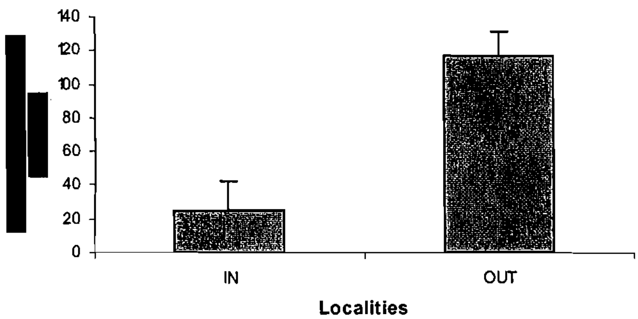
Catches per unit effort for eelpout were statistically indistinguishable inside versus outside the WOMGC, or across the three trawled habitats.

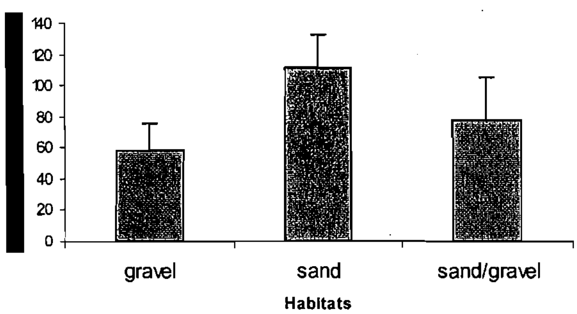




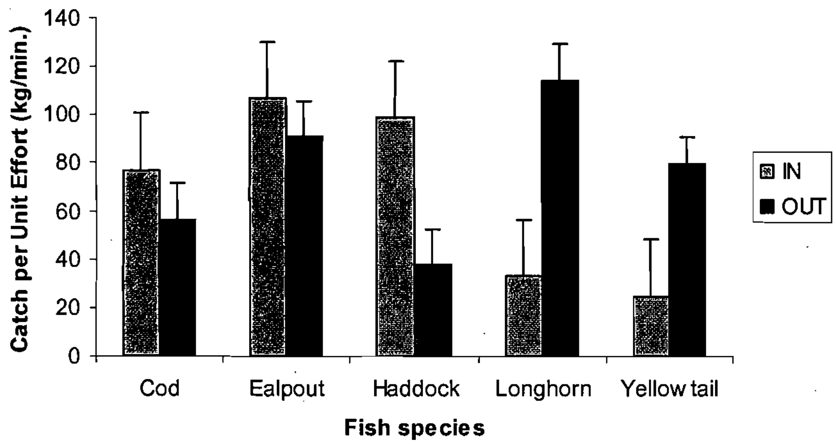
5. Yellowtail

Yellowtail flounder were much more abundant outside than inside the WGOMC. Though they appeared to be more strongly associated with sand than with gravel habitats, this trend was not significant.





Biomass of All the five fish species (IN & OUT)



B. Preliminary Analysis of Stable Istotopic Values for Cod, Haddock, Eelpout and Longhorn Sculpin.

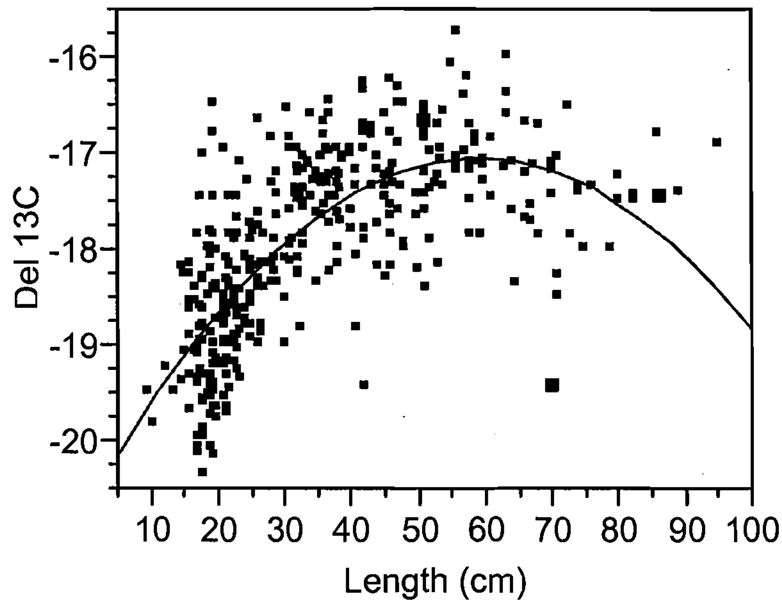
Hypotheses 4 and 5 are being tested in two ways- first, by using stomach contents analysis to determine instantaneous trophic level from the observed prey, and second, by testing for significant differences between stations (within species and size class) in the degree of enrichment by stable heavy nitrogen (delN^{15}) in the tissues of predatory fishes. Heavy nitrogen is enriched moving up the food chain, reflecting an average trophic level exhibited by an organism during the previous four to six weeks (the time required for tissue turnover).

In each case, we first tested the hypothesis that isotopic enrichment (delC and delN) increased with fish size. If the null was rejected, subsequent analyses (to test for habitat and management area effects) were conducted on the residuals after the effects of length were removed.

1. Cod

Del C vs length

The relationship between fish length and delC13 in Cod was strongly curvilinear. This suggests that young cod, up to ca. 30cm in length, fed principally on prey whose tissues were dominated by the light isotope of stable carbon, C12. In the environment where we were working, this is probably indicative of feeding on prey closely tied to the pelagic food chain phytoplankton as primary producers. Larger specimens exhibited higher enrichment by C13, and hence higher delC values, most likely reflecting an ontogenetic switch from midwater to benthic prey. At very large sizes, some cod exhibited light delC values. This would be expected if they had switched to feeding largely on herring, pollack, sand lance, or other chiefly zooplanktivorous fishes.



