IV B. Habitat Enhancement Project

Chapter 1: Artificial Reef Site Selection Model

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Introduction

Despite its common use as a mitigation tool, artificial reef development is rarely subjected to a rigorous site selection process prior to deployment. Although many states within the U.S. have artificial reef plans with guides on site selection methods, these guidelines focus primarily upon physical variables (i.e. shipping channels, commercial fishing, or substrate) and methods necessary to obtain local, state, and federal permits (e.g. Wilson et al. 1987, Stephan et al. 1990; Figely 2005; U.S. Dept. of Commerce 2007). The majority of scientific effort is placed on studying the artificial reefs post-installation to develop successional time series and quantitative assessments of community dynamics (e.g. Ardizzone et al. 1989; Reed et al. 2006; Thanner et al. 2006). While these post-deployment results are important for judging the effectiveness of reefs, they can fall short in providing managers the details necessary for informed decision making, regarding future siting for mitigation reefs. Indeed, inadequate site selection is one of the most common causes of unsuccessful artificial reefs (Mathews 1985; Chang 1985; Tseng et al. 2001; Kennish et al. 2002).

Exclusion mapping, where cartographic information is used to exclude undesirable areas, is one of the most popular methods utilized by managers and scientists to select sites for habitat restoration and/or artificial reef deployment (Pope et al. 1993; Gordon Jr. 1994; Tseng et al. 2001; Kennish et al. 2002; Kaiser 2006). While this method is useful for initially eliminating areas where obvious conflicts (with navigation, fishing activities, oil and gas platforms, etc.) are likely to arise, this process does not provide managers with the particular physical and biological information needed to understand the ecology of a prospective site for artificial reef development.

A number of criteria have been identified as important to the artificial reef site selection process, including: currents (Nakamura 1982; Baynes and Szmant 1989), wave action (Nakamura 1982; Duzbastilar et al. 2006), proximity to natural habitat (e.g. Carter et al. 1985b; Chang 1985; Spieler et al. 2001), substrate stability (Mathews 1985), and existing benthic communities (Carter et al. 1985b; Mathews 1985; Bohnsack and Sutherland 1985; Hueckel et al. 1989). Although these site selection criteria have been summarized in the literature (Yoshimuda and Masuzawa 1982; Carter et al. 1985b; Ambrose 1994; Sheng 2000), there are few examples of projects that have investigated each criterion prior to reef deployment (but see Hueckel and Buckley 1982; Tseng et al. 2001; Kennish et al. 2002). Additionally, the natural presence of larvae has not been included as a criterion in the site selection process, despite the importance of larval delivery to the success of a newly deployed artificial reef with goals of enhancing production (Carter et al. 1985b; Pratt 1994). Although exclusion mapping could take the majority of these parameters into account, there are no published examples of a study that combines exclusion mapping with physical and biological field measurements used to evaluate the suitability of a site for artificial reef deployment.

In 2004, the Massachusetts Division of Marine Fisheries (*MarineFisheries*) received monetary compensation from Algonquin Gas Transmission

Company to provide mitigation for impacts resulting from the construction of a 48-km natural gas pipeline, the "HubLine", in Massachusetts Bay, Massachusetts, U.S.A. A substantial amount of the impacted bottom along the pipeline footprint was comprised of rocky substrate, a habitat type that cannot be easily restored. Hard-bottom habitat is critical to several life stages of commercially important species in this region, including American lobster (*Homarus americanus*), Atlantic cod (*Gadus morhua*), yellowtail flounder (*Limanda ferruginea*), Atlantic sea scallops (*Placopecten magellanicus*), and numerous other fishes and invertebrates (Wahle and Steneck 1992; Tupper and Boutilier 1995; Johnson et al. 1999; Packer et al. 1999). As mitigation for the assumed impacts of hard-bottom habitat loss, *MarineFisheries* constructed a series of cobble/boulder reefs in Massachusetts Bay designed to target different life history stages of invertebrate and vertebrate species (see Appendix IVB.A for reef design specifications).

Prior to deployment, a thorough site selection technique was developed with the aim of promoting a successful reef. Our goals were to (1) utilize exclusion mapping as an initial means of selecting target areas for reef deployment, (2) collect data *in situ* to develop a comprehensive record of biological and physical parameters for each prospective site, and (3) create a rigorous but simple site selection process that could be adapted for use by others interested in artificial reef development. American lobster (*H. americanus*) was selected as the target species for these investigations due to local commercial importance of the species. This is one of the first examples of a site selection model that included natural larval supply as a criterion. Furthermore, the selection process presented here uniquely integrates procedures recommended by multiple investigators into a comprehensive model encompassing both biological and physical criteria.

Materials and methods

Exclusion Mapping. Nine general and two project-specific site selection criteria were used to determine the optimal site for an artificial reef in Massachusetts Bay (Table IVB1.1). Following the identification on these criteria, we developed a simple model to identify potential sites using a geographic information system (GIS) (ESRI ArcGIS 9.0). Three criteria were included in the GIS model: substrate, bathymetry, and proximity to the HubLine pipeline. Prior to running the model, the substrate and depth data layers were "clipped" to create a 300-m border on either side of the pipeline's path (a detailed description of the commands used in this model is listed in Appendix IVB.B). This delineated area represented the project's maximum acceptable distance away from the pipeline based on mitigation requirements. The clipped substrate and bathymetry data were coded to represent prime, potential, and unsuitable areas (Table IVB1.2). Next, the data layers were converted to a grid file, where each grid cell (10 m^2) contained the reclassified value for that particular substrate or depth. These categorical indices were then reclassified into numerical values (Table IVB1.2). Using the ArcGIS raster calculator, numerical values from both data layers were multiplied to produce a site-suitability data layer. This layer was used to identify prime sites for the artificial reef (Figure IVB1.1); we then selected 24 potential sites for further investigation that fell within areas delineated as "prime."

Depth Verification and Slope Calculation. After completing the initial selection process using exclusion mapping, bathymetry data were collected *in situ* on all 24 sites to verify the GIS datalayer. Based on the reef design, each potential site footprint was 140 x 50 m in size (Appendix IVB.A). Depth data were collected using sonar within the footprint of the site (Appendix IVB.B). Depth was adjusted to account for tidal stage. Slope was calculated based on the difference between the depths of measured points and the distance between those points. Sites that were too shallow or too deep (< 5 m or > 15.1 m), and sites that had slopes over 5º were eliminated from further consideration (Table IVB1.1, Yoshimuda and Masuzawa 1982). This process eliminated 10 potential sites leaving 14 sites in consideration (Figures IVB1.2 & IVB1.3).

Table IVB1.1. Criteria for selecting a site for habitat enhancement in Massachusetts Bay.

Criterion	Description	Reference
General criteria		
Accessibility	Area needed to be suitable for safe small boat operation and recreational use of the reef, and in a location that did not interfere with commercial vessel traffic.	Tseng et al. 2001; Kennish et al. 2002
Current	Areas with strong tidal currents were avoided to prevent scouring and to allow SCUBA monitoring of the reef. Some current was necessary to deliver nutrients and larvae to the reef, and to maintain a well-oxygenated environment. Sites were oriented for maximum exposure to the current.	Nakamura 1982; Baynes and Szmant 1989
Depth and wave action	Required water depths deep enough for navigation and to protect the reef from wave action, but shallow enough to promote larval settlement. Target depth range was 5 - 9.9 m; 10 - 15 m was also acceptable.	Nakamura 1982; Duzbastilar et al. 2006
Established habitat and/or proximity to established habitat	Existing natural reefs were avoided to minimize further impacts to hard-bottom habitat. The artificial reef needed to be in fairly close proximity to a natural reef for comparison of the two sites.	Carter et al. 1985; Ambrose 1994; Spieler et al. 2001
Natural larval supply	Prospective sites were tested for the presence of a natural larval supply, specifically targeting postlarval crustaceans such as American lobster.	This study
Substrate	Substrate consisting of firm sediment types that provided a stable platform for the cobble and boulder were needed. Soft, muddy sediments, silt, and shifting fine sand were avoided to minimize reef sinking.	Yoshimuda and Masuzawa 1982; Mathews 1985
Slope	Sites with slopes over 5º were eliminated for reef stability.	Yoshimuda and Masuzawa 1982
Water quality	Water around the potential sites needed to have low turbidity and low siltation rates. Adequate light penetration was necessary to establish primary productivity.	Yoshimuda and Masuzawa 1982
User conflicts	Consideration was given to potential conflicts with other user groups, including commercial and recreational fishers.	Kennish et al. 2002
Project-specific criteria		
Proximity to the pipeline pathway	Areas <30 m away from the pipeline were targeted, although sites up to 300 m away from the pipeline were considered.	This study
Proximity to cobble fill areas on the pipeline	Proximity to points where the pipeline was covered with cobble fill was considered because the fill point would serve as a comparison area for mitigation research.	This study

Substrate Composition. To determine the composition of the surficial substrate at each site, underwater surveys using SCUBA were conducted along two 50-m transects per potential site. The two parallel transects were deployed at 45º angles to the 140 x 40-m footprint such that each transect bisected about half of the reef area (Appendix IVB.B). Divers quantified substrate type in continuous 5 x 2-m sections, gauging swath-width with a 2-m PVC bar, along each transect. Each divers collected data on one side of the transect. Using a ruler for reference, coarse surficial substrate was visually classified according to the Wentworth scale (i.e. bedrock, boulder, cobble; Wentworth 1922) while fine substrates were placed into broad categories such as sand, mud, or silt. These data were categorized as primary (sediment type that constituted more than 50% of the area), secondary (sediment type that constituted between 10 and 50% of the area),

Table IVB1.2. Reclassification values for (*a*) bathymetry and (*b*) substrate data used in the exclusion mapping model. Depth range and substrate type were reclassified based on biological and physical constraints.

Original value	Reclassified value	Reasoning for reclassification	Numerical value
(*a*) *Bathymetry*			
0 – 4.9 m	Unsuitable	Navigational concerns, wave action	0
5 – 9.9 m	Prime	Ideal larval settlement depth, safe SCUBA depth	2
10 – 15 m	Potential	Acceptable larval settlement depth, reduced bottom time for divers	1
>15.1 m	Unsuitable	Too deep for many larvae, and SCUBA	0
(b) Substrate (Knebel 1993)			
Deposition = silt, very fine sand	Unsuitable	Not capable of supporting reef weight	0
Erosion or nondeposition I = boulder to coarse sand	Unsuitable	Existing productive habitat	0
Sediment reworking = fine sand to silty clay	Potential	Potential sedimentation problems	1
Erosion or nondeposition II = granule/pebble to fine sand	Prime	Capable of supporting reef weight	2

or underlying (sediment type found directly beneath the primary and secondary substrates). For example, Massachusetts Bay is characterized by large areas of boulder and cobble with sand or granule underlying; consequently, data from this type of area could be classified as: primary = boulder, secondary = cobble, and underlying = sand. If the majority of the substrate was the same throughout the quadrat, primary and secondary substrates were recorded as the same type. For example, if a quadrat consisted of 95% cobble and 5% shell litter, we recorded both the primary and secondary substrates as cobble, while the shell litter was recorded as tertiary.

Divers also conducted a qualitative "hand burial" test every 5 m to obtain a general index of the relative ability of the substrate to support the weight of a reef. Each diver made a fist with their hand and attempted to press it deep into the substrate. Hand burial depth was coded on a scale of 1 – 3 depending on how far the hand was buried (see Appendix IVB.B).

Divers qualitatively estimated the abundance of benthic macroinvertebrates and vertebrates seen during these dives. Once dives on a prospective site were complete, divers filled out a species presence/absence form (Appendix IVB.C), estimating the percent coverage of algae and encrusting invertebrate species as well as counts for mobile benthic vertebrates and invertebrates.

Although wave action was considered by following Nakamura's (1982) depth suggestions when screening potential sites, divers also ranked the presence of sand ripples on sites as an indicator of wave presence. Sand ripples were classified into three categories: large (> 13.1 cm height), small (2.5 – 13 cm), or none.

<u>Weighting and Ranking Analysis</u>. A weighting and ranking system was developed to incorporate multiple aspects of the site selection criteria. Data used in this portion of the study included: primary and secondary surficial substrates, underlying sediment, sand ripple presence, site proximity to the pipeline, and site proximity to cobble fill points along the pipeline (areas along the pipeline armored with rock) (Table IVB1.3).

For each potential site, we assigned a numerical score to every data category based upon how well the site met the selection criteria (Table IVB1.3). Categories possessing more than one type of classification (i.e. surficial substrates) were weighted by the areal proportion of that classification using the assigned numerical score. For example, if a site had 70% pebble (prime score = 3) and 30% silt (poor score = 1) as

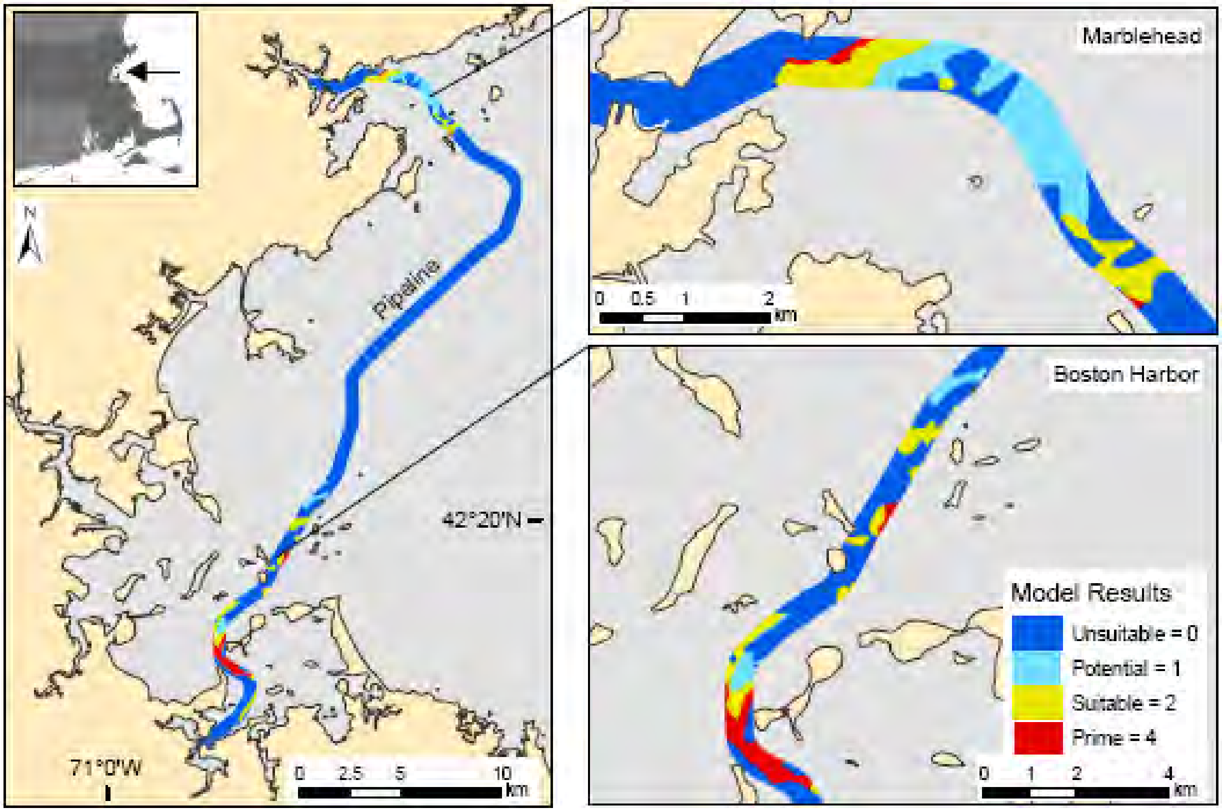

Figure IVB1.1. Results of the initial exclusion mapping model for habitat enhancement in Massachusetts Bay, Massachusetts, USA. Numerical values representing prime, potential, and unsuitable depth and sediment were multiplied using the GIS raster calculator to produce the suitability data layer.

primary surficial substrates, the following calculation was performed to obtain a final score: (0.70 x 3) + (0.30 x 1) = 2.4.

