Northeast Consortium: Final Report

Are We Using Herring to Farm Lobsters? The Effect of Herring Bait on Lobster Growth, and the Fate of Discarded Bait on Bottom Habitat

(Project award #: 02-566)

Period of Performance: June 2002 – June 2005

Submission Date: July 1, 2005

Project Partners:
Jonathan H. Grabowski, Gulf of Maine Research Institute
Erika J. Clesceri, USA-International Development
Philip O. Yund, University of New England
Matt Weber, F/V Griffen
Phil Poland, F/V Charlene Gail
Mike Myrick, F/V Shannon Rose

Submitted by:

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Jonathan H. Grabowski, Ph.D.
Gulf of Maine Research Institute
350 Commercial St.
Portland, Maine 04101

Gulf of Maine Research Institute

Abstract

Several hypotheses have been generated to explain recent surges in lobster landings in the Gulf of Maine. Research on lobster population dynamics has focused primarily on early postlarval life stages, so that our current understanding of the importance of herring bait on sublegal lobsters remains limited. In order to assess the affects of herring bait on lobster population dynamics, we sampled diet composition (stomach content analyses), tissue production (nitrogen stable isotope ratio analyses), and growth (mark-recapture experiments) of large (66-83 mm CL) and small (45-65 mm CL) sublegal lobsters in seasonally closed sites around Monhegan Island vs. fished sites around the Georges Islands in mid-coast Maine during the summer and fall of 2002 and 2003. Herring bones were more prevalent in the diet of lobsters at open sites, and were more prevalent in the summer. Smaller lobsters from open sites contained more natural prey (i.e., crabs, mussels, clams, polychaetes, urchins, etc.) than those from closed sites. Stable nitrogen isotope ratio analyses indicated that lobsters derive 33.7-68.6% (large) and 10.9-35.6% (small) of their tissue from herring bait. Recaptured lobsters from the Georges Islands that molted outgrew those from Monhegan by 16.2%. Quadrat and trap sampling suggested that lobster densities are similar between sites, but lobsters are larger at closed (Monhegan) sites. Collectively, these results support the notion that herring bait may be very important for lobster population dynamics in the Gulf of Maine, and therefore, the contribution of herring bait should be considered when developing management policies that affect fishing effort.

Introduction

Commercial fishery landings of the American lobster (*Homarus americanus*) in the Gulf of Maine have risen over the past two decades in spite of intense fishing pressure while other regional fisheries have collapsed or failed to recover to historic levels. Because the lobster fishery currently accounts for a disproportionately large percentage of the total fishery value in the Gulf of Maine, research identifying why landings continue to thrive in spite of such intensive fishing effort is critical to the economy of coastal Maine. The thousands of tons of herring annually used as bait to catch lobsters in coastal Maine have been posited as the mechanism driving recent surges in lobster landings. In addition, herring bait is likely to have had consequences for nearshore benthic communities.

This study used a variety of methodological approaches involving multiple scientific disciplines (ecology and biogeochemistry) to address questions of interest to the scientific and fishing communities of Maine in addition to the coastal managers charged with regulating the state's fishing industries. As awareness has grown that population dynamics of different commercially harvested species are likely to be linked, these possible connections have drawn support for multi-species or ecosystem based approaches to management (Jennings and Kaiser 1998, Botsford et al. 1997). Collaborations among scientists and lobster fishermen in this project have proven successful and increased both the efficiency of research by creating a much more diverse research team with a broader knowledge base and dissemination of results to the potential stakeholders.

While the consequences of the use of herring bait on herring population dynamics (or at least fishing pressures) is fairly clear, the effects of herring bait on lobster populations has received substantially less attention, although equally important. There are two scientific questions that can be asked to investigate the link among lobster populations, herring populations, and the nearshore bottom habitat and organisms. *First*, has growth of the lobster population been fueled at least in part by the consumption of bait? Herring bait enters the lobster diet in at least three ways: a) consumption by undersize lobsters, b) consumption by adults that subsequently escape traps, and c) consumption of discarded bait. The possible effects of bait consumption on lobster growth and survival have not been quantified yet, though such effects are widely anticipated by both fishermen and scientists. *Second*, what are the consequences of relocating that much herring biomass into coastal waters? If discarded bait is not eaten by lobsters, what is its fate, and what are the likely effects on coastal bottom habitats and ecosystems? What are there consequences for coastal groundfish communities? We evaluated by how much herring (*Clupea harengus*) bait contributes to the production of lobster biomass by quantifying the diet composition and growth of lobsters in areas with vs. without bait. We also quantified the fate of discarded herring bait in shallow nearshore waters in Maine.

Objectives

1. Determine the proportion of lobster diet and lobster tissue derived from herring bait.

2. Assess the impact of a bait-augmented diet on lobster growth.

3. Quantify the initial fate of discarded herring bait on the benthic community.

Hypotheses

H1: Herring bait is an important food source for sublegal lobsters

H2: Herring bait augments lobster growth rates

H3: Discarded herring bait is consumed predominately by lobsters

Methods

<u>Study Site</u>
We conducted investigations in mid-coast Maine near Monhegan Island because the lobster fishery seasonally closes from the end of May until early December when water temperatures are warmer and consequently lobster feeding activity and growth rates are expected to be greater. Sites around Monhegan Is. were compared to sites around the Georges Islands where fishing occurs in the summer and fall. Subtidal (10-15 m depth) sites were selected for lobster dietary, growth, and density analyses. Sites were selected based on bottom type. In particular, we chose sites that contained a mixture of mud/shell bottom and loose cobble rock habitat after conferring with R. Steneck.

Objective 1. Determine the proportion of lobster diet and lobster tissue derived from herring bait.

Stomach Content Analyses

To determine the prevalence of herring bait in the diet of lobsters and potential changes in lobster diet composition as a consequence of herring bait, stomach content sampling of lobsters was conducted in June 2002 at Monhegan and Georges Is sites. This initial sampling period was scheduled directly after the Monhegan Is. lobster fishery closed on May 30, 2002. Stomach content sampling was conducted in June to determine if lobster diets vary between open and closed areas directly after the closure occurs. Sampling involved collection and analysis of ~10 lobsters from each of two size classes, and sampling was also conducted in October to detect seasonal differences in diet composition (small 45-65 mm carapace length [CL]; large 66-83 mm CL) at each of two sites around Monhegan Is. and the Georges Is (10 individuals X 2 subsites/region X 2 regions X 2 size classes X 2 seasons = 160 lobsters). During each sampling event, lobsters were collected via SCUBA and stomach contents and tissue samples were removed and preserved for analysis in the laboratory. Total stomach contents were weighed, and individual items were identified, weighed, and enumerated (where possible).

Nitrogen Isotope Ratios

Stable isotope ratios of nitrogen are effective natural tracers of the flow of organic matter in ecosystems (Frye and Sherr 1984, Owens 1987, Peterson and Howarth 1987, Wada et al. 1991, Robinson 2001). Of the nitrogen atoms on earth, approximately 99.6337% are the "normal" ^{14}N; the remaining 0.3663% are a heavier ^{15}N form (Robinson 2001). Biogeochemical processes alter the ratio of these two isotopes, and the relative abundance of the heavier isotope is expressed as $\delta^{15}N$ on a parts per thousand (‰) scale. We conducted an analysis of the isotope signature of the natural prey of lobsters at our study sites (as reviewed by Lawton and Lavalli 1995) vs. herring. Our results indicate a differential ranging from 2.3 to 5.5‰ between herring and three common elements of lobster diet (Table 1). These $\delta^{15}N$ differences will propagate up the food chain and should be reflected in lobster tissue.

