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Identification of Juvenile Groundfish Habitat within Nearshore Waters of the Gulf of Maine

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Research team in the field aboard F/V Tenacious

Final Report Submitted to the National Marine Fisheries Service (NMFS) Northeast Region Office (NERO) Cooperative Research Project Partners Initiative (CRPI)

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Abstract

Cod population dynamics elsewhere (i.e., in Canadian and Scandinavian waters) have been linked to characteristics of juvenile habitat in short-term empirical and long-term survey studies. Given the historical value of groundfish fisheries in New England and the current depleted status of several of these fish species, identification of habitats rich in food and refuge for juvenile cod and other groundfish is necessary within nearshore waters of the Gulf of Maine. We utilized a small-mesh 70-m wide otter trawl to assess the effects of season (spring through fall), bottom depth (25-75 m), closure status (in vs. out of the Western Gulf of Maine Closure), and landscape setting (along the edges of rock ledge & boulder habitats and on mud isolated from hard bottom) on the distribution and abundance of juvenile groundfish and predator communities. Additionally, we assessed how these factors influence the diet composition, size, condition factor, and survival (i.e., we sampled the stomach contents of predatory fish captured in each tow) of the following target species: Atlantic cod (*Gadhus morhua*), haddock (*Melanogrammus aeglefinus*), and goosefish (*Lophius americanus*). In the central portion of the Gulf of Maine, the abundance of juvenile and adult cod was very low. Habitat had little effect on the ecology of either of the other two target species in this region. Meanwhile, abundances of juveniles for all three species in and around the Western Gulf of Maine Closure Area (WGMCA) were low, and goosefish were more abundant outside of the closure. This counterintuitive finding, which is similar to findings from studies elsewhere in the Gulf of Maine, suggests that the northern portion of the WGMCA may not be important nursery grounds for these valuable species. However, both adult cod and haddock abundances were greater along the edges of structured habitat than on mud bottom only inside the closure, which could signal the recovery of important habitat types inside the WGMCA. Goosefish condition was greater along the edges of structured habitat regardless of closure status, indicating that they are relatively immobile and forage more effectively in this habitat.

Key words: Atlantic Cod, condition index, diet composition, essential fish habitat, goosefish, groundfish, haddock, length-weight relationship, marine closure area, predator-prey interactions, Western Gulf of Maine Closure Area

Introduction

Fisheries managers have responded to the heightened pressures on fish populations globally through a number of proactive and retroactive measures, such as setting fish quotas, restricting entry to the fishery, and setting up temporal and spatial closures. In the United States, with the 1996 Amendment to the Magnuson-Stevens Fishery Conservation and Management Act, the National Marine Fisheries Service and fishery management councils have had the difficult task of identifying and describing essential fish habitat for all federally managed species (National Oceanographic and Atmospheric Administration 1998). Determination of EFH will require information on which habitats are important foraging and refuge grounds, and consequently contribute disproportionately to fish production locally and regionally. Protection of fish populations will hinge upon effective determination of EFH (Lindholm et al. 2001). Yet data on several life history phases of the vast majority of fish species are severely lacking and hinder this process. Therefore, studies that increase our understanding of fish demographics as a function of habitat will benefit efforts to manage fisheries more effectively.

Fully understanding the habitat requirements of a demersal fish necessitates identifying all of the habitats occupied at each life-history stage and the impacts of habitat on population dynamics (Lindholm et al. 2001). While adult habitat usage can be inferred from fishery-dependent catch data, modern fishing gear is designed to reduce or eliminate juvenile catches. Consequently, catch data alone provide little insight into juvenile habitat usage. Catch patterns prior to reductions in trawl mesh size provide evidence of habitat usage by slightly smaller sub-adults,

but even the smallest meshes previously fished were not effective at catching very young juveniles (especially 0 and 1 year age classes).

Initially, scientific work on habitat usage by juvenile fish in the northwest Atlantic focused largely on laboratory studies, which demonstrated that juvenile cod prefer structured habitats (i.e., cobble, sea grass, kelp and sponge habitats) when predators are present (Gotceitas and Brown 1993, Gotceitas et al. 1995, Fraser et al. 1996, Gotceitas et al. 1997, Lindholm et at. 1999). Field surveys from inshore sites in the Canadian maritime provinces have confirmed that juvenile cod associate with structured habitats such as sea grass beds and cobble/boulder habitat with high relief, suggesting that predation risk is high during early life-history phases (Keats et al. 1987, Gotceitas et al. 1997, Gregory and Anderson 1997, Grant and Brown 1998, Cote et al. 2001, Laurel et al. 2003). Analyses of long-term cod datasets from Scandinavian waters have also suggested that cod population dynamics are largely influenced by seabed habitat characteristics because they determine both food and refuge availability for juveniles (Bjornstad et al. 1999, Fromentin et al. 2001). More recent work has demonstrated that the distribution of 0-age cod is density-dependent in Placentia Bay, Newfoundland (Robichaud and Rose 2006). Although the range of juvenile cod expanded in years with greater recruitment, the sites with greatest cod abundance were consistent across years with low and high recruitment, suggesting that the location or the physical and biological characteristics of these sites are optimal for juvenile cod.

Field surveys of nursery habitats for demersal fishes have demonstrated the importance of vegetated habitats in estuarine waters of Maine (Lazzari et al. 2001). Yet few field studies of

juvenile habitat usage have been conducted in nearshore waters of the Gulf of Maine with the exception of some recent work by Peter Auster and colleagues on Stellwagan Bank (e.g., Auster et al. 2001, Lindholm and Auster 2003). Assessment of juvenile fish usage of and population dynamics in nearshore habitats elsewhere in the Gulf of Maine is necessary to determine which bottom types function as juvenile groundfish habitat (i.e., which habitats should be designated as EFH) and contribute disproportionately to the production of adult fish such as cod. Because strong linkages between juvenile habitat and cod population dynamics have been identified elsewhere, critical foraging and refuge habitats for juvenile groundfish need to be examined throughout the Gulf of Maine. We collected critical data on how habitat affects the growth and survival of juvenile cod and other important groundfish species, which has important implications for cod population dynamics and fishery management.

The habitat experienced by a fish includes both non-living, physical (i.e., abiotic) and biological (i.e., biotic) components. For example, a given habitat may be valuable to a fish because it contains physical shelter from predators and food to eat. However, these biotic and abiotic components are not independent because the nature of the physical substrate largely determines which organisms are present. Although habitat is most often recognized on physical criteria, the importance of different habitat types is as much biological as physical (e.g., Auster and Langton, 1999).

Most juvenile fish can utilize a variety of habitats. Therefore simple evidence of abundance patterns (where fish are and how many are present) may not indicate the true ecological value of each habitat. Juvenile fish utilize critical habitat as foraging grounds and to avoid predators.

Coupling an understanding of these processes with abundance patterns will enhance our understanding of which habitats are critical to fish production locally and regionally. This information will in turn provide fisheries managers with the data needed to more clearly identify and define essential fish habitat for groundfish species in the Gulf of Maine. We conducted a trawl survey to determine how season, water depth, closure status, and landscape setting influence the ecology of juvenile stages of important groundfish species in the Gulf of Maine. We hypothesized that juvenile groundfish abundance, growth, condition factor, and survivorship would be greatest along the edges of structured habitat. We also predicted that sites within the Western Gulf of Maine Closure Area would contain elevated abundance of groundfish with high condition and greater gut fullness if the WGMCA is achieving its intended goal of rebuilding fish stocks by providing critical foraging and refuge habitat for juvenile groundfish.

Methods

Sampling design

We conducted two separate trawl surveys in order to investigate the ecology of the early life-history phases of groundfish species in the Gulf of Maine. We selected sampling sites after consulting with both fishing partners (Proctor Wells and Marshall Alexander) regarding the locations of rock and mud substrates as well as through the use of existing bottom habitat maps and NMFS nautical charts. For each trawl survey, we utilized trawl nets that were identical to those used in the ME/NH inshore trawl survey and were designed to catch small fish (see description of net below). More complex habitats are unable to be trawled effectively because nets are easily entangled by large boulders and capture a lower proportion of fish (i.e., net

efficiency is reduced) because fish can more easily evade the net as boulders pull the net off the bottom. Therefore, we did not sample within the more complex, boulder and rock ledge habitats. This is unfortunately an inherent limitation of trawl sampling as a method for sampling fish. However, the advantages of trawl sampling (e.g., relatively large sample size, quantitative assessment of fish density, less selective than gill net, trap, and hook-and-line methods) explain why this is the preferred sampling method among federal (NOAA-NMFS) and state agency scientists that are responsible for assessing fish stocks in estuarine and marine waters throughout the U.S. Although we initially intended to use traps to assess juvenile groundfish use of different habitats, we were unable to catch any of the targeted groundfish during the initial sampling period, and consequently focused our efforts on trawling.

Because we were unable to sample within rocky habitats with trawl nets, we focused on the ecology of juvenile fish assemblages within mud habitat adjacent to rock-ledge and boulder fields vs. mud habitat isolated from these structured habitats. This landscape-scale approach permitted us to identify how these suites of habitats influence the ecology of juvenile groundfish. Ecologists elsewhere have demonstrated that mud bottom adjacent to more complex seagrass beds provides critical foraging grounds for predators and prey that reside within vegetated habitat that is rich in refuge (Summerson and Peterson 1984).

Survey I. The effects of season, depth, and landscape setting on the ecology of juvenile groundfish in the central portions of the Gulf of Maine

We selected 5 pairs of sites (1 site that was adjacent to ["edge landscape"] and 1 that was isolated by > 2 km ["mud landscape"] from rock bottom) at each of the three depths along a transect perpendicular to the shore line that is southeast of Cape Small, Maine (Figure 1). Prior to initiating trawl sampling efforts, we verified that edge landscapes were in fact adjacent to rock ledge and cobble bottom using a drop camera system. Specifically, we deployed a drop camera along a transect that was perpendicular to the hard bottom and surveyed from within the rock ledge and boulder habitats to the mud habitat directly adjacent to this hard bottom.

We conducted trawl surveys seasonally in the summer of 2004 and the spring and fall of 2005 on the F/V Tenacious in the nearshore portions of the Gulf of Maine at 25, 50, and 75 m. We sampled with a small-mesh trawl using similar methodology (i.e., net width and length, mesh size, towing speed etc.) to the ME/NH inshore trawl survey (see ME/NH inshore trawl survey protocol at http://www.maine.gov/dmr/rm/trawl/reports.htm for more detailed information regarding the net design). Tows were short duration (~15 minutes) at a fixed speed of ~2.4 knots/hr to ensure consistent sampling. Tows were conducted at 4 pairs of sites at each depth during the first two sampling periods. In the final sampling period (October 2005), lobster trap activity had extended beyond the 3 mile limit and precluded us from conducting sampling efforts except at 1 shallow site during this sampling period.

Survey II. The effects of season, closure status, and landscape setting on the ecology of juvenile groundfish in the Western Gulf of Maine Closure Area

The second trawl survey was conducted on the F/V Dee Dee Mae II inside and just outside of the northern portions of the Western Gulf of Maine Closure Area (WGMCA). Because we were working on different vessels for each survey, net efficiencies likely varied between the boats, which would make it difficult to compare directly the results from both studies. Furthermore, since our sampling efforts described in Survey 1 were situated in the central portions of the Gulf of Maine, Survey 1 provided an adequate initial description of the effects of depth and season on juvenile fish habitat associations. Therefore, we avoided attempting to conduct a similar survey to Survey 1 in the western portions of the Gulf of Maine, and instead focused our trawling efforts in Survey 2 inside vs. outside the WGMCA to determine whether this closure is facilitating the recovery of key groundfish species such as Atlantic cod, which is a key management question. By focusing our sampling efforts in vs. out of the WGMCA, this design permitted us to determine more rigorously how fish habitat associations differ in vs. out of the closure area.

We selected 5 pairs (1 edge and 1 mud landscape) of sites both inside the northern portions of the WGMCA and an additional 5 site pairs in waters open to fishing just outside of the northern areas of the WGMCA. Similar to Survey 1, we verified the edge habitats using a drop camera prior to initiating sampling efforts. We conducted trawl sampling efforts at 4 pairs of sites in and out of the closed area in the fall of 2004 and spring of 2005. This factorial design permitted us to examine the individual and interactive effects of season, closure status, and landscape setting.

Total fish abundance and biomass

All fish and crustaceans captured in each tow were separated by species (or species groups for some non-target invertebrates and pelagic fish), counted and weighed during both surveys. For non-target species that were quite abundant such as northern shrimp (*Pandaleus borealis*), silver hake (*Merluccius bilinearis*), and clupeids, all fish were weighed and subsamples of randomly selected groups were weighed and counted. We were consequently able to estimate the number of highly abundant species captured by dividing the total weight by the subsample weight and multiplying this product by the number of individuals in the subsample.

Distribution, abundance, feeding ecology, and condition of target species

In survey 1 (i.e., central Gulf of Maine), all individuals of the following three target species (Atlantic cod, haddock, goosefish), were counted, measured (standard length and total length), and weighed. Stomach contents were removed from each individual and stored in 10% formalin. Individual dietary items were identified to species (where possible), counted, and weighed in the laboratory. Intact stomachs were weighed, and this value was divided by the weight of the whole fish in order to create an index of stomach fullness for comparison among habitats. In addition to stomach fullness measures, fish condition was compared using fish weight relationships and Fulton's K ($K=100*[\text{Fish Weight}/\text{Fish Length}^3]$). Fulton's K has been used effectively to determine differences in cod stock condition at larger spatial scales throughout the north Atlantic (Ratz and Lloret 2003).

Predatory fish

Dietary analyses of predatory fishes have been utilized in previous studies to infer the impacts of habitat on patterns of prey fish abundance (Hindell et al. 2003). In this study, we examined the stomach contents of predators in order to assess how closure status, habitat type, and season collectively influence the presence of juvenile fish in the diet of predators. Potential juvenile fish predators include adult predatory (teleost) fishes, and to a lesser extent, cetaceans and elasmobranchs. Because Link et al. (2002) found that most groundfish are rarely found in the stomachs of elasmobranchs and sampling the diet of cetaceans is not feasible, we focused our sampling efforts on adult predatory teleost fish. Examination of ~200 spiny dogfish stomachs during the first sampling period confirmed that gadid and other groundfish families were not present in their diet. Predatory fishes caught in trawls were identified, counted, and weighed. Stomach contents were removed from all adult fish, stored in 10% formalin, and returned to the laboratory where each stomach was examined for the presence of juvenile fish.

Results

Trawls averaged approximately fifteen minutes (see Appendix A). ANOVAs determined that the length of trawls did not differ as a function of season, depth, or habitat in Survey 1 or season, closure status, or habitat in Survey 2 ($p > 0.10$ for all main effects and interaction terms). Each trawl tow sampled approximately 22,000 m^2 of surface bottom. Forty-two fish species were identified from a total of 97 tows conducted during the two trawl surveys (Table 1). Several crustacean and other invertebrate species were also captured in the two surveys.

Survey I. The effects of season, depth, and landscape setting on the ecology of juvenile groundfish in the central portions of the Gulf of Maine

Fish biomass captured in the central Gulf of Maine trawl survey was greatest during the summer of 2004. In this season, average fish biomass totaled 314.4 Kg per tow, and was dominated by spiny dogfish (34.3%), Atlantic herring (27.6%), and silver hake (21.4%) (Table 2). Dogfish and Atlantic herring biomass were greatest at the shallow and intermediate sites during the summer, whereas silver hake biomass was twice as great at the deep sites. After these three species, biomass of red hake (4.8%), goosefish (2.7%), American plaice (2.2%), and white hake (2.0%) contributed most to the overall fish catch. Invertebrates caught in the spring totaled 10.6 Kg per tow with northern shrimp (74.7%), lobsters (9.5%), squid (8.3%), and Jonah crabs (3.7%) accounting for over 95% of the total invertebrate biomass. Northern shrimp biomass was almost an order of magnitude greater at the deep sites, whereas lobsters were only caught at the shallow and mid sites, and were slightly more common in the edge habitat.

Fish biomass in the spring of 2005 totaled only 15.0% (47.2 Kg/tow) of fish biomass landed in the previous summer (Table 2). The reduced catch in the spring relative to the previous summer was largely a consequence of reduced herring and silver hake biomass and the absence of spiny dogfish. In the spring, Atlantic herring contributing 51.2% of the total biomass, and was followed by American plaice (13.9%), silver hake (10.8%), and longhorn sculpin (8.0%). Herring biomass once again was greatest at the shallow and intermediate depths as well as at the shallow edge sites. Unlike herring, silver hake biomass was greatest at the deep sites. As in the

summer, longhorn sculpins were most abundant at shallow depths and nonexistent at the deep sites during the spring sampling period. Total invertebrate biomass in the spring (20.9 Kg/tow) was nearly double that of the previous summer. As in the summer, invertebrate biomass was dominated by northern shrimp (75.4%) in the spring, and American lobster biomass again ranked second among invertebrate species groups. Northern shrimp were more prevalent offshore at the deep sites, whereas lobsters were most abundant at the shallow edge sites.

Although fish biomass in the fall (76.5 Kg/tow) was still far below the amount caught during the previous summer, it was nearly double the amount caught in the spring largely because of the return of spiny dogfish at our sites in the fall (Table 2). Excessive lobster trap gear in the fall of 2005 unfortunately prevented trawl sampling at our shallow sites. Fall fish biomass was dominated by spiny dogfish (49.5%), which was twice as abundant at the deep than at the mid sites. Atlantic herring contributed 14.4% of total fish biomass in the fall, followed by American plaice (8.1%), silver hake (6.6%), goosefish (5.5%), red hake (3.7%), thorny skate (2.9%), Atlantic torpedo (2.7%), and white hake (2.6%). As in the previous two seasons, Atlantic herring was most abundant at shallow edge sites. Invertebrate biomass was greatest in the fall and nearly double totals from the spring and four times greater than those in the summer. Northern shrimp accounted for 87.4% of total invertebrate biomass, and the American lobster comprised 10.1%. Similar to the previous two sampling periods, biomass of northern shrimp was greatest and the American lobster was lowest at the deep sites.

The distribution, abundance, and feeding ecology of Atlantic cod were influenced mostly by season and depth rather than habitat (Table 3). In the summer, cod abundance did not differ

among depths, whereas in the following spring cod were more abundant at the deep sites. Seasonal patterns in cod abundance also were dependant upon habitat type (Figure 2). Specifically, cod were more abundant on mud than on edge in the spring, but did not differ between habitats in the summer. Cod total length and condition did not vary as a function of season, depth, and habitat (Table 3; Figure 3). Although the number of juvenile cod that was captured was small and thus did not permit a more extensive examination, the diet composition of juvenile cod consisted primarily of small crustaceans such as mysids, euphausids, and northern shrimp (Table 4). Adult cod were piscivorous and consumed a mixture of crustaceans and several fish species. Clupeids and silver hake were the dominant fish prey found in the diet of adult cod.

In comparison to cod, haddock were more largely influenced by habitat and foraged primarily on invertebrates. Haddock abundance varied significantly with season (Table 5). Haddock were much more abundant in the summer than in the spring (Figure 4). Although the effect of habitat was not significant, there was a slight trend of greater haddock abundance on mud than on edge habitat. There also was a trend of greater abundances of juvenile haddock at the shallow and mid sites, whereas adult haddock were predominately caught further offshore at the intermediate and deep sites. Haddock total length varied with season and depth together (Figure 5). In the summer, haddock size increased with water depth. Meanwhile, in the following spring haddock size was greatest at intermediate depths. Haddock condition did not vary with season, depth or habitat (Table 5; Figure 6). The diet of juvenile haddock consisted primarily of polychaetes, but also included bivalves, crustaceans, and brittle stars (Table 6). All 4 of these prey categories were prevalent in juvenile haddock from both habitats. Polychaetes were also the dominant prey

item found in the stomachs of adult haddock. Bivalves occurred more frequently and were relatively more important in the diet of adult haddock in comparison to that of juveniles. Adult haddock also consumed a wider diversity of echinoderms than did juveniles. Finally, a higher percentage of adult haddock stomachs were empty on mud than on edge habitats.

Of the three target species, goosefish was the most abundant and piscivorous. The abundance of goosefish was influenced by season and depth (Table 7). Goosefish were most abundant at shallow and mid sites in the summer (Figure 7). In the spring, goosefish abundance at these shallower sites was lower and did not differ from the deep sites. Goosefish TL was greater in the summer than in the following spring (Figures 8 and 9), but did not differ between habitats or across depths. The effects of season, depth, habitat, and their interactions did not influence the condition of goosefish. Although both juvenile and adult goosefish consumed both crustaceans and fish, older goosefish transitioned to foraging on predominately larger crustaceans and fish (Table 8). In particular, adults consumed more northern shrimp and fewer euphausids and mysids. Furthermore, adults also consumed a higher percentage of clupeids and unidentified gadids, whereas fish consumed by juveniles were predominately smaller, eel-like fishes such as fourbeard rockling and silver hake. We also found lobsters in 5 of the 174 stomachs analyzed. At all depths, unidentified gadids were more important in the diet of both juvenile and adult goosefish captured on the edge as compared to those in the mud habitat. A slightly higher percentage of the stomachs of juvenile and adult goosefish were empty when caught on the edge vs. the mud habitat.

Predatory fish species included adults of the three target species, skates, Atlantic spiny dogfish, and an occasional large white hake or sea raven. Examination of the stomach contents of these predators revealed that only goosefish consumed a wide diversity of gadids (fourbeard rockling [especially by juveniles], silver hake, white hake, red hake, and unidentified gadids). Given the low abundance of juvenile cod and haddock sampled in this study, it is unlikely that unidentified gadids were cod and haddock. Commercially valuable groundfish species were not prevalent in the stomachs of cod and haddock. Although the gape width of skates limits their ability to ingest larger prey, we did locate a small number of unidentified young-of-year (YOY) fish in the stomach of skates (Grabowski, unpub. data). Examination of the stomach contents of approximately 200 dogfish revealed that dogfish consume mostly pelagic forage fish rather than groundfish. Only one goosefish was consumed by a predator, which happened to also be an adult goosefish captured at a mid site in the mud.

Survey II. The effects of season, closure status, and landscape setting on the ecology of juvenile groundfish in the Western Gulf of Maine Closure Area

Both habitat and closure status largely influenced the distribution and abundance of fish and invertebrates in the western Gulf of Maine in the fall of 2004 (Table 9). Total fish biomass (348.6 Kg per tow) was 50-60% greater at edge than at mud sites both in and out of the closure. Adult spiny dogfish biomass, which accounted for 42.9% of total fish biomass, was greater at edge sites regardless of closure status. Unlike adults, juvenile spiny dogfish (2.0%) were more abundant on the mud than the edge. The Acadian redfish biomass (16.7% of total fish) was twofold greater along the edge habitats. Redfish biomass was twofold greater inside the closure than out. Silver hake (12.5%) biomass on the edge was twice that of the mud habitats and was

almost an order of magnitude greater outside of the closure. Atlantic herring (8.4%) was tenfold greater outside of the closure but did not vary between habitat types. Similar to total fish biomass, total invertebrate biomass (average of 25.5 Kg per tow) was greater in the closure by a factor of two because northern shrimp (89.0% of total invertebrate) biomass was much greater in the closure than outside. Anemone biomass (5.4%) was an order of magnitude greater at the edge sites, indicating that these sites were located adjacent to more structured hard bottom.

Total fish biomass in the spring of 2005 (114.9 Kg per tow) was approximately a third of fish biomass landed in the previous fall in and around the WGMCA (Table 9). This reduction in fish biomass was largely a consequence of spiny dogfish, which were almost entirely absent at our sampling sites in the spring. As in the previous fall, fish biomass in the spring was substantially greater in the edge than in the mud habitat. In the spring, Acadian redfish accounted for 46.6% of the total fish biomass, and it was 2-4 times as abundant at edge that at mud sites. All 3 of our target species in this survey ranked among the top 10 in fish biomass caught in the spring: Atlantic cod (4th: 7.3%), goosefish (5th: 5.1%), and haddock (10th: 1.2%) (see results for each individual species below). Silver hake biomass (10.1%) ranked 3rd among fish species landed in the spring. Similar to the fall, silver hake biomass was much greater outside the closure than in during the spring. In the spring, total invertebrate biomass once again was greatest in the closure as a consequence of northern shrimp (94.6% of total invertebrate biomass). However, the closure only increased northern shrimp biomass in the mud habitat. As in the fall, anemone biomass was greater in the edge than the mud habitats regardless of closure status.

The trawl survey revealed that the distribution, abundance and feeding ecology of Atlantic cod vary as a function of season and interactions between closure and habitat. Cod abundance was significantly greater in the spring than in the fall by a factor of 2 (Table 10; Figure 10). Cod abundance also varied with closure and habitat (significant closure * habitat interaction). Outside of the closure, habitat did not affect cod abundance, whereas inside the closure cod were almost an order of magnitude more abundant in the edge habitat. Cod were also more abundant at edge sites in than out of the closure; however, this pattern was reversed in the mud habitat (i.e., cod biomass outside > inside the closure at mud sites). Only season influenced cod total length (Table 10), which were slightly larger in the fall than in the spring (Figures 11 and 12). Cod condition did not vary as a function of season, closure status, or habitat type. Juvenile cod consumed a mixture of clupeids and crustaceans (i.e., mostly euphausids and northern shrimp) (Table 11). In addition to these species, adult cod consumed a wider diversity of fish and crustaceans (i.e., mysids as well as hermit and cancer crabs). Clupeids, which were the most important diet component inside the closure, were also more prevalent in the diet of cod caught at edge than at mud sites both in and out of the closure.

Similar to cod, both closure and habitat substantially influence the ecology of haddock around the WGMCA. Although overall abundance of haddock captured in this survey was low, significantly more haddock were captured in the edge than in the mud habitat (Table 12; Figure 13). There was a trend for the interaction between edge and habitat. Similar to cod, differences in haddock abundance due to habitat type were much more pronounced inside the closure. Because no haddock were caught in the mud habitat in the closure, we removed habitat from the model and instead conducted two-way ANOVAs to analyze the effects of season and closure

status on haddock size and condition separately (Table 12). Haddock were larger inside the closure in the fall, but this pattern reversed in the spring (Figures 14 and 15). Haddock condition did not differ among seasons, in vs. out of the closure, or their interaction. Because we landed a total of just 3 juvenile haddock during the 32 tows around the WGMCA, here we present only adult haddock diet patterns from this survey (Table 13). Adult haddock consumed mostly mollusks, polychaetes, and crustaceans, whereas fish (Clupeidae) were present in only one haddock stomach.

In comparison to cod and haddock, the distribution and abundance of goosefish were influenced primarily by closure status. Goosefish were more abundant (Table 14; Figure 16) and smaller (Figures 17 and 18) outside than in the closure. Careful examination of size frequency distributions for goosefish in vs. out of the closure revealed that juvenile goosefish abundances are very low inside the closure (see Appendix B: M. Smith's Master's Thesis, which was a component of this study, entitled 'Reserve and habitat effects on the distribution, abundance, and feeding ecology of goosefish around the Western Gulf of Maine Closure Area'). In contrast to goosefish abundance and size patterns, only season and habitat influenced the condition of goosefish (Figure 17). Goosefish condition was greater in the spring, whereas the condition of goosefish caught in the edge was greater than those caught in the mud. Juvenile goosefish consumed mostly crustaceans (mysids and northern shrimp) and small, eel-like fishes (silver hake, fourbeard rockling, and eelpouts). Outside of the closure, fish were more prevalent in the diet of juvenile goosefish in the edge than in the mud habitat. Adult goosefish consumed a wider diversity of fish including larger individuals than those consumed by juveniles, but northern

shrimp were still an important component (especially by number) of the diet composition of adult goosefish.

As in survey 1 (central Gulf of Maine), we examined the stomachs of a couple hundred fish predators including the three target species, skates, and an occasional large white hake or sea raven during the second survey. Once again, only goosefish consumed a wide diversity of gadids. Juvenile cod and haddock were not identified in a single stomach, though it is possible that unidentified gadids in the stomach of goosefish could have been these species. Still, given that juvenile cod and especially haddock were largely absent from the Survey 2 study area, it is highly unlikely that goosefish are consuming a large proportion of juvenile cod and haddock in this region. Only one YOY goosefish was identified in the stomachs of predators, which was found in a cod captured on the edge habitat outside of the closure.

Conclusions

Although much empirical work has suggested that YOY cod and other important groundfish species recruit to inshore bottom to utilize seagrass and kelp beds as nursery grounds during the early phases of life, it is less certain which habitats support elevated abundances of older juveniles as they migrate offshore prior to maturing. As fish grow, they eventually become less vulnerable to predators. Thus the tradeoff between using refuge and foraging for high quality prey begins to shift from the former to the latter. While hard bottom typically contains physical structure from rock and attached epifauna and epiflora, soft-bottom mud habitats have been recognized as important foraging grounds that can support greater rates of trophic transfer. The purpose of the survey in the central Gulf of Maine was to identify which bottom type serves as critical bottom (i.e., elevates abundance, improves condition, and/or affects the diet composition of juvenile fish), and how juvenile fish associations with bottom habitat change as they mature and migrate offshore. We also wanted to address how these relationships change seasonally.

We did not find that habitat is an important factor in the distribution and abundance of juvenile cod, haddock, and goosefish in the central Gulf of Maine region. However, very few juvenile and adult cod were landed in this survey, suggesting that (a) they are constrained to more structured bottom habitat, so that sampling the edge habitat was an insufficient measure of the distribution and abundance of juvenile cod, (b) trawl surveys in this study were ineffective at capturing this species efficiently, or (c) nearshore waters of the central portion of the Gulf of Maine does not support high abundances of this important species.

Our first hypothesis is possible, but highly unlikely given that we were targeting older juveniles that are much more mobile than YOY of fish and typically have migrated from inshore areas to more offshore ledges by this life stage. It is possible that we vastly underestimated the abundance of these three species, but they have been captured effectively elsewhere in the Gulf of Maine by the ME/NH inshore trawl survey (ITS). We designed our study to mimic the protocols (including net design, tow speed, protocols, etc.) of the ME/NH ITS for comparative purposes and we were sampling on a Northeast 54' that is a sister ship of the boat used in the ME/NH ITS. We also captured a higher abundance of adults for these three species, which would presumably be more capable of evading a moving net. Thus we conclude that the nearshore waters of the central portion of the may not serving as important nursery habitat for larger (i.e., 2-4 year olds) juvenile cod.