Next, a weighting system was developed based on the relative importance of each criterion to the project goals. Substrate variables were assigned the highest weights: primary = 50%, secondary = 15%, and underlying = 15%, since proper substrate was necessary for creating a stable reef, and existing hard-bottom habitat was to be avoided. The remaining criteria were assigned the following weights to represent their importance in the selection process: wave action = 10%, proximity to the pipeline = 5%, and proximity to cobble fill points along the pipeline = 5% (Table IVB1.3). Numerical scores for each data category were multiplied by the category's assigned weight. The final weighted scores were summed for each site. Sites with the highest scores contained the majority of the required physical attributes in the selection process.

In addition to the ranking analysis, a principle component analysis (PCA) was conducted using all sites, based on the original scores from each data category per site. The PCA was used to examine how particular variables affected the sites' overall scores, and to determine the degree of similarity among sites based on relative strengths of criteria used to assess the sites. The PCA demonstrated how high and low-ranking sites clustered in comparison to each other.

The weighting and ranking analysis did not consider biological aspects of the sites; therefore, qualitative notes on the abundance and diversity of macroinvertebrates and vertebrates were considered post-ranking analysis. In order to avoid placing the reef on a naturally productive area, one site was eliminated because of high species abundance and diversity. At this point, the number of potential sites was narrowed to six.

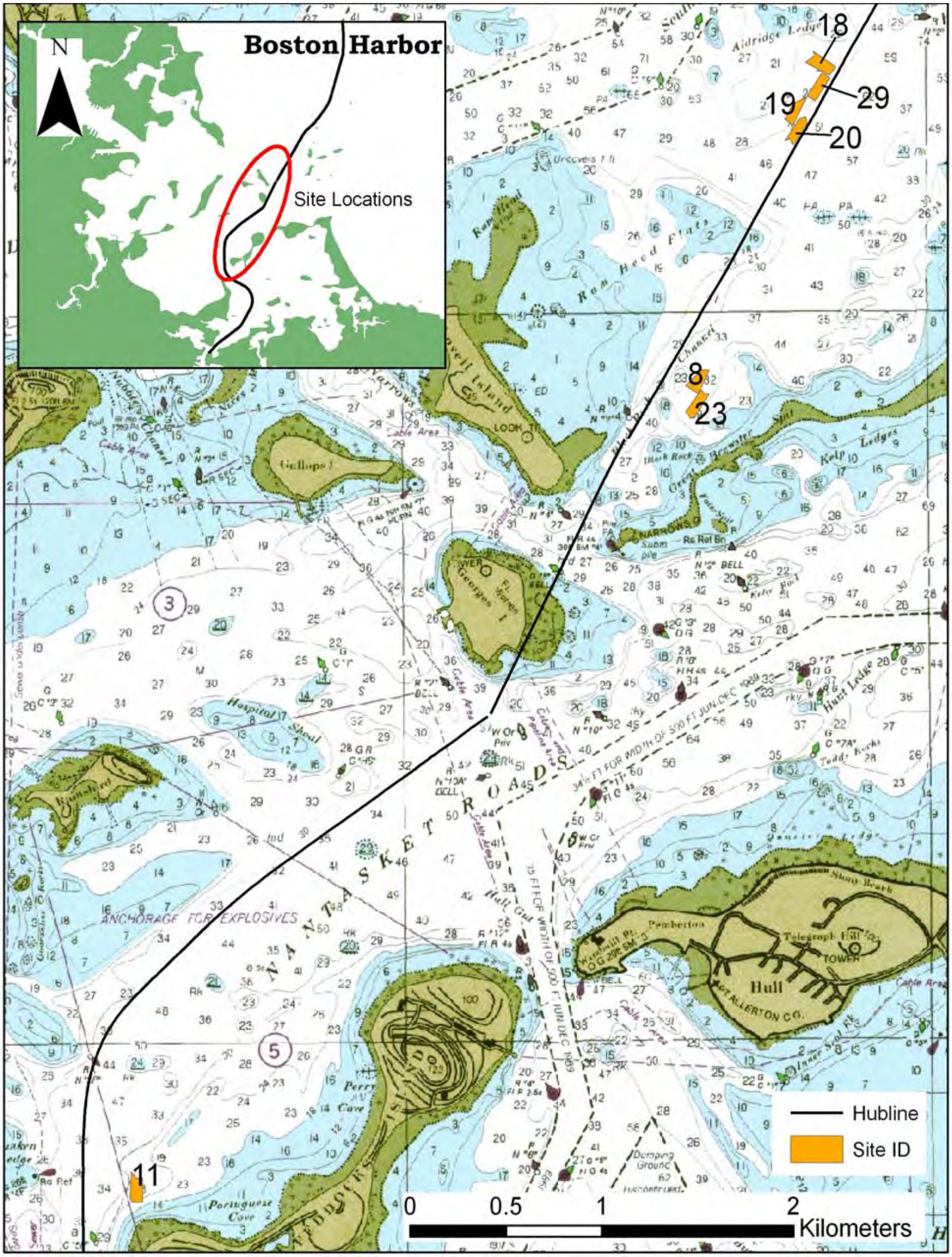

Figure IVB1.2. Location of potential sites in Boston and Hull following slope and depth eliminations.

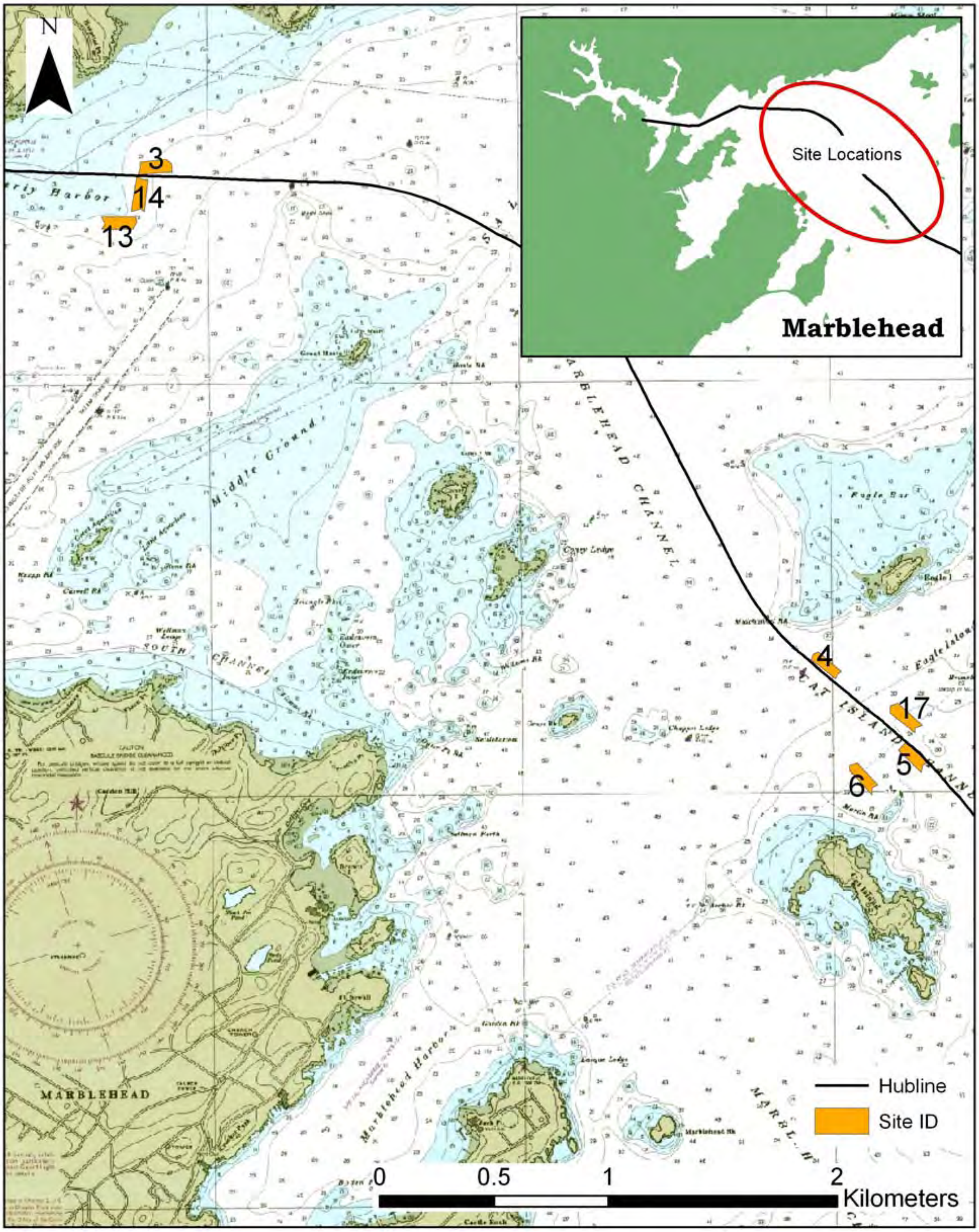

Figure IVB1.3. Location of potential sites in Beverly and Marblehead following slope and depth eliminations.

Table IVB1.3. Assignment of numerical scores based upon data classifications for the site ranking analysis.

Data category	Description of data categories	Classification	Numerical score
Primary surficial substrate	Boulder, cobble, silt	Poor	1
	Pebble, granule, sand, shack, shell debris	Prime	3
Secondary surficial substrate	Boulder, silt	Poor	1
(see Wentworth, 1922 for	Flat cobble	Potential	2
description of substrate type)	Pebble, granule, sand, shack, shell debris, hard clay	Prime	3
Underlying sediment	Soft clay, silt	Poor	1
	Hard clay, granule, sand	Prime	3
Wave action / sand ripple	Large sand ripples (>13.1 cm height)	Poor	1
	Small sand ripples (2.5 - 13 cm height)	Potential	2
	No sand ripples	Prime	3
Proximity to the pipeline	150 - 300 m from pipeline	Poor	1
	30 - 150 m from pipeline	Potential	2
	<30 m from pipeline	Prime	3
Proximity to cobble fill on	>150 m from fill point	Poor	1
pipeline	30 – 150 m from fill point	Potential	2
	Adjacent to fill point (<30 m)	Prime	3

Current Direction Meter and Qualitative Transect Surveys. Prior to conducting thorough transect surveys on each of the six sites, we wanted to obtain a relative estimate of the predominant current direction near each footprint. Our goal was to use these data to shift sites, if necessary, such that the rectangular reef would be perpendicular to the predominant current (Baynes and Szmant 1989).

We designed an effective, low-cost current direction meter to estimate the predominant current direction near each of the potential sites. The current direction meter collected information from four directions: (1) north / south, (2) east / west, (3) northeast / southwest, and (4) northwest / southeast. A concrete base was constructed with a rebar stake placed vertically in the center and eye bolts on all four corners for lowering and lifting the device. Four 30-cm long PVC tubes (7.6 cm diameter) were mounted horizontally onto the

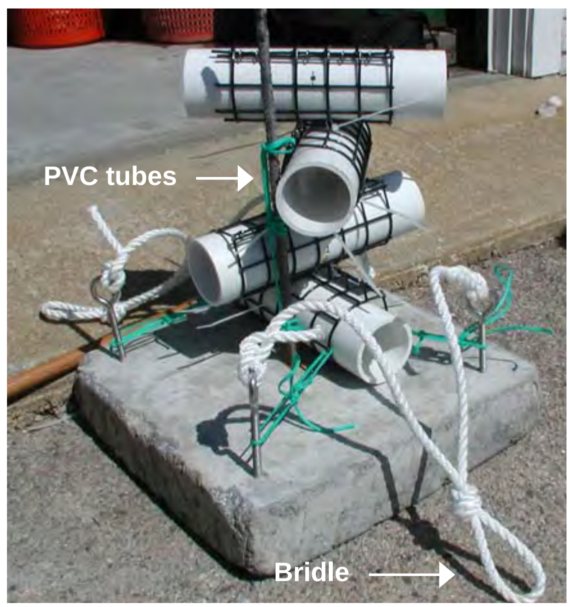

Figure IVB1.4. Current direction meter. Image shows position of stacked PVC tubes on a concrete base and bridles used for deployment and retrieval.

stake and angled 45º from the previous tube (Figure IVB1.4). Small holes were drilled through the top and bottom of the tube's midpoint. We used the dissolution of molded plaster of paris blocks to measure water motion (similar to "clod cards;" Doty 1971). The blocks were filed to a weight between 30 - 33 g. Prior to deployment, each block was weighed and suspended through the holes into the center of the tubes by a wire running through the block. The current direction meter was lowered to the bottom and oriented by divers using a compass such that the uppermost tube faced north/south. After a soak time of 48 to 72 hours the current direction meter was retrieved. Blocks were allowed to dry for at least four days before they were weighed again. The block with the greatest weight loss was the block in the tube facing the predominant current. Using these data, we adjusted the orientation of potential sites as necessary.

Comprehensive visual surveys using SCUBA were conducted along 140-m transects on each of the properly oriented sites (sites were oriented perpendicular to the predominant current; Baynes and Szmant 1989). Three lengthwise transects were established along the sides and center of each footprint. Divers qualitatively noted habitat type and species diversity of macroinvertebrates and vertebrates on both sides of the transect. The viability of each site was discussed post-dive. Sites possessing hard-bottom habitat or comparatively high sampled species diversity were eliminated. Results of this survey were used to narrow the number of prospective sites to three.

Benthic Air-Lift Sampling. Using methods described by Wahle and Steneck (1991), the three potential sites, the pipeline fill point, and two natural rocky reefs were air-lift sampled in order to compare densities of mobile benthic macrofauna (Figure IVB1.5). Air-lift sampling provided two important datasets: it established baseline information on the sites prior to reef installation, and it allowed us to compare relative sampled species diversity and larval settlement on potential reef sites versus nearby natural reefs. If potential reef sites had similar densities of benthic macrofauna and/or species diversity when compared to the natural reefs, sites were eliminated to prevent disruption of existing productive habitat.

