HubLine Impact Assessment, Mitigation, and Restoration

Completion Report
of the
Massachusetts Division of Marine Fisheries

Submitted to the
Executive Office of Environmental Affairs

Period Covered:
2003 - 2008

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July 14, 2009

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Executive Summary

This report summarizes monitoring and mitigation/restoration activities of the Division of Marine Fisheries (*MarineFisheries*) during the period 31 May 2003 through 31 May 2008 in response to assumed impacts from the construction of the HubLine natural gas pipeline in Massachusetts Bay. This program represents the first, large-scale, comprehensive effort by *MarineFisheries* to assess and mitigate for impacts from a major marine construction project in Massachusetts coastal waters.

The "HubLine" natural gas pipeline was constructed by Algonquin Gas Transmission Company in Massachusetts Bay during 2002-2003. This 29.4 mile long, 24" to 30" diameter pipe runs from Salem/Beverly to Weymouth and is buried at a minimum depth of 3 ft. with several exceptions. Horizontal directional drilling, conventional dredging, jetting, plowing, and blasting were all part of the construction process and collectively, they were assumed to have exerted an impact on the marine environment and living resources. Depending upon the type of equipment used, the area of disturbed sediments along the pipeline pathway caused by trenching and back-filling varied to as wide as ~70ft.

Specific Time-Of-Year (TOY) work windows were defined in the permitting process by the reviewing agencies in order to minimize the impact of construction activities on e.g., migratory movements or spawning seasons and the associated vulnerability of eggs and larvae of various species. Exceeding recommended TOY's beyond 30 April 2003 and 31 May 2003 work window end dates resulted in monetary compensation to the Commonwealth by Algonquin for mitigation and restoration for any short or long-term impacts to aquatic resources and habitat and for assessment. *MarineFisheries* was the designated lead agency in receipt of these funds and with the responsibility to provide effective mitigation and/or restoration of aquatic resources and habitat.

Public input and an inter-agency steering committee were solicited to help develop a monitoring plan and suite of mitigation/restoration proposals. The mitigation proposals included work in four areas: eelgrass restoration, habitat enhancement, anadromous fish restoration, and shellfish propagation. Recovery monitoring was initiated in 2003-2004 and all mitigation efforts were implemented during 2004-2008 and included mitigation-specific monitoring and evaluation of relative success in meeting program objectives.

<u>Assessment Projects</u>
MarineFisheries' post-construction assessment activities of the HubLine pathway were multi-faceted and intended to evaluate impacts from the construction and monitor recovery. This long term effort included specific assessment and monitoring plans which, in some cases, were associated with related and co-occurring mitigation project field activities. Acoustic and optical surveys of sediment and biota, species diversity investigations and on-going *MarineFisheries* surveys helped to contribute to the evaluation of potential impacts. Commercial lobster sea sampling, ventless lobster trap monitoring, early benthic phase lobster suction sampling, and standardized bottom trawl survey data were incorporated into the final assessment of relative abundance trends for species inhabiting the impacted area.

Acoustic and Optical Surveys of Pipeline Pathway
Monitoring studies were initiated by *MarineFisheries* in August 2003 with several localized sampling efforts. SCUBA surveys provided baseline data for future recovery monitoring and indicated that significant changes in vegetation and re-colonization of crustaceans and finfish had occurred in a relatively short time since the pipe was laid. There was no definitive evidence found during 2003 surveys conducted by either *MarineFisheries* or by Algonquin's subcontractors that surface-laid pipe or its trench construction blocked the seasonal inshore migration of lobsters.

Broader-based, multi-year monitoring of the pipeline pathway began in March 2004 after the construction schedule of trench back-filling and leveling was projected to be completed. Sonar and video monitoring indicated impacted

sediments along the 29.4-mile path had not yet been restored to pre-construction quality. A considerable amount of relief was evident in elongated spoil piles 1-2m in elevation. Width of disturbed sediments along the pathway generally significantly exceeded estimates provided during the pre-construction review process and approached 25 m (75ft). Overall, most of the back-filled trench, especially areas with cobble deposition or a cobble sand mix suggested early stages of flora and fauna colonization.

A series of 19 permanent monitoring sites, representing an array of habitat types, were established from this initial sonar imaging and surveyed in subsequent years.

Sediment Relief Monitoring—Sonar
Standardized transects, representative of relief profile, were defined at each site for annual relief monitoring with side-scan sonar (2004-2006). Side scan relief measurements were calculated from the shadow component of each site's side scan sonar record and reflect vertical profile relative to the surrounding natural seabed. Relief was also evaluated with multibeam sonar (2006-2007) which allowed interpretation of relief by calculating depth differentials.

Four years after pipeline construction, relief created by trenching and back-filling persisted at most sites. Side scan data exhibited some changes to relief morphology and elevation at all sites; some exhibited subtle changes while others showed moderate to major changes. Most of the sites which exhibited smoothing or weathering were at depths <70ft where the impact of storm surge is more likely to affect the ocean floor. Analyses of multibeam data for changes >0.25m, indicated little difference in the profiles of all sites between 2006 and 2007.

ROV Video Monitoring
Most sites already exhibited some algal growth plus various macro-invertebrate and finfish species presence when ROV video surveys began in 2004. It is clear that mobile species repopulated the construction area relatively quickly. However, video imaging of the 19 sites in 2007 indicated that full recovery had not yet occurred. More algal, hydroid, and sponge growth was present on nearby natural bottom compared to sites on the back-filled pipeline trench.

Algal growth and invertebrate and finfish presence/abundance was related to bottom type and depth. Sites at >50 ft depth exhibited invertebrate and finfish presence, but minimal attached growth. Hard substrate facilitated attachment of algae, but the proliferation of algal growth was largely dependent upon shallow water depths to allow light penetration for photosynthesis. A more detailed analysis of hard bottom recovery is provided in the mitigation section of this report, **Section IVB: Habitat Enhancement Project**.

Species Diversity
In 2007, benthic infaunal communities at 5 soft-bottom stations located along the HubLine pipeline construction route were investigated for evidence of impact from the construction process which occurred between 2002 and 2003. Results indicate that biological samples taken on the disturbed HubLine trench and on natural bottom adjacent to it were more similar to each other then when compared across stations. Pipeline trenching and trench back-filling may have originally impacted these benthic infaunal communities, but this 2007 survey indicated that the benthic communities along the HubLine route appeared to be largely recovered. Their species diversity and evenness values were similar to those at ambient control stations located outside the HubLine area of disturbance and within the mean baseline range of MWRA's Harbor Outfall Monitoring program.

Species diversity of epibenthic fauna on hard-bottom sites was investigated in 2005 and 2007. The 2005 analyses demonstrated that natural reef sites had a higher measure of species richness than similar, but disturbed, sediment on a HubLine site. Biological monitoring during 2006-2007 allowed comparative evaluations of species diversity using three SCUBA survey procedures: 1) air-lift suction sampling, 2) transect surveys, and 3) percent cover evaluations in quadrats. In most cases, species diversity on the natural reef was significantly different and still higher, with some seasonal variation, than that on the HubLine back-filled trench approximately 4 years after pipeline construction.

Commercial Lobster Sampling
Initial concerns about pipeline construction effects on the commercial lobster fishery in Massachusetts Bay focused our attention on enhancing existing commercial lobster sea sampling activities in the general Massachusetts Bay area in calendar year 2003. *MarineFisheries'* commercial lobster sea sampling is a cooperative effort with commercial lobstermen and is conducted twice per month during May-November when over 90% of commercial lobster landings occur. Standardized catch rate trends encompassing the HubLine study period depict a general downward trend from 1999-2007, however, this is consistent with a broader-based downward trend elsewhere in the Gulf of Maine.

Suction Sampling Juvenile Lobsters
Suction sampling of early benthic phase (EBP) lobsters also was conducted in the Massachusetts Bay area to help evaluate larval lobster settlement in the area of construction. Sampling was conducted annually, using a diver-operated suction device, and augmented with site-specific suctioning of impacted sediments on the pipeline pathway.

Generally, catch densities increased through about 2004-2005 then declined thereafter to 2002-2003 levels. However, interpretation of these data should be done cautiously since they are characterized by high variances. Consequently, these time series show no obvious correlation with the 2002-2003 HubLine construction period.

Ventless Lobster Trap Survey
A pilot ventless lobster trap survey was started in fall, 2004 (October-November) as part of HubLine assessment initiatives to assist with monitoring the lobster population in and around the HubLine-affected region. An expanded 80 station, seven month survey was subsequently launched in Massachusetts Bay in 2005 and 2006. This research design, if modified for finer-scaled site investigations, represents a potentially useful tool for evaluating future marine construction projects.

The use of ventless gear extends lobster size structure information to the smaller sizes that do not normally occur in commercially-deployed vented traps. Trap placement was stratified by bottom sediment type and bathymetry.

No significant trends in catch per unit effort (CPUE) by substrate type were observed throughout Massachusetts Bay. However, depth (or its associated temperature gradient) was an important variable influencing catch rates and size distribution. Sublegal CPUE was fairly evenly distributed throughout the study area in all three years, while legal CPUE was consistently higher in the deepest strata.

A 3-year, October-November, time series (2004-2006) of these data was inadequate to draw meaningful conclusions about lobster relative abundance trends, since it was not only too short (at the time of this writing) but did not encompass the entire molting season. However CPUE of sublegals was significantly less in 2004 compared to 2005 and similar to 2006, while legal CPUE exhibited no differences across years.

This initial effort led to a coastwide survey, adopted by the Atlantic States Marine Fisheries Commission (ASMFC), which was implemented in coastal waters from Maine to Long Island, NY in 2006, 2007, and 2008. The ASMFC coastwide ventless trap survey is based on the sampling methodology and survey design developed for this initial ventless trap sampling effort, and it is planned to continue indefinitely as an additional means to monitor American lobster relative abundance in U.S. coastal waters.

Bottom Trawl Survey Trends
MarineFisheries' bottom trawl survey data were used to evaluate relative abundance trends for selected species from the HubLine study area. This bottom trawl survey was not a HubLine-funded effort and it was not designed to detect fluctuations in abundance on a fine geographic scale, e.g., the HubLine trench, but its statistical precision is appropriate for detecting larger scale changes as may be evident in annual trends.

Relative biomass (mean weight per tow) and relative abundance (mean catch per tow in number of animals) from 1978-2007 was analyzed for Atlantic cod, winter flounder, yellowtail flounder, American lobster, and Sea Scallops. Species trend analyses did not depict any obvious relationship with the HubLine construction period.

Mitigation Projects

Four mitigation projects were undertaken by *MarineFisheries* staff. They addressed eelgrass restoration, habitat enhancement, anadromous fish restoration (including anadromous fish run restoration, smelt restoration, and shad restoration), and shellfish restoration and stock enhancement:

Eelgrass Restoration Project

The primary goal of the *MarineFisheries* Eelgrass Restoration Project was to re-establish eelgrass in Boston Harbor as partial mitigation for assumed impacts to the environment from the pipeline construction. Restoration of eelgrass habitat will provide shelter, food, and has the potential to positively affect abundance of a number of finfish and invertebrate species judged to be potentially impacted.

Extensive site selection work was conducted during fall 2004 and spring 2005 to identify areas suitable for eelgrass growth. Twelve sites were originally identified, received (phase I) small scale test transplants (200 shoots in a $1m^2$ area), and were monitored for survival. Five of those sites exhibited acceptable survival and were selected for secondary test transplants (phase II, 1000 shoots) and later full-scale plantings between 2005 and 2006: Long Island North , Long Island South, Peddocks E, Portuguese Cove, off the west side of Peddocks Island, and Weymouth.

Planting was conducted using a combination of hand- and frame-planting, and seed dispersal followed by monitoring for shoot density expansion. The site selection process achieved successful results at 4 of our 5 sites. Shoot density expanded significantly and by late 2007, total areal coverage was over 2 hectares (~ 5 acres).

Biological monitoring was undertaken to determine ecosystem function of transplanted beds compared to existing beds in Boston Harbor, a healthy bed in Nahant, and an unvegetated control site in Boston Harbor. Parameters investigated included demersal, epibenthic, and benthic infaunal species richness and diversity; percent cover of eelgrass; shoot density; above-ground biomass; and, leaf area index. Transplant sites compared favorably to existing Boston Harbor eelgrass beds, and approached healthy beds in Nahant for several indices.

Hydrodynamic modelling results indicated that it was unlikely that seeds would spread naturally from existing remnant beds in Boston Harbor to sites we selected. However, it did show that, with our planted beds as "feeders," natural spreading via seed shoots was likely within and near most transplant locations, thus more efficiently focusing restoration efforts.

Outreach was an important part of the Eelgrass Restoration Project. We provided a "hands-on" educational experience for members of the community and promoted stewardship of this valuable resource. Volunteers were an essential part of our restoration effort. We enlisted the help of a number of volunteer divers and shore helpers. A total of 428 hours were donated by 155 volunteers during our restoration activities.

Habitat Enhancement Project

In March-April, 2006, *MarineFisheries* constructed a six unit cobble-boulder reef off Boston Harbor in order to provide partial mitigation for the assumed impacts to biological resources and habitat from HubLine construction. This Project enhances complex substrate in Massachusetts Bay, thereby providing niches for multiple life stages of numerous finfish and invertebrate species.

Reef Site Selection

A simple site selection model used seven systematic steps: exclusion mapping, depth and slope verification, surficial substrate assessment, data weighting and subsequent ranking analysis, visual transect surveys, benthic air-lift sampling, and larval settlement collector deployment. allowed us to select a site for habitat enhancement at a target depth that received little wave action, had no slope, and possessed a surficial substrate type that could support the weight of a reef. The site also had the presence of a natural larval supply and low species diversity prior to reef installation. Each step in this site selection model was designed for adaptation by others interested in future artificial reef development.

Artificial Reef Monitoring Program:
An intensive, long-term monitoring program was implemented to measure ecological variation on the artificial reef and to determine how well the artificial reef met specific goals. Two primary questions were addressed with this monitoring program: (1) can a cobble/boulder artificial reef establish similar levels of species abundance and diversity as a nearby natural reef, and (2) if so, in what timeframe? *MarineFisheries* also investigated smaller scale questions such as: does the artificial reef augment post-larval lobster settlement and the settlement of other fish and invertebrates; does the artificial reef provide mitigation for the hard-bottom encrusting community; and does the artificial reef provide shelter for multiple life stages of various marine organisms?

To investigate these questions, a research plan was developed which incorporated three different monitoring methods: annual air-lift sampling for crustacean and fish larvae, semi-annual small fish trap sampling, and seasonal permanent transect sampling using SCUBA. Four primary areas were monitored: the artificial reef, a nearby natural reef, a cobble fill point on the HubLine pipeline, and a sand site. Results from the first year and a half of monitoring showed that young-of-the-year lobster densities on the artificial reef, as determined by air-lift sampling, were similar to the natural reef, HubLine, and sand. Fish trap sampling showed that significantly more cunner, Massachusetts' most common reef-dwelling species, were caught on the artificial reef and the HubLine than on the natural reef and the sand and that cunner had high site fidelity, only occasionally moving from one site to another. The artificial reef had the highest diversity of enumerated species, yet the lowest diversity of species assessed by percent cover. This difference was likely due to species life histories, as the artificial reef quickly attracted mobile invertebrates and fish species that preferred complex habitat with high relief, whereas sessile, slower-growing species take longer to settle and establish.

Results from each step in this process ultimately

Species composition on the artificial reef will most likely take years to follow fluctuations in composition similar to that of a natural reef. The HubLine cobble fill point is a few years older than the artificial reef and does not yet mimic the natural reef in species abundance or diversity. If the artificial reef never resembles a natural reef or if it takes more than five to ten years to reflect the conditions of a natural reef, the effectiveness of artificial reefs as mitigation tools in New England waters should be viewed cautiously. However, in the present timeframe of comparison, some conclusions can be drawn from this on-going monitoring program. The cobble and boulder artificial reef did provide habitat for the hard-bottom encrusting community, larval settlement occurred in similar densities to adjacent comparison sites, and the abundance of cunner is currently higher on the artificial reef than the natural reef.

Anadromous Fish Restoration Project (3 Parts)
The Anadromous Fish Restoration Project enhanced the anadromous fish resources in the embayments and associated watersheds adjacent to the HubLine Pipeline. These are resources that were potentially impacted by the HubLine construction. The project consisted of propagation/stocking, monitoring, construction and repair of anadromous fish passage, and improvements to habitat. There were three parts to this restoration effort:

1. <u>The Anadromous Fish Passage Enhancement Project</u> had the objective of enhancing and increasing the spawning habitat for alosid fishes (alewives, *Alosa pseudoharengus*; blueback herring, *Alosa aestivalis*; American shad, *Alosa sapidissima*). *MarineFisheries* selected and completed 20 projects in 13 systems in the HubLine region that (a) ranged from minor to major fishway improvements, (b) created new

passage for anadromous fish, (c) evaluated the feasibility for restoring anadromous fish populations, (d) restored or enhanced spawning habitat, and (e) developed innovative technology for assessing river herring passage and run size.

2. The Rainbow Smelt Culture and Enhancement Project assisted the restoration of rainbow smelt (*Osmerus mordax*) populations in several river systems in the Massachusetts Bay area. A two-year pilot project began in 2004 using HubLine funds to develop smelt culture and early life-stage marking techniques. This effort was linked to a NOAA Protected Species Program grant to develop population indices for smelt. The population index project developed fyke net sampling stations in 2004 and 2005 that also served as a source for mature smelt for laboratory culture and for re-capturing marked smelt that were stocked in specific rivers. The project goals were to achieve high survival of smelt eggs in a hatchery incubation setting, develop otolith marking protocols and verify restoration success following stocking in a control river.

Approximately 5.3 million marked smelt larvae were stocked into the Crane River during 2005-2008. The analysis of age-1 smelt otoliths from 2008 fyke net catches at restoration river stations found 16% of the Crane River age-1 smelt and 14% of the North River age-1 smelt were stocked as larvae by this project. Conclusions cannot be reached on the contributions of larvae stocked in 2005 and 2006 because these smelt were marked as eggs and subsequent investigations found that the OTC mark in smelt marked as eggs did not persist in hatchery specimens reared for one year. The smelt larvae stocked in 2007 and 2008 were marked as larvae with 500 mg/l OTC which our laboratory investigations indicated is more durable than the egg marking and does not negatively influence egg or larval survival.

Smelt fyke nets successfully captured smelt at all six stations during 2005-2008 revealing unique population signals of spawning run seasonality, age composition, and size at age. This technique shows promise for tracking age composition and cohort strength. The catch data also contributed information on other species of diadromous fish that are poorly documented in Massachusetts.

We believe these efforts mark the first time rainbow smelt have been reared on a dry diet and to maturity in a closed-loop hatchery system. The recapture of OTC-marked rainbow smelt in the Crane River is also a novel achievement that may develop into a restoration tool that can be applied in other river systems. Continued sampling and larval stocking in 2009 should provide a better assessment of the contribution of stocking to smelt runs and the overall utility of these methods for smelt population restoration.

3. The American Shad Propagation Project is a collaborative effort between *MarineFisheries* and the U.S. Fish and Wildlife Service to restore viable populations of shad to the Charles and Neponset Rivers by establishing a fry-stocking program and improving fish passage in these systems. Significant fish passage improvements were made to the Charles River, but passage in the Neponset River was not projected to be realized during this study period, so all American shad fry production was allocated to the Charles River.

Despite coincident high water flow events in the Merrimack River that limited broodstock availability, the HubLine American Shad Propagation Project successfully produced and stocked shad fry in the Charles River between 2005 and 2008. In June 2005, following infrastructure installation, limited pilot production was conducted at Essex Dam and at the North Attleboro National Fish Hatchery and by spring 2006, full-scale spawning and rearing was operational at the Nashua and North Attleboro National Fish Hatcheries and at Essex Dam. From 2006 through 2008, approximately 3000 adult American shad broodstock were captured at the Essex Dam, Merrimack River, injected with hormone and successfully spawned. A total 3.6 million shad fry were immersed in an oxy-tetracycline bath to mark their otoliths and stocked in the Charles River.

Otolith marking allows identification and quantification of hatchery-origin shad in 3-4 years when these fish reach maturity and return to spawn. A successful restoration will be indicated in future years by the presence of a greater number of naturally-spawned individuals as compared to hatchery-spawned individuals.

Shellfish Stock Enhancement Project

The Shellfish Stock Enhancement Project is restoring/enhancing soft-shell clam (*Mya arenaria*) populations in five Boston Harbor communities Winthrop, Quincy, Weymouth, Hingham and Hull. The soft-shell clam was identified as an impacted species from the construction of the HubLine gas pipeline along near shore areas. Restoration is being conducted through cooperative programs with local municipalities, commercial shellfishers, and Salem State Northeast Massachusetts Aquaculture Center (NEMAC), with funding and technical assistance from *MarineFisheries.*

In 2006, the study team seeded over one million hatchery-reared juvenile clams within five enhancement sites on tidal flats in Quincy, Weymouth and Hingham. Clam size, sediment type and beach kinetics were found to significantly influence clam survival. Planted clams larger than 10mm in length exhibited a higher survival rate than smaller juveniles. Juvenile clams that were planted in silty mud did not survive. Similarly, enhancement sites that were exposed to significant tidal current, stream flows, wind driven waves or vessel wake suffered high levels of clam mortality.

During summer 2007, an additional 870,000 juvenile clams that averaged between 10.5 to 16.8 mm SL were stocked at eight enhancement sites in Hull, Winthrop, Quincy, Weymouth and Hingham. In 2008, 42 plots were seeded with 756,000 seed clams at four enhancement sites in Winthrop, Quincy and Weymouth. Subsequently, temporary restrictions placed on the sale of seed clams from the NEMAC hatchery facility reduced the plan to plant 1.62 million clams. Routine pathology tests of juvenile clams within Salem State's hatchery revealed the presence of an ectoparasite which warranted further investigation by *MarineFisheries*.

A controlled harvest of two of the 2006 enhancement plots was undertaken. Legal-sized clams were depurated at the Newburyport plant and later sold by the Master digger. Under-sized clams were replanted within the harvested plots.

Efforts to collect wild clam spat were unsuccessful. No significant numbers of YOY clams were found within any of the 44 spat collectors that were sampled. This was likely due to currently small resident spawning stocks of softshell clams in Boston Harbor since this collection method has been used successfully in other coastal Massachusetts areas.

HubLine Impact Assessment, Mitigation, and Restoration

Completion Report
May 31, 2003-May 31, 2008

I. Introduction

This report summarizes monitoring and mitigation/restoration activities of the Division of Marine Fisheries (*MarineFisheries*) during the period 31 May 2003 through 31 May 2008 in response to assumed impacts from the construction of the HubLine natural gas pipeline in Massachusetts Bay. The "HubLine" natural gas pipeline was constructed by Algonquin Gas Transmission Company in Massachusetts Bay during 2002-2003. This 29.4 mile long, 24" to 30" diameter pipe runs from Salem/Beverly to Weymouth and is buried at a minimum depth of 3 ft. with several exceptions (Figure I.1). Horizontal directional drilling, conventional dredging, jetting, plowing, and blasting were all part of the construction process and collectively, they were assumed to have exerted an impact on the marine environment and living resources. Depending upon the type of equipment used, the area of disturbed sediments along the pipeline pathway caused by trenching and back-filling varied to as wide as ~70ft.

Specific Time-Of-Year (TOY) work windows were defined in the permitting process by the reviewing agencies in order to minimize the impact of construction activities on e.g., migratory movements or spawning seasons and the associated vulnerability of eggs and larvae of various species. Exceeding recommended TOY's beyond 30 April 2003 and 31 May 2003 work window end dates resulted in monetary compensation to the Commonwealth by Algonquin for mitigation and restoration for any short or long-term impacts to aquatic resources and habitat and for assessment. *MarineFisheries* was the designated lead agency in receipt of these funds and with the responsibility to provide effective mitigation and/or restoration of aquatic resources and habitat and impact assessment.

II. Program Administration and Public Process

A HubLine Mitigation and Restoration Coordinator (Bruce T. Estrella) was assigned to administer, develop, and manage a mitigation/restoration and monitoring/assessment program and associated costs. An administrative budget was prepared for operation and support of HubLine-related activities. Expenditure organization and accounting associated with the management of the budget, designing, implementing, and supervising research projects, purchasing, contracting, and hiring are among the responsibilities of this program coordinator.

Duties were initiated with the development of an accounting system to monitor and collate expenses incurred by the HubLine Program. A *MarineFisheries* internal steering committee was chosen to provide initial guidance to the HubLine mitigation and restoration program. An informational brief was drafted for committee discussion to provide members with the HubLine construction project background. This included assumed impacts to marine resources and habitat from the construction, funding granted to mitigate those impacts, a list of assessment, monitoring, mitigation, and restoration proposals recommended to date, and a timeline for our future activities.

A public process was implemented by November 2003 to solicit input on mitigation/restoration project selection criteria and project ideas. We defined the public process to include a public announcement and comment period during October 28- November 28, 2003 and the creation of an Inter-Agency Steering Committee to seek input from interested stakeholders and relevant state and federal agencies. The Steering Committee, which included representatives of the MA Department of Environmental Protection,

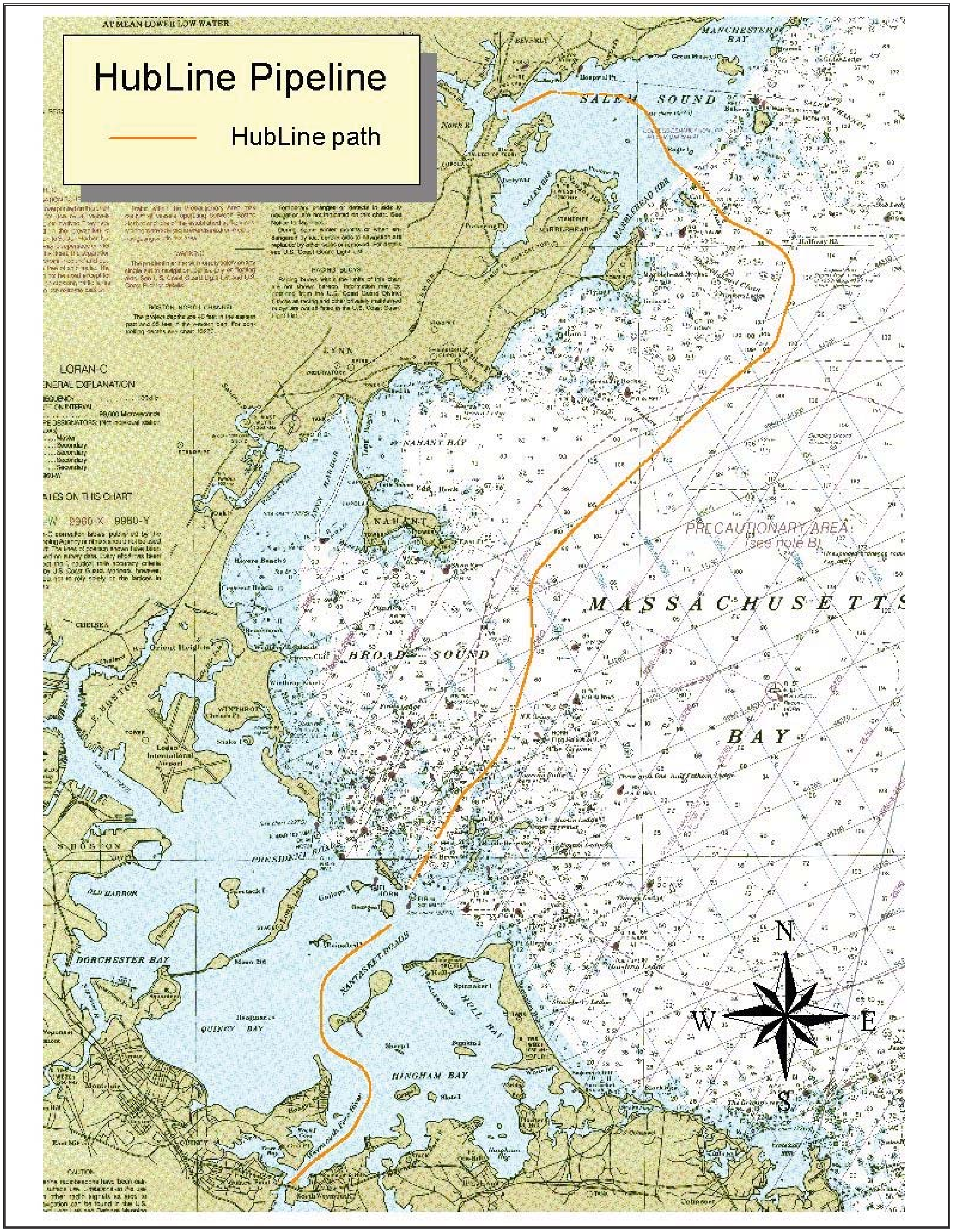


Figure I.1. Route of HubLine natural gas pipeline in Massachusetts Bay.

National Marine Fisheries Service, Coastal Zone Management, Environmental Protection Agency, Conservation Law Foundation, and Marine Fisheries Commission, met twice during winter 2003/2004 to help us define a mitigation/restoration work plan. On 23 December 2003, we presented an array of optional mitigation ideas to the Steering Committee. These were a product of a review of all available inter-agency documents and communications associated with the environmental review process for the HubLine construction, the scientific literature on mitigation and restoration studies, and contributions from key *MarineFisheries*' project leaders (Internal Steering Committee) with expertise on specific resources. Ideas favored by the Committee were developed into full proposals which were reviewed by the Committee on 24 February 2004. The proposals include work in four areas: eelgrass restoration, habitat enhancement, anadromous fish restoration, and shellfish propagation. All mitigation efforts were planned for implementation during 2004-2008 and include monitoring and evaluation of relative success in meeting program objectives.

III. Monitoring and Assessment

Post-construction assessment activities of the HubLine pathway were multi-faceted and intended to evaluate impacts from the construction and monitor recovery. This long term effort included specific assessment and monitoring plans which, in some cases, were associated with related and co-occurring mitigation project field activities. Acoustic and optical surveys of sediment and biota, species diversity investigations and on-going *MarineFisheries* surveys helped to contribute to the evaluation of potential impacts. Commercial lobster sea sampling, ventless lobster trap monitoring, early benthic phase lobster suction sampling, and standardized bottom trawl survey data were incorporated into the final assessment of relative abundance trends for species inhabiting the impacted area.

III A. Acoustic and Optical Surveys of Pipeline Pathway

1. Short Term Transect Surveys of Unburied Pipe

1.1. Surveys of Unburied Pipe -- TRC Solutions Contract

Assessment of impacts of pipeline construction began in June 2003. The exceeding of spring TOY work window end dates raised concerns about potential impacts to American lobster (*Homarus americanus*) and the associated fishery via interference with seasonal onshore migration of lobsters. This resulted in the immediate need to evaluate the effect of surface laid pipe or open trench on the seasonal onshore migration of American lobster. Accordingly, of the funds allocated to the Commonwealth for assessment, a portion was spent by Algonquin on a contracted diver video and ROV survey of lobsters in the vicinity of the pipeline. The survey was conducted during a 12-day period in June and July, 2003, however, it was originally intended to occur prior to pipe burial. The study did not report higher concentrations of lobsters on the east side of the pipe which would have indicated that the pipe was an impediment to inshore (westward) migration of lobsters (Anonymous 2003). However, since back-fill plowing had already begun, these results are considered inconclusive.