Table 1. Nitrogen isotope ratios (‰) for natural prey and herring from our study sites in the Gulf of Maine. Values are the mean ± 1 SD for 4-6 replicate individuals.

Prey Source	$\delta^{15}N$
Natural	
Cancer Crabs (*Cancer* spp.)	9.5±0.1
Green urchin (*Strongylocentrotus droebachiensis*)	6.3±0.2
Mussels and clams	7.1±0.2
Bait	
Herring (*Clupea harengus*)	11.8±0.1

The likely mechanism for these differences in $\delta^{15}N$ for herring vs. other lobster prey items is a process called trophic transfer enrichment (Ehleringer et al. 1986). When processing food, animals excrete ^{14}N disproportionately more than the heavier isotope ^{15}N, so that subsequent

enrichment of ^{15}N in tissues results in heavier nitrogen isotope ratios for these animals relative to their prey. The general expectation is that ^{15}N should be enriched by about 3.4 ‰ in each transfer between trophic levels (Eggers and Jones 2000); therefore, our preliminary results suggest that herring are about one to one and a half trophic levels above typical lobster prey. Information on the feeding biology of these prey species supports that contention: sea urchins and mussels are herbivores, while herring feed on herbivorous (when juveniles) and carnivorous (when adults) copepods. Because lobsters are a trophic level above their prey (by definition), the absolute value of $\delta^{15}N$ for lobster will be higher than the prey $\delta^{15}N$. Nevertheless, the relative difference in lobster $\delta^{15}N$ between baited and un-baited areas due to consumption of herring should be easily detectable if herring constitute a major portion of lobster diet. Nitrogen isotope ratios offer a potential advantage over analysis of stomach contents because they measure the integrated assimilated diet (Wainright et al. 1993), which is a function of both average diet throughout the lifespan and actual assimilation (as opposed to simple intake). The percentage of assimilated diet attributable to herring can be calculated from the differences in $\delta^{15}N$ between baited and unbaited sites or over time periods if fishing pressure changes (e.g., Monhegan Is. in the late spring [open] vs. in the fall [closed]).

Lobster tissues were sampled for nitrogen stable isotope ratio analysis in June and October at Monhegan and Georges Is. sites (tissues were sampled from lobsters used for gut content analyses). Lobster sampling was conducted in June directly after the Monhegan Is. fishery closed so that if herring is important to the diet of lobsters, it should be apparent in the tissues after several months of fishing. Conversely, we sampled in October to capture lobster tissue values several months after the fishery was closed in order to determine the isotope values of lobsters that have been feeding on natural prey in the absence of herring for the past several months. Therefore, if herring is important to the diet of lobsters in the Gulf of Maine, maximum contrasts in isotopic signatures between open and closed sites should be apparent by October, and between Monhegan in June (recently open) vs. October (closed). Samples were freeze dried and analyzed using an elemental analyzer coupled to a mass spectrometer at the University of North Carolina at Chapel Hill.

Objective 2. Assess the impact of a bait-augmented diet on lobster growth.
In order to assess the effects of herring bait on lobster growth, we conducted mark-recapture experiments at seasonally closed (Monhegan Island) and open sites (Georges Islands) in 2002. Lobsters were tagged at the beginning of July 2002 prior to initial summer molting, and recapture of lobsters was initiated in October 2002. Lobsters were tagged using streamer tags (Floy Tag Co. – FTSL-73), which were implanted in the muscle tissue directly between the carapace and abdomen where tag retention through molt cycles is high. We tagged a total of 3117 lobsters in July at Monhegan Island and Georges Islands (~800 lobsters were measured, sexed, tagged and released at two sub-sites in both closed and open sites). Recapturing lobsters initially involved diver collection and trapping by three industry members using modified traps. In order to bolster recovery of tagged lobsters, we initiated a tag reward through the lobster fishing industry (Monhegan, Cushing, Friendship and Port Clyde) starting in December 2002. We quantified the percentage of recaptured lobsters that molted and percent growth of those that molted for seasonally closed vs. open sites. The effect of herring bait presence on lobster growth was analyzed using an unpaired t-test.

Lobster density sampling was conducted in summer (August) and fall (October) with 1-m^2 quadrat samples. At each site, ten quadrat samples were conducted randomly in each of two habitats (mud bottom vs. rock-cobble), and lobster density, size, and sex ratio were quantified within each quadrat sample. Relative abundance of lobsters at each size stage was quantified at both open and closed sites in the summer (July) and fall (October-November) of 2002 using modified traps. Traps were baited and depth, location, and deployment time were recorded during trap sampling.

Objective 3. Quantify the initial fate of discarded herring bait in the benthic community.
To quantify the initial fate of discarded bait on benthic communities within the shallow waters of the Gulf of Maine, video assays of discarded herring bait were conducted in late August and early September. In particular, herring bait pieces (ten per deployment) were attached to a grid on the bottom of a metal frame and lowered to the sea floor in 10-15 m depth. Video footage of the grid permitted determination of the fate of each bait piece so that we were able to quantify the proportion of discarded bait consumed by lobsters, crabs and other benthic organisms. Bait trays were filmed for one hour or until all ten bait pieces had been consumed, and we conducted multiple bait tray deployments.

Statistical Analyses

For isotope data, the effects of season (summer vs. fall) and fishing pressure (closed vs. open) on lobster δN values were analyzed using Analysis of Variance for each lobster size class in both 2002 and 2003 separately. The assumption of homogeneous variances was examined using a Cochran's test (Underwood 1981). A t-test was performed to determine whether lobster growth is influenced by fishing pressure.

Design Changes & Unexpected Difficulties

Our original proposal also included assessment of the effects of herring bait on lobster population dynamics in eastern portions of the Gulf of Maine where the Canadian fishery is seasonally closed during the summer and fall. In 2002, we applied for a permit to conduct similar field work in New Brunswick, Canada off the coast of Grand Manan. Because this permit was denied, we doubled our sampling effort in mid-coast Maine to adequately address each of our research objectives. Specifically, we selected 2 sites each around Monhegan and the Georges Islands where we conducted dietary analyses. We also tagged twice as many lobsters as we had originally intended at each of these sites to determine the effects of herring bait on lobster growth. Furthermore, we collected data on the relative abundance and density of lobsters at fished vs. unfished sites.

Data

Data have been collected for the following parameters:
a) Nitrogen stable isotope ratios
b) Stomach content analyses (total stomach weight, total weight of herring bone and natural prey)
c) Lobster growth rates ([lobster final size - lobster initial size]/lobster initial size)

d) Lobster size frequencies (# of lobsters per trap within each size frequency)
*See **Images** section below for graphical presentation of the major findings.* Data will be made available upon successful publication of major findings in peer-reviewed journals.

Results & Conclusions

1. Determine the proportion of lobster diet and lobster tissue derived from herring bait.
The proportion of lobsters with herring in their stomach was 2 to 3 times higher at open (Georges Islands) than at seasonally closed sites (Monhegan Island) for both large and small lobsters (Figure 1). Herring bait was twice as prevalent during sampling in June than in October regardless of site or size. Lobsters from open sites had up to 7 times more herring (g/stomach) in their diet than did lobsters from closed sites. For smaller lobsters, stomach fullness of lobsters from open sites was greater than that of lobsters at seasonally closed sites (Figure 2). Stomach fullness of larger lobsters did not vary between sites in June, whereas stomach fullness of lobsters from closed sites was greater than at open sites in October. Small lobsters from open sites consumed more natural prey (g/stomach) than small lobsters from closed sites (figure 3). Larger lobsters from open sites consumed more natural prey in June, whereas natural prey was more prevalent in the diet of larger lobsters at seasonally closed sites in October.