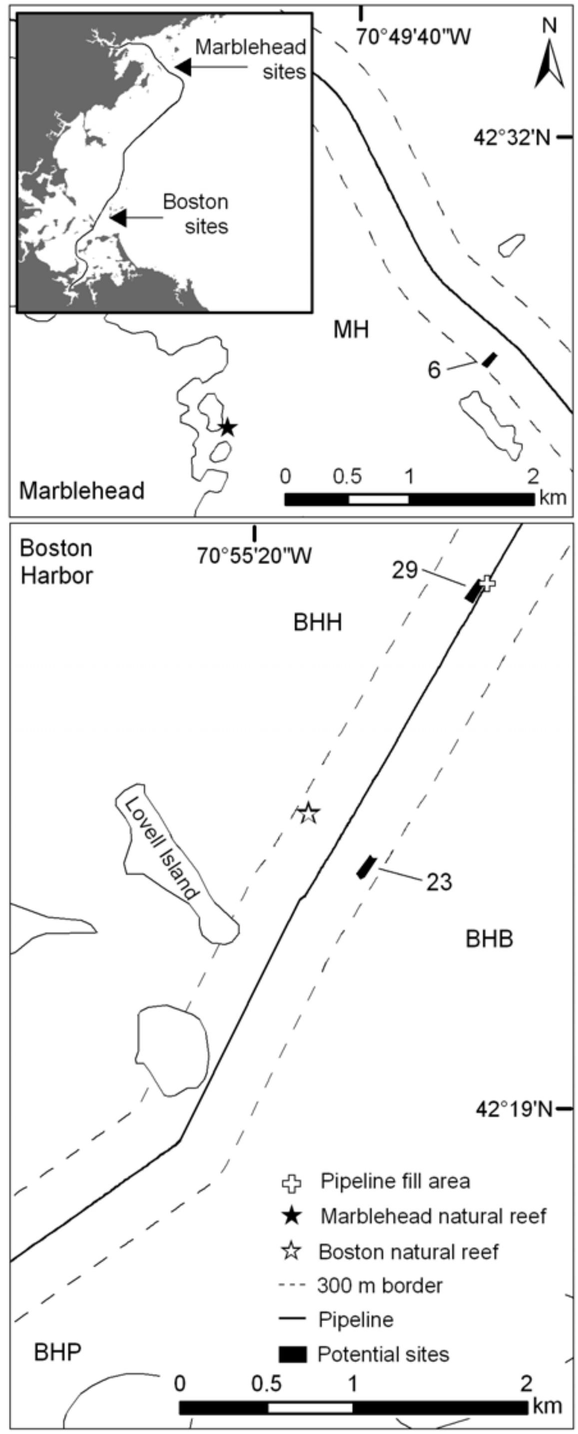

Figure IVB1.5. Location and orientation of final three potential sites, natural reefs, and the pipeline cobble fill point. Map also depicts general target areas for habitat enhancement: Marblehead (MH), Boston Harbor near the Hypocrite Channel (BHH), Boston Harbor near the Brewster Spit (BHB), and Boston Harbor near Peddocks Island (BHP).

At each site, twelve 0.5-m^2 quadrats were haphazardly placed on the substratum at least 2 m apart. Large boulders and patches of sand were avoided on the natural reefs (Wahle and Steneck 1991), whereas sand was primarily sampled on the potential reef footprints. The air-lift sampling device consisted of a PVC tube supplied with air from a SCUBA tank to create a vaccuum. Sampling a quadrat in cobble habitat involved pushing the lift tube (fitted with a 1.5-mm nylon mesh collection bag) slowly over the bottom while moving rocks individually until few interstitial spaces remained. If no rocks were present, such as on the potential reef sites, the lift tube was simply moved over the area of the quadrat until the entire quadrat had been sampled. Gastropods, polyplacophorans bivalves, decapods, echinoderms, solitary tunicates, and fish were identified to the lowest practical taxon and enumerated. Polychaetes were not counted (except for scale worms: families Polynoidae and Sigalionidae) because most were destroyed in the process. Species that were not readily identifiable in the field were preserved in alcohol and identified in the laboratory.

The following hypotheses were tested: (1) there is a difference in decapod crustacean density by site, (2) there is a difference in young-of-the-year (YOY) lobster density by site and, (3) there is a difference in sampled species diversity among sites.

A one-way ANOVA was used to investigate differences in mean decapod crustacean density by site (SPSS 9.0 statistical software). Data were $\lg_{10}(x + 0.1)$ transformed to meet the assumption of homogeneity and a post hoc comparison was conducted using a Tukey HSD test. YOY density data were examined by site using a non-parametric Kruskal-Wallis test and follow-up pairwise comparisons using permutation testing at 1000 iterations (Microsoft Excel 2002, Sprent 1989). Using all the enumerated species data, the Shannon index was used to assess diversity on each potential reef site and the nearby natural reefs (Krebs 1999).

Larval Settlement Collectors. All three potential reef sites lacked prime postlarval lobster settling habitat (i.e. cobble and boulder; Wahle and Steneck 1991 and 1992), which may explain the low levels of postlarval lobster settlement at the sites (see air-lift sampling results). Therefore, we used a modified settlement collector design (Incze et al. 1997) to determine if postlarvae would settle in these areas when provided with cobble habitat. Our 0.5-m^2 collectors (70.6 cm length x 70.6 cm width x 30.5 cm height) were built using coated wire (3.8 cm mesh) with a layer of Astroturf ™ on the bottom (Figure IVB1.6). Each collector was filled with 15 - 25-cm diameter cobble and lowered from the boat using a built-in bridle (Appendix IVB.B). Ten collectors were placed on each of the three sites in July prior to the postlarval lobster settlement season (Lawton and Lavalli 1995). Collectors remained on the bottom for two months before retrieval. Divers relocated the collectors and covered them with a thin 2-mm mesh screen to prevent escapement during the retrieval. Buoyed lines were tied to the collector bridle and the collector was hauled to the surface using a winch. All the rocks and Astroturf ™ from each collector were inspected and species were recorded following the same methods used in air-lift sampling.

The larval settlement collector data were used to address our primary hypothesis; young-of-the-

Figure IVB1.6. Settlement collector loaded with rocks and ready for deployment.

year (YOY) lobster or larvae of other species settle at these sites when provided with their preferred habitat. Two additional hypotheses were investigated using these data: (1) there is a difference in juvenile and adult lobster density by site and (2) there is a difference in sampled species diversity among sites. Data collected to investigate these hypotheses also indicated which species might initially colonize the artificial reef and how the reef would be utilized by a target species, American lobster.

A simple present/absent rule was used to address our primary hypothesis, whereby if YOY lobster or other YOY of other species were recorded in the collector we concluded that the site had a natural larval supply. Limited sample sizes prevented a more quantitative analysis on postlarval settlement. The second hypothesis was investigated by running a one-way ANOVA and a post-hoc Tukey HSD test on the mean number of lobster per 1 m^2 by site (SPSS 9.0 statistical software). Diversity indices (Shannon index) were calculated for each potential reef site (Krebs 1999).

Results

Exclusion Mapping. The GIS model results indicated general areas that had the most potential for successful artificial reef development; within these areas 24 sites (and five alternate sites to be used only if the other sites failed to meet the site selection criteria) were selected near naturally occurring hard bottom. The model allowed us to eliminate 80% of prospective reef area prior to field assessments (Figure IVB1.1).

Depth Verification and Slope Calculation. Eight sites were eliminated due to unsuitable depth or slope; the remaining 16 sites had slopes ranging from 0º to 5º. After careful consideration of these 16 sites, three more sites were eliminated due to known poor larval settlement in the area (*MarineFisheries*, unpublished data), high siltation rates, and concerns for diver safety due to heavy boat traffic. At this point Site 29, an alternate site, was included in the selection process because of the large number of eliminated sites and the need to fill a gap in a prospective area; this brought the total number of potential sites to fourteen (Figures IVB1.2 & IVB1.3).

All 14 remaining sites were within 11 km to the nearest harbor, and in the 6 – 15-m mean low water depth range, therefore meeting the accessibility criteria (Table IVB1.1). No sites were located within shipping channels marked on navigational charts. Additionally, no commercial fishing activities aside from lobstering were expected to occur within potential site areas due to shellfish closures and shallow, undesirable depths for mobile gear fishing practices such as trawling (Table IVB1.1).

Substrate Composition and Weighting and Ranking Analysis. Sites 3, 13, 14, and 17 (all in Marblehead = MH), the lowest ranking sites, were eliminated due to the presence of large sand ripples or silty substrate (Table IVB1.4, Figure IVB1.7). The "hand burial" test confirmed that the sediments at these sites would not be able to support the weight of the reef. Site 4 (MH) was eliminated because it had the highest relative species abundance and diversity of all the potential sites. Site 11 (Boston Harbor near Peddocks Island) was eliminated due to heavy boat traffic and poor larval settlement (MADMF, unpublished data).

The PCA analysis revealed that some of the high ranking sites (such as 11 and 18) ranked well for different strengths in the various data categories, while the two highest-ranking sites had comparable qualities (sites 20 and 29) (Table IVB1.4). (Figure IVB1.8). Sites that scored poorly (3, 13, and 14) were grouped together, indicating that they had similar weaknesses.

After these initial eliminations, we were prepared to select two final sites within each of the three areas considered for reef development: (1) MH, (2) Boston Harbor near the Hypocrite Channel (BHH), and (3) Boston Harbor near the Brewster Spit (BHB) (Figure IVB1.5). The top two remaining sites within each of these regions were: (1) MH sites 5 and 6, (2) BHH sites 18 and 20 and, (3) BHB sites 8 and 23 (Table IVB1.4).

Current Direction Meter and Qualitative Transect Surveys. Due to time constraints, we only obtained replicates from the current direction meter in one of the three major areas of consideration. In BHB, the predominant current direction was north/south (n = 1), BHH was east/west (n = 3), and the MH region was

Table IVB1.4. Weighted scores by data category and final ranking analysis results. Note: All sediments are surficial substrates. Low scores indicate poor ability to meet site selection criteria. Ranks with the lowest values indicate the best sites. A = alternate site.

Site ID	Primary sediment	Secondary sediment	Underlying sediments	Wave action	Proximity to pipeline	Proximity to cobble fill	Total	Ranking within area	Overall rank
(a) Marblehead									
3	0.60	0.23	0.20	0.30	0.15	0.05	1.520	4	12
4	1.45	0.45	0.45	0.20	0.15	0.05	2.746	1	7
5	1.43	0.41	0.45	0.20	0.15	0.05	2.688	3	10
6	1.50	0.44	0.45	0.20	0.05	0.05	2.693	2	9
13	0.50	0.15	0.15	0.30	0.05	0.05	1.200	7	14
14	0.50	0.15	0.15	0.30	0.15	0.05	1.300	6	13
17	1.50	0.45	0.45	0.10	0.10	0.05	2.646	5	11
(b) Boston Harbor Hypocrite Channel									
18	1.41	0.39	0.45	0.30	0.15	0.10	2.799	3	4
19	1.46	0.42	0.45	0.20	0.10	0.15	2.786	4	6
20	1.50	0.45	0.45	0.30	0.15	0.15	3.000	1	1
29A	1.50	0.44	0.45	0.30	0.15	0.15	2.985	2	2
(c) Boston Harbor Brewster Spit									
8	1.44	0.39	0.45	0.30	0.10	0.05	2.731	2	8
23	1.50	0.45	0.45	0.30	0.05	0.05	2.796	1	5
(d) Boston Harbor Peddocks Island									
11	1.50	0.45	0.45	0.30	0.05	0.05	2.800	1	3

northwest/southeast (n = 1). These data indicated that Site 6 needed to be rotated in order to position the potential reef footprint perpendicular to the current (Baynes and Szmant 1989). Transect survey data were collected after this site was re-oriented.

Based on the qualitative survey data, sites 5, 8, and 18 were eliminated due to concerns about further impacting existing hard bottom habitat. Sampled species diversity was compared among remaining sites and sites with lower species diversity were retained for further analysis. Site 6 (MH), Site 20 (BHH), and Site 23 (BHB) were the three final sites selected for further consideration. Following this selection, we were informed that

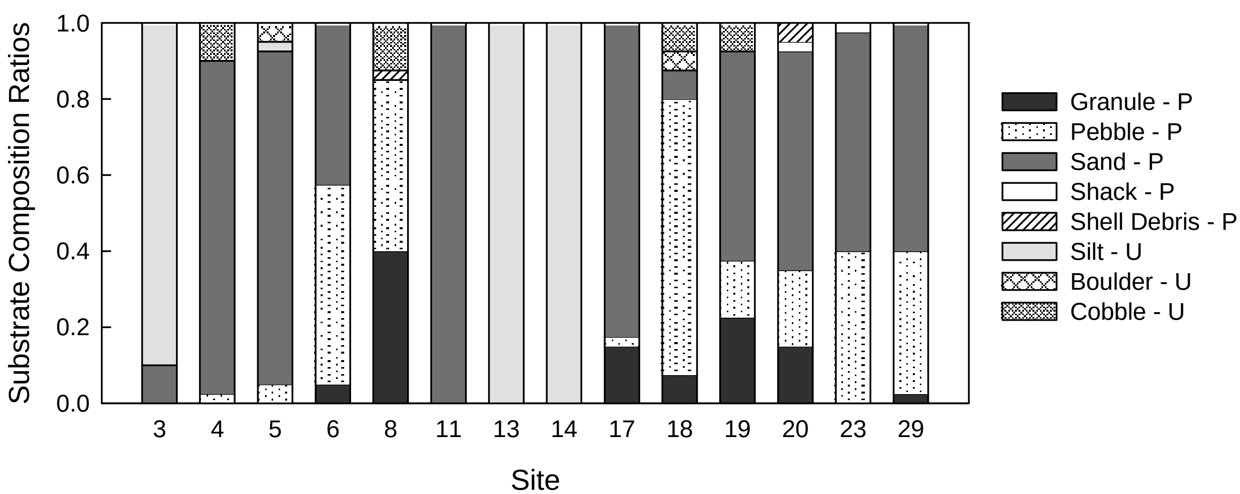

Figure IVB1.7. Primary surficial substrate composition of the 14 potential sites. P = prime substrate for artificial reef deployment, U = unsuitable substrate for reef deployment.