1.2. Surveys of Unburied Pipe -- *MarineFisheries*

Additional monitoring studies were initiated by *MarineFisheries* in August 2003 with several localized sampling efforts. *MarineFisheries*' staff conducted underwater video monitoring and diver transect surveys to describe and quantify biota in and near the trenches of three sections of exposed pipe (two 500' and one 1800' section) off Boston on August 11, 2003 (Figure IIIA1.2). Algonquin representatives had indicated that burial of these sections to the mandated depth of 3-10ft) was not possible due to ledge and they planned on covering them with stone. Concerns were raised because this was an unplanned activity for this time of year which could affect finfish or crustacean presence in adjacent natural habitat. In

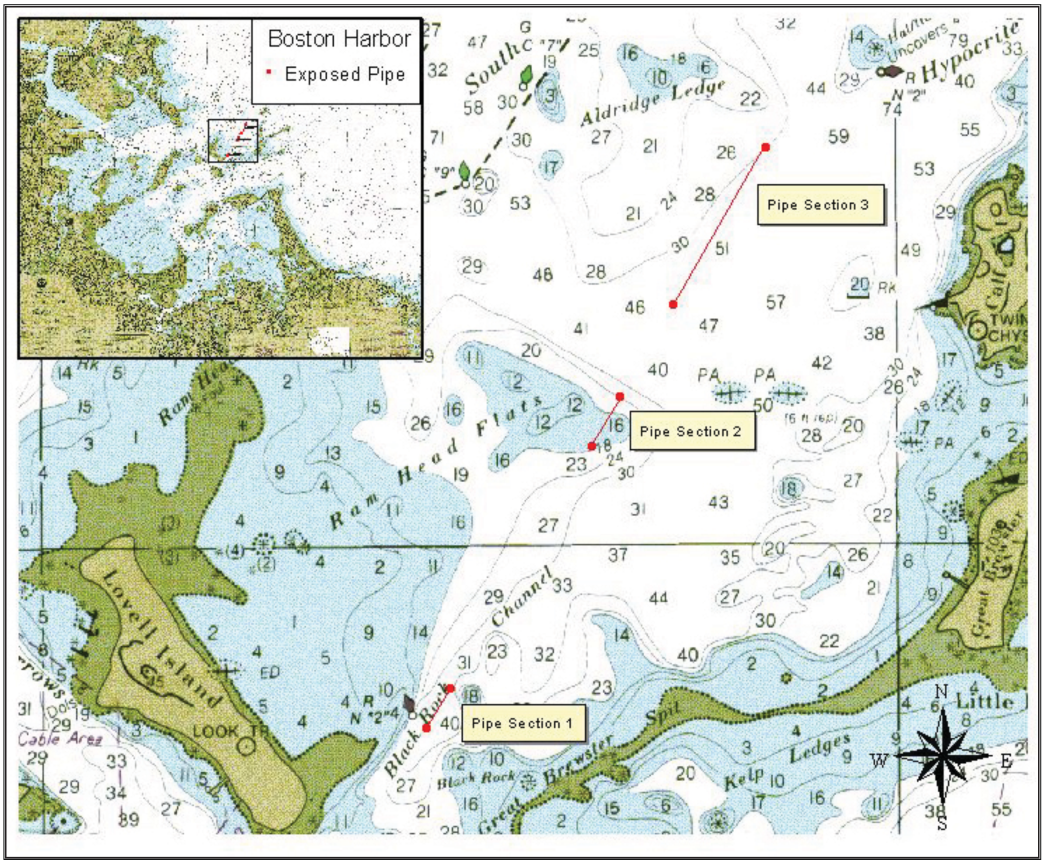


Figure IIIA1.2. Location of three sections of exposed pipe targeted for DMF SCUBA surveys, August 11, 2003.

advance of this action, we devised and deployed a sampling strategy to evaluate the potential impact on fauna and flora which may have re-populated the area. A request was made to Algonquin's representatives to place marker buoys on the pipe sections in question to facilitate locating the sites.

Our survey design included observational and video transects along the center of each pipe section and also parallel transects 30' to either side of center to provide an overview. Perpendicular, "across-pipe" 60' transects were also planned at 100' intervals to characterize the bottom sediments and enumerate finfish and invertebrates. Perpendicular transect length was established by doubling the projected 30' footprint of the area designated for fill (30' out from each side of the pipe centerline).

Two ~ 500+ ft. sections were evaluated, but a dive on the third and longest section (1800+ ft) was not possible because its marker buoy was not located. At this point the current was very strong and the fog was too thick to risk drift dives at this location to find the 3rd exposed section, particularly with boat traffic in the area.

This monitoring effort indicated that significant changes in vegetation and re-colonization of crustaceans and finfish had occurred in a relatively short time since the pipe was laid.

2.0 Long Term Surveys of Back-Filled Trench

MarineFisheries' "long-term" surveys began after the original schedule of pipeline trench filling and leveling was completed by Algonquin and its contractors (Table IIIA2.1). (Additional back-filling occurred thereafter at specific sites via permit amendments, but this did not affect our survey activities.)

2.1 Acoustic and Optical Survey Methodology

In order to monitor changes in vegetation, re-colonization in the disturbed area, and sediment relief recovery we undertook a sonar and video monitoring effort to provide post-construction baseline information. As-built coordinates of the pipeline pathway were acquired from Algonquin's subcontractor, TRC Environmental Corporation, and baseline imaging of the disturbed sediments using sonar and video equipment aboard the 65' NOAA R/V Gloria Michelle was initiated.

Side scan and ultimately multibeam sonar were deployed to monitor sediment relief. (This sediment imaging effort also contributed to the site selection process for the naturalistic reef; see Section IV.) A dual camera sled system was initially set up for surveillance of the pipeline pathway and DVD recording hardware and GPS video-overlay electronics were interfaced. ROV cameras eventually replaced the sled system. Video data assisted in the ground-truthing of sonar records and both helped us to monitor sediment relief recovery, floral succession, and faunal recolonization of the disturbed sediments. Diver surveys (associated with related HubLine mitigation projects) were also conducted to complement this work. Multi-year assessments were made to track the recovery of species diversity on the disturbed sediments relative to control sites.

Surveys were conducted along the pipeline pathway using NOAA's 65' R/V Gloria Michelle as a research platform and were confined to a minimum operating depth of about 20ft MLW. The vessel was operated from the Pt. Allerton USCG Base in Hull, Massachusetts. Inshore,

Table IIIA2.1. Schedule of *MarineFisheries'* sonar and optical surveys conducted on the HubLine pipeline, Massachusetts Bay, 2004-2007.

	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.
2004									
Video Sled	X	X		X		X		X	X
Side Scan Sonar	X	X				X			X
Benthos C3D/ Sonar	X								
ROV				X		X		X	X
2005									
ROV				X	X			X	X
Side Scan Sonar				X	X			X	X
2006									
ROV				X				X	
Side Scan Sonar				X	X				
Multibeam Sonar				X	X				
2007									
ROV				X					
Multibeam Sonar				X					

shallow water area segments (< 20 ft.), previously not surveyed due to the R/V Gloria Michelle's draft, were surveyed with a smaller contracted vessel resulting in near complete coverage of the back-filled trench across all but the shallowest depths. Exceptions included each terminus of the underwater pipeline and certain locations at the mouth of Boston Harbor because they were in shallow rocky areas that prevented safe navigation and towing of equipment.

American Underwater Search and Survey, Ltd. (AUSS), conducted the side-scan sonar surveys and participated in the ROV surveys conducted by Ocean Eye, CJ Industries, Inc. *MarineFisheries* personnel conducted the video sled, SCUBA, and multibeam surveys.

The suite of equipment operated from the survey vessels included:

Navigation: Vessel's DGPS and a Hypack Max program on a laptop computer

Survey: EG&G DF1000 dual frequency digital sonar in the 500kHz mode (2004)

Edgetech 272 dual frequency analog sonar in 500kHz mode (2004-2006)

Benthos C3D bathymetric side scan sonar (March 2004)

Marine Sonic sonar in 900 kHz mode (November 2004)

Marine Fisheries' one and two camera system mounted to drift and on an AUSS towfish (March, April, June, August 2004)

Benthos MiniRover Mark II ROV (2004-2007)

Outland Technology ROV Model 1000 (October 2006)

Simrad EM3002 multibeam sonar (2006-2007)

Sonar images recorded during 2004 surveys were reviewed in order to evaluate sediment type and relief. Nineteen permanent sites were then established from this analysis for future monitoring (Figure IIIA2.1). These sites were representative of various sediment types, topographical features, and depth along the pipeline pathway. Forty-six concrete moorings with tethered sonar reflectors were constructed and deployed at these sites to help ensure accuracy in the re-surveying of these locations. Surveys of these "sentinel" sites began in June 2005.

2.1.1 Side Scan Sonar Survey 2004-2006

Standardized transects, representative of relief profile, were defined at each site for annual relief monitoring. Relief measurements were calculated from the shadow component of each site's side scan sonar record and reflect vertical profile relative to the surrounding natural seabed. Side scan measurements were facilitated by the berm pattern left by trench back-fill plowing. Trench backfilling equipment typically leaves a tell-tale pattern of berms similar to that in Figure IIIA2.2. This pattern, although partially obscured at some sites due to permit-required dumping of fill, provided "landmarks" for annual relief measurements along standardized transect coordinates. These "landmarks" were outer and inner berms on the west side of the trench, three points in the center of the trench, and outer and inner berms on the east side of the trench (Figure IIIA2.2).

Relief changes evaluated with side scan sonagrams during the 2004-2006 period are depicted in Figure IIIA2.3 for 15 sites for which data were available.

All sites exhibited some changes to relief morphology and elevation; some sites exhibited subtle changes while others showed moderate to major changes. Current speed and bottom morphology may have channelled water flow and intensified dynamics at some sites. Thus enhancing the ageing or weathering effect resulting in the smoothing of features over time. Most of the sites which exhibited smoothing were at depths <70ft where the impact of storm surge is more likely to affect the ocean floor.

Figure IIIA2.1. Map of HubLine natural gas pipeline pathway and *MarineFisheries'* sonar and video survey sites in Massachusetts Bay.

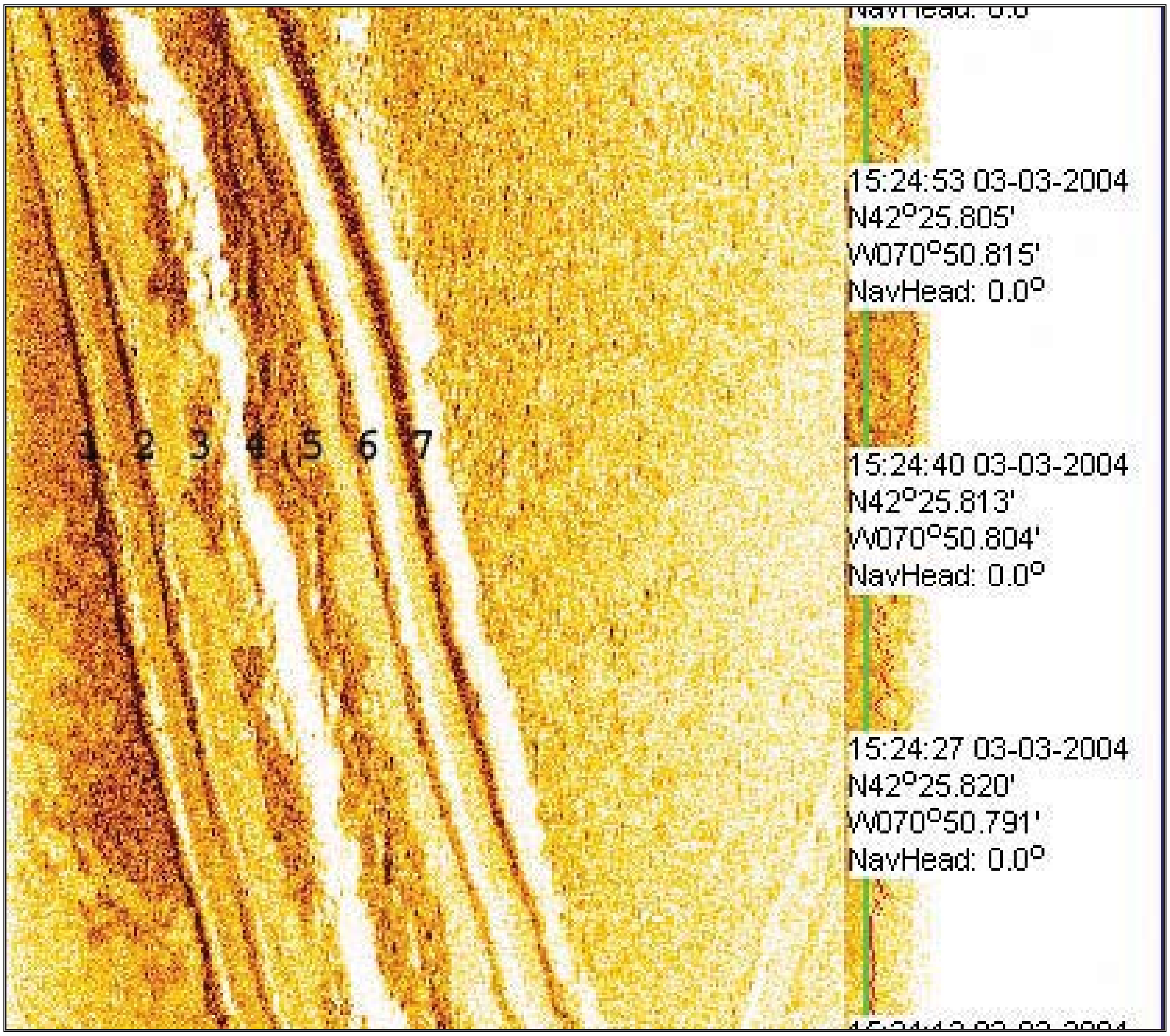


Figure IIIA2.2. Side scan image showing typical berm pattern left by plow in back-filled pipeline trench (1 =outer berm-west, 2 = inner berm-west, 3 = trench-west, 4 = trench-center, 5 = trench-east, 6 = outer berm-east, and 7 = inner berm-east).

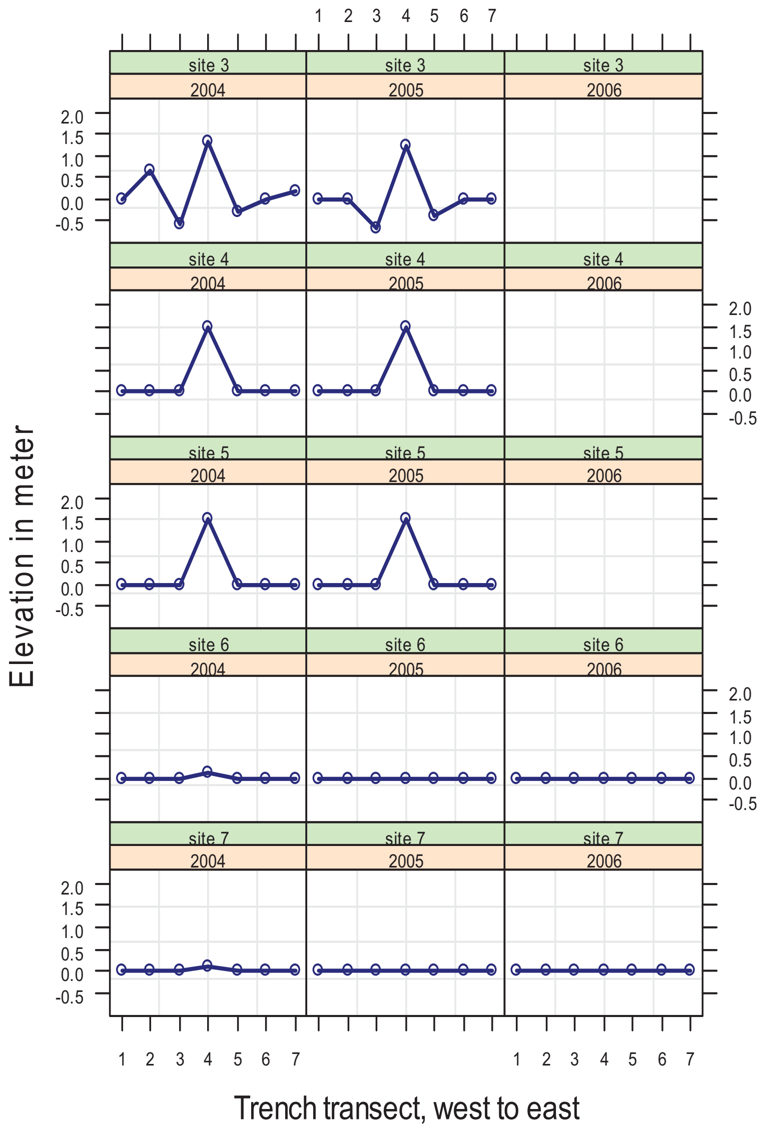


Figure IIIA2.3. Relief changes observed at seven points along standardized transects at HubLine sites 3-17 during 2004-2006 side-scan sonar surveys. The seven points correspond to berms created by trench backfill equipment and their measurements (1-7) are displayed in a West to East orientation. (Side scan images for sites 3, 4, and 5 in 2006 were either missing due to the inability to survey caused by the presence of pot gear and vessel traffic or image quality was inadequate for generating elevations; sites 1,2,18, and 19 were too shallow to tow sonar equipment.)

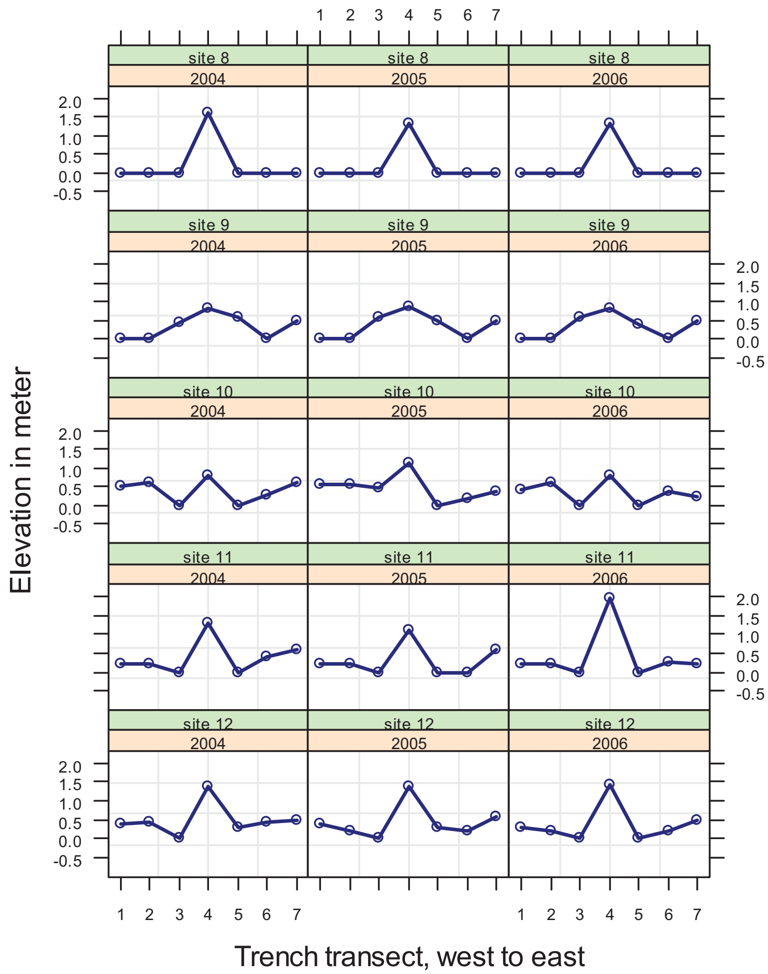


Figure IIIA2.3 (*Continued*). Relief changes observed at seven points along standardized transects at HubLine sites 3-17 during 2004-2006 side-scan sonar surveys. The seven points correspond to berms created by trench backfill equipment and their measurements (1-7) are displayed in a West to East orientation. (Side scan images for sites 3, 4, and 5 in 2006 were either missing due to the inability to survey caused by the presence of pot gear and vessel traffic or image quality was inadequate for generating elevations; sites 1,2,18, and 19 were too shallow to tow sonar equipment.)

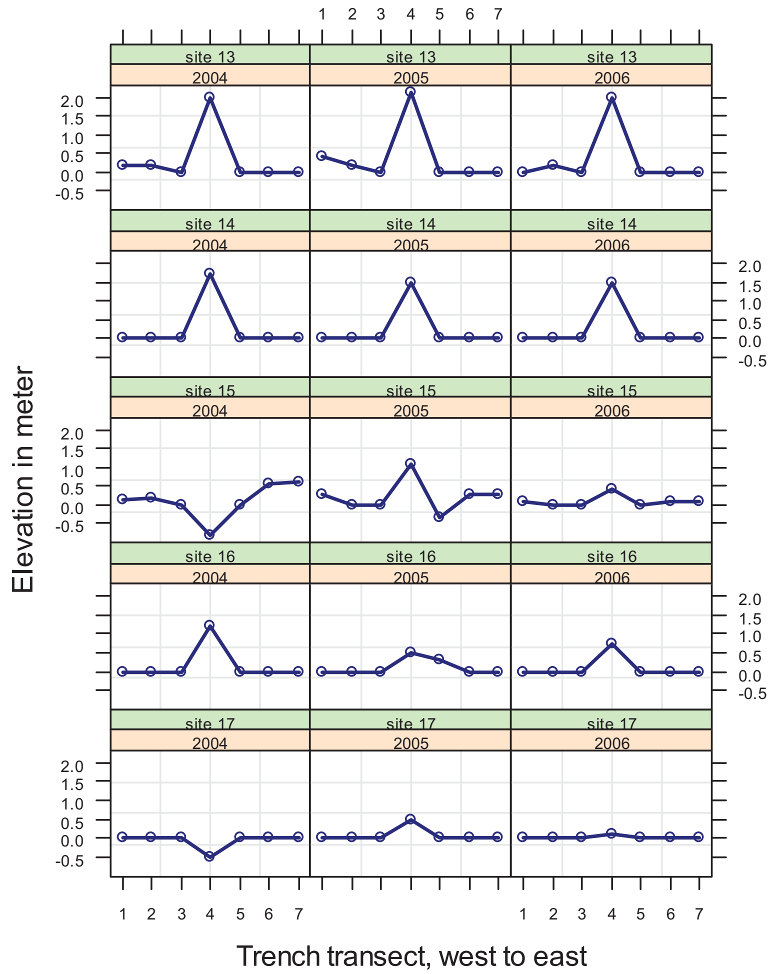


Figure IIIA2.3 (*Continued*). Relief changes observed at seven points along standardized transects at HubLine sites 3-17 during 2004-2006 side-scan sonar surveys. The seven points correspond to berms created by trench backfill equipment and their measurements (1-7) are displayed in a West to East orientation. (Side scan images for sites 3, 4, and 5 in 2006 were either missing due to the inability to survey caused by the presence of pot gear and vessel traffic or image quality was inadequate for generating elevations; sites 1,2,18, and 19 were too shallow to tow sonar equipment.)

2.1.2 Multibeam Sonar Survey 2006-2007
Relief changes from 2006-2007 were evaluated with multibeam sonar data which allows interpretation of relief by calculating depth differentials (Figure IIIA2.4). A Kongsberg EM3002 300 kHz multibeam system was used to image the pipeline pathway in 2006 and 2007 using equiangular beam spacing. A Seapath 200 with dual-antennas was used for navigation and a Seatex MRU 6 for motion correction. The transducer, MRU, and a sound velocity probe were mounted together using a bow-mounted bracket on the R/V Gloria Michelle. A sound velocity profiler was also used regularly throughout both surveys.

The survey was run from the south to the north (Hull to Salem) in both years. In 2007, data was collected on both legs of the survey.

All analyses, including calibration and refraction corrections, were conducted in CARIS HIPS/SIPS software. Sites were analyzed using the best data available considering salinity correction, tide correction, and site coverage (e.g., if a site was imaged more than once, the best imaging was used; multiple passes over a single site were not used in the gridding). Data was gridded at 1m resolution.

Pre-established standardized profile transects were analyzed to correspond to profiles generated with sidescan sonar data and to compare the gridded multibeam bathymetric data from each year.

Assessment of vertical and horizontal accuracy. Vertical and horizontal accuracy of the technique was assessed by analysis of "static" hard bottom relief (concrete armored section of pipeline) at Site 8 across years. The site profile was characterized by a pronounced berm in the center, 1.5m high. The peaks between the years lined up perfectly on a horizontal plane, and were 0.185m different vertically. This suggests that changes (at least) in excess of 0.185m should be considered significant. At sites with very rough seafloors, measurements may be less accurate due to both acoustic reflection errors and error introduced by gridding.

Tide correction. The pipeline runs across Massachusetts Bay and into two estuarine harbors at each pipeline terminus. The tide station used for corrections was Boston Harbor (NOAA Station 8443970). Therefore, consistent or relatively minor (< 25cm) changes in the profiles are likely due to correction artifacts.

Salinity and refraction. Refraction errors due to rapid salinity changes were evident in some survey lines. Since the multibeam system generates the best data at the center beams, these errors were most apparent in the outer beams. Although refraction was accounted for in CARIS, some sites (e.g., 8, 9, 10, 11, and 16) do show the most significant changes between survey years at the edges of the profiles. Also, these changes are remarkably consistent across the sites. The eastern side of each site is consistently deeper in 2006, and the western side is consistently shallower in 2006. It is unlikely that these changes are real.

Position offset. There was a minor position offset between survey lines that were run during the morning of the survey in 2006.

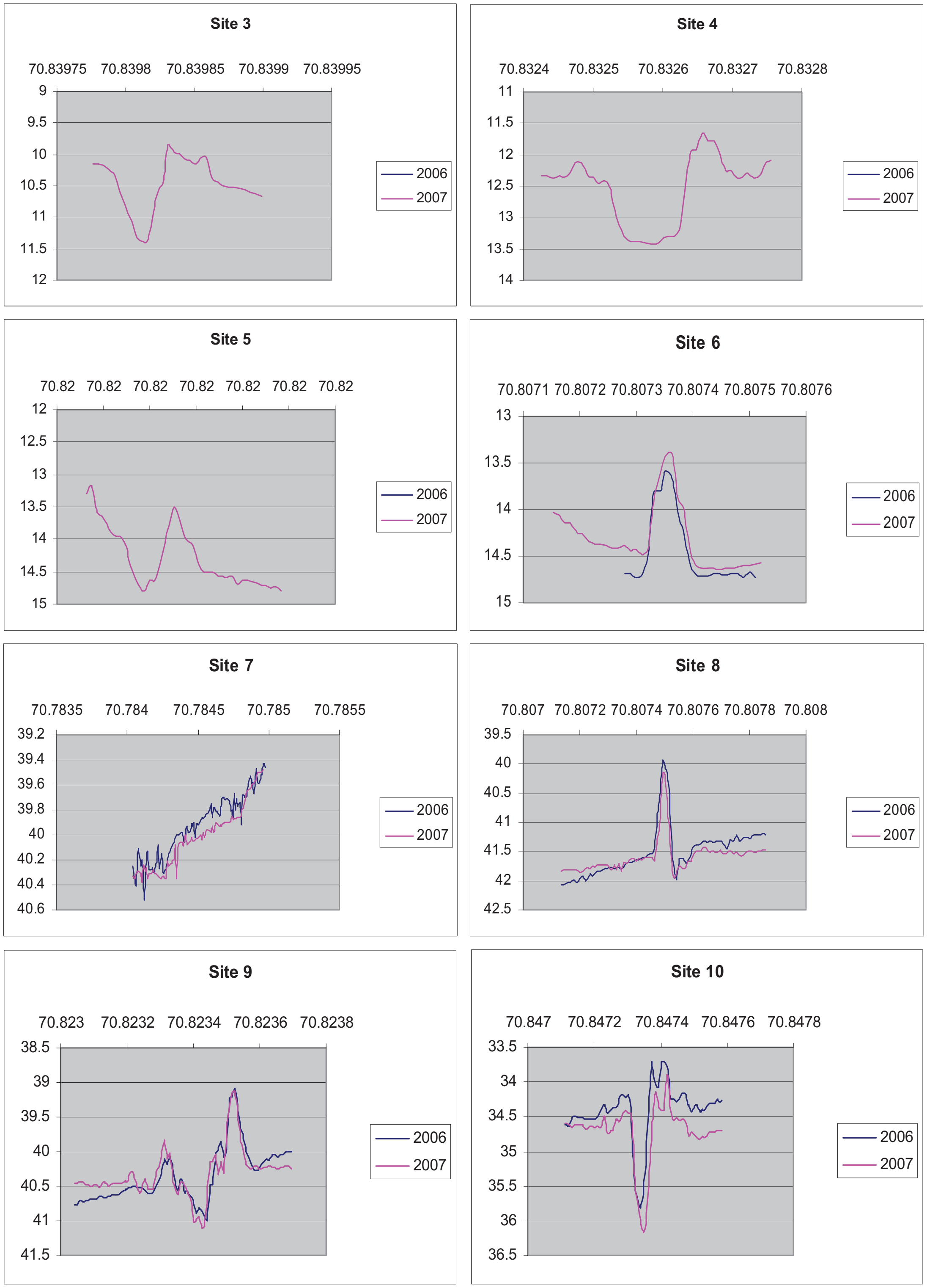


Figure IIIA2.4. Site relief profiles calculated with multibeam sonar imaging, 2006-2007.