Although we caught more juvenile haddock than cod in this survey, we did not demonstrate conclusive habitat effects on their abundance, condition, or diet. These results suggest that there is not a strong connection between habitat and haddock in the nearshore waters of central Gulf of Maine. Juvenile haddock forage primarily on polychaetes, bivalves, and small crustaceans, which are readily available in either habitat. These results also suggest that juvenile haddock in this region are large enough to move between habitat types without risk of being consumed by predators. Similar to haddock, we captured a greater abundance of goosefish in this survey than cod. We also did not find differences between the two habitats in the abundance or size of goosefish.

The Western Gulf of Maine Closure Area was designed to permit recovery of bottom habitat and associated fauna to provide refuge and foraging grounds for commercially valuable groundfish species such as Atlantic cod, haddock, and goosefish. This region was selected in part because it contains important habitats such as the cobble, gravel, and rock-ledge bottom that comprise Jeffreys Ledge. These habitats are thought to serve as an important nursery for juvenile groundfish, motivating managers to close a large section of the western Gulf of Maine to mobile gear that encompasses the entirety of Jeffrey's Ledge. However, we found very few juveniles of the three target species (especially haddock) in the study area, and juvenile goosefish were far more abundant outside the closure, suggesting that the northern portion of the WGMCA is not important nursery habitat for these critical species. Investigations of groundfish further south in the central portions of the WGMCA have also found very low abundances of juvenile cod and other commercially important species that the closure was designed to benefit.

Although the WGMCA may not serve as nursery habitat for cod, haddock and goosefish, we did find evidence that the closure influences adult populations of the two gadid species. In particular, adult cod and haddock were much more abundant along structured edge bottom than on isolated mud inside the closure, whereas their abundances did not differ between habitats outside of the closure. This pattern suggests that fishing activity along the edge of structure, which is a habitat often targeted by groundfishermen because it typically contains high abundances of fish, outside of the closure maybe intense enough to reduce their abundances in this habitat. However, this hypothesis can not fully explain the distribution of these two commercially valuable species in and around the WGMCA because both cod and haddock were less abundant in the edge habitat inside than out of the closure. This pattern suggests that adult

cod and haddock are likely aggregating along the edge of structured habitat inside the closure, which could be a consequence of recovering prey resources from the absence of mobile, bottom-disturbing gear, or the absence of mobile gear that disperses fish aggregations from potentially preferred habitats.

While our study indicated that overall fish biomass is generally greater on the edge of structure than on isolated mud, surprisingly, total fish biomass was slightly lower inside than out of the closure. Several potentially important forage species such as Atlantic herring, silver hake and American plaice were more abundant outside of the closure, whereas Acadian redfish were more abundant inside the WGMCA. All of these species were generally more abundant at edge rather than mud sites, which could explain why the condition of goosefish was also greater in this habitat. Although previous studies have not established strong habitat preferences for goosefish and we did not find elevated abundances in either habitat, increased condition in goosefish along the edge of structure suggests that goosefish are relatively immobile on shorter time scales (i.e., weeks) and may be food limited on mud bottom.

Finally, trawl surveys are an effective means of sampling fish assemblages in relatively unstructured mud bottom. The obvious advantage of trawl surveys is that this method is capable of surveying a large volume of water and bottom habitat effectively, thereby potentially providing a density of fish per unit bottom area or water volume assuming that gear efficiency does not differ among treatments. Unfortunately this technique is limited to relatively unstructured bottom in order to avoid gear entanglement issues. Scientists at Canada Department of Fisheries and Oceans (Don Clark) and ME-DMR (Sally Sherman) have both noticed elevated

abundances of cod in nets that accidentally surveyed more structured bottom and became entangled. Thus, additional methods of quantifying fish densities need to be developed that are insensitive to bottom type in order to determine more conclusively how structured bottom influences the distribution and abundance of commercially important bottom species such as codfishes and goosefishes. Until they are developed, we may need to rely upon other methods of surveying fish such as data on visitation rates and relative abundance obtained from gillnetting, trapping, hook-and-line sampling, and video surveys. These methods have been incorporated into studies elsewhere that assess juvenile fish use of structured habitats (Grabowski et al. 2005). Witman and Sebens (1992) and Steneck (1997) also used video surveys and found evidence of higher abundances of adult cod further offshore on ledges and banks in the Gulf of Maine.

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Table 1. Scientific and common names of species caught in trawl surveys.

	Scientific Name	Common Name	Family
	Hagfishes		
1	*Myxine glutinosa*	Atlantic hagfish	Myxinidae
	Cartilaginous Fishes		
1	*Squalus acanthias*	spiny dogfish	Squalidae
2	*Torpedo nobiliana*	Atlantic torpedo	Torpenidae
3	*Raja erinacea*	little skate	Rajidae
4	*Raja ocellata*	winter skate	Rajidae
5	*Raja radiata*	thorny skate	Rajidae
6	*Raja senta*	smooth skate	Rajidae
	Bony Fishes		
1	*Alosa pseudoharengus*	alewife	Clupeidae
2	*Brevoortia tryannus*	Atlantic menhaden	Clupeidae
3	*Clupea harengus*	Atlantic herring	Clupeidae
4	*Osmerus mordax*	rainbow smelt	Osmeridae
5	*Brosme brosme*	cusk	Gadidae
6	*Enchelyopus cimbrius*	fourbeard rockling	Gadidae
7	*Gadus morhus*	Atlantic cod	Gadidae
8	*Melanogrammus aeglefinus*	haddock	Gadidae
9	*Merluccius bilinearis*	silver hake	Gadidae
10	*Pollachius virens*	pollock	Gadidae
11	*Urophycis chuss*	red hake	Gadidae
12	*Urophycis tenuis*	white hake	Gadidae
13	*Lophius americanus*	goosefish	Lophidae
14	*Sebastes fasciatus*	Acadian redfish	Scorpaenidae
15	*Prionotus carolinus*	northern searobin	Triglidae
16	*Hemitripterus americanus*	sea raven	Cottidae
17	*Myoxocephalus octodecemspinosus*	longhorn sculpin	Cottidae
18	*Aspidophoroides monopterygius*	alligatorfish	Agonidae
19	*Cyclopterus lumpus*	lumpfish	Cyclopteridae
20	*Tautogolabrius adspersus*	cunner	Labridae
21	*Lycenchelys verrilli*	wolf eelpout	Zoarcidae
22	*Macrozoarces americanus*	ocean pout	Zoarcidae
23	*Lumpenus lumpretaeformis*	snakeblenny	Stichaeidae
24	*Cryptacanthodes maculatus*	wrymouth	Cryptocanthodidae
25	*Scomber scombrus*	Atlantic mackerel	Scombridae
26	*Peprilus triacanthus*	butterfish	Stomateidae
27	*Anarhichas lupus*	Atlantic Wolffish	Anarhichadidae
28	*Paralichthys oblongus*	fourspot flounder	Bothidae
29	*Scophthalmus aquosus*	windowpane	Bothidae
30	*Glyptocephalus cynoglossus*	witch flounder	Plueronectidae
31	*Hippoglossoides platessoides*	American plaice	Plueronectidae
32	*Hippoglossus hippoglossus*	Atlantic halibut	Plueronectidae
33	*Pleuronectides ferruginea*	yellowtail flounder	Plueronectidae
34	*Pseudopleuronectes americanus*	winter flounder	Plueronectidae
35	*Reinhardtius hippoglossoides*	Greenland halibut	Plueronectidae

	Invertebrates	
1	Porifera	sponge
2	Actiniaria	anemone
3	Bivalvia	unidentified bivalve
4	Veneridae	hard clam
5	Myidae	softshell clam
6	Cardiidae	cockle
7	*Plactopecten magellanicus*	sea scallop
8	*Neptunea despecta*	Ten-ridge whelk
9	Octopodidae	octopus
10	Teuthoidea	squid
11	*Asterias rubens*	starfish
12	*Henricia sanguinolenta*	blood star
13	Asteroidea	box starfish
14	Holothuroidea	sea cucumber
15	Decapoda	unidentified shrimp
16	*Pandalus borealis*	northern shrimp
17	*Crangon sp.*	Crangon shrimp
18	*Homarus americanus*	American lobster
19	*Clibinarius* spp.	hermit crab
20	*Hyas* spp.	spider crab
21	*Cancer irroratus*	rock crab
22	*Cancer borealis*	Jonah crab
23	*Chionoecetes opilio*	snow crab
24	*Lithodes maja*	northern stone crab
25	*Carcinus maenas*	green crab
26	*Geryon quinquedens*	red deepsea crab

Table 2. The effects of depth and habitat type on the abundance and biomass of all organisms captured in trawl survey 1 (i.e., central Gulf of Maine) in the a. summer of 2004, b. spring of 2005, and c. fall of 2005.

a. Summer (2004)

	SHALLOW								MID								DEEP							
	EDGE				MUD				EDGE				MUD				EDGE				MUD			
Prey Species	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE
HAGFISHES																								
ATLANTIC HAGFISH					0.3	0.3	0.050	0.050													0.3	0.3	0.035	0.035
CARTILAGINOUS FISHES																								
SPINY DOGFISH (JUVENILE)	3.5	2.0	1.368	1.197	6.0	3.2	1.165	0.829	9.5	5.7	1.756	1.263	23.5	7.2	3.860	1.446	65.5	47.4	15.600	11.900	40.0	18.8	7.325	3.725
SPINY DOGFISH	117.0	66.3	197.660	110.740	61.3	39.5	104.520	62.818	99.3	82.1	125.590	100.490	98.8	54.0	158.640	85.560	19.3	6.0	22.100	8.520	7.8	3.7	8.648	3.104
ATLANTIC TORPEDO					0.3	0.3	4.610	4.610																
WINTER SKATE	1.3	0.9	1.158	0.942	0.5	0.3	0.463	0.267																
THORNY SKATE																	4.0	0.4	3.450	2.070	1.8	0.6	3.245	1.104
SMOOTH SKATE																					0.3	0.3	0.200	0.200
BONY FISHES																								
ATLANTIC MENHADEN									3.3	3.3	0.189	0.189	0.8	0.8	0.495	0.495	4.0	4.0	4.910	4.910			0.025	0.025
ATLANTIC HERRING	1550.0	852.4	298.380	211.320	396.0	173.2	66.615	35.824	624.0	310.8	73.710	53.495	243.5	79.1	34.500	14.385	114.0	40.0	17.800	6.660	182.8	61.0	29.145	14.176
FOURBEARD ROCKLING					2.3	2.3	0.058	0.058	3.3	1.3	0.111	0.044	3.0	1.5	0.140	0.067	2.8	1.4	0.120	0.070	6.0	2.9	0.273	0.134
ATLANTIC COD	1.0	0.6	0.156	0.095					0.3	0.3	0.035	0.035	0.3	0.3	0.038	0.038	0.5	0.5	0.610	0.610	0.8	0.5	1.248	0.724
HADDOCK	3.3	2.9	0.283	0.247	11.5	8.6	1.730	0.945	5.5	1.8	7.675	6.014	13.3	3.9	4.373	2.592	1.5	1.3	1.480	1.710	1.8	0.5	2.123	1.045
SILVER HAKE	679.7	536.1	51.105	41.384	605.3	220.4	35.800	8.664	1202.0	567.9	69.600	33.105	899.8	251.7	37.350	22.502	1592.0	374.0	95.700	10.800	1388.8	145.3	119.660	12.534
POLLOCK																					0.3	0.3	0.023	0.023
RED HAKE	47.3	27.6	11.476	5.130	72.0	25.0	10.525	4.085	97.8	12.4	18.670	3.625	120.3	16.8	20.935	1.777	56.5	20.6	15.800	6.210	47.0	18.8	12.596	5.832
WHITE HAKE	8.0	7.3	1.035	0.969	10.0	2.7	1.340	0.279	9.0	4.2	1.830	0.858	14.0	4.5	2.433	1.131	29.5	13.9	19.300	10.100	30.3	6.1	11.460	1.078
GOOSEFISH	9.3	3.1	5.016	1.977	8.8	4.5	7.808	5.099	6.1	3.1	20.453	7.528	10.0	1.1	11.985	5.926	3.0	1.4	3.680	0.710	2.0	0.7	2.864	2.042
ACADIAN REDFISH	4.0	4.0	0.155	0.155									0.3	0.3	0.015	0.015	5.5	3.8	0.550	0.470	6.8	2.4	0.615	0.209
NORTHERN SEAROBIN													0.5	0.5	0.058	0.058								
SEA RAVEN	0.3	0.3	0.170	0.170					0.3	0.3	0.438	0.438									0.3	0.3	0.050	0.050
LONGHORN SCULPIN	98.5	28.4	9.910	1.521	70.5	28.7	8.200	2.631	7.3	3.6	1.346	0.662	12.8	7.1	1.449	0.838	0.3	0.3	0.020	0.020	0.3	0.3	0.030	0.030
ALLIGATORFISH	0.3	0.3	0.003	0.003																				
LUMPFISH	0.5	0.5	0.010	0.010					0.3	0.3	0.078	0.078	0.3	0.3	1.700	1.700	0.5	0.3	1.130	0.780				
CUNNER	0.8	0.5	0.018	0.014																				
WOLF EELPOUT					0.3	0.3	0.004	0.004																
WRYMOUTH					4.3	3.9	0.214	0.206	1.8	0.8	0.166	0.064									1.0	1.0	0.060	0.060
ATLANTIC MACKEREL									0.3	0.3	0.003	0.003												
BUTTERFISH	8.8	3.5	0.859	0.049	3.5	1.4	0.145	0.077	1.3	0.9	0.060	0.040	1.8	0.5	0.098	0.028								
FOURSPOT FLOUNDER	0.3	0.3	0.050	0.050					0.3	0.3	0.025	0.025	0.3	0.3	0.005	0.005								
WINDOWPANE	0.3	0.3	0.019	0.019																				
WITCH FLOUNDER	0.3	0.2	0.045	0.040	2.8	3.2	0.630	0.728	11.0	5.7	1.968	1.019	20.8	12.8	4.040	2.637	30.5	12.6	5.770	2.630	21.8	2.3	4.620	0.488
AMERICAN PLAICE	39.8	8.2	2.199	0.482	70.5	12.3	4.305	1.180	101.0	30.4	11.895	4.473	135.5	16.1	12.180	1.633	47.8	18.6	5.860	2.220	48.8	12.6	5.523	1.551
YELLOWTAIL FLOUNDER	0.5	0.5	0.125	0.125					0.3	0.3	0.028	275.000	0.5	0.3	0.128	0.128								
WINTER FLOUNDER	17.5	12.6	1.875	1.262	8.3	7.3	1.059	0.796	0.5	0.3	0.251	0.145	0.3	0.3	0.053	0.053								

a. Summer (continued)

	SHALLOW								MID								DEEP							
	EDGE				MUD				EDGE				MUD				EDGE				MUD			
Prey Species	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE
INVERTEBRATES																								
ANEMONE									1.0	1.0	0.245	0.245	0.5	0.5	0.250	0.250	1.5	0.3	0.500	0.070	1.0	0.0	0.294	0.024
UNIDENTIFIED BIVALVE					4.8	4.8	0.025	0.025	5.0	3.3	0.093	0.066												
HARD CLAM					0.5	0.5	0.030	0.030									1.8	1.0	0.160	0.110	1.0	0.6	0.021	0.020
SEA SCALLOP					0.5	0.5	0.050	0.050					0.5	0.5	0.030	0.030	0.5	0.3	0.020	0.010	0.5	0.3	0.019	0.011
SQUID	4.3	2.0	1.493	1.201	4.0	1.5	0.460	0.237	5.0	1.5	0.267	0.107	8.0	3.4	0.483	0.297	20.5	7.4	0.890	0.370	36.5	10.3	1.685	0.327
STARFISH	0.5	0.5	0.003	0.003					0.8	0.8	0.008	0.008	1.8	1.1	0.012	0.005	18.5	13.6	0.230	0.120	17.8	10.9	0.156	0.087
SEA CUCUMBER					0.5	0.5	0.008	0.008																
NORTHERN SHRIMP	291.3	260.2	1.365	1.220	1007.8	659.4	4.763	3.087	448.0	146.3	2.178	0.653	655.3	180.8	3.215	0.800	4581.0	1871.0	22.100	8.520	2568.3	1348.1	13.858	6.684
AMERICAN LOBSTER	7.0	1.6	2.663	0.902	2.8	1.6	1.203	0.700	1.5	0.9	1.193	0.473	1.3	0.6	0.970	0.515								
SPIDER CRAB																					0.5	0.5	0.030	0.030
ROCK CRAB	0.3	0.3	0.030	0.030																	1.3	1.3	0.183	0.183
JONAH CRAB	6.3	5.0	1.015	0.924	6.3	2.3	0.823	0.300	1.8	0.9	0.327	0.134					0.5	0.3	0.040	0.020	2.3	1.9	0.130	0.088
SNOW CRAB																					0.3	0.3	0.023	0.023
GREEN CRAB					0.3	0.3	0.001	0.001													1.0	1.0	0.020	0.020

b. Spring (2005)

	SHALLOW								MID								DEEP							
	EDGE				MUD				EDGE				MUD				EDGE				MUD			
Prey Species	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE
CARTILAGINOUS FISHES																								
SMOOTH SKATE																	0.5	0.5	0.435	0.257				
THORNY SKATE					0.3	0.3	0.034	0.034									1.3	0.5	3.248	1.697	0.3	0.3	2.2	2.2
WINTER SKATE	2.5	1.0	2.181	0.861	1.3	0.6	0.754	0.391	0.3	0.3	0.25	0.25	0.3	0.3	0.2	0.2								
BONY FISHES																								
CLUPEID SPP.	315.8	315.8	0.235	0.235	100.0	100.0	2.085	2.085	108.0	108.0	2.235	2.235	80.5	80.5	2.31	2.31	7.3	7.3	0.16	0.16	68.5	68.5		
ALEWIFE					0.3	0.3	0.01	0.01									1.0	1.0	0.20	0.20				
ATLANTIC HERRING	509.3	366.1	22.096	10.004	730.8	657.9	26.082	19.47	1146.0	843.5	31.15	18.3	2467.0	2068.0	47.286	32.744	245.8	113.3	12.446	6.444	154.5	83.1	6.011	3.144
RAINBOW SMELT					0.3	0.3	0.01	0.01	0.3	0.3	0.002	0.002	1.0	0.4	0.011	0.004								
CUSK																	0.3	0.3	0.275	0.275				
FOURBEARD ROCKLING	0.3	0.3	0.006	0.006	0.5	0.3	0.017	0.014	1.8	0.9	0.119	0.07	17.3	16.6	0.031	0.017	2.5	1.7	0.086	0.067	4.0	1.1	0.119	0.055
ATLANTIC COD					0.8	0.8	0.271	0.271					0.8	0.5	0.523	0.336	1.3	0.3	1.234	0.657	2.3	0.3	2.29	1.221
HADDOCK	0.5	0.3	0.023	0.014	0.5	0.5	0.014	0.014	0.3	0.3	0.013	0.013	0.8	0.5	1.408	1.398	0.3	0.3	0.008	0.008	0.3	0.3	0.033	0.033
SILVER HAKE	13.5	4.6	0.313	0.086	17.3	12.3	0.813	0.677	72.3	35.8	4.626	3.14	110.3	46.3	6.902	3.477	153.5	45.4	9.521	2.72	128.0	37.9	8.301	1.677
POLLOCK					0.5	0.5	0.093	0.093																
RED HAKE	1.0	1.0	0.109	0.109	1.8	1.0	0.21	0.133	2.8	1.3	0.298	0.137	5.0	1.2	0.566	0.161	7.5	3.3	1.024	0.487	8.3	2.0	1.336	0.331
WHITE HAKE	2.0	1.4	0.098	0.059	3.3	1.7	0.17	0.09	6.0	1.8	0.217	0.091	6.0	0.9	0.338	0.074	2.8	1.5	0.261	0.167	5.0	0.8	0.421	0.194
GOOSEFISH	2.3	0.5	0.766	0.21	3.3	1.3	1.18	0.36	3.8	1.4	2.826	1.542	4.5	1.2	1.876	0.661	2.0	0.9	0.446	0.308	2.0	0.7	0.591	0.326
ACADIAN REDFISH	1.0	0.7	0.028	0.018	1.3	0.8	0.048	0.028	2.3	0.9	0.164	0.075	10.5	3.7	0.556	0.237	6.3	4.1	0.39	0.206	2.5	1.5	0.014	0.02
SEA RAVEN									1.0	0.7	1.082	0.903	0.5	0.3	0.511	0.496								
LONGHORN SCULPIN	71.8	33.2	11.109	2.19	54.0	27.8	6.391	2.419	14.5	7.4	2.328	0.951	13.8	3.2	2.442	0.61	1.5	0.6	0.248	0.156	1.0	0.6	0.175	0.101
ALLIGATORFISH	0.8	0.8	0.003	0.003																				
LUMPFISH					0.3	0.3	0.002	0.002	0.3	0.3														
CUNNER					0.3	0.3	0.002	0.002									0.3	0.3	0.021	0.021				
WOLF EELPOUT	0.3	0.3	0.002	0.002	0.5	0.3	0.013	0.007					0.3	0.3	0.005	0.005								
OCEAN POUT	0.8	0.3	0.05	0.021	0.3	0.3	0.008	0.008	0.8	0.8	0.091	0.091	0.3	0.3	0.055	0.055								
WRYMOUTH					0.8	0.8	0.056	0.056	2.0	2.0	0.171	0.171	2.8	1.5	0.206	0.106	1.5	1.2	0.1	0.089	1.5	0.6	0.051	0.045
FOURSPOT FLOUNDER									0.3	0.3	0.105	0.105												
WINDOWPANE	0.8	0.5	0.081	0.073	1.8	0.8	0.106	0.036	2.0	0.9	0.116	0.05	0.8	0.3	0.055	0.029	0.3	0.3	0.01	0.01	0.3	0.3	0.028	0.028
WITCH FLOUNDER	4.0	1.4	0.021	0.015	4.8	1.9	0.052	0.019	13.0	4.9	0.112	0.083	17.8	9.7	0.149	0.058	23.3	2.9	0.386	0.102	31.3	3.3	0.521	0.222
AMERICAN PLAICE	77.0	8.8	4.271	0.711	83.0	7.8	4.645	1.226	98.0	11.9	6.981	1.22	138.8	30.5	10.317	2.162	55.8	5.5	5.721	0.845	71.8	15.1	7.541	2.152
YELLOWTAIL FLOUNDER	0.3	0.3	0.108	0.108	0.5	0.5	0.179	0.179	1.3	0.5	0.306	0.182	1.8	0.6	0.386	0.143					0.5	0.5	0.095	0.059
WINTER FLOUNDER	9.5	4.0	1.151	0.415	6.3	1.8	0.764	0.165	4.0	1.8	0.759	0.337	4.0	1.1	0.623	0.281	0.3	0.3	0.016	0.016	0.3	0.3	0.024	0.024
GREENLAND HALIBUT													0.5	0.5	0.094	0.094								

b. Spring (continued)

	SHALLOW								MID								DEEP							
	EDGE				MUD				EDGE				MUD				EDGE				MUD			
Prey Species	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE
INVERTEBRATES																								
SPONGE													0.3	0.3	0.048	0.048			0.154	0.154				
ANEMONE	0.3	0.3	0.005	0.005					0.5	0.3	0.078	0.078	1.0	1.0			1.8	0.8	0.48	0.377	22.5	21.8	1.065	0.683
SOFTSHELL CLAM					0.5	0.5	0.008	0.008	9.8	9.3	1.196	1.196	7.0	5.5	0.021	0.021	14.0	14.0	0.044	0.044	9.0	6.0	0.011	0.011
HARD CLAM					0.8	0.8	0.076	0.076			0.054	0.054	0.3	0.3	0.029	0.029					0.5	0.5		
COCKLE																	6.5	6.5	0.021	0.021	1.5	1.5	0.009	0.009
SEA SCALLOP									0.5	0.5	0.046	0.046	0.3	0.3			0.8	0.8	0.026	0.026				
WHELK													0.3	0.3	0.025	0.025								
OCTOPUS					0.3	0.3	0.013	0.013																
STARFISH	16.0	16.0	0.109	0.109	0.8	0.5	0.002	0.002	1.0	1.0			1.3	1.3	1.321	1.321	69.8	59.6	0.578	0.504	159.3	100.3	1.13	1.085
BOX STARFISH													81.3	81.3	0.496	0.496								
BRITTLESTAR													0.5	0.5										
NORTHERN SHRIMP	956.0	396.8	5.59	2.418	884.8	367.1	5.001	2.224	1201.3	233.4	7.29	1.575	2017.0	392.7	12.271	2.151	1845.3	890.7	24.525	4.512	4503.3	1308.7	42.556	12.029
CRANGON SHRIMP									0.5	0.3	0.002	0.002												
AMERICAN LOBSTER	25.8	3.1	8.767	3.045	12.5	5.2	2.849	1.132	4.0	2.4	1.266	0.56	5.0	3.0	2.324	0.669	0.5	0.5	0.241	0.241	0.8	0.5	0.564	0.375
ROCK CRAB	3.5	1.4	0.616	0.237	6.3	4.7	1.031	0.665	7.3	4.0	1.04	0.609	9.8	4.7	1.618	0.586	0.3	0.3	0.033	0.033	0.8	0.5	0.196	0.1
SNOW CRAB									0.3	0.3											0.8	0.5	0.106	0.106
NORTHERN STONE CRAB																	0.3	0.5	0.059	0.059	0.8	0.8		
RED CRAB																	0.5	0.5	0.121	0.121	1.0	0.7	0.109	0.109

c. Fall (2005)

	SHALLOW	MID								DEEP							
		EDGE				MUD				EDGE				MUD			
	Not Avaliable	Abundance	SE	Weight	SE	Abundance	SE	Weight	SE	Abundance	SE	Weight	SE	Abundance	SE	Weight	SE
Prey Species		(#)		(Kg)		(#)		(Kg)		(#)		(Kg)		(#)		(Kg)	
CARTILAGINOUS FISHES																	
SPINY DOGFISH (JUVENILE)																	
SPINY DOGFISH		6.3	3.4	35.703	23.767	7.5	3.9	12.770	8.664	29.3	12.6	52.108	22.865	26.3	17.7	51.020	34.901
ATLANTIC TORPEDO										0.3	0.3	8.125	8.125				
WINTER SKATE																	
THORNY SKATE		1.0	1.0	0.290	0.290	0.3	0.3	1.650	1.650	0.5	0.5	1.525	1.525	1.8	0.6	5.541	3.495
BONY FISHES																	
ATLANTIC HERRING		521.3	379.8	19.159	12.064	218.0	133.3	9.888	7.591	86.3	43.5	6.444	3.182	127.0	85.1	8.138	5.678
FOURBEARD ROCKLING		3.5	1.7	0.144	0.063	1.3	0.5	0.054	0.026	4.3	3.1	0.210	0.155	2.0	1.1	0.123	0.057
ATLANTIC COD										0.3	0.3	0.213	0.213				
SILVER HAKE		40.5	2.9	1.909	0.555	50.3	17.5	3.194	0.928	93.8	7.2	9.053	1.055	57.0	13.4	5.905	2.094
RED HAKE		8.8	4.9	1.613	0.896	8.8	2.0	1.660	0.546	21.3	3.0	4.011	0.601	18.3	4.8	4.166	1.372
WHITE HAKE		9.8	2.9	1.917	0.376	15.0	3.7	1.929	0.755	7.5	2.5	1.654	0.440	8.8	1.3	2.318	0.581
GOOSEFISH		6.3	2.6	2.791	1.503	5.3	2.7	2.616	1.147	3.8	0.8	6.150	1.346	2.8	0.8	5.181	1.222
ACADIAN REDFISH		12.0	5.7	0.045	0.030	10.0	7.4	0.050	0.028	4.3	1.4	0.143	0.092	6.8	3.1	0.061	0.050
NORTHERN SEAROBIN		0.5	0.5	0.053	0.053												
SEA RAVEN						0.5	0.5	0.246	0.246								
LONGHORN SCULPIN		6.5	2.2	0.749	0.231	8.8	2.6	1.295	0.463								
ALLIGATORFISH		0.3	0.3	0.005	0.001												
LUMPFISH														0.3	0.3	0.088	0.088
WRYMOUTH		0.3	0.3	0.246	0.246	0.5	0.3	0.063	0.047	0.3	0.3	0.025	0.025	0.8	0.8	0.076	0.076
ATLANTIC MACKEREL		10.5	5.2	0.446	0.223	3.8	2.2	0.318	0.163	9.8	4.9	0.408	0.184	8.8	5.8	0.365	0.239
BUTTERFISH		5.5	2.3	0.159	0.091	7.8	3.5	0.450	0.395	1.3	0.5	0.025	0.009	0.3	0.3	0.009	0.009
FOURSPOT FLOUNDER		0.3	0.3	0.048	0.048												
WINDOWPANE		0.5	0.5	0.094	0.054	0.8	0.8	0.146	0.146								
WITCH FLOUNDER		12.3	4.5	0.916	0.580	30.3	15.0	0.648	0.307	37.5	8.5	1.891	0.820	49.0	12.3	2.061	0.840
AMERICAN PLAICE		180.8	31.5	5.944	1.598	113.3	22.2	5.680	1.385	82.3	20.8	7.440	1.682	57.0	6.5	5.774	1.133
ATLANTIC HALIBUT						0.3	0.3	0.416	0.411								
WINTER FLOUNDER		0.5	0.3	0.056	0.039	1.8	1.2	0.466	0.379								

c. Fall (continued)

	SHALLOW	MID								DEEP							
		EDGE				MUD				EDGE				MUD			
Prey Species	Not Avaliable	Abundance (#)	SE	Weight (Kg)	SE	Abundance (#)	SE	Weight (Kg)	SE	Abundance (#)	SE	Weight (Kg)	SE	Abundance (#)	SE	Weight (Kg)	SE
INVERTEBRATES																	
SPONGE		0.3	0.3	0.096	0.096					0.3	0.3	0.203	0.203				
ANEMONE		0.3	0.3	0.088	0.088									0.5	0.5	0.126	0.126
SEA SCALLOP		1.0	0.7	0.029	0.020	0.3	0.3	0.038	0.038	1.3	0.9	0.048	0.032	0.5	0.3	0.018	0.012
SQUID		10.8	6.0	0.623	0.423	16.5	12.1	0.709	0.505	2.5	1.5	0.113	0.078	2.8	1.3	0.076	0.009
STARFISH						0.3	0.3			0.3	0.3	0.004	0.004	0.5	0.5	0.004	0.004
NORTHERN SHRIMP		5112.5	1727.6	15.384	4.192	5976.8	1039.6	18.815	3.710	10457.0	3729.2	52.365	12.821	10621.5	2494.1	57.085	13.155
AMERICAN LOBSTER		29.5	14.1	9.640	3.700	19.5	10.4	6.356	3.671					0.5	0.5	0.540	0.540
JONAH CRAB		3.5	1.8	0.325	0.189	4.3	1.6	0.406	0.179	1.3	0.8	0.091	0.053	1.0	0.4	0.088	0.052
SNOW CRAB														0.8	0.8	0.040	0.020
NORTHERN STONE CRAB						0.3	0.3	0.053	0.053	1.5	0.9	0.604	0.245	1.0	0.4	0.373	0.126