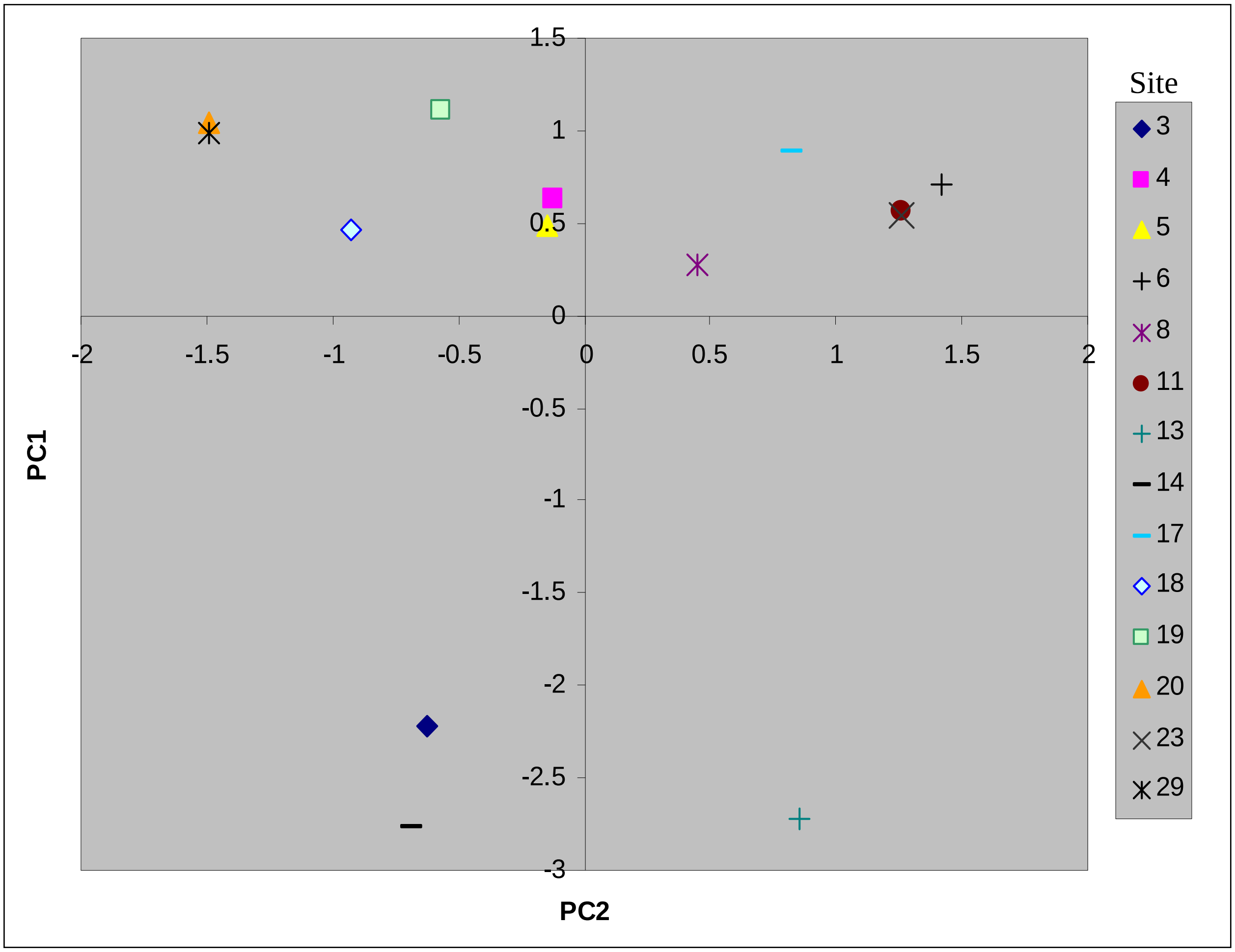

Figure IVB1.8. Principal component analysis comparing similarity of potential artificial reef sites (by site ID).

Site 20 was located within the buffer zone of an area of archeological concern (Massachusetts Board of Underwater Archaeological Resources, pers. comm.). Therefore, alternate Site 29 (the second highest ranking site) was substituted for Site 20 in the BHH region.

Final Three Site Descriptions. Site 6 in Marblehead (MH) was located adjacent to Cat Island outside of the shipping channel (Figures IVB1.3 and IVB1.5). The primary substrates at this site were pebble, granule and sand (Figure IVB1.9). All three of these substrate types were desirable because they tend to support lower species diversity and abundance of macroinvertebrates and vertebrates than cobble and boulder. The secondary substrates on this site were sand, pebble, and granule with a small percentage of cobble. We were not concerned with the small amount of cobble as secondary substrate because it was not found in large enough quantities to create the interstitial spaces necessary to support high species abundance and diversity. The underlying substrates of sand and granule were considered strong enough to support the weight of a reef. No species on this site were observed in abundances greater than 2 - 5 counts per 140-m. transect. The only species seen of commercial importance were the sea scallop (*Placopecten magellanicus*), rock crabs (*Cancer irroratus*), and lobster (*Homarus americanus*), although only two to five individuals of each species were observed. There was a fair amount of drift algae (unattached to substrate) on the site, most likely the result of a strong Nor'easter that passed through the region one week before sampling. Sampled species abundance and diversity values on this site were lower than at all

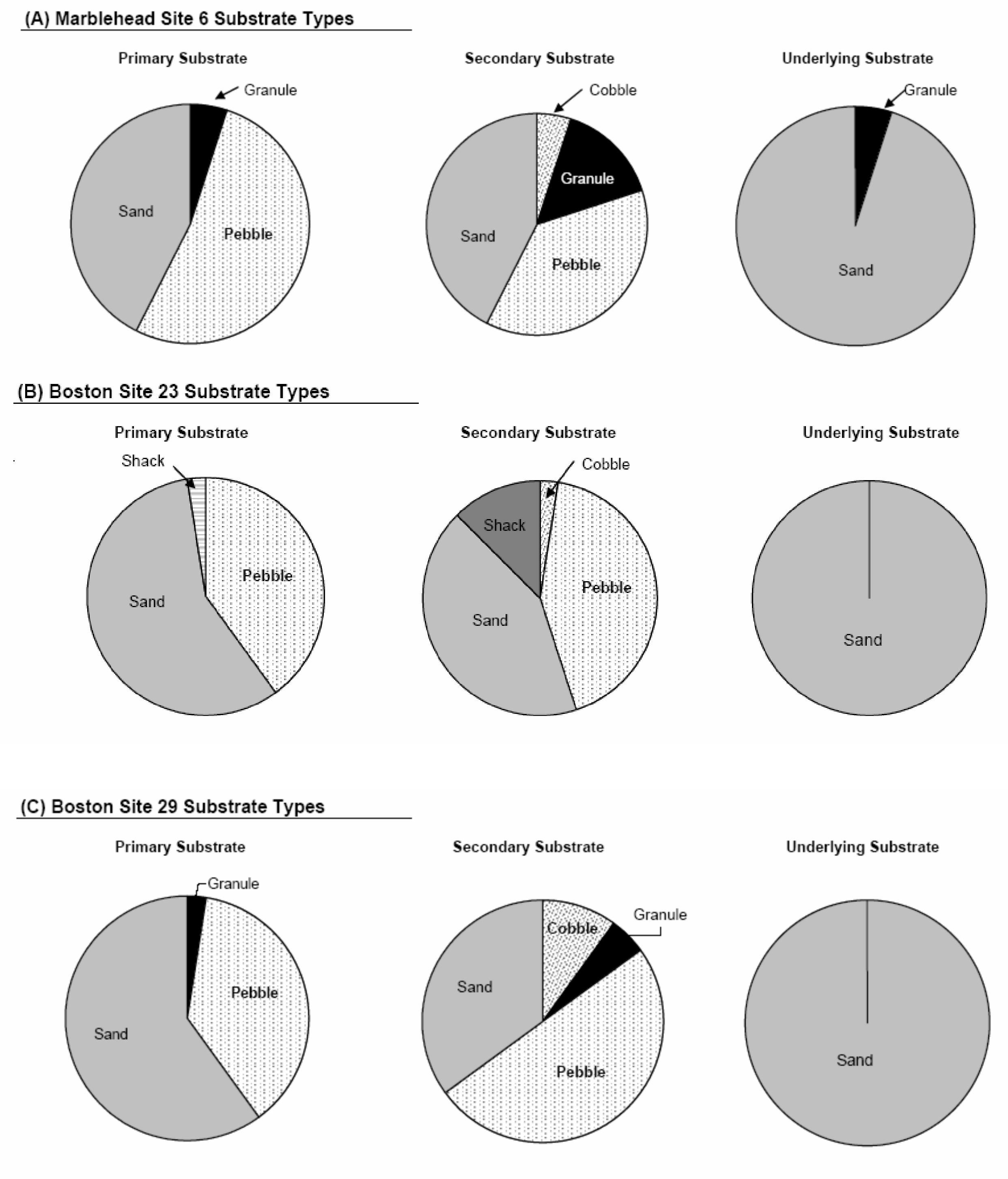

Figure IVB1.9. Primary, secondary, and underlying sediment proportions of the final three potential sites.

other potential sites in the Marblehead (MH) region. Site 23 was located

just north of the Brewster Spit in Boston (BHP) waters off Lovell Island (Figures IVB1.2 and IVB1.5). The primary substrates at this site were pebble and sand with a small percentage of shell shack (Figure IVB1.9). The secondary substrates also met our criteria for site selection, consisting primarily of sand, shack and pebble with a small amount of cobble. Again, we were not concerned with the small amount of cobble as secondary substrate because it was not found in large enough quantities to support high species abundance and diversity of macroinvertebrates and vertebrates. The underlying substrate of sand was considered strong enough to support the weight of the habitat enhancement area.

Two species of non-commercially important invertebrates, the horse mussel (*Modiolus modiolus*) and hydroids were recorded in high abundance (100 - 200 individuals) along sections of our 140-m transect dives. Other species recorded in very low densities (no counts greater than 6-10 along 140-m transects) consisted of *Cancer sp*. crabs, razor clams (*Ensis directus*), lobster (*H. americanus*), northern cerianthid anemones (*Cerianthus borealis*), sea stars (*Asterias* sp. and *Henricia* sp.), moon snails (*Lunatia heros*), grubby sculpin (*Myoxocephalus aenaeus*), sea scallop (*P. magellanicus*), skates (*Raja* sp.), spider crabs (*Libinia emarginata*), and winter flounder (*Pseudopleuronectes americanus*). Algal coverage was less than 1% for all species noted on transects. Despite this site having a higher range of observed species abundance when compared to other two final sites, its species diversity was much lower than the other sites in Boston near the Brewster Spit.

Site 29 was located just east of Lovell Island and just south of the Hypocrite Channel in Boston (BHH) (Figures IVB1.2 and IVB1.5). The primary substrates were sand and pebble and a small amount of granule (Figure IVB1.9). The secondary substrates were pebble and sand with a small percentage of cobble and granule. The cobble recorded here was not found in large enough quantities to create substantial interstitial space and, therefore, was not expected to support high species abundance and diversity of macroinvertebrates and vertebrates. The underlying substrate of sand was considered strong enough to support the weight of the reef. When compared to the other two final sites, species abundance and diversity appeared to be the lowest at Site 29. Species that were noted in densities of 11 - 25 individuals per 140-m transect included crabs (*Cancer* sp.) and sponges (*Isodictya palmata*). Species noted in low densities (1 – 10 per 140-m transect) included lobster (*H. americanus*), sea stars (*Henricia* sp.), grubby sculpin (*M. aenaeus*), skates (*Raja* sp.), and northern cerianthid anemones (*C. borealis*). Algal coverage was less than 1% (kelp) and a thin diatom film was noted to be covering 25 to 50% of the pebble and sand substrate.

Benthic Air-Lift Sampling. As expected, significantly more decapod crustaceans were found on the two natural reef sites (Marblehead = 52.33 m^{-2}, s.e. = 4.52, n = 12; Boston = 41.83 m^{-2}, s.e. = 6.58, n = 12) than the three potential reef sites (Site 23 (BHP) = 14.67 m^{-2}, s.e. = 2.12, n =12; Site 29 (BHH) = 14.17 m^{-2}, s.e. = 2.25, n = 12; Site 6 (MH) = 14.00 m^{-2}, s.e. = 3.50, n = 12), ($F_{5, 66}$ = 12.85, $p < 0.05$; Tukey HSD, $p < 0.05$, Figure IVB1.10). The pipeline cobble fill point (mean = 25.50 m^{-2}, s.e. = 3.61, n = 12) was similar to the Boston natural reef, as well as the potential reef sites (Tukey HSD, $p > 0.05$, Figure IVB1.10). However, the pipeline had a significantly lower crustacean density than the Marblehead natural reef (Tukey HSD, $p < 0.05$, Figure IVB1.10). No significant differences were detected between the two natural reef sites or among the three potential reef sites (Tukey HSD, $p > 0.05$, Figure IVB1.10).

Young-of-the-year (YOY) lobster densities were significantly lower on the potential reef sites (all

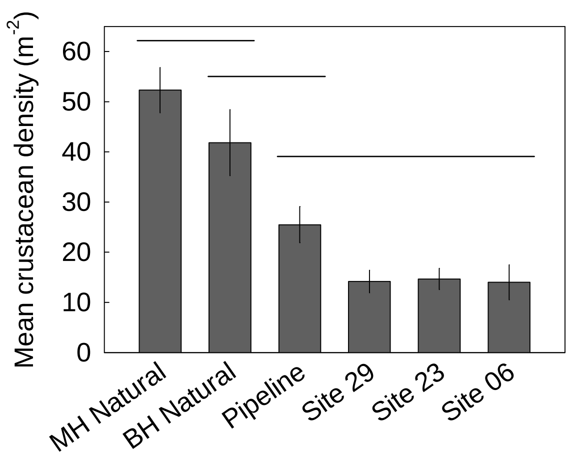

Figure IVB1.10. Mean decapod crustacean density by site as determined by air-lift sampling (n = 12 for each site). MH = Marblehead, BH = Boston Harbor. Horizontal bars indicate statistical similarity based on a post-hoc Tukey HSD test (α = 0.05). Standard error bars are shown.

three sites = 0 m^{-2}, n = 12) than the natural reef sites (Marblehead = 1.17 m^{-2}, s.e. = 0.46, n = 12; Boston = 1.33 m^{-2}, s.e. = 0.38, n = 12) (Kruskal-Wallis test, H/D = 11.5, $p < 0.05$; permutation tests, $p < 0.05$, Figure IVB1.11). YOY lobster density on the pipeline (mean = 0.83, s.e. = 0.30, n = 12) was similar to all other sites (permutation tests, $p > 0.05$, Figure IVB1.11). There was no significant difference in YOY lobster density on the two natural reefs. The three potential reefs were similar in that they had no larval lobster settlement (permutation tests, $p > 0.05$, Figure IVB1.11).

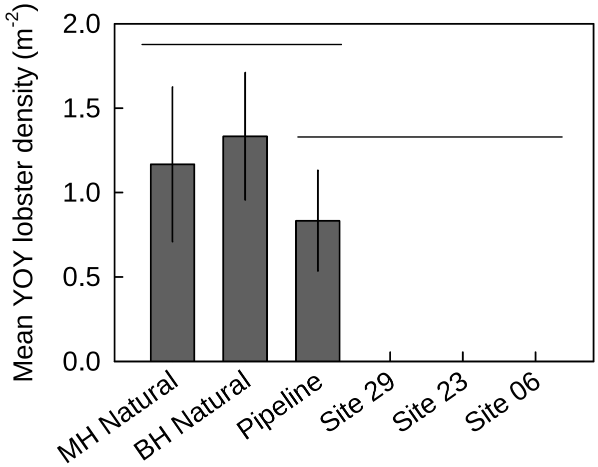

Figure IVB1.11. Mean young-of-the-year lobster density by site as determined by air-lift sampling (n = 12 for each site). MH = Marblehead, BH = Boston Harbor. Horizontal bars indicate statistical similarity based on permutation testing at 1000 iterations (α = 0.05). Standard error bars are shown.

As expected, the two natural reef sites had higher sampled species diversity than the potential reef sites (Table IVB1.5). Of the three potential reef sites, Site 6 (MH) had the highest species diversity and Site 23 (BHP) had the lowest diversity (Table IVB1.5).