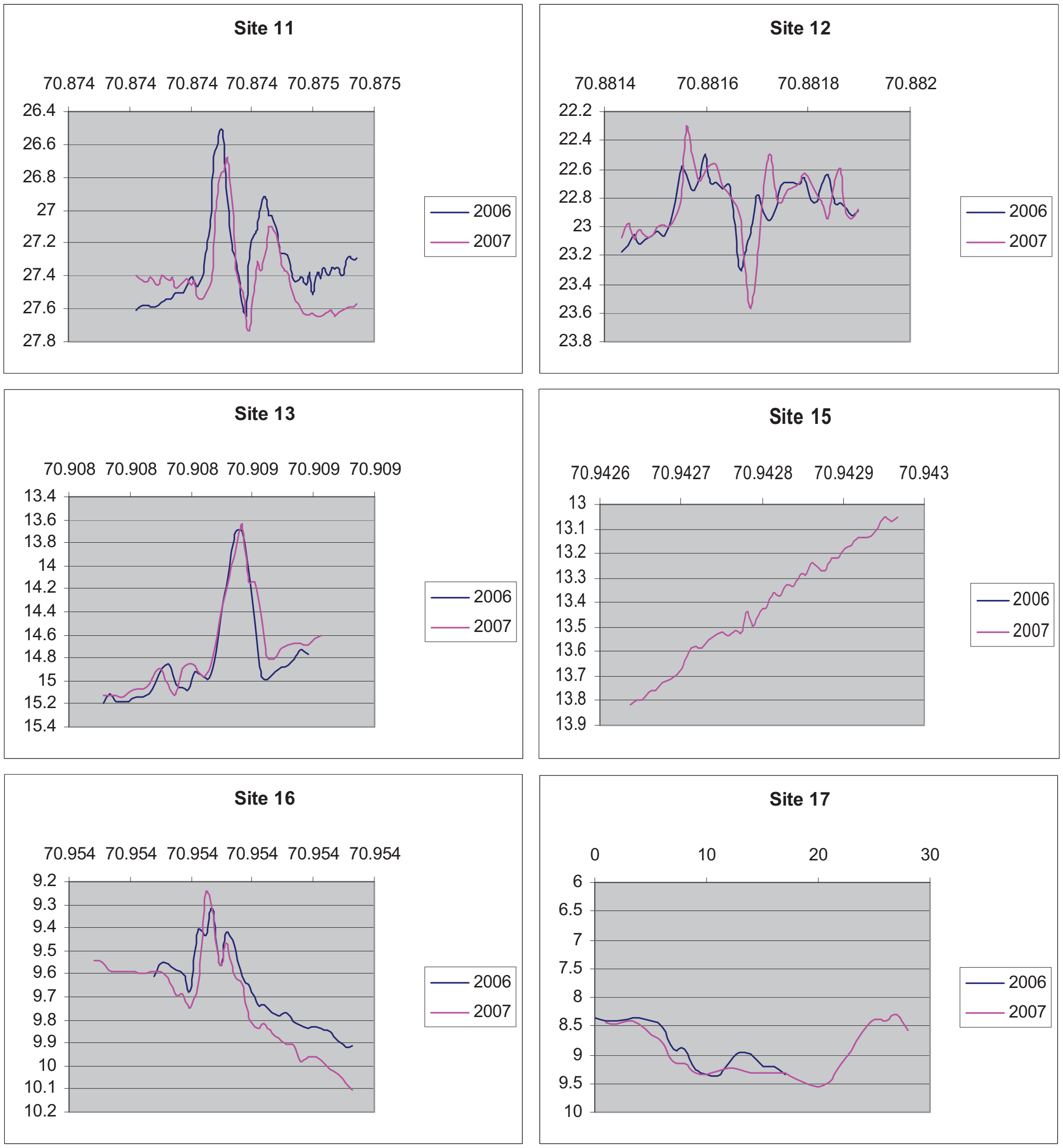


Figure IIIA2.4 (*Continued*). Site relief profiles calculated with multibeam sonar imaging, 2006-2007.

When degree and pattern of error was defined and evaluated, it was apparent that the majority of the differences between years could be explained by the vagaries of the acoustics including beam refraction, the gridding process, and environmental data adjustments during post-processing, e.g., for tide and salinity. Resulting analyses of multibeam data for changes >0.25m, indicated little difference in the profiles of all sites between 2006 and 2007 (Table IIIA2.2). Reliable quantification of finer changes beyond this was difficult with this method.

The multibeam survey method is potentially useful for examining relief changes between years, however, one must account for a number of pertinent variables. Frequent sound profiling is needed to improve comparative analyses and facilitate differentiation between data artifacts and real differences. Sites with "fixed" seafloor should be used to evaluate horizontal and vertical error across surveys.

Table IIIA2.2. Changes in site relief profiles measured with multibeam sonar.

Site	% of line changed >0.25m	Standard deviation of change
6	17.39	0.10
7	2.97	0.09
8	18.60	0.18
9	15.38	0.18
10	53.97	0.24
11	34.43	0.20
12	14.63	0.19
13	6.25	0.14
16	0.00	0.08
17	30.00	0.18

2.1.3. ROV Video Surveys

Video from ROV surveys of the 19 sites (4-136 ft depth range) was reviewed, described, and evaluated for evidence of re-vegetation and re-colonization. A comparison of 2004 with 2005 data depicted an algal growth and invertebrate and finfish presence/abundance which was related to bottom type and depth. Hard substrate facilitated attachment of algae, but the proliferation of algal growth was largely dependent upon shallow water depths to allow light penetration for photosynthesis. Most sites had already exhibited algal growth and the presence of various macro-invertebrate and finfish species when *MarineFisheries* surveys began in 2004. Clearly, mobile species had repopulated the area relatively quickly. Dernie *et al*. (2003) reported this response to sediment disturbance, but it is generally coupled with low species diversity. Lewis *et al*. (2002) found a similar response from the benthic invertebrate community to the impacts of pipeline construction. Biological monitoring of this Mitigation Program's artifical reef installation during 2006-2007 also provides supportive evidence for these observations (see Habitat Enhancement Project in Section IVB of this report). The lack of an available documented construction timeline complicated an evaluation of site changes since we did not know when specific construction activities occurred at each site during the 2002-2003 pipeline construction period.

Of 13 sites at depths <50 ft, all exhibited invertebrate and finfish species presence and algal growth, but only 7 of these sites showed any obvious changes between 2004 and 2005. Most of the changes were characterized by increases in algal growth, but one of them clearly showed increased invertebrate presence while one showed less growth in 2005 due to added fill. Of the 6 sites at >50 ft depth, all sites exhibited invertebrate and finfish presence, but minimal algal growth. Only one of these sites (68-84 ft) exhibited increased sponge and hydroid growth on cobble in 2005.

Between 2005 and 2006, 7 of the 13 sites at depths <50 ft exhibited changes primarily in algal, hydroid, bryozoan, and sponge growth and areal coverage. Three of 6 sites >50 ft in depth exhibited change between 2005 and 2006. The change in two sites (>100 ft) was primarily in invertebrate and finfish presence while the third site (56-67 ft) exhibited additional hydroid, and bryozoan coverage on cobble.

Comparison of the impacted areas with nearby natural bottom indicated that more algal, hydroid, and sponge growth was present compared to sites on the trench. Four years after construction, complete recovery had not yet occurred. A more detailed analysis of hard bottom succession in the vicinity of the back-filled trench was conducted as part of the Habitat Enhancement segment of this Program’s mitigation efforts and can be found in Section IVB of this completion report.

2.1.4. Summary of Acoustic and Optical Survey Results

Evaluation of sediment recovery was complicated by the presence of cobble fill at 12 of 15 sites for which sonar data were available. Sonar and video imaging indicated that 4 years after construction the disturbed sediment along the 29.4-mile path had not been restored to pre-construction quality as required in the construction permit. A considerable amount of relief persisted in the form of elongated spoil piles 1-2m in elevation. Residual excessive relief had been the subject of permit review meetings in 2004 with state and federal regulatory agencies and additional fill was subsequently added to some locations, but not to others based on a consideration for impacts to fauna which were already recolonizing.

Sites which received cobble fill could not be expected to exhibit ageing or reduction of elevation over time. However, it is conceivable that soft-bottom sediments which are disturbed by trenching and back-filling activities may be modified and/or leveled by currents and storm surge. Nevertheless, areas with comparatively low current velocity or deeper water sediments which are less affected by strong winds, may not recover naturally. Sites <70 ft in depth exhibited more ageing or smoothing of features over time than deeper sites which was likely due to a greater susceptibility to storm surge at shallower depths.

Sediments disturbed by trenching and trench back-filling along the pathway generally exceeded estimates provided during the pre-construction review process and approached 25m (75ft) width. This is important information relative to evaluation of the impact of future similar marine construction projects.

Overall, most of the back-filled trench, especially areas with cobble deposition or a cobble sand mix suggested early stages of flora and fauna colonization. The shallower sites appeared to have more attached growth (bryozoans and hydroids) than the deeper sites. Finfish and crustaceans, including lobsters, were observed infrequently.

Acknowledgements

Gratitude is extended to H. Arnold Carr, AUSS; Kathryn Ford, *MarineFisheries;* and Bill Campbell, Ocean Eye for their work in conducting acoustic and ROV video surveys, to *MarineFisheries* Conservation Engineering personnel Mark Szymanski and Mike Pol for video equipment configuration and sled operation, to Steve Voss for his assistance with GIS mapping, field work, and video post-processing, and to Katie Manfredi for ROV video analysis. Kate Lin Taylor, Catie O'Keefe, and Ross Kessler also assisted in field surveys and Steve Correia was helpful with graphics programming.

III B. Species Diversity Assessment

1.0 Soft Bottom Species Diversity

Surveys of benthic infauna along the HubLine pipeline pathway were conducted to assess species diversity and evaluate recovery of biotic communities in the sediments disturbed by construction.

Methods

In June 2007, replicate samples were collected by SCUBA with 6”diameter acrylic sediment core tubes from each of five paired sites (4 samples per site, 20 total) representing disturbed and adjacent natural "soft" bottom sediments along the pipeline (Figure IIIB1.1).

Sample naming reflects the numerical order in which the paired samples were collected and the location of each station. For example, at site # 1 (Figure IIIB1.1), the disturbed sediment replicates were named 1 HUB which indicates that this sample was taken along the impacted area of the HubLine pipeline route and 1 OFF is the paired sample to 1 HUB that was taken 50 m away in an area that was adjacent, but unlikely to have been impacted by pipeline construction.

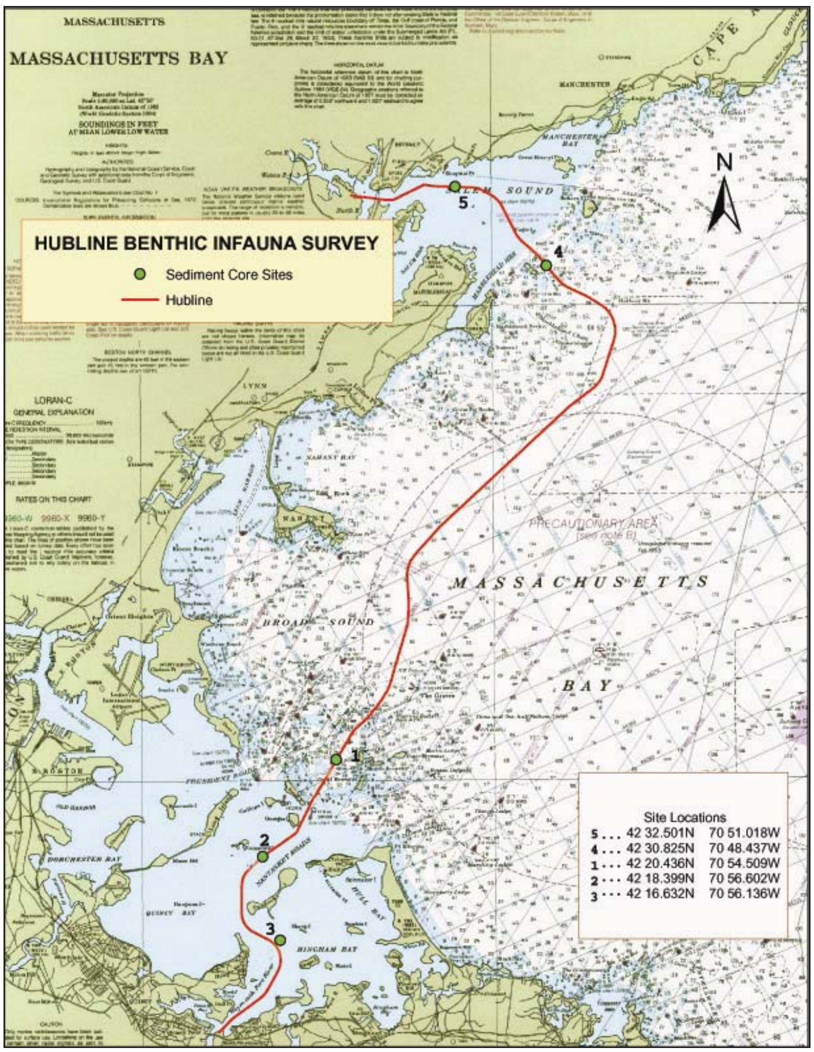


Figure IIIB1.1. Map of Massachusetts Bay with five soft-bottom sites used to evaluate species diversity of benthic infauna; sites are numbered in order of data collection.

Benthic samples were preliminarily sorted by *MarineFisheries.* They were stained with Rose Bengal to facilitate removal of small organisms from the sediment, viewed under a dissecting microscope, and each organism was removed and assigned to major taxonomic groups that included polychaete families, oligochaetes, bivalves, gastropods, amphipods, isopods, tanaidaceans, and miscellaneous taxa such as anemones, nemerteans, and tunicates. Specimens were then identified and enumerated. During the identification process, names of organisms and counts were recorded on specially designed data sheets. These data were later entered electronically into an Excel spreadsheet. ENSR Marine and Coastal Center, Woods Hole, was contracted to assist with identification of species and in the analysis of these data. The substance of that work is presented here. Benthic data was analyzed for community parameters including calculation of numbers of species and individuals per sample. A secondary tier of parameters was calculated to further assess community patterns and structure.

PRIMER 6.0 software package of statistical routines (Clarke and Gorley 2008) was used to calculate diversity indices, including Shannon's H′ (base 2), Pielou's evenness value J′, and Fisher's alpha (Clarke and Gorley, 2001) as well as Bray-Curtis similarity, and Principal Component Analysis (PCA). The Shannon index, which is based on information theory, has been popular with marine ecologists for many years, but this index assumes that individuals are randomly sampled from an infinitely large population and that all species are present in the sample (Pielou 1966, 1975; Magurran 1988). Neither assumption correctly describes the biological samples collected in most marine benthic programs. Fisher's log-series model of species abundance (Fisher *et al*. 1943) has been widely used, particularly by entomologists and botanists (Magurran 1988). Taylor's (1978) studies of the properties of this index found that it was the best index for discriminating among subtly different sites. Hubble (2001) considered Fisher's log-series alpha model as the fundamental biodiversity parameter and promoted the use of this index for studies of diversity in all environments. For the purpose of testing hypotheses, all three diversity indices were calculated. Multivariate measurements were also calculated to further elucidate benthic infaunal community patterns.

Results

The HubLine benthic samples were collected over a large geographic area including Salem Sound, Hingham Bay, and outer Boston Harbor (Figure IIIB1.1) and consequently represent a variety of habitats. While grain size samples were not taken in association with the infaunal samples, inferences regarding sediment texture were made with an understanding of species habitat preferences. The most comprehensive marine soft-bottom sampling program within the United States exists as a component of the long-term Massachusetts Water Resources Authority (MWRA) Harbor Outfall Monitoring Program. The HubLine benthic infaunal dataset can be directly compared to the MWRA dataset because several of the HubLine Stations were sampled from areas that have been historically assessed as part of the MWRA Program. HubLine benthic infaunal results from Stations 1, 2, and 3 can be directly compared with the MRWA Boston Harbor dataset while HubLine Station 4 can be compared to the MWRA Farfield Station dataset. HubLine Station 5 is within an area not sampled by the MWRA Programs; however, this station is located within an anthropogenically impacted Harbor similar to those sampled as part of the Boston Harbor MWRA monitoring program.

Species Richness

A total of 95 species were identified from the 5 replicated, paired HubLine samples (Appendix IIIB1.A). Number of species per sample ranged from 12 species at 4 HUB to 45 species at 2 OFF (Table IIIB1.1). In general, the paired stations were more similar to each other when the five replicated OFF stations were compared to the five replicated HUB stations. For example, 2 HUB had 41 species and 2 OFF had 45 species. The exception to this trend and the only station that showed a significant difference when the number of species at the HUB station was compared to the paired OFF station was Station 1. The number of species identified at 1 HUB (n=32) was significantly greater than 1 OFF (n=18) (X^2=3.84, p=0.05, df=1). Number of individuals ranged between 58 at 1 OFF and 180 at 2 OFF. Species richness is much higher for the MWRA Program with the number of species approaching 250, however, it is important to note that MWRA has been sampling for nearly 20 years and, thus, has a much larger database. In addition, MWRA's samples are taken with a 0.10 m^2 modified Ted Young Van Veen grab that samples a greater area, affording a statistically better chance to obtain more species as compared to 6" cores used in the HubLine Program.

Diversity and Evenness

The Shannon diversity (H′) was highest at Station 2 HUB (4.36) and lowest at Station 5 OFF (1.43). The remaining stations had H′ diversity ranging between 4.16 to 3.05. Diversity (H) tended to be higher and more similar along the HUB stations when compared to the paired OFF stations with subtle differences. For example, Station 2 OFF had a nearly identical Shannon-Weiner diversity index to 3 HUB (3.78 and 3.73, respectively) while 2 HUB had an H′ diversity of 4.35 and 3 OFF had a diversity of 3.35. Stations 5 HUB and 5 OFF had a similar number of species (21 and 20, respectively), however, 5 OFF had an exceptionally low diversity with a value of 1.43. Station 5 HUB had diversity which was more similar to the other stations with a value of 3.09. Overall, H′ values were similar to diversity measurements from Farfield and Boston Harbor benthic infaunal stations sampled as part of the MWRA Program with a Farfield mean baseline H′ of 3.74 (1992-2006) (Maciolek *et al.* 2007).

Pielou's evenness (J′) was generally higher at HUB stations when compared to OFF stations except for Station 4 where 4 HUB and 4 OFF had nearly identical evenness (0.852685 and 0.852841, respectively). All stations are above the MWRA Threshold set for evenness that ranges between 0.56 to 0.68 for the Farfield benthic community, except for Station 5 OFF that had very low evenness (0.33) as a consequence of low abundance and species richness.

Mean log-series *alpha* ranged from 56.40 at Station 4 OFF to 5.82 at Station 5. Station 4 HUB and 4 OFF had 12 and 16 species, respectively. These two stations had nearly identical evenness and had an H′ diversity that differed by only 0.36. However, the log-series *alpha* measurement for these two stations was 7 times higher at 4 OFF when compared to 4 HUB. Station 4 OFF had many more "singleton" species identified, which accounted for the high log-series alpha calculation. The baseline mean for log-series *alpha* for the MWRA Farfield stations (1992-2006), which includes stations within Massachusetts Bay, off Gloucester Harbor, and Cape Cod Bay, is 13.4 (Maciolek *et al.* 2007). The HubLine Stations 1 HUB, 2 HUB, 2 OFF and 4 OFF were the only 4 stations above the MWRA Farfield baseline mean for log-series alpha, however, all stations sampled as part of the HubLine program had a log-series alpha value that was above the MWRA Boston Harbor mean value of 8.5 except Station 5 OFF.

Table IIIB1.1. Diversity measurements for HubLine Infaunal Samples

	Number of Species	No. Individuals	J' (Evenness)	Log Series alpha Fisher	Shannon Weiner H'
1 HUB	32	60.5	0.833528	27.52809	4.167642
1 OFF	18	58	0.769203	8.941261	3.207518
2 HUB	41	160.5	0.812888	17.78861	4.35509
2 OFF	45	180	0.689559	19.25823	3.786958
3 HUB	27	128	0.786328	10.4489	3.738901
3 OFF	30	131	0.684242	12.17015	3.357501
4 HUB	12	27.5	0.852685	8.111446	3.056845
4 OFF	16	18.5	0.852841	56.40494	3.411364
5 HUB	21	62	0.704584	11.17522	3.094757
5 OFF	20	174.5	0.332743	5.827067	1.438093

Dominant Species

Up to the top 10 dominant species at each station are listed within Appendix IIIB1.B, along with the percent contribution of each to the total community. Differences of dominant species by station were likely a consequence of sediment texture and resulted in paired HUB/OFF stations having more similarity to each other than when the HUB stations or OFF stations were compared as separate groups.

- 1 HUB and 1 OFF had 60 and 58 individuals, respectively and shared 4 of the 6 species that comprised the only 9 dominants available at these two stations. Polychaetes dominanted these two stations. *Lumbrineris tenuis*, *Nephyts cornuta*, *Aricidia cathrinae*, and *Prionospio steenstrupi* were numerically dominant among the two stations. 1 HUB had a greater number of *Leptochirus pinguis* (amphipods) when compared to 1 OFF but the number of individuals of this species were relatively small (8 and 1.5, respectively).

- 2 HUB and 2 OFF had two species of amphipods (*Leptochirus pinguis* and *Ampelisca vadorum*) within the top 10 dominants suggesting these stations were both occupied by tube mats. Polychaetes also were among the top dominants and included the same polychaete dominants as found at Station 1 HUB and 1 OFF (*Lumbrineris tenuis*, *Nephyts cornuta*, *Aricidia cathrinae*, and *Prionospio steenstrupi*). Station 2 had a greater Shannon-Weiner index when compared to both 1 HUB and 1 OFF, but the log-series alpha was greater for 1 HUB when compared to 2 HUB and 2 OFF and the communities that typically develop among amphipod tube mats may contribute to these differences.

- 3 HUB and 3 OFF have species that are commonly found in sandy habitats (e.g., *Exogene hebes* and *Clymenella torquata*, and *Telina agilis*) as well as three species of amphipods. While there are shared species of polychaetes at Station 3 when compared to the other stations, the overall community at Station 3 is different than the communities found at the other stations and is likely due to the fact that that sediment texture has a greater component of sand. Shannon-Weiner diversity was similar when Station 3 was compared to Station 2 but log-series alpha was slightly lower (both HUB and OFF). Station 2 and Station 3 likely had an amphipod tube mat component.

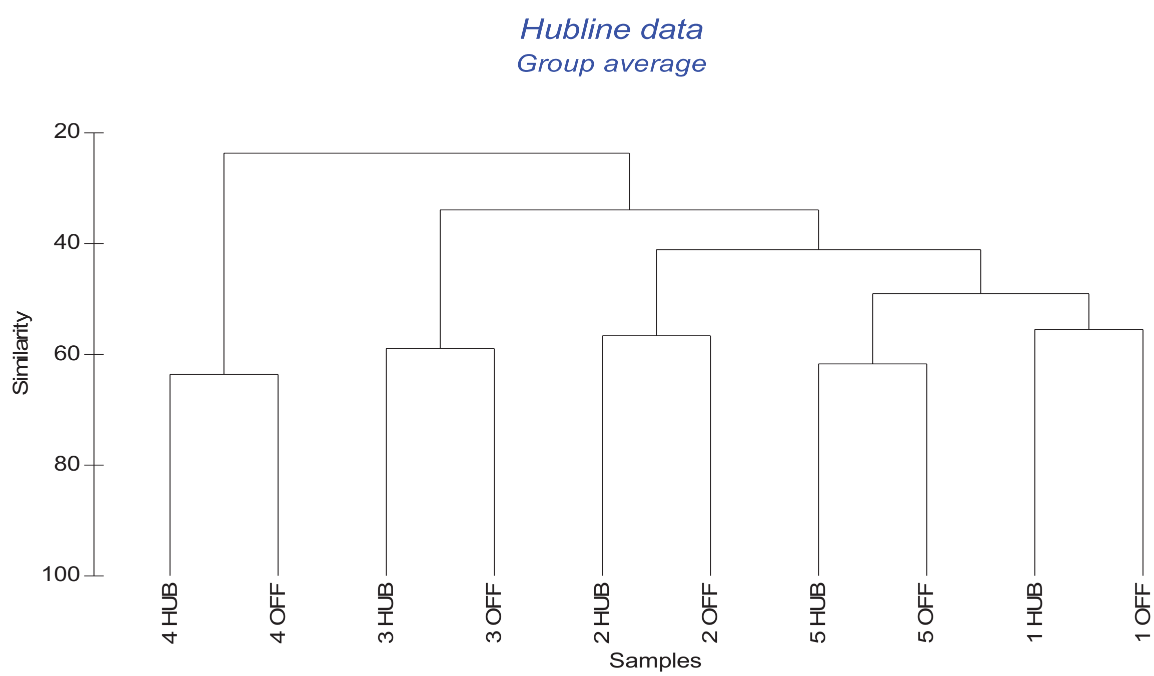
- 4 HUB and 4 OFF had very few species and individuals. While some polychaetes found within Station 4 samples (e.g., *Aricidia catherinae*) were consistently found among all stations including 4 HUB and 4 OFF, this station had *Echinarachnius parma* dominant at both Station 4 locations suggesting the sediment at this station was comprised of a coarse sand and influenced by dynamic wave action causing sand wave formation. Station 4 HUB and 4 OFF are more similar to each other than any other stations sampled on or off the HubLine route. *Exogene hebes* and *Cyclocardia boreallis* were also found at 4 HUB and indicate that the sediment is largely comprised of sand.

- 5 HUB and 5 OFF were comprised of species characteristic of muddy sediments although the number of species at both stations was low. Abundance of Nephtys cornuta, a predacious polychaete, at 5 OFF was extremely high with 141 individuals affecting both diversity measurements and evenness. There were polychaetes and amphipods present in low numbers at both Station 5 locations. Stations 5 OFF and 5 HUB were more similar to each other in species composition then to other stations, however, both Station 5 samples were more similar in species composition to both Station 1 samples than to Stations 2, 3, or 4 (likely due to the lack of sandy sediment texture).

Multivariate Analysis

Similarity Analysis--The Bray-Curtis analysis (Figure IIIB1.2) of these data (after a fourth-root transformation to decrease the influence of species with high abundances) resulted in a pattern where Stations grouped together (e.g., 1 HUB and 1 OFF were more similar to each other than any other station). Station 5 and Station 1 form a cluster with Station 2 and 3 forming a separate branch. Station 4 which was likely to have the greatest component of sand and most wave dynamic, based on species identified, formed its own cluster separate from Stations 1, 2, 3, and 5. Paired stations showed at least 60% similarity. Stations 1 and Stations 5 clustered together with approximately 45% similarity.

Figure IIIB1.2. HubLine Data Bray-Curtis Similarity



PCA-H analysis--The PCA-H analysis (based on the similarities) separated the cluster groups discussed above along several multidimensional axes, with axes 1, 2 and 3 collectively accounting for 55% of the total variation (Figures IIIB1.3A and IIIB1.3B). These three axes most likely represent a combined sediment grain size and regional depth gradient effect; however, these factors are not clearly assignable to any of the axes. Axis 1 may represent separation based on sediment type as this seems to be the factor driving similarity of stations in the Bray-Curtis analysis. Similar to the Bray-Curtis results, Stations 1 and 5 clustered together while Stations 2 and 3 clustered nearer to each other (this is clearer in Figure IIIB1.3B). The separation of Station 4 from the other stations is likely due to the relatively high abundance of *Echinarachnius parma* (sand dollar) and low species richness at this station. E*chinarachnius parma* comprised 20% of the total abundance of individuals at 4 HUB and 10% of individuals at 4 OFF.

Figure IIIB1.3A. Top-down view of 3-D Principal Component Analysis (PCA).

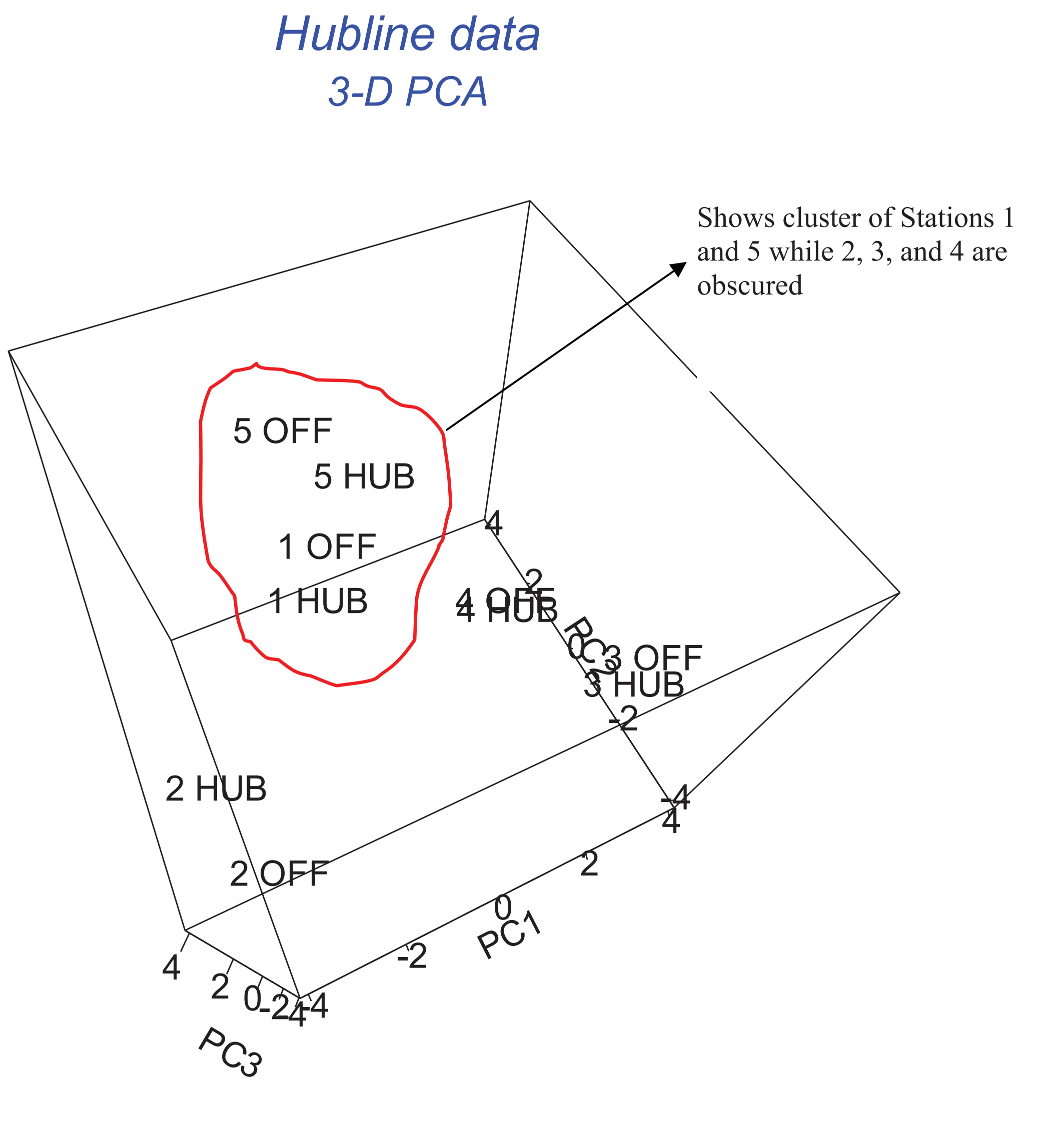
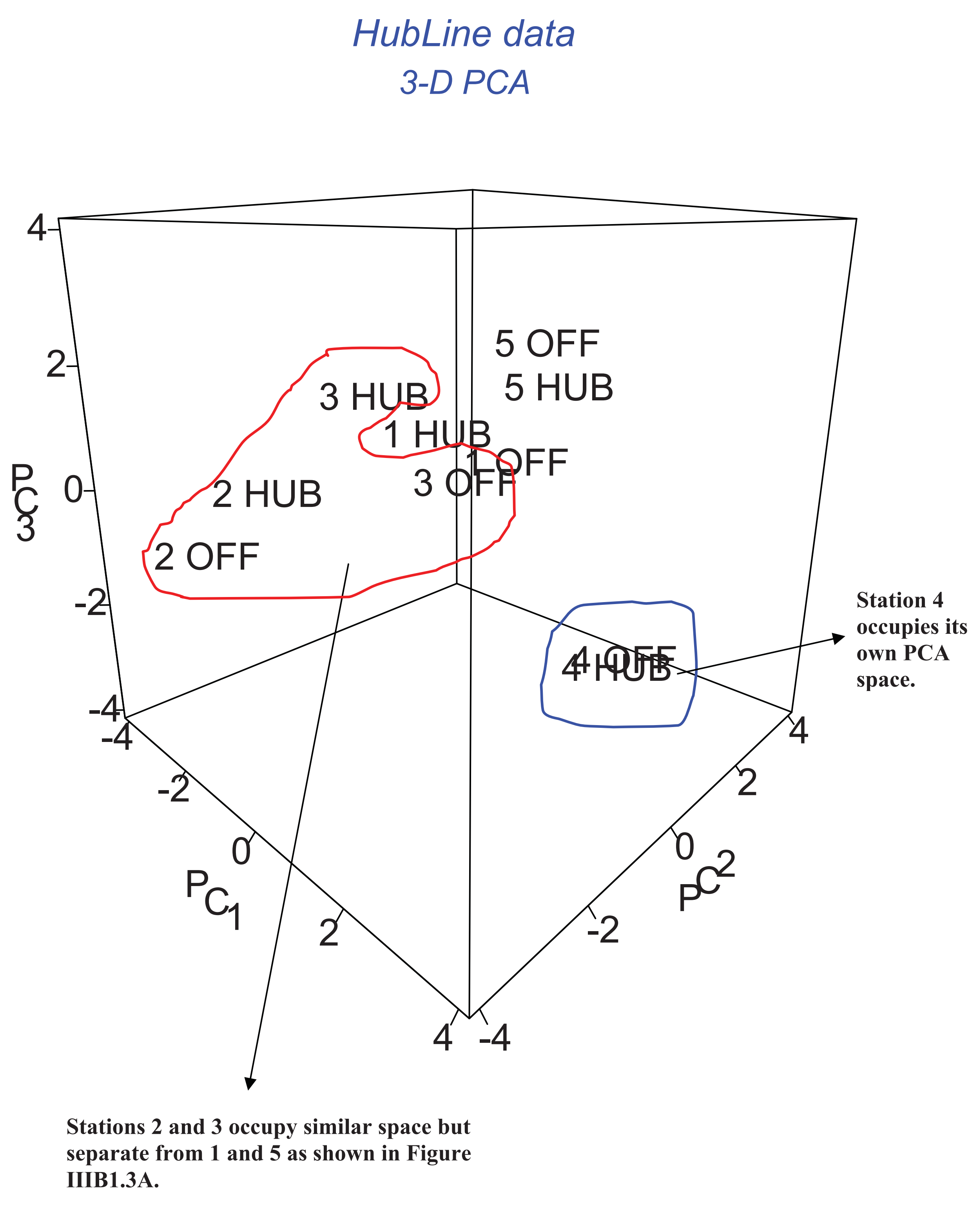


Figure IIIB1.3B. Side view of Figure IIIB1.3A showing 3-dimentional PCA results.