Table 3. The effects of season (summer vs. fall), depth (shallow, mid, and deep), and habitat (edge vs. mud) on the a. abundance, b. size (TL), and c. condition factor of cod captured in survey 1 (i.e., central Gulf of Maine) were analyzed using three-way ANOVAs. The spring season was not included in the analysis because the high density of cod traps at 40-60 m depth in May and June prevented us from sampling several of our shallow sites.

a. Abundance

	DF	SS	F-Value	P-Value
Season	1	1.3	2.6	0.12
Depth	2	7.6	7.4	0.002
Habitat	1	0.8	1.5	0.23
Season*Depth	2	4.0	3.9	0.03
Season*Habitat	1	3.0	5.8	0.02
Depth*Habitat	2	1.6	1.6	0.22
Season*Depth*Habitat	2	0.4	0.4	0.70
Residual	36	18.5		

b. Size

	DF	SS	F-Value	P-Value
Season	1	34,351.4	1.7	0.21
Depth	2	51,285.1	1.2	0.31
Habitat	1	1,724.6	0.1	0.78
Season * Depth	2	20,383.4	0.5	0.62
Season * Habitat	1	648.0	0.0	0.86
Depth * Habitat	2	6,162.1	0.2	0.86
Residual	21	435,758.9		

c. Condition

	DF	SS	F-Value	P-Value
Season	1	5.31E-07	0.2	0.69
Depth	2	1.18E-05	1.9	0.18
Habitat	1	1.80E-08	0.0	0.94
Season * Depth	2	1.01E-05	1.6	0.22
Season * Habitat	1	6.89E-07	0.2	0.64
Depth * Habitat	2	5.07E-07	0.1	0.92
Residual	21	6.60E-05		

Table 4. The effects of depth (shallow, mid, and deep) and habitat (edge vs. mud) on the diet of a. juvenile and b. adult cod captured in survey 1 (i.e., central Gulf of Maine). Data from different seasons are pooled below. The frequency of occurrence (%FO) is the number of stomachs with prey(i) divided by number of stomachs with food. The weighted abundance (%W) is the total weight of prey(i) divided by the total weight of all prey. The numerical abundance (%N) is the total number of prey(i) divided by total number of all prey. The index of relative importance (IRI) is equal to (%N + %W) x FO for each prey item.

a. Juvenile cod (< 400 mm TL)

	SHALLOW								MID								DEEP							
	MUD				EDGE				MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
MOLLUSCA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bivalvia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca unid.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
POLYCHAETA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CRUSTACEA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphipoda																								
Mysidacae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40.0	3.2	6.9	404	-	-	-	-
Euphausiidae	100.0	29.0	100.0	12900	-	-	-	-	-	-	-	-	-	-	-	-	40.0	96.8	93.1	7596	50.0	9.1	50.0	2955
Decapoda	-	-	-	-	33.3	9.2	50.0	1971	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pandalus borealis	-	-	-	-	33.3	20.2	50.0	2338	-	-	-	-	-	-	-	-	-	-	-	-	50.0	69.1	50.0	5955
CHORDATA					-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M. bilinearis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gadidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clupeidae	-	-	-	-	-	-	-	-					-	-	-	-					-	-	-	-
L. americanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sebastes fasciatus	-	-	-	-					-	-	-	-					-	-	-	-	-	-	-	-
Scomber scombrus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Urophycis spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Unid Fish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANIMAL REMAINS		71.0				70.6				100.0				100.0								21.7		
Number sampled	2				4				2				1				5				3			
Number empty	1				1				1				0				0				1			

b. Adult cod diet (>400 mm TL)

	SHALLOW								MID								DEEP							
	MUD				EDGE				MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
MOLLUSCA																								
Bivalvia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca unid.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CRUSTACEA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphipoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.3	0.04	1.2	18	-	-	-	-
Mysidacae	-	-	-	-	-	-	-	-	33.3	0.1	9.1	305	-	-	-	-	-	-	-	-	-	-	-	-
Euphausiidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28.6	5.4	89.4	2711	-	-	-	-
Pandalus borealis	100.0	32.7	50.0	8270	-	-	-	-	33.3	4.6	18.2	758	-	-	-	-	42.9	2.4	3.5	253	60.0	10.5	37.5	2880
CHORDATA																								
M. bilinearis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.0	56.9	25.0	1638
Gadidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clupeidae	100.0	67.3	50.0	11730	-	-	-	-	100.0	95.4	72.7	16810	-	-	-	-	28.6	61.7	3.5	1865	-	-	-	-
L. americanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sebastes fasciatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.3	7.7	1.2	127	-	-	-	-
Scomber scombrus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Urophycis spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unid Fish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.3	9.9	1.2	159	60.0	25.0	37.5	3750
ANIMAL REMAINS																		12.9				7.6		
Number sampled	1				0				3				0				7				5			
Number empty	0								0								0				0			

Table 5. The effects of season (summer vs. fall), depth (shallow, mid, and deep), and habitat (edge vs. mud) on the a. abundance, b. size (TL), and c. condition factor of haddock captured in survey 1 (i.e., central Gulf of Maine) were analyzed using three-way ANOVAs. The spring season was not included in the analysis because the high density of cod traps at 40-60 m depth in May and June prevented us from sampling several of our shallow sites.

a. Abundance

	DF	SS	F-Value	P-Value
Season	1	374.1	11.6	0.002
Depth	2	153.0	2.4	0.11
Habitat	1	85.3	2.6	0.11
Season*Depth	2	134.0	2.1	0.14
Season*Habitat	1	75.0	2.3	0.14
Depth*Habitat	2	51.0	0.8	0.46
Season*Depth*Habitat	2	45.9	0.7	0.50
Residual	36	1165.5		

b. Size

	DF	SS	F-Value	P-Value
Season	1	62,089.6	6.2	0.01
Depth	2	100,741.9	5.0	0.01
Habitat	1	23,521.4	2.3	0.13
Season * Depth	2	70,208.8	3.5	0.03
Season * Habitat	1	7,670.1	0.8	0.38
Depth * Habitat	2	20,700.7	1.0	0.36
Season * Depth * Habitat	2	22,316.1	1.1	0.33
Residual	145	1,459,436.1		

c. Condition factor

	DF	SS	F-Value	P-Value
Season	1	9.75E-05	0.9	0.34
Depth	2	5.08E-05	0.2	0.79
Habitat	1	9.32E-06	0.1	0.77
Season * Depth	2	5.28E-05	0.2	0.78
Season * Habitat	1	3.49E-05	0.3	0.57
Depth * Habitat	2	6.12E-05	0.3	0.75
Season * Depth * Habitat	2	6.62E-05	0.3	0.74
Residual	117	0.01		

Table 6. The effects of depth (shallow, mid, and deep) and habitat (edge vs. mud) on the diet of a. juvenile and b. adult haddock captured in survey 1 (i.e., central Gulf of Maine). Data from different seasons are pooled below. The frequency of occurrence (%FO) is the number of stomachs with prey(i) divided by number of stomachs with food. The weighted abundance (%W) is the total weight of prey(i) divided by the total weight of all prey. The numerical abundance (%N) is the total number of prey(i) divided by total number of all prey. The index of relative importance (IRI) is equal to (%N + %W) x FO for each prey item.

a. Juvenile haddock (<300 mm TL)

	SHALLOW								MID								DEEP							
	MUD				EDGE				MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
MOLLUSCA																								
Bivalvia	4.6	0.0	1.5	7	-	-	-	-	9.1	1.0	7.9	81	-	-	-	-	-	-	-	-	-	-	-	-
Nuculidae	9.1	0.0	3.0	28	6.7	0.0	3.4	23	18.2	1.4	19.1	373	-	-	-	-	-	-	-	-	-	-	-	-
Nuculanidae	-	-	-	-	-	-	-	-	27.3	0.9	23.8	674	-	-	-	-	50.0	0.3	25.0	1265	-	-	-	-
Astartidae	-	-	-	-	-	-	-	-	4.6	0.0	1.6	7	-	-	-	-	-	-	-	-	-	-	-	-
POLYCHAETA	90.9	94.9	30.3	11381	93.3	94.2	27.1	11317	77.3	80.3	33.3	8781	85.7	87.0	75.0	13883	50.0	24.9	50.0	3745	-	-	-	-
CRUSTACEA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphipoda	36.4	0.5	31.8	1176	40.9	0.5	52.5	2168	-	-	-	-	7.1	0.1	6.3	46	-	-	-	-	100.0	100.0	100.0	20000
Cumacea	13.6	0.0	4.6	63	-	-	-	-	-	-	-	-	7.1	0.1	6.3	46	-	-	-	-	-	-	-	-
Mysidacea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pandalus borealis	-	-	-	-	-	-	-	-	13.6	4.4	4.8	125	-	-	-	-	50.0	74.8	25.0	4990	-	-	-	-
ECHINODERMATA																								
Ophiuroidea	50.0	2.6	28.8	1570	46.7	2.9	17.0	929	27.3	0.8	9.5	281	14.3	0.4	12.5	184	-	-	-	-	-	-	-	-
ANIMAL REMAINS		1.9				2.4				11.3				12.4										
Number sampled	30				15				28				17				2				2			
Number empty	8				0				6				3				0				1			

b. Adult haddock (>300 mm)

	SHALLOW								MID								DEEP							
	MUD				EDGE				MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
MOLLUSCA																								
Bivalvia	-	-	-	-	-	-	-	-	31.3	0.1	9.3	294	50.0	0.1	15.9	800	83.3	1.1	18.0	1591	50.0	0.6	16.7	865
Nuculidae	-	-	-	-	-	-	-	-	43.8	0.8	16.8	771	66.7	0.6	9.1	647	83.3	3.6	40.1	3640	33.3	1.2	22.2	779
Nuculanidae	-	-	-	-	-	-	-	-	62.5	2.9	34.6	2344	50.0	2.0	25.0	1350	33.3	0.3	1.7	67	33.3	0.9	11.1	400
Astartidae	-	-	-	-	-	-	-	-	12.5	0.1	3.7	48	-		-	-	33.3	0.0	2.5	84	-	-	-	-
Myidae	-	-	-	-	-	-	-	-	6.3	0.0	0.9	6	-	-	-	-	50.0	0.3	5.1	270	-	-	-	-
Cardiidae	-	-	-	-	-	-	-	-	6.3	0.5	0.9	9	-	-	-	-	16.7	0.1	1.7	30	-	-	-	-
Cuspidariidae	-	-	-	-	-	-	-	-					16.7	0.0	2.3	39	16.7	0.1	0.9	16	-	-	-	-
Tellinidae	-	-	-	-	-	-	-	-	6.3	0.2	0.9	7	-	-	-	-	16.7	0.0	2.5	42	-	-	-	-
POLYCHAETA	100.0	100.0	100.0	20000	-	-	-	-	87.5	89.5	23.4	9879	100.0	93.0	22.7	11570	66.7	86.2	7.7	6263	66.7	42.7	22.2	4329
CRUSTACEA																								
Amphipoda	-	-	-	-	-	-	-	-	6.3	0.0	0.9	6	16.7	0.0	2.3	39	-	-	-	-	-	-	-	-
Mysidacae	-	-	-	-	-	-	-	-	6.3	0.1	0.9	6	-	-	-	-	16.7	0.1	0.9	17	-	-	-	-
Pandalus borealis	-	-	-	-	-	-	-	-	6.3	2.0	0.9	18	-	-	-	-	-	-	-	-	16.7	24.8	5.6	508
ECHINODERMATA																								
Goniopectinidae	-	-	-	-	-	-	-	-	18.8	0.8	5.6	120	33.3	1.8	9.1	364	-	-	-	-	-	-	-	-
Synaptidae	-	-	-	-	-	-	-	-	6.3	0.3	0.9	8	-	-	-	-	-	-	-	-	-	-	-	-
Ophiuroidea	-	-	-	-	-	-	-	-	-	-	-	-	66.7	1.1	11.4	834	66.7	1.5	18.8	1354	66.7	0.6	22.2	1521
CHORDATA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unid Fish	-	-	-	-	-	-	-	-	-	-	-	-	16.7	1.0	2.3	55	-	-	-	-	-	-	-	-
ANIMAL REMAINS										2.7				0.4				6.8				29.2		
Number sampled	1				0				16				6				6				7			
Number empty	0				0				0				0				0				1			

Table 7. The effects of season (summer vs. fall), depth (shallow, mid, and deep), and habitat (edge vs. mud) on the a. abundance, b. size (TL), and c. condition factor of goosefish captured in survey 1 (i.e., central Gulf of Maine) were analyzed using three-way ANOVAs. The spring season was not included in the analysis because the high density of cod traps at 40-60 m depth in May and June prevented us from sampling several of our shallow sites.

a. Abundance

	DF	SS	F-Value	P-Value
Season	1	216.8	16.0	0.0003
Depth	2	193.2	7.1	0.003
Habitat	1	5.3	0.4	0.53
Season*Depth	2	94.5	3.5	0.04
Season*Habitat	1	0.1	0.0	0.94
Depth *Habitat	2	8.2	0.3	0.74
Season*Depth *Habitat	2	2.2	0.1	0.92
Residual	36	487.5		

b. Size

	DF	SS	F-Value	P-Value
Season	1	181,295.3	9.4	0.002
Depth	2	87,102.5	2.3	0.11
Habitat	1	3,614.0	0.2	0.67
Season*Depth	2	15,141.5	0.4	0.68
Season*Habitat	1	1,345.7	0.1	0.79
Depth*Habitat	2	24,232.9	0.6	0.53
Season*Depth*Habitat	2	10,079.6	0.3	0.77
Residual	236	4,544,534.5		

c. Condition factor

	DF	SS	F-Value	P-Value
Season	1	0.0000094	0.15	0.70
Depth	2	0.0000583	0.46	0.63
Habitat	1	0.0000002	0.00	0.96
Season*Depth	2	0.0000520	0.41	0.66
Season*Habitat	1	0.0000590	0.93	0.33
Depth*Habitat	2	0.0000869	0.69	0.50
Season*Depth*Habitat	2	0.0001195	0.95	0.39
Residual	231	0.01457285		

Table 8. The effects of depth (shallow, mid, and deep) and habitat (edge vs. mud) on the diet of a. juvenile and b. adult goosefish captured in survey 1 (i.e., central Gulf of Maine). Data from different seasons are pooled below. The frequency of occurrence (%FO) is the number of stomachs with prey(i) divided by number of stomachs with food. The weighted abundance (%W) is the total weight of prey(i) divided by the total weight of all prey. The numerical abundance (%N) is the total number of prey(i) divided by total number of all prey. The index of relative importance (IRI) is equal to (%N + %W) x FO for each prey item.

a. Juvenile goosefish (<300 mm TL)

	SHALLOW								MID								DEEP							
	MUD				EDGE				MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
CRUSTACEA																								
Mysidae	20.8	0.7	49.0	1034	5.3	0.0	4.8	25	31.8	0.3	33.3	1068	26.1	1.3	59.4	1584	-	-	-	-	16.7	4	68.3	1207
Euphausiidae	-	-	-	-	-	-	-	-	4.6	0.1	1.7	8	-	-	-	-	12.5	0.5	16.7	215	16.7	1.4	4.9	105
Pandalus borealis	8.3	0.6	3.9	37	26.3	4.3	23.8	739	40.9	11.3	26.7	1554	34.8	8.2	14.1	776	25	24.6	33.3	1448	25	9.9	7.3	430
CEPHALOPODA	4.2	4.2	2.0	26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHORDATA																								
Enchelyopus cimbrius	20.8	7.8	13.7	447	10.5	2.9	14.3	181	22.7	11.6	11.7	529	21.7	18.8	7.8	577	25	20	33.3	1333	25	11.8	9.8	540
Merluccius bilinearis	4.2	10.7	2.0	53	5.3	17.9	4.8	120		-	-	-	8.7	15.0	3.1	157	-	-	-	-	-	-	-	-
Urophycis spp.	-	-	-	-	-	-	-	-	4.6	18.2	1.7	92	-	-	-	-	-	-	-	-	8.3	2.6	2.4	42
Unid Gadidae	4.2	2.6	3.9	27	5.3	0.8	4.8	30	-	-	-	-	4.4	1.3	1.6	13	-	-	-	-	8.3	17.8	2.4	168
Sebastes fasciatus	4.2	0.5	2.0	11	-	-	-	-	9.1	2.9	6.7	87	-	-	-	-	-	-	-	-	-	-	-	-
Lumpenus lumpretaeformis	-	-	-	-	-	-	-	-	9.1	10.8	3.3	128	4.4	1.5	1.6	14	-	-	-	-	-	-	-	-
Pleuronectiformes	8.3	20.5	3.9	203	10.5	19.3	9.5	302	-	-	-	-	4.4	13.8	1.6	68	-	-	-	-	-	-	-	-
Clupeidae	16.7	31.4	9.8	688	21.1	6.1	19.1	532	27.3	17.4	3.3	565	13.0	10.8	4.7	202	-	-	-	-	8.3	21.8	2.4	201
Unid Fish	20.8	6.6	9.8	341	15.8	39.3	19.1	923	9.1	19.3	11.7	282	17.4	11.2	6.3	305	12.5	1.5	16.7	228	8.3	1.3	2.4	31
ANIMAL REMAINS		14.4				9.4				8.2				17.9				53.5				29.4		
Number sampled	30				25				31				40				10				16			
Number empty	6				6				9				17				2				4			

b. Adult goosefish (>300 mm TL)

	SHALLOW								MID								DEEP							
	MUD				EDGE				MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
CRUSTACEA																								
Euphausiidae	-	-	-	-	-	-	-	-	2.6	0.0	2.7	7	-	-	-	-	-	-	-	-	-	-	-	-
Pandalus borealis	29.2	2.2	25.8	818	11.1	0.2	9.1	103	33.3	3.9	38.4	1409	25.9	1.1	22.4	609	37.5	11.5	58.3	2618	50	17.1	65.7	4140
Homarus americanus	-	-	-	-	-	-	-	-	2.6	0.2	1.4	4	-	-	-	-	-	-	-	-	-	-	-	-
CEPHALOPODA	-	-	-	-	-	-	-	-	-	-	-	-	7.4	0.7	4.1	36	6.3	7.5	4.2	74	12.5	9.8	5.7	194
CHORDATA																								
Squalus acanthias	-	-	-	-	-	-	-	-	2.6	2.3	1.4	10	-	-	-	-	-	-	-	-	-	-	-	-
Enchelyopus cimbrius	12.5	7.1	9.7	210	-	-	-	-	15.4	6.2	9.6	243	-	-	-	-	-	-	-	-	6.3	5.3	5.7	69
Merluccius bilinearis	-	-	-	-	-	-	-	-	20.5	16.4	12.3	588	25.9	16.5	14.3	798	12.5	21.7	8.3	375	6.3	6.0	2.9	56
Urophycis spp.	-	-	-	-	-	-	-	-	2.6	2.1	1.4	9	3.7	3.4	4.1	28	-	-	-	-	-	-	-	-
Unid Gadidae	16.7	19.6	12.9	543	33.3	23.7	45.5	2304	2.6	1.9	1.4	9	7.4	2.3	2.0	32	6.3	11.2	4.2	97	12.5	31.3	5.7	463
Sebastes fasciatus	4.2	2.5	3.2	24	-	-	-	-	2.6	0.1	1.4	4	3.7	0.7	2.0	10	6.3	20.3	4.2	154	-	-	-	-
Lophius americanus	-	-	-	-	-	-	-	-	2.6	1.0	1.4	6	-	-	-	-	-	-	-	-	-	-	-	-
Cryptacanthodes maculatus	4.2	1.8	3.2	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Myoxocephalus octodecemspinosus	8.3	5.2	3.2	70	-	-	-	-	-	-	-	-	3.7	7.7	2.0	36	-	-	-	-	-	-	-	-
Pleuronectiformes	4.2	4.2	3.2	31	-	-	-	-	23.1	28.3	13.7	970	22.2	17.1	14.3	697	6.3	1.1	4.2	33	6.3	1.1	2.9	25
Clupeidae	25.0	39.2	29.0	1705	55.6	60.1	45.5	5871	15.4	18.1	9.6	427	22.2	31.2	26.5	1281	12.5	14.2	8.3	281	6.3	9.3	5.7	95
Unid Fish	12.5	4.2	9.7	174	-	-	-	-	10.3	3.1	5.5	89	14.8	5.0	8.2	195	12.5	5.9	8.3	178	12.5	5.3	5.7	138
ANIMAL REMAINS		14.1				16.0				16.5				14.3				6.7				14.9		
Number sampled	32				16				48				40				18				20			
Number empty	9				7				10				13				2				4			

Table 9. The effects of closure status and habitat on the abundance and biomass of all organisms captured in trawl survey 2 (i.e., Western Gulf of Maine Closure Area survey) in the a. fall of 2004 and b. spring of 2005.

a. Fall (2004)

	IN								OUT							
	EDGE				MUD				EDGE				MUD			
Prey Species	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE
CARTILAGINOUS FISHES																
SPINY DOGFISH (JUVENILE)	19.5	10.4	6.535	3.524	47.8	25.1	11.060	4.726	8.3	4.5	1.865	1.405	43.5	12.3	8.855	2.431
SPINY DOGFISH	232.8	175.0	210.633	127.460	69.5	16.1	109.880	24.178	132.8	48.2	177.859	70.818	58.5	24.9	99.858	34.804
THORNY SKATE	1.8	0.5	7.215	2.735	0.5	0.3	1.375	1.214	1.3	0.5	5.600	2.735	0.3	0.3	0.600	0.600
SMOOTH SKATE	0.5	0.3	0.433	0.291	1.0	0.7	0.948	0.720	0.3	0.3	0.430	0.267	0.3	0.3	0.159	0.159
BONY FISHES																
ATLANTIC MENHADEN															4.860	4.860
ATLANTIC HERRING	6.0	2.8	4.084	3.023	12.0	4.1	4.288	2.415	218.0	78.9	46.230	16.421	68.3	55.6	63.210	53.743
FOURBEARD ROCKLING	0.3	0.3	0.002	0.002	3.0	0.6	3.821	3.726	2.5	1.7	0.131	0.101	4.3	2.4	0.149	0.081
ATLANTIC COD	3.8	1.7	14.608	7.262	1.0	0.4	2.408	2.027	1.3	0.5	2.751	1.000	1.3	0.5	5.950	2.131
HADDOCK	3.5	2.4	6.545	4.365					0.5	0.3	0.086	0.051	0.3	0.3	0.288	0.288
SILVER HAKE	187.0	77.0	14.226	5.447	99.5	49.9	7.115	3.068	1,409.0	621.4	96.065	39.019	810.0	268.4	56.275	18.585
POLLOCK	0.3	0.3	0.065	0.065	4.3	4.3	13.540	13.540	0.3	0.3	0.025	0.025	0.3	0.3	1.250	1.250
RED HAKE	22.8	11.0	6.973	3.584	32.8	15.9	11.360	5.121	38.3	14.2	11.025	3.851	23.5	2.4	7.240	0.531
WHITE HAKE	3.5	1.2	2.621	0.600	7.0	1.4	8.635	3.066	8.5	4.0	11.750	8.538	8.0	1.4	7.315	3.366
GOOSEFISH	0.5	0.3	0.336	0.195	1.5	0.6	1.695	0.873	5.3	1.9	4.093	2.384	4.3	0.5	5.611	2.454
ACADIAN REDFISH	1,065.3	646.8	110.705	72.713	774.3	216.1	50.925	23.896	411.8	305.7	45.678	31.838	320.7	204.7	25.848	16.764
SEA RAVEN	0.5	0.3	0.585	0.341					0.3	0.3	0.114	0.114				
LONGHORN SCULPIN	1.5	0.6	0.166	0.089					0.5	0.5	0.056	0.056				
ALLIGATORFISH	0.3	0.3	0.003	0.003												
LUMPFISH	0.5	0.3	0.700	0.436	2.0	1.7	9.220	3.881	0.8	0.5	1.380	0.855	0.5	0.5	1.005	1.005
OCEAN POUT	1.0	0.6	0.039	0.022												
ATLANTIC WOLFFISH									0.3	0.3	2.050	2.050				
BUTTERFISH									0.3	0.3	0.015	0.015				
WITCH FLOUNDER	8.3	0.9	2.508	0.689	17.8	9.1	2.195	0.698	23.8	7.6	4.345	1.582	18.5	5.3	3.120	1.443
AMERICAN PLAICE	113.8	22.4	8.6	1.4	51.8	8.6	4.2	0.6	164.5	25.5	8.6	0.8	170.5	30.4	11.5	1.3
YELLOWTAIL FLOUNDER									0.3	0.3	0.011	0.011				
WINTER FLOUNDER									18.0	17.7	30.888	30.771				

a. Fall (continued)

	IN								OUT							
	EDGE				MUD				EDGE				MUD			
Prey Species	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE	Abund. (#)	SE	Weight (Kg)	SE
INVERTEBRATES																
ANEMONE	7.5	3.6	3.506	1.766	1.8	1.4	0.838	0.688	2.0	1.1	1.045	0.561	0.3	0.3	0.120	0.120
COCKLE	0.5	0.5														
SEA SCALLOP	2.0	1.4	0.023	0.020	0.8	0.5	0.030	0.200	0.5	0.5	0.004	0.004				
TEN-RIDGE WHELK																
OCTOPUS	0.5	0.3	0.019	0.012												
SQUID	13.5	6.1	0.563	0.170	6.5	2.0	0.378	0.046	20.8	9.2	2.835	2.331	19.0	7.6	0.856	0.360
STARFISH	1.0	0.7	0.208	0.146	0.3	0.3	0.053	0.053								
NORTHERN SHRIMP	3,373.3	1,390.8	27.050	11.424	4,431.0	927.0	34.910	8.253	1,496.0	962.8	11.998	7.719	2,082.0	1,145.5	16.750	9.227
AMERICAN LOBSTER	0.3	0.3	0.600	0.600												
HERMIT CRAB	0.3	0.3														
SPIDER CRAB	0.3	0.3	0.001	0.001												
JONAH CRAB									0.5	0.5	0.038	0.038				
SNOW CRAB					0.3	0.3	0.081	0.081								

b. Spring (2005)

	IN								OUT							
	EDGE				MUD				EDGE				MUD			
Prey Species	Abundance (#)	SE	Weight (Kg)	SE	Abundance (#)	SE	Weight (Kg)	SE	Abundance (#)	SE	Weight (Kg)	SE	Abundance (#)	SE	Weight (Kg)	SE
CARTILAGINOUS FISHES																
SPINY DOGFISH	0.8	0.8	1.415	1.415					1.8	1.4	3.423	2.959	0.3	0.3	0.750	0.750
LITTLE SKATE									0.5	0.3	0.625	0.375				
WINTER SKATE									0.3	0.3	0.900	0.900				
THORNY SKATE	1.8	1.1	2.498	1.563	1.0	0.4	1.485	0.865	0.5	0.5	0.905	0.905	0.5	0.3	3.925	2.647
SMOOTH SKATE	0.5	0.3	0.418	0.257	2.8	0.9	1.800	1.375	0.3	0.3	0.116	0.116	0.5	0.3	0.285	0.165
BONY FISHES																
ATLANTIC HERRING	11.8	5.9	1.635	1.024	1.5	1.2	0.225	0.181	146.0	132.4	9.858	7.975	54.8	51.8	3.608	3.248
FOURBEARD ROCKLING	1.0	0.7	0.017	0.010	3.3	1.4	0.108	0.038	3.3	1.5	0.119	0.050	2.0	1.2	0.063	0.036
ATLANTIC COD	5.8	1.9	16.013	10.878	0.3	0.3	0.023	0.023	3.8	0.9	8.352	3.241	4.0	1.4	9.209	6.993
HADDOCK	1.5	0.6	1.391	0.781					1.5	0.5	3.373	2.095	0.8	0.5	0.956	0.571
SILVER HAKE	46.5	35.6	3.908	3.182	19.3	9.8	1.318	1.097	267.0	81.6	24.800	7.191	189.3	70.7	16.296	4.996
POLLOCK	0.3	0.3	0.750	0.750	0.3	0.3	0.925	0.925					0.3	0.3	0.750	0.750
RED HAKE	27.8	13.9	4.945	2.554	9.8	2.5	2.605	0.629	17.5	3.6	3.266	0.965	10.5	8.1	2.510	1.908
WHITE HAKE	0.8	0.9	0.350	0.261	5.8	2.0	0.683	0.287	3.8	1.1	1.095	0.439	7.0	2.8	1.643	0.615
GOOSEFISH	2.8	1.7	5.813	4.038	3.8	0.3	6.920	3.078	5.8	0.6	5.556	1.379	6.3	3.6	5.047	1.549
ACADIAN REDFISH	1,186.5	574.4	80.805	41.384	213.8	64.8	47.863	16.650	662.0	538.3	72.475	41.333	149.5	61.3	13.170	6.133
SEA RAVEN	2.8	0.5	1.738	0.522					1.3	0.8	0.808	0.672				
LONGHORN SCULPIN	5.3	2.3	0.854	0.425	0.3	0.3	0.020	0.020	1.5	1.0	0.158	0.118	0.3	0.3	0.195	0.195
ALLIGATORFISH	0.5	0.3	0.003	0.001												
LUMPFISH									0.5	0.5	0.001	0.001				
OCEAN POUT	3.0	1.9	0.520	0.377					2.0	1.4	0.056	0.039	0.5	.5.	0.026	0.026
WRYMOUTH	1.5	1.5	0.120	0.120					0.3	0.3	0.013	0.013				
ATLANTIC WOLFFISH									0.3	0.3	1.875	1.875				
FOURSPOT FLOUNDER													0.3	0.3	0.073	0.073
WITCH FLOUNDER	6.3	4.4	0.830	0.466	8.3	5.6	2.180	1.055	35.5	11.2	5.935	2.951	22.3	5.7	2.338	0.407
AMERICAN PLAICE	85.0	22.7	5.316	1.028	25.3	4.0	1.720	0.413	194.8	32.2	41.565	27.354	204.5	98.0	14.845	7.266
YELLOWTAIL FLOUNDER									1.0	1.0	0.333	0.333	2.0	1.7	0.695	0.490
WINTER FLOUNDER									0.5	0.3	0.065	0.050	4.8	2.5	0.380	0.263

b. Spring (continued)