Stable nitrogen isotope ratio values were lower for small lobsters from Monhegan Is. than for those at Georges Is. during either sampling period (Figure 4a). Isotope values for small lobsters in June were generally higher than isotope values of lobsters in October regardless of site. For large lobsters, once again isotope values of lobsters from Monhegan Is. were lower than values of lobsters from the Georges Is. during either sampling period (Figure 4b). However, the difference between sites in isotope values of large lobsters was greatest in the fall, with isotope values at open sites (Georges Is.) much greater than seasonally closed sites (Monhegan Is.). Although isotope values of large lobsters in October were generally lower than lobster isotope values in June, the magnitude of this effect was much greater at Monhegan Is.

In order to determine the proportion of lobster production derived from herring bait, we first estimated a fractionation coefficient (measure of trophic transfer enrichment) for nitrogen isotopes because animals tend to disproportionately retain heavier isotopes and have heavier nitrogen isotope values than their dietary members. For each size class, we calculated a fractionation coefficient by subtracting the average value of the natural prey from Monhegan lobsters that were sampled in the fall (Figure 5). Monhegan lobsters sampled in the fall have not had access to herring bait for several months and should have tissue signatures indicative of a diet of natural prey. Because values for natural prey vary (i.e., crab values tended to be slightly higher than urchins, mollusks, etc.) and previous dietary studies have suggested that variability exists in the diet composition of lobsters, we calculated fractionation coefficients for a range of lobster diets. Using dietary information from this study and previous investigations (Elner and Jamieson 1979, Jamieson et al. 1981, Elner and Campbell 1987, Lawton 1987, Hudon and Lamarche 1989), we estimated that crabs account for up to 50% of the diet of lobsters and that crabs, mollusks (i.e., mussels, clams and small scallops) and urchins are the three most important components of the diet.

Because crabs tend to account for a larger proportion of the diet of larger lobsters and urchin populations have been widely reduced at our study sites from harvesting efforts, crabs probably account for a greater proportion of the diet of larger lobsters at Monhegan Is. For larger lobsters, fractionation coefficients varied from 2.1 ‰ (50% crab diet) to 0.8‰ (100% crab diet), whereas fractionation coefficients varied from 2.9‰ (crab absent from diet) to 2.2 (50% crab diet) for smaller lobsters. For each size class, the fractionation coefficient was then added to the value of herring to estimate the value of a lobster diet that is comprised solely of herring. We then used this estimate (100% herring diet) and the isotope values for Monhegan lobsters sampled in October (100% natural prey diet) to determine the importance of herring in the diet of lobsters in mid-coast Maine. In particular, we compared these isotope values to Monhegan lobsters from June and calculated the relative proportion of lobster tissue derived by herring bait (Table 6). Utilizing this method for each natural prey diet discussed above, we calculated that herring bait is responsible for deriving 33.7-54.8% of the tissue production of large lobsters and 10.9-12.6% of smaller lobsters.

2. Assess the impact of a bait-augmented diet on lobster growth.
We tagged a total of 2257 large and 860 small lobsters (Table 2). We tagged a greater proportion of large lobsters because small lobsters were much more difficult to capture, especially at Monhegan Is. Lobster sex information was determined from tagged lobsters because we sexed a larger volume of lobsters while marking lobsters than during any other sampling technique. Female lobsters always accounted for greater than 50% regardless of size or site. Female lobsters generally accounted for ~60% of the total population, except for small lobsters at Monhegan Is., which accounted for 51.3%.

Table 2. Breakdown of total # of lobsters tagged, average size and % female for each size class at each site.

	Large				Small			
	Total Tagged	Avg. Size (mm CL)	Total Female	% Female	Total Tagged	Avg. Size (mm CL)	Total Female	% Female
Monhegan Is.	1178	75.9	702	59.6%	312	59.2	160	51.3%
Georges Is.	1079	74.3	670	62.1%	548	58.8	327	59.7%
Total	2257	75.1	1372	60.8%	860	59.0	487	55.5%

Extensive diving and modified trapping in October 2002 resulted in the recovery of only 10 tagged lobsters. Industry participation from Monhegan, Cushing, Friendship and Port Clyde resulted in the recapture of an additional 47 lobsters between November 2002 and January 2003. Fifty-two of the 57 lobsters recaptured were originally in the large size category (45-65 mm CL); therefore, molt frequency and growth results are only presented for large lobsters (66-83 mm CL). In order to tag the largest possible volume of lobsters as quickly as possible at each site in July, we tagged 'soft' and 'hard' shell lobsters. Because soft shell lobsters have molted more recently, they were less likely to have molted by the fall/winter. Hence, we excluded soft shell lobsters from our analysis of the proportion of lobsters that had molted at each site. Of those recaptured that were hard shell lobsters when tagged, 67.8% of Monhegan Is. lobsters vs. 88.9% from Georges Is. had molted (Figure 7a). Differences in growth increments between soft and hard shell lobsters did not vary within each site, so we included both soft and hard lobsters in our analysis of lobster growth. Of the recaptured lobsters that had molted, Georges Is. lobsters grew

16.2% (measured as the percent gain in carapace length) than lobsters from Monhegan Is (Figure 7b).

Lobster densities did not differ between Monhegan Is. and Georges Is. for either habitat type in the summer (Figure 8a). Lobster densities also did not differ between habitats at each site in the summer. In the fall, lobster densities once again did not differ between open and closed sites. However, lobsters were almost completely absent from mud bottom at both sites in the fall. In both sampling periods, lobsters measured during quadrat sampling were substantially larger at Monhegan Is. than at the Georges Is. Trap abundance results also indicated little difference in total lobster abundance between Monhegan Is. and Georges Is. (Figure 9). There was a slight trend ($p = 0.08$) of greater lobster abundances at Georges Is. than at Monhegan Is. in the summer, but abundances were very similar in the fall. Trap sampling also indicated that lobsters were larger on average at Monhegan Is. than at Georges Is (Figure 10). At Monhegan, legal lobsters were more prevalent than any other size category in both the summer and fall. Conversely, lobsters ranging from 76-80 mm CL were more abundant than any other size category at Georges Is.

3. Quantify the initial fate of discarded herring bait in the benthic community.
Video assays of discarded bait were used to quantify the initial fate of discarded bait in mid-coast Maine. Discarded bait was rapidly consumed in each assay in under an hour, with lobsters in particular but also crabs (*Cancer* spp.) consuming the vast majority of bait. Bait stations were also visited by fish (predominately pollock *Pollachius virens*), but we did not observe any successful foraging events by fish. Attaching bait to a frame might have confounded this experiment by favoring predators with appendages (i.e., lobsters and crabs) that can remove bait from the trays more readily. We also did not observe seal or birds, two common consumers of herring bait, foraging on bait trays during the experiment, which is likely because we conducted our experiment on the sea bottom.

Major Findings: Impacts, Applications, & Future Research

Dietary analyses indicated that herring bait has important consequences for the diet of lobsters, for competition between different size classes of lobsters, and potentially for benthic community structure. In particular, our results suggest that up to half of tissue production of larger lobsters in mid-coast Maine may be derived from herring bait. A greater understanding of the lobster diet composition and the fractionation coefficient of lobsters will enhance the resolution of our estimate of the importance of herring bait in deriving lobster tissue production. Although smaller lobsters derived a much smaller proportion of their diet from herring, herring bait could be affecting these lobsters indirectly by removing competitive pressure from larger lobsters for natural prey, explaining why smaller lobsters from fished sites consumed more natural prey than at closed sites. Site-specific differences between Monhegan Is. and Georges Is. (i.e., differences in prey availability) could also partially explain why small lobsters from Georges Is. foraged more successfully on natural prey. Stable nitrogen isotope values of both large and small lobsters from June were lower at Monhegan, indicating either that prey communities are different between sites or tissue-turnover rates are more rapid than originally expected. Comparison of the diet composition of lobsters at open and closed sites suggested that herring bait could alter

diet composition with consequences for the benthic community. Further analysis of herring bait driven changes in diet composition must be compared to the benthic community at each site to determine how herring bait is influencing benthic communities in coastal Maine.