Conclusions

Overall, the benthic communities along the HubLine route appeared to be largely recovered since species diversity was similar to the ambient, control stations located outside the HubLine area of disturbance. This conclusion is based on the investigation of the benthic infaunal communities at 5 soft-bottom stations located along the HubLine pipeline construction route for evidence of impact from the construction process which occurred between 2002 and 2003. Replicate core samples were collected on and off the trench at each of the 5 stations in 2007.

Multivariate statistics allow for visualization of data similarities. Both the Bray-Curtis similarity and PCA show that the grouping of stations is related to the organisms identified from them in addition to a possible sediment grain size and regional depth gradient effect for these organisms. Station grouping is not related to pipeline trenching and/or back-filling effects.

Analyses suggest that biological samples taken on the HubLine trench (HUB) and adjacent to the HubLine trench (OFF) were more similar to each other (e.g., 1HUB to 1OFF) then when compared across stations. Pipeline trenching and trench back-filling may have originally impacted these benthic infaunal communities, but this 2007 survey indicates their species diversity and evenness values are within the mean baseline range of MWRA's Harbor Outfall Monitoring program.

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2.0 Hard Bottom Species Diversity

Between 2005 and 2007 species diversity surveys were conducted in conjunction with the *MarineFisheries* Habitat Enhancement Project's reef siting and biological monitoring efforts and were planned in order to enhance HubLine recovery assessment activities. SCUBA surveys of "hard" bottom sites on and off the HubLine's back-filled trench provided data for comparative analyses of fauna on this sediment type.

Pre-Reef Installation

A preliminary comparative analysis of biota at several "hard" bottom sites was conducted from survey data collected prior to the reef construction in 2005. Suction sampling was used to gather quantitative data on species abundance and diversity from a site impacted by pipeline construction (HubLine fill point) and two control sites at natural reefs (Marblehead Natural and Boston Natural; Figure IIIB.2). The suction sampling device consisted of a PVC lift tube supplied with air from a SCUBA tank. Samples were air-lifted into a mesh nylon bag attached to the upper end of the suction tube. At each site, ½ m^2 quadrats were haphazardly placed on the substratum at least 2 m apart until a total of 12 replicates were completed at each site.

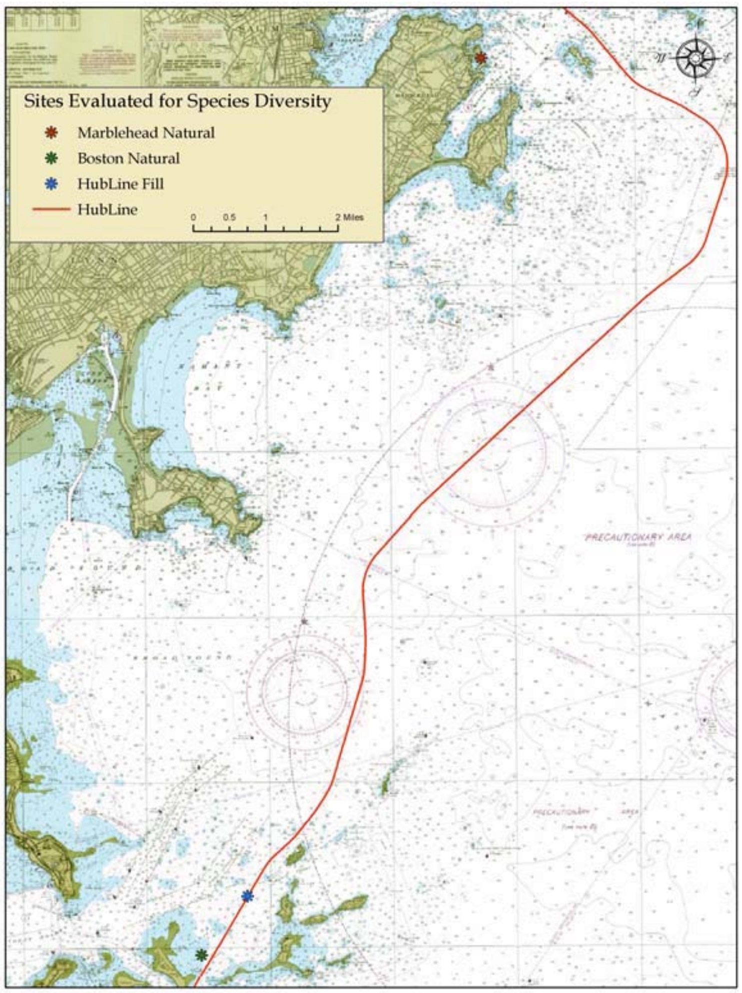

Figure IIIB.2. Map of Massachusetts Bay with three site locations used to evaluate species diversity.

Species densities, calculated per m^2, indicated that larval crustacean settlement was highest on the natural reefs and lowest on the HubLine site (Table IIIB.1), but postlarval lobsters were present at all three sites. The HubLine site had the lowest density of all size lobsters. Three benthic finfish species, the radiated shanny, cunner, and rock gunnel, showed no definitive trends across sites (Table IIIB.2).

A comparison of species abundance and diversity by site is depicted in Figure IIIB.3. The two natural reefs had higher species diversity and lower abundance than the disturbed site. The HubLine site had the highest abundance, but its species diversity was extremely low, consisting primarily of small whelks and crustacean larvae. This high abundance and low diversity is characteristic of disturbed sediment (Dernie *et al*. 2003; Lewis *et al*. 2002).

Three species diversity indices were calculated on the suction sampling data in order to compare natural cobble sites to the HubLine site. All three analyses (Shannon-Weiner, Simpson, and JackKnife) demonstrated that the natural reef sites had the higher measure of species richness than the disturbed sediment on the HubLine site (Table IIIB.3).

Table IIIB.1. Mean density in number per m^2 of suction-sampled crustaceans, 2005.

	Marblehead Natural	Boston Natural	HubLine Fill
Mean YOY Lobster Density*	1.17	1.33	0.83
Standard Error	0.46	0.38	0.30
Mean Density of all Lobsters*	5.33	3.00	1.67
Standard Error	0.71	0.67	0.48
Mean Density of All Crustaceans*	52.33	41.83	25.50
Standard Error	4.52	6.58	3.61

* n = 12 quadrats per site

Table IIIB.2. Mean density in number per m^2 of suction-sampled finfish, 2005*.

	Radiated Shanny	Cunner	Rock Gunnel	Total Standard Error
Marblehead Natural	0.42	0.08	0.08	0.26
Boston Natural	0.17	0.08	0.33	0.19
Hubline Fill	0.58	0.17	0	0.23

* n = 12 quadrats per site

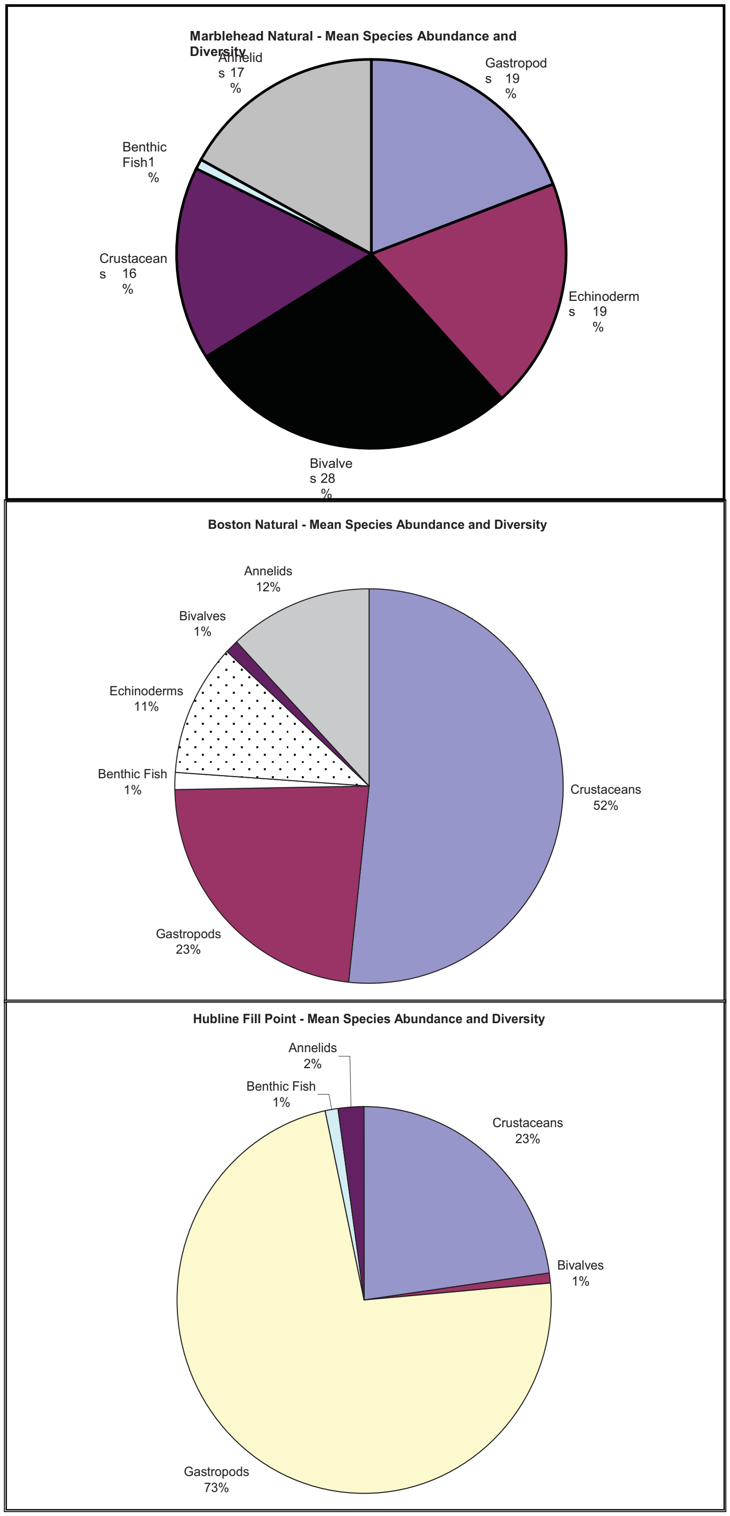

Figure IIIB.3. Mean species abundance from suction sampling (percentages calculated from number of individuals per 1/2 m^2 quadrat) and species diversity for three cobble "reef" sites, 2005.

Table IIIB.3. Results of species diversity analyses by site from2005 suction sampling data. Lower values indicate lower diversity.

	Marblehead Natural	Boston Natural	HubLine (Back-filled Site)
Species count	26	21	12
Individual count	677	496	818
Shannon-Wiener Diversity Index			
N statistic	9.21	7.30	2.57
H statistic (Ln of N)	2.22	1.99	0.94
Simpson	0.84	0.83	0.44
JackKnife	29.67	25.58	15.67
Upper CI	36.04	32.04	19.20
Lower CI	23.30	19.12	12.13

Post-Reef Installation

During 2006-2007 biological monitoring allowed comparative species diversity evaluations on the new artificial reef site, a natural reef, sand, and a disturbed site on the HubLine trench (cobble-filled area) (refer to Section IVB in this report for a comprehensive data treatment). These data are helpful in analyzing recovery of disturbed substrate.

Surveys of biota were conducted in three ways: 1) air-lift suction sampling (finfish, mollusks, and mobile invertebrates, except polychaetes), 2) transect (swath) surveys (mobile macroinvertebrates, solitary tunicates, bivalves, and fish) and 3) percent cover evaluations in quadrats (encrusting tunicates, sponges, barnacles, and macroalgae). Results of Shannon-Weiner diversity analyses were used to compare the natural reef site to the disturbed HubLine site and are reported in Table IIIB.4. In most cases, the species diversity on the natural reef was significantly different and still higher, with some seasonal variation, than that on the HubLine back-filled trench approximately 4 years after pipeline construction.

Table IIIB.4. Shannon-Weiner diversity index results from three survey data sets, 2006-2007.

	Natural Reef (H' statistic)	**HubLine** (Back-filled Site) (H' statistic)	**Natural vs. HubLine** Bonferroni-adjusted alpha = 0.008
Air-Lift Suction Data	1.80	1.58	t = 3.931, Sig. Different
			Bonferroni-adjusted alpha = 0.01
Transect Survey			
Spring	1.14	1.72	t = 9.22, Sig. Different
Summer	1.25	1.57	t = 4.60, Sig. Different
Fall	1.42	1.14	t = -2.08 ------
Winter	0.35	0.94	t = 6.08, Sig. Different
Percent Cover			
Spring	2.410	1.722	t = 3.72, Sig. Different
Summer	2.613	1.530	t = 5.67, Sig. Different
Fall	2.867	0.920	t = 9.31, Sig. Different
Winter	2.330	1.130	t = 9.72, Sig. Different

These results are not surprising since it takes years for encrusting organisms, sponges, algae, and other sessile invertebrate communities to develop and provide a balanced environment for predators and foraging species. Larger, mobile epibenthic macroinvertebrate and finfish species can repopulate an area relatively quickly which may explain the mixed transect survey results.

Acknowledgements
Gratitude is extended to H. Arnold Carr, AUSS and *MarineFisheries* staff Ross Kessler, Terry O'Neil, Neil Churchill, and Wesley Dukes for assistance with sediment core sampling and sample processing, sorting and identification. Pam Neubert, ENSR provided assistance with soft-sediment benthic infaunal identification, data analysis and interpretation. David Chosid, Kelly Whitmore, and Julie Barber, calculated hard bottom species diversity indices.

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III C. Enhanced Commercial Lobster Sea Sampling in Massachusetts Bay

Initial concerns about pipeline construction on the commercial lobster fishery in Massachusetts Bay focused our attention on enhancing existing commercial lobster sea sampling activities in the general Massachusetts Bay area and in the MA portion of the southern Gulf of Maine in calendar year 2003. Two additional contract Fisheries Technicians were hired to conduct this work and their efforts nearly doubled the usual number of commercial sea sampling trips in the area of concern during 2003.

This commercial sea sampling is a cooperative effort with commercial lobstermen and is conducted at least twice per month during May-November when over 90% of commercial lobster landings occur. Data are from a subset of the fleet and *MarineFisheries* has continued commercial lobster sea sampling in order to monitor trends in this important fishery.

The marketable catch in number of lobster per trap, standardized to 3 set-over-days (CTH'_3; Estrella and McKiernan 1989) was calculated by month (May-November) during 1999-2007 for the Massachusetts Bay areas of Beverly-Salem and Boston Harbor (Figure IIIC.1). Annual CTH'3 for the two areas are displayed in Figure IIIC.2. The data depict a general downward trend from 1999-2007, however this is consistent with a broader-based downward trend elsewhere in the Gulf of Maine. These data need to be interpreted cautiously since they comprise catch rates of legal-sized lobsters which were hatched and settled out as post-larvae 6-8 years earlier. Trends in these data are a reflection of not only survival during the pelagic larval period and settlement success, but natural mortality during their sub-legal term and fishing mortality upon reaching minimum legal size.

Figure IIIC.1. May-November CTH'3 by year (1999-2007) for American lobster from from the Beverly-Salem and Boston Harbor areas of Massachusetts Bay.

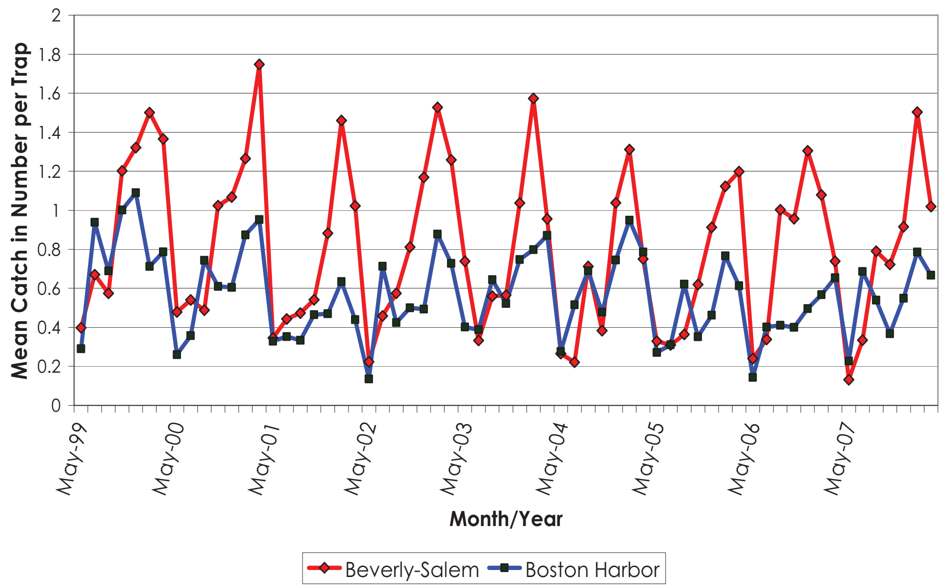
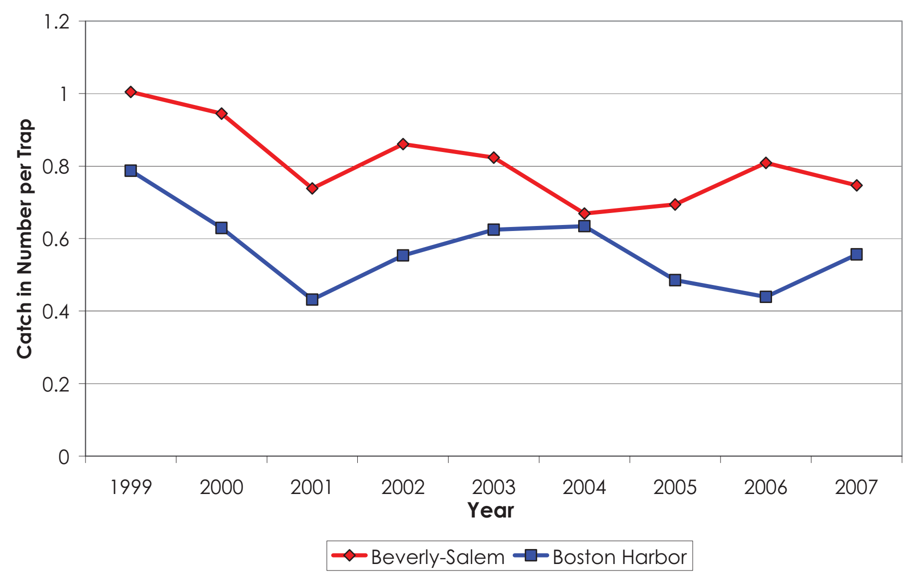


Figure IIIC.2. CTH'3 by year for American lobster from the Beverly-Salem and Boston Harbor areas of Massachusetts Bay, 1999-2007.



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III D. Suction Sampling of Early Benthic Phase Lobsters

The partially HubLine-funded *MarineFisheries* suction sampling of early benthic phase (EBP) lobsters in the Massachusetts Bay area was used to help evaluate potential HubLine impacts on larval lobster settlement relative to previous years (Figure IIID.1). Sampling was conducted using a diver-operated suction device. Sampling design and equipment was standardized according to the strategy defined by Wahle (1993). The suction device consisted of a 3" PVC lift tube supplied with air from a SCUBA tank. Samples were air-lifted into a 1.5 mm mesh nylon bag attached to the upper end of the suction tube. At each site, 0.5 m^2 quadrats were haphazardly placed on the substratum at least 2 m apart. Large boulders and large patches of sand were avoided. Sampling a quadrat in cobble habitat involved slowly moving the lift tube over the bottom while carefully moving rocks individually (Figure IIID.2). Rocks were removed until no interstitial spaces remained.

Experimental EBP sampling by diver-operated suction equipment in MA coastal waters began in 1995. Due to the short length of the time series, indices have yet to be related directly to commercial catch rates or landings. The effects of natural mortality occurring between settlement and recruitment to commercial size are unclear, making it difficult to interpret trends and their effect on the fishery.

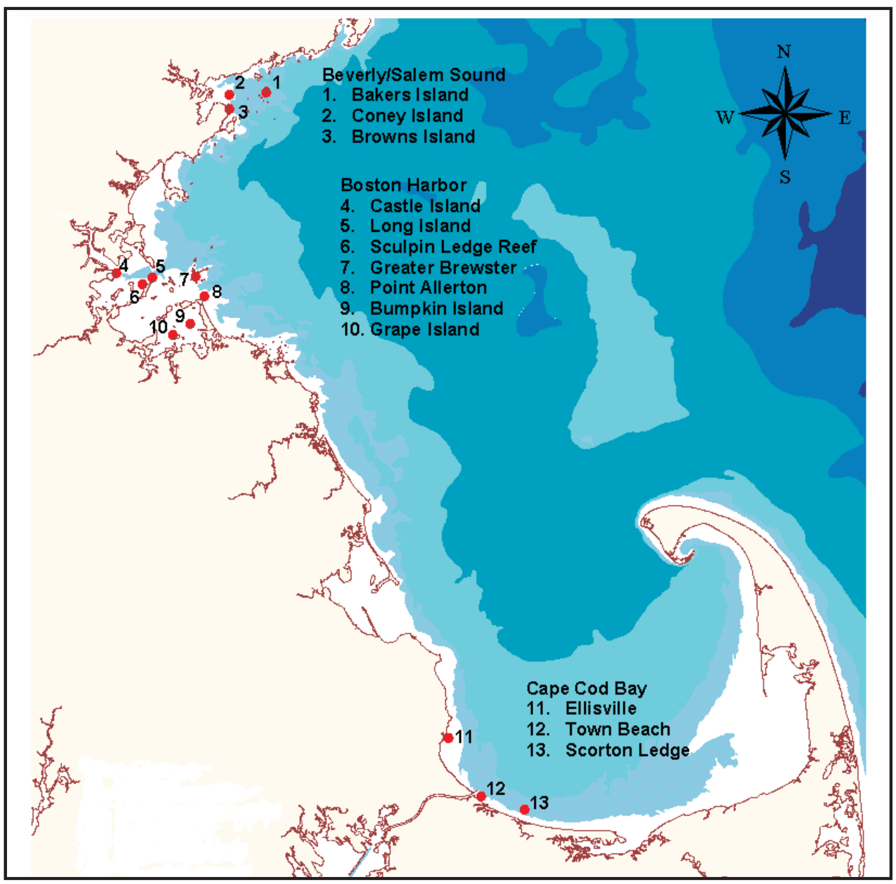
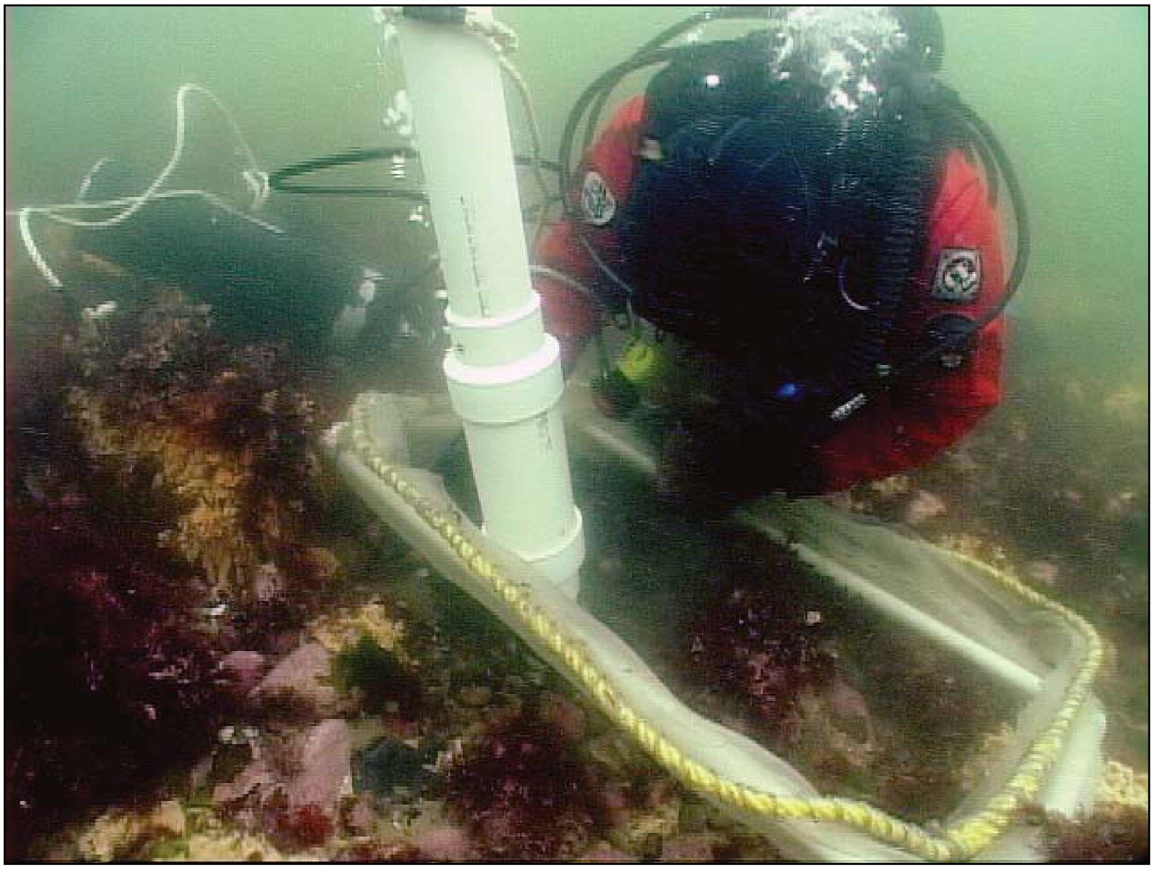


Figure IIID.1. Suction sampling sites occupied in Massachusetts coastal waters north of Cape Cod, 2006.

Figure IIID.2. View of typical SCUBA suctioning operation within a 1/2 m^2 quadrat.



The densities of young-of-the-year (YOY) lobsters (<14mm CL) from regions in the vicinity of the HubLine construction, i.e., Salem Sound, Boston Harbor, and Cape Cod Bay, are depicted in Figure IIID.3. These are post-larval lobsters which had recently settled out of the pelagic stage to the bottom-dwelling stage. The densities of early benthic phase lobsters (0-25mm CL) are presented in Figure IIID.4. This group includes YOY sizes through 25 mm CL at which juveniles tends to become mobile and seek alternative shelter.

Generally, catch densities increased through about 2004-2005 then declined thereafter to 2002-2003 levels. However, interpretation of both sets of these data should be done cautiously since they are characterized by high variances. Consequently, these time series show no obvious correlation with the 2002-2003 HubLine construction period.

Figure IIID.3. Densities of YOY Lobsters (0-14mmCL) in the MA portion of the Gulf of Maine, 1995-2007.

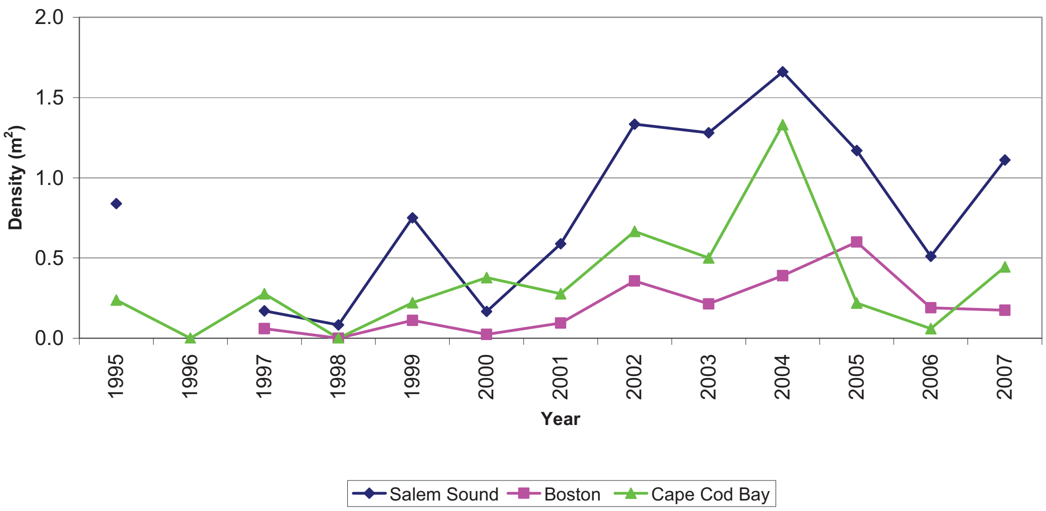
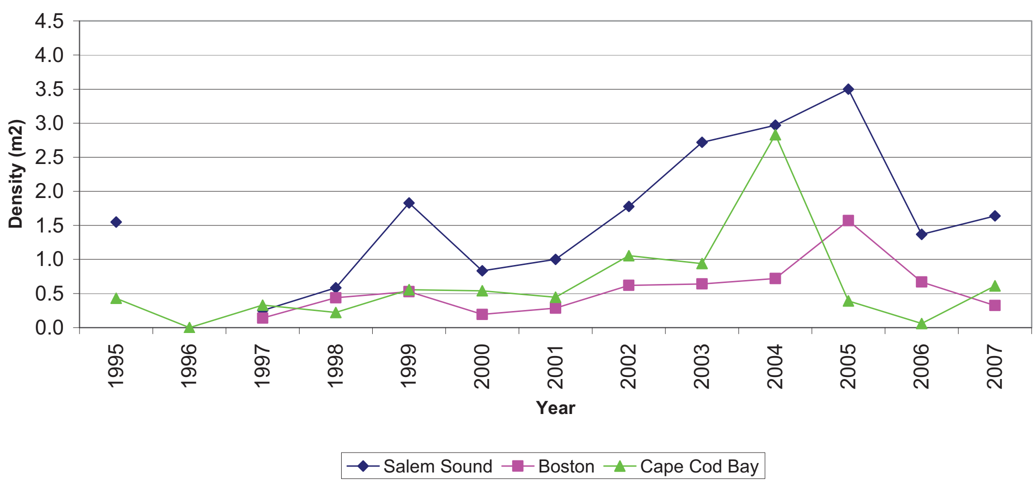


Figure IIID.4. Densities of EBP Lobsters (0-25mm CL) in the MA portion of the Gulf of Maine, 1995-2007.