	IN								OUT							
	EDGE				MUD				EDGE				MUD			
Prey Species	Abundance (#)	SE	Weight (Kg)	SE	Abundance (#)	SE	Weight (Kg)	SE	Abundance (#)	SE	Weight (Kg)	SE	Abundance (#)	SE	Weight (Kg)	SE
INVERTEBRATES																
SPONGE	0.3	0.3	0.045	0.045					0.3	0.3	0.003	0.003	0.3	0.3	0.095	0.095
ANEMONE	11.0	2.7	3.401	1.452	4.0	1.8	0.473	0.203	4.5	2.1	2.210	1.072	1.5	0.9	0.690	0.439
UNIDENTIFIED BIVALVE	4.5	2.2	0.026	0.018					0.5	0.3	0.008	0.003	0.3	0.3	0.001	0.001
COCKLE																
SEA SCALLOP	0.5	0.3	0.020	0.020									0.3	0.3	0.015	0.009
TEN-RIDGE WHELK									0.3	0.3	0.018	0.020	0.3	0.3	0.020	0.020
OCTOPUS	0.5	0.5	0.015	0.015					0.8	0.5	0.009	0.007	0.3	0.3	0.003	0.003
STARFISH	0.8	0.5	0.120	0.073	0.3	0.3	0.080	0.080	1.8	0.2	0.018	0.018	12.8	11.1	0.348	0.087
BLOOD STAR					0.3	0.3	0.008	0.008								
NORTHERN SHRIMP	3,156.5	1,054.3	25.880	8.508	13,286.3	9,259.4	93.410	67.366	5,085.6	2,953.7	24.095	13.444	3,224.5	947.7	17.695	5.482
AMERICAN LOBSTER									1.8	1.0	0.905	0.554	1.5	1.2	0.351	0.296
HERMIT CRAB	0.3	0.3	0.001	0.001												
SPIDER CRAB	0.3	0.3	0.001	0.001												
JONAH CRAB									0.3	0.3	0.069	0.069	1.0	1.0	0.220	0.220
NORTHERN STONE CRAB									0.3	0.3	0.006	0.006				

Table 10. The effects of season (spring vs. fall), closure status (in vs. out), and habitat (edge vs. mud) on the a. abundance, b. size (TL), and c. condition factor of cod captured in survey 2 (i.e., Western Gulf of Maine Closure Area survey) were analyzed using three-way ANOVAs.

a. Abundance

	DF	SS	F-Value	P-Value
Season	1	21.1	4.35	0.05
Closure	1	0.1	0.03	0.87
Habitat	1	32.0	6.59	0.02
Season*Closure	1	8.0	1.65	0.21
Season*Habitat	1	3.1	0.64	0.43
Closure *Habitat	1	36.1	7.44	0.01
Season*Closure *Habitat	1	4.5	0.93	0.35
Residual	24	116.5		

b. Size

	DF	SS	F-Value	P-Value
Season	1	280,170	4.46	0.04
Closure	1	55,212	0.88	0.35
Habitat	1	71,651	1.14	0.29
Season *Closure	1	7,287	0.12	0.73
Season *Habitat	1	90,124	1.44	0.23
Closure*Habitat	1	182,381	2.90	0.09
Season *Closure*Habitat	1	1,546	0.02	0.88
Residual	75	4,708,974		

c. Condition factor

	DF	SS	F-Value	P-Value
Season	1	0.000053	0.01	0.91
Closure	1	0.001277	0.32	0.57
Habitat	1	0.000033	0.01	0.93
Season *Closure	1	0.002468	0.62	0.43
Season *Habitat	1	0.000123	0.03	0.86
Habitat*Closure	1	0.000253	0.06	0.80
Habitat*Closure*Season	1	0.000002	0.00	0.98
Residual	74	0.294905		

Table 11. The effects of closure status and habitat type on the diet of a. juvenile and b. adult cod captured in survey 2 (i.e., Western Gulf of Maine Closure Area survey). Data from different seasons are pooled below. The frequency of occurrence (%FO) is the number of stomachs with prey(i) divided by number of stomachs with food. The weighted abundance (%W) is the total weight of prey(i) divided by the total weight of all prey. The numerical abundance (%N) is the total number of prey(i) divided by total number of all prey. The index of relative importance (IRI) is equal to (%N + %W) x FO for each prey item.

a. Juvenile cod (< 400 mm TL) diet

	IN								OUT							
	MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
CNIDARIA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MOLLUSCA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
POLYCHAETA	-	-	-	-	-	-	-	-	14.3	0.6	2.5	44	-	-	-	-
CRUSTACEA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	9.1	0.2	1.2	13	-	-	-	-	-	-	-	-
Isopoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mysidacae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Euphausiidae	-	-	-	-	27.3	13.0	92.7	2886	28.6	18.6	87.5	3034	16.7	0.4	14.2	244
Paguridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Canceridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pandalus borealis	-	-	-	-	36.4	29.6	4.8	1252	28.6	32.9	7.5	1155	50.0	10.5	42.9	2670
Homarus americanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHORDATA																
M. bilinearis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gadidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clupeidae	100.0	100.0	100.0	20000	9.1	37.5	1.2	352	-	-	-	-	16.7	81.5	28.6	1839
L. americanus	-	-	-	-	-	-	-	-	-	-	-	-	16.7	1.9	14.2	269
Sebastes fasciatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scomber scombrus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Urophycis spp.	-	-	-	-	-	-	-	-	14.3	46.1	2.5	695	-	-	-	-
Unid Fish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANIMAL REMAINS						19.7				1.8				5.7		
Number sampled	2				12				9				7			
Number empty	1				1				2				1			

b. Adult cod (> 400 mm TL) diet

	IN								OUT							
	MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
CNIDARIA	-	-	-	-	-	-	-	-	9.100	0.800	1.900	-	-	-	-	-
MOLLUSCA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	4.5	1.8	1.4	14	-	-	-	-	-	-	-	-
POLYCHAETA	-	-	-	-	9.1	0.2	1.4	15	-	-	-	-	-	-	-	-
CRUSTACEA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Isopoda	-	-	-	-	4.5	0.0	0.7	3	-	-	-	-	-	-	-	-
Mysidacae	-	-	-	-	4.5	0.1	5.7	26	9.1	0.0	15.4	140	-	-	-	-
Euphausiidae	-	-	-	-	31.8	3.4	70.7	2356	54.5	1.1	57.7	3205	40.0	6.2	79.2	3416
Paguridae	-	-	-	-	4.5	0.1	0.7	4	-	-	-	-	-	-	-	-
Canceridae	-	-	-	-	4.5	2.5	0.7	14	-	-	-	-	-	-	-	-
Pandalus borealis	33.3	0.8	20.0	693	40.9	4.1	7.1	458	18.1	1.3	3.8	92	60.0	11.1	13.2	1458
Homarus americanus	-	-	-	-	4.5	0.7	0.7	6	-	-	-	-	-	-	-	-
CHORDATA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M. bilinearis	-	-	-	-	13.6	12.5	2.1	199	18.1	15.4	3.8	348	-	-	-	-
Gadidae	-	-	-	-	-	-	-	-	-	-	-	-	20.0	25.7	1.9	552
Clupeidae	33.3	93.2	80	5768	36.4	66.1	7.9	2694	27.3	55.8	11.5	1837	20.0	11.0	1.9	258
L. americanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sebastes fasciatus	-	-	-	-	-	-	-	-	18.1	20.8	5.8	481	20.0	37.5	3.8	826
Scomber scombrus	-	-	-	-	4.5	5.9	0.7	30	-	-	-	-	-	-	-	-
Urophycis spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unid Fish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ANIMAL REMAINS			6.3			2.3				4.4				8.4		

Table 12. a. The effects of season (spring vs. fall), closure status (in vs. out), and habitat (edge vs. mud) on the a. abundance of haddock caught in survey 2 (i.e., Western Gulf of Maine Closure Area survey) were analyzed using a three-way ANOVA. The effects of season and closure status on the b. size (TL), and c. condition factor of haddock captured in survey 2 were analyzed using two-way ANOVAs. The effect of habitat was removed from these 2 ANOVAs because the scarcity of haddock in the mud habitat prevented orthogonal analysis.

a. Abundance

	DF	SS	F-Value	P-Value
Season	1	0.1	0.04	0.85
Closure	1	2.0	0.60	0.44
Habitat	1	18.0	5.43	0.03
Season*Closure	1	6.1	1.85	0.19
Season*Habitat	1	1.1	0.34	0.57
Closure*Habitat	1	8.0	2.42	0.13
Season*Closure*Habitat	1	3.1	0.94	0.34
Residual	24	79.5		

b. Size

	DF	SS	F-Value	P-Value
Season	1	17,504	2.34	0.14
Closure	1	7,132	0.96	0.34
Season*Closure	1	152,297	20.40	0.0001
Residual	28	209,011		

c. Condition factor

	DF	SS	F-Value	P-Value
Season	1	0.0002	0.95	0.34
Closure	1	0.0004	1.76	0.20
Season*Closure	1	0.0002	0.95	0.34
Residual	27	0.0061		

Table 13. The effects of closure status and habitat type on the diet of adult haddock captured in survey 2 (i.e., Western Gulf of Maine Closure Area survey). Data from different seasons are pooled below. The frequency of occurrence (%FO) is the number of stomachs with prey(i) divided by number of stomachs with food. The weighted abundance (%W) is the total weight of prey(i) divided by the total weight of all prey. The numerical abundance (%N) is the total number of prey(i) divided by total number of all prey. The index of relative importance (IRI) is equal to (%N + %W) x FO for each prey item.

a. Adult haddock (>300 mm TL)

	IN								OUT							
	MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
CNIDARIA	-	-	-	-	11.1	39.0	4.1	478	-	-	-	-	-	-	-	-
MOLLUSCA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bivalvia	-	-	-	-	50.0	6.1	65.5	3580	33.3	1.3	7.7	300	-	-	-	-
POLYCHAETA	-	-	-	-	27.8	14.3	3.4	492	-	-	-	-	-	-	-	-
CRUSTACEA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mysidacae	-	-	-	-	5.5	0.0	0.7	4	33.3	6.2	30.8	1232	33.3	1.3	47.4	1622
Euphausiidae	-	-	-	-	5.5	7.6	24.1	174	33.3	23.5	61.5	2831	-	-	-	-
Pandalus borealis	-	-	-	-	11.1	7.7	1.4	101	-	-	-	-	16.7	19.9	47.4	1124
Homarus americanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ECHINODERMATA																
Ophiuroidea	-	-	-	-	5.5	0.0	0.7	-	-	-	-	-	-	-	-	-
CHORDATA																
Clupeidae	-	-	-	-	-	-	-	-	-	-	-	-	16.7	58.2	5.3	1060
ANIMAL REMAINS						25.2				69.2				20.7		
Number sampled	0				19				5				7			
Number empty	0				1				2				1			
					116.5	99.9	99.9		99.9	100.2	100.0	4362.3	66.7	100.1	100.1	3806.1

Table 14. The effects of season (spring vs. fall), closure status (in vs. out), and habitat (edge vs. mud) on the a. abundance, b. size (TL), and c. condition factor of goosefish captured in survey 2 (i.e., Western Gulf of Maine Closure Area survey) were analyzed using three-way ANOVAs.

a. Abundance

	DF	SS	F-Value	P-Value
Season	1	19.5	2.13	0.16
Closure	1	87.8	9.57	0.005
Habitat	1	1.5	0.17	0.69
Season*Closure	1	0.8	0.09	0.77
Season*Habitat	1	2.5	0.28	0.60
Closure*Habitat	1	3.8	0.41	0.53
Closure*Habitat*Season	1	0.3	0.03	0.86
Residual	24	220.3		

b. Size

	DF	SS	F-Value	P-Value
Season	1	5,008	0.19	0.66
Closure	1	169,267	6.54	0.01
Habitat	1	3,233	0.12	0.72
Season*Closure	1	6,661	0.26	0.61
Season*Habitat	1	21,839	0.84	0.36
Closure*Habitat	1	1,249	0.05	0.83
Closure*Habitat*Season	1	551	0.02	0.88
Residual	115	2,978,138		

c. Condition factor

	DF	SS	F-Value	P-Value
Season	1	1.00	8.39	0.005
Closure	1	0.09	0.80	0.37
Habitat	1	0.48	4.07	0.046
Season*Closure	1	0.19	1.57	0.21
Season*Habitat	1	0.02	0.15	0.70
Closure*Habitat	1	0.18	1.54	0.22
Closure*Habitat*Season	1	0.07	0.59	0.45
Residual	113	13.40		

Table 15. The effects of closure status and habitat type on the diet of a. juvenile and b. adult goosefish captured in survey 2 (i.e., Western Gulf of Maine Closure Area survey). Data from different seasons are pooled below. The frequency of occurrence (%FO) is the number of stomachs with prey(i) divided by number of stomachs with food. The weighted abundance (%W) is the total weight of prey(i) divided by the total weight of all prey. The numerical abundance (%N) is the total number of prey(i) divided by total number of all prey. The index of relative importance (IRI) is equal to (%N + %W) x FO for each prey item.

a. Juvenile goosefish (<300 mm TL)

	IN								OUT							
	MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
CRUSTACEA																
Mysidae	-	-	-	-	-	-	-	-	6.3	0.0	7.1	45	22.7	0.1	62.2	1415
Pandalus borealis	-	-	-	-	-	-	-	-	12.5	2.6	14.3	211	18.1	3.4	4.4	142
CEPHALOPODA	-		-	-	50.0	13.8	25.0	1940	-	-	-	-	-	-	-	-
CHORDATA																
Enchelyopus cimbrius	-	-	-	-	100.0	80.8	50.0	13080	31.3	37.0	35.7	2276	22.7	23.1	11.1	777
Merluccius bilinearis	-	-	-	-	-	-	-	-	-	-	-	-	4.5	16.1	2.2	82
Urophycis spp.	-	-	-	-	-	-	-	-	-	-	-	-	4.5	6.4	2.2	39
Unid Gadidae	-	-	-	-	50.0	2.3	25.0	1365	12.5	9.2	7.1	204	-	-	-	-
Sebastes fasciatus	-	-	-	-	-	-	-	-	-	-	-	-	4.5	0.2	2.2	11
Macrozoarces americanus	50.0	64.8	50.0	5740	-	-	-	-	-	-	-	-	-	-	-	-
Hippoglossoides platessoides	-	-	-	-	-	-	-	-	-	-	-	-	9.0	26.3	4.4	277
Unid Pleuronectidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unid fish tissue	50.0	35.2	50.0	4260	-	-	-	-	31.3	31.7	35.7	2110	22.7	7.6	11.1	425
ANIMAL REMAINS	-	-	-	-	-	3.1	-	-	-	19.5	-	-	-	16.8	-	-
Empty Stomachs	3				1				4				4			
Total Stomachs	6				3				20				26			

b. Adult goosefish (>300 mm TL)

	IN								OUT							
	MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
CRUSTACEA																
Mysidacae	-	-	-	-	-	-	-	-	7.0	0.0	16.1	113	-	-	-	-
Pandalus borealis	33.3	2.7	26.7	979	33.3	1.2	15.4	553	35.7	2.0	32.3	1225	50.0	6.6	40.0	2330
CEPHALOPODA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHORDATA																
Enchelyopus cimbrius	-	-	-	-	33.3	1.8	3.8	186	7.1	2.2	3.2	38	-	-	-	-
Merluccius bilinearis	8.3	0.3	6.7	58	-	-	-	-	14.3	12.1	6.5	266	-	-	-	-
Urophycis spp.	8.3	19.4	6.7	217	3.3	2.1	3.8	19	-	-	-	-	-	-	-	-
Unid Gadidae	16.7	13.4	20.0	558	3.3	4.9	3.8	29	7.1	1.3	3.2	32	8.3	51.4	13.3	537
Sebastes fasciatus	25.0	32.9	26.7	1490	25.0	6.0	7.7	343	-	-	-	-	-	-	-	-
Macrozoarces americanus	-	-	-	-	-	-	-	-	-	-	-	-	8.3	2.4	13.3	130
Hippoglossoides platessoides	-	-	-	-	-	-	-	-	35.3	25.8	20.0	1617	8.3	6.3	6.7	108
Unid Pleuronectidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unid fish tissue	-	6.4	-	-	16.7	0.2	7.7	132	7.1	0.9	3.2	29	8.3	0.9	13.3	118
Clupeidae	16.7	19.6	13.3	549	50.0	78.0	57.7	6785	35.7	53.0	16.1	2467	16.7	15.3	13.3	478
ANIMAL REMAINS		5.2				5.8				2.7				17.1		
Empty Stomachs	3				1				4				2			
Total Stomachs	15				13				21				14			

Figure 1. Location of study sites in the Gulf of Maine. Survey 1 was conducted south and east of Cape Small at water depths of 50 to 150 m (i.e., central Gulf of Maine). Survey 2 was conducted further west along just in and out of the northern portions of the Western Gulf of Maine Closure Area.

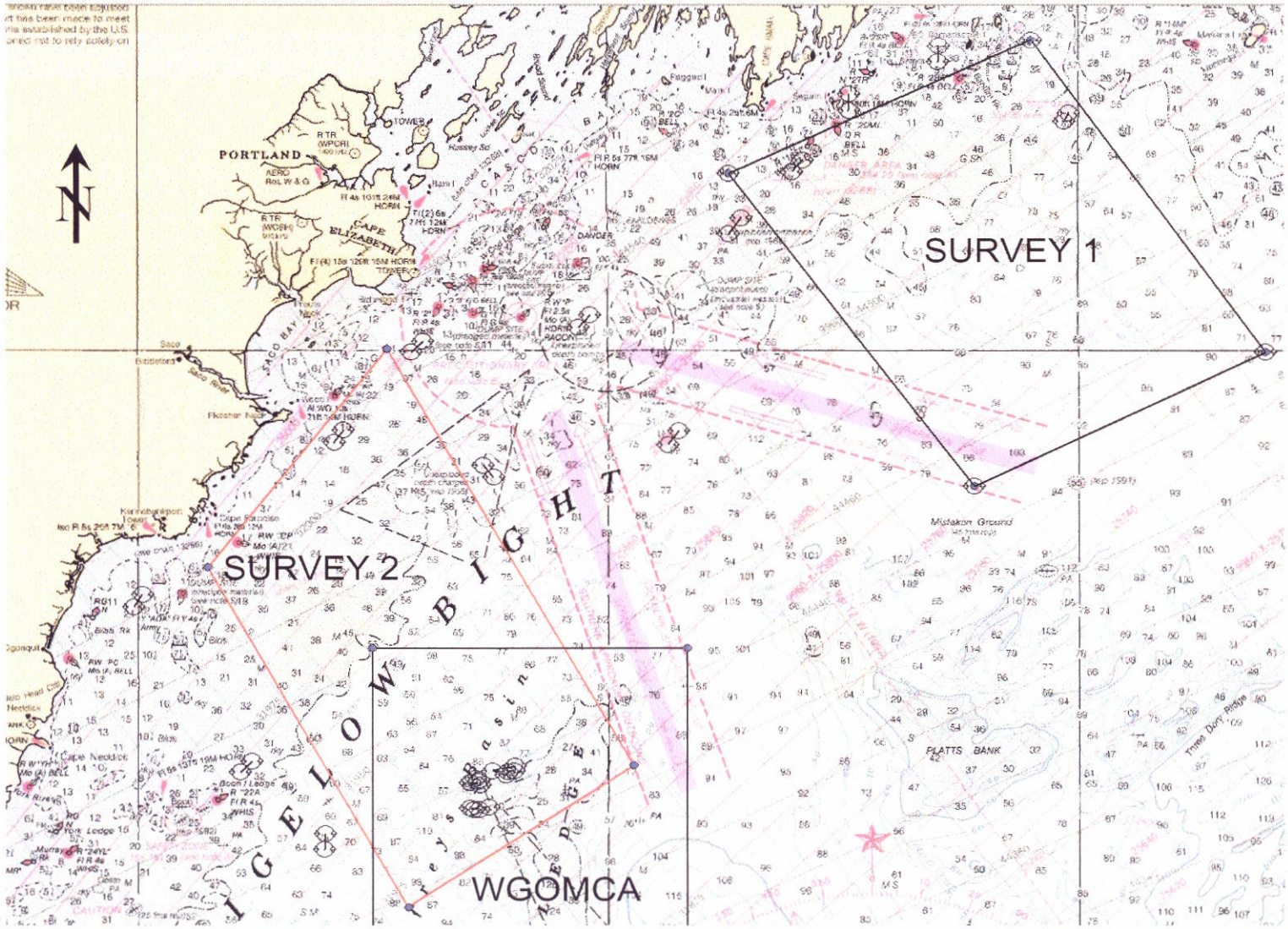


Figure 2. The effects of a. season and depth and b. season and habitat on the abundance of cod caught in trawl survey 1 (i.e., central Gulf of Maine). Error bars represent +1 Standard Error (SE).

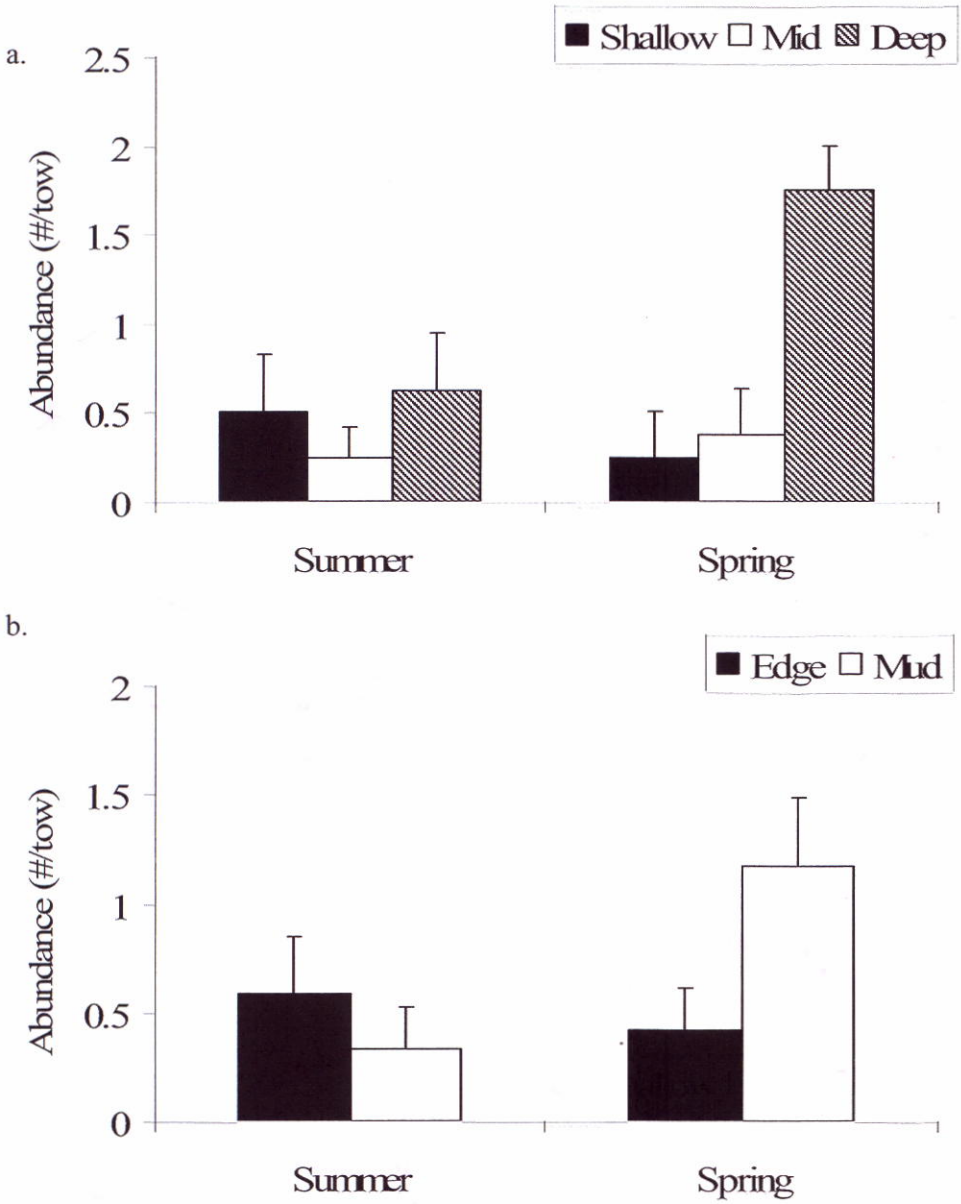


Figure 3. The relationship between length and weight for Atlantic cod captured in survey 1 (i.e., central Gulf of Maine).

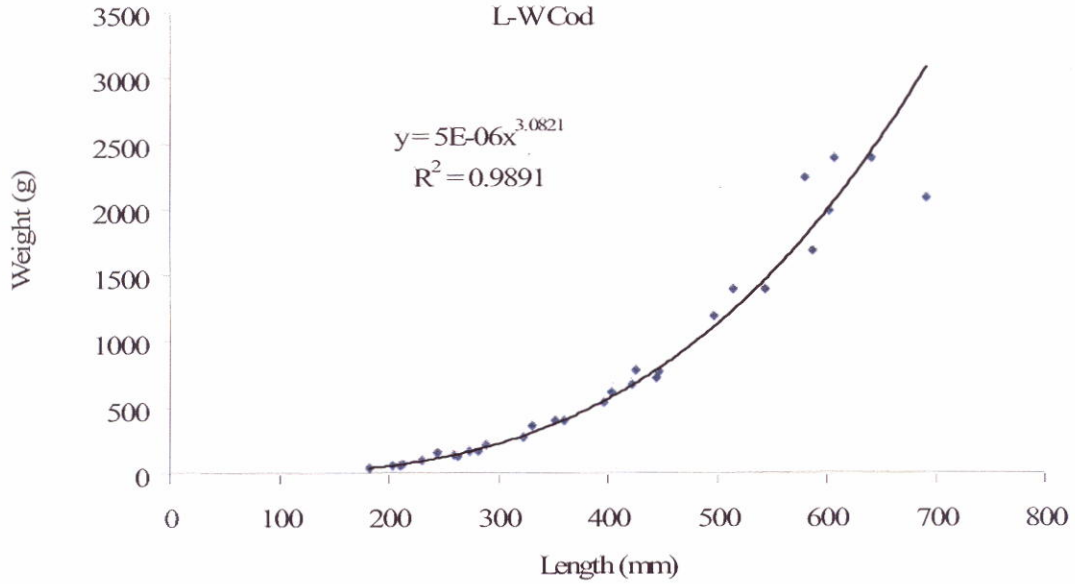


Figure 4. The effect of season on the abundance of haddock caught in trawl survey 1 (i.e., central Gulf of Maine). Error bars represent +1 SE.

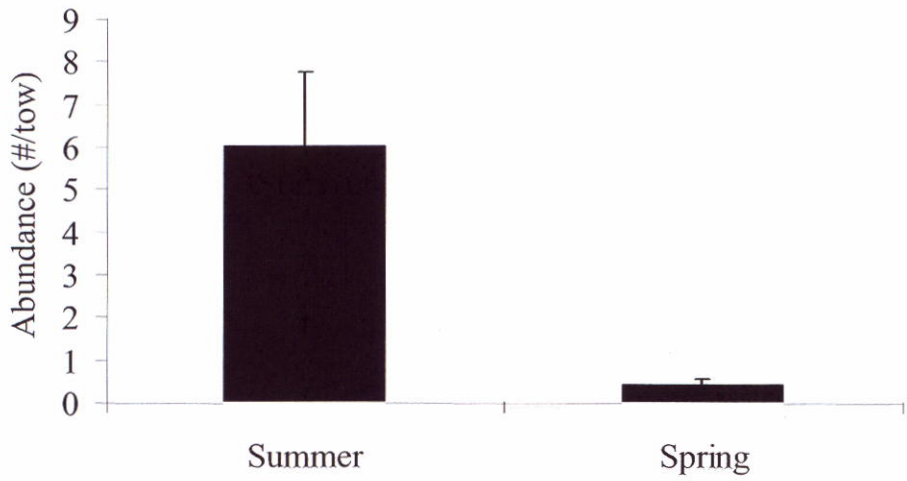
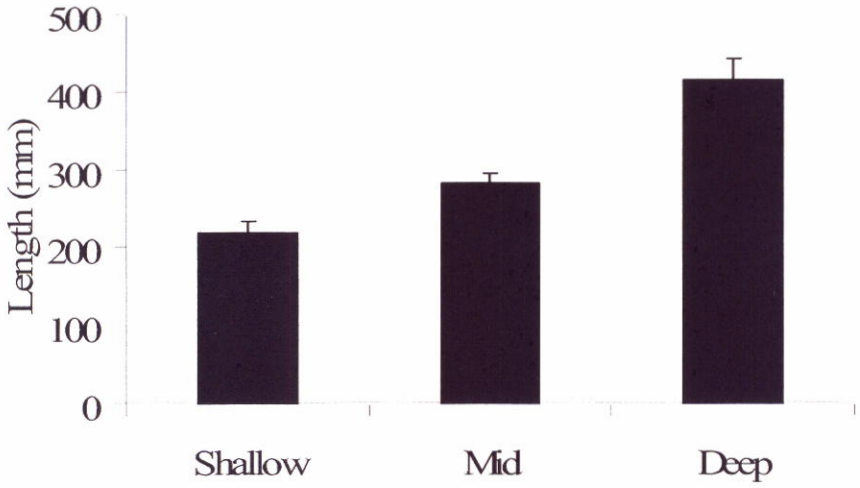


Figure 5. The effects of a. depth and b. season and depth on the size (TL) of haddock caught in trawl survey 1 (i.e., central Gulf of Maine). Error bars represent +1 SE.

a. Depth



b. Season and depth

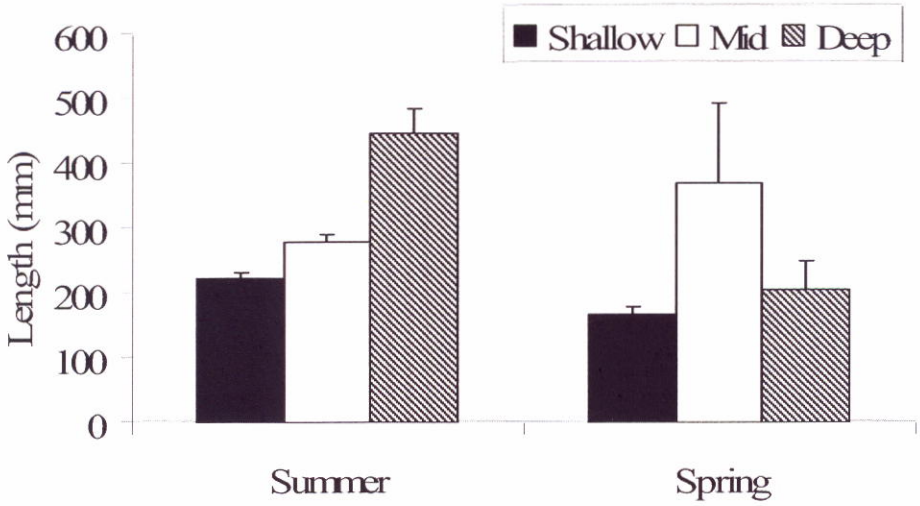


Figure 6. The relationship between length and weight for haddock captured in survey 1 (i.e., central Gulf of Maine).