Summary of Fit

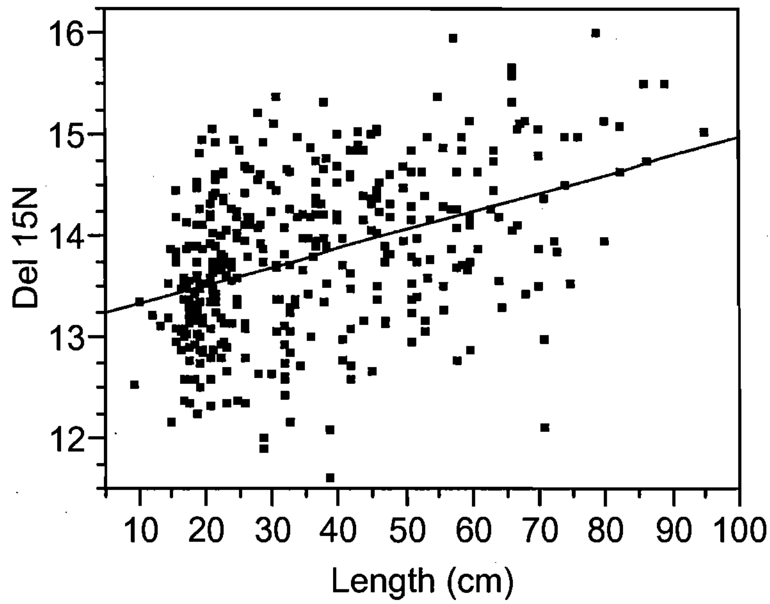
RSquare	0.524953
RSquare Adj	0.522393
Root Mean Square Error	0.645874
Mean of Response	-17.956
Observations (or Sum Wgts)	374

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	171.02279	85.5114	204.9881
Error	371	154.76379	0.4172	**Prob > F**
C. Total	373	325.78658		**<.0001**

Analysis of Del N vs Length

Cod exhibited a size/age-dependent enrichment in heavy nitrogen as they grow larger, but with a great deal of scatter about the common line indicating substantial variation due to factors other than size. We removed the effect of size to explore factors bearing on the residual variance.



Summary of Fit

RSquare	0.169271
RSquare Adj	0.167038
Root Mean Square Error	0.718517
Mean of Response	13.81396
Observations (or Sum Wgts)	374

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	39.13273	39.1327	75.7994
Error	372	192.05142	0.5163	Prob > F
C. Total	373	231.18414		<.0001

With Cod Length normalized (analysis of residuals)

All habitats In & Out
Del C

ANOVA on delC residuals with removal of size revealed significant differences in mean delC among cod caught in different habitats. Cod of any given size caught on sand had lower delC values than those of similar size caught over boulder, gravel, or mixed sand/gravel seabottom.

Summary of Fit

Rsquare	0.033948
Adj Rsquare	0.025942
Root Mean Square Error	0.639086
Mean of Response	-0.0007
Observations (or Sum Wgts)	366

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	**Prob > F**
Habitat	3	5.19560	1.73187	4.2403	**0.0058**
Error	362	147.85193	0.40843		
C. Total	365	153.04753			

Each pair t-test

Level	- Level	p-Value
boulder	sand	**0.0021893**
sand/gravel	sand	**0.0071780**
boulder	gravel	**0.0325075**
sand/gravel	gravel	0.1092921
gravel	sand	0.0865119
boulder	sand/gravel	0.5112546

Del N

DelN15 also differed significantly among cod of any given size caught over different bottom types. The most obvious component of this pattern was that cod in boulders exhibited higher delN than in any other habitat.

Summary of Fit

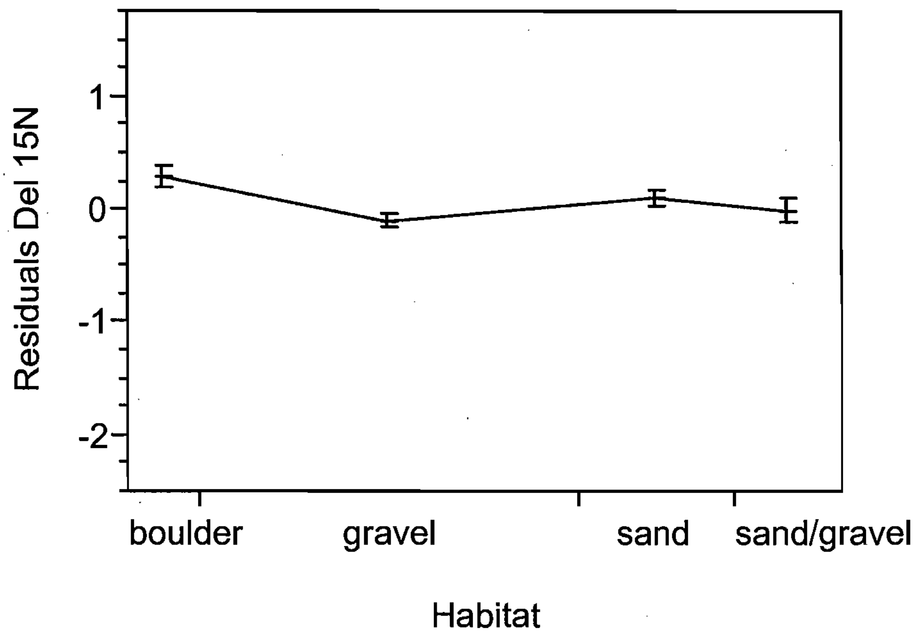
Rsquare	0.032627
Adj Rsquare	0.02461
Root Mean Square Error	0.707846
Mean of Response	0.001724
Observations (or Sum Wgts)	366

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	**Prob > F**
Habitat	3	6.11738	2.03913	4.0697	**0.0073**
Error	362	181.37868	0.50105		
C. Total	365	187.49607			

Each pair t-test

Level	- Level	p-Value
boulder	gravel	**0.0021696**
boulder	sand/gravel	**0.0497182**
sand	gravel	**0.0242233**
boulder	sand	0.2034709
sand	sand/gravel	0.3457898
sand/gravel	gravel	0.3762365



IN VS OUT

There was a strong effect attributable to the WGOMC, and the suggestion of an interaction between habitat and WGOMC effects.