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III E. Ventless Lobster Trap Survey

Staff: Robert Glenn, Tracy Pugh, Coordinators
Steve Voss, Fisheries Supervisor
Steve Wilcox, Fisheries Supervisor

Completion Report – Robert Glenn and Tracy Pugh

Introduction

In the fall of 2004 *MarineFisheries* initiated a pilot ventless lobster trap survey in Massachusetts Bay with funding from the HubLine Mitigation Fund. This survey was designed to monitor lobster (*Homarus americanus*) relative abundance and size distribution over a variety of habitats and depths in Massachusetts Bay. Sediment and depth were used as the survey strata, since these two variables are known to influence the spatial distribution of lobsters at any given time of year (Aiken and Waddy 1986, Thomas 1968, Cooper 1970, Cobb 1971, Cooper *et al* 1975, Hudon 1987, Able *et al* 1988, Wahle and Steneck 1991).

The survey had three main goals:

- Characterize size distribution and relative abundance of American lobster in Massachusetts Bay.
- Document the relative importance of substrate type and depth as it pertains to American lobster abundance and distribution.
- Develop a pilot project for a coastwide fishery-independent monitoring program for American lobster.

The initial pilot effort consisted of forty randomly selected sampling stations distributed proportionately among fifteen strata (four fully-defined sediment strata, one "mixed" sediment strata, and three depth strata). Each ventless trap trawl was hauled twice in October and November of 2004 respectively. This pilot effort allowed us to make inferences about the CPUE and size-distribution of American lobsters by sediment type and depth range.

Based on what we learned during the 2004 pilot season, the survey methodology was adjusted (see Methods) and the survey was expanded to eighty stations. Traps at these stations were hauled twice per month for seven months (May through November) in 2005 and 2006. Funding for the expanded survey was provided by the Northeast Consortium. In addition to the ventless trap survey work in 2006, *MarineFisheries* initiated a bottom sediment verification survey with the intent of verifying the accuracy of the original sediment data layer we used to stratify our survey. The sediment data layer used in the stratification process was generated from a report (Knebel 1993) that combined existing sonar records from a number of different projects to produce maps of the sedimentary environments for Boston Harbor and Massachusetts Bay. In some instances, and to varying degrees, these records were verified using photographs and/or bottom grab samples. In other instances there are no records of visual verification of sediment types. The areal arrangement and concentration of the side scan sonar transects also varied according to the purposes of the original projects, thus the data used to create the overall sediment map were spatially variable. Three general sediment types were described using a geologic classification; erosional/non-depositional, depositional, and sediment reworking (which could have features in common with both erosional and depositional environments).

In order to accurately describe the sediment on which the ventless trap survey was conducted, we needed to visually confirm the type of sediment present at each sampling location. This verification allowed us to correct inaccuracies in the sediment classification data layer and permitted examination of lobster distribution and relative abundance in relation to habitat type with a great degree of confidence that the traps were indeed fished on a particular bottom type. This work also gave us an opportunity to verify that the geologic description used by USGS coincided with a meaningful biological description of habitat.

Out of the original forty stations that were sampled in October and November of 2004 with HubLine funding, twenty-six of these stations were also sampled in 2005 and 2006. Consequently, the data from these twenty-six stations sampled during October and November, 2004 to 2006, represent a three year time series over which we can compare relative abundance (CPUE) and size distribution by our depth strata and revised sediment strata. The data and synthesis presented here finalize the reporting requirements for the original 2004 pilot survey funded by the HubLine Mitigation Fund. This report supersedes any previous HubLine progress reports by incorporating corrected bottom sediment classification data into the survey stratification and subsequent analysis.

Only data from stations sampled in all three survey years are included in this report to allow comparisons among years. A detailed report of all data collected in 2005 and 2006 can be found at: http://www.northeastconsortium.org/ProjectView.pm?id=4862&on_update=RECORDSET_refresh_list

Methods

Study Area

The ventless trap survey was conducted in Massachusetts Bay, within the territorial waters of the Commonwealth of Massachusetts. The study area was bounded on the west side by the coastline of Massachusetts, from approximately the southwestern tip of Gloucester, MA to Scituate, MA in the south. The eastern-most boundary of the study area was approximately the 70° 43' West longitude line.

Survey Design

The habitat characteristics of depth and sediment type were the basis for the survey stratification scheme. Depths are generally not greater than 50 meters within the study portion of Massachusetts Bay. The three depth strata of interest were defined based on the range of depths in which lobsters are typically fished in inshore waters. They are: 0 - 15 m, 16 - 30 m, and > 30 m. A variety of bottom sediments are present within the study area, ranging from silty muds to boulders and ledge outcrops. Sediment types were classified into four primary categories in Massachusetts Bay (Knebel 1993), Erosional 1 (Boulder), Erosional 2 (Pebble), Depositional (Mud), and Sediment reworking (Sand/gravel).

A 15 second latitude/longitude grid was created over the study area using the ETGeoWizards extension for ArcGIS. This grid was intersected with the existing sediment (Figure IIIE.1) and bathymetry (Figure IIIE.2) datalayers to create a new shapefile in which each grid cell contained both sediment and bathymetry attributes. The resulting attributes table was exported to Excel, and columns were added for each category of sediment and depth (four sediment categories and three depth ranges). The percent cover which each of these categories occupied within a cell was calculated relative to the total area of the cell. The grid cell was then assigned a final sediment and depth category, based on which sediment category and which depth category comprised at least 75% of the cell's surface area. The final strata assigned to that grid cell was the combination of sediment and depth. The resulting table with calculations of percent cover and grid cell strata designation was joined to the existing attribute table of the 'grid with bathymetry and sediments' shapefile (Figure 3).

Employing the 75% designation effectively increased the number of fully defined cells. Grid cells defined as "mixed" were removed from the station selection, with the exception of one station that was placed adjacent to the HubLine Habitat Enhancement Project in Boston Harbor. Twelve strata were defined based on the four sediment types and three depth zones (Figure IIIE.3), however only eleven strata had sufficient cells to include in the sampling design. A total of seven permanent sampling stations (grid cells) were chosen randomly for each of the eleven strata (Table IIIE.1, Figure IIIE.3). Three additional stations located within Boston Harbor were added with the intention of monitoring lobster relative abundance in the vicinity of the recently constructed HubLine gas pipeline and on-going mitigation efforts. Thus there were a total of eighty sampling stations throughout the Massachusetts Bay area.

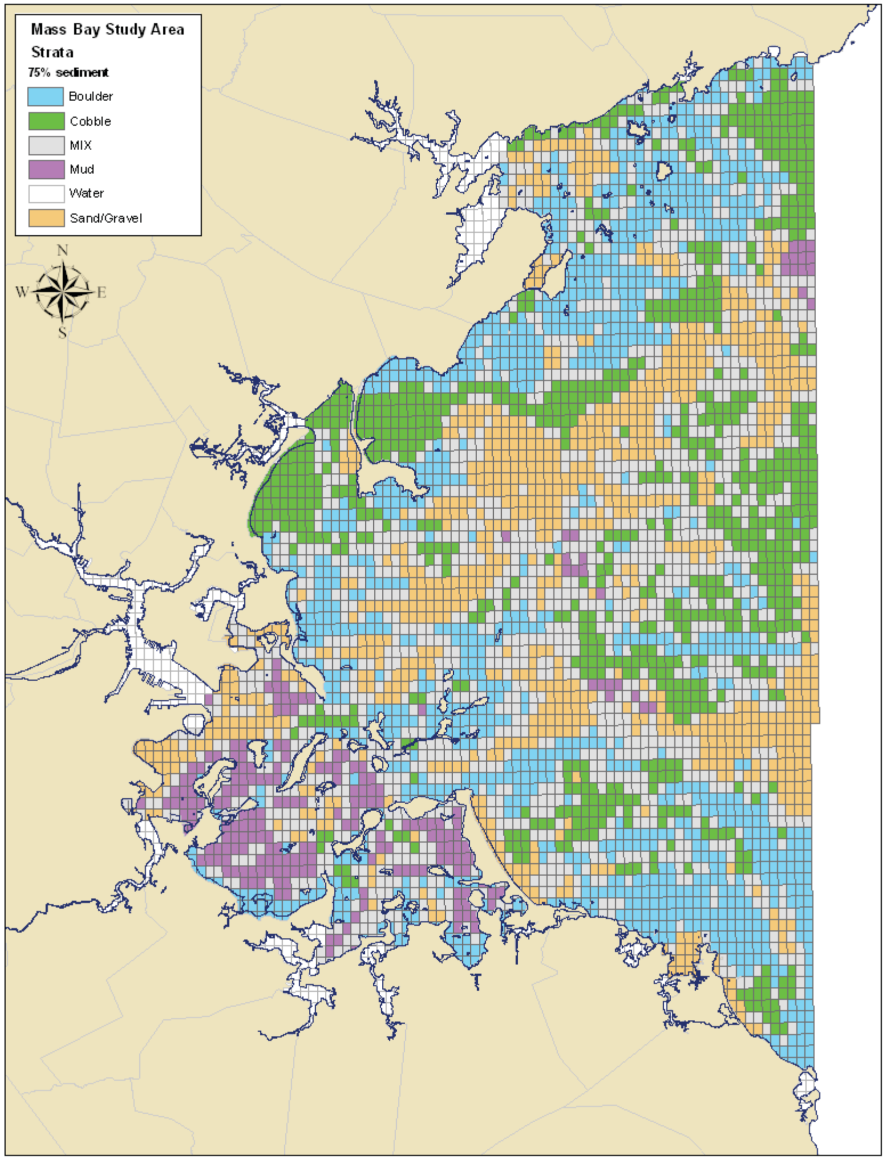

Figure IIIE.1. Four sediment types in Massachusetts Bay with 15 second latitude/longitude grid overlaid.

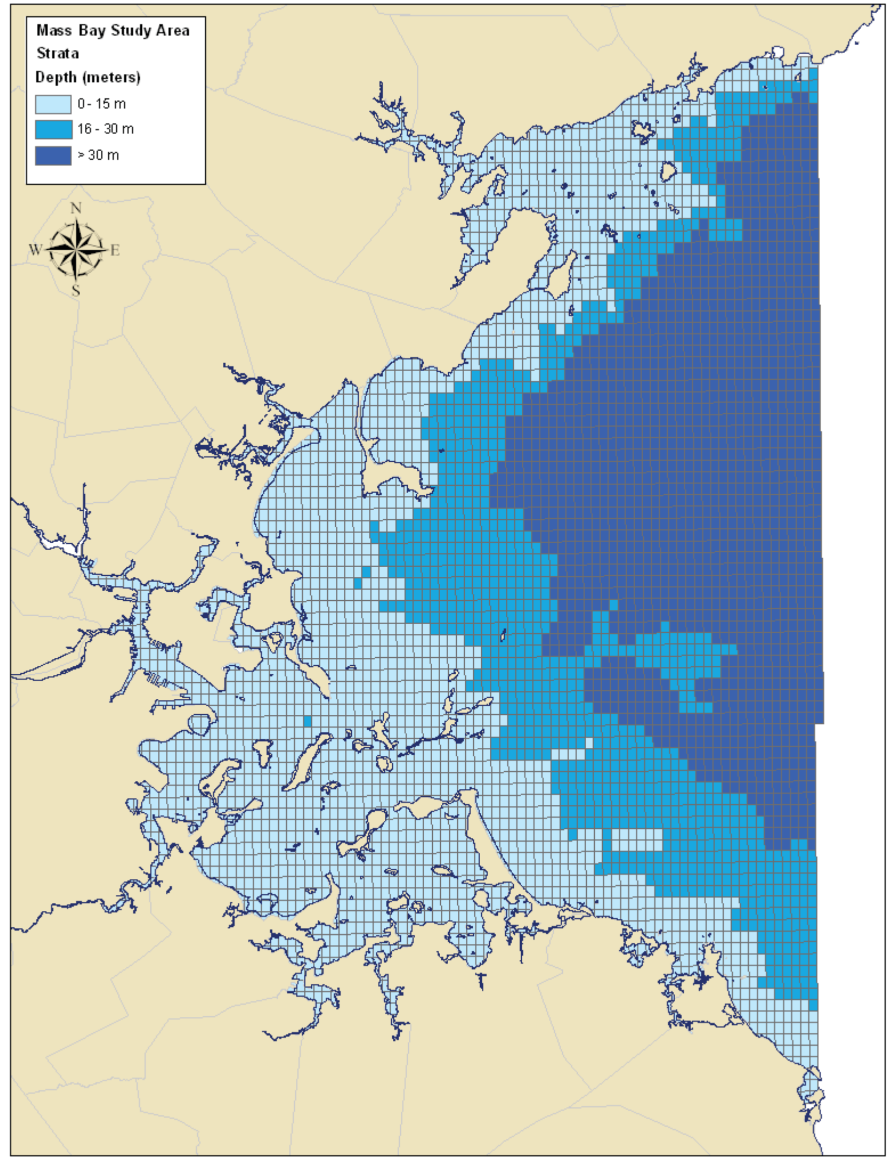

Figure IIIE.2. Three depth ranges in Massachusetts Bay with 15 second latitude/longitude grid overlaid.

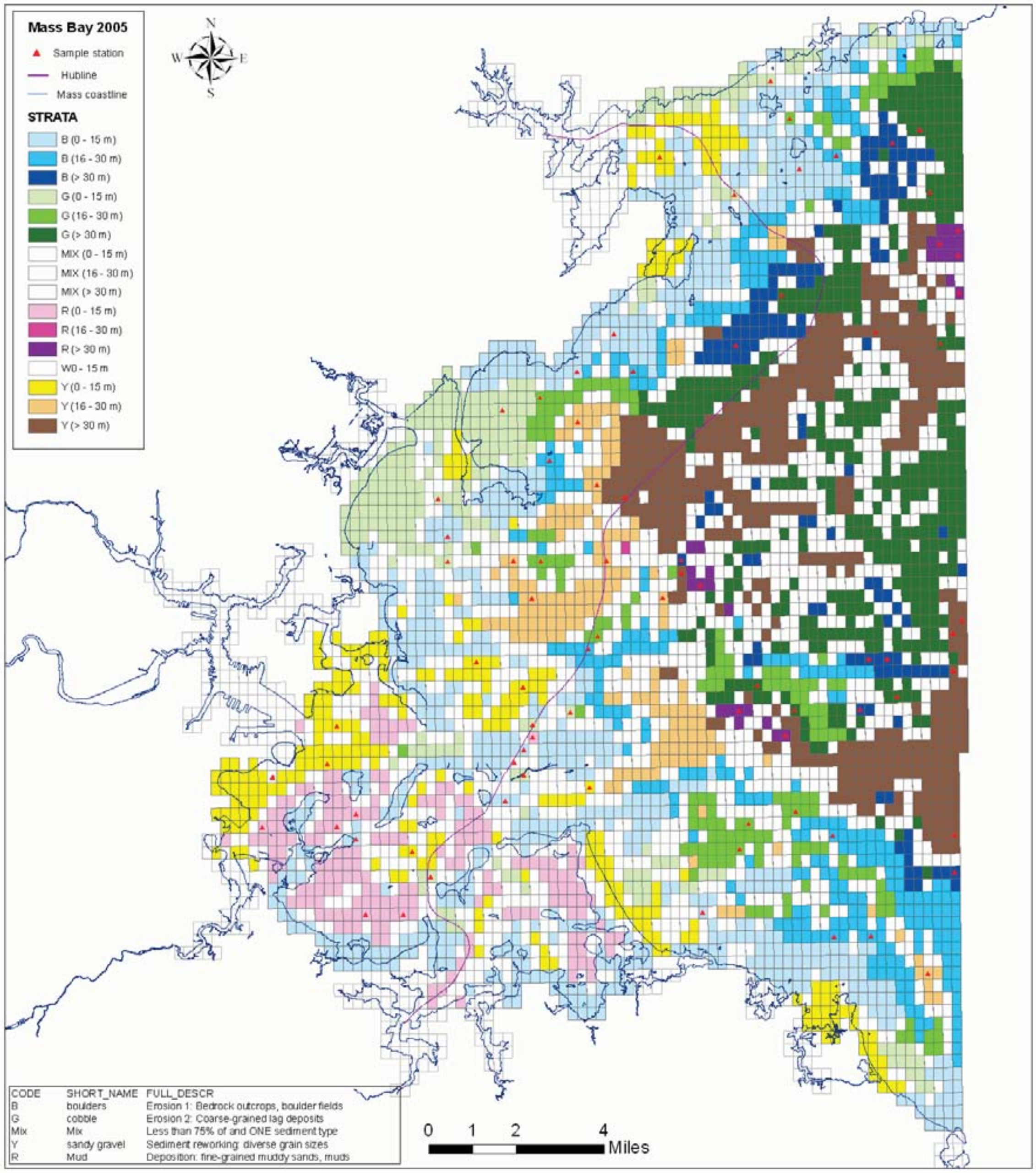

Figure IIIE.3. Massachusetts Bay study area with grid cells defined by sediment and depth. Sampling stations are shown as red triangles.

Table IIIE.1. Number of six-trap trawls cross-tabulated by survey strata. There were too few mid-water mud strata cells to include in the sampling design; one station was added in the "mixed" sediment 0 to 15 m strata.

	Boulder	Pebble	Mud	Gravel
0 to 15 m	7	9	7	7
16 to 30 m	7	7	0	7
> 30 m	7	7	7	7

Sampling Methods

Each of the twenty-six stations was sampled with one six-trap trawl, in which vented and ventless lobster traps were alternated (three of each per trawl, see Figure IIIE.4). Lobster traps were constructed with one-inch wire mesh, five-inch entrance head rings, one kitchen and one parlor, and overall dimensions of 40” x 21” x 14”. Escape vents in the vented traps were standard LMA 1 (Lobster Management Area 1) rectangular vents ($1^{15}/_{16}$” x $5^{3}/_{4}$”). All gear was rigged to meet or exceed Federal “whale-safe” regulations. All lines (vertical, ground, and gangions) were negatively buoyant. Break-away links (600 lbs break-away strength) were incorporated at each buoy.

Stations were sampled twice per month in October and November of 2004, and from May through November in 2005 and 2006. The semi-monthly sampling frequency of this design enhanced the temporal resolution of the survey, making it more likely to capture seasonal aspects of lobster distribution and abundance.

Trap deployment, maintenance, and hauling were contracted to commercial lobstermen. Survey gear was hauled on a three to five day soak time to standardize catchability among trips. All trawls were reset in the same assigned location after each haul. *MarineFisheries* staff accompanied the fishermen on each sampling trip to record CPUE and biological data. Sea samplers used the standard *MarineFisheries* lobster trap sampling protocol, wherein a series of parameters are recorded: catch in number of lobster, number of trap hauls, set-over-days, trap and bait type, carapace length (to the nearest mm), sex, shell hardness, culls and other shell damage, external gross pathology (including shell disease symptoms), mortality, and presence of extruded ova on females (ovigerous). After each haul, trawl location was confirmed with the stations original coordinates via GPS. Trawl location was confirmed with the station’s original coordinates after each haul via GPS. Depth at mean low water for each trawl location was recorded from NOAA navigational charts as a coastwide standard to avoid variability from tidal fluctuations.

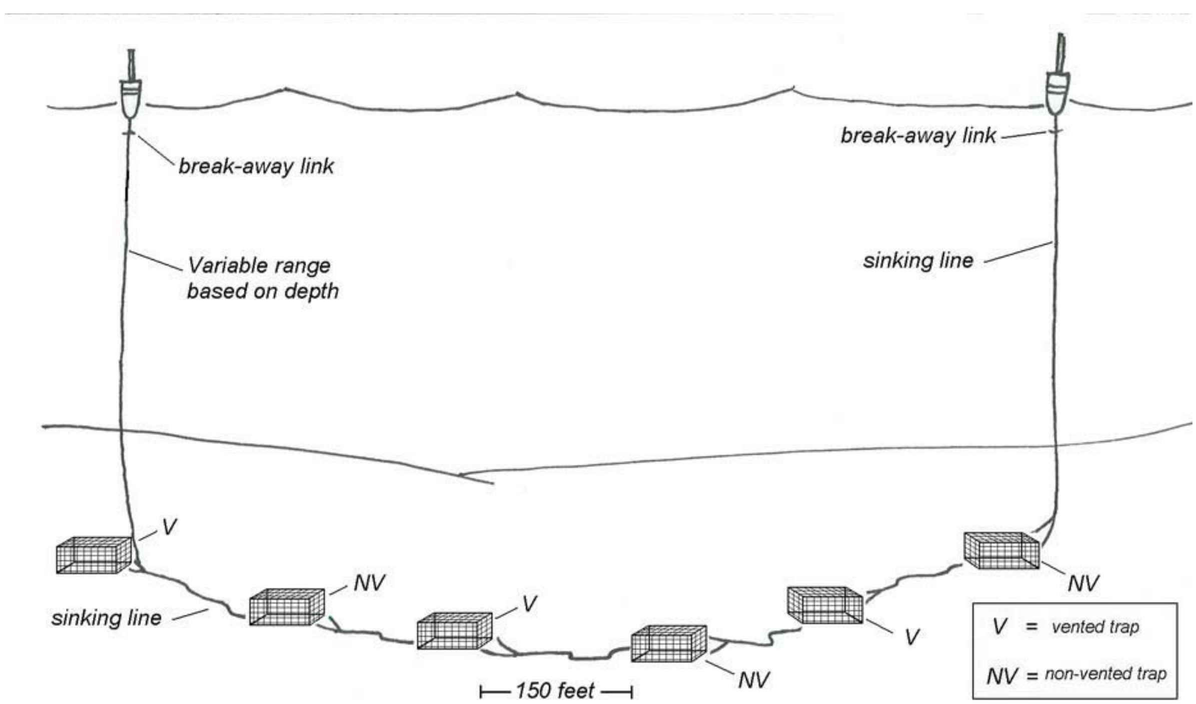

Figure IIIE.4. Diagram of gear configuration for the *MarineFisheries* ventless trap survey.

Analytical Procedures

Data were keypunched into a relational database. A computer auditing process was used to uncover keypunch and recording errors and statistical analyses were performed using SPSS statistical software.

After completion of the sediment verification process, strata were re-defined at each ventless trap sampling station (see Sediment Verification results). All trap survey data analyses were conducted with the corrected strata instead of the original strata.

General catch characteristics were generated and examined for each strata, including; sex ratio, percent egg-bearing females, percent v-notch, and percent of the catch with shell disease. Catch size distributions were examined by strata. Statistical comparisons of size distributions were made using the Kolmogorov-Smirnof test with a Bonferroni adjustment to account for type II error biases associated with multiple comparisons.

Relative abundance (expressed as catch per unit effort, CPUE) was examined by pooling catch data from each trap within the six-trap trawl at each sampling station. As such all CPUE data presented are as mean catch per trawl haul. This was done to avoid biases associated with the lack of independence of traps within a trawl and to include the range of selectivity from both trap types (vented and non-vented) into an independent sampling unit. CPUE data were examined graphically for normality. Because of the higher frequency of observations with zero or few lobsters, CPUE data were highly skewed to the right and appeared to assume a Poisson distribution. To remedy this problem and allow for parametric testing CPUE data were transformed to the square root plus one. This transformation was successful and CPUE data assumed a normal distribution. CPUE data were generated by strata separately for legal and sublegal size classes. Unless specified otherwise, the term "legal" lobster includes all lobsters ≥ 82.6 mm, and "sublegal" lobster refers to all lobsters less than this size (82.6 mm or 3 ¼" , the minimum size in effect in the study area). A two-factor ANOVA (strata and year) with Tukey's HSD post-hoc analysis was used to examine differences in relative abundance.

Sediment Verification

To collect sediment data, an underwater video camera system was purchased from SharkMarine Technologies, Inc. (Ontario, CA) and deployed from contracted commercial lobster vessels at each sampling station (Figure IIIE.5 A,C). The camera system consisted of an underwater color video camera (SV-DSP-Zoom2, 380,000 pixels, 40x zoom, depth rating 600 m), two underwater lights (250 watts), and two scaling lasers (Figure IIIE.5B). A topside control unit provided power controls, video recording and still image capture options, and controls to adjust light levels, as well as a view screen. The system was mounted on a custom-designed stainless steel frame (Apple Machine and Tool, Co., Acushnet, MA) (Figure IIIE.5C).

Figure IIIE.5. Underwater camera system; A) system ready for deployment from contracted vessel, B) close up of camera and lasers, C) system mounted on frame and ready for deployment.

The navigational software Offshore Navigator (MAPTECH) was run on a laptop linked to a GPS with an external antenna to provide a real-time position of the vessel within the boundary of each sampling station. Multiple still images were taken at each station, in a pattern that generally consisted of several transects diagonally crossing the station's area (Figure IIIE.6). Transect direction and camera drop locations were determined visually by the camera operator, who provided direction to the vessel captain. The spacing of camera drops along transects within a station ranged from approximately 90 meters to 160 meters apart. A waypoint was taken at each camera drop to record the latitude and longitude of each photo.

The live video feed generated by the system allowed the camera operator to delay image capture until any particles stirred up by the drop frame were clear, and provided the ability to adjust the focus as necessary. Multiple photos were taken at each drop, sometimes including zoomed images if particular features were present that might aid in sediment identification (worm castings, e.g.).

For those stations where visibility was too poor to capture useful still images, a grab sample was taken (15.2 cm x 15.2 cm sample area, Wildco® Petite Ponar Grab). If the image in the camera view screen did not clear sufficiently for analysis, the camera was retrieved and the grab sample immediately deployed. The grab was lowered and retrieved by hand from the stern of the boat, and emptied into a fish tote. A digital photo was taken of each grab sample, and sediment type was determined based on a gross examination of the sample. Thus, each waypoint has a visual record of the bottom.

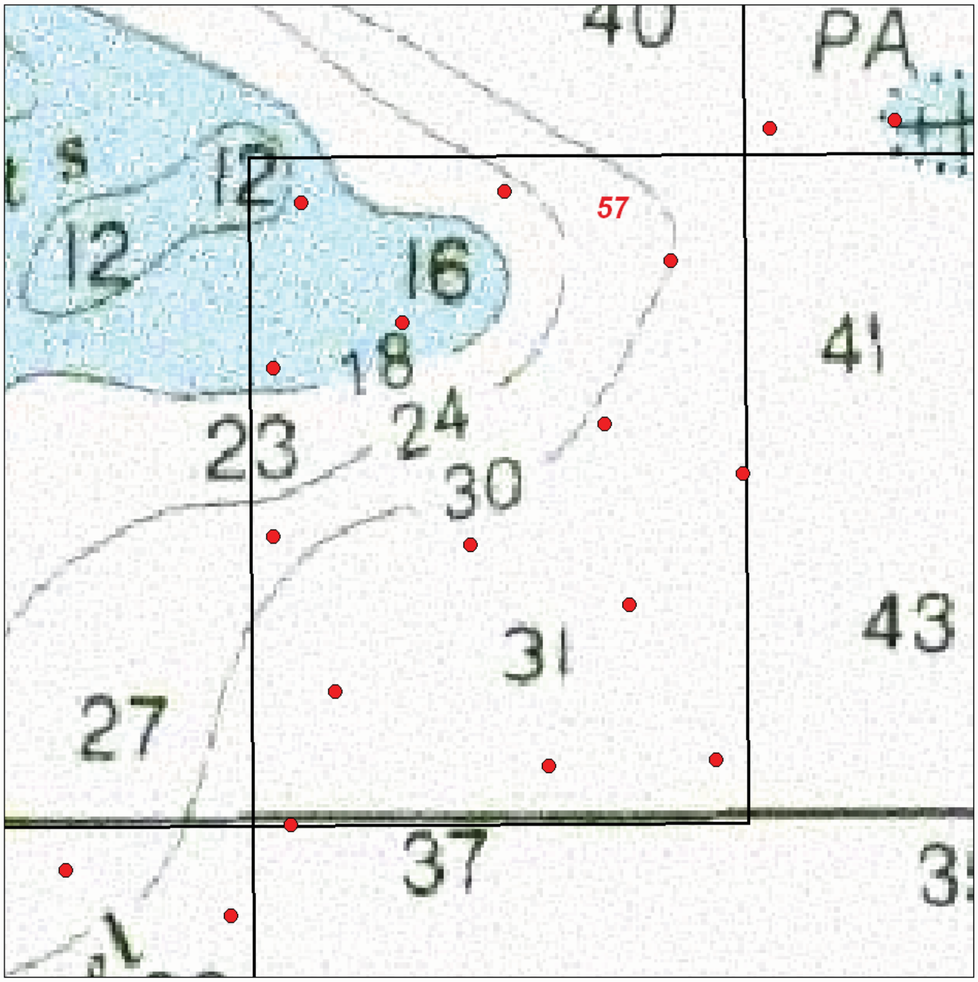

Figure IIIE.6. Example of sediment verification sampling pattern at a ventless trap sampling station; waypoints for each camera drop taken at station 57 (black rectangle).

Photos from each camera drop were analyzed by selecting the image with the most clarity at the full scale, and displaying the image on a computer monitor with an overlaid grid consisting of twelve boxes (Figure IIIE.7). The percent cover for each category of substratum was visually determined for each of the twelve boxes, which were then averaged to produce the mean percent cover of each substratum per photo.

In order to minimize the statistical variability related to over-stratification, the eight primary sediment categories were combined to represent either “featureless” or “complex” sediments. The categories of mud, sand, gravel, and shell debris were considered to be featureless, while the pebble, cobble, and boulder categories were considered complex. The value for algal percent cover was added into the total for the primary substrate, as it was assumed algae was obscuring the predominant sediment type.