<u>Larval Settlement Collectors</u>. Site 23 was the only site with YOY lobster; however, the three sites experienced settlement of other species of decapod crustaceans and fish. Site 23 had significantly more juvenile and adult lobster in the settlement collectors (mean = 6.75 m^{-2}, s.e. = 1.00, n = 8) than the other two potential reef sites (Site 29 = 2.40 m^{-2}, s.e. = 0.40 n = 10; Site 6 = 2.67 m^{-2}, s.e. = 0.47, n = 9) ($F_{2, 24} = 14.08$, $p < 0.05$; Tukey HSD, $p < 0.05$, Figure 1.12). Site 29 and Site 6 had similar densities of lobster (Tukey HSD, $p > 0.05$, Figure IVB1.12). Site 23 had the highest sampled species diversity in the settlement collectors, whereas the diversity at Site 6 was the lowest (Table IVB1.5).

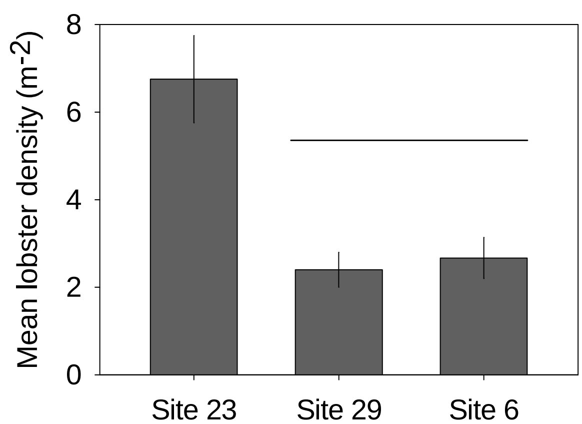

Figure IVB1.12. Mean juvenile and adult lobster density in settlement collectors by potential reef site (Site 23, n = 8; Site 29, n = 10; Site 6, n = 9). Horizontal bars indicate statistical similarity based on a post-hoc Tukey HSD test (α = 0.05). Standard error bars are shown.

Table IVB1.5. Shannon index of diversity results.

Area	H' value
(a) Air-lift sampling	
Marblehead natural	2.22
Boston Harbor natural	1.99
Site 23	0.99
Site 29	1.03
Site 6	1.92
(b) Settlement collectors	
Site 23	2.04
Site 29	1.84
Site 6	1.46

Discussion

A systematic seven step process was used to ultimately select Site 29 as the location for the artificial reef. Each step in the selection model addressed our criteria and provided valuable input toward the goal of selecting an appropriate site. The majority of these steps led us to our three final sites; data gathered from the settlement collectors and air-lift sampling was then considered to select Site 29.

Of the three final prospective sites, Site 23 experienced the highest level of postlarval settlement. However, during the two-month period the collectors were deployed on Site 23, the rocks and Astroturf ™ became partially buried under a layer of fine sand and silt. Early benthic phase lobster and other benthic species typically excavate burrows underneath cobble for shelter (Lawton and Lavalli 1995). This layer of fine substrate may have made the collectors at Site 23 more suitable for settling postlarvae because of the additional shelter it offered. The sand and silt could also explain why Site 23's collectors had the highest sampled species diversity when compared to the other two sites' collectors, which did not experience high sedimentation rates. Despite these results, the partial burial of the cobble in two months indicated that there was high potential for siltation and reef burial at Site 23. Due to these concerns, Site 23 was eliminated from consideration.

Site 29 in Boston Harbor near the Hypocrite Channel and Site 6 in Marblehead were the two sites remaining in the selection process. Although neither site had postlarval lobster present in the settlement collectors, many other young-of-the-year decapod crustacean and fish species were recorded at the sites. Air-lift sampling the adjacent natural reefs also demonstrated that postlarval lobster and other larval species were present near the prospective reef sites. Thus, the data from air-lift sampling and the settlement collectors allowed us to conclude that adequate levels of larval settlement would occur at either of these sites.

The results of the species diversity analyses and the weighting and ranking analysis were used to determine the best site for reef development. The air-lift sampling results demonstrated that Site 29 had lower existing species diversity than Site 6, while the settlement collector results indicated that Site 29 could potentially have higher species diversity than Site 6 if cobble habitat was present. Since our site selection criteria required avoidance of naturally productive areas (i.e. Site 6), and because Site 6 ranked much lower than Site 29, Site 29 was selected for reef placement (Table IVB1.4, Figure IVB1.5).

Throughout this year-long process, areas where improvements and simple adaptations to our seven step model could be made were noted. The first of the seven steps, exclusion mapping, allowed us to target prime areas for habitat enhancement prior to conducting any field work. A lack of georeferenced data for Massachusetts Bay limited development of this model. Therefore, we worked with the minimum requirements for this model: bathymetry and substrate data. The model could be easily modified for future projects to include other selection criteria such as existing pipeline pathways, popular commercial or recreational fishing areas, or marine protected areas. Kennish et al. (2002) demonstrated that larger datasets were valuable in the site selection process when developing exclusion mapping models.

Depth verification and slope calculation constituted the second step in the selection process. Verifying the results of the mapping model in the field proved to be extremely valuable, as some of the bathymetry datasets contained inaccurate information. Although sites were eliminated due to unsuitable slope or depth, it was also necessary to discard sites with highly variable depths. Uneven depths confound the ability to answer questions involving species composition on newly installed reefs.

The third step, surficial substrate surveys, was designed to quantify substrate on each site for the weighting and ranking analysis. These surveys also provided verification of the substrate data layer for portions of Massachusetts Bay. This proved to be an important step because several of the sites (3, 13, and 14) were located in "prime" areas for reef deployment according to the GIS model (Figure IVB1.1), yet *in situ* verification revealed that the substrate at these sites was too soft to support the weight of a reef (Figure

IVB1.7). The hand burial method did not provide us with information that could not be gathered from quantitative substrate surveys alone, thus this method could be eliminated from the process.

During these dives, the relative abundance of species on each site was qualitatively noted in order to avoid placing the reef on naturally productive areas. Although these observations were informative, quantitative data collection would have been more instructive. Quantitative data could have been incorporated into the weighting and ranking analysis also, rather than subjectively taken into account at the end of the analysis.

The weighting and ranking analysis (fourth step) was influential in targeting areas that met our project's criteria. Maintaining three separate geographic regions in our analysis gave us flexibility in case one of the areas did not meet all of our selection criteria. This aspect was crucial because high siltation rates were recorded at Site 23 during the final weeks of site selection, requiring the elimination of that site and consideration of alternatives. For future projects, the weighting and ranking step should be adapted to include pertinent project specific criteria, and the weighting scheme changed to suit the project's goals.

The PCA analysis, which was conducted using the original scores from the weighting and ranking analysis, did not provide us with information additional to that gained from the later analysis, however it did provide confirmation. If the PCA analysis was conducted on the original data, rather than the scores from each site, the results may have been more useful.

Although the current meter did not provide data specific to our site selection model, collecting this information allowed us to design properly oriented sites that maximized settlement, aeration, and nutrient delivery (Baynes and Szmant 1989). Our current meter is an example of an innovative, low-cost design that can be used to determine predominant current direction in many types of ecological applications. Most instruments capable of measuring current speed and direction are cost-prohibitive or too complicated to build for small-scale projects (Maida et al. 1993). Although other commercially-available instruments are more precise in their measurements, our device provided useful information regarding current direction. While a larger sample size would have enhanced our ability to verify the design's precision, in the instance where we were able to obtain replicates (n = 3), the predominant current direction was consistent among samples.

The fifth step, final qualitative transect surveys, allowed us to visually confirm the suitability of each site and narrow the number of potential sites to three. No major alterations were needed to improve the method for future site selection models.

Results from the two final steps, air-lift sampling and settlement collectors, proved to be the most beneficial data obtained. These procedures sampled the species naturally present in each area and indicated which species might initially settle on the reef. Settlement collectors also provided ancillary information on sedimentation rates at each site, which was an influential factor in the site selection process. Observed decapod crustacean densities, young-of-the-year (YOY) lobster densities and sampled species diversity from the air-lift sampling were, as expected, higher on the natural reefs than the potential reef sites. Natural rocky reefs generally support more diverse epifaunal and macroalgal communities than sandy habitat (Lenihan and Micheli 2001; Whitman and Dayton 2001). These data were evidence that the reef would not be placed on a site that already had comparably high densities of macroinvertebrates or vertebrates.

The pipeline cobble fill area appeared to represent a type of intermediate stage hard-bottom habitat, possibly because this "reef" was only two years old when it was sampled. The age of this artificial reef may explain why the site's crustacean densities were similar to the Boston natural reef and the potential sites, and why the YOY densities were similar to both natural reefs and the potential reef sites. Additionally, it is well known that recently disturbed areas tend to maintain lower species diversity until succession eventually increases diversity (Connell 1978; Sousa 1979). This may explain why the pipeline fill point had the lowest species diversity of all the sites.

Finally, the air-lift sampling results from the three potential reef sites confirmed that we would not be impacting areas that already provided habitat for settling lobster postlarvae because no YOY lobster were recorded on these sites. The species diversity analysis of these air-lift sampling data also allowed us to eliminate Site 6 because it had the highest species diversity of the three potential sites.

Although settlement collectors have primarily been used in larval settlement studies (Incze et al. 1997; Cruz and Adriano 2001; Montgomery and Craig 2003), this study is potentially the first to use collectors as a tool in an artificial reef site selection model. The settlement collector results from Site 23 suggest that larval settlement and sampled species diversity are higher when burrowing habitat is provided. Thus, future projects would benefit from adding a layer of fine sand on top of the Astroturf ™ (Figure IVB1.6) to more closely approximate preferred habitat and reflect natural conditions. In spite of this, the larval settlement and species diversity data obtained from the remaining two sites were important factors in the final site selection process.

Acknowledgements

We thank the following colleagues for their assistance with this project: Bruce Estrella, Ross Kessler, Alison Leschen, Vincent Malkoski, Derek Perry, Tracy Pugh, Stefanie Stielow, Steven Voss, and Steve Wilcox. Captains John Barrett, John Carver, and Bill Kelley provided invaluable assistance with the settlement collector portion of this study. Kathleen Castro and Joseph DeAlteris offered advice that contributed to the initial development of our site selection process. James Dimond designed the current meter and provided discerning guidance throughout this process.

IV B. Habitat Enhancement Project (Continued)

Chapter 2: Artificial Reef Monitoring Program

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Introduction

Although artificial reef development has occurred throughout the world for several decades (see Bohnsack and Sutherland 1985 for review), the use of artificial reefs as a mitigation tool has only recently become popular (e.g. Davis 1985; Hueckel et al. 1989; Ambrose 1994; Foster et al. 1994; Pratt 1994; Burton et al. 2002). Mitigation reefs are traditionally developed to alleviate human impacts to the marine environment such as destruction to marine habitats from construction (Davis 1985; Hueckel et al. 1989; Foster et al. 1994) and discharge from power plants (Carter et al. 1985a and 1985b; Ambrose 1994). Although several mitigation reefs have been well-studied, little data exist on whether or not artificial reefs can effectively mitigate for these types of impacts across different geographic regions and ecosystem regimes.

In order to better understand the biological processes that occur on newly deployed artificial reefs, artificial reefs are typically compared to nearby natural reefs (e.g. DeMartini et al. 1989; Carr and Hixon 1997; Perkol-Finkel and Benayahu 2004a, Perkol-Finkel et al. 2005). Perkol-Finkel et al. (2004, 2006 and 2007) found that in order for an artificial reef to resemble a natural reef (if that is the goal of the mitigation process) the artificial reef must have similar structural features such as vertical relief, spatial orientation, and rugosity. Their research also suggested that unless the artificial reef is composed of the same material as the natural reef (i.e. rock for rock), species assemblages on the two sites are likely to remain different indefinitely. These findings may explain the typical disparity in species assemblages when comparing natural and artificial reefs (Rilov and Benayahu 2000; Badalamenti et al. 2002; Perkol-Finkel and Benayahu 2004a, Perkol-Finkel et al. 2006). The majority of artificial reef material used in the U.S. is either concrete or scrap material (Bohnsack and Sutherland 1985). If the objective of a mitigation reef is to provide habitat such that the artificial reef eventually becomes similar in species composition to natural reefs, it is plausible that the vast majority of mitigation reefs will not achieve this goal.

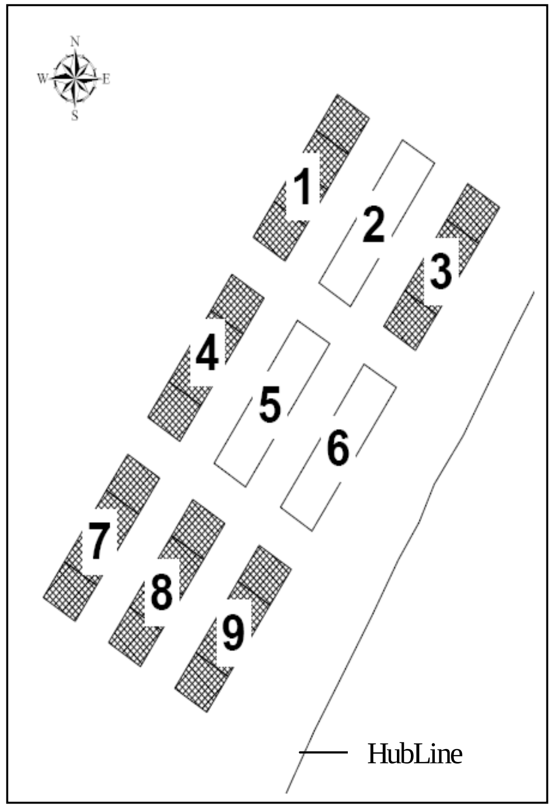
Although several projects have constructed artificial reefs with similar structural complexity and substrate as natural reefs, and consequently compared the artificial reef to a natural reef (Carter et al. 1985a; Ambrose and Swarbrick 1989; DeMartini et al. 1989; Hueckel et al. 1989), none of these studies were conducted in the temperate waters of the northwest Atlantic. Yet, artificial reefs have been used by various Atlantic states to enhance fisheries or provide mitigation for habitat loss (e.g. Foster et al. 1994; Steimle and Figley 1996, Burton et al. 2002). Only one of these artificial reefs has been constructed with natural materials (Castro et al. 2001). This artificial reef specifically targeted American lobster (*Homarus americanus*) and thus, no published information exists on the development of the entire marine community on this reef. Newly deployed artificial reefs in the northwest Atlantic will likely develop marine communities on a different ecological scale than the better-studied tropical, subtropical, or eastern Pacific systems.