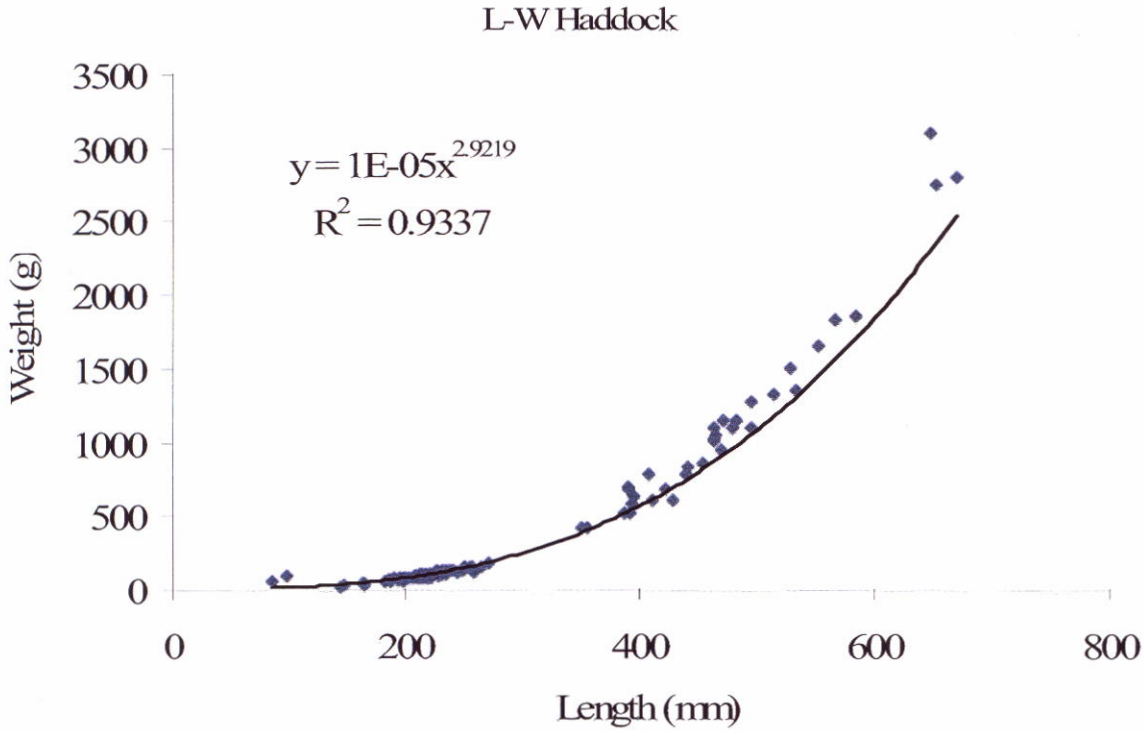


Figure 7. The effects of season and depth on the abundance of goosefish caught in trawl survey 1 (i.e., central Gulf of Maine). Error bars represent +1 SE.

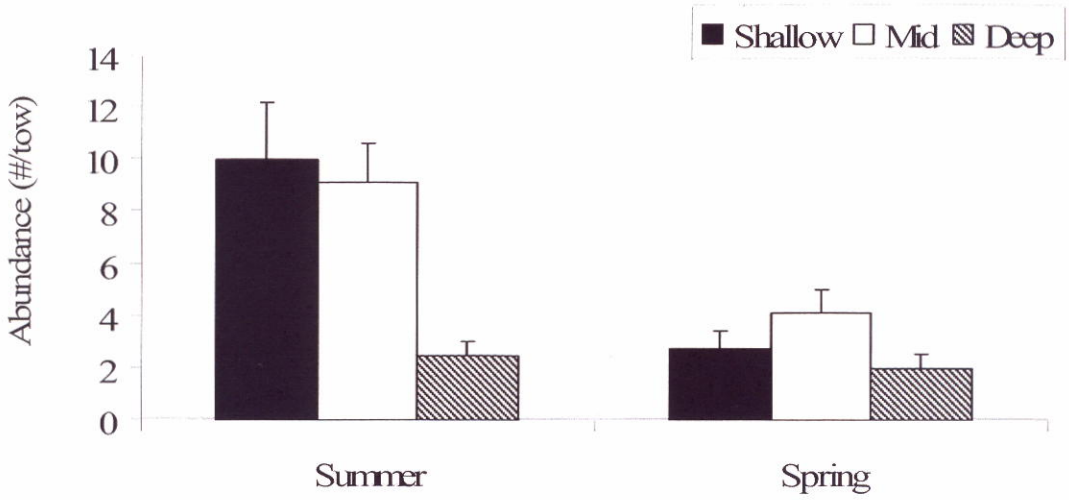


Figure 8. The effect of season on the size (TL) of goosefish caught in trawl survey 1 (i.e., central Gulf of Maine). Error bars represent +1 SE.

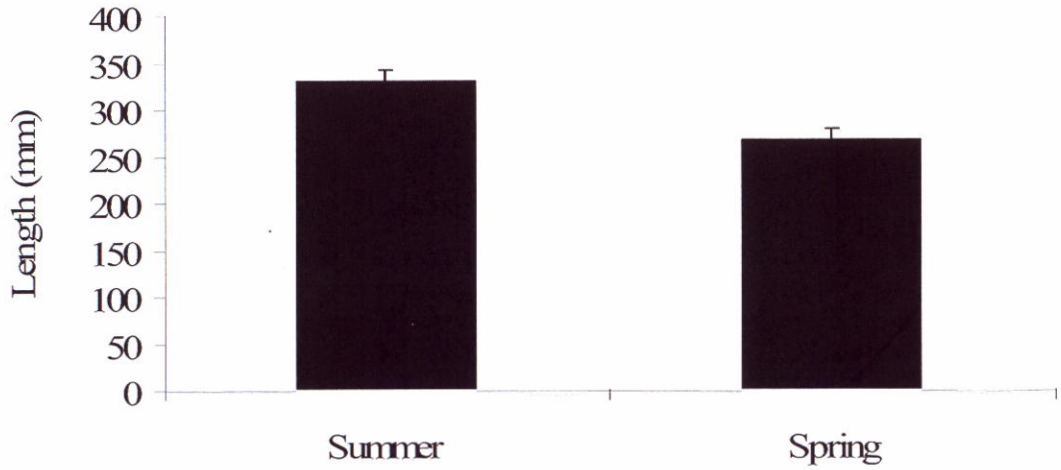


Figure 9. The relationship between length and weight for goosefish captured in survey 1 (i.e., central Gulf of Maine).

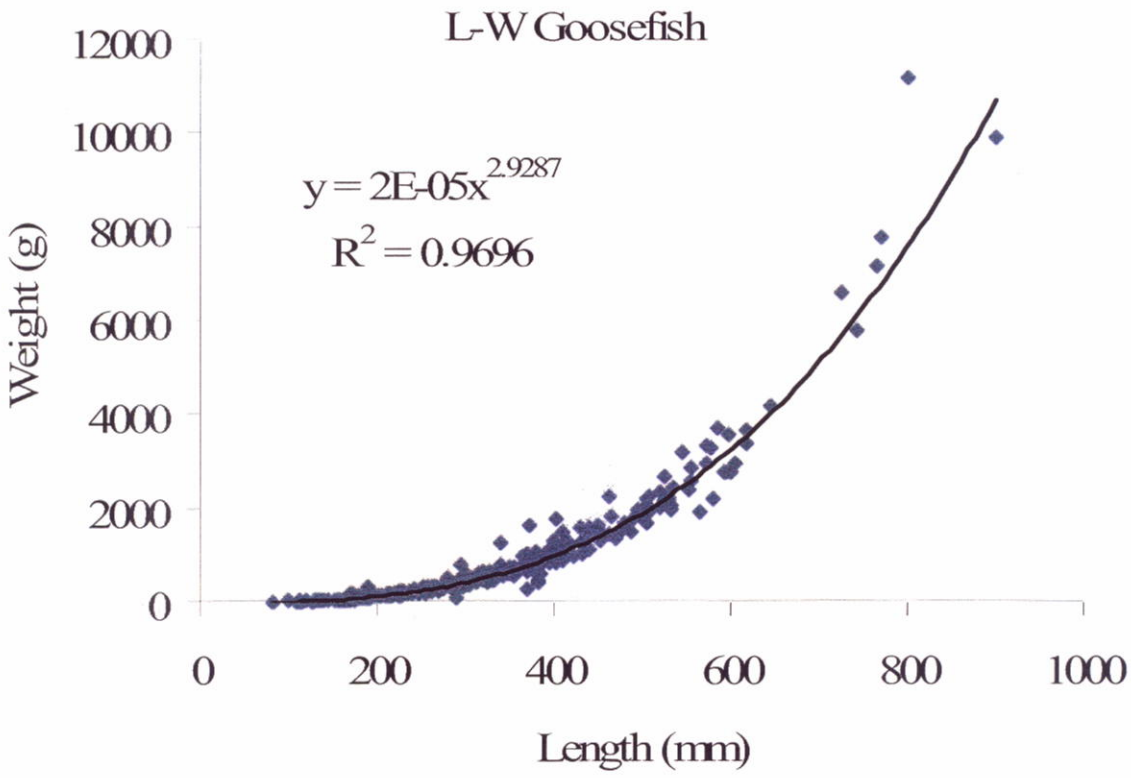
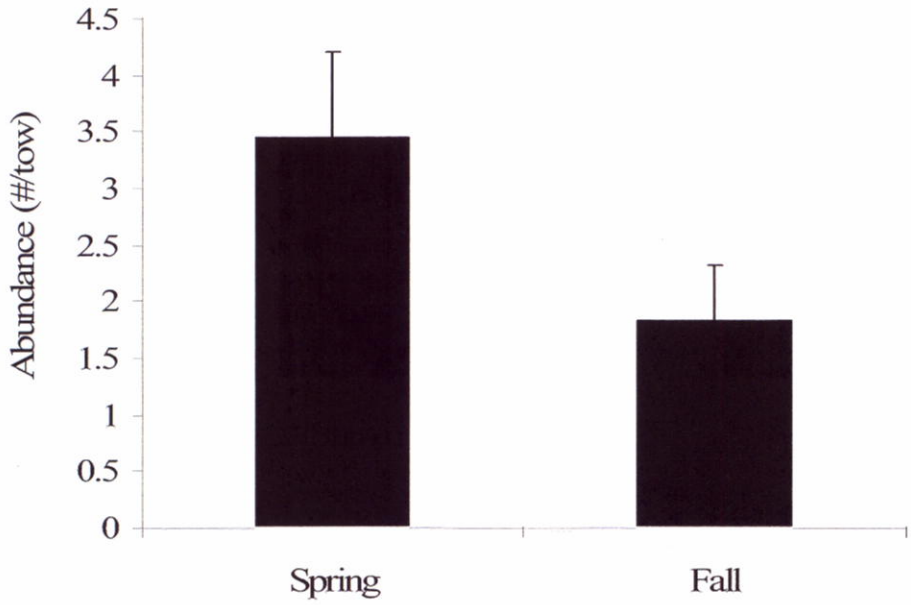


Figure 10. The effects of a. season and b. closure status and habitat on the abundance of cod caught in trawl survey 2 (i.e., Western Gulf of Maine Closure Area survey). Error bars represent +1 SE.

a. Season



b. Closure and habitat

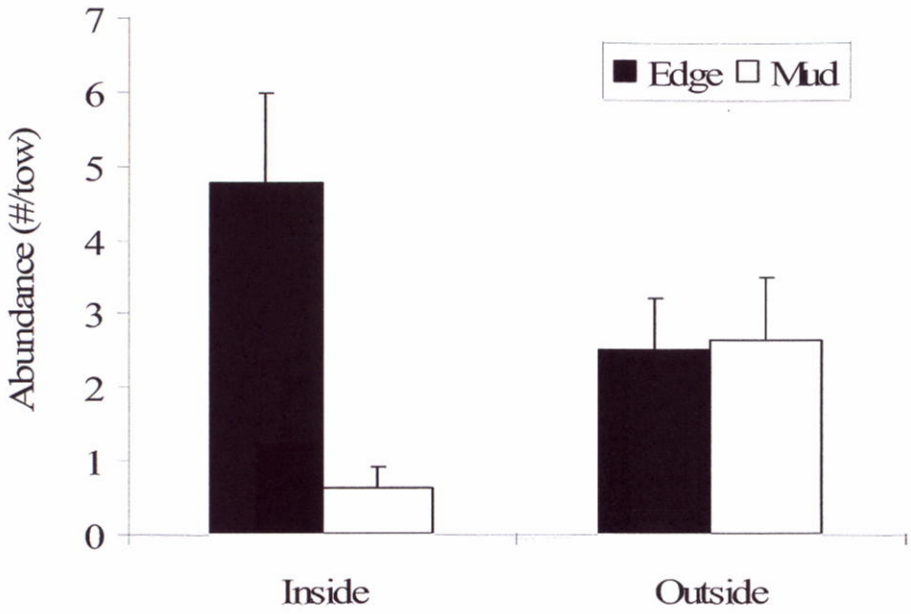


Figure 11. The effect of season on the size (TL) of cod captured in trawl survey 2 (i.e., Western Gulf of Maine Closure Area survey). Error bars represent +1 SE.

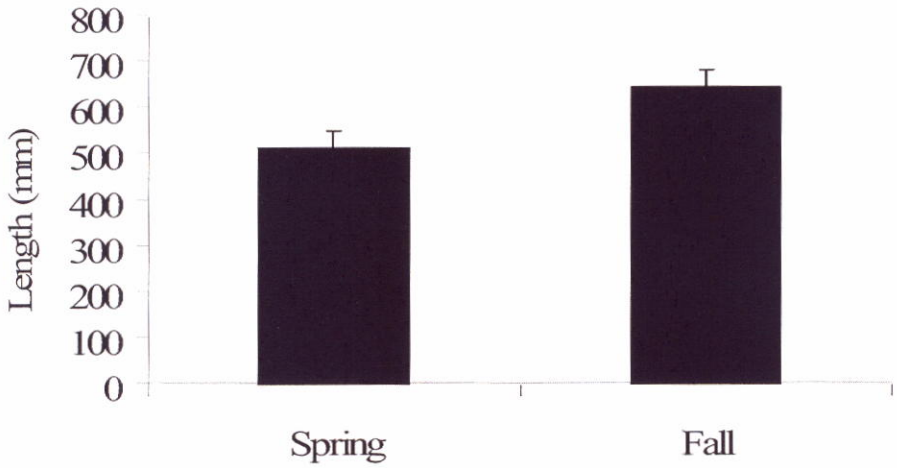


Figure 12. The relationship between length and weight for cod captured in survey 2 (i.e., Western Gulf of Maine Closure Area survey).

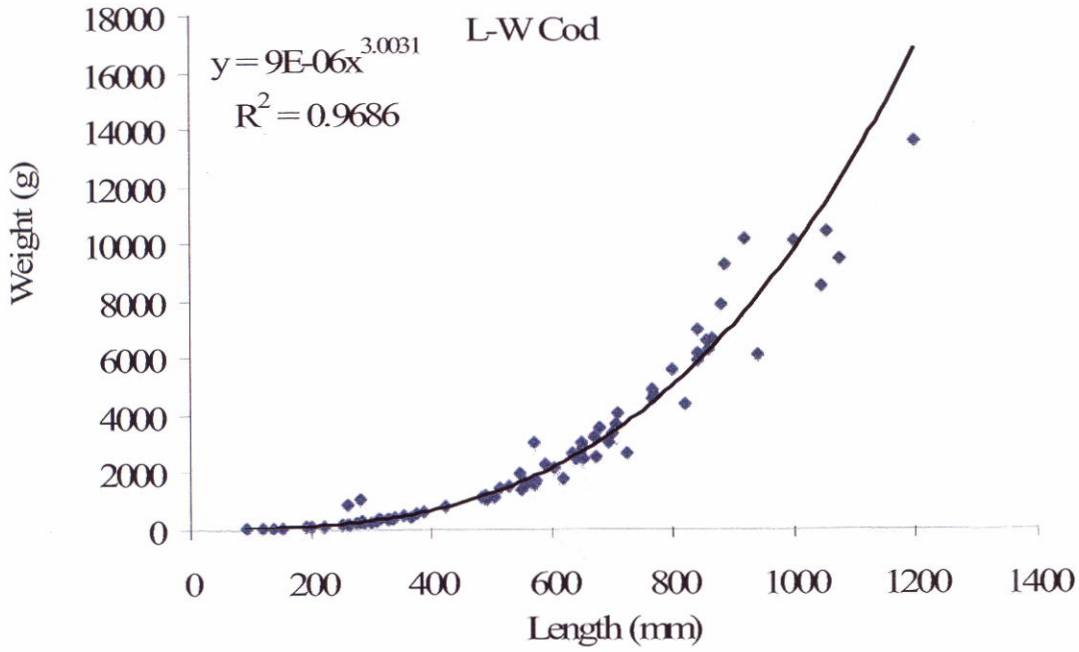


Figure 13. The effect of habitat on the abundance of haddock caught in trawl survey 2 (i.e., Western Gulf of Maine Closure Area survey). Error bars represent +1 SE.

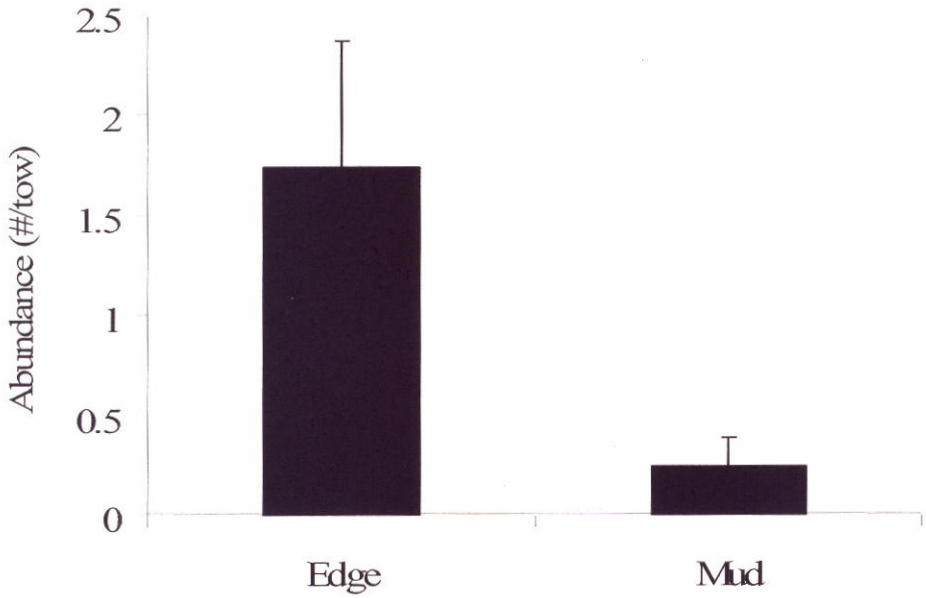


Figure 14. The effects of season and closure status on the size (TL) of haddock caught in trawl survey 2 (i.e., Western Gulf of Maine Closure Area survey). Error bars represent +1 SE.

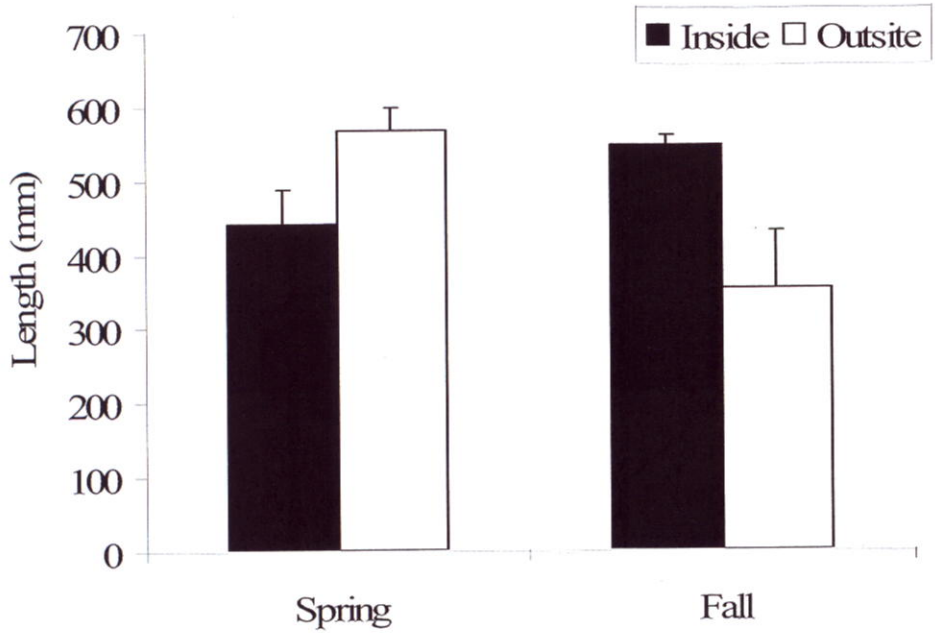


Figure 15. The relationship between length and weight for haddock captured in survey 2 (i.e., Western Gulf of Maine Closure Area survey).

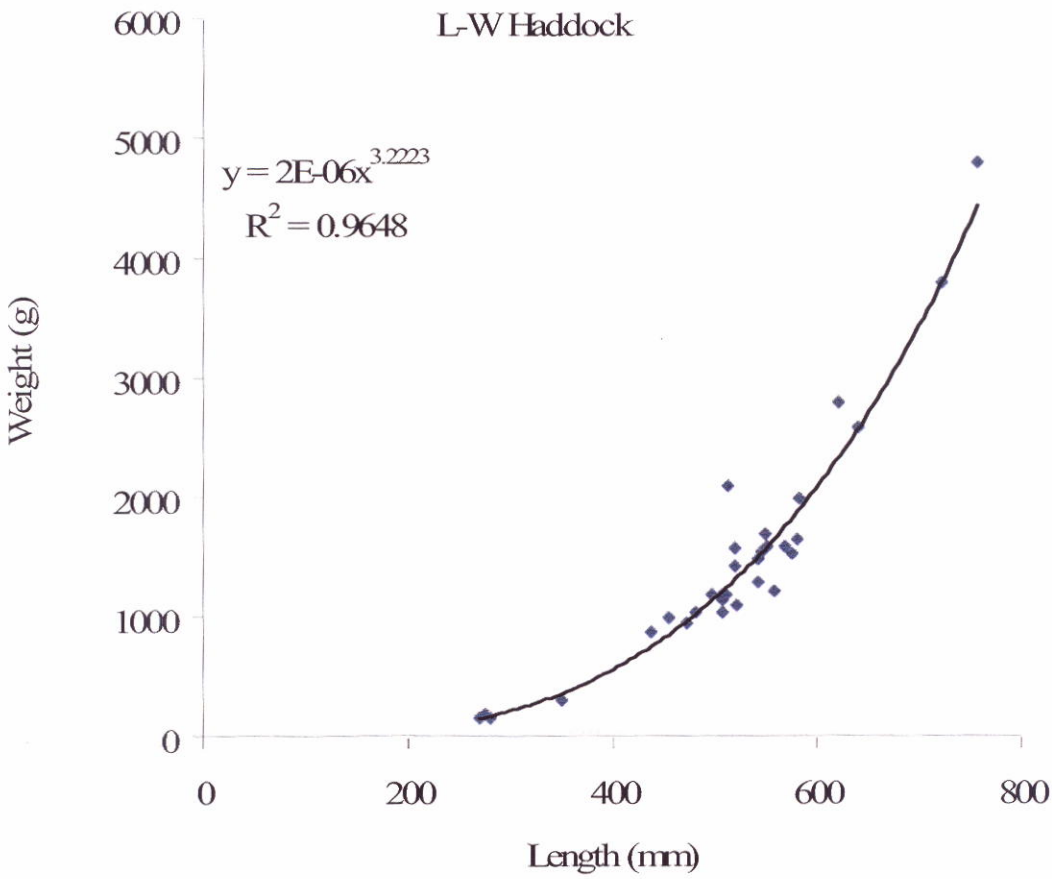


Figure 16. The effect of closure status on the abundance of goosefish caught in trawl survey 2 (i.e., Western Gulf of Maine Closure Area survey). Error bars represent +1 SE.

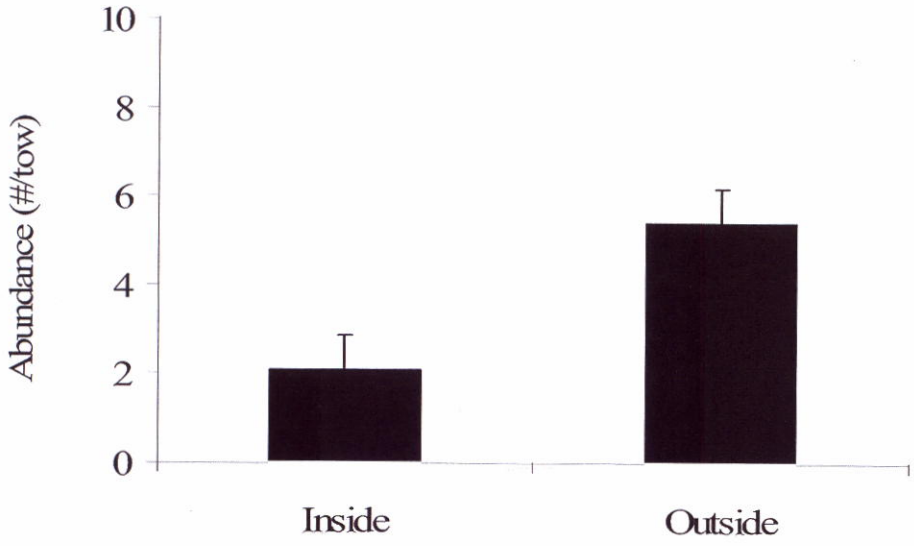
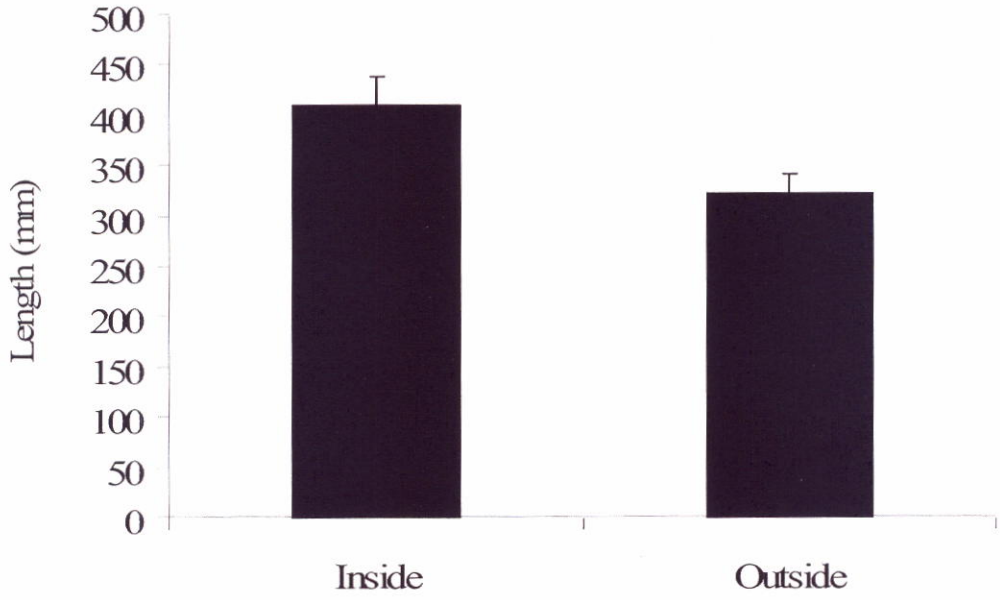


Figure 17. a. The effect of closure status on the size (TL) of goosefish from trawl survey 2 (i.e., Western Gulf of Maine Closure Area survey). b. The effects of i. season & ii. habitat on the condition of goosefish caught in trawl survey 2. Error bars represent +1 SE.

a. Size



b. Condition

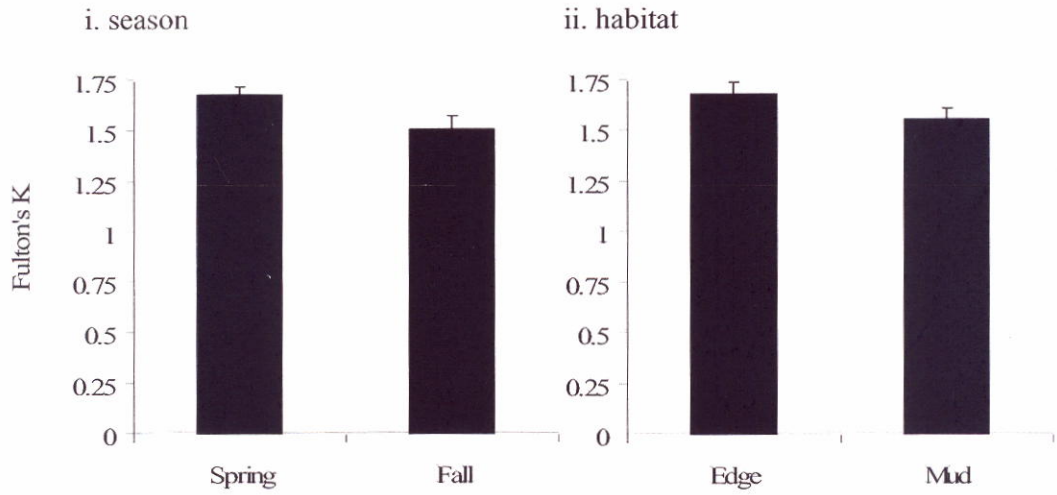
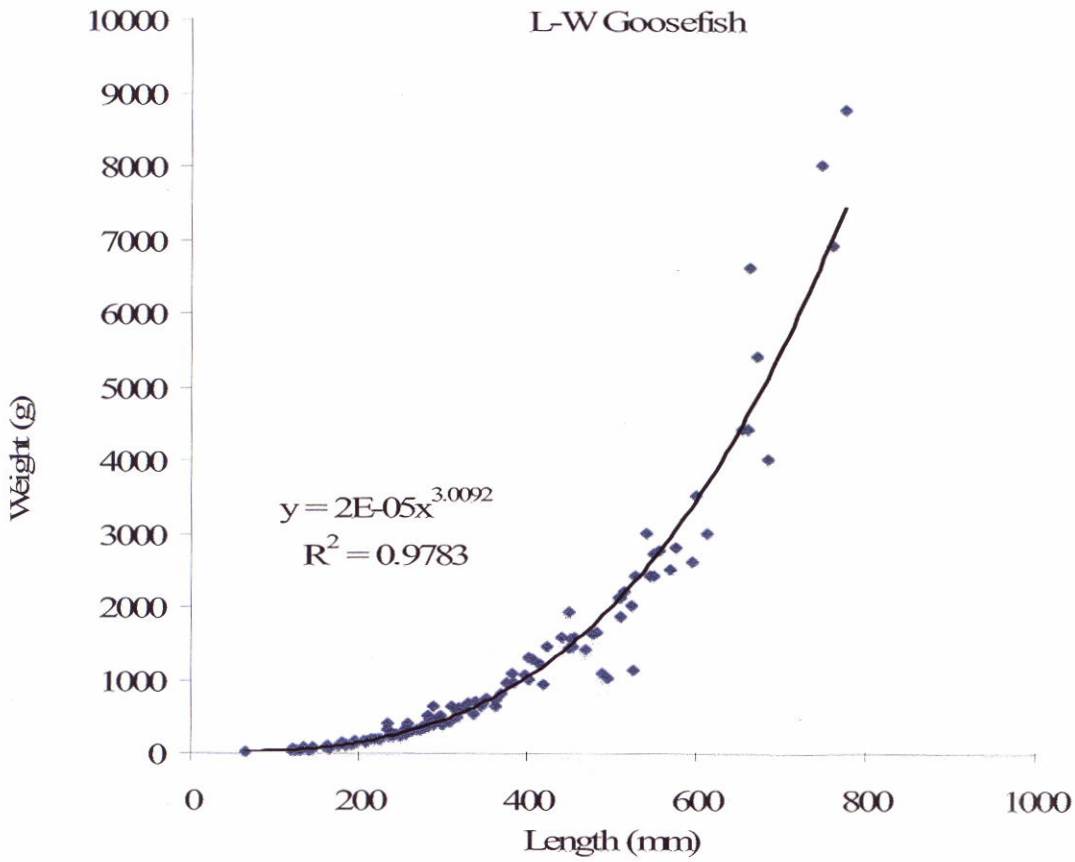


Figure 18. The relationship between length and weight for goosefish captured in survey 2 (i.e., Western Gulf of Maine Closure Area survey).