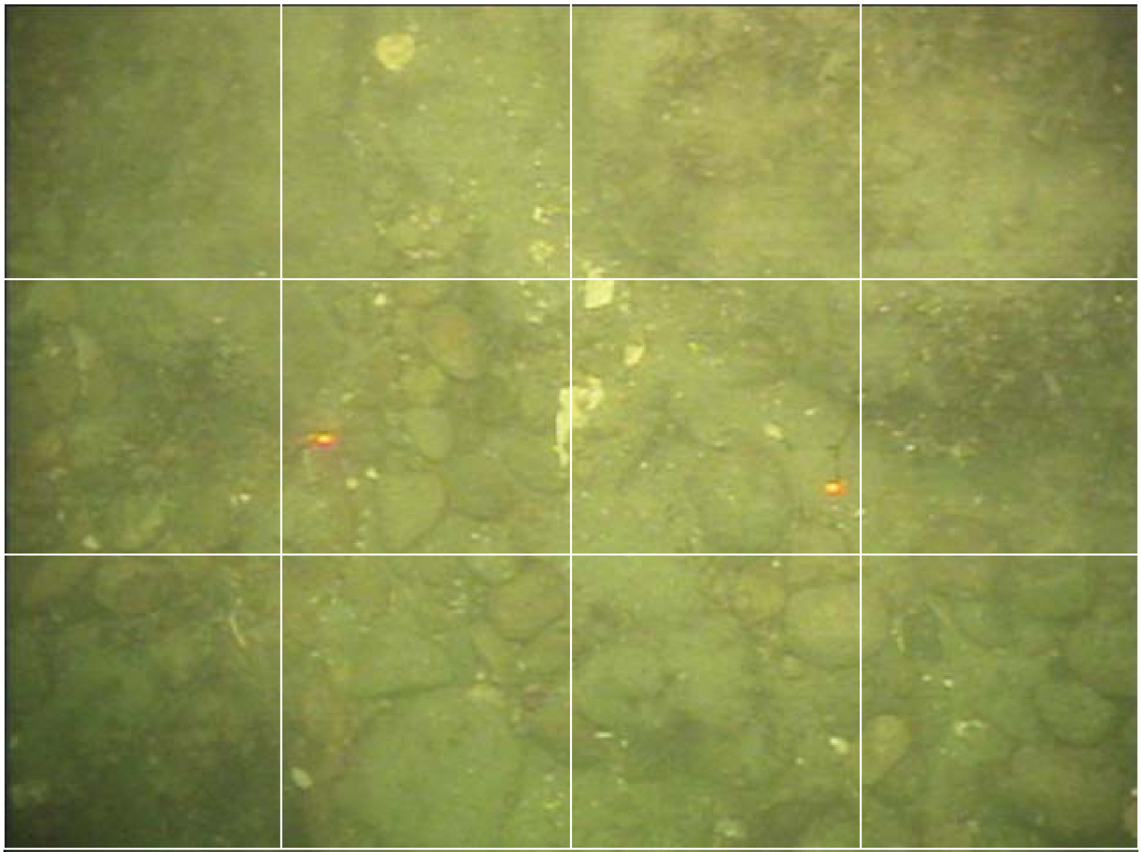

Figure IIIE.7. Example of photo with the 12 cell analysis grid overlaid.

The waypoints for each photo, with the associated percent-featureless sediment characterization, were loaded into ArcGIS 9.0 in order to map the sediments present at each station. The data were interpolated based on the percentage of featureless sediments with the Spatial Analyst feature in GIS, using the Inverse Distance Weighted method. The resulting data layer was clipped to the boundaries of each station, then converted into a feature class with four sediment divisions (based on the percent of featureless sediments); 0%-15% = "rocky", 15% - 50% = "rocky mix", 50% - 85% = "featureless mix," >85% = "featureless." The percentage of each station cell that each of these divisions comprised was then calculated, and a final sediment classification for each station was determined. A station was classified as *Featureless* if the "featureless" sediment division comprised >85% of the station's surface area. Otherwise, the station was classified as *Complex*.

The new sediment classifications for each sampling station were used to re-stratify the survey stations, using the original three depth divisions and the two new sediment divisions, for a total of six strata.

Only results for the twenty-six stations sampled during all three ventless trap survey periods (2004 - 2006) are presented in this report.

Results and Discussion

<u>Sediment Verification Results</u>
An average of thirteen photos were taken at each ventless trap sampling station, with a range of six to sixteen photos (Figure IIIE.8, Table IIIE.2). There were a couple of stations where shallow water or high densities of fixed fishing gear prevented us from accessing the entire station, thus limiting the number of photos taken. Sediment types observed in the bottom photos ranged from featureless sediments like mud and sand to rocky high-profile sediments like boulder and cobble (Table IIIE.2). The rocky areas were frequently composed of a mix of rock sizes with sand or mud underlying, providing a heterogeneous habitat for benthic animals such as lobster.

All of the photos at each station were assigned a value that represented the percent of featureless sediments present, and used to extrapolate the sediments present throughout the station (Table IIIE.3). The results of the GIS interpolation yielded areas that fell into four sediment divisions; rocky (<15% featureless), rocky mix (15% – 50% featureless), featureless mix (50% - 85% featureless), and featureless (≥ 85% featureless) (Figure IIIE.9). The percent cover of each of these divisions within a station was then used to determine the new classification for that station; Featureless (≥ 85% featureless sediments) or Complex (< 85% featureless sediments). We used 85% as the dividing line because a station with 85% of its surface area composed of barren sediments is likely to provide few options in the way of shelters, meaning higher exposure to predators, and fewer options for foraging. A station with a surface area composed of less than 85% barren substrate is more heterogeneous, offering more options for shelter and foraging. Because so much of a lobster's life history revolves around shelters (molting, mating, foraging, protection from predation, see, e.g.; Lawton and Lavalli 1995, Tremblay and Smith 2001, Karnofsky *et al.* 1989, Atema and Cobb 1980, Watson *et al*. 1999), we wanted to be relatively conservative in our definition of habitat which is functionally featureless. If a station is composed of more than 15% complex sediment types, we presume there is opportunity for more than one lobster to establish and maintain a shelter in that area.

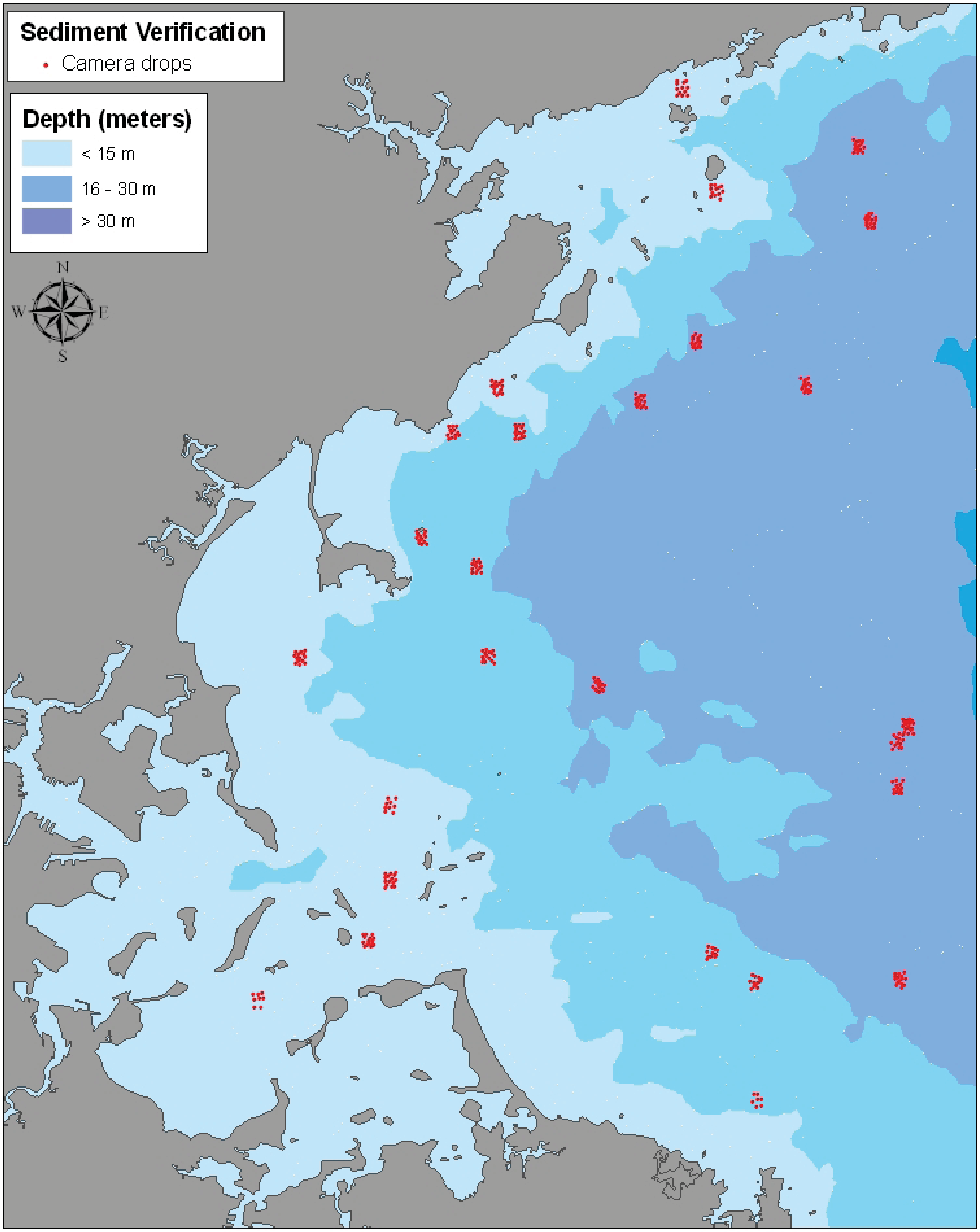

Figure IIIE.8. Massachusetts Bay study area with all camera drop waypoints at each ventless trap sampling station.

Table IIIE.2. Summary data for sediment verification at each ventless trap sampling station including; station ID, center point location (Lat./Long.), number of camera drops, and the mean percent cover of each sediment category.

Station ID	Latitude	Longitude	# Camera drops	Silt/mud	Sand	Shell fragments	Whole shell	Weed	Gravel	Pebble	Cobble	Boulder	Other
1	42.5563	-70.7979	12	30.21	48.82	1.04	0.00	4.86	3.33	1.46	0.21	0.00	10.07
3	42.5396	-70.7312	15	99.94	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	42.5271	-70.7854	12	0.00	7.71	2.71	0.14	14.58	12.50	46.39	7.57	8.26	0.21
9	42.5188	-70.7271	16	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	42.4854	-70.7937	15	16.94	77.50	2.17	0.00	0.00	0.00	1.11	2.22	0.00	0.06
15	42.4729	-70.8687	14	0.00	22.74	1.13	1.01	12.02	19.58	21.01	3.33	18.87	0.30
16	42.4729	-70.7521	15	82.78	5.89	0.94	0.00	0.00	0.94	6.78	2.61	0.00	0.17
17	42.4688	-70.8146	15	31.17	15.83	0.33	1.00	0.00	5.78	9.22	16.67	20.06	0.00
19	42.4604	-70.8854	13	46.15	21.54	1.92	0.00	8.46	1.35	5.00	0.13	15.38	0.06
20	42.4604	-70.8604	15	7.56	30.44	2.83	0.00	0.67	8.44	23.50	14.56	11.89	0.11
24	42.4313	-70.8979	12	46.32	2.43	5.90	0.00	4.72	1.94	12.01	12.22	14.03	0.42
25	42.4229	-70.8771	14	92.50	0.00	0.00	0.00	0.00	0.00	2.80	1.13	3.45	0.00
29	42.3979	-70.9437	14	1.85	68.69	1.19	0.00	0.00	3.93	12.26	11.37	0.00	0.71
32	42.3979	-70.8729	15	71.06	0.00	0.22	0.00	0.00	0.06	10.94	13.61	4.17	0.00
35	42.3896	-70.8312	14	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	42.3771	-70.7146	13	87.05	0.00	0.19	0.00	0.00	0.96	9.81	1.73	0.00	0.00
40	42.3729	-70.7187	13	78.85	0.00	0.38	0.00	0.00	0.32	13.27	5.96	0.00	0.96
45	42.3604	-70.7187	13	10.83	32.76	0.06	0.00	0.00	3.53	17.24	16.79	18.46	0.32
46	42.3563	-70.9104	9	0.00	77.04	1.67	0.00	11.11	3.06	6.85	0.28	0.00	0.00
57	42.3354	-70.9104	14	0.00	76.79	2.68	0.95	3.75	2.38	12.26	1.19	0.00	0.00
63	42.3188	-70.9187	15	5.50	21.17	0.22	0.00	1.11	44.83	25.67	1.28	0.00	0.22
65	42.3146	-70.7896	12	0.00	38.75	0.49	0.00	1.04	17.85	24.42	15.42	1.46	0.00
70	42.3063	-70.7729	13	0.00	9.74	0.64	0.00	31.28	3.27	21.92	16.35	16.35	0.00
71	42.3063	-70.7187	15	0.00	93.00	1.39	0.00	0.00	2.61	2.83	0.17	0.00	0.00
72	42.3021	-70.9604	8	98.96	0.00	0.94	0.00	0.00	0.00	0.10	0.00	0.00	0.00
78	42.2729	-70.7729	6	0.00	46.81	1.53	0.00	0.56	4.58	21.81	8.89	15.83	0.00

Table IIIE.3. Strata classification data for each ventless trap station, including center point (Lat/Long), number of camera drops, depth strata, original sediment strata, the mean percent of featureless sediment type (includes mud, sand, and gravel), and the new sediment strata.

Station ID	Latitude	Longitude	# Camera drops	Depth strata	Original sediment strata	Percent featureless	New sediment strata
1	42.5563	-70.7979	12	0 - 15 m	Pebble	99.84	featureless
3	42.5396	-70.7312	15	> 30 m	Pebble	100.00	featureless
7	42.5271	-70.7854	12	0 - 15 m	Boulder	0.00	complex
9	42.5188	-70.7271	16	> 30 m	Pebble	100.00	featureless
13	42.4854	-70.7937	15	> 30 m	Pebble	88.98	featureless
15	42.4729	-70.8687	14	0 - 15 m	Boulder	0.00	complex
16	42.4729	-70.7521	15	> 30 m	Sand/gravel	45.77	complex
17	42.4688	-70.8146	15	> 30 m	Boulder	14.01	complex
19	42.4604	-70.8854	13	0 - 15 m	Boulder	58.17	complex
20	42.4604	-70.8604	15	16 - 30 m	Boulder	9.16	complex
24	42.4313	-70.8979	12	16 - 30 m	Boulder	4.21	complex
25	42.4229	-70.8771	14	16 - 30 m	Sand/gravel	90.85	featureless
29	42.3979	-70.9437	14	0 - 15 m	Pebble	67.87	complex
32	42.3979	-70.8729	15	16 - 30 m	Sand/gravel	7.42	complex
35	42.3896	-70.8312	14	> 30 m	Mud	100.00	featureless
38	42.3771	-70.7146	13	> 30 m	Sand/gravel	52.62	complex
40	42.3729	-70.7187	13	> 30 m	Sand/gravel	24.23	complex
45	42.3604	-70.7187	13	> 30 m	Sand/gravel	0.00	complex
46	42.3563	-70.9104	9	0 - 15 m	Sand/gravel	75.53	complex
57	42.3354	-70.9104	14	0 - 15 m	Boulder	53.43	complex
63	42.3188	-70.9187	15	0 - 15 m	Boulder	14.10	complex
65	42.3146	-70.7896	12	16 - 30 m	Pebble	0.00	complex
70	42.3063	-70.7729	13	16 - 30 m	Boulder	0.00	complex
71	42.3063	-70.7187	15	> 30 m	Sand/gravel	88.23	featureless
72	42.3021	-70.9604	8	0 - 15 m	Sand/gravel	100.00	featureless
78	42.2729	-70.7729	6	16 - 30 m)	Boulder	0.00	complex

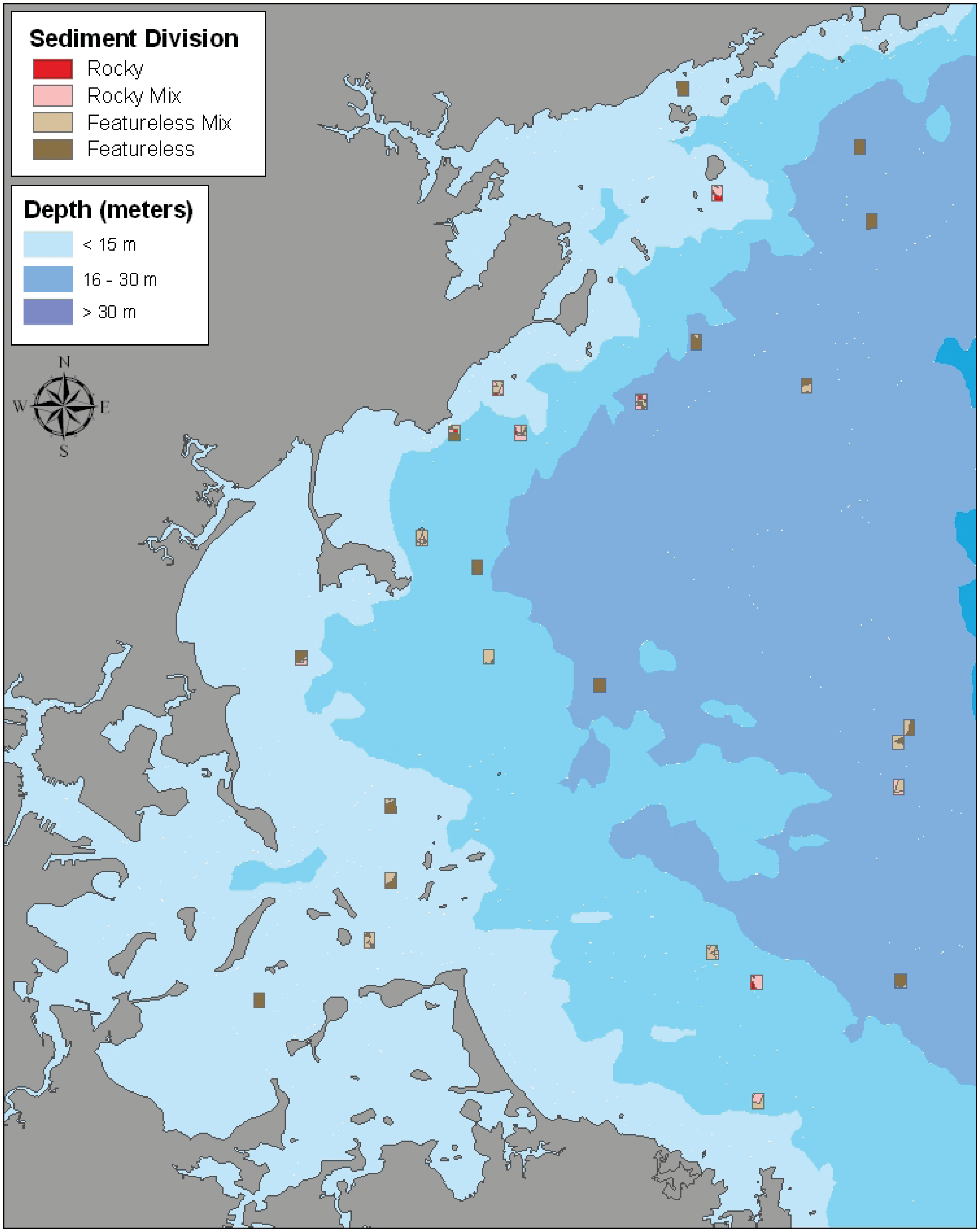

Figure IIIE.9. Results of the GIS interpolation. Four divisions of sediments, based on a scale of percent featureless sediment, present at each sampling station: Rocky: 0 – 15% featureless, Rocky Mix: 15% – 50% featureless, Featureless Mix: 50% - 85% featureless, Featureless: >85% featureless.

Eight stations were classified as featureless, and eighteen were classified as complex (Figure IIIE.10, Table IIIE.4). Re-stratification of the survey stations yielded six strata (Table IIIE.4) which were used in the analysis of the ventless trap survey catch data.

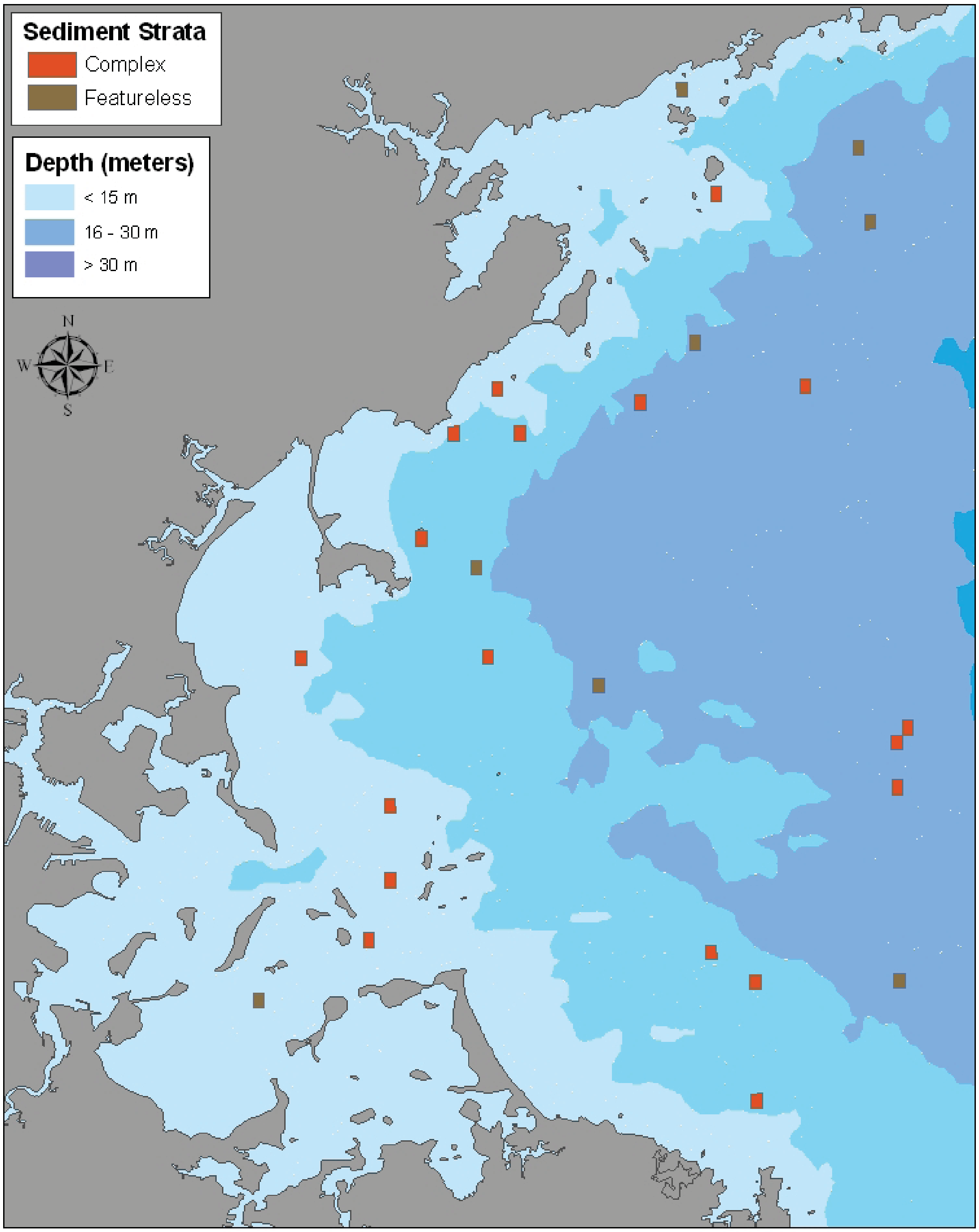

Figure IIIE.10. Ventless trap survey stations with new sediment strata classification: red = complex, brown = featureless.

Table IIIE.4. New strata for the ventless trap survey and the number of survey stations in each strata.

	Sediment	
Depth	Complex	Featureless
0 - 15 m	7	2
16 - 30 m	6	1
> 30 m	5	5

Originally, the sediment strata were boulder, pebble, sand/gravel, and mud. Boulder and pebble were considered to be complex sediments, while sand/gravel and mud were grouped as featureless sediments. Ten of the twenty-six stations have been altered with the new classification, having changed from complex to featureless or vice versa (Table IIIE.3). All of the changes occurred with stations that were originally classified as pebble or as sand/gravel. Thus the original data layer, derived from Knebel's (1993) report, generally classified the extremes of the sediment scale reliably well, while the middle grain size sediments were not as well defined. Some of our reclassifications may also be related to the spatial scale over which the original data were extrapolated (relatively few data points interpolated over a relatively large geographic area).

The number of stations that had to be re-classified demonstrates the necessity of our sediment verification project. While large scale sediment datasets based on remote sensing techniques provide a good starting point to examine the habitats present in an area, they are of limited use for fine-scale biological studies. Sediment data used in ecological studies, or population assessment studies, needs to match the scale over which sampling is occurring. In our case, using the large scale sediment map derived from Knebel's report was a mismatch in scale.

Although we sampled only 0.0023% of the surface area at each survey station, the spatial coverage of sediment sampling at each station was good. While it is possible we may have missed small patches of a particular sediment type, those small patches, taken in total within the entire sampling station area, would not have altered the functional habitat designation assigned to that station. Furthermore, only data from camera drops within each particular survey station were used to extrapolate the sediments present throughout that station, so there were many data points in a relatively small geographic area.

Ventless Trap Survey Catch Results
Results are based on October and November sampling periods from 2004 – 2006 at twenty-six stations, and include a total of 286 trawl hauls. A total of 16,895 lobsters were observed during these sampling periods. More than 90% of the lobsters observed each year were sublegal (<83 mm CL).

There were some trends in lobster size distribution by strata within each year of sampling (Figures IIIE.11 – IIIE.13). Lobsters in the deep complex strata were significantly larger than those in the other two complex strata and those in the shallow and mid-depth featureless strata in 2004 (Figure IIIE.11, α` = .0033). Similarly, in 2005, lobsters in the deep complex strata were significantly larger than lobsters in any other strata (Figure 12, α` = .0033). Also in 2005, the size distribution of lobsters in the mid-complex strata was similar to the size distribution in deep featureless strata, but different from all other strata (α` = .0033). While 2006 sampling revealed no significant differences in lobster size distributions by sediment type, trends similar to 2004 and 2005 were visible (Figure IIIE.13). Generally, lobsters in the deep complex strata tended to be larger than in other strata, while the lobsters in the shallow strata (both bottom types) tended to be smaller than in other strata. These trends are consistent with lobster life history, in that as lobsters grow from early benthic phase to adulthood, their range of movements and habitat utilization increase (see, e.g., Cobb and Wahle 1994, Lawton and Lavalli 1995).

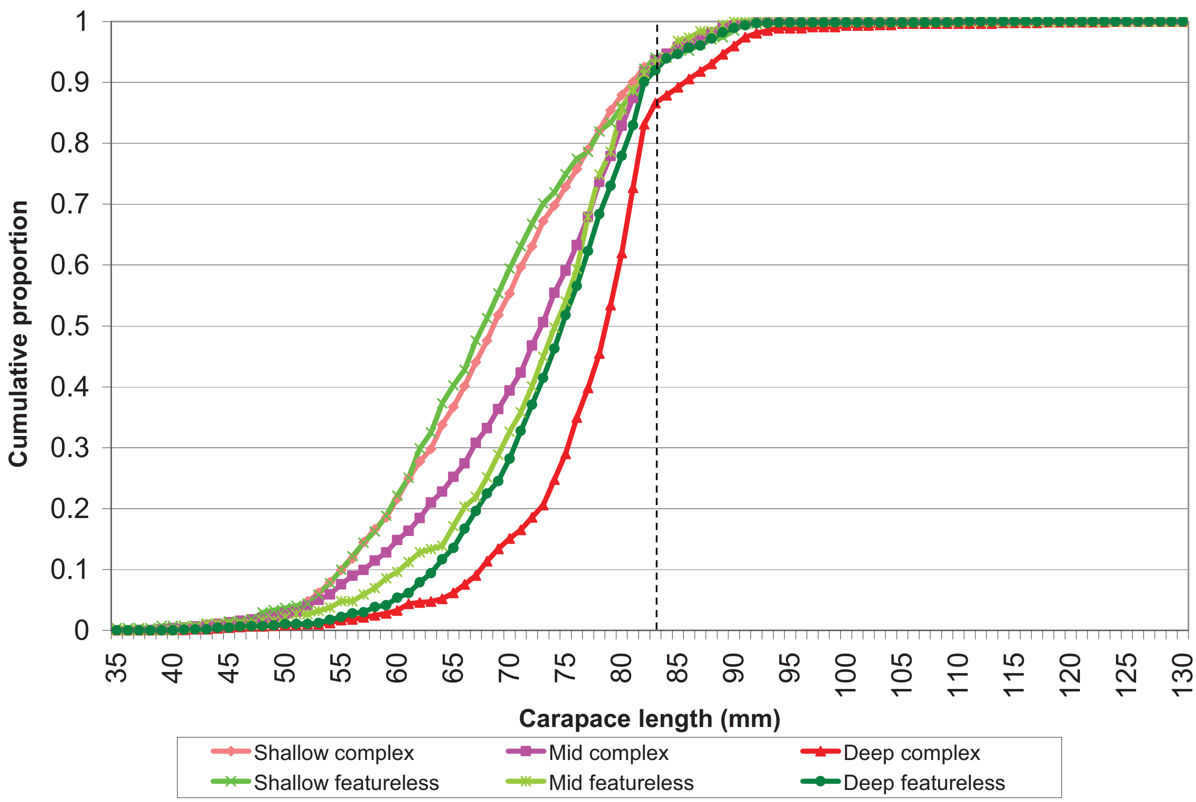

Figure IIIE.11. Lobster size distribution by strata, fall 2004.