Because lobsters grew more at open (Georges Is.) than closed (Monhegan Is.) sites, the mark-recapture results suggest that bait augments lobster growth in the Gulf of Maine. The mark-recapture results also indicated that a larger proportion of recaptured lobsters from fished sites had molted. Recaptured lobsters that had not molted probably molted in the winter or early spring when water temperatures are colder. If colder water temperatures adversely affect lobster growth rates, differences in growth rates between open and closed sites might have been even more pronounced (i.e., the effect of herring bait on lobster growth could be even greater). Conducting lobster diet sampling and mark-recapture experiments in open and closed sites a) from additional regions of the Gulf of Maine and b) across multiple years will increase the confidence of these findings and help managers determine the potential implications of management policies (e.g., lobster pot limits, exit-to-entry ratios, etc.) for lobster population dynamics in the Gulf of Maine.

Lobster density (from quadrat sampling) and abundance (from trap sampling) results both suggested that lobster densities/abundances do not differ between open and closed sites. Quadrat sampling indicated that habitat use was dependent on season. Specifically, lobsters were equally distributed between cobble bottom and mud/shell hash bottom in the summer, but were non-existent in mud/shell hash bottom habitats in the fall. Lobsters may be more vulnerable to predation in the fall because of seasonal patterns in molting frequency (i.e., if a higher proportion of lobsters molted in early fall than in early summer, a greater proportion of lobsters would have recently molted and hence would be more vulnerable to predation) or abundances of lobster predators. Lobsters may also be responding to seasonal patterns in reproductive and migratory behavior.

Both sampling methods indicated that lobsters were larger on average at closed sites at Monhegan Is. than at fished sites in Georges Is. In particular, smaller, sublegal lobsters were caught in greater abundances in fished waters at Georges Is., whereas large sublegals and legal sized lobsters were caught in greater proportions in Monhegan Is. This difference could be a consequence of removal of adult lobsters from fished areas, a result of larger lobsters deterring smaller ones from entering pots, or differences in size-frequencies that are independent of fishing activities. Anecdotal evidence suggests that lobster populations that are further offshore tend to be slightly larger than inshore populations. Because Monhegan Is. is further offshore than Georges Is., this fishery independent factor could partially explain why Monhegan Is. lobsters were larger. In addition to consuming bait in the traps, lobsters were the primary consumer of discarded herring bait. However, this experiment needs to be conducted again at a wide range of sites to increase our understanding of the fate of discarded bait.

Lobsters would most likely not consume herring without the existence of these two fisheries. Thus, it is not surprising that these two species historically have been considered separately by managers. However, a major implication of this study is that herring as bait is having a disproportionately large influence on lobster landings in the Gulf of Maine. Given that the popularity of lobsters has resulted in dramatic price increases over the past couple of decades,

demand for herring as bait will continue to exert pressure on the fishery. Therefore, this study coupled with the impacts of the lobster fishery on the demand for herring indicate that these two fisheries should be considered by managers in concert.

In addition to the suggestions above, further research directions on the impacts of herring bait on lobster population dynamics should include the following: 1) Incorporation of quantitative dietary information in population models that attempt to predict lobster population abundances in the Gulf of Maine. 2) Utilization of other analytical methods such as lipid analysis to assess the accuracy of estimates from nitrogen stable isotope ratios. 3) Assessment of the direct and indirect impacts of herring bait subsidies on benthic community structure. 4) Ecosystem consequences of these two fisheries on associated species in both inshore and further offshore food webs such as the benthos but also cod fishes, sea gulls, and mammals.

Partnerships

Successful completion of sampling efforts to achieve the proposed goals has hinged upon collaboration among scientists, government officials, and fishermen. In particular, our successful partnerships with fishermen in Cushing (Phil Poland & Mike Myrick) and Monhegan (Matt Webber) greatly facilitated the completion of field investigations in 2002 and 2003. For instance, relying on these fishermen to operate vessels and facilitate selection of field sites has enabled us to operate much more efficiently. Fishermen involvement in diet sampling and marking lobsters has increased both the quality and quantity of work that we are capable of in the field. This project has also relied on the diverse backgrounds of each partner. For example, it was necessary to tag ~ 3200 to recapture enough marked lobsters to detect statistical differences between growth rates of lobsters in fished vs. closed areas. We opted to have fishermen collect lobsters via trapping rather than dive for lobsters, saving immeasurable amounts of energy and resources. Collecting lobsters recaptured by the industry enabled us to simultaneously quantify relative abundance of lobsters at Monhegan and the Georges Islands, resulting in additional information. Furthermore, over fifty fishermen from Monhegan Island, Cushing, Port Clyde, and Friendship reported lobsters, which resulted in a much broader network of fishermen hearing about and participating in our research project. Given that fishermen have long suspected that they are potentially farming lobsters via herring bait in the nearshore and inshore waters of the Gulf of Maine, their keen interest and invaluable participation in this project was not surprising. Thus, this project achieved the Northeast Consortium goal of fostering meaningful collaborations between fishermen and scientists.

The subsequent collaborative proposals that we have proposed are further evidence of the strength of these interactions:

a) The effects of herring bait on lobster population dynamics and benthic community structure (funded by Maine Sea Grant, the Davis Foundation, the Lobster Advisory Council, and the Burnham Foundation; industry project partners include Matt Weber, Mike Myrick, Phil Poland, Jeremy Cates, Greg Thompson, Eric Thompson, and Evan Mawhinney).

b) We submitted an unsuccessful planning grant to NEC in 2002 to address the importance of competition (cancer crabs *Cancer spp.* and green crab *Carcinus maenas*) and predation (cod

Gadhus Morhua and sculpins) for juvenile lobster population dynamics in the northern Gulf of Maine (industry project partner: Jeremy Cates).

c) We submitted an unsuccessful planning grant to NEC in 2004 to determine whether multibeam acoustic devices can be utilized to assess groundfish populations on offshore banks and ledges in the Gulf of Maine (industry project partner: Matt Weber).

d) We submitted an unsuccessful planning letter to NEC in 2005 to determine whether interactions among the lobster fishing industry and scallop enhancement efforts can be used to promote higher survival on enhanced scallop beds (industry project partners: Matt Weber and Mike Myrick).

Related Projects

This project was supported by the Davis Foundation, the Maine-Lobster Advisory Council, and the Gulf of Maine Research Institute. We have also continued this avenue of research through a 2004 Maine Sea Grant project entitled 'The effects of herring bait on lobster population dynamics and the benthic community.'

Presentations

Grabowski, J. H., E. J. Clesceri, A. Baukus, J. Gaudette, and P. O. Yund. 2005. Are we farming lobsters in the Gulf of Maine? American Society of Limnologists and Oceanographers, Summer Meeting. June 19-24, Santiago de Compostela, Spain.

Grabowski, J. H., E. J. Clesceri, A. Baukus, J. Gaudette, and P. O. Yund. 2005. Are we farming lobsters in the Gulf of Maine? Benthic Ecology Meetings, April 6-9, Williamsburg, Virginia.