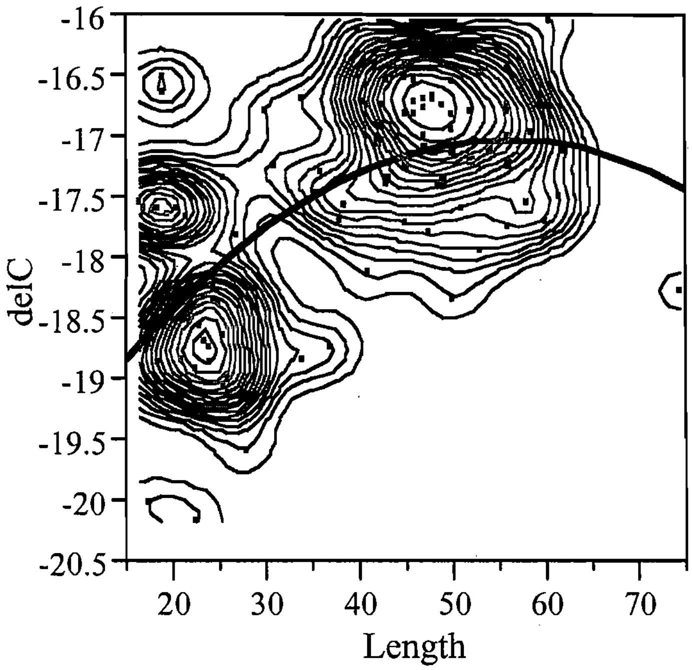
Habitat	N	P Values WGOMC In/Out	Season	Pattern
Sand	**80**	**ns**	**.0001*****	**2005 > 2004**
Sand/Gravel	**52**	**ns**	**.0031****	**2005 > 2004**
Gravel	**195**	**.0263 ***	**.0001*****	**higher INSIDE (2005>2004)**
Boulder	**36**	**.0114 ***	**ns**	**higher INSIDE**

The general impression was that there was a strong hard-bottom WGOMC in/out effect, plus a year effect reflecting higher fish densities and biomass on soft bottoms during the spring 2005 sampling than during the two 2004 periods.

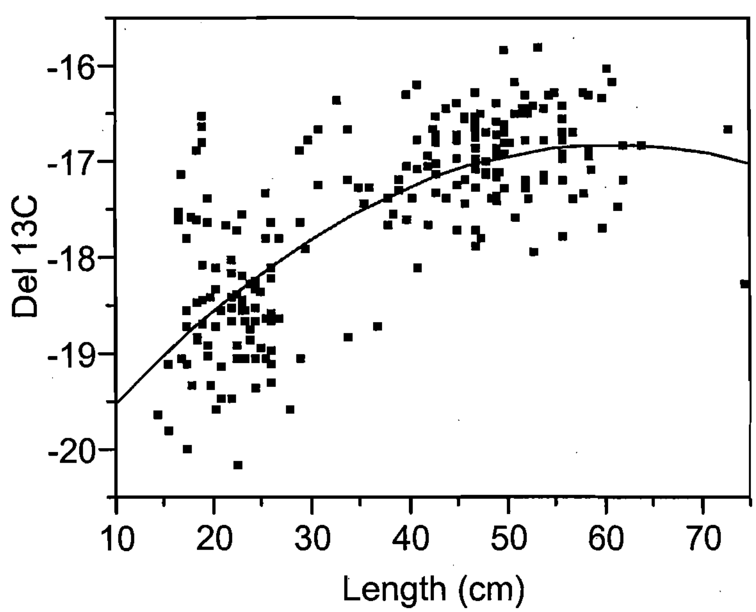
2. Haddock

Del C vs length

As indicated in the density topography of the data in the first graph below, our haddock catches were bimodally distributed toward the small and large end of the size spectrum.



However, the range in sizes was sufficiently filled out to examine length-dependent relationships in stable isotope signatures. The relationship between length and delC was curvilinear, roughly as in cod, with a light signature in the smallest haddock, becoming heavier quickly with size and leveling out among larger individuals.



Summary of Fit

RSquare	0.54659
RSquare Adj	0.542411
Root Mean Square Error	0.655623
Mean of Response	-17.587
Observations (or Sum Wgts)	220

Analysis of Variance

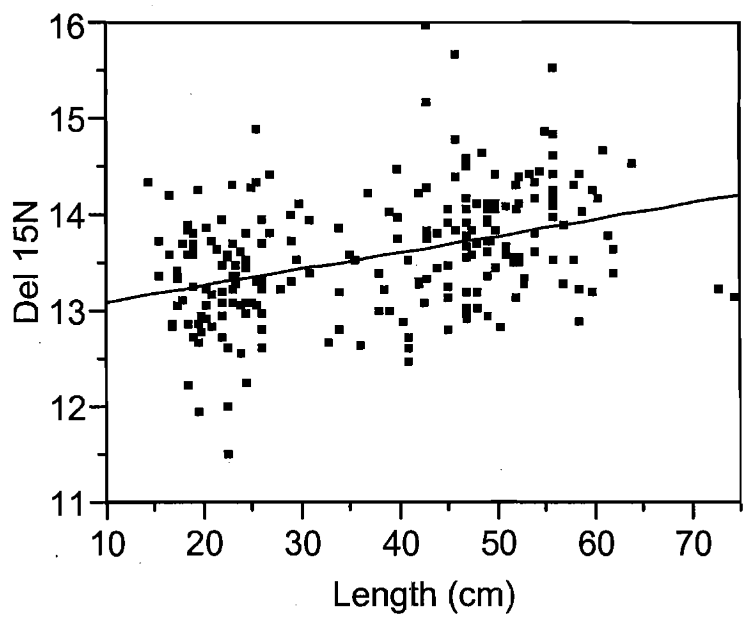
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	112.44467	56.2223	130.7977
Error	217	93.27571	0.4298	Prob > F
C. Total	219	205.72038		<.0001

Haddock Length Normalized

Once the effects of size were removed, there was no detectable difference in delC of haddock across habitats.