In March and April of 2006, the Massachusetts Division of Marine Fisheries *(MarineFisheries*) installed a six-unit artificial cobble/boulder reef in Boston Harbor, Massachusetts. This reef was constructed as part of a mitigation effort to enhance habitat for marine invertebrates and finfish near the recently constructed HubLine pipeline. The reef materials consisted of cobble and boulder obtained from a nearby quarry in an attempt to provide the most effective in-kind mitigation for the loss of hard-bottom habitat (see Appendix IVB.A for reef design information). The artificial reef was designed to provide a heterogeneous environment for multiple life history stages of marine organisms. A mixture of rock sizes was used to target various phases of crustaceans and fish (Cobb 1971, Dixon 1987, Wahle 1992, Wahle and Steneck 1992, Tupper and Boutilier 1995 and 1997, Dorf and Powell 1997, Bigelow and Schroeder 2002, Pappal et. al. 2004). *MarineFisheries* developed and implemented an intensive, long-term monitoring program to measure ecological variation on the artificial reef and to determine how well the artificial reef met particular goals. Two primary questions were addressed with this monitoring program: (1) will 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? We also investigated smaller scale questions such as: does the artificial reef augment settlement of post-larval lobster and other finfish and invertebrates; does the artificial reef provide mitigation to the hard-bottom encrusting community; and does the artificial reef provide shelter to multiple life stages of various marine organisms?

Methods

To evaluate the success of the reef project, a structured monitoring program was designed to characterize and track larval settlement and the development of invertebrate and finfish assemblages on the reef. This program primarily included seasonal visual dive surveys along permanent transects, semi-annual small fish trapping and tagging, and annual larval air-lift sampling. Permanent transect sampling began in fall 2005 and the other surveys were instituted primarily in spring/summer 2006.

Unique identification numbers were assigned to each artificial reef and control unit for descriptive purposes (Figure IVB2.1). Throughout the remainder of this report, the reef and sand units



FigureIVB 2.1. Assigned identification numbers for artificial reef units and sand areas. Sand = white, artificial reef unit = gray.

are referred to using their unique numbers.

Multibeam Survey

Prior to the construction of the artificial reef, a multibeam survey of the selected site was conducted to confirm bathymetry and bottom type (Figure IVB2.2). Immediately following the reef's construction, side-scan sonar and multibeam surveys were conducted again over the artificial reef and the nearby HubLine fill point (areas along the pipeline armored with cobble) (Figures IVB2.3 & IVB2.4). The surveys provided confirmation that the reef units were deployed and spaced as planned and allowed for measurement of the individual reef units. The maps also provided a reference for measurement of any future reef movement due to storms or resulting wave action.

Permanent Transect Surveys

Permanent transects were used to quantify temporal changes in species abundance and diversity across four sites including: (1) the artificial cobble/boulder reefs, (2) sand controls, (3) a nearby natural cobble/boulder reef, and (4) the HubLine fill point. In order to make comparisons across seasons, the permanent transects were sampled in May (spring), early August (summer), and late October (fall) of 2006. Winter sampling was completed in March 2007, spring sampling in May and June 2007, and summer sampling in July 2007. Following the 2007 summer sampling, the reefs will be sampled annually in July and August in subsequent years. Permanent sampling methodology allows for repeated survey of the same transects over time on each site (Figure IVB2.5).

Prior to collecting data on the sites, a permanent 40-m transect was established at each survey site. In winter 2005, divers assembled permanent transects on a site which eventually became reef ID number 7, sand areas 2 and 5, a shallow natural reef off Lovell Island near our final reef location designated as Site 29 in Chap. 1), and the HubLine fill point (Figure IVB2.5). These five transects were established prior to reef construction in order to document changes in habitat and species abundance and diversity post-reef installation. In the spring of 2006, the natural reef survey site was changed to a site with a depth

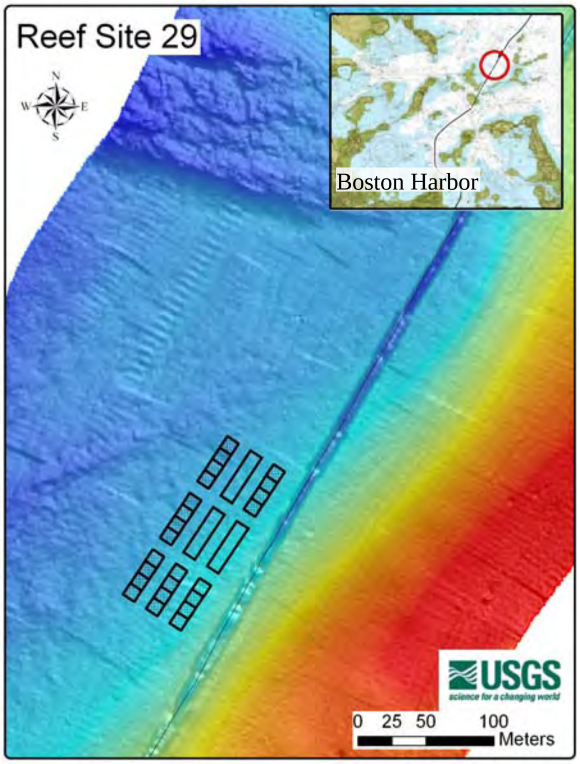


Figure IVB2.2. Multibeam and side-scan sonar survey results from a pre-construction survey in January 2006. Location of the planned reef area (Site 29) is shown over the sonar image; hashed areas depict areas where reef units were to be constructed, open bars depict sand sites.

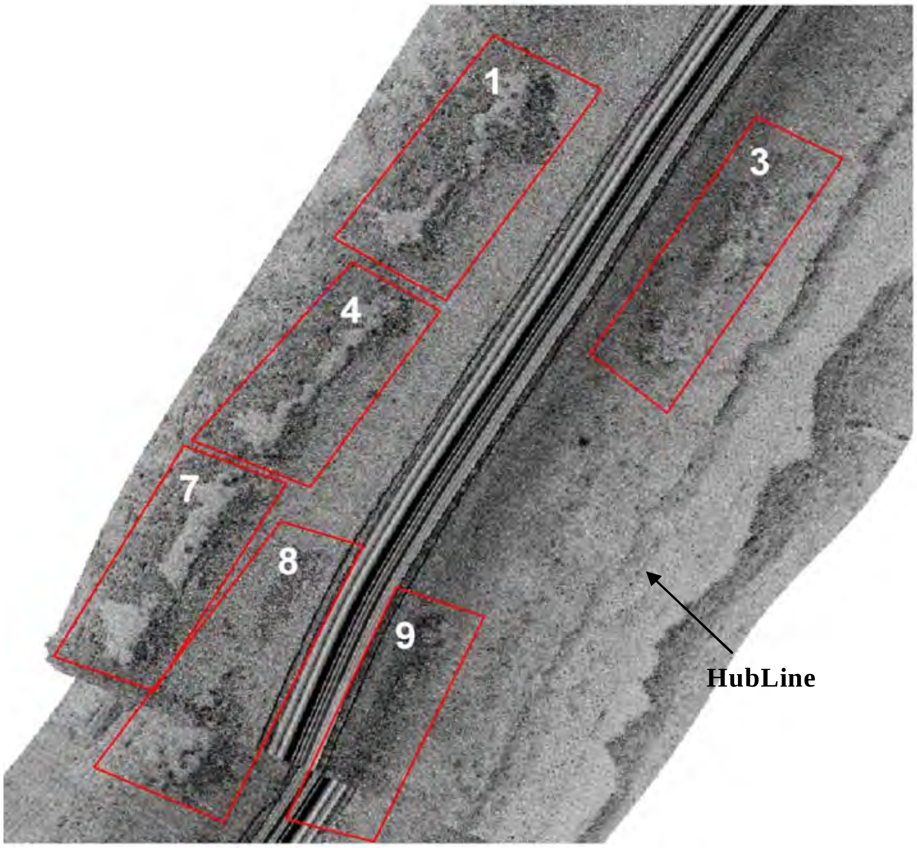


Figure IVB2.3. Side-scan sonar survey, conducted in May 2006, of the artificial reef units (outlined with their unique ID numbers) and the HubLine cobble fill point (ribbon-like line in center is the track of the vessel).

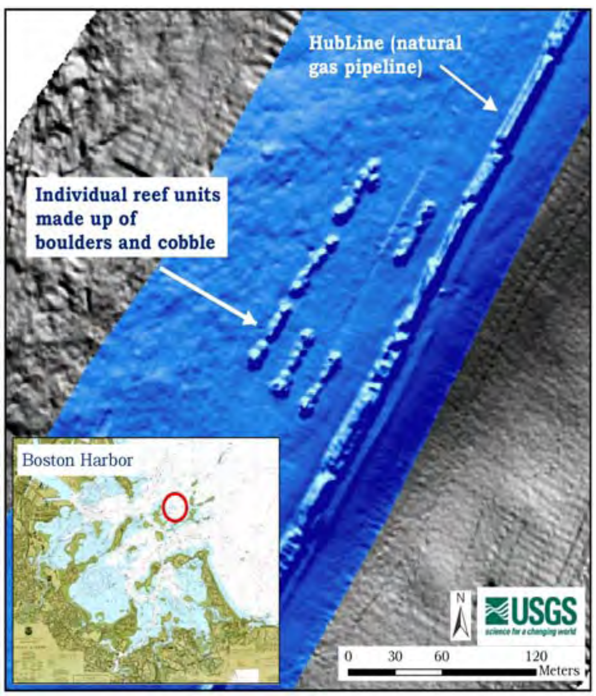


Figure IVB2.4. Results from the multibeam survey, conducted post-construction in July 2006, showing the location of the artificial reef units in relation to the HubLine cobble fill area.

which was more similar to that of the artificial reef (Figure IVB2.5).

It should be noted that when divers were not working on a transect, no transect line was left on the seafloor. Rather, the start and end points of the transect were permanently marked with subsurface buoys. Divers used a known compass bearing to set the transect tape on the same area prior to each data collection.

All transects were sampled in the spring and summer of 2006, and a sub-set was sampled in the fall of 2006 and winter of 2007. All sites were sampled in the spring of 2007 except for two of the sand areas. Transects included in the sub-sample for each site (artificial reef, HubLine, natural reef, and sand) were selected randomly. At the minimum, the set of sub-sample transects were surveyed each season. One change was made to the sub-sample set during the survey period. The natural reef transects initially selected for sub-sampling were transects 1 and 2. However, after completing an analysis of substrate, it was apparent that transect 2 was the

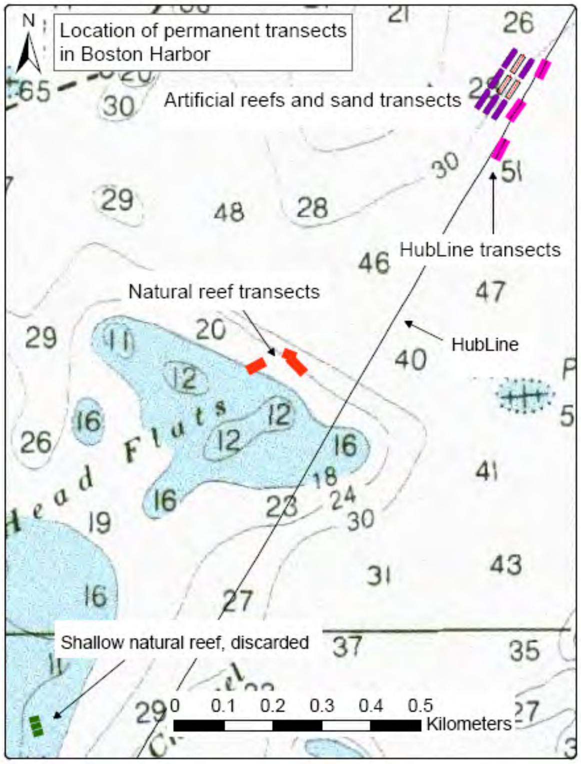


Figure IVB2.5. Location of permanent transects deployed on the artificial reef, sand, HubLine, and natural reef.

least similar of the three transects in substrate composition to the artificial reefs. Thus, transect 3 was included and transect 2 was eliminated from the sub-sample set in the summer of 2007.

Transects on the HubLine fill point and artificial reefs ran down the middle and/or top of the rocky mounds. The natural reef did not have a distinct mound, although there was occasionally a visible edge to the natural reef. We avoided placing the natural reef transects along the edge and instead ran the transects through rocky fields. On the sand sites, transects were set through the center of each control area (Figure IVB2.1).

Divers quantified all mobile macroinvertebrates (e.g. whelks, echinoderms, crustaceans, etc.), most sessile macroinvertebrates (e.g. solitary tunicates, anemones, etc.), and fish in continuous 5 x 2-m sections along the transect using a 2-m PVC "swath" bar (Figure IVB2.6). Each diver collected data on their respective side of the transect until the entire transect was sampled. Rocks were not lifted, but interstitial spaces were carefully inspected for organisms, such as lobsters or crabs. If a particular species within the swaths was highly numerous or densely packed (e.g. solitary tunicates), abundance within the swath was estimated.

A 1-m^2 PVC quadrat with a ¼-m^2 inset quadrat was used to assess substrate type, algal coverage, and encrusting or sessile invertebrate coverage (e.g. colonial tunicates or sponges) (Figure IVB2.7). Each diver collected data on one side of the transect. The meter marks on which to place four quadrats (two on each side) within each 10-m segment of the transect were randomly selected. This occurred four times to sample the entire 40-m transect (16 quadrats total, eight on each side of the transect). To minimize observer variability throughout the field seasons, only four divers trained in data collection techniques conducted these surveys.

Surficial substrate was classified visually, within the 1-m^2 quadrat, according to the Wentworth scale (Wentworth 1922). Substrate was quantified into four main categories: primary (sediment type that constituted more than 50% of the area), secondary (sediment type that constituted between 10 and 50% of the area), tertiary (any other sediments that constituted < 10% of the area) and underlying (sediment type found directly underneath the primary and secondary substrates). The "underlying" substrate was defined as the lowest-lying substrate that divers could visually identify. Therefore, if divers saw sand underneath the rocks, the underlying substrate was recorded as sand. However, if divers observed only rocks in the quadrat, the underlying substrate was recorded as cobble or boulder, depending on the rock size. Percent coverage of algae, sponges, and encrusting tunicates was visually estimated within the 1-m^2 quadrat (using a 1% cover disc for reference). If half of an individual or colony (alga, sponge, tunicate, etc.) was inside the quadrat and half was outside of the quadrat, coverage of the half that was inside the quadrat was estimated. Because newly deployed artificial reefs are dynamic systems, new species were regularly sighted. When a new species was observed, it was recorded and added to the datasheets for future surveys.

A comprehensive checklist of all species likely to be seen in Massachusetts Bay was reviewed following each survey to document each species

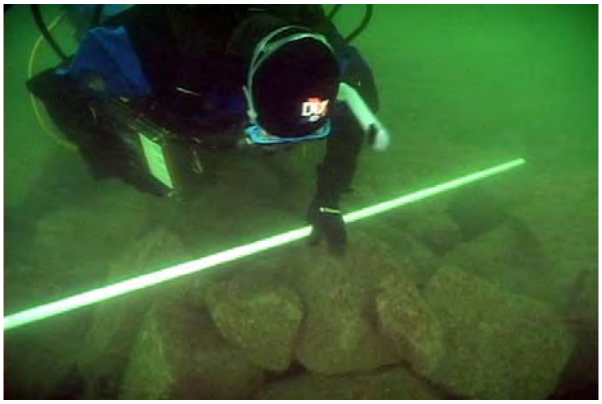


Figure IVB2.6. Diver collecting data on the artificial reef using a swath bar.