Grabowski, J. H., E. J. Clesceri, A. Baukus, J. Gaudette, and P. O. Yund. 2004. Are we farming lobsters in the Gulf of Maine? Maine Sea Grant-Policy Advisory Committee, Augusta, Maine, fall 2004.

Grabowski, J. H., E. J. Clesceri, A. Baukus, and P. O. Yund. 2004. Are we using herring to farm lobsters? The effects of herring bait on diet composition and growth of the American Lobster. World Fisheries Congress (WFC), May 2-6, Vancouver, British Columbia.

Grabowski, J. H. 2004. Are we using herring to farm lobsters? The effects of herring bait on diet composition and growth of the American Lobster. University of South Alabama, Dauphin Island Sea Laboratory seminar series, February 26.

Grabowski, J. H., E. J. Clesceri, A. Baukus, and P. O. Yund. 2003. Are we using herring to farm lobsters? The effects of herring bait on diet composition and growth of the American Lobster. Ecological Society of America (ESA), August 3-8, Savannah, Georgia.

Grabowski, J. H., E. J. Clesceri, A. Baukus, and P. O. Yund. 2003. Are we using herring to farm lobsters? The effects of herring bait on diet composition and growth of the American Lobster. Benthic Ecology Meetings (BEM), March 28-30, Groton, Connecticut.

Grabowski, J. H., E. J. Clesceri, A. Baukus, and P. O. Yund. 2003. Are we using herring to farm lobsters? The effects of herring bait on diet composition and growth of the American Lobster. Maine Fishermen's Forum, February 27-March 1, Rockland, Maine.

Student Participation

High School Students: Dan Gayer
Undergraduate Students: Michelle Bunker (UMaine), Kate Williams (University of New England), Adam Baukus (University of New Hampshire)
Graduate Students: Melissa Smith (University of New England), Trisha Cheney (Dalhousie University)

Published Reports and Papers

To date one manuscript has been submitted to a peer-reviewed journal but has yet to be published:

Use of Herring Bait to Farm Lobsters in the Gulf of Maine. 2005. Jonathan H. Grabowski, Erika J. Clesceri, Adam Baukus, Matthew Weber, Philip O. Yund.

See Appendix A for GMRI newsletter and Portland Press Herald story on this study. This project was also featured on Portland's Channel 13 6:00 PM News during Doug's Discoveries in June 2005.

Acknowledgements

Successful completion of sampling efforts to achieve the proposed goals has hinged upon collaboration among scientists, government officials, and fishermen. Special thanks to Matt Weber, Phil Poland, and Mike Myrick, whose field knowledge and vessel operation skills have been integral to the successful completion of this research. We are greatly appreciative to the lobster fishing communities from Monhegan, Cushing, Friendship and Port Clyde for reporting recovery of tagged lobsters. Thanks to Robert Russell and to the Maine-Department of Marine Resources for the use of video equipment to determine the fate of discarded bait. Thanks to Brian Tarbox and Chris Heinig for loaning us modified traps to collect sublegal lobsters. The Gulf of Maine Research Institute facilitated this project by bringing together this research team and administering the grant (thanks in particular to Laura Taylor Singer, Don Perkins, Amy Smith, Jill Harlow, Janet Underhill, John Annala, Margaret Williams, and Traci Simpson). This research project was conducted out of the Darling Marine Center. Funding for this project was provided by the Northeast Consortium, The Davis Foundation, The Lobster Advisory Council, and The Gulf of Maine Research Institute.

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Images

Figure 1. Stomach content analysis. Proportion of a. small (45-65 CL) and b. large (66-83 CL) lobsters with herring bones present in the stomachs in the summer and fall from closed and open sites.

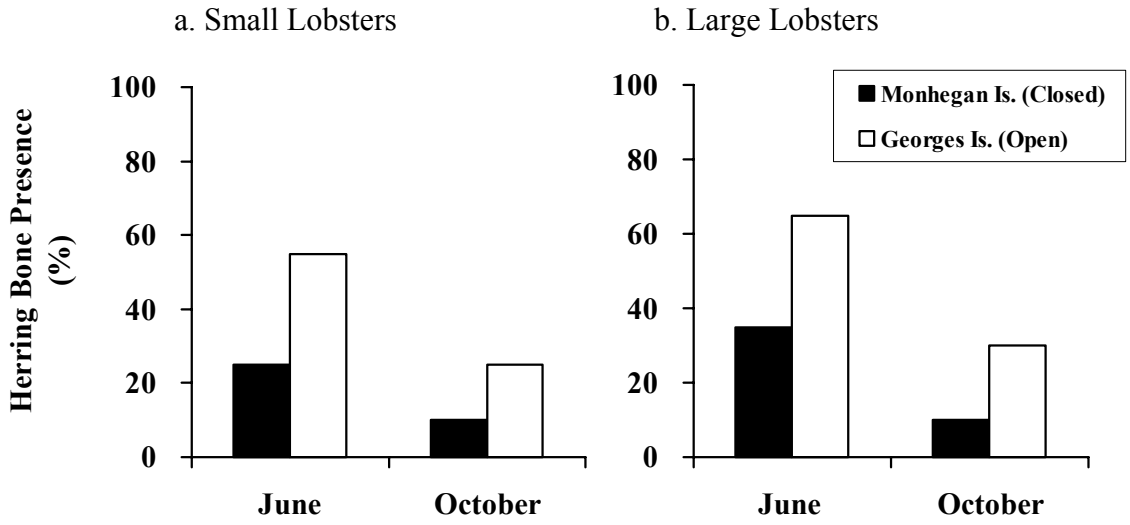


Figure 2. Stomach content analysis. Average stomach fullness (g) of a. small (45-65 CL) and b. large (66-84 CL) lobsters with herring bones present in the stomachs in the summer and fall from closed and open sites. Error bars denote +1 standard error (SE).

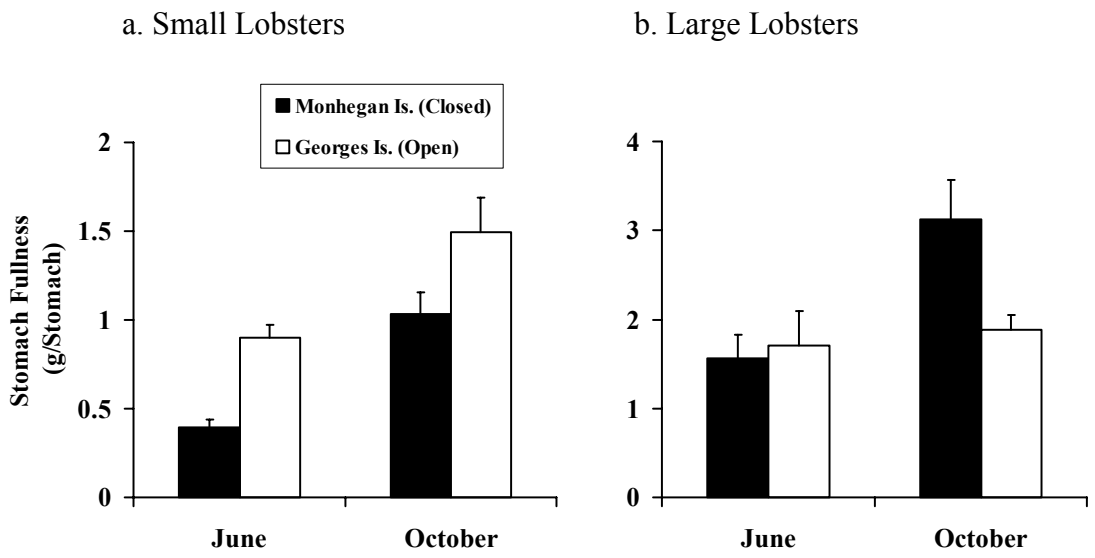


Figure 3. Stomach content analysis. Average weight of natural prey (cancer crabs, urchins, mollusks, polychaetes, etc.) in the stomachs of a. small (45-65 CL) and b. large (66-83 CL) lobsters in the summer and fall from closed and open sites. Error bars denote +1 SE.