Appendix A. Start and finish times and coordinates for each tow conducted in Survey 1 in the c. summer of 2004, d. spring of 2005 and e. fall of 2005 as well as survey 2 in the a. fall of 2004 and b. spring of 2005.

e. Summer 2004 (Survey 1)

			Tow Start			Tow Finish		
TRAWL	SITE	HABITAT	Latitude	Longitude	TIME	Latitude	Longitude	TIME
1	Shallow	Edge	4341.59	6940.83	7:20:00	4340.91	6940.92	7:36:00
2	Shallow	Mud	4341.19	6941.82	12:38:00	4341.80	6940.92	12:54:00
3	Deep	Mud	4329.96	6954.98	7:03:00	4329.46	6655.39	7:18:05
4	Deep	Edge	4330.02	6954.62	10:03:00	4330.40	6953.91	10:13:46
5	Mid	Mud	4336.11	6955.31	1:45:00	4335.74	6956.19	2:03:02
6	Mid	Edge	4336.01	6955.29	2:30:00	4336.35	6954.60	2:44:30
7	Mid	Mud	4335.34	6946.36	7:07:05	4336.91	6946.63	7:22:00
8	Mid	Edge	4334.92	6946.64	12:10:07	4335.56	6946.68	12:26:06
9	Deep	Edge	4329.48	6947.80	14:59:00	4328.80	6947.78	15:14:35
10	Deep	Mud	4329.53	6947.73	7:08:39	4328.90	6947.49	7:24:36
11	Shallow	Mud	4337.57	6945.11	9:08:32	4338.15	6945.17	9:23:15
12	Shallow	Edge	4338.41	6945.37	11:42:44	4339.15	6945.34	11:59:48
13	Mid	Mud	4336.63	6950.44	2:39:41	4336.02	6950.67	2:55:03
14	Mid	Edge	4336.99	6950.22	6:45:03	4336.51	6950.90	7:01:30
15	Deep	Edge	4327.74	6954.04	9:41:57	4327.22	6954.52	9:57:38
16	Deep	Mud	4328.17	6954.50	10:39:42	4327.59	6954.90	10:56:07
17	Shallow	Edge	4337.30	6954.87	12:41:03	4337.74	6954.12	12:58:39
18	Shallow	Mud	4336.76	6953.55	2:43:34	4337.30	6954.02	2:58:09
19	Deep	Mud	4331.46	6948.28	3:57:29	4332.00	6947.81	4:12:57
20	Deep	Edge	4331.44	6948.75	7:11:48	4332.09	6948.66	7:27:07
21	Mid	Mud	4334.89	6948.93	9:10:49	4335.39	6948.28	9:27:07
22	Mid	Edge	4335.30	6948.23	11:06:22	4335.11	6949.05	11:21:15
23	Shallow	Edge	4338.37	6951.28	1:18:54	4338.01	6951.93	1:33:57
24	Shallow	Mud	4337.62	6951.45	3:06:12	4338.24	6951.29	3:21:58

b. Spring 2005 (Survey 1)

			Tow Start			Tow Finish		
TRAWL	SITE	HABITAT	Latitude	Longitude	TIME	Latitude	Longitude	TIME
1	Deep	Edge	4327.72	6954.77	9:10:22	4327.26	6955.40	9:25:42
2	Deep	Mud	4328.29	695355.00	10:49:18	4328.00	6954.83	11:02:25
3	Mid	Mud	4334.72	6949.14	12:31:35	4335.21	6948.54	12:47:27
4	Mid	Edge	4335.27	6948.35	14:05:23	4335.47	6947.89	14:16:27
5	Shallow	Mud	4337.57	6945.11	15:30:40	4338.12	6945.62	15:46:39
6	Shallow	Edge	4339.15	6945.02	16:21:10	4338.56	6945.47	16:37:12
7	Shallow	Edge	4337.79	6951.63	7:52:30	4337.49	6952.20	8:05:28
8	Shallow	Mud	4337.69	6951.47	8:41:56	4337.31	6952.21	8:57:33
9	Mid	Edge	4335.02	6946.60	10:05:26	4335.59	6946.65	10:18:55
10	Mid	Mud	4335.17	6946.27	10:50:52	4335.73	6946.37	11:05:28
11	Deep	Edge	4330.14	6947.46	12:18:18	4329.49	6947.62	12:34:31
12	Deep	Mud	4328.83	6947.52	13:12:30	4329.58	6947.44	13:29:41
13	Mid	Edge	4336.29	6955.10	7:07:33	4335.85	6955.84	7:23:15
14	Mid	Mud	4335.57	6956.27	8:15:29	4335.11	6956.98	8:31:26
15	Deep	Edge	4330.11	6954.57	9:41:09	4330.46	6953.99	9:55:50
16	Deep	Mud	4329.95	6955.17	10:52:50	4329.73	6956.03	11:08:53
17	Shallow	Edge	4337.12	6954.50	0:52:15	4337.60	6954.49	1:03:02
18	Shallow	Mud	4336.93	6954.03	1:32:20	4337.30	6954.49	1:43:50
19	Shallow	Edge	4337.45	6951.41	7:12:54	4336.97	6952.08	7:28:10
20	Shallow	Mud	4337.13	6951.63	8:21:30	4336.65	6952.19	8:35:42
21	Mid	Mud	4336.00	6950.70	9:23:48	4335.51	6951.28	9:39:44
22	Mid	Edge	4335.78	6450.29	10:51:21	4336.03	6951.13	11:06:35
23	Deep	Edge	4331.30	6948.83	12:48:12	4331.94	6948.46	13:04:33
24	Deep	Mud	4331.45	6948.22	13:54:30	4332.07	6948.05	14:09:10

c. Fall 2004 (Survey 2)

			Tow Start			Tow Finish		
TRAWL	SITE	HABITAT	Latitude	Longitude	TIME	Latitude	Longitude	TIME
1	Deep	Mud	4328.16	6953.92	8:18:34	4328.73	6953.41	8:34:40
2	Mid	Edge	4334.74	6946.80	10:35:30	4335.48	6946.67	10:50:48
3	Mid	Mud	4334.00	6947.05	11:58:34	4394.54	6946.64	12:14:06
4	Mid	Mud	4336.16	6955.06	7:46:41	4335.90	6955.87	8:02:00
5	Mid	Edge	4336.33	6955.06	9:16:30	4335.95	6955.77	9:32:22
6	Deep	Mud	4329.74	6955.63	10:49:40	4329.08	6955.75	11:05:18
7	Deep	Edge	4329.16	6955.80	12:04:30	4329.56	6955.09	12:20:15
8	Deep	Edge	4327.92	6954.83	1:21:25	4328.47	6954.48	1:37:25
9	Shallow	Mud	4337.41	6954.57	15:14:38	4337.75	6953.98	15:27:12
10	Mid	Edge	4336.89	6949.97	8:15:32	4336.33	6950.53	8:31:16
11	Mid	Mud	4336.78	6950.32	9:39:24	4336.18	6950.82	9:55:05
12	Mid	Edge	4334.99	6949.49	10:58:19	4335.01	6948.71	11:14:06
13	Mid	Mud	4334.64	6948.56	11:39:17	4334.18	6949.20	11:54:10
14	Deep	Edge	4331.80	6948.67	12:36:35	4331.14	6948.92	12:52:01
15	Deep	Mud	4331.26	6948.50	1:18:00	4331.77	6947.92	1:33:35
16	Deep	Edge	4329.63	6947.86	2:16:35	4328.99	6947.99	2:32:22
17	Deep	Mud	4328.96	6947.73	2:57:16	4329.69	6947.46	3:14:01

d. Fall 2004 (Survey 2)

			Tow Start			Tow Finish		
TRAWL	SITE	HABITAT	Latitude	Longitude	TIME	Latitude	Longitude	TIME
1	Outside	Mud	4305.7	7019.0	9:24:28	4305.2	7018.4	9:41:34
2	Outside	Edge	4306.1	7017.0	11:54:29	4306.6	7018.4	12:10:03
3	Inside	Edge	4307.6	7009.0	14:15:01	4307.6	7009.9	14:30:15
4	Inside	Mud	4308.8	7008.5	15:48:49	4308.6	7009.2	16:04:06
5	Outside	Edge	4307.2	7021.9	9:45:19	4306.6	7021.6	10:00:40
6	Outside	Mud	4307.2	7020.4	11:46:35	4307.6	7021.0	12:01:49
7	Inside	Edge	4308.4	7013.0	14:05:20	4308.2	7013.8	14:20:20
8	Inside	Mud	4309.0	7011.3	16:00:00	4309.1	7010.4	16:15:29
9	Outside	Edge	4316.2	7013.0	8:55:16	4316.6	7012.3	9:10:11
10	Outside	Mud	4315.5	7012.0	10:48:09	4315.8	7011.3	11:03:32
11	Inside	Mud	4314.2	7009.4	13:22:57	4314.5	7008.6	13:39:17
12	Inside	Edge	4314.4	7010.9	14:55:58	4314.5	7011.0	15:11:02
13	Outside	Edge	4315.2	7001.7	8:46:25	4315.8	7002.0	9:02:03
14	Outside	Mud	4314.5	7002.3	10:36:15	4313.9	7002.2	10:51:54
15	Inside	Edge	4310.5	7003.8	12:15:36	4310.9	7003.3	12:30:28
16	Inside	Mud	4311.9	7005.2	14:12:12	4312.5	7005.1	14:27:08

e. Spring 2005 (Survey 2)

			Tow Start			Tow Finish		
TRAWL	SITE	HABITAT	Latitude	Longitude	TIME	Latitude	Longitude	TIME
1	Outside	Edge	4316.4	7001.8	9:46:24	4316.0	7002.0	10:01:38
2	Outside	Mud	4314.1	7002.1	11:53:08	4314.0	7003.0	12:08:36
3	Inside	Mud	4314.4	7008.8	1:21:31	4314.8	7008.1	1:36:49
4	Inside	Edge	4314.1	7011.1	2:41:49	4314.7	7010.8	2:57:03
5	Outside	Mud	4305.3	7018.4	8:52:24	4304.8	7018.0	9:07:03
6	Outside	Edge	4306.2	7018.0	10:15:54	4306.7	7018.4	10:31:18
7	Outside	Mud	4307.6	7022.6	12:13:15	4307.8	7021.9	12:29:09
8	Outside	Edge	4306.7	7022.3	2:08:53	4307.2	7022.2	2:24:15
9	Inside	Mud	4309.1	7009.2	9:03:35	4309.1	7008.4	9:18:52
10	Inside	Edge	4308.5	7009.0	10:29:08	4308.4	7009.8	10:44:34
11	Outside	Mud	4314.8	7012.7	12:12:00	4316.3	7012.5	12:27:24
12	Outside	Edge	4317.3	7012.5	2:10:18	4316.7	7012.8	2:27:07
13	Inside	Edge	4308.5	7008.3	8:53:03	4308.4	7009.1	9:08:35
14	Inside	Mud	4307.2	7010.2	10:48:34	4307.3	7009.4	11:03:47
15	Inside	Edge	4310.3	7003.7	12:02:39	4310.7	7003.3	12:16:05
16	Inside	Mud	4312.3	7008.6	1:43:33	4312.8	7006.0	1:59:13

Appendix B:

RESERVE AND HABITAT EFFECTS ON THE DISTRUBUTION, ABUNDANCE AND FEEDING ECOLOGY OF GOOSEFISH, *LOPHIUS AMERICANUS* (VALENCIENNES 1837) IN WESTERN GULF OF MAINE

BY

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B. Sc. Honours Marine Biology, Dalhousie University, 2002

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ABSTRACT

RESERVE AND HABITAT EFFECTS ON THE DISTRUBUTION, ABUNDANCE AND FEEDING ECOLOGY OF GOOSEFISH, *LOPHIUS AMERICANUS* (VALENCIENNES 1837) IN WESTERN GULF OF MAINE

By

Melissa Dawn Smith

University of New England, June 2006

INTRODUCTION

Over two-thirds of the world's harvested fish stocks are considered to be either reduced or threatened as a consequence of overexploitation (Hutchings 2000, Jackson et al. 2001, Pauly et al. 2002). Technological advancements combined with increased fishing pressure in many regions of the world continue to undermine efforts to conserve and rebuild fish stocks (FAO 2000, Gell and Roberts 2003, Myers and Worm 2003). Traditional management methods have varied in their effectiveness for sustaining fish stocks on commercially important species. Yet, one promising fishery management strategy is the use of marine reserves, or conservation areas where fishing is prohibited to enhance depleted populations (Russ and Alcala 1996, Kelly et al. 2000, Roberts et al. 2001). Marine reserves can potentially benefit multiple commercially harvested fish species within one region (Auster 1998, Murawski 2000, Lindholm et al. 2001). A reprieve from fishing pressure may allow fish to aggregate within the reserve, which potentially increases spawning stock biomass. If spawning biomass increases within the reserve, broadly dispersed larvae may spill over into open fishery areas and potentially increase regional fish productivity (Bohnsack 1998, Gell and Roberts 2003, Russ et al. 2003, Murawski et al. 2004).

Marine reserves augment population growth in several ways. First, reserves provide a spatial refuge in which directed fishing mortality is either reduced (partial reserve) or eliminated (no-take reserve). By limiting overall fishing pressure, by-catch and fishing mortality is also reduced. Fish species that are heavily targeted may show the greatest effects once fishing pressure is removed (Halpern and Warner 2002).

Second, reserves can protect site-specific spawning aggregations (i.e., seasonal or year-round spawning sanctuaries) (Bohnsack 1998, Dayton et al. 2000). Reserves that protect traditional spawning grounds of overfished species may reduce fishing pressure during mating season. Fish protected within reserves may also attain larger sizes and thus increase fecundity. No-take zones have been implemented in Belize to protect historical spawning grounds for the dwindling Nassau grouper (*Epinephelus striatus*) spawning aggregations (Sala et al. 2001). Seasonal closures intended to protect the spawning stocks may be enough to increase recruitment regionally potentially increasing future harvest yield (Roberts 1997). Excess larvae from a reserve or closure may be transported by water currents to locations outside the reserve and, consequently, increase the recruitment potential of an over harvested fish stock. Reserves that encompass a source population have a greater seeding potential as source populations are self-sustaining and may produce excess eggs and larvae to seed outlying areas.

Lastly, marine reserves may protect seafloor habitat types including sandy bottom, eel-grass beds, gravel based substrate and complex cobble/boulder landscapes. Destructive fishing practices, for example dredging and bottom trawling, degrades the benthic habitat by flattening vertical structure created by sponges and corals (Collie et al. 1997, Auster 1998, Watling and Norse 1998). These habitats have been associated with juvenile and adult demersal species such as Atlantic cod, *Gadus morhua*, (Witman and Sebens 1992, Cote et al. 2004). Lindholm *et al.* (1999) suggested that juvenile Atlantic cod use complex habitat to reduce predation risk. Restricting benthic fishing methods from local areas known as traditional nursery grounds may allow biogenic structures to rebuild, increasing the complexity of habitats within established reserves. Increased

habitat complexity may benefit juvenile groundfish, although juvenile habitat usage is not yet completely understood. Usage may depend on fish activities such as feeding, resting or hiding from predators. Therefore, it has been suggested reserves not only provide relief from fishing mortality but also a safe refuge for fish aggregations to grow, thus restoring depleted populations (Bohnsack 1998).

Although marine reserves have been used effectively to facilitate the recovery of depleted fish stocks, they do not represent a panacea for overexploited fish resources (Bohnsack 1998, Dayton et al. 2000, Botsford et al. 2003, Halpern 2003). How the reserve will effect surrounding fish populations will depend on settlement cues, larval retention and current dynamics of both the reserve and outlying areas (Crowder et al. 2000). Placing a reserve in an area known to be a sink population will not be sustainable because a sink population relies on another distinct population to supply new recruits. The potential influence of reserves on adjacent fisheries through larval dispersal or adult spawning aggregations will be dependent on the location and goals set for the reserve. Fish species with high mobility and ambiguous migration patterns pose temporal and spatial problems (Polacheck 1990) because it is difficult to design reserves that fully encompass their movements among habitat patches and thus these fish species may not reap the benefits of marine reserves as would less mobile, territorial species. Correspondingly, traditional management tools such as quotas, total allowable catch limits and single-species moratoriums have been vital in certain stock recovery programs (i.e., goliath grouper, *Epinephelus itajara*, has rebounded since a 1990 moratorium in the Gulf of Mexico; see Shipp 2004). Thus, reserves may not be applicable depending on the fish stock in question and traditional management tools may be the only option.

Marine scientists and managers have struggled with choosing the appropriate size and shape that maximize benefits while attempting to also minimize the costs associated with closing an area. Reserves should be large enough to protect sessile and mobile species during important life history stages (e.g., postlarval settlement, spawning aggregations) while minimizing the economic loss to the industry (Bohnsack 1998). Halpern (2003) suggests reserve effects scale directly with reserve size. Large reserves may protect a multitude of species, incorporating life-histories of resident and transient fish species. Larger reserves encompass more diverse habitats potentially utilized by juvenile and adult fish (Halpern 2003, Hastings and Botsford 2003). However, small reserves in close proximity to each other (a reserve network) have been utilized especially in tropical regions where target fish are territorial and less mobile and sessile animals are patchily distributed (i.e., coral colonies). These networks allow small localized protection where target species are known to occur. Thus, size and shape of the reserve should be scaled appropriately after careful consideration of the goals set for the reserve and the ecology (spawning behaviour, migratory routes, feeding ecology) of the targeted species.

Reserves must be established with clear management directives and monitored to ensure these directives are being achieved (Bohnsack 1998, Shipp 2004). Thus, transfer of fishing pressure must be considered when planning a reserve. If restrictions to fishing effort from other fishing methods are not to be included in the reserve mandate, then managers should institute additional guidelines such as effort control and fish quotas to ensure alternative fishery methods remain sustainable. To ensure future sustainability of

fish resources, a combination of marine reserve management and traditional fishery management practices should be examined (Dayton et al. 2000).

In the Gulf of Maine (GoM), several closed areas have been established to restrict fishing activities such as gillnetting, scallop dredging, and mid-water and bottom trawling (Murawski et al. 2000). A portion of these reserves have been designated essential fish habitat closed areas due to specific regulations that eliminate fishing activities using bottom tending gear. These fishing practices are thought to have degraded valuable habitat prior to the closure's inception. The loss of critical fish habitat could limit settlement and survival rates of post-larval fish species that have specific habitat requirements. Thus, the closures in the GoM not only protect diminished fish stocks, but also protect seafloor habitat utilized by these demersal fish species from the detrimental effects of dredging and bottom trawling.

The largest closure in the GoM is the Western Gulf of Maine Closure Area (WGMCA) which covers 2,962 km^2 of seascape (Fig. 1). The WGMCA was established May 1, 1998 under the Sustainable Fisheries Act (SFA) of 1996 (Public Law 104-297). The SFA reauthorized and amended the Magnuson-Stevens Fishery Conservation and Management Act to include measures to protect essential fish habitat during various life stages of fish, reduce by-catch and to rebuild overfished stocks (Rosenberg et al. 2000). The WGMCA encompasses parts of Stellwagen Bank, Jeffrey's Ledge and Wildcat Knoll. Within the WGMCA there are several habitat types such as mud, gravel, cobble, exposed rock ledge and a mix of biogenic structures that are potentially used by groundfish. These shallow waters were historically productive fishing and nursery

grounds (Ames 1997, Kurlansky 1997), especially for cod. The WGMCA's overall goal was to reduce cod mortality and preserve juvenile habitat (Anon 2004).

Currently, the WGMCA is off-limits only to vessels capable of catching groundfish with bottom-tending gear under the New England Multispecies Fishery Management Plan. As a partial fish reserve, mid-water trawling for pelagic fish species is allowed and charter boats using rod and reel or hand-lines are authorized to enter the closure. The western portion of the WGMCA also overlaps with the goosefish gillnet exempted area fishery (see Fig. 1). This targeted gillnet fishery for goosefish is seasonal: July 1 to September 14. The partial protection offered in the WGMCA should reduce by-catch, which occurs frequently during bottom trawl fishing (Thrush et al. 1998). Managers need to be wary of partial reserves, however. Although a partial reserve may reduce fishing induced mortality by limiting specific types of fishing activities and protecting habitat, this reduced effort may be counterbalanced by increased effort from other, unregulated fishing activities. This transfer of fishing pressure is difficult to assess and thus can hinder managers and scientists ability to gauge reserve effectiveness. For instance, gillnetting, hook and line fishing, mid-water trawling in the WGMCA may have increased after the closure was established, and consequently, could counteract the intended management goals of this closure.

In the WGMCA, none of the exempted fisheries (i.e., mid-water trawling, charter boat companies) target juveniles or affect benthic habitat. The goal set for the WGMCA is to ensure nursery habitat protection for dwindling cod while also reducing groundfish mortality from mobile gear fisheries. Commercially important groundfish species in the GoM managed by the New England Multispecies Fishery Management Plan include cod,

haddock (*Melanogrammus aeglefinus*), American plaice (*Hippoglossoides platessoides*) and goosefish (*Lophius americanus*).

Goosefish have been commercially fished since the early 1970's as by-catch. A directed fishery for goosefish was established in 1991 in an effort to compensate for a decline in other traditional groundfish species. Landings have steadily increased by an order of magnitude from 2,600 MT in 1982 to 27,000 MT in 1998. However, records indicate a noticeable drop in landings between 1998 and 2000 to 20,900 followed by a slow rise since 2000, averaging 24,100 MT between 2001-2003 (NEFSC 2000). Perhaps one of the more discouraging fishery trends has been the consistent decrease in mean goosefish size over the past three decades in the following three fishery-independent trawl surveys: 1780 mm reported by Wenner (1978) in the 1970's, 1115 mm sampled by Armstrong (1985) in the 1980's and 790 mm recorded in the Maine-New Hampshire Inshore Trawl Survey during Spring 2004 (Sherman et al. 2005a). Of further concern is that size at maturity has decreased over the last two decades. Armstrong (1987) reported length at 50 percent maturity (L_{50}) as 368.6 mm for males and 487.0 mm for females, whereas Hartley (1995) more recently calculated L_{50} to be 361 mm and 319 mm for males and females, respectively. Atlantic cod (Barot et al. 2004, Hutchings 2005), American plaice (Barot et al. 2005) and North Sea plaice, *Pleuronectes platessa*, (Grift et al. 2003) have all experienced similar decreases in size at maturity as a consequence of fishing pressure.

Seasonal differences in the distribution and abundance of goosefish have been documented in previous studies conducted in the GoM, Southern New England and in the Northwest Atlantic (Armstrong 1987, Hartley 1995, Maravelias and Papaconstantinou

2003, Laurenson et al. 2005). Diet composition has also been shown to vary with season (Crozier 1985, Laurenson and Priede 2005). Yet, it is unknown how a reserve effect interacts with seasonal differences in goosefish distribution, abundance and feeding ecology. The WGMCA may have an increased diversity of prey available that might increase condition and survivorship of goosefish.

It is unclear which types of habitat limit juvenile and adult groundfish abundance and whether reserves such as the WGMCA will effectively benefit this species. I investigated whether season, habitat and reserve status collectively influence goosefish distribution, abundance, feeding ecology, and condition in the Gulf of Maine. I hypothesized that the abundance of *L. americanus* would be higher inside the reserve due to reductions in fishing pressure. Because the fishing industry targets large goosefish, I posited that larger goosefish should be more abundant inside the reserve. Steimle (1999) reports goosefish favour open, sandy bottoms. I suspected adult goosefish would use mud bottom more frequently as they do not need to hide from predators and are able to bury while waiting for prey. Juvenile goosefish, on the other hand, may need to balance the risk of foraging with predator avoidance and thus may utilize more complex habitats. Lastly, incorporating season into the survey design permitted investigation of seasonal differences in diet composition over habitats and to determine if habitat usage by goosefish changed depending on season and prey composition. I hypothesized that diet composition will change as community composition and available prey choices change with season.

MATERIALS

Study Species

Goosefish (F. Lophiidae) range from the southern Grand Banks of Newfoundland down to Cape Hatteras, North Carolina with a eurybathic distribution from mean low water to a depth of 900 m (Bigelow and Schroeder 1953, Markle and Musick 1974, Wenner 1978, Scott and Scott 1988). After a pelagic larval phase, goosefish settle and become a slow-growing, benthic dwelling, sit-and-wait predator that consume both pelagic and benthic fish prey, as well as invertebrates (Crozier 1985, Armstrong 1987). Goosefish utilize the first spine of their dorsal fin to attract prey (Fig. 2). Due to their large mouth and elastic stomach, goosefish are capable of consuming prey that is equal in length to themselves and up to one half of their own body weight. Goosefish are relatively slow swimmers and at times walk over substrate by using their pectoral fins (Steimle et al. 1999, Laurenson et al. 2004). Because goosefish are less mobile than many other groundfish species such as cod and haddock, populations may be more likely to benefit from a reserve. Thus, if goosefish do not benefit from the protection of the WGMCA, its effectiveness for other groundfish species is likely to be limited.

Site Selection and Sampling Design

A factorial design using an otter trawl to sample fish biomass was employed to test the effects of season (spring vs. fall), reserve (in vs. out) and habitat type (mud vs. edge of structured habitat) on the distribution, abundance, feeding ecology, and condition

of goosefish. In September of 2004, trawl sites were selected using a drop tow camera to classify the following two habitat types: (mud) relatively featureless mud bottom isolated (~1.5 km) from gravel or cobble structure, and (edge) bottom adjacent to these more complex habitats. Sampling was conducted in the fall (2005) and spring (2006), with 4 replicate sites each inside and outside the reserve (8 total sites). Each site included two habitat stations. A total of 16 tows (2 reserve treatments X 4 sites X 2 habitats) were conducted during each season. Depth ranged from 16.5 – 26.2 m over the 16 sites.

Sampling Protocol

All sampling was conducted from the F/V De Dee Mae II. This vessel is a Down East 54 foot (16.5 m) stern trawler with a 22 foot (6.7 m) beam and a 9 foot (2.7 m) draft. Goosefish were sampled with a 20 m otter trawl net with a 5 cm cod end fitted with a 2.5 cm mesh liner to retain juveniles as well as adults (see Sherman et al. 2005a for net specifications). Trawl tows were fixed at 15 minutes long at a towing speed of 2.3 - 2.5 knots. Tow time began when the winch brake was tightened, signifying that the net was on the seafloor bottom. The tow ended when the brake was loosened and cable hauling commenced. Upon retrieving the net, goosefish were enumerated, measured to the nearest millimetre (TL – total length) and individually weighed. Stomachs were removed on board and preserved in 10% formalin and seawater. Goosefish continued to feed in the trawl, as evidenced by the occasional prey that were located in the goosefish's buccal cavity and esophagus. Consequently, these "prey" items, plus an additional prey item with no visible signs of digestion located in the stomach of one individual fish with no visible signs of digestion were excluded from our analysis. In the laboratory, samples

were transferred from the 10% formalin to 70% Ethanol. Excess fluid was removed prior to recording weight of whole stomachs. Prey contents were enumerated, identified to the lowest taxonomic level possible and weighed to the nearest tenth of a gram.

Data Analyses

The effects of season, reserve and habitat on abundance, size, Fulton's K condition factor (Fulton 1904), and prey fullness index (PFI) were analyzed using two- and three-way ANOVAs. Abundance was quantified as the total number of goosefish per tow. Thus, abundance had only one value per tow. Replications for all other dependent variables depended on the abundance of goosefish sampled. Total length (TL; mm) was used as an indicator of size. Length frequency distributions were also calculated for *L. americanus* in and out of the WGMCA. In particular, the frequency of four non-overlapping 200 mm TL size classes were used determine which length classes of goosefish may differ with reserve status. Differences in abundance of goosefish in vs. out of the reserve for each size category were assessed using t-tests. A condition factor (Fulton's K) was used to assess overall goosefish physiological status by evaluating how weight scales with length. Fulton's K was calculated for each fish as:

$$K = W/L^3 * 1000 \qquad (1)$$

where W = weight of goosefish (g) and L= length (mm). A PFI was constructed for each prey category by:

$$PFI = W\ prey_i\ in\ stomach_j\ /\ W\ of\ fish_j * 100 \qquad (2)$$

A 3-way ANOVA was used to analyze the effects of season, reserve and habitat on PFI of adult fish. However, juvenile goosefish were not prevalent inside of the reserve. Thus, for the juvenile PFI analyses, reserve effect was excluded and only the effects of habitat and season on Mysidacea, Pandalidae and Gadidae PFI in juveniles were analysed via a 2-way ANOVA.