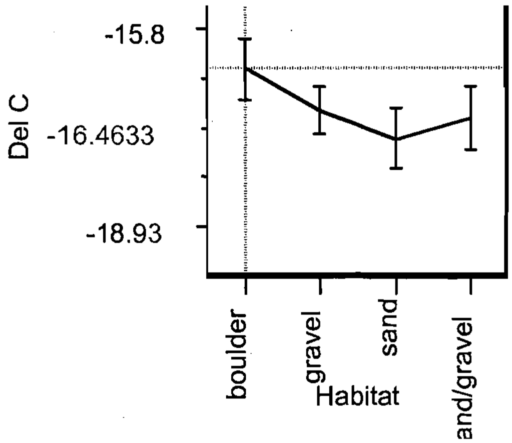
Del N vs length

DelN increased linearly with length in haddock, as in cod, but the amount of increase is smaller than that seen in cod.



Habitat-Dependent Feeding Behavior From DelC

On boulders, haddock tissues were enriched in heavy carbon (high delC13), indicating that they fed more on prey that eat benthos. On other habitats the delC13 values for haddock of any given size were lower (lighter), indicating a forage base that was itself feeding on plankton.



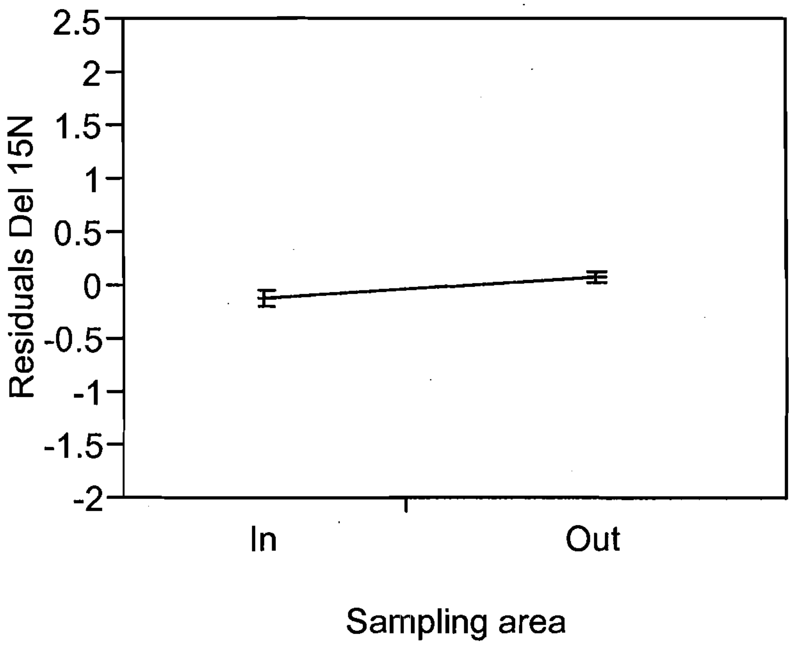
Source	Nparm	DF	Sum of Square s	F Ratio	Prob > F
Habitat	3	3	5.63 947 31	3.77 96	0.01 84

In vs Out

No management effect was detectable for delC; however, delN was significantly higher in haddock of any given size outside than inside the WGOMC.

Del C: ANOVA-Not significant p=0.8

Del N: ANOVA (significant)



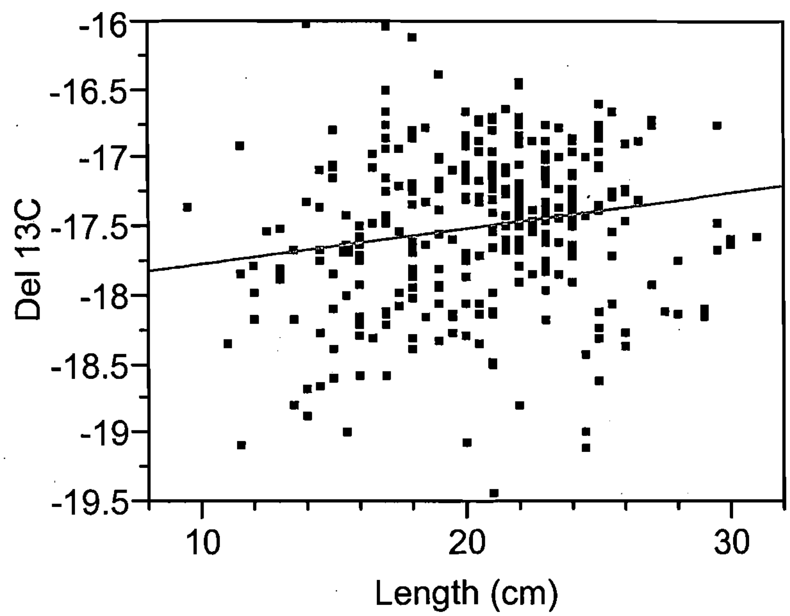
Summary of Fit

Rsquare	0.025723
Adj Rsquare	0.021084
Root Mean Square Error	0.59919
Mean of Response	-0.00072

4. Longhorn

Longhorn sculpin exhibited a significant and approximately linear enrichment in both delC and delN with size, with substantial scatter.

Del C vs length



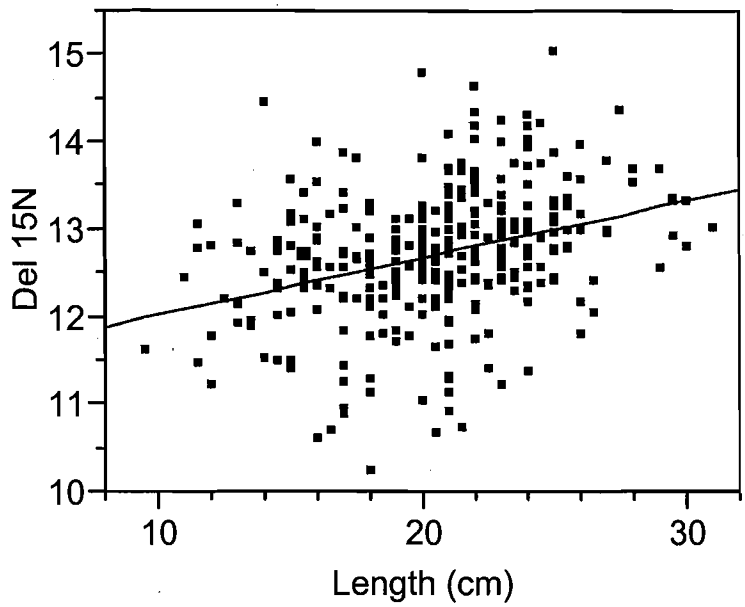
Summary of Fit

RSquare	0.032193
RSquare Adj	0.029187
Root Mean Square Error	0.56368
Mean of Response	-17.5002
Observations (or Sum Wgts)	324