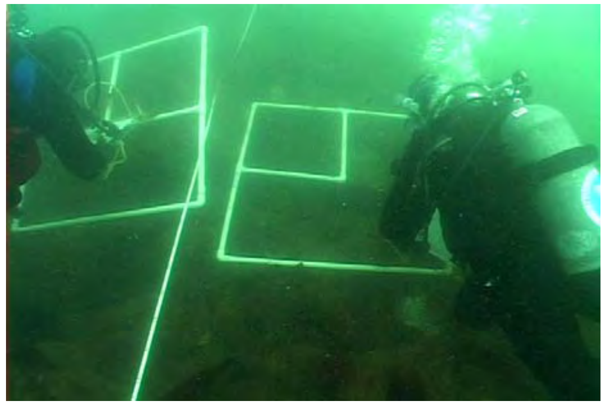


Figure IVB2.7. Diver collecting data on the artificial reef using quadrats.

presence/absence. If a species was present, the overall percent cover or number of individuals observed on the site was estimated. If a species was observed that was not on the presence/absence list, it was added.

Temperature, light, and water transparency. Temperature monitors were installed alongside one artificial reef unit and one natural reef transect. The monitors were fixed approximately 25 cm above the sea floor. The monitors logged bottom temperature hourly and were collected and redeployed on an annual basis. In the summer of 2007 light monitors were placed in the same area as the temperature monitors. Water transparency (horizontal) was estimated visually by divers at the start of each permanent transect survey and categorized as: 0 – 1.6, 1.7 – 3.1, 3.2 – 4.6, 4.7 – 6.1, 6.2 – 7.6, 7.7 – 9.1, or 9.2 – 10.6 m.

Monitoring photographs. In order to obtain a qualitative record of changes in species abundance and diversity, permanent photo stations were installed on artificial reefs 7 and 9, on HubLine transect 3, and transect 1 of the natural reef. An orange-painted rebar stake was driven into the substrate near a large boulder or cobbles to mark each site and support a camera bipod. The "bipod" (two legs) was built from ½"-PVC tubing and had four fixed camera attachment points (labeled with unique ID numbers) along the center bar. In order to consistently photograph the same area, the rebar stake was employed as a hinge pin for one leg of the bipod, allowing for the accurate positioning of the bipod unit along a known compass bearing. The camera and housing system were attached to the center bar on the attachment point that positioned the camera accurately over the desired rock(s). The bearing from the rebar to the stabilizing leg and location of the camera attachment point ID was recorded for the first set of photograph on each site. The same bearing and attachment points were used for all subsequent photographs. The camera was zoomed out to the widest angle, with the flash and macro function enabled. This report includes photographs taken from December 2006 through July 2007.

Substrate. Proportions of each substrate type within the primary and secondary surficial substrate and underlying substrate categories were calculated. Substrate data were averaged from all transects at each site separately, including the HubLine, sand, and artificial reefs. Natural reef transects were analyzed independently because each transect varied considerably in substrate type.

Species diversity. Species diversity analyses (Shannon index) were conducted on permanent transect survey data to investigate changes in diversity across sites and over time. Because species were assessed using two different measures of abundance based on whether or not discrete individuals could be identified, two separate analyses were run. One analysis included only enumerated species (counts of individuals collected in quadrats or swaths), and the other included only species that were assessed by estimation of their percent of surface coverage within a quadrat. Enumerated species included all species sampled in swath surveys and also blue mussels (*Mytilus edulis*), whose counts were collected in quadrat surveys. Counts of cunner (*Tautogolabrus adspersus*) were removed because observers did not record this species consistently across sites. For sessile or encrusting species assessed by percent cover within quadrats, the average cover on each site in each season was calculated. Average percent cover was then used as the metric of abundance in the diversity analysis, replacing abundance of individuals of each species (Magurran 1988).

For the diversity analyses, records were separated by season to avoid repetitive sampling (Magurran 1988). When sample size varied within a season, it was standardized by randomly selecting a subset of transects from the total. Species counts were then summed across quadrats within each transect by season. Shannon indices of diversity were generated for each site by season of survey. A Student's *t* statistic was calculated for pairwise comparisons of diversity across sites but only within each season (Magurran 1988). A *t* statistic was also calculated to compare diversity by season on the artificial reef. A Bonferroni adjusted alpha value of 0.008 was used to determine the significance of the pairwise comparisons (Sokal & Rohlf 1995) among sites within a season, while an adjusted alpha value of 0.016 was used for comparisons between seasons on the artificial reefs. The alpha value was adjusted to account for the increased probability of type I error associated with making multiple pairwise comparisons.

Species densities. Swath and quadrat data were used to obtain density information on selected species. Species chosen for this analysis were either relatively common or species that were potential indicators for gauging development of the artificial reefs. These species included: red filamentous algae, common kelp (*Laminaria sp*.), sponges, solitary tunicates, blue mussels (*Mytilus edulis*), Cancer crabs (*Cancer irroratus* and *Cancer borealis*), and American lobster (*Homarus americanus*). Because our experimental design was created for long-term monitoring, it was not possible to conduct statistical tests on a single year of data. A larger, repeated measures dataset will be obtained over the next few years. However, the collected data are presented for comparison of trends among sites and seasons.

Lobster density by rock size. Differences in lobster density by rock size were estimated using a non-parametric test (Kruskal-Wallis) and pairwise comparisons (Mann-Whitney test). A Bonferroni adjusted alpha value of 0.003 was used for pairwise comparisons. Prior to conducting these analyses, however, substrate type (collected in quadrats) and lobster observations (collected in swaths) were coded by rock size. Primary surficial substrate data were grouped by swath meter mark across all seasons; each 5-m swath section was assigned the substrate type that occurred most commonly within that particular section of the transect. For example, if a swath section had eight records of boulder and two records of cobble, the section was coded as "boulder" for this analysis. If a lobster was recorded in that swath section, then that lobster was coded as using boulder habitat. Coding was complete after every lobster record was assigned a corresponding substrate type. Data from all sites and seasons were combined in this analysis.

Fish Tagging Study

In 2006, we conducted a semi-annual fish trapping study to compare movements, abundance, and length-frequency of small structure-associated fishes, specifically cunner (*Tautogolabrus adspersus*), on the artificial reefs, sand, natural reef, and HubLine fill point. Traps were set six times in the spring (May/June) and five times in the fall (October) with targeted soak times of two to three days between sets. Weather constraints resulted in an actual soak time of two to six days.

To trap fish, we used eel pots (Figure IVB2.8) weighted with a brick and rigged with a 20-m line and surface buoy. The traps were baited with quartered herring placed in plastic mesh bait bags. We used GIS to select seven waypoints on each of the four sites: artificial reef, sand, natural reef, and HubLine (Figure IVB2.9). Traps were placed at least 12 m apart; most traps were 30 m apart. In the fall, the natural reef location was moved because the spring site had limited hard-bottom habitat at depths similar to the artificial reefs (Figure IVB2.9).

Figure IVB2.8. Eel pot used in the small fish trap-sampling and tagging study.

When the fish traps were hauled, captured fishes and crustaceans were placed immediately into a cooler with ambient seawater and processed. Carapace length or width was measured to the nearest 0.1 mm for all lobsters and crabs, respectively. If a lobster was captured, it was measured and sexed, tagged with a unique ID knuckle tag, and released (Figure IVB2.10). For all fish species, total length was measured to the nearest 0.1 mm using a measuring board. Cunner with a total length of 7.5 mm or greater (spring) or 8.0 mm or greater (fall), were tagged with Floy Fingerling tags (Figure IVB2.11). After a brief holding period of 10 to 15 minutes to allow the fish to recover from post-capture tagging stress, all tagged individuals (including lobsters) were released at the surface over the site on which they were captured.

<u>Catch rate analysis</u>. Prior to completing any analyses involving catch rates, a scatter plot was used to determine if there was a relationship between soak time and catch. No relationship was evident, so further catch rate analyses were conducted. Cunner catch data were examined to determine if catch rate differed by season, site and

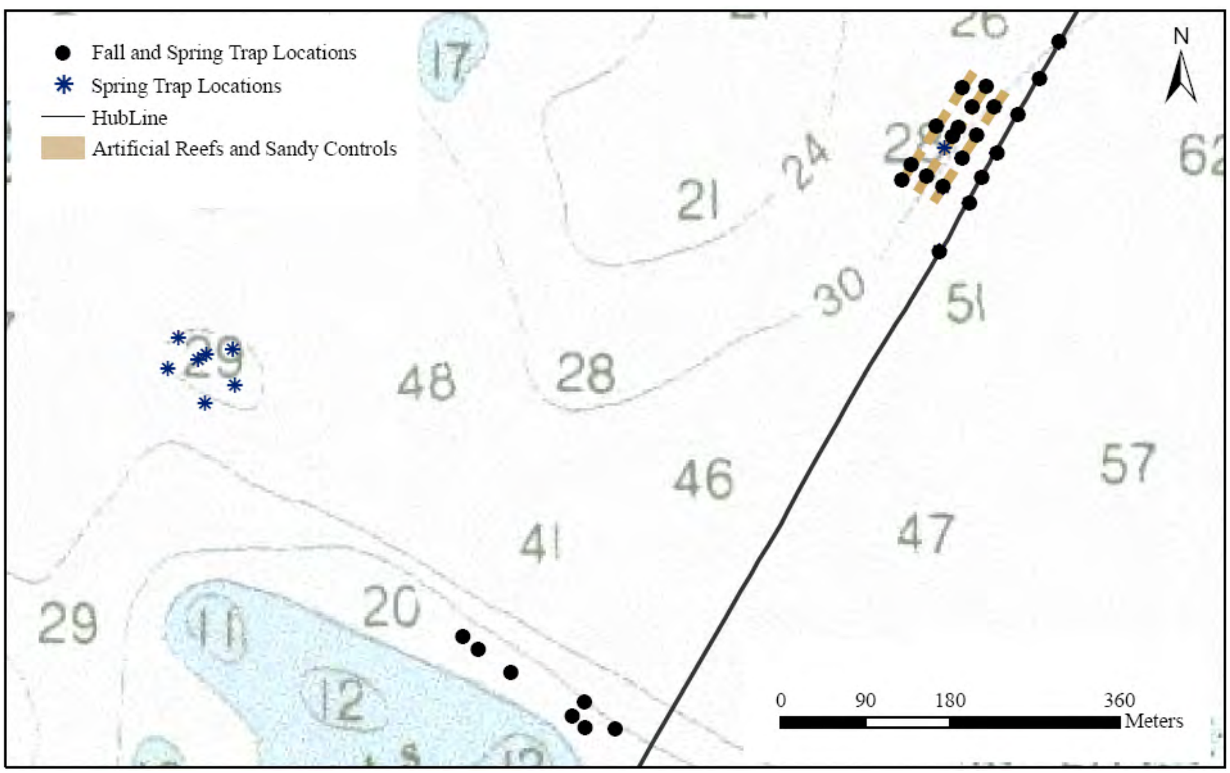


Figure IVB2.9. Locations of fish traps set in the spring and fall of 2006. Note: Spring locations represented by the stars were not resampled in the fall.

Figure IVB2.10. Juvenile lobster tagged with a knuckle tag.

individual artificial reef units. Data from all sites were combined by season and a one-way ANOVA was conducted on mean catch rate by season. Catch data were ln (x +1) transformed for this analysis to meet the assumptions of the ANOVA. With no difference in catch rate between seasons, the seasonal data were combined by site. A non-parametric test (Kruskal-Wallis) with follow-up pairwise comparisons (Mann-Whitney test) was performed to determine differences in catch among sites. A Bonferroni adjusted alpha of 0.008 was used in the comparisons. Next, using only data from the individual reef units, we conducted a one-way ANOVA and a follow-up Tukey test on cunner catch rates among reef units.

A one-way ANOVA was also run on the HubLine traps to determine if a difference existed in catch rate along a north-south gradient. These analyses were not run on lobsters or crabs because catch rates were minimal.

Cunner length-frequency. Cunner length-frequency was investigated by season and by site. A one-way ANOVA was run to determine if there was a difference in cunner length by season (data were *ln* transformed). Because there was a difference in mean length by season, the data were separated by season for further analysis. The cumulative percent frequency of total length was calculated by site within each season. Pairwise comparisons (Kolmogorov-Smirnov test) were conducted on frequency data to investigate differences in length distributions by site. A Bonferroni adjusted alpha value of 0.008 was used.

Cunner growth. Average growth of cunner was determined by calculating the mean difference in total length for cunner tagged in the spring and then recaptured in the fall. For multiple recaptures, the first recapture in the fall was used in the calculation.

Cunner movement. Cunner movement was examined by mapping tag and recapture locations. This graphically demonstrated the relative strength of cunner site fidelity in each area and qualitatively illustrated movement patterns.

We tested whether there was a difference in the total length of cunner that were recaptured on a different site than their original tagging location

Figure IVB2.11. Tagged cunner. Note: Thread on the fish on right was trimmed prior to release.

compared to cunner that were recaptured on the site at which they were tagged. The cumulative percent frequency of total cunner length was calculated for the fish that "moved" versus the fish that did not move. A pairwise comparison (Kolmogorov-Smirnov test) was conducted on the frequency data to investigate differences in length distributions of fish that moved versus fish that did not move.

Air-lift Sampling

The *MarineFisheries* Coastal Lobster Investigations Project conducts annual surveys to quantify the relative abundance of early benthic phase American lobster in Massachusetts coastal waters (Glenn et al. 2007). In the summer of 2006, the artificial reef, sand, HubLine fill point, and natural reef were added to the annual Massachusetts Bay air-lift sampling plan to compare larval lobster settlement among sites (Figure IVB2.12). These stations will continue to be monitored. Three of the sites were air-lift sampled in 2005 as well, prior to reef installation.