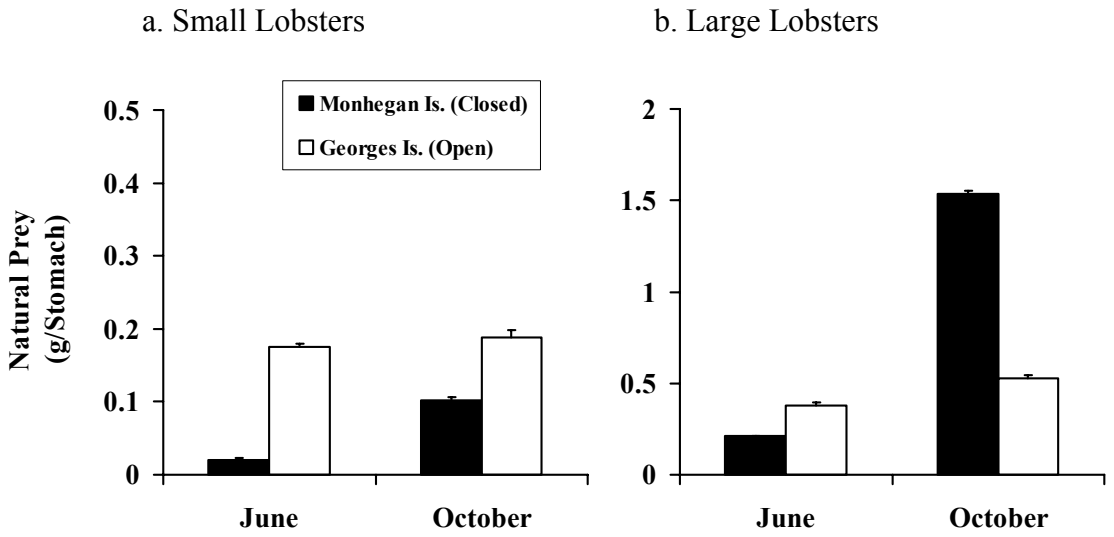


Figure 4. Nitrogen stable-isotope ratio analysis. Nitrogen stable-isotope ratios for a. small (45-65 CL) and b. large (66-83 CL) lobsters in the summer and fall from closed and open sites. Nitrogen stable-isotope ratios are an integrated measure of the relative contribution of each dietary member as it is assimilated into tissue. Error bars denote +1 SE.

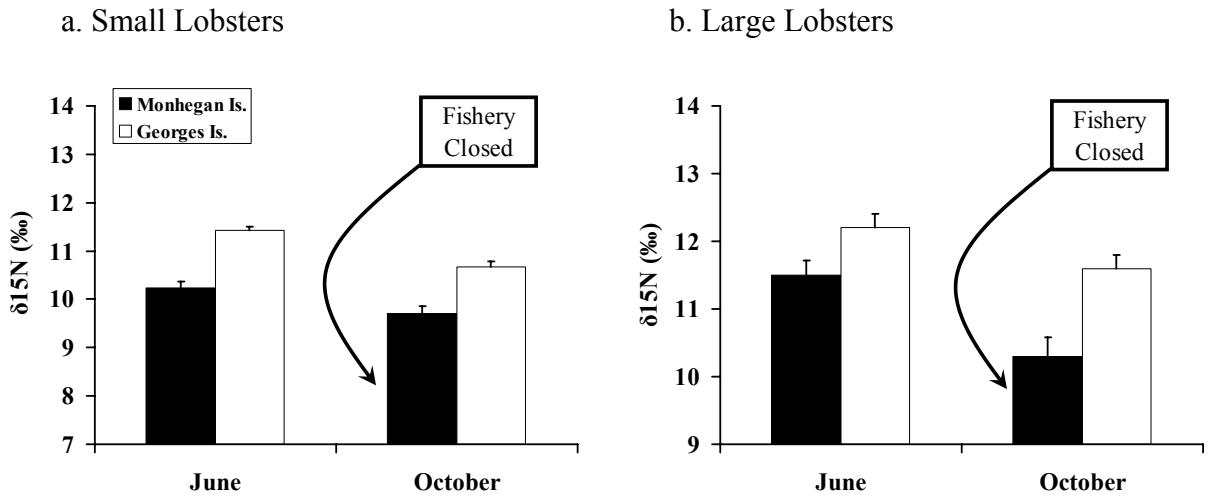


Figure 5. Nitrogen stable-isotope ratio analysis. Fractionation coefficients were calculated for large (depicted here) and small lobsters by subtracting the isotopic values of lobster prey from the value of Monhegan lobsters that have not consumed herring recently (Monhegan lobsters from October). Error bars denote +1 SE.

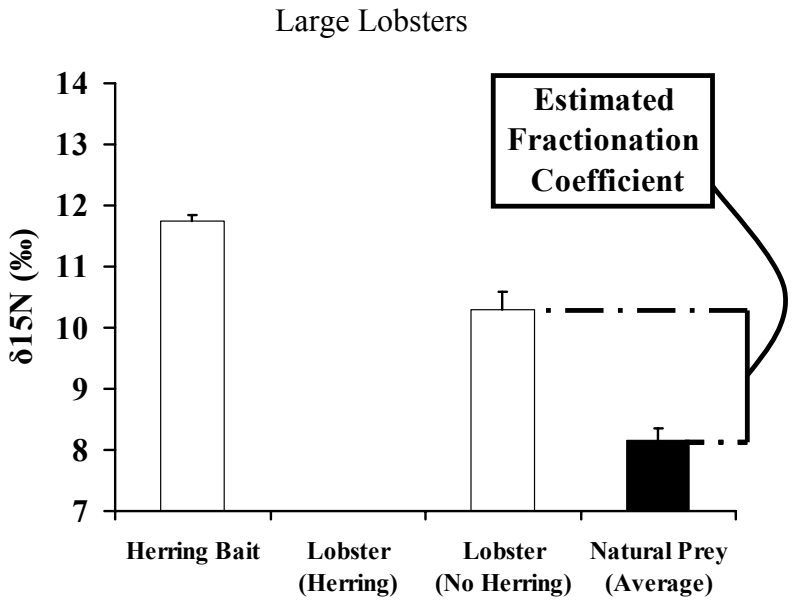


Figure 6. Nitrogen stable-isotope ratio analysis. The proportion of the lobster diet that is comprised of herring for a. small and b. large lobsters from lobsters at Monhegan where fishing is seasonally closed. Isotope values for lobsters that feed only on herring were calculated by adding the fractionation coefficient for lobsters to herring isotope values. Isotope values of lobsters that recently had access to herring bait (June samples) were then compared to this range of values for lobsters that feed 100% on herring vs. completely on natural prey (October Samples). Error bars denote +1 SE.