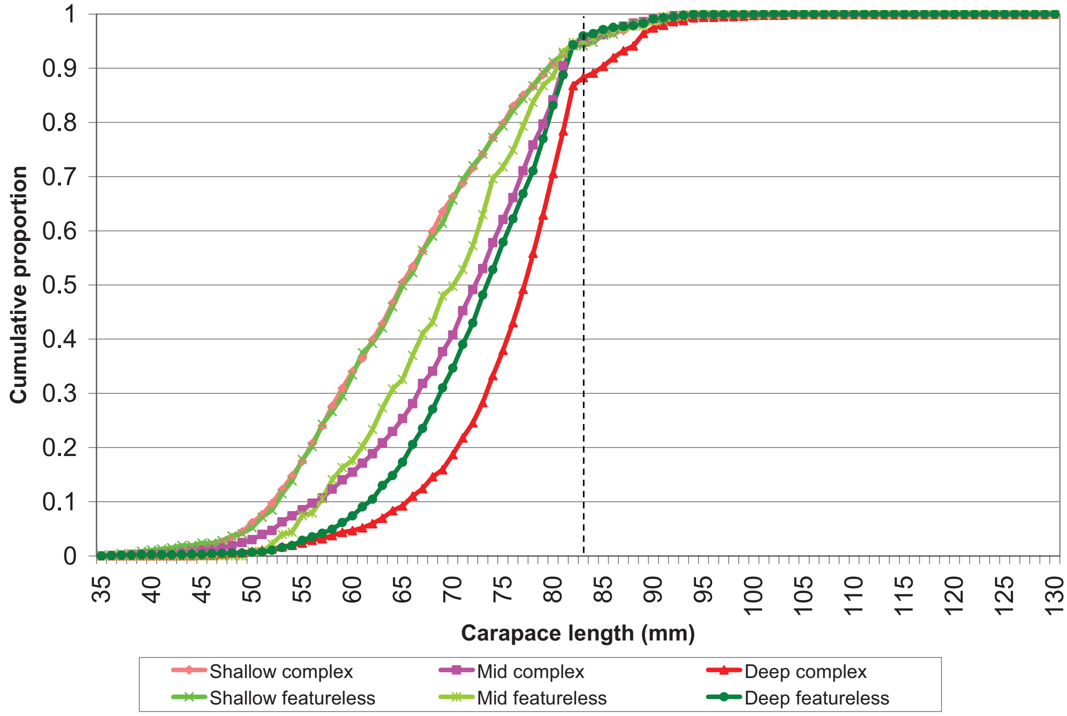

Figure IIIE.12. Lobster size distribution by strata, fall 2005.

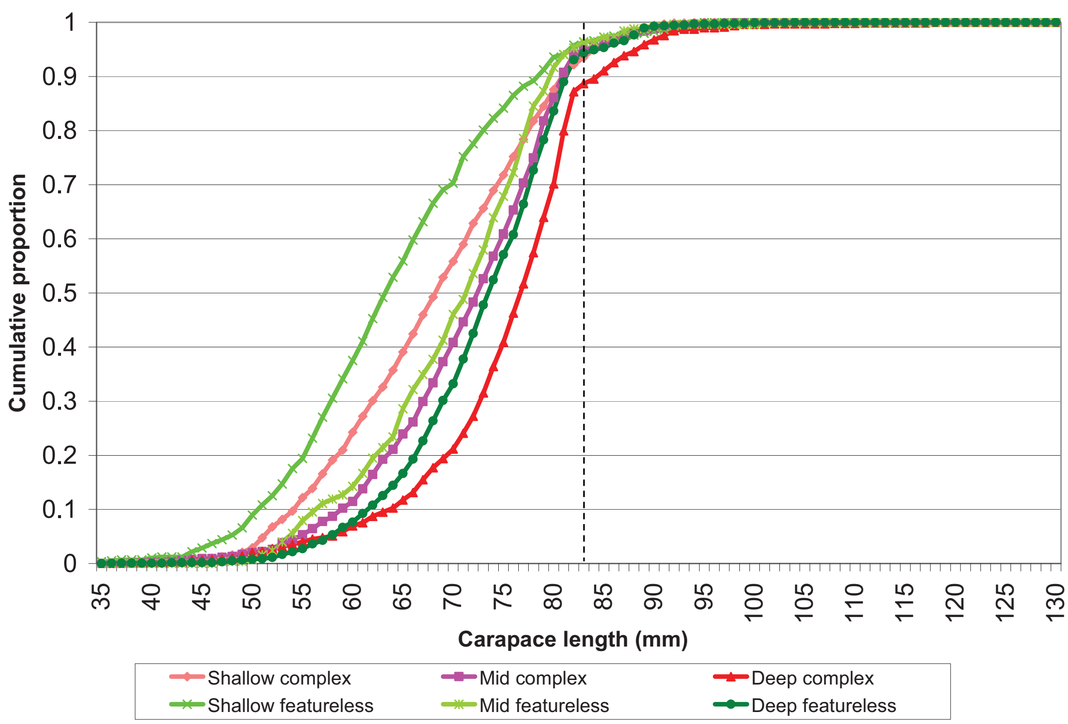

Figure IIIE.13. Lobster size distribution by strata, fall 2006.

Generally the composition of the lobster catch varied from 40% to 60% female (Figure IIIE.14). Females made up the lowest percentage of the catch in the shallow featureless habitat, while the mid-depth complex habitat (16 – 30 m) was consistently, but only slightly, female-biased.

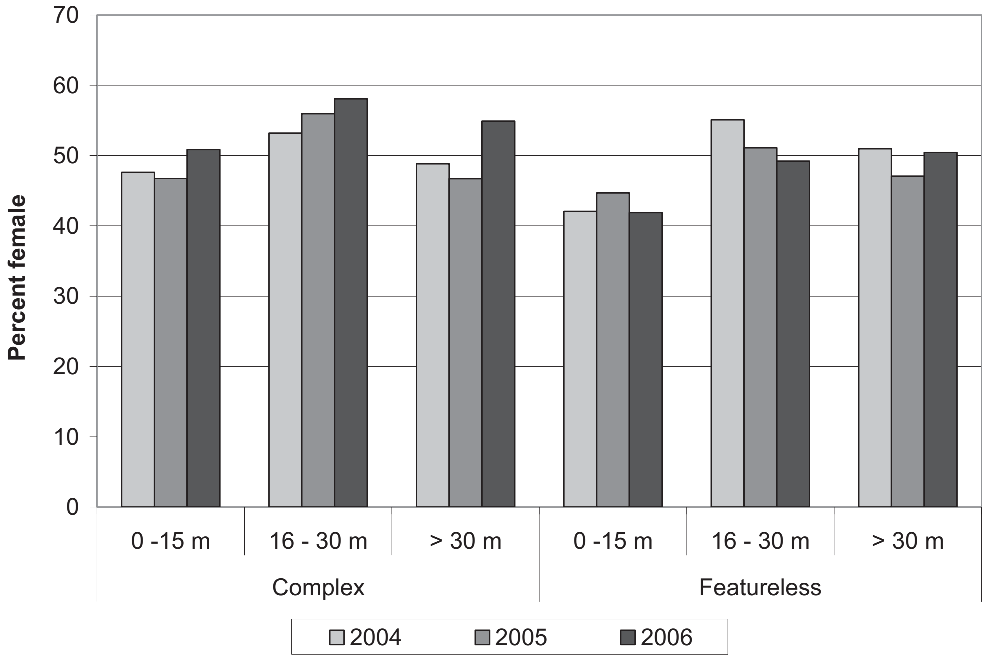

Figure IIIE.14. Percent of the catch that was female by strata for 2004 - 2006.

The percentage of females observed with eggs was low, mostly less than six percent (Figure IIIE.15). Egg extrusion typically takes place in late summer and fall in this region (*MarineFisheries* unpub. data), so most of the eggs observed in this time period were freshly extruded. These low values are likely related to the large numbers of sublegal lobsters observed. Less than fifty percent of female lobsters in this region reach sexual maturity before they reach minimum legal size (Estrella and McKiernan 1989), so most of the females observed in the ventless trap survey were likely immature lobsters. The deeper regions, where slightly higher percentages of females were egg-bearing, are also regions where the size distribution is slightly larger (see Figures IIIE.11 – IIIE.13, e.g.), thus mature lobsters may have been more prevalent in these areas.

Environmental conditions which lobsters encounter in each strata are likely important driving forces behind the observed trends in both sex ratio and egg-bearing females. The shallow areas inside Boston Harbor and Salem Sound are at the mouths of estuaries and are therefore subject to more environmental variability, primarily in temperature and salinity. Male lobsters tend to be more tolerant of this type of environment (Howell *et al*. 1999, Jury et. al 1994, and Watson et. al 1999). The temperature and salinity in deeper coastal areas tend to be relatively stable, providing a more favorable environment to female and egg-bearing female lobsters. It is possible that egg-bearing female lobsters seek out areas of stable temperature and salinity regimes due to the enhanced egg development (Templemen 1940) and increased larval survivorship (Templemen 1936) afforded by these environments. Furthermore, substantial egg loss has been documented in European lobsters (*Homarus gammarus)* exposed to low salinities (Wickins *et al* 1995).

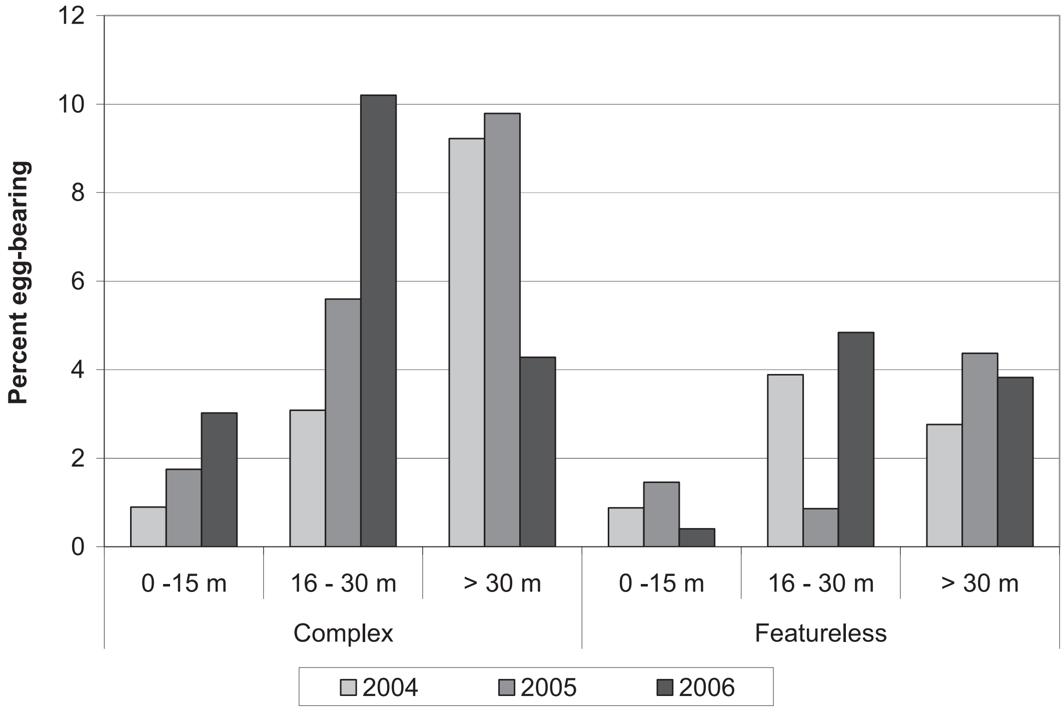

Figure IIIE.15. Percent of the female catch that were bearing eggs by strata for 2004 - 2006.

An examination of salinity data recorded by the Massachusetts Water Resources Authority (MWRA) at a station adjacent to the inner Boston Harbor ventless trap stations, compared to salinity data collected by GoMoos Buoy A (offshore to the southeast of Gloucester, near the northeastern portion of the ventless study area), demonstrates the more variable nature of the inshore portions of the study area (Figure IIIE.16). The salinity at the inner Boston Harbor station ranged from 28.2 to 32 ppt, a total variation of four parts per thousand, over the two year time period. In contrast, the GoMoos buoy, located farther offshore, had relatively stable readings that ranged from 31.8 to 32.9 ppt, a maximum difference of only one part per thousand over the same time frame. Similarly, the bottom temperature at shallow locations inside Boston Harbor is more variable than deeper locations in coastal Massachusetts Bay (Figure IIIE.17). These apparent environmental influences on the demographics of lobster sex ratio have important implications relative to monitoring lobster stocks. This demonstrates that sampling across a broad area and throughout all potential substrate types and depths is critical to accurately characterizing important lobster population parameters like sex ratio, as well as accurately estimating population abundance by sex.

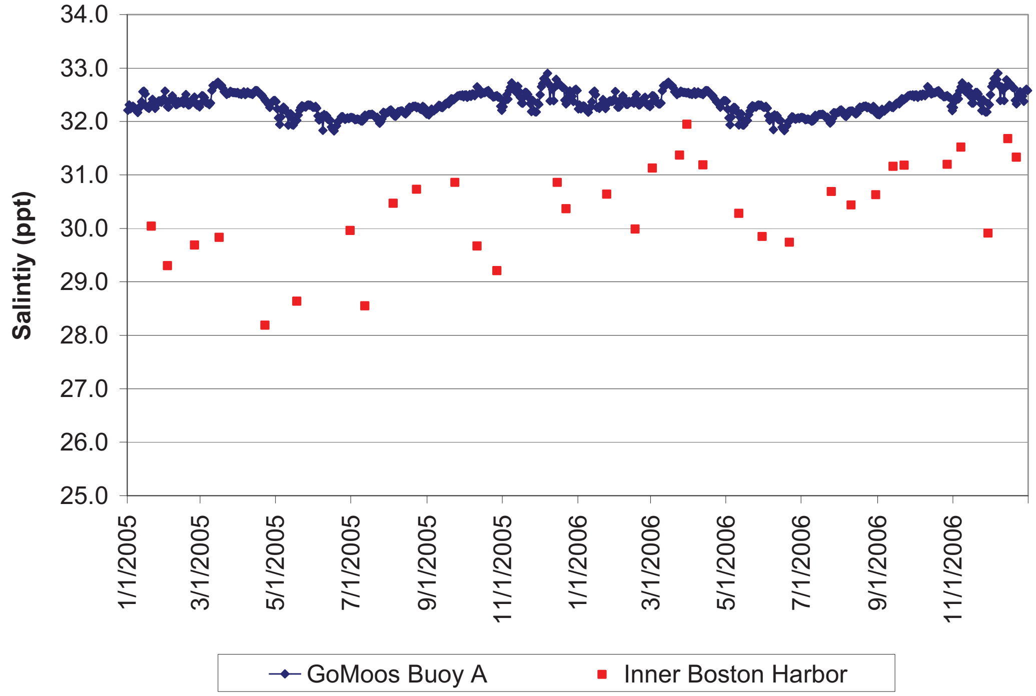

Figure IIIE.16. Bottom water salinity in Inner Boston Harbor (Dorchester Bay) and at GoMoos Buoy A (SE of Gloucester, 65 m depth) in 2005 and 2006 (Data provided by Massachusetts Water Resource Authority, and Gulf of Maine Ocean Observing System).

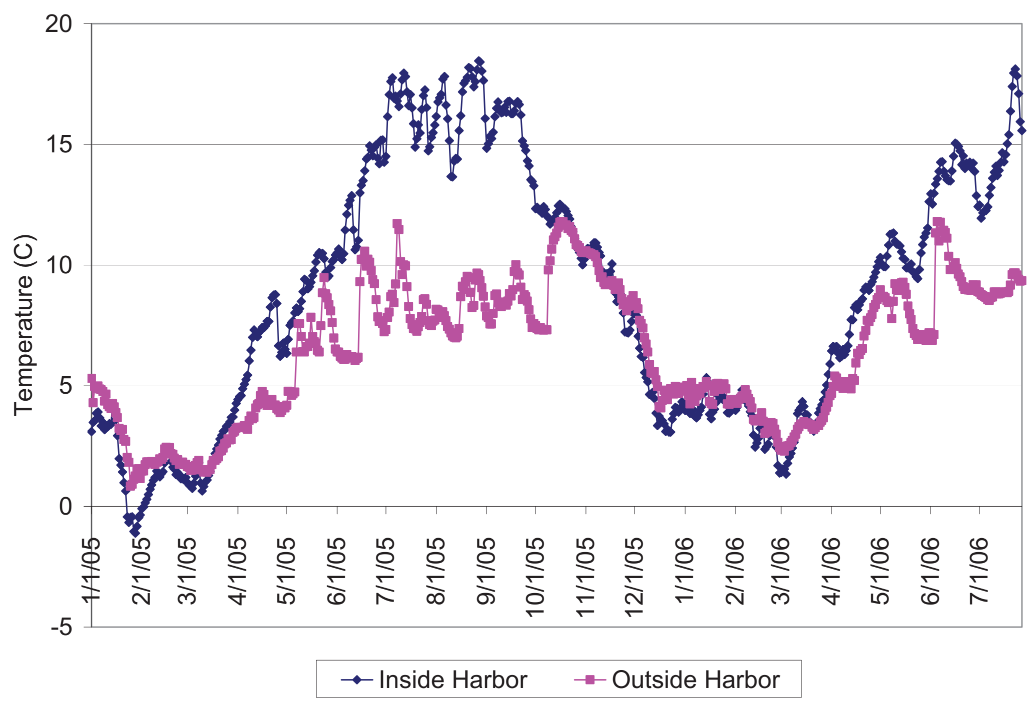

Figure IIIE.17. Daily mean bottom water temperature at inner Boston Harbor (Sculpin Ledge, 20ft) and outside Boston Harbor (Martin's Ledge, 70ft.) *(MarineFisheries* unpublished data).

Mean relative abundance of sublegal lobsters varied by year and strata (Figure IIIE.18, Table IIIE.5). Catch of sublegals in 2004 was significantly less than in 2005 (Tukey's HSD p = 0.0018), but not different than catch in 2006, nor was the catch different from 2005 to 2006. Sublegal catch in deep water featureless habitat was significantly higher than in deep water complex habitat (Tukey's HSD p = 0.006). While not significant, there were other visible trends in the catch data. Within each year, the catch of sublegals in the deep water complex strata was generally lowest (with the exception of 2004, when shallow featureless strata exhibited the lowest catch). In 2004, there was a trend of decreasing catch with depth in complex, but increasing catch with depth in featureless habitat. No trends were visible in 2005, and in 2006 there was a very slight trend of decreasing catch with depth in both bottom types.

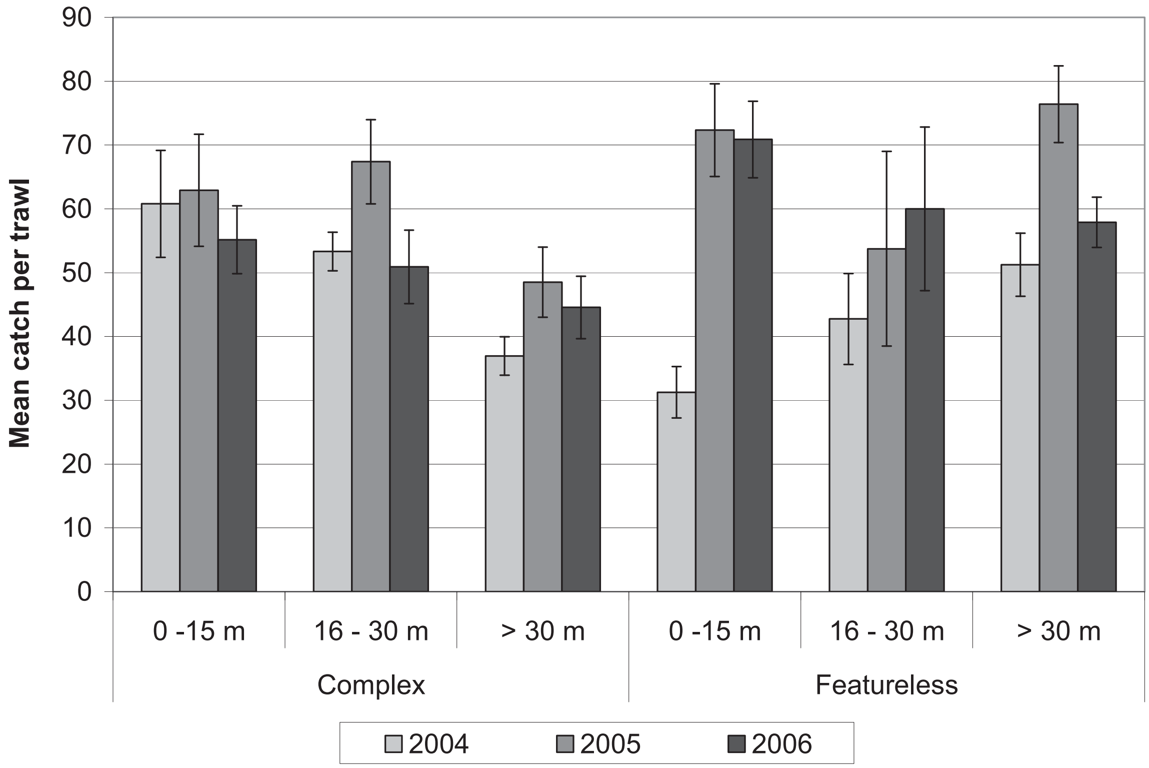

Figure IIIE.18. Mean catch per trawl (± S.E.) of sublegal lobsters by strata for 2004 – 2006.

Table IIIE.5. Two-way ANOVA results (fixed factors Year and Newstrat) for sublegal mean catch per trawl haul (√ + 1 transformed).

	df	F	p
year	2	6.4419	0.0019
newstrat	5	3.2175	0.0077
year * newstrat	10	1.4197	0.1712

Average catch of legal lobsters varied by strata (Figure IIIE.19, Table IIIE.6). There were no differences in mean catch detected from year to year, however, legal catch in 2004 was generally higher than in other years in most strata (except in shallow featureless strata). Catch in deep water complex habitat was significantly higher than in any other strata (Tukey's HSD p < .01). This is likely related to the fact that these data were collected in October and November, when lobsters tend to move to deeper nearshore and offshore waters (Fogarty *et al.* 1980).

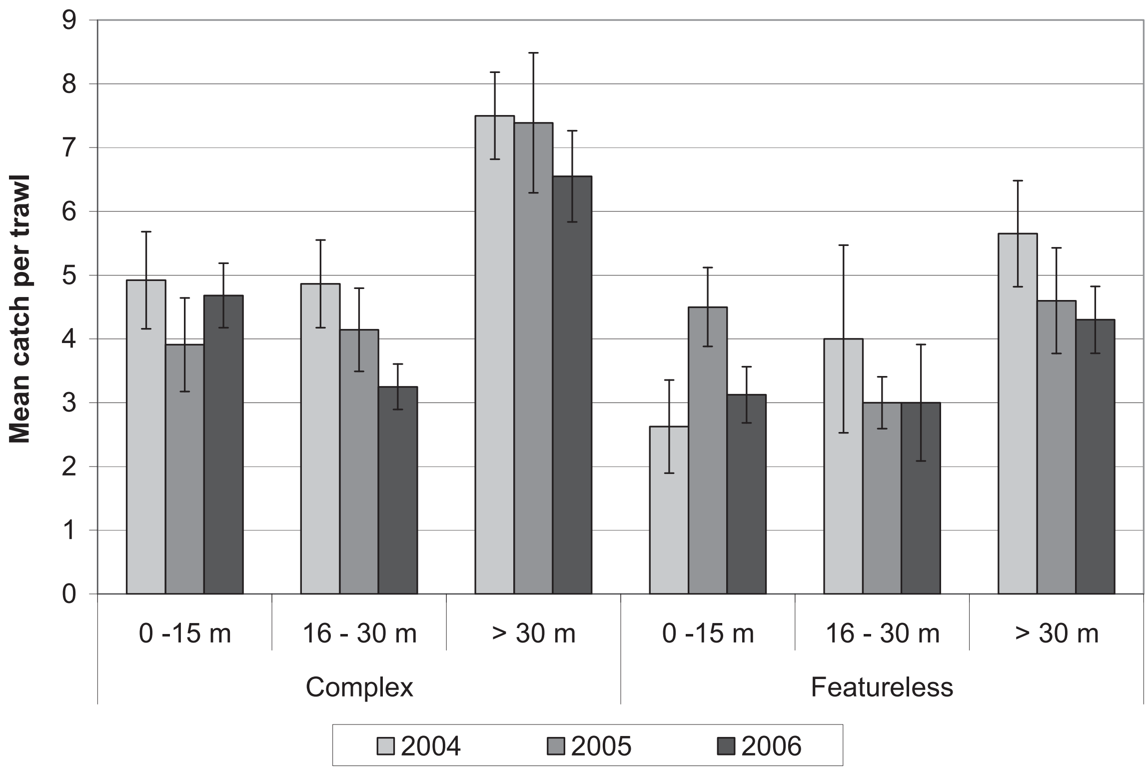

Figure IIIE.19. Mean catch per trawl (± S.E.) of legal lobsters by strata for 2004 – 2006

Table IIIE.6. Two-way ANOVA results (fixed factors Year and Newstrat) for legal mean catch per trawl haul (√ + 1 transformed).

	df	F	p
year	2	0.6177	0.5399
newstrat	5	8.3244	0.0000
year * newstrat	10	0.6221	0.7946

The maps in Figures IIIE.20 and IIIE.21 (sublegal and legal, respectively) represent the mean catch per trawl at each station and are reflective of the spatial distribution of lobster within the study area. There was a greater range of observed CPUEs among stations in 2004 as compared to 2005 and 2006 (Figure IIIE.20). There was a moderate amount of inter-annual variability in the catch at most stations; only four stations (in four different strata) had consistent catch rates over all three years.

The average catch of legal lobsters at each station generally varied from one to five or five to ten lobsters per trawl haul (Figure IIIE.21). The highest catch of legals observed was ten to twenty-five lobsters, at Station 38 in 2005. This station was one of three to have legal catch rates of at least five to ten lobsters per trawl haul in all three years. Average catch of legal lobsters at each station was always less than the sublegal catch. Catch rates of legal lobsters were consistently higher at stations in deeper water across all three years. This is likely related in part to the time of year, as fall is generally when lobsters begin to move offshore into deeper waters (Fogarty *et al*. 1980). Also, there is less fishing effort in the vicinity of the deep-water stations, which has the potential to influence legal catch rates in the survey as lobsters are removed via commercial fishing.

There were no discernable spatial trends (North vs. South or East vs. West) in sublegal or legal lobster catch observed in any of the three years. This suggests that the differences observed in mean catch by strata were being driven by the stratification factors, notably depth, instead of regional factors.

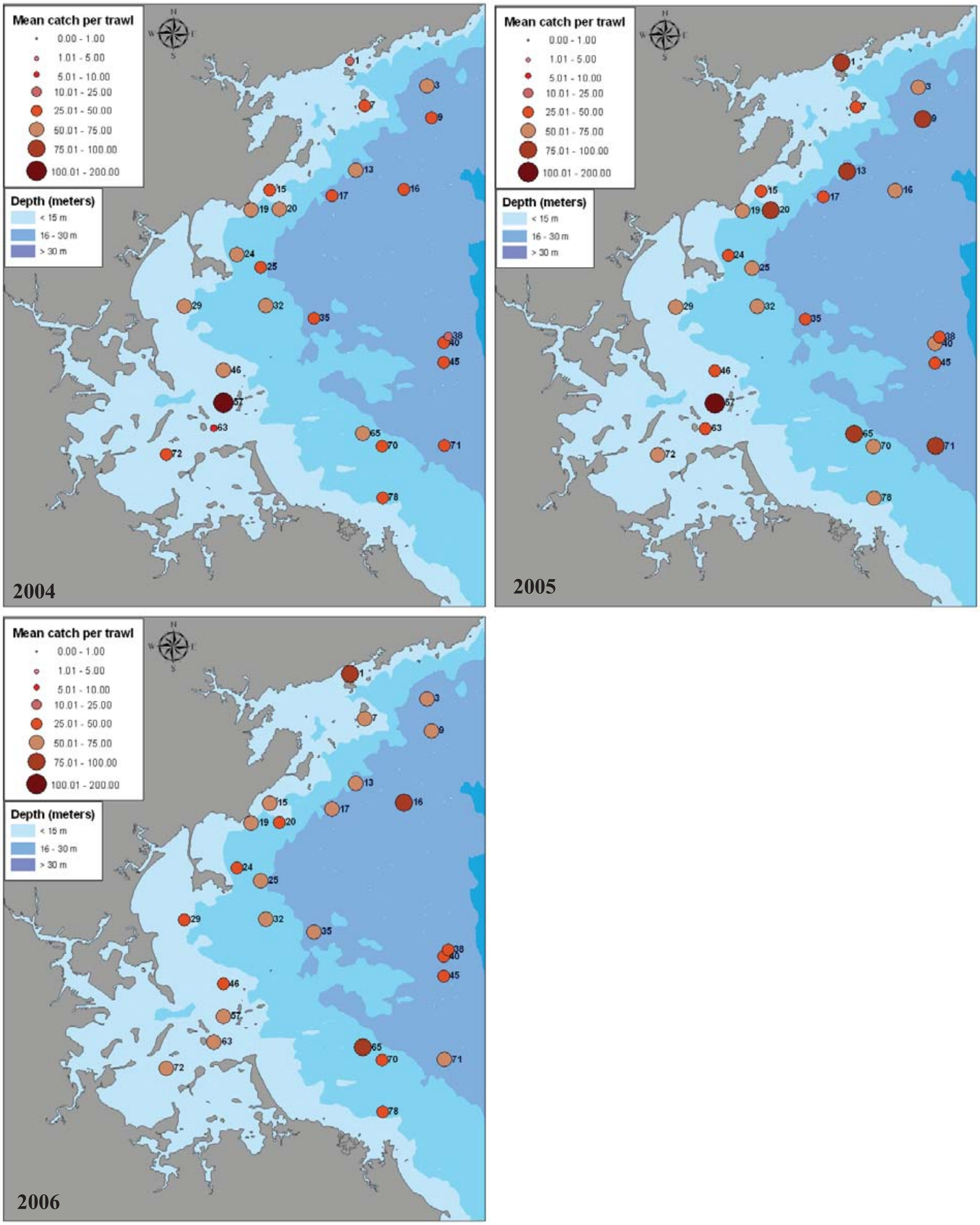

Figure IIIE.20. Average catch per trawl haul of sublegal lobsters at each sampling station, 2004 – 2006.