Air-lift sampling was conducted to gather quantitative data on the species present at each location as well as presence/absence data on particular benthic species and algae. Sampling design and equipment were standardized according to the methods defined by Wahle and Steneck (1991). The diver-operated suction device consisted of a 7.5-cm 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. The normal air-lift sampling routine consisted of haphazardly placing ½-m^2 quadrats on the substratum at least 2 m apart until a total of 12 samples were taken. This routine was used on the natural reef site (large boulder and patches of sand

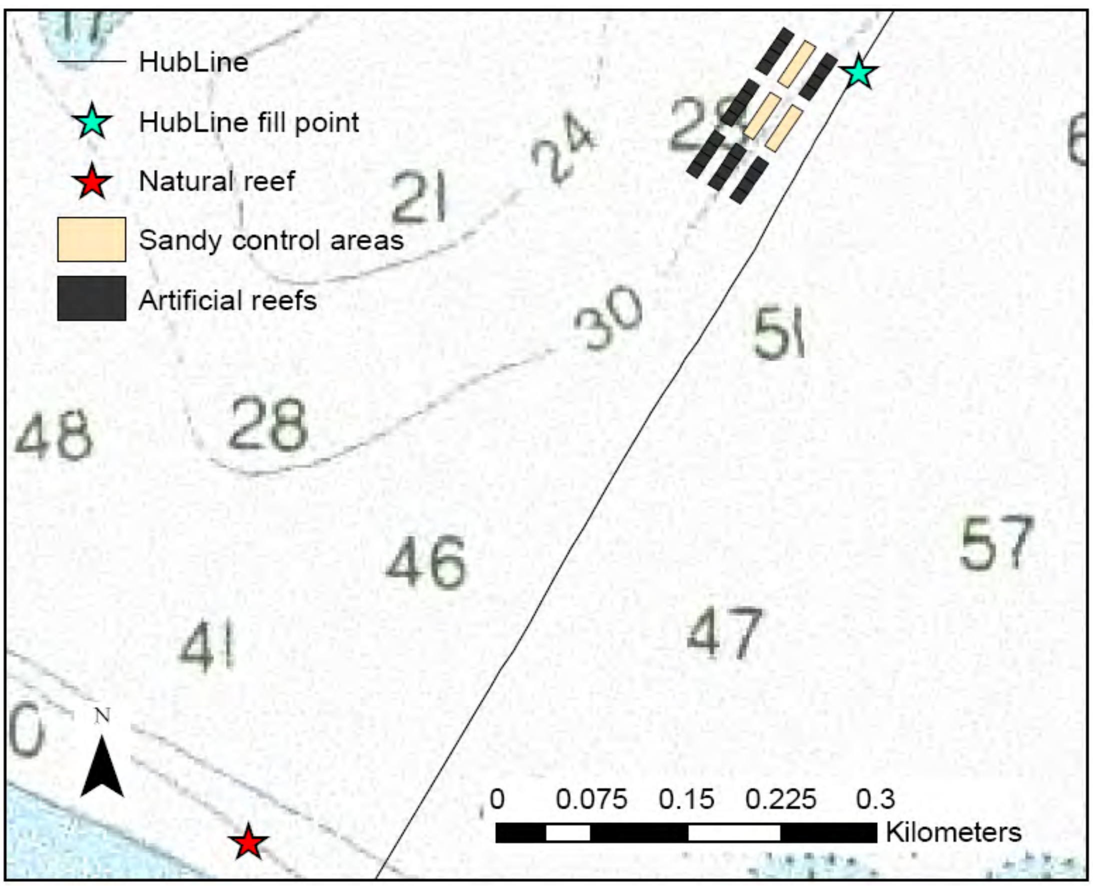


Figure IVB2.12. Location of 2006 air-lift sampling sites.

were avoided) and on the sand. A slightly different protocol was followed for the HubLine fill point and artificial reef since they had distinct edges. Since we had hypothesized that prevailing east/west currents could affect larval settlement on either side of the reefs, we sampled half of the HubLine and artificial reef on the east side and half on the west side. The sampling side (east or west) was randomly assigned to the artificial reef quadrats prior to the start of the dive. We also wanted to determine if there was a difference in settlement of larvae by rock size on the artificial reef. Thus, on each reef unit, one ½-m^2 quadrat was used to sample each of four rock sizes (small cobble, large cobble, small boulder, and large cobble/small cobble mix). The two largest rock sizes (large boulder and large boulder/small boulder mix) were not sampled due to the impracticality of turning those rocks over. In order to identify which reef, rock size, and side (east/west) on which the sample was collected, waterproof identification tags were placed into each sample bag underwater immediately following the collection. Quadrats were haphazardly placed within the desired area on the edge where the rock met the sand. Overturned rocks were replaced after suctioning ceased at each quadrat on the HubLine and the artificial reef. We sampled 12 quadrats on the HubLine (6 east and 6 west) and 24 quadrats on the artificial reef (4 per reef unit, 12 total on the east side and 12 total on the west). Sampling each quadrat in cobble habitat involved slowly pushing the lift tube over the bottom while moving rocks individually until few interstitial spaces remained. When sampling the sand, the air-lift device was moved over the sand until the entire quadrat was sampled. Samples were sorted on the surface and all flora and fauna were recorded. Lobsters were sexed and measured (carapace length) to the nearest 0.1 mm. Encrusting species and algae were recorded as present or absent, while individuals of other species were enumerated. Polychaetes were not counted (except for scale worms, families Polynoidea and Sigalionidae) because they were destroyed in the air-lift process.

Species diversity. Species recorded from the air-lift sampling were tallied for each site. The Shannon index of diversity was used to compare species diversity across sites. A Student's *t* statistic was calculated for pairwise comparisons of diversity among sites (Magurran 1988) using a Bonferroni adjusted alpha value of 0.008. Data from 2006 and 2007 were used in these analyses.

Lobster density by site. A non-parametric test (Kruskal-Wallis) with follow-up pairwise comparisons (Mann-Whitney test) was conducted to test for differences in lobster density by site. We used a Bonferroni adjusted alpha value of 0.008. Data from 2006 and 2007 were combined for this analysis. For all density analyses, the data were standardized to 1 m^2.

Young-of-the-year lobster density by site. A non-parametric test (Kruskal-Wallis) with follow-up pairwise comparisons (Mann-Whitney test) was used to test for differences in young-of-the-year (YOY) lobster density by site. A Bonferroni adjusted alpha value of 0.008 was used to account for the possibility of increased type I error. Data from 2006 and 2007 were combined for this analysis.

Young-of-the-year Cancer crab density by site. Differences in settlement of YOY Cancer crabs by site were examined by running a one-way ANOVA with follow-up Tukey tests. Data from 2006 and 2007 were combined for this analysis.

Early benthic phase lobster by site. Early benthic phase (EBP) lobster densities were initially combined across sites to assess whether there were differences in densities by year (2005 - 2007, Kruskal-Wallis test). A Kruskal-Wallis test was run on EBP lobster densities by site with survey years combined. A Bonferroni adjusted alpha value of 0.017 was used in follow-up pairwise comparisons (Mann-Whitney test) to detect differences by site. Data from the sand sites were not included in this analysis due to the absence of lobster.

Lobster density by rock size. A one-way ANOVA was used to test for differences in lobster density by rock size. Data were ln (x+1) transformed to meet the assumptions of the ANOVA. Data from 2006 and 2007 were combined for this analysis.

Young-of-the-year lobster density by rock size. A Kruskal-Wallis test was used to test for differences in post-larval lobster settlement by rock size. Follow-up pairwise comparisons (Mann-Whitney test, Bonferroni adjusted alpha value = 0.008) were used to test for differences in YOY lobster density by rock size. Data from 2006 and 2007 were combined for this analysis.

Young-of-the-year lobster density by east or west. A Mann-Whitney test was run to determine if post-larval lobster settlement was different on the east and west sides of the HubLine or the artificial reef. Data from 2006 and 2007 were combined for this analysis.

Results

Permanent Transect Surveys

Temperature, light, and water transparency. Temperature data from June 2006 through June 2007 indicated that the artificial reef and the natural reef had similar temperature regimes (Figure IVB.2.13). However, the residuals of these data showed that between October 2006 and May 2007 the natural reef was on average ~0.2 ºC colder than the artificial reef (Figure IVB2.14). Light data from July 18, 2007 to August 1, 2007 indicated that the artificial reef had slightly more light than the natural reef (Figure IVB2.15). The residuals of these data indicated that the artificial reef received an average of ~4 lux more than the natural reef during this period (Figure IVB2.16).

Water transparency ranged from the 1.7 – 3.1-m category to the 9.2 – 10.6-m category over the course of survey from May 2006 to August 2007 (Figure IVB2.17). Water clarity was generally higher in the winter months (November 2006 to March 2007) than in the spring and summer months (May to October 2006 and April to August 2007).

Monitoring photographs. Although only three seasons of bottom photographs were taken on the sites, the photographs demonstrated changes in the biota on the artificial reef, natural reef, and HubLine.

The first photographs taken on Reef 9 in December 2006 showed little algal growth on the artificial reef, a few solitary tunicates, and high coverage of barnacles and hydroids (Figure 2.18a). In March 2007, red filamentous algae and a diatom film had grown over much of the reef (Figure IVB2.18b). Yet, by June 2007 much of the red filamentous algae had declined and there was

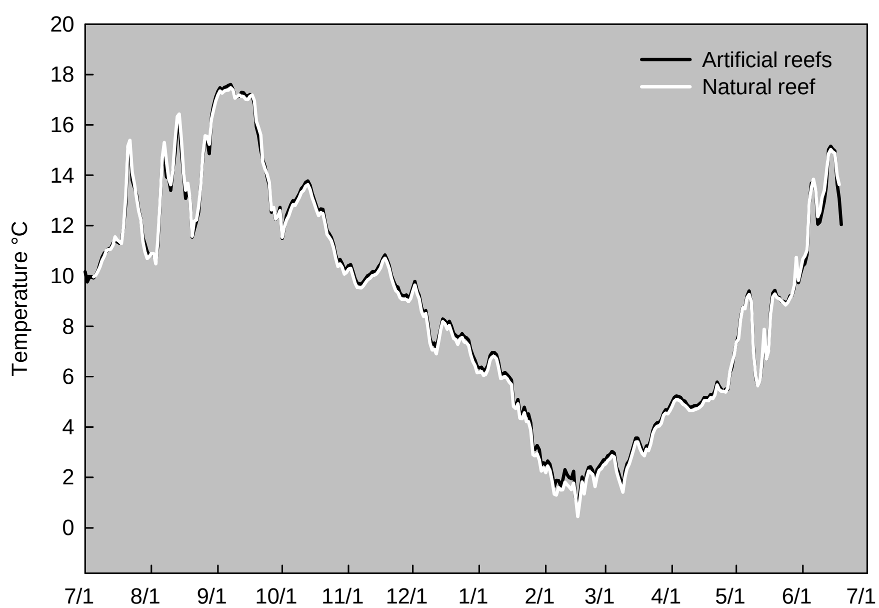


Figure IVB2.13. Temporal changes in bottom temperature on the artificial and natural reefs from July 1, 2006 to July 1, 2007.

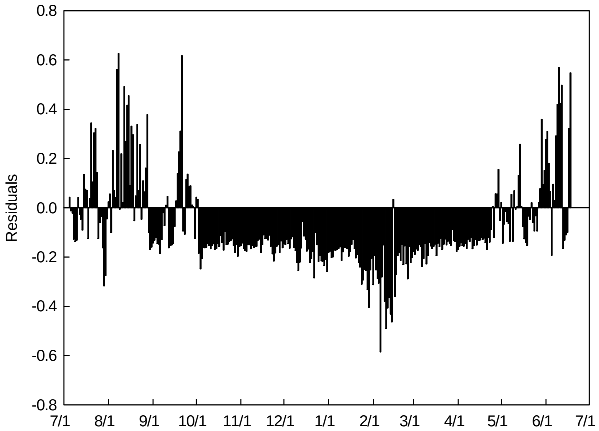


Figure IVB2.14. Temperature residuals between the artificial and natural reefs from July 1, 2006 to July 1, 2007. Negative values indicate when the natural reef was colder than the artificial reef.

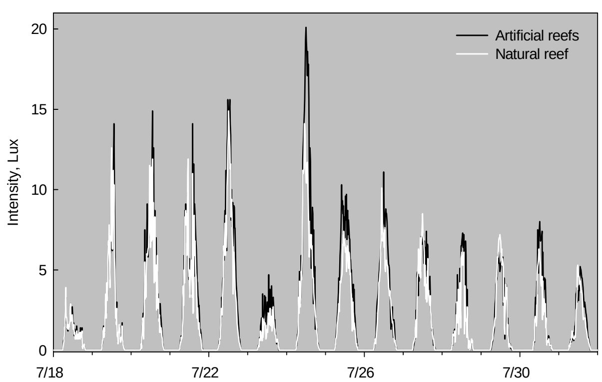


Figure IVB2.15. Daily changes in light intensity (lux) on the artificial and natural reefs in July 2007.

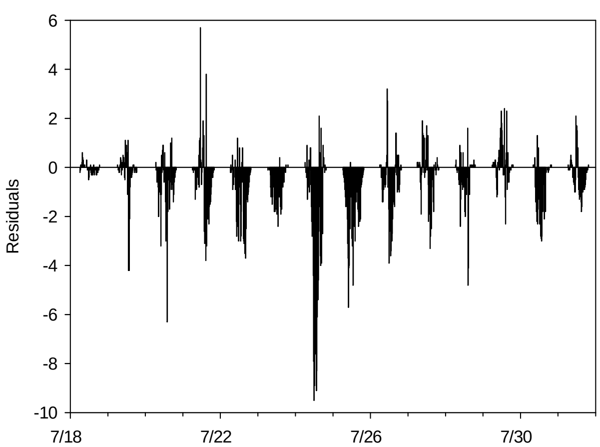


Figure IVB2.16. Light intensity residuals between the artificial and natural reefs in July 2007. Negative values indicate when the natural reef had less light than the artificial reef.

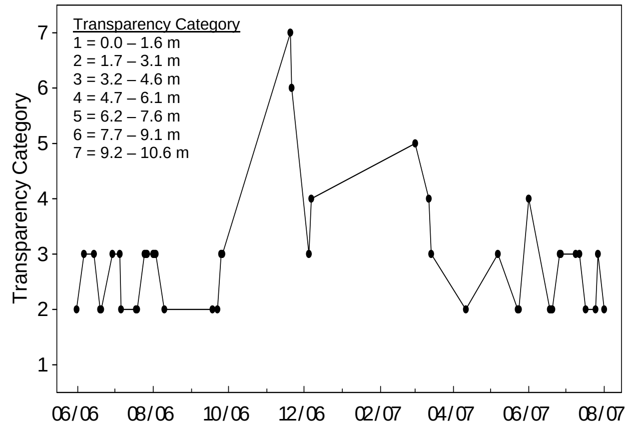


Figure IVB2.17. Water transparency estimated by divers at the start of each permanent transect survey.

evidence that a broad, leafy red algae (*Membranoptera alata*) had recruited to the reef (Figure IVB2.18c). A juvenile kelp recruit, most likely *Laminaria* sp., was also noted in the spring (Figure IVB2.18c). By the summer of 2007, encrusting tunicates had recruited to one of the rocks. One species appeared to be *Didemnum* sp. an invasive colonial tunicate (Figure IVB2.18d).

The second photograph station on the artificial reef (Reef 7) was not constructed until March 2007, therefore only three seasons of photographs exist (Figure IVB2.19). In March 2007, the area was covered predominantly by barnacles, red filamentous algae, and a thin diatom film (the brown layer over the barnacles) (Figure IVB2.19a). Coverage of the red filamentous algae decreased noticably between March and June 2007 (Figures IVB2.19a & b) but increased from June to July 2007 (Figures IVB2.19b & c). Coverage of other species of broad-leafed red algae also increased. It is apparent in the July 2007 photographs, that other benthic organisms (worms and a diatom film) grew over the barnacles, although it was not possible to identify them to species using the photographs.

The HubLine photographs depicted an increase in red algal growth from December 2006 to May 2007 (Figures IVB2.20a - c) and a slight decline from May to July 2007 (Figures IVB2.20c & d). Small encrusting tunicates (orange dots in Figure IVB2.20a), evident on the rocks and sponge (*Halichondria panicea*) in the December 2006 photograph, appeared to have either died off or been covered by algae by June 2007. Barnacles and hydroids