Stomach content analyses were also conducted separately for juveniles and adults. Information on goosefish diet from Armstrong *et al.* (1996) and size at maturity from Steimle *et al.* (1999) indicate goosefish experience an ontogenetic diet shift around 200-250 TL as well as a physiological shift towards reproductive maturity beginning at 320 mm TL (males) and 360 mm TL (females). From these estimates, and for the purpose of this study, goosefish less than or equal to 300 mm TL were considered juveniles whereas those above 301 mm TL were classified as adults. Diet analyses were calculated to determine an index of relative importance (IRI), modifying the methods of Pinkas *et al.* (1971).

$$IRI_i = (\%N_i + \%W_i) \times FO_i \qquad (3)$$

Where the frequency of occurrence (FO_i) is the number of stomachs with $prey_i$ divided by number of stomachs with food, the weighed abundance ($\%W_i$) is the total weight of $prey_i$ divided by the total weight of all prey, and the numerical abundance ($\%N_i$) is the total number of $prey_i$ divided by total number of all prey). These individual components of an IRI were calculated based on methods described by Hyslop (1980).

RESULTS

Abundance and Distribution

A total of 121 goosefish were caught during the spring and fall sampling trips ranging in size from 65 to 775 mm TL. Habitat and season did not affect *L. americanus* abundance (Table 1). Counter to my hypothesis, twice as many goosefish were caught outside the reserve (significant reserve effect - Table 1; Fig. 3). Goosefish mean length (mm) did not vary significantly with habitat or season, but did differ as a function of reserve status (Table 2). In particular, mean length of goosefish within the reserve was 27% higher than that of goosefish outside the reserve (Table 2; Fig. 4). To examine the combined pattern of size and abundance, length frequency distributions in and out of the reserve were calculated *a posteriori*. Student's T-Tests on the effects of reserve status on goosefish abundance in each size class indicated that there were significantly fewer individuals inside the reserve for the two smaller size categories (Fig. 5; 0-200 size class: F=6.3158, P=0.018; 201-400 size class: F=5.9471, P=0.021; 401-600 size class: F=0.3797, P=0.542; 601-800 size class: F=0.0838; P=0.774).

Condition Factor

Both season and habitat, but not their interaction, influenced goosefish condition factor (Table 3). Goosefish condition was significantly higher in the edge habitat for both seasons (Table 3; Fig. 6). Goosefish condition was significantly higher in the spring than the fall (Table 3; Fig. 7). Finally, a marginally non-significant trend was observed

for the interaction between habitat and reserve status. The increase in goosefish condition in edge habitats was much more pronounced inside the reserve (Table 3, Fig. 8).

Diet Composition

One-hundred eighteen stomachs were collected over two seasons. Of the fifty-five juvenile (<300 mm TL) goosefish stomachs sampled, 12 were empty. Percent of empty stomachs sampled inside the reserve on the mud habitat was 50%, while edge was 33%. Empty stomachs sampled outside the reserve were 20% and 15% for mud and edge habitat, respectively. Table 4 shows the breakdown of stomach contents for juvenile goosefish caught in each habitat type both in and out of the reserve pooled over spring and fall sampling seasons. Prey species from the family Mysidacea were found only in stomachs outside of the reserve, occurring in 22% of stomachs in the edge habitat and 6.3% of stomachs in the mud habitat. Although mysid relative weight was low in both the edge (0.06%) and mud habitat (0.1%); numerically mysids constituted a much larger fraction of the available prey (59.6% edge and 7.1% mud). Another shrimp, *Pandalus borealis*, was also found in stomachs of fish caught outside of the reserve, occurring both in edge (18.1%) and mud (12.5%) habitat. Relative weight contribution of *P. borealis* was 3.3% and 4%, respectively, for mud and edge habitat treatments, while numerical abundance was 8.5% in edge and 14.3% in mud habitat.

Juvenile goosefish preyed upon a variety of demersal fish species. Four-bearded rockling (*Enchelyopus cimbrius*) was found in stomachs caught inside the reserve on

edge habitat (100%) and outside the reserve on both mud (0.5%) and edge (22.7%) habitat. *Enchelyopus cimbrius* relative weight contribution ranged from 0.5% to 83.3% in the mud habitat outside the WGMCA and in the edge habitat inside the reserve, respectively. Their numerical contribution to total prey also was dependent on habitat type and location (0.4% to 60%). Other gadiformes that occurred less frequently included silver hake, *Merluccius bilinearis*, (FO=4.5%, W=19%, N=2%) and the true hakes, *Urophycis* spp. (FO=4.5%, W=8%, N=2%). Other demersal species that were consumed included Acadian redfish, *Sebastes fasciatus*, (FO=4.5%, W=0.3%, N=2%), ocean pout, *Macrozoarces americanus*, (FO=50%, W=65%, N=50%) and American plaice, *Hippoglossoides platessoides,* (FO=9%, W=31.5%, N=4%). Unidentified fish tissue was common among all sites sampled (see Table 4).

Sixty-three adult goosefish stomachs were analyzed, 10 were empty. Percent of empty stomachs sampled inside the reserve on the mud habitat was 20%, while edge was 7%. Empty stomachs sampled outside the reserve were 19% and 14% for mud and edge habitat, respectively. *Pandalus borealis* was found in one-third of the stomachs of adult goosefish inside the reserve in both habitats, but contributed only 2.8-3.1% of the relative weight of prey (Table 5). Total prey composition of adult goosefish inside the reserve was comprised of 20% or more of *P. borealis*. *Pandalus borealis* had a slightly higher frequency of occurrence in adult goosefish stomachs outside the reserve compared to adult goosefish stomachs sampled inside the reserve (FO=50% edge; FO=35% mud). Weight contribution of *P. borealis* in adult goosefish stomachs analyzed outside the reserve was lower in the mud habitat than the edge habitat (W=7.9% edge, W=2.1% mud). Numerically, *P. borealis* accounted for at least 20% of the prey items found in

stomach inside the reserve and at least 32% of prey items found in stomachs outside of the reserve (see Table 5).

Adult *L. americanus* preyed on several demersal and pelagic fish species, including the following Gadiformes: *E. cimbrius, M. bilinearis, Urophycis* spp and unidentified Gadidae. *Sebastes fasciatus* were found in a quarter of adult goosefish stomachs sampled within the reserve. Yet, numerically, all these species only comprised 13% of the prey components sampled from edge and 26% from mud habitat. American plaice occurred in adult goosefish stomachs sampled outside of the reserve only (FO= 8.3% edge; FO=28.6% mud) and were numerically only 17% of total prey items consumed by adult goosefish in both mud and edge habitat outside the reserve. Clupeidae occurred in adult goosefish stomachs in both habitats, regardless of reserve status. The relative contribution of clupeids to the diet of goosefish ranged from 18 to 78% when present (Table 5).

Prey Fullness Index

To further investigate how season and habitat affect goosefish diet and potentially condition, I analyzed prey composition in juvenile and adult goosefish. For juvenile goosefish, mysids, *P. borealis*, and four-bearded rockling (*E. cimbrius*) were important prey items comprising 71.6% of the total prey items consumed (see Table 4). The PFI for both mysids and *P. borealis* did not vary significantly with habitat or season (Table 7, 8). However, the PFI for four-bearded rockling was significantly higher in juvenile goosefish

sampled in the mud habitat in the fall season (significant habitat x season interaction, Table 6; Fig. 9).

Adult goosefish prey on more fish species than juveniles. Prey species important for adult *L. americanus* include Gadiformes, Pleuronectidae and Clupeidae. Season, reserve status, and habitat type did not affect the PFI of Gadiformes and Pleuronectidae in the diet of adult goosefish (Table 9, 10). Clupeids were found only in adult goosefish stomachs. Clupeid PFI in the diet of adult goosefish differed seasonally (Table 11). The interaction between habitat and reserve also significantly affected clupeid PFI in adult goosefish (Table 11). The PFI of Clupeids in the spring was 32 times greater than in the fall (Fig.10). Clupeids contributed significantly to the adult goosefish's diet on the edge habitat inside the reserve, but PFI did not differ between habitats outside the reserve (Fig. 11).

DISCUSSION

Goosefish Distribution within the WGMCA

Reserve status had a big influence on the distribution and abundance of goosefish in our study. Typically, marine reserves are established to protect juvenile fish populations by providing safe refuge to ensure juvenile survival and growth (Alcala and Russ 1990, Bohnsack 1998, Russ and Alcala 2003). Marine reserves have also been established to protect the benthic habitat and communities from destructive fishing practices (Thrush et al. 1998, Murawski et al. 2000). Surprisingly, goosefish were overall less abundant inside the WGMCA than out. This differential occurred because juvenile (<400 mm) goosefish were much more abundant (~5 times greater) outside the reserve. This result suggests that the WGMCA does not contain critical habitat for juvenile goosefish, in spite of eight years of protection to allow recovery of important benthic habitats and prey resources. Furthermore, contrary to my hypothesis, the abundance of larger goosefish did not differ as a function of reserve status. Thus, it appears that the WGMCA also does not provide typical reserve benefits (i.e., reduced fishing mortality) for adult goosefish.

There are several possible hypotheses to explain the counterintuitive result of greater juvenile goosefish abundance outside of the reserve. First, differences in larval supply may be influencing the population structure of juvenile goosefish inside versus outside the WGMCA (i.e., goosefish recruitment may be lower in the WGMCA). Second, reduced fishing pressure in the WGMCA may have resulted in locally increased predator abundance that leads to increased predation on juvenile goosefish. Third,

nursery habitat required for settlement, survival and growth of juvenile goosefish may either be limited or nonexistent inside the WGMCA. And lastly, the reduced abundance of juvenile goosefish within the reserve might be explained by a limitation of food resources.

Recent studies on goosefish spawning and larvae patterns have suggested that the spawning areas are centered in the Mid Atlantic Bight. Fewer larvae were collected in the GoM, though effort was comparable (Steimle et al. 1999; Able and Chambers 2003). Although larval recruitment varies at large scales (i.e., the GoM vs. southern New England and the Mid Atlantic Bight), there is little evidence of goosefish recruitment gradients on smaller scales. Given that our study area encompasses a small portion of western Gulf of Maine, it is unlikely that larval recruitment differed in vs. out of the reserve.

The WGMCA is a multispecies reserve. After eight years of protection, some fish species found within the reserve may have considerably increased in abundance because of the release of fishing pressure or a reduction in by-catch mortality. It is possible that an increase in juvenile goosefish predators inside the reserve may be limiting the abundance of juvenile goosefish. Predators of juvenile goosefish include tiger shark (*Galeocerdo cuvier*), sandbar shark (*Carcharhinus plumbeus*) and skates (*Raja* spp.). This goosefish study was a part of a larger project. Of the ~600 predator stomachs analyzed, only two juvenile goosefish were observed (Smith et al., unpub. data) suggesting that consumption rates for teleost predators are very low. However, our sampling methods did not catch any large sharks. Therefore, I cannot definitively

evaluate the possibility that elevated predation rates from other types of predators are affecting the distribution of juvenile goosefish.

The higher abundance of juvenile goosefish outside the WGMCA might be the result of an interaction between fishing disturbance and goosefish feeding ecology. The diet components of juvenile and adult goosefish overlap somewhat, but each group uses specific prey items not utilized by the other. Juvenile goosefish utilize crustaceans and smaller fish while adult goosefish prey upon larger and more bulky fish species (Table 4-5) (Crozier 1985, Armstrong et al. 1996). Dominant prey items for juvenile goosefish include mysids, pandalid shrimp and small, eel-like fish (i.e., four-bearded rockling, *E. cimbrius*, silver hake, *Merluccis bilinearis* and the true hakes, *Urophycis* spp) (Table 4). In turn, the prey utilized by this eel-like fish group also includes mysids, as well as polychaete worms, and small bivalves (Bowman et al. 2000, M. Smith, unpubl. data). Bottom trawling around the periphery of the WGMCA creates a disturbance of the benthic habitat (Watling and Norse 1998, Freese et al. 1999, Murawski et al. 2005). Polychaetes, brittle stars, and molluscs may become readily available to a host of vertebrate predators including juvenile fish species that juvenile goosefish in turn prey upon (Engel and Kvitek 1998). Flatfish, for example, prey predominately on polychaetes and bivalves (Bowman et al. 2000) and have been linked with foraging on damaged invertebrate fauna from trawling activity (Piet et al. 2000). Flatfish biomass tended to be higher in tows outside the reserve (Smith et al., unpub. data) suggesting that flatfish may also be utilizing the additional prey resources made available by trawling. If the disturbance created by trawling outside the reserve increases available prey resources, juvenile goosefish may aggregate outside of the reserve to forage.

Furthermore, during ROV observations for *L. piscatorius* in the north-east Atlantic, Laurenson *et al.*(2004) suggested monkfish aggregations were initiated by minor sediment disturbance from equipment use and these aggregations might be related to food supply. The main components of juvenile goosefish diet, mysids and four-beard rockling, were more prevalent in the stomachs of goosefish caught outside the reserve, which supports this hypothesis of food resource aggregations (Table 4).

In contrast to the pattern for juvenile goosefish, adult abundance was similar inside vs. outside the reserve. This result could be a consequence of similar food resources for the adults in and out of the reserve. Alternatively, the partial reserve status of the WGMCA, which allows a directed gillnet fishery for adult goosefish during several months of the year may also explain why adult populations did not differ in vs. out of the reserve.

If food availability is increased outside the reserve, why did adult goosefish abundance not also vary with reserve status? Larger fish prey that juvenile goosefish are physically incapable of consuming due to gape limitations (Gordoa and Macpherson 1990) contributed substantially to the diet of adult goosefish. Adult goosefish prey items were also more varied, including a wider variety of fish species (Table 5). One probable explanation for adult goosefish distribution and abundance patterns is an increase in available prey for larger goosefish inside the reserve. Adult goosefish are capable of consuming larger prey sizes and thus are not as limited as juvenile goosefish (Laurenson and Priede 2005). Additionally, adult goosefish were opportunistic foragers, consuming a variety of prey, both small and large.

Clupeids, which contributed largely to adult goosefish diet in both habitats, were found in goosefish stomachs inside and outside of the reserve (Table 5). Further, clupeid biomass was similar throughout sampling tows, suggesting wide-spread distribution (M. Smith, pers. ob.). Clupeids migrate daily within the water column, rising to the surface to feed before returning to depths. When clupieds are near the seafloor, they are available as prey to goosefish. Clupeid consumption has also been documented for white anglerfish, *L. piscatorius*, (Crozier 1985, Laurenson and Priede 2005). Clupeids are a schooling pelagic fish group and this schooling behaviour may explain the large quantities of clupeids identified in adult goosefish stomachs. Goosefish digestion rates are suspected to be slow (Crozier 1985) and a pattern of decreased feeding rate with an increase of goosefish length has been documented by Armstrong *et al.* (1996). Therefore, adult goosefish may not need to forage as often if their diet consists of clupeids or other large fish prey. A large foraging event may sustain energy demands of adult goosefish over a longer period of time. Consequently, adult goosefish may have a more sedentary lifestyle because of their opportunistic foraging practices and may remain within the reserve boundaries. Clupeids are consumed in large quantities when present, satisfying adult goosefish dietary needs and possibly reducing their foraging distance and time inside the reserve.

Diet and Trophic Ecology

Although habitat and seasons effects on goosefish abundance and size were minimal, these factors, along with reserve status, influenced goosefish condition. Reserve effects on diet and condition factor of goosefish were dependent upon habitat type. Prey

fullness index results indicated that clupeids contributed significantly to adult goosefish diet in the edge habitat only inside the WGMCA (Fig. 11) which might explain why the condition factor of goosefish was also higher in the edge habitat rather than mud only inside the reserve (Fig. 8). Clupeids are consumed in large quantities and are nutritionally valuable prey item. Although abundance of clupeids did not differ significantly inside vs. outside of the reserve, these results suggest that adult goosefish inside the reserve utilized clupeids more often then other fish species. Thus, habitat and reserve status apparently influence together not only goosefish foraging behaviour, but assimilation of important dietary components which impacts goosefish condition. These results also suggest that edge habitat may offer more prey opportunities than mud habitat, especially when protected from bottom damaging activities.

Although results did not indicate significant differences in habitat usage during this study, it is plausible that goosefish still may benefit energetically from edge habitat more so than mud. Condition factor results indicate goosefish have a higher weight to length scale over the edge habitat than mud habitat type. By making the assumption that a higher weight at a given length for an individual goosefish translates to an increase in net energy intake once body maintenance is completed, this increase in energy should be a result of an increase in food consumption. Therefore, juvenile and adult goosefish may benefit from foraging near the edge habitat. Coincidently, trawling activity typically occurs near edge habitat, thus potentially disturbing habitat that is accessible for juvenile goosefish. Juvenile goosefish may have increased benefits utilizing the edge habitat aside from food resources. Edge habitat may provide shelter space to reduce the risk of predator interactions. Goosefish sampled in the edge habitat during both seasons had a

higher condition factor than goosefish sampled in the mud habitat inside the reserve only. This suggests that edge habitat protected from destructive fishing methods may indeed benefit both juvenile and adult goosefish condition factor by allowing goosefish adjacent to structured habitat to forage more effectively.

Goosefish condition was higher during the spring than in the fall. Goosefish migrate seasonally between shallow and deep waters (Hartley 1995, Able and Chambers 2003). These seasonal migrations might also be linked with prey resource availability. Seasonal variation in condition factor may be influenced by changes in community structure and prey abundance. Clupeid biomass was higher in the spring than in the fall (Smith et al., unpubl. data), which could explain why the condition of goosefish was greater in the spring. During the spring, the PFI for clupeids was substantially higher than the PFI in the fall (Fig. 10). Goosefish may be able to follow the schools of pelagic prey as these prey schools enter shallower waters during the spring months. An alternative explanation for seasonal variation in goosefish condition could be that goosefish spawning in the summer reduces their condition substantially because of large energy allocation required by this activity.

Changes in community structure may influence competition for shared prey resources between adult goosefish and other predators. Spiny dogfish (*Squalus acanthias*) were abundant in the tows conducted during the fall sampling season only (Smith et al., unpubl. data). On examination of spiny dogfish stomach contents, stomachs with food items consisted mostly of silver hake and herring, *Clupea harangus*, (M. Smith, pers. ob.). Both silver hake and herring were found in the stomachs of goosefish from the fall sampling season (Table 5). Therefore, dogfish may compete directly with

adult goosefish during the fall for clupeids and silver hake. This pattern could possibly lead to reduced availability of clupeid resources for adult goosefish in the fall and lower the condition factor of the individuals sampled.

The comparison of the diet composition of goosefish collected in the western GoM with those in previous studies confirms that goosefish forage on a wide variety of prey and that prey availability varies by location (Bowman et al. 2000). Clupeids were commonly found in goosefish stomachs in this study, but were rare in Armstrong *et al.* (1996). However, Bowman *et al.* (2000) documented stomach content analysis of goosefish from six geographical locations in the northwest Atlantic including the GoM. Results from the Bowman *et al.* (2000) study indicated clupeids comprised 13% of total prey weight. Thus, diet composition results from previous diet studies of *L. americanus* along with this study emphasize the regional differences that occur in goosefish prey species. Prey composition is dependent on community structure found within the goosefish's environment.

Goosefish diet was comparable to other studies conducted on *L. americanus* (Armstrong et al. 1996; Bowman et al. 2000), and the congeneric white anglerfish, *L. piscatorius*, (Crozier 1985; Laurenson and Priede 2005). Cannibalism has been documented for this species (Bigelow and Schroeder 1953; Armstrong 1987); however, no evidence of cannibalism was observed during this study. There was a clear ontogenetic diet shift towards piscivory around the 200-250 mm TL as seen by Armstrong *et al.* (1996). In my diet analyses, the occurrence of four-bearded rockling in juvenile goosefish predominately around 200 mm TL suggested that goosefish begin consuming four-bearded rockling at the inception of its ontogenetic shift to a piscivorous

lifestyle. During the spring, ocean pout (*Macrozoarces americanus*) was frequently observed in juvenile goosefish at the cusp of the diet shift while four-bearded rockling was less frequent. The occurrence of ocean pout in the stomachs of juvenile goosefish may imply that four-bearded rockling were not readily available as a prey resource during the spring, and ocean pout was utilized instead as it is similar in body shape. The PFI of four-bearded rockling (Fig. 9) suggests that rockling may have been available in higher quantities during the fall, thus comprising a larger portion of juvenile goosefish prey. These results suggest that juvenile goosefish utilize a functional fish group that is characterized by slender, eel-like fish such as four-bearded rockling, ocean pout, and juvenile silver hake, white hake (*Urophycis tenius*) and red hake (*Urophycis chuss*). Crozier (1985) reported small *L. piscatorius* consuming common dragonette (*Callionymus lyra*) and snake blenny (*Lumpenus lampretaeformis*) more often than large *L. piscatorius*. Laurenson and Priede (2005) found that small *L. piscatorius* (less than 300 mm) forage primarily on sandeel (*Ammodytes marinus*). The diet composition of small *L. piscatorius* differed seasonally. For instance, Laurenson and Priede (2005) showed that the importance of sandeel in goosefish diet was inversely related to the presence of Norway pout (*Trisopterus esmarkii*). Norway pout was found to occur frequently and in high abundance in L. piscatorius stomachs sampled during January to March, but was rarely occurred during April to June, when sandeel was prevalent. Both of these north-west Atlantic studies on *L. piscatorius*, a species once confused with *L. americanus* (Armstrong 1987), support my hypothesis of juvenile goosefish utilizing a functional prey group of slender, eel-like fish and also that seasonal variation may dictate which prey fish in this functional group is consumed.

Smaller goosefish may forage primarily on small, eel-like fishes because of their body shape. When these prey items were excised from the stomach, fish were found to be compactly folded within the stomach; this was not observed for clupeids and other larger and less slender fish prey items (Smith, pers. ob.). Juvenile goosefish have less prey types available due to the limitation imposed by their gape width and buccal cavity (Gordoa and Macpherson 1990).

As lophiids grow, they begin eating larger fish (Crozier 1985, Gordoa and Macpherson 1990, Armstrong et al. 1996, Laurenson and Priede 2005, Walmsley et al. 2005). In adult *L. americanus* stomachs, adult redfish (*Sebastes fasciatus*), flatfish (Pleuronectidae), gadids and clupeids were dominant fish dietary components. Clupeids appear to be a year-round food source for *L. americanus*, with juvenile and adult specimens identified in goosefish stomachs in the GoM. In contract, clupeids in the northeast Atlantic were found to be seasonally preyed upon by *L. piscatorius* (Crozier 1985; Laurenson and Priede 2005).

CONCLUSION

The WGMCA was established in part to protect juvenile groundfish habitat, while also reducing the fishing effort of important traditional fish stocks. However, the results from this study indicate that juvenile goosefish are more abundant outside the WGMCA. This pattern suggests that juvenile goosefish may be attracted to trawled habitat locations and potentially benefit energetically from an increase in prey resources. If this explanation holds for juvenile goosefish, what is the likely impact of this reserve and trawling disturbance on juvenile cod and haddock, two of the traditionally harvested groundfish species?

Although goosefish exhibit behaviours different than typical groundfish species, both juvenile and adult goosefish have similarities with juvenile and adult cod. Juvenile goosefish and juvenile cod both prey on invertebrates and juvenile fish species that may aggregate after trawling occurs. It has been documented in previous literature that juvenile cod and haddock predominantly forage on benthic invertebrates and crustaceans that may be drawn to trawling disturbance (Bowmen et al. 2000). Thus, there is a possibility that juvenile cod and haddock abundance may be influenced by trawling disturbance for prey resources. Also, it is possible that other juvenile demersal fish species are also attracted to trawling disturbance aggregations for prey resources. Adult goosefish and cod have similar diets, including herring, silver hake and northern shrimp (Bowman et al. 2000).

The effects of reserve on adult goosefish abundance and distribution may not be detectable with this sampling method due to their mobility. This study may not have had

the sampling power to determine if the WGMCA influences goosefish abundance and distribution. However, goosefish are a slow growing, demersal fish species and might be slow to respond to reserve protection (Halpern and Warner 2002). Similarly, after closure areas on Georges Bank, cod were slow to recover (Murawski et al. 2000). Because the WGMCA was not designed to protect and rebuild goosefish populations, goosefish within the reserve may still be exposed to increased fishing pressure because of the Goosefish Gillnet Exemption Area.

The quantity of juveniles sampled in this study was surprisingly high considering larval dispersal and the source-sink dynamics in the Western GoM. The Middle Atlantic Bight is suspected to be the spawning center for goosefish (Armstrong 1987, Steimle et al. 1999). Eggs and larvae are then advected up towards Georges Bank and Western GoM in late summer and early fall. The location of the WGMCA may not be suitable for goosefish stock rehabilitation. If goosefish populations in the western GoM are primarily supplied by larvae from goosefish spawning activity in the Middle Atlantic Bight, the WGMCA goosefish are a sink population. Goosefish tagging studies may be necessary to identify small and large scale migration patterns and to determine whether goosefish populations further south are responsible for repopulating northern populations.

Reserves may contain important foraging grounds for juvenile and adult groundfish including goosefish. With less disturbance inside the WGMCA, benthic community structure should be more complex than habitats that are routinely trawled (Collie 1998, Watling and Norse 1998). But it is still unclear if habitat inside the WGMCA offers better foraging for goosefish. Isotope sampling may provide additional trophic level information not attainable through stomach content analysis.

The outcome of this study suggests that positive reserve effects should not be assumed, regardless of the long term protections. Regular sampling of closed versus open areas to assess temporal changes is recommended. Management of closed areas should include research initiatives in their mandate including baseline sampling prior to the closure being implemented. There is a definite need to monitor reserves over time so managers can assess whether or not the intended goals are being achieved.

TABLES

Table 1: Results from ANOVA on abundance of goosefish (α= 0.05). *SS* Sums of Squares.

	df	SS	P-value
Season	1	19.5	0.16
Reserve	1	87.7	**0.005**
Habitat	1	1.5	0.69
Season X Reserve	1	0.7	0.77
Season X Habitat	1	2.5	0.60
Reserve X Habitat	1	3.7	0.53
Season X Reserve X Habitat	1	0.2	0.86
Error	24	220.2	

Table 2: Results from ANOVA on mean length (mm) of goosefish (α= 0.05). *SS* Sums of Squares, *MS* mean square.

	df	SS	P-value
Season	1	5008.1	0.66
Reserve	1	169267.0	**0.01**
Habitat	1	3233.1	0.73
Season X Reserve	1	6660.6	0.61
Season X Habitat	1	21838.7	0.36
Reserve X Habitat	1	1248.6	0.83
Season X Reserve X Habitat	1	551.0	0.88
Error	115	2978117.3	

Table 3: Results from ANOVA on condition factor of goosefish (α= 0.05). *SS* Sums of Squares.

	df	SS	P-value
Season	1	0.013	**0.0003**
Reserve	1	0.001	0.36
Habitat	1	0.008	**0.004**
Season X Reserve	1	0.001	0.25
Season X Habitat	1	0.001	0.24
Reserve X Habitat	1	0.003	**0.10**
Season X Reserve X Habitat	1	0.001	0.22
Error	115	0.104	

Table 4: : Diet analysis for juvenile goosefish (< 300 mm TL).

	IN								OUT							
	MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
CRUSTACEA																
Mysidae	-	-	-	-	-	-	-	-	6.3	0.0	7.1	45	22.7	0.1	62.2	1415
Pandalus borealis	-	-	-	-	-	-	-	-	12.5	2.6	14.3	211	18.1	3.4	4.4	142
CEPHALOPODA	-		-	-	50.0	13.8	25.0	1940	-	-	-	-	-	-	-	-
CHORDATA																
Enchelyopus cimbrius	-	-	-	-	100.0	80.8	50.0	13080	31.3	37.0	35.7	2276	22.7	23.1	11.1	777
Merluccius bilinearis	-	-	-	-	-	-	-	-	-	-	-	-	4.5	16.1	2.2	82
Urophycis spp.	-	-	-	-	-	-	-	-	-	-	-	-	4.5	6.4	2.2	39
Unid Gadidae	-	-	-	-	50.0	2.3	25.0	1365	12.5	9.2	7.1	204	-	-	-	-
Sebastes fasciatus	-	-	-	-	-	-	-	-	-	-	-	-	4.5	0.2	2.2	11
Macrozoarces americanus	50.0	64.8	50.0	5740	-	-	-	-	-	-	-	-	-	-	-	-
Hippoglossoides platessoides	-	-	-	-	-	-	-	-	-	-	-	-	9.0	26.3	4.4	277
Unid Pleuronectidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unid fish tissue	50.0	35.2	50.0	4260	-	-	-	-	31.3	31.7	35.7	2110	22.7	7.6	11.1	425
ANIMAL REMAINS	-	-	-	-	-	3.1	-	-	-	19.5	-	-	-	16.8	-	-
Empty Stomachs	3				1				4				4			
Total Stomachs	6				3				20				26			

Table 5: Diet analysis for adult goosefish (> 300 mm TL).