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3.40322	3.40322	10.7109
Error	322	102.31056	0.31773	Prob > F
C. Total	323	105.71378		0.0012

Del N vs length



Summary of Fit

RSquare	0.116306
RSquare Adj	0.113561
Root Mean Square Error	0.720173
Mean of Response	12.71068
Observations (or Sum Wgts)	324

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	21.98005	21.9801	42.3794
Error	322	167.00520	0.5186	Prob > F
C. Total	323	188.98525		<.0001

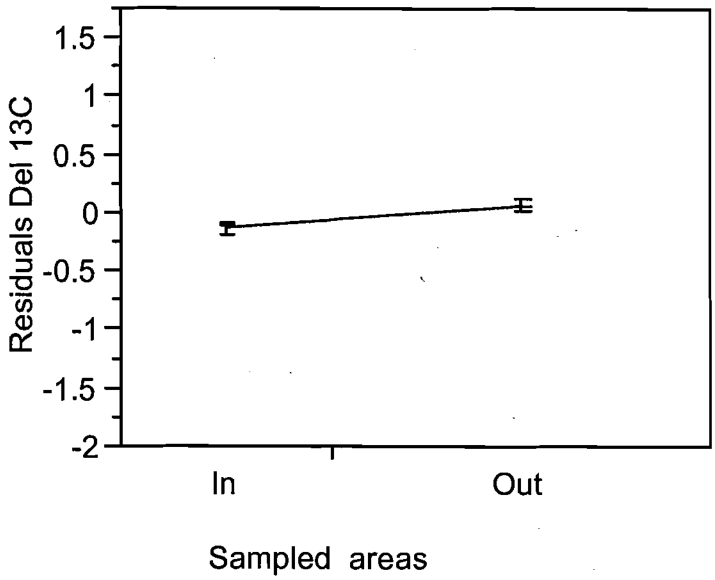
Longhorn (Length normalized)

Size-corrected values for delC and delN did not differ significantly across habitats. With the effects of size removed, longhorn sculpin delC was significantly higher outside than inside the WGOMC. delN in longhorn sculpin did not differ in any way attributable to a management (closure) effect.

All habitats (ANOVA) Not significant

Del C p=0.7
Del N p=0.7

In vs Out
Del C (Significantly different)



Summary of Fit

Rsquare	0.027333
Adj Rsquare	0.024215
Root Mean Square Error	0.561116
Mean of Response	0.002367
Observations (or Sum Wgts)	314

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
In & Out	1	2.76043	2.76043	8.7674	0.0033
Error	312	98.23340	0.31485		
C. Total	313	100.99383			

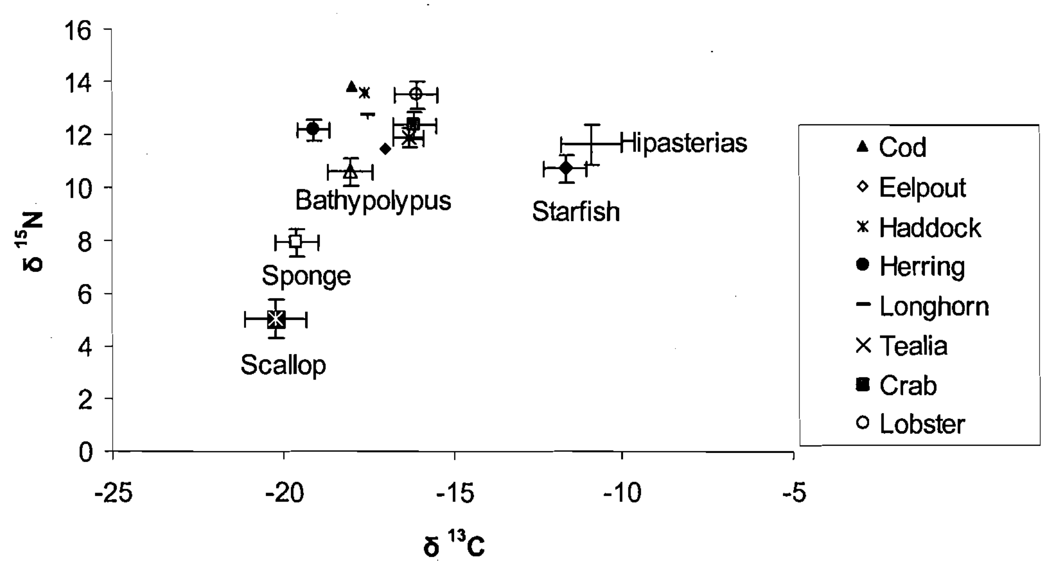
Del N (not significant) p=0.3

Overall Mean Values for Groundfishes and Reference Organisms on Stellwagen Bank

Mean values for several fish species and reference organisms are presented in Table 1.