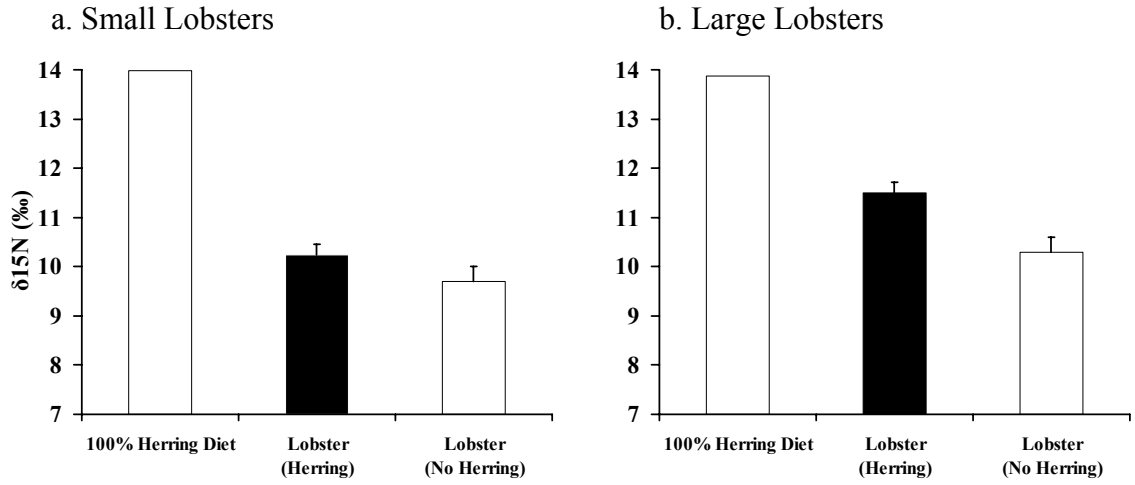


Figure 7. Mark-recapture results. a. The percentage of recaptured lobsters that molted from Monhegan and Georges Islands. b. Average percent growth in carapace length of lobsters that molted from each site. Error bars denote +1 SE.

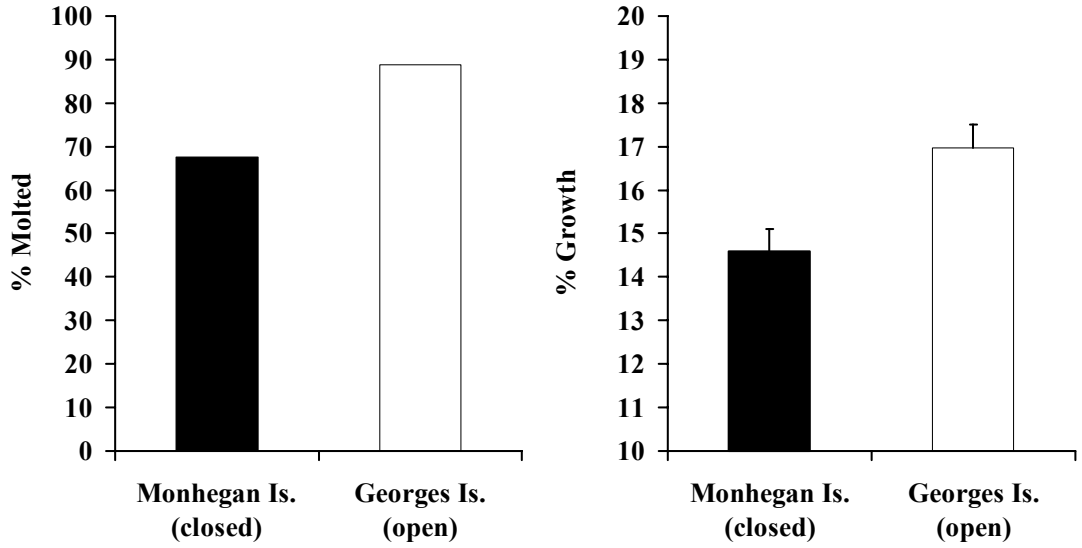
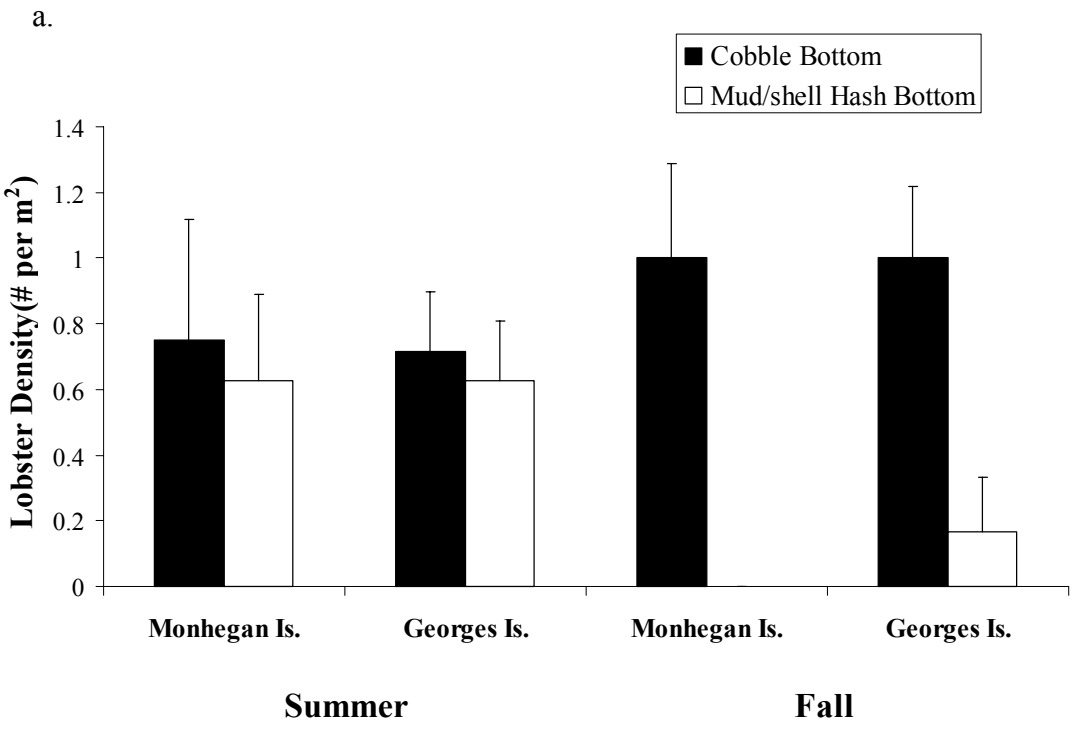


Figure 8. a. Lobster density results from 1-m^2 quadrat sampling in the summer and fall of 2002 within cobble bottom and mud/shell hash bottom habitats at Monhegan Is. and the Georges Is. b. Average lobster size from quadrat sampling in the summer and fall of 2002 at Monhegan Is. and the Georges Is. Error bars are +1 SE.