	IN								OUT							
	MUD				EDGE				MUD				EDGE			
Prey Species	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI	%FO	%W	%N	IRI
CRUSTACEA																
Mysidacae	-	-	-	-	-	-	-	-	7.0	0.0	16.1	113	-	-	-	-
Pandalus borealis	33.3	2.7	26.7	979	33.3	1.2	15.4	553	35.7	2.0	32.3	1225	50.0	6.6	40.0	2330
CEPHALOPODA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHORDATA																
Enchelyopus cimbrius	-	-	-	-	33.3	1.8	3.8	186	7.1	2.2	3.2	38	-	-	-	-
Merluccius bilinearis	8.3	0.3	6.7	58	-	-	-	-	14.3	12.1	6.5	266	-	-	-	-
Urophycis spp.	8.3	19.4	6.7	217	3.3	2.1	3.8	19	-	-	-	-	-	-	-	-
Unid Gadidae	16.7	13.4	20.0	558	3.3	4.9	3.8	29	7.1	1.3	3.2	32	8.3	51.4	13.3	537
Sebastes fasciatus	25.0	32.9	26.7	1490	25.0	6.0	7.7	343	-	-	-	-	-	-	-	-
Macrozoarces americanus	-	-	-	-	-	-	-	-	-	-	-	-	8.3	2.4	13.3	130
Hippoglossoides platessoides	-	-	-	-	-	-	-	-	35.3	25.8	20.0	1617	8.3	6.3	6.7	108
Unid Pleuronectidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unid fish tissue	-	6.4	-	-	16.7	0.2	7.7	132	7.1	0.9	3.2	29	8.3	0.9	13.3	118
Clupeidae	16.7	19.6	13.3	549	50.0	78.0	57.7	6785	35.7	53.0	16.1	2467	16.7	15.3	13.3	478
ANIMAL REMAINS		5.2				5.8				2.7				17.1		
Empty Stomachs	3				1				4				2			
Total Stomachs	15				13				21				14			

Table 6: Partial fullness index for four-bearded rockling in the diet of juvenile goosefish (α= 0.05). *SS* Sums of Squares.

	df	SS	P-value
Season	1	95.7	**0.09**
Habitat	1	17.0	0.48
Season X Habitat	1	111.7	**0.07**
Error	52	1710.3	

Table 7: Partial fullness index for *P. borealis* in the diet of juvenile goosefish (α= 0.05). *SS* Sums of Squares.

	df	SS	P-value
Season	1	0.0004	0.25
Habitat	1	1.479	0.98
Season X Habitat	1	0.019	0.90
Error	52	56.8	

Table 8. Partial fullness index for Mysids in the diet of juvenile goosefish (α= 0.05). *SS* Sums of Squares.

	df	SS	P-value
Season	1	0.063	0.18
Habitat	1	0.031	0.35
Season X Habitat	1	0.038	0.30
Error	52	1.800	

Table 9. Partial fullness index for Gadiformes in the diet of adult goosefish (α= 0.05). *SS* Sums of Squares.

	df	SS	P-value
Season	1	3.4	0.48
Reserve	1	5.4	0.38
Habitat	1	1.0	0.71
Season X Reserve	1	7.1	0.31
Season X Habitat	1	12	0.68
Reserve X Habitat	1	0.8	0.74
Season X Reserve X Habitat	1	13.4	0.17
Error	58	394.2	

Table 10. Partial fullness index for Pleuronectids in the diet of adult goosefish (α= 0.05). *SS* Sums of Squares.

	df	SS	P-value
Season	1	0.799	0.72
Reserve	1	12.694	0.15
Habitat	1	0.007	0.97
Season X Reserve	1	0.799	0.72
Season X Habitat	1	0.484	0.78
Reserve X Habitat	1	0.007	0.97
Season X Reserve X Habitat	1	0.484	0.78
Error	111	679.953	

Table 11: Partial fullness index for Clupeids in the diet of adult goosefish (α= 0.05). *SS* Sums of Squares.

	df	SS	P-value
Season	1	107.881	**0.0099**
Reserve	1	38.909	0.12
Habitat	1	21.643	0.24
Season X Reserve	1	21.538	0.24
Season X Habitat	1	12.534	0.37
Reserve X Habitat	1	81.806	**0.024**
Season X Reserve X Habitat	1	35.607	0.13
Error	58	880.633	

FIGURES

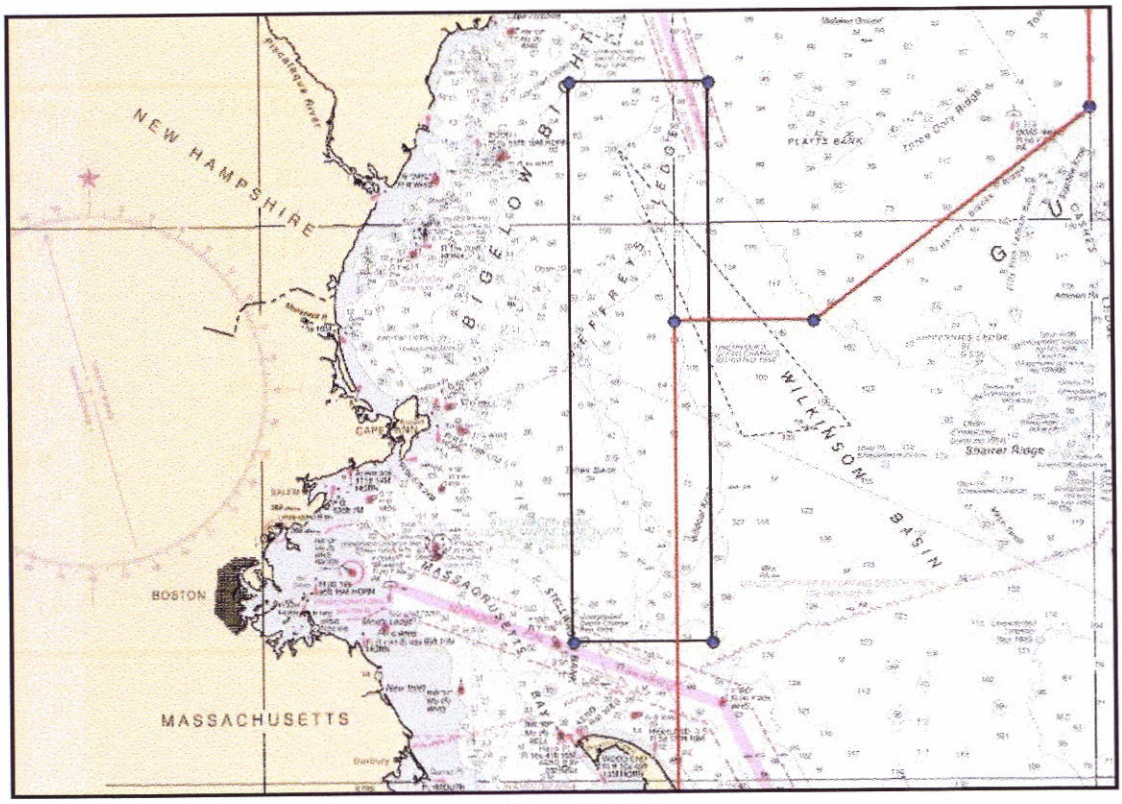

Figure 1: Western Gulf of Maine Closure Area is shown in back. The Goosefish Gillnet Exemption Area extends from the shoreline east to the red line.

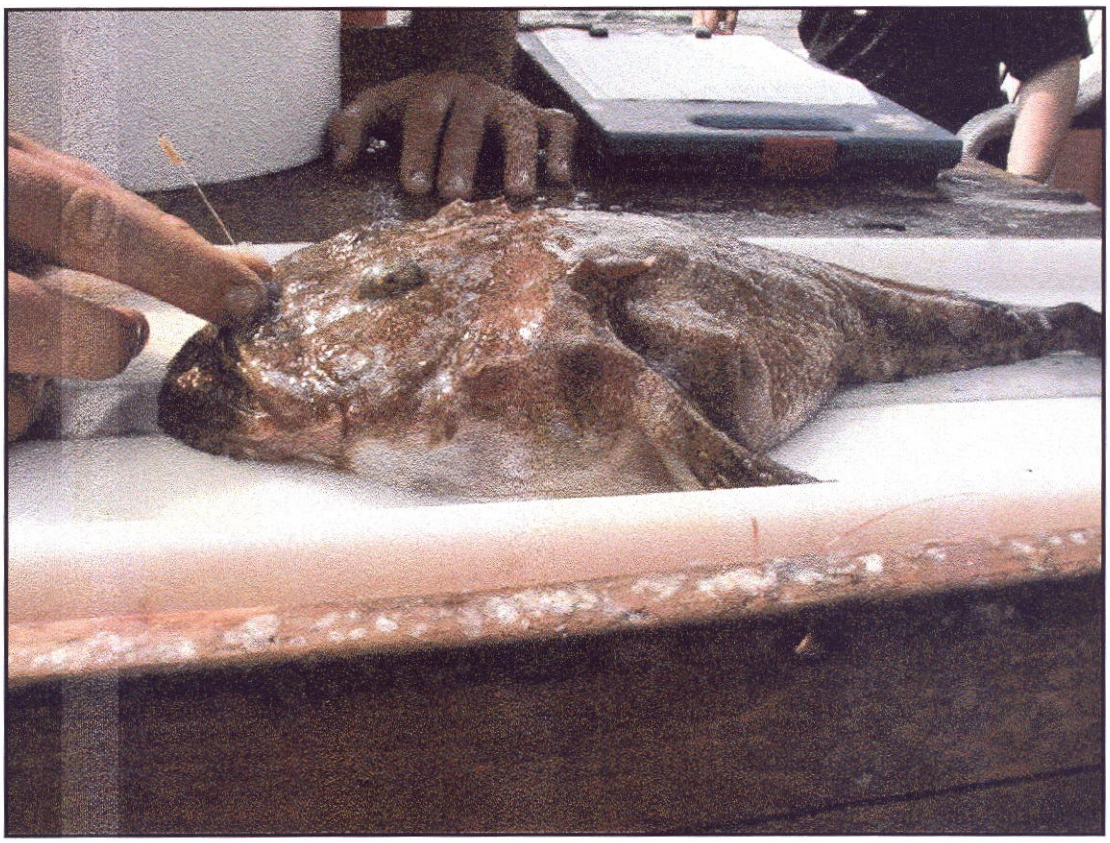

Figure 2: Goosefish, *Lophius americanus*, with lure.

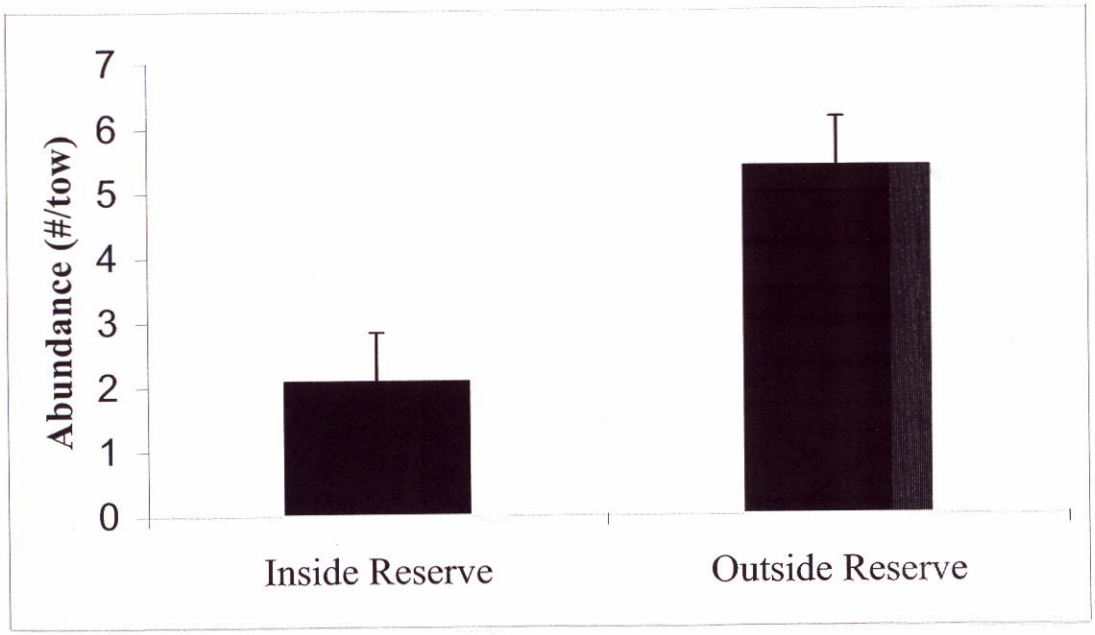

Figure 3: Mean abundance of goosefish caught inside the reserve vs. outside the reserve. Bars indicate one standard error.

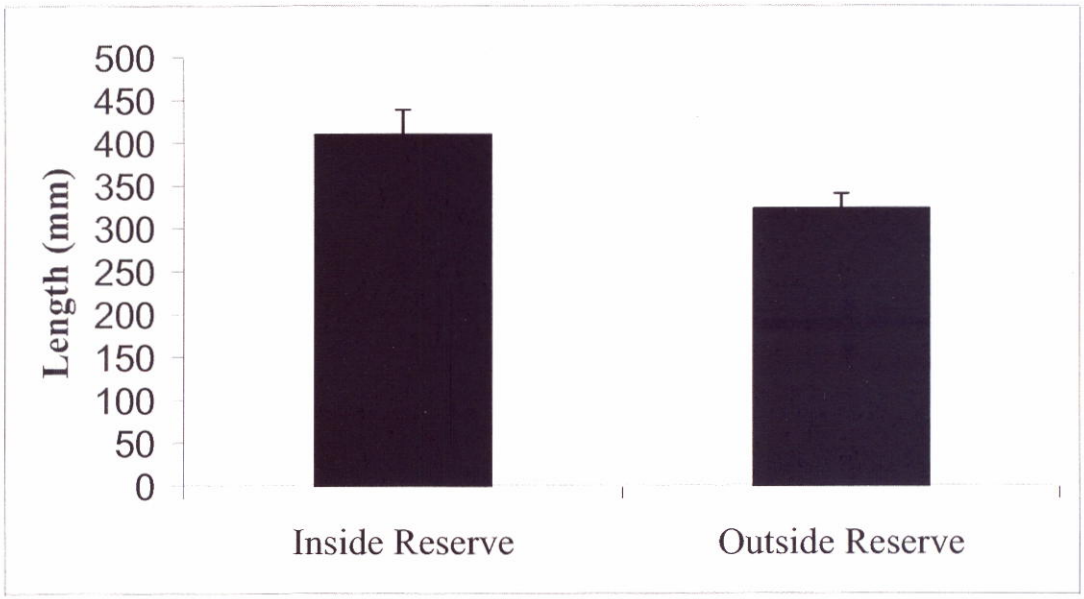

Figure 4: Mean length of goosefish caught inside the reserve vs. outside the reserve. Bars indicate one standard error.

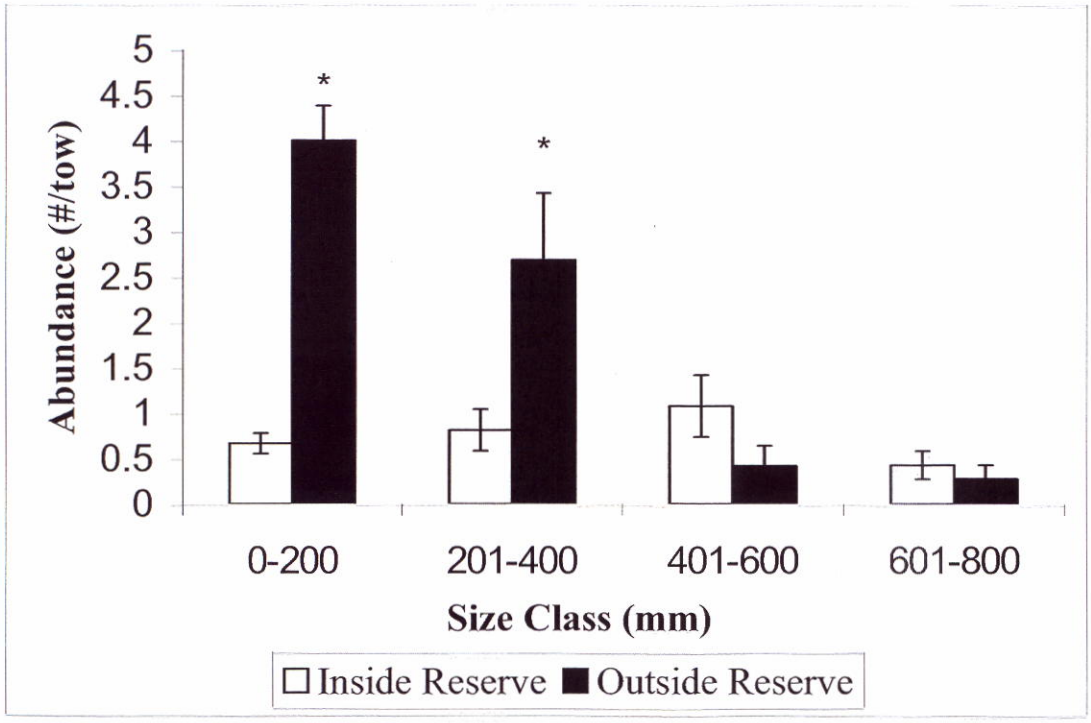

Figure 5: Average goosefish abundance per tow for four size classes. Bars indicate one standard error. Asterisk (*) denotes significant difference in abundance between inside the reserve vs. outside the reserve ($P \leq 0.02$).

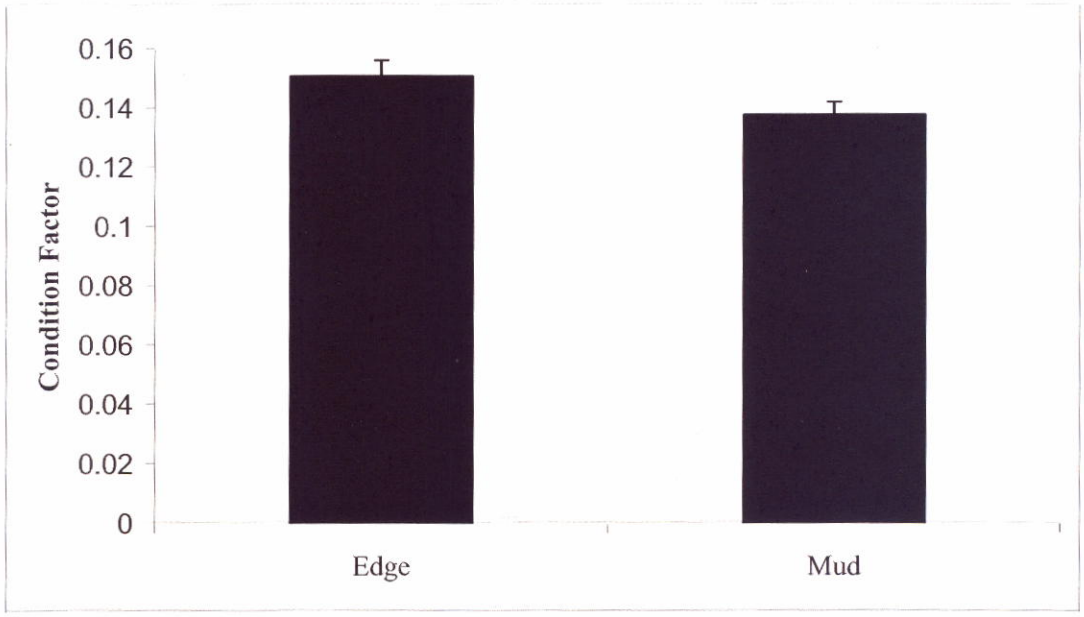

Figure 6: Mean condition factor of goosefish was significantly higher in the edge habitat over both seasons. Bars indicate one standard error.

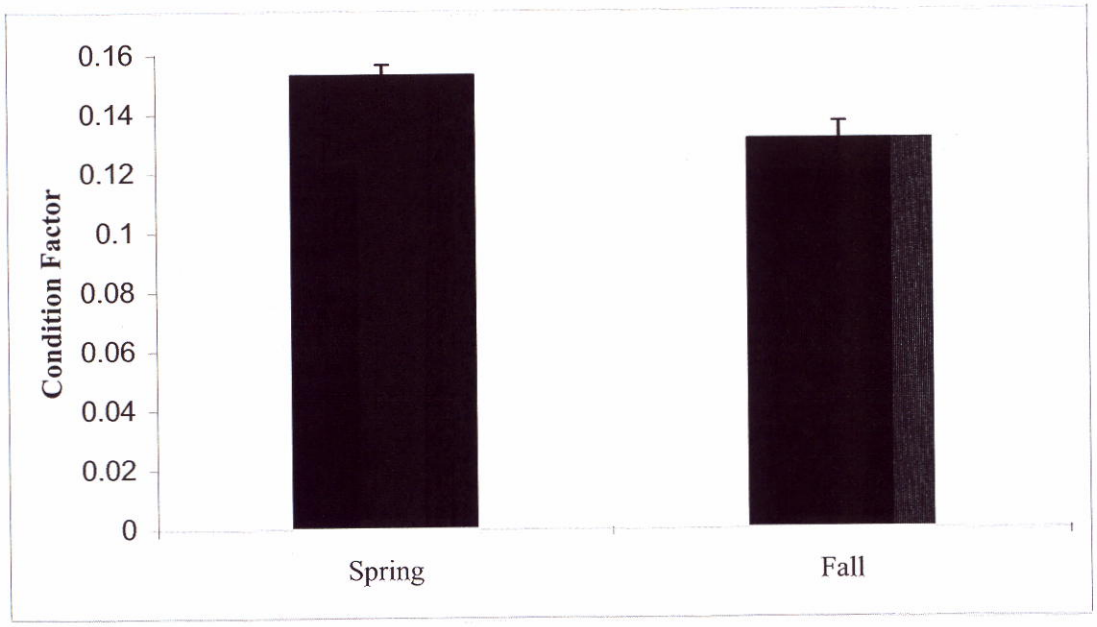

Figure 7: Mean condition factor of goosefish was significantly higher in the spring season than in the fall season. Bars indicate one standard error.

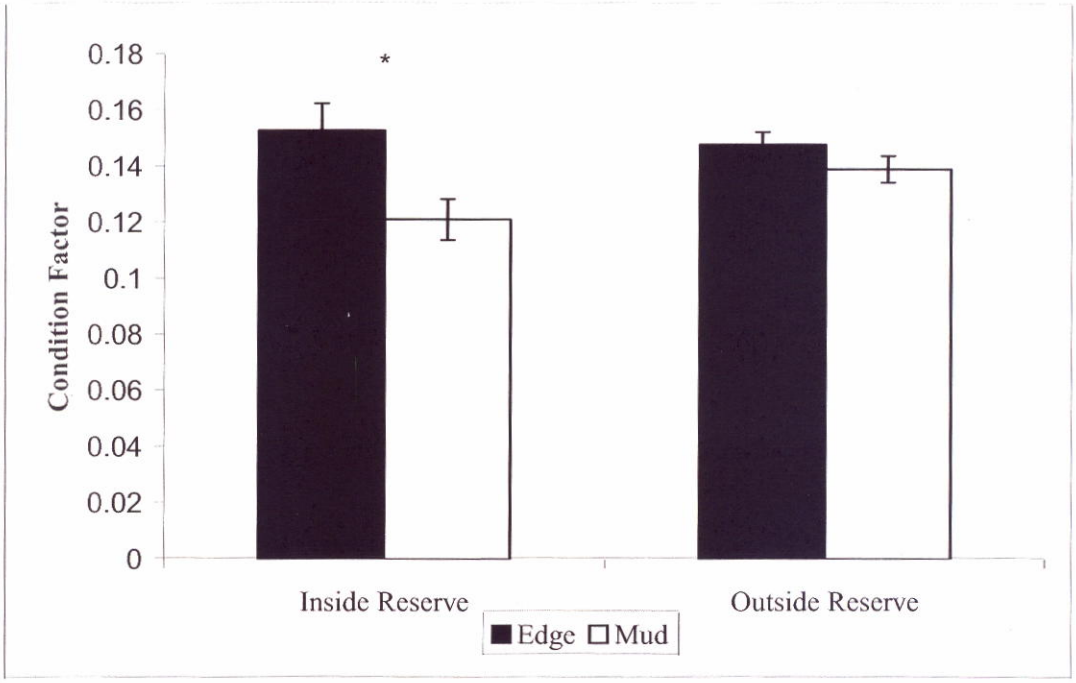

Figure 8: Condition factor of goosefish sampled on edge habitat inside the reserve is significantly higher than mud habitat. Condition factor did not vary between habitats outside the reserve.

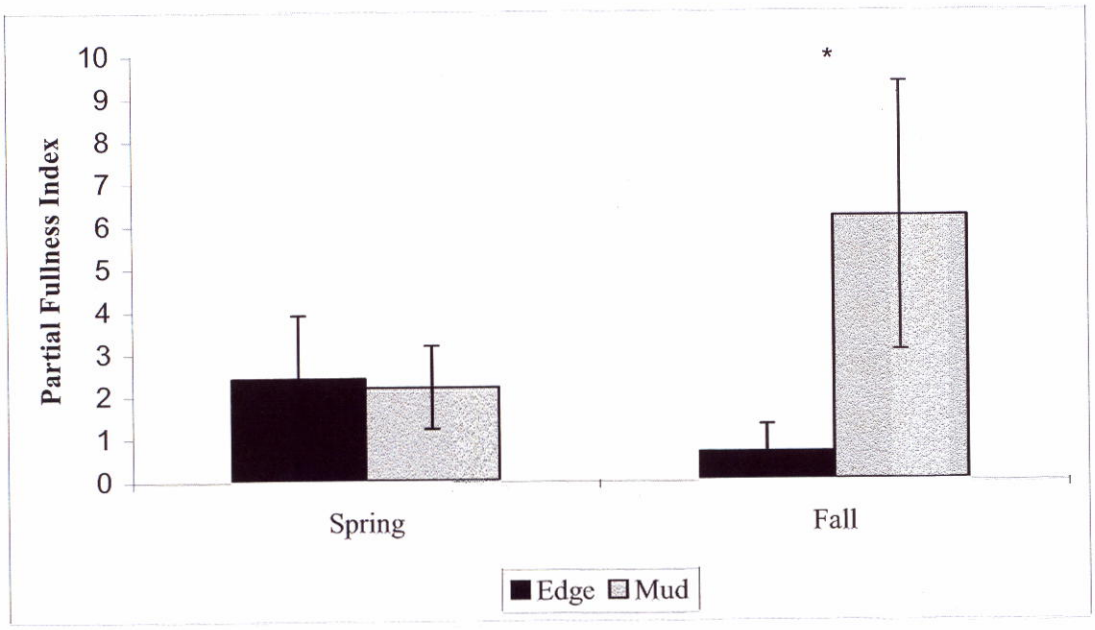

Figure 9: Mean partial fullness index for four-bearded rockling. Mean PFI was significantly higher in the mud habitat than edge during Fall, while there was no significant variation in the Spring. Bars indicate one standard error.

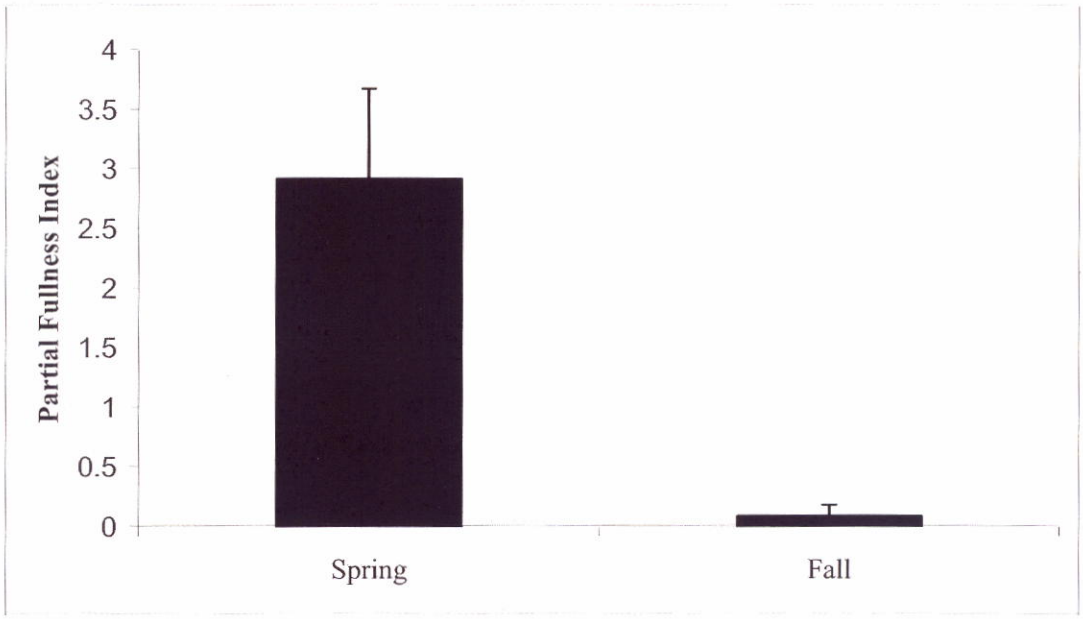

Figure 10: Mean partial fullness index of clupeids in adult goosefish diet PFI clupeids. Clupeids had a significantly higher PFI in Spring vs. Fall. Bars indicate one standard error.

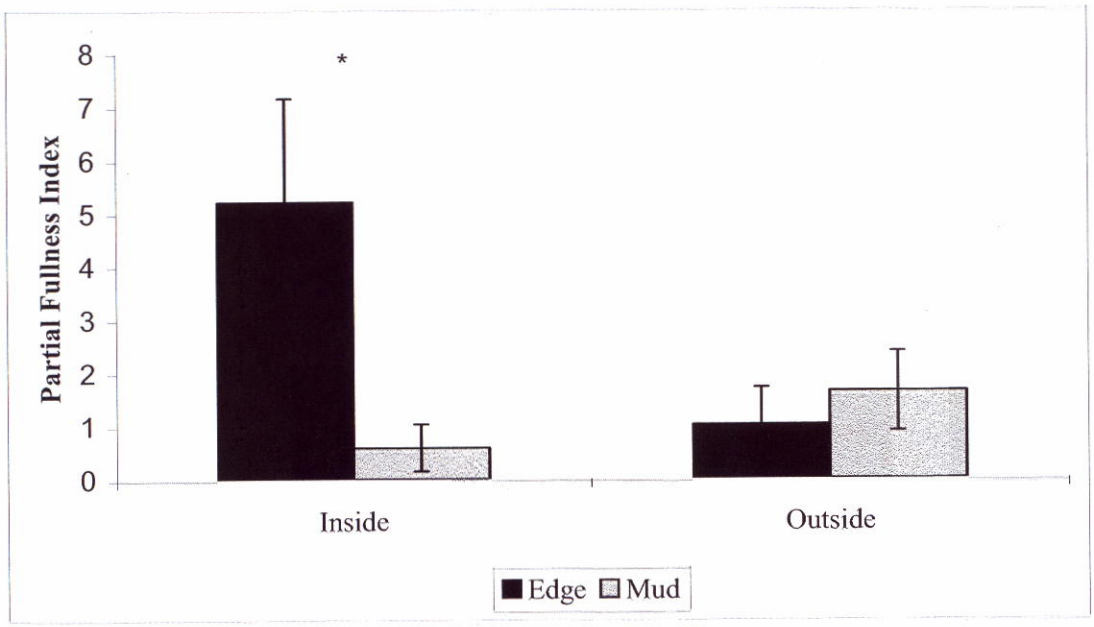

Figure 11: Mean partial fullness index of clupeids in adult goosefish diet. Inside the reserve only, PFI of clupeids was significantly higher on the edge habitat. Bars indicate one standard error.

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