Table 1. Mean stable carbon and nitrogen isotope signatures of specimens sampled from Stallwagen Bank

Organic samples	*n*	Mean $\delta^{13}C$	SE	Mean $\delta^{15}N$	SE	Size range (cm)
Cod	374	-17.956	0.04632	13.814	0.03803	9.5-95
Eelpout	264	-16.986	0.05513	11.456	0.04526	19-89
Haddock	220	-17.587	0.06039	13.5781	0.04958	14.5-74.5
Herring	4	-19.098	0.44789	12.1525	0.36771	15-22
Longhorn	133	-17.49	0.07767	12.6992	0.06377	11-30
Starfish	2	-11.67	0.63342	10.715	0.52001	
Hipasterias	1	-10.91	0.89579	11.61	0.73541	
Lobster	2	-16.065	0.63342	13.505	0.52001	
Tealia	4	-16.302	0.44789	11.89	0.36771	
CRAB	2	-16.13	0.63342	12.355	0.52001	
Bathypolypus	2	-18.02	0.63342	10.595	0.52001	
Scallop	1	-20.24	0.89579	5.03	0.73541	
Sponge	2	-19.595	0.63342	7.925	0.52001	



Scatter plot of δ^{13} C and δ ^{15}N stable isotope values (‰) of specimens from Stellwagen Bank

Several organisms depicted in this scatter plot were included as reference taxa, to mark the isotopic composition of important prey types or creatures of fixed trophic level. The sea scallop, for example, exhibited very light delN15 and delC15 ratios, in keeping with the expectation that it feeds on phytoplankton whose carbon comes largely from the atmosphere. The greater delN15 enrichment for sponge (Cliona) was interesting and we are not sure what to attribute this too, since the carbon is still very light; perhaps the sponge either feeds upon or otherwise derives carbon from heterotrophic bacteria. Other organisms listed above feed higher in the food web and draw from a variety of carbon sources. The value shown here for herring is perhaps the most interesting: the carbon is light as expected for a pelagic feeder, but the animals (full grown Atlantic herring) are surprisingly rich in heavy nitrogen. This suggests that they were feeding on large, predatory zooplankton or even fishes at the time these samples were taken. Atlantic herring might be particularly good sentinel species for the pelagic food web in the Gulf of Maine, especially since samples could be obtained on a regular basis from the herring fishery.

3. DISCUSSION

The goal of the WGOMC was to facilitate stock rebuilding for groundfishes by reducing fishing mortality, particularly for Atlantic cod. Though perhaps not explicit, it was probably also hoped that the closure would increase growth and survival, by safeguarding the integrity of juvenile habitat that provides refuge from predators, and by protecting benthic communities that provide forage to groundfishes young and old. In other words, the overall ecological integrity of the southern Gulf of Maine should be enhanced by conservation measures such as the Western Gulf of Maine Closure.

Fishery restrictions reduce income and reliability of a fishery in the short term in hopes of a long-term improvement. Since management restrictions exact a perceived sacrifice, it is expected that industry participants would demand accountability for the restrictions in terms of regular assessments of management efficacy, measured with a degree of scientific rigor sufficient that the community will accept and learn from the outcomes and adapt the next cycle of management measures accordingly. Given the dire condition of the Gulf of Maine fisheries, management measures such as the Western Gulf of Maine Closed Area have been put into effect without such accountability. However, even if the WGOMCA is regarded as an essential precautionary measure, it is still important to know if it works, as a guide to future decision making.

This project was an attempt to examine the effects of the WGOMCA using one conventional method (sampling by means of a trawl) and one unconventional one (stable isotope analysis). The WGOMCA was not designed as a good experiment. There is no designated control area, the experimental effect is at best partial (only mobile bottom-tending gear were excluded), the experiment was not replicated (there is only one WOMGCA), and there was no standing program by the National Marine Fisheries Service that could follow the outcome of the closure in addition to the NEFSC's other commitments. Despite these shortcomings, it seemed possible that we could at least test one very important hypothesis: spatial processes operate at a scale at which the WGOMC *could* work even though groundfishes are capable of swimming long distances. What we found supports this hypothesis. We discovered spatial patterns in abundance that could be attributable to the WGOMCA. More importantly, differences in stable isotopic composition inside versus outside the WGOMCA indicated that the closure influenced the ecology of the benthic communities in this region, and that fishes were resident in this relatively small area long enough to experience knock-on effects from the WGOMCA's distinctive ecology.

A. A note on trawling as a means of estimating WGOMC effects on fish abundance

Ours were not the first standardized trawls conducted inside and outside the Western Gulf of Maine Closed Area in a manner designed specifically to reveal differences in abundance or biomass. The National Marine Fisheries service conducted a study that consisted of paired trawls, just inside and just outside of the WGOMCA, one year following the institution of the closure. The data from those trawls were analyzed as one product of the current study, and comprised the Masters dissertation for Mr. Kevin Blinkoff (Blinkoff 2006, Boston University). Blinkoff worked with Jason Link to assess the abundance of groundfishes at 12 trawl shots, in the following design: In vs. Out of the WGMOCA, western (shallow) vs. east (deep) margins of the closed area, with three trawl shots in each of the four cells. All twelve trawls were in deeper water than that investigated here.

Blinkoff found that for NMFS survey trawls, catch variability was so high that it was very difficult to achieve statistical confidence that the more apparent patterns, visible on inspection, were real. Indeed, in order to statistically validate even very large and seemingly consistent differences in abundance (e.g., a 100% difference in cod abundance inside vs. outside the WGOMC) would require so many replicate samples that the sampling activity itself would constitute a major disturbance to the habitat in the closed area. For example, to have an eighty percent chance of validating this pattern statistically, it would have required that the study consist minimally of 32 trawl samples. 16 trawl samples within the WGOMC (plus 16 outside), repeated 2 – 4 times per year to encompass seasonal variation, would be a major disturbance to a management area in which the whole objective is to eliminate this kind of disturbance. Sensitivity adequate to make definitive statements about more modest differences in fish biomass or density would require a monumental sampling effort, so extensive that it would involve severe physical disturbance to a large proportion of the bottom that the closure is itself trying to put off limits to this kind of interference. We must conclude that trawling is not the ideal approach to monitoring fish abundance, if the objective is to monitor spatial effects attributable to management regime over small areas such as the WGOMCA. We urge that other methods be developed post haste and suggest that without such alternatives, the performance of the WGOMCA as a fisheries management tool will not be known with any degree of confidence.

One species of fish was abundant and consistent enough in distribution during the NMFS In/Out survey for Blinkoff to test for a statistically significant difference relative to the WGOMCA. That species was the dogfish, and it exhibited a pattern that was the precise opposite of what we found in the current study. One year after the closure, during this single bout of sampling, dogfish catches were much higher outside than inside the WGOMCA.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure ___. Study design for NMFS trawl survey inside and outside of the WGOMC, one year after closure went into effect. Grey border: Stellwagen Bank National Marine Sanctuary. Black border: Western Gulf of Maine Closure. Courtesy of Kevin Blinkoff.