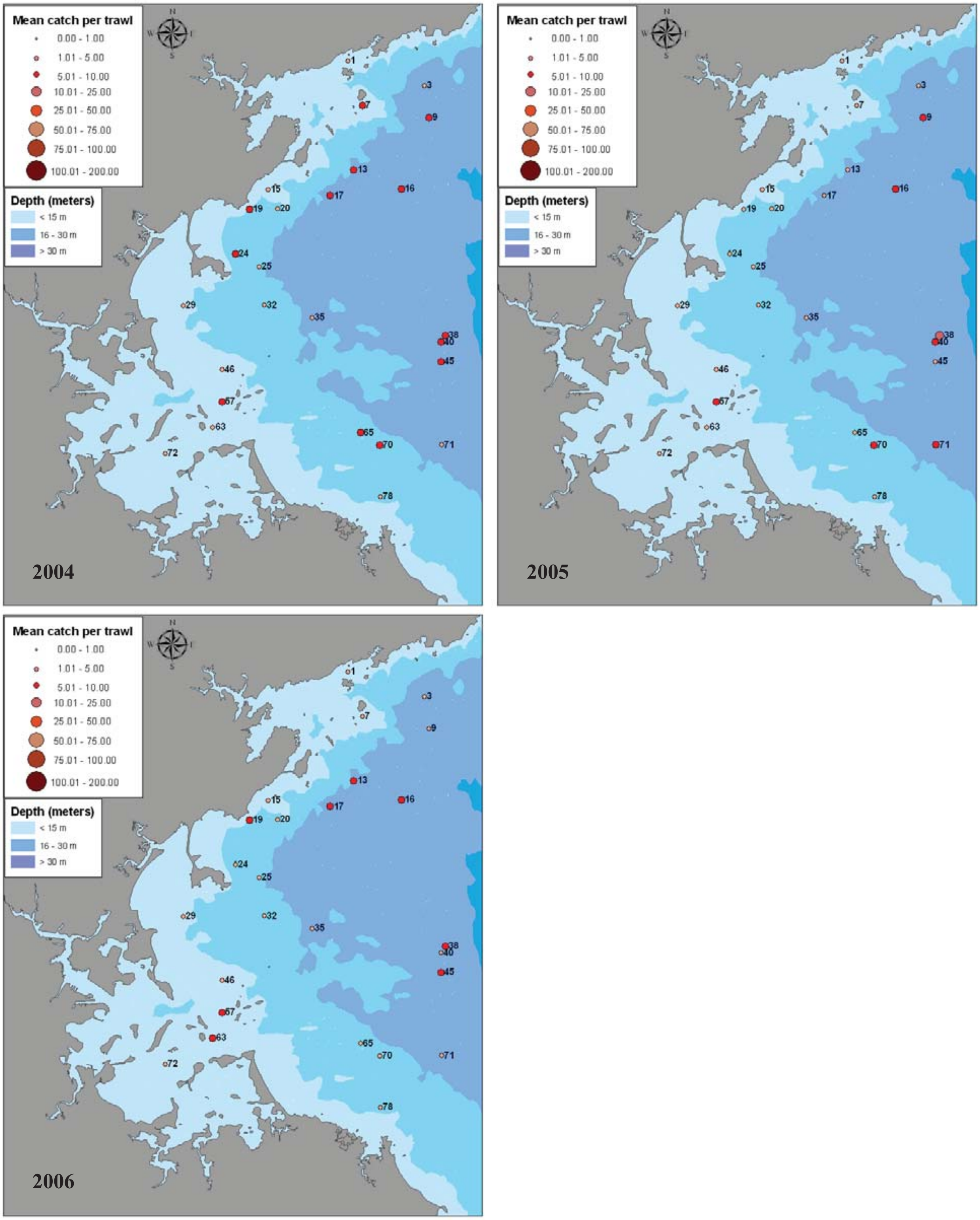

Figure IIIE.21. Average catch per trawl of legal lobsters at each sampling station, 2004 – 2006.

Conclusions and Future Research

The Massachusetts Bay ventless trap pilot sampling effort initiated in 2004 with HubLine funds provided an excellent platform to assess the methodology and survey design of a broad scale random stratified ventless trap survey for American lobster. This initial effort led to an expanded 80 station, seven month survey in Massachusetts Bay in 2005 and 2006, and also led to a coastwide survey, adopted by the Atlantic States Marine Fisheries Commission (ASMFC), which was implemented in coastal waters from Maine to Long Island, NY in 2006, 2007, and 2008. The ASMFC coastwide ventless trap survey is based on the sampling methodology and survey design developed for this initial ventless trap sampling effort, and it is planned to continue indefinitely as an additional means to monitor American lobster relative abundance in U.S. coastal waters.

While stratification by both substrate and depth seems logical for American lobster, we did not observe any significant trends in CPUE by substrate type. This lack of relationship between substrate type and CPUE could be related to differences in the daily scale of lobster movement and the scale of our sampling grid. It is possible that lobsters were moving into featureless sediment stations from adjacent areas, beyond the sampling grid, which had complex sediments (hard bottom). An alternative explanation for the lack of relationship between sediment type and CPUE is that the relative efficiency of the traps varied by sediment type. For example, lobsters on complex substrates may be less likely to trap because of increased shelter and prey opportunities. Depth, however, was an important variable influencing catch rates and size distribution. Thus the results of this survey suggest that future surveys should be depth stratified, but that stratification by substrate may not be useful.

There were no apparent regional trends (North to South) in the CPUE of sublegal and legal lobsters within the study area. Sublegal CPUE was fairly evenly distributed throughout the study area in all three years, while legal CPUE was consistently higher in the deepest strata. This observation supports our expectation that the trends in CPUE by depth were indeed driven by depth or its associated temperature gradient and not site specific-differences in catch rates. Sublegal lobsters tend not to make seasonal migrations, making them more likely to be evenly distributed in the fall when the sampling occurred, whereas legal-sized lobsters tend to migrate to deeper water in the fall.

The 3-year, October-November, time series is inadequate to draw meaningful conclusions about relative abundance trends, since it does not encompass the entire molting season. However CPUE of sublegals was significantly less an 2004 compared to 2005 and similar to 2006, while legal CPUE exhibited no differences across years.

One of the next steps for ventless trap surveys involves defining the actual area on the bottom that is sampled by each trap type, thus allowing us to use the relative abundance estimates for each strata to estimate lobster density. This process will require that each strata be treated separately, as the factors that influence the area of trap attraction will vary by strata characteristics (Miller 1990, Tremblay and Smith 2001, Tremblay *et al* 2006).

Another avenue of future research is examination of the possibility and degree of trap saturation that may be occurring in the ventless traps. It is possible that behavioral interactions of lobsters in and around the traps may be influencing the catch retained, and it is important to understand the degree to which this may influence catch characteristics. These factors could impact the survey's ability to differentiate between periods of moderate abundance and high abundance, and as such should be a high priority for future research.

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III F. Bottom Trawl Survey Trends for Selected Species

MarineFisheries' Coastwide Resource Assessment bottom trawl survey indices were calculated for selected finfish and invertebrate species found in the HubLine area of construction. The survey is conducted semi-annually (May and September) throughout Massachusetts coastal waters and generates stratified-random relative abundance indices for available marine species. The time series began in 1978 and is currently conducted aboard NOAA's 65' R/V Gloria Michelle. A ¾ North Atlantic type two-seam trawl (39' headrope/51' footrope) is fished with a 3.5" rubber disc chain sweep and 6' x 40", 325lb rectangular wooden doors. Net mesh varies depending upon the section (3.5",wings and square; 2.5", body and codend; 0.25", codend liner).

Focus was placed on relative abundance trends for selected species from the survey's Region 5 (Massachusetts Bay to the New Hampshire border, Figure IIIF.1) because it encompasses the HubLine study area. However, it should be noted that this bottom trawl survey was not designed to detect fluctuations in abundance on a fine geographic scale, e.g., the HubLine trench. The statistical precision of a survey's indices is a critical factor in one's ability to determine annual differences in parameters. Within a stratified-random design, trawl frequency, i.e., number of tows per square mile, is a key element of statistical precision and this survey's precision may be more appropriate for detecting larger scale changes.

Other considerations for data interpretation include the influence of large annual differences in young-of-the-year catches on fluctuations in annual abundance indices for many species, Atlantic cod in particular. In addition, a species distribution may vary, thereby contributing to annual variation in catch. These issues can be exacerbated when examining a limited geographic area, particularly when the study area is smaller than the overall range of the species.

Nevertheless, analyses of long term survey time series trends can be useful in evaluating the general status of the selected species. Relative biomass (mean weight per tow) and relative abundance (mean catch per tow in number of animals) from 1978-2007 is graphed for Atlantic cod (Figure IIIF.2), winter flounder (Figure IIIF.3), yellowtail flounder (Figure IIIF.4), American lobster (Figure IIIF.5), and Sea Scallops (Figure IIIF.6).

Spring and Fall biomass and abundance trends for Atlantic cod oscillated without apparent trend during the 1978-2007 time series (Figure IIIF.2). However, focus on the spring season, when cod are more available, reveals that spring biomass was below the time series median during most of the 1990's, and since 1999, biomass has been above the median in all but one year. Spring abundance trended higher since 1999 after a period of low indices during 1990-1998.

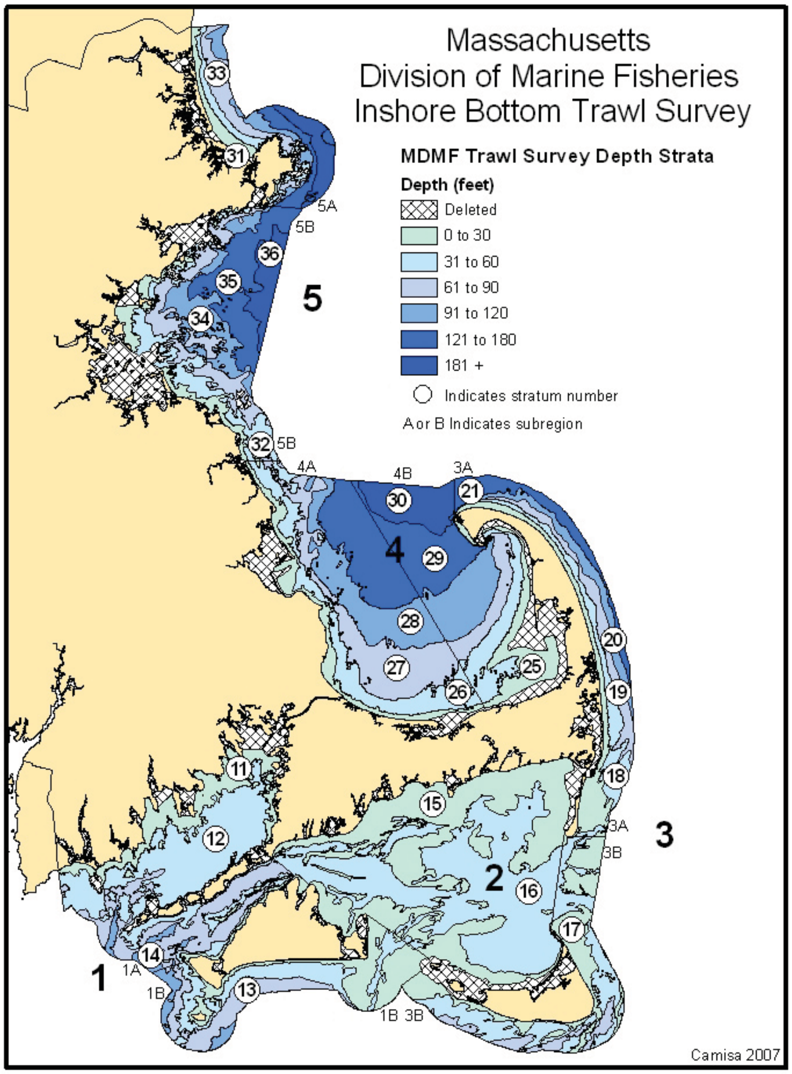


Figure IIIF.1. Massachusetts inshore bottom trawl survey study area showing Region 5 represented by depth strata 31through 36.

With the exception of the fall abundance data which fluctuated without trend since 1985, annual biomass and abundance data for yellowtail flounder fluctuated upward in recent years (Figure IIIF.3).

Winter flounder indices were low during the 1980's, strengthened during the late 1990's, peaked between 2000 and 2003, then declined in the last 3-4 years of the series (Figure IIIF.4).

American lobster biomass and abundance data peaked in the early to mid 1990's (Figure IIIF.5), however, survey biomass and abundance levels before and after this peak were similar.

Sea scallop biomass and abundance, was higher in the latter half of the time series, declining to the time series median by 2007 (Figure IIIF.6).

Figure IIIF.2. ***Marine Fisheries*** **bottom trawl survey trends for Atlantic cod from Massachusetts Bay (state waters from North River to NH border), 1978-2007. (Red line: Loess Smoothed Index, span=0.05, degree=2; black line: time series median).**

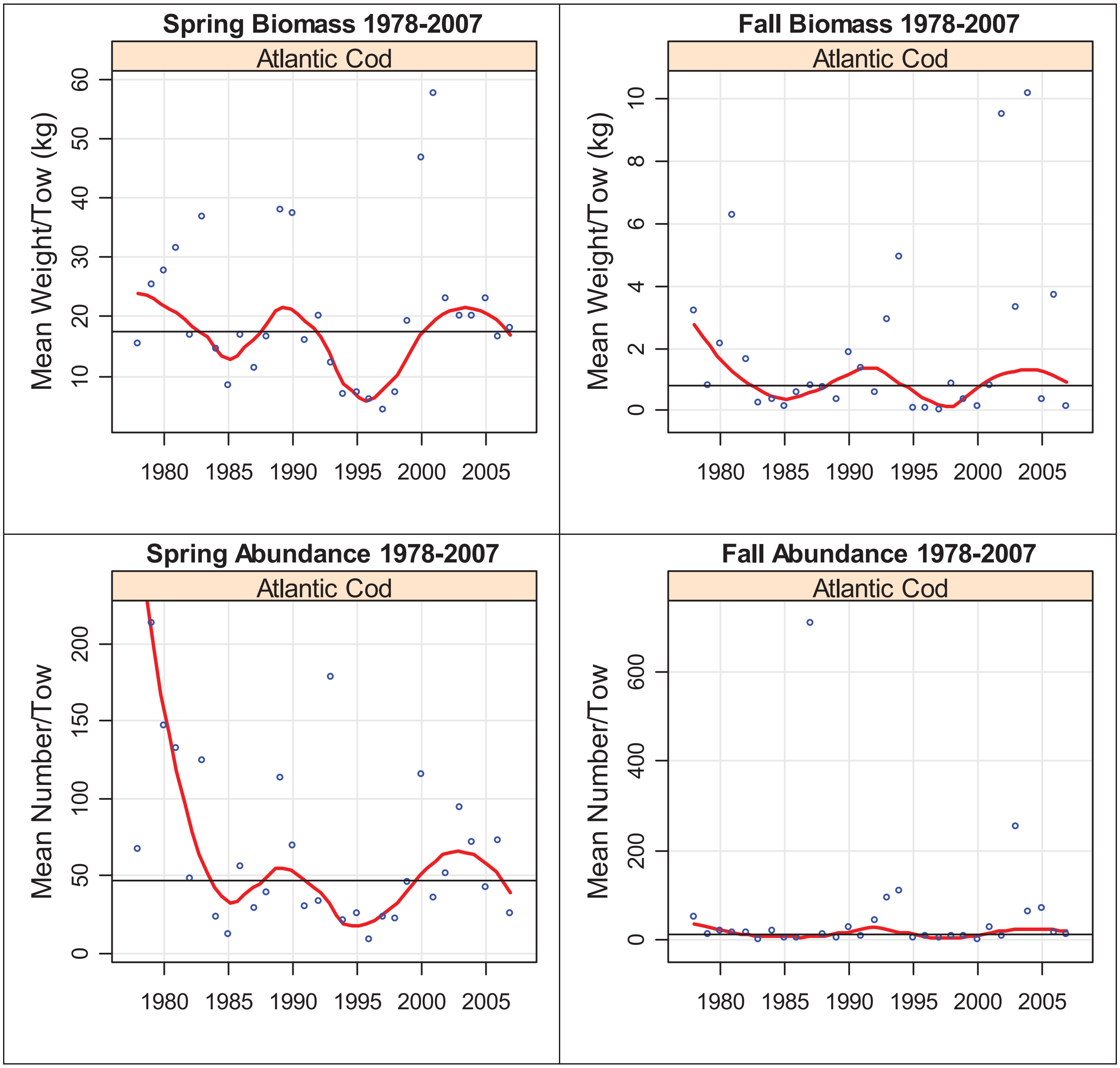


Figure IIIF.3. ***Marine Fisheries* bottom trawl survey trends for yellowtail flounder from Massachusetts Bay (state waters from North River to NH border), 1978-2007. (Red line: Loess Smoothed Index, span=0.05, degree=2; black line: time series median).**

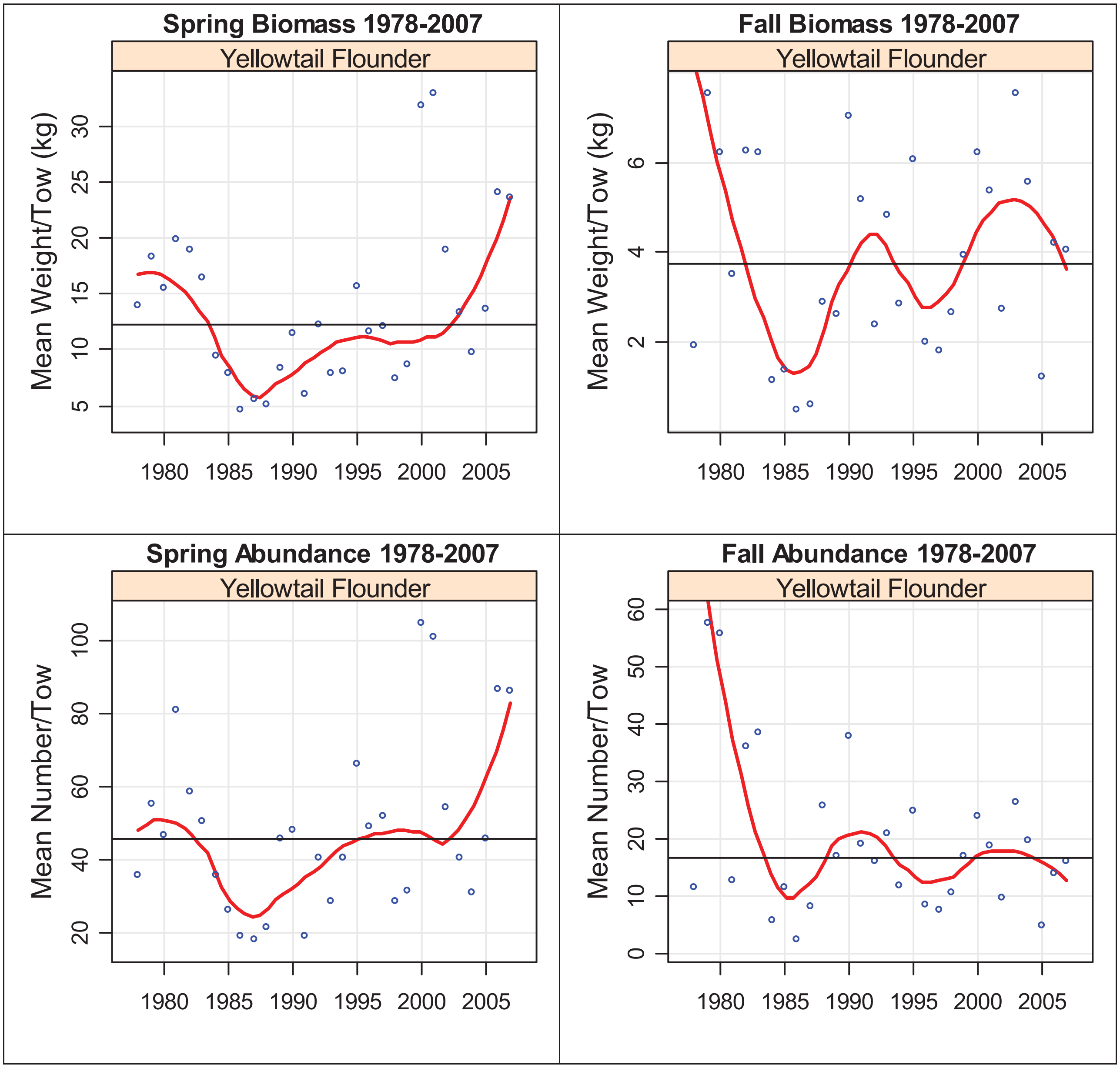


Figure IIIF.4. ***Marine Fisheries*** **bottom trawl survey trends for winter flounder from Massachusetts Bay (state waters from North River to NH border), 1978-2007. (Red line: Loess Smoothed Index, span=0.05, degree=2; black line: time series median).**

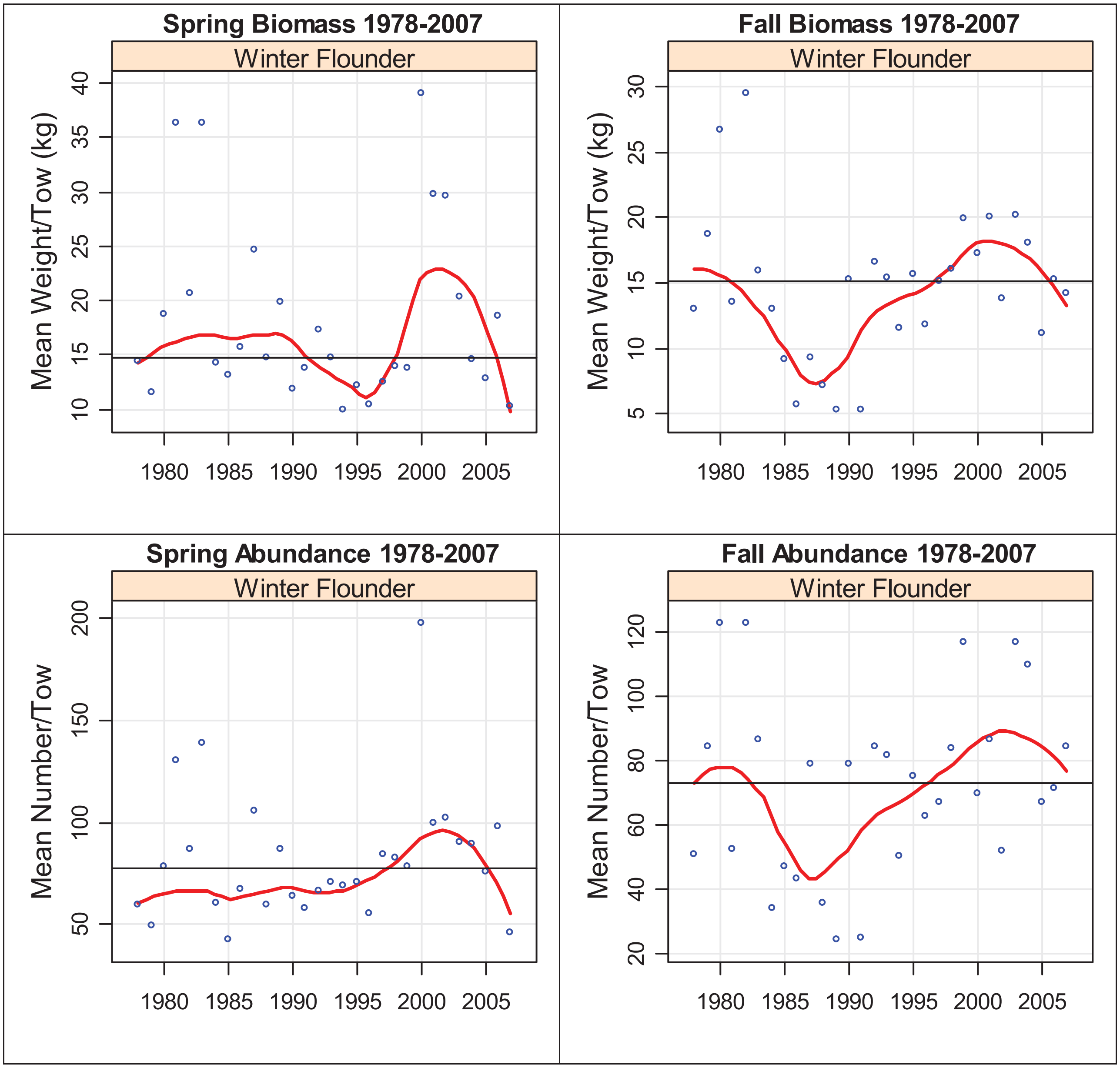


Figure IIIF.5. ***Marine Fisheries*** **bottom trawl survey trends for American lobster from Massachusetts Bay (state waters from North River to NH border), 1978-2007. (Red line: Loess Smoothed Index, span=0.05, degree=2; black line: time series median).**

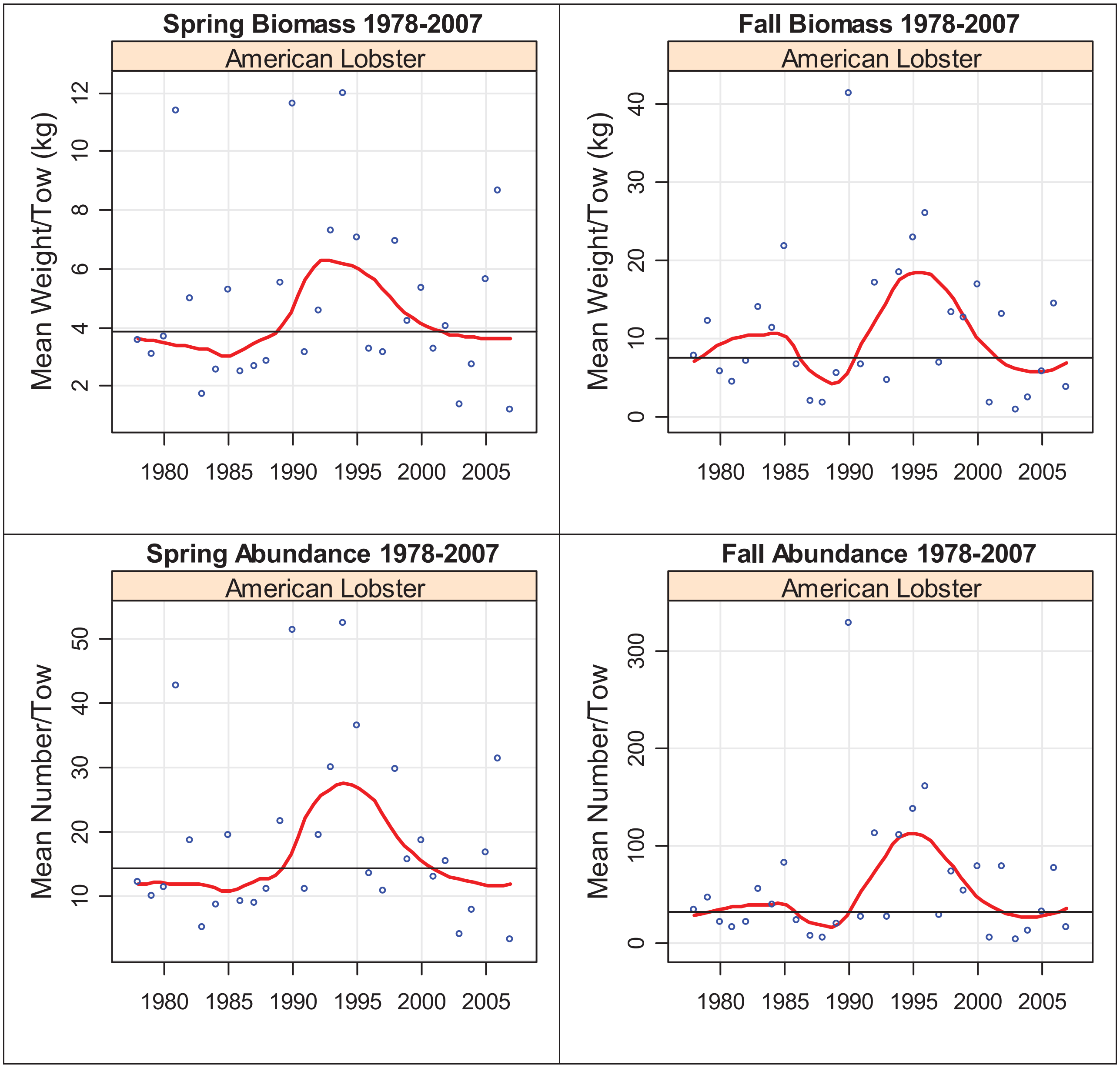
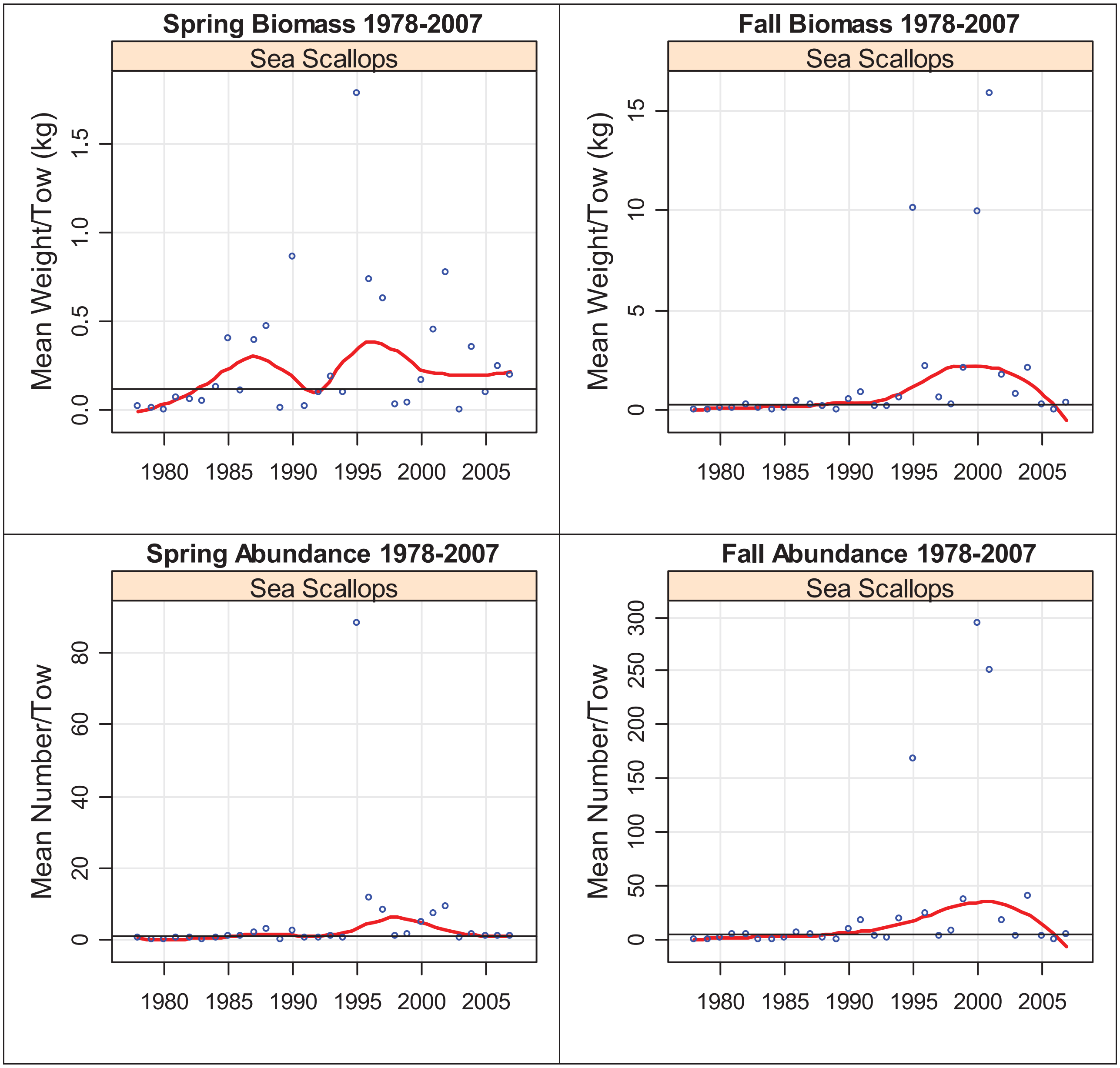


Figure IIIF.6. ***Marine Fisheries*** **bottom trawl survey trends for sea scallops from Massachusetts Bay (state waters from North River to NH border), 1978-2007. (Red line: Loess Smoothed Index, span=0.05, degree=2; black line: time series median).**



Acknowledgements

Appreciation is extended to M. Camisa for assistance with graphical display of bottom trawl survey trends and to D. McKiernan for technical review of the Monitoring and Assessment report sections.