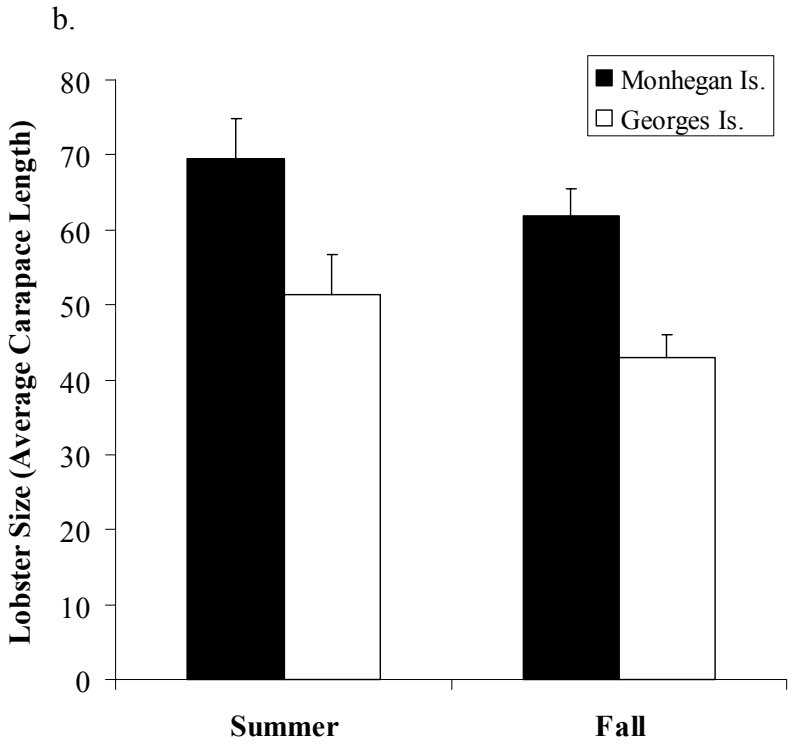


Figure 9. Lobster abundance and size-frequency results from traps. Relative abundance of lobsters caught in trap sampling in summer and fall at Monhegan Is. (seasonally closed) vs. Georges Is (open). Error bars denote +1 standard error.

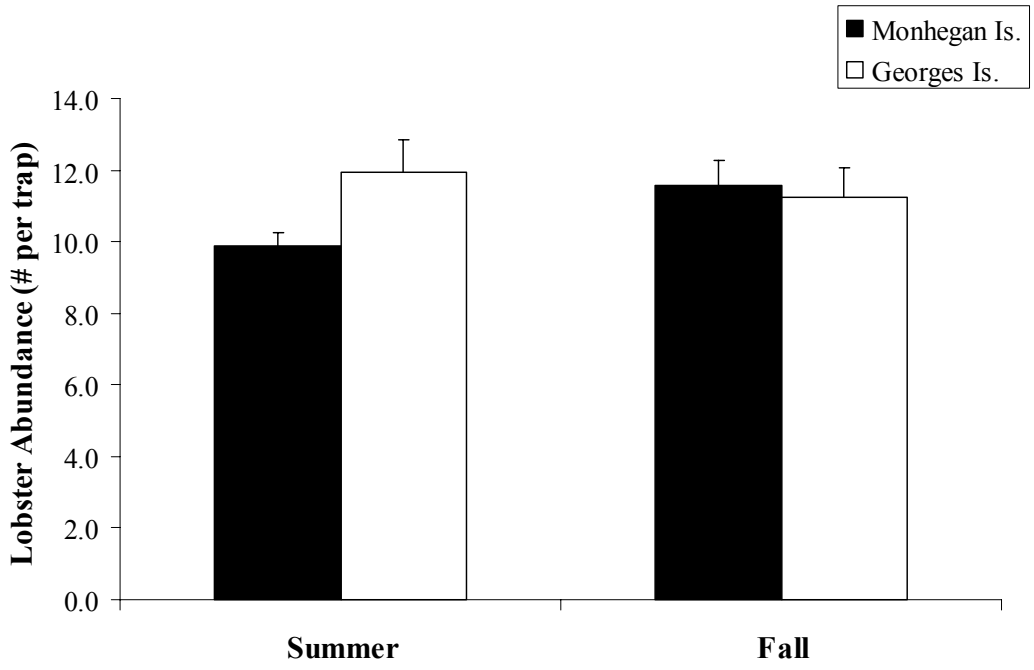
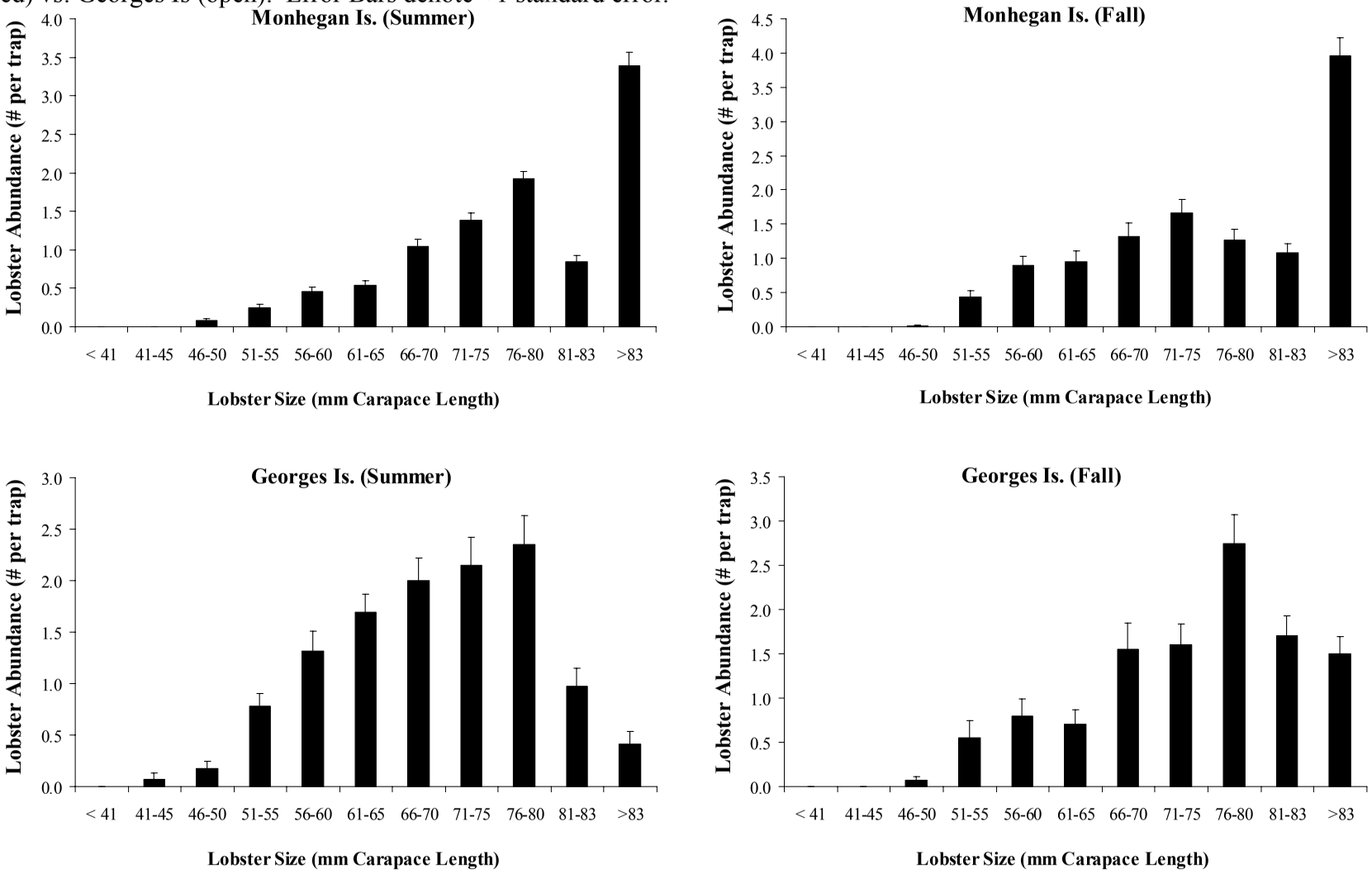


Figure 10. Relative abundance of lobsters in each size class caught in trap sampling in summer and fall at Monhegan Is. (seasonally closed) vs. Georges Is (open). Error Bars denote +1 standard error.



Appendix A: Newsletters and newspaper articles