The NMFS study was conducted only one year post-closure while our sampling began six years post-closure and continued through the ensuing 18 months: a spring, a fall, and the following spring season. The trawls taken in this study were shorter in distance (about .5 nautical miles vs. ca. 5 nm) and duration (15 vs. 30 mins) so as to better sample within a single habitat. The tows were also more numerous, using a smaller trawl than those used in the NMFS study. These changes were designed to reduce statistical noise by increasing the chances that any sample was taken entirely within a single habitat (seabottom type) and by allowing time for more trawls to be completed. In addition, sampling was deliberately stratified by habitat, with three towable habitats: gravel, sand,

and mixed sand-gravel. A fourth habitat, deep mud, would be sampled in a subsequent study (since granted, and now in progress). A fifth habitat, boulder piles, was sampled using jigging gear to obtain a limited number of doc and haddock for study. Boulder habitat is also being examined in greater detail in a follow-up study.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure ______. Due to high between-trawl variance, it would have been necessary to increase sampling effort by nearly a factor of three to obtain statistical validation of the 100% difference observed in cod biomass/tow during the NMFS 1-year post-closing study of the WGOMC. Data from Blinkoff 2005.

In addition to problems of statistical power raised by the inherently high variance of trawl catches, attempts to make abundance estimates at fine spatial scales were vexed by additional challenges. While with effort we were able to make within-habitat comparisons inside versus outside of the WGOMCA, the areas within any particular habitat that were actually available for sampling were much smaller than the apparent extent of that habitat as indicated by the USGS' excellent seabottom map. Off-limits were areas with known wrecks, boulders, or other sorts of hangs, as well as areas set with lobster gear. This was sometimes most of an area targeted for sampling, leaving small regions within which sampling was still possible. In the end we would call the sampling random-intended, but highly constrained. This will be one serious problem for future studies.

B. Abundance Patterns Detected in This Study

Factor analysis was employed to test the hypothesis that patterns of fish abundance could in part be explained by the WGOMCA, by season, or by habitat. Two significant factors were recovered. Factor 1 was related to WGOMCA in/out effects (ANOVA $p < .001$), and was unrelated to habitat, season, or season times in/out effects. Factor 2 captured variation related to the interaction between season and in/out effects (ANOVA $p < .005$). Along this factor, the in/out effect was strongest for any particular species during that season when it was most abundant.

Four species of groundfishes were more abundant inside than outside of the WGOMCA, though this pattern was statistically significant for only three. Dogfish ($p < .01$) and red hake were clearly more abundant within the closure, witch flounder were also significantly more abundant inside ($p < .05$), and the effect for haddock was borderline ($p < .06$). Much of the pattern in dogfish was driven by a single sampling period, fall 2004, when dogfish abundance was extremely high. At this time, it appeared that dogfish were actually aggregated within the WGOMCA.

Four species of groundfishes exhibited the opposite pattern, with significantly greater abundance outside the closure, than within it. These were longhorn sculpin ($p < .001$), yellowtail flounder ($p < .01$), sea raven ($p < .01$), and winter or blackback flounder ($p < .05$).

Some species showed no statistically significant differences attributable to the closure: cod, eelpout, Pollack, dab, windowpane, herring, wolfish, and the skates. Other species were not caught in sufficient numbers to make an assessment: goosefish, silver hake, fourspot flounder, alligatorfish, redfish, cunner, halibut, lumpfish, fluke, and butterfish.

Looking over those species that were more abundant inside the closure, it is apparent that these are taxa normally associated with habitats (grave, mixed sand-gravel, mud) that are most prevalent within the Sliver. Similarly, species most abundant outside the closure are taxa commonly associated with sandy environments, the habitat type most prevalent to the west of the Sliver. This raises an important question in interpreting our results. Were the observed effects due to closure itself, or might they have developed secondary to overall differences in the representation of different habitats inside versus outside of the WGOMCA? In other words, were yellowtails more abundant outside of the closure due to a closure effect, or due to the likelihood that yellowtails will gather in greater numbers in an area where most of the available habitat is sand, even if you happen at that moment to be fishing on gravel and there are plenty of yellowtails there, too? This possible spatial confound is unavoidable in studies of the WGOMC, because there is a general west-east trend in the geological structure of Stellwagen Bank and adjacent areas. It may never be possible to know for certain that fine-scale variation in fish distribution and abundance in this region is the result of management as opposed to underlying habitat and topography. This is a second challenging design problem that future studies of the WGOMCA must consider.

The two most important insights from our analysis of biomass and abundance data in this study are that trawling is not an ideal means of testing spatial abundance hypotheses, and that dogfish are obviously a serious problem- not only for fishermen who fish Stellwagen, but also for understanding WGOMC effects on Stellwagen Bank. The dogfish themselves are likely to significantly alter ecosystem processes in the Closure if they choose regularly to aggregate there. For ecosystem-based management to succeed in the Gulf of Maine, the ecosystem effects of seasonal movements and aggregation patterns of dogfish and other key species must be understood and taken into account.

C. Stable Isotope Analyses of Food Web Structure

As expected, fish species that were known to habitually feed on the benthos exhibited more enriched (less negative) values for delC than planktivores. For example, Scallop and sponge were very light- both are filter feeders on phytoplankton (scallope) and on bacterioplankton and particulate organic matter (sponges). Herring were light, as expected for a pelagic-feeding zooplanktivore. The two deepwater octopus specimens that we examined were composed of surprisingly light carbon as well.

DelN values, reflecting trophic position, also followed expected trends, though the limited spread in values across species near the upper end of the scale indicates a substantial degree of omnivory and very catholic diets generally. One notable surprise is the high value for lobster, suggesting that they are not subsisting on sea urchins or other benthic invertebrates (unless they are specializing in carrion feeders such as crabs, which seems unlikely). The high delN may be a reflection that a large proportion of the lobster diet in this area is composed either of lobster bait or fish frames.

Our results from stable isotope analysis follow basic expected trends, indicating that stable isotope analysis is providing sensible results. Thus emboldened, we can state with some confidence that despite the broad overlaps among species, we were nonetheless able to detect both habitat and management effects when looking within species, on size-corrected data.

4. Value of Project to Habitat Information Associated With Fishery Conservation and Management

This project began when a fisherman, Mr. Paul Vitale, approached the Massachusetts Fishermens' Partnership with an hypothesis. It was this: rolling closures designed to protect cod spawn and young might in fact do the opposite, when spawn and juvenile fish predators- postulated to be mostly skates and perhaps dogfish- flood back into the region upon its reopening each year. Kaufman then added this hypothesis to a range of other postulated food web effects attributable to area closures. The closure-opening-predation hypothesis was cut from the study in review, so it remains an interesting issue. We did detect a host of other food web patterns suggesting a strong, if rather complicated effect of the WGOMCA on Stellwagen Bank food webs in the sand, gravel, and mixed sand-gravel habitats. Curiously, a powerful seasonal dogfish effect that differentially affects the WGOMCA cropped up as one of the principal confounds in this study.

The effects of bottom trawling on sea bottom habitats are among the most contentious of all gear impact issues (Schratzberger et al., 2002; Kaiser et al., 2000). Bottom trawling-, which can catch a broad array of species and disturb benthic habitats- has been painted by some conservationists with a broad brush as an unsound practice for sea bottoms under all circumstances (Watling and Norse, 1998). Others recognize that trawling over hard bottoms can negatively impact benthic organisms and biogenic habitat structure, but are less convinced that there is lasting damage to soft bottom environments, as these are normally subject to frequent natural disturbance (Committee on the Ecosystem Effects of Fishing, 2002; Duplisea et al., 2001; Kaiser, 1998). The sum of evidence suggests that the greatest impacts of mobile bottom gear are felt in rocky habitats at all depths, in muddy habitats at depths beyond the reach of storm disturbance, and in muddy sands that are mechanically stabilized by a combination of location effects and biological activity. The rocky habitats are covered by sessile invertebrates that are the foundation of this ecological community and are destroyed by mechanical action during trawling. Deep mud and mechanically stable muddy sand are habitats structured by the tube-building activities of infaunal invertebrates, as well as by physical structure above the mud-water interface created by burrowing anemones, amphipods, sea scallop, and so forth.

Our results indicate that the fish abundance patterns differ in accordance with the WGOMCA, but these effects are mixed, different species showing different patterns. Similarly, the feeding habits of fishes differ generally inside versus outside the WGOMCA, but the pattern is not simple. The results support the hypothesis that trawling alters the composition and food web structure of a benthic fish community. What is required now is a closer look at how prey communities differ inside versus outside, and experiments to puzzle out the actual chains of cause and effect.

Fishermen have proposed that under some conditions trawling could have beneficial effects. Almost nothing is known, however, about the combined multispecies effects of trawling (and other fishing methods) on the food webs that produce the fishes we eat. Indeed, our understanding of marine food webs in general is rather limited, and suppositions based on experience from terrestrial systems are often flawed. For example, it appears that marine food webs- or at least the marine food webs in our region, exhibit extremely high levels of connectivity (e.g., 50% vs. values closer to 10% more typical for terrestrial systems; Link 2002). In other words, marine fishes act much more as trophic generalists than do their terrestrial vertebrate counterparts. This leads to an extremely complex food web with many possible links, only a fraction of which are active at any given moment. Part of this complexity must be due to the large range of sizes that marine fish species subtend during growth, and to their highly plastic life histories. Whatever the ultimate basis for this phenomenon, it suggests that our regional marine food web is not only complex, but probably also highly volatile. Our results also reveal some degree of habitat-dependence, dependence upon time of year, and most interesting, variation that is at the least consistent with a management regime effect. The results suggest that the food web will respond to the addition or subtraction of the region's top carnivore: human beings, and to the habitat alteration associated with human predation on groundfishes.

This work has demonstrated that the ratios of naturally occurring stable isotopes of carbon and nitrogen are sensitive to ecological changes associated with the feeding habits of fishes caught inside versus outside of the WGOMCA. This has several important implications that managers might like to consider. First, isotopic signatures in fish flesh generally reflect the preceding one to two months of a fish's feeding activities. In other words, the result of mass spectroscopy analysis is a number that can, when compared to the signatures of other organisms, be used as a proxy for the mean trophic position of that individual in the community for the two months prior to capture. The only way that we could have seen differences between similar-sized members of the same species caught inside versus outside of the Closure, is if those individuals had been spending an appreciable part of the past two months segregated by management regime. In other words, these fishes may not be quite so mobile as we'd thought. Other evidence to this effect is accumulating. Acoustic telemetry on cod inhabiting boulder habitat on Stellwagen Bank has shown that a large percentage (up to half) of the tagged individuals have remained within a small area (or returned frequently to it) for periods of at least 13 months. The implication is that local area management can be an effective tool for fisheries and aquatic wildlife conservation in the Gulf of Maine. Yes, fishes exhibit mobility, but they also exhibit sedentary behavior, and do so to a sufficient extent that the value of area management to marine conservation in this region can not be dismissed out of hand.

The notion that fishes might remain in one spot for a month or two is hardly revolutionary; fishermen are fully aware of this and also many other patterns of residence and movement amongst their quarry. Patterns of residence and aggregation have important implications for management that must be taken into account. One of these, aggregations for spawning, are the basis of rotating groundfish closures. Historically, however, we are drawing upon this knowledge very selectively: there are spawning closures, but no consideration of the ecological effects of resident populations and seasonal aggregations of other sorts. The future of area-based management, and of ecosystem-based management, rests in part on a fuller appreciation and application of this kind of knowledge. Fishermen rely on precisely this sort of information to make a living. Perhaps the most important outcome of this study is its contribution to a general appreciation that putting scientists to work side by side with fishermen is a good and efficient approach to the objective study of human-marine ecosystem interactions. Most scientists would kill for the opportunity to do the same with an orca, yet human fishermen are by far the more significant predator in most parts of today's oceans. From the scientist's standpoint they are at least as fascinating as orcas, and more conversant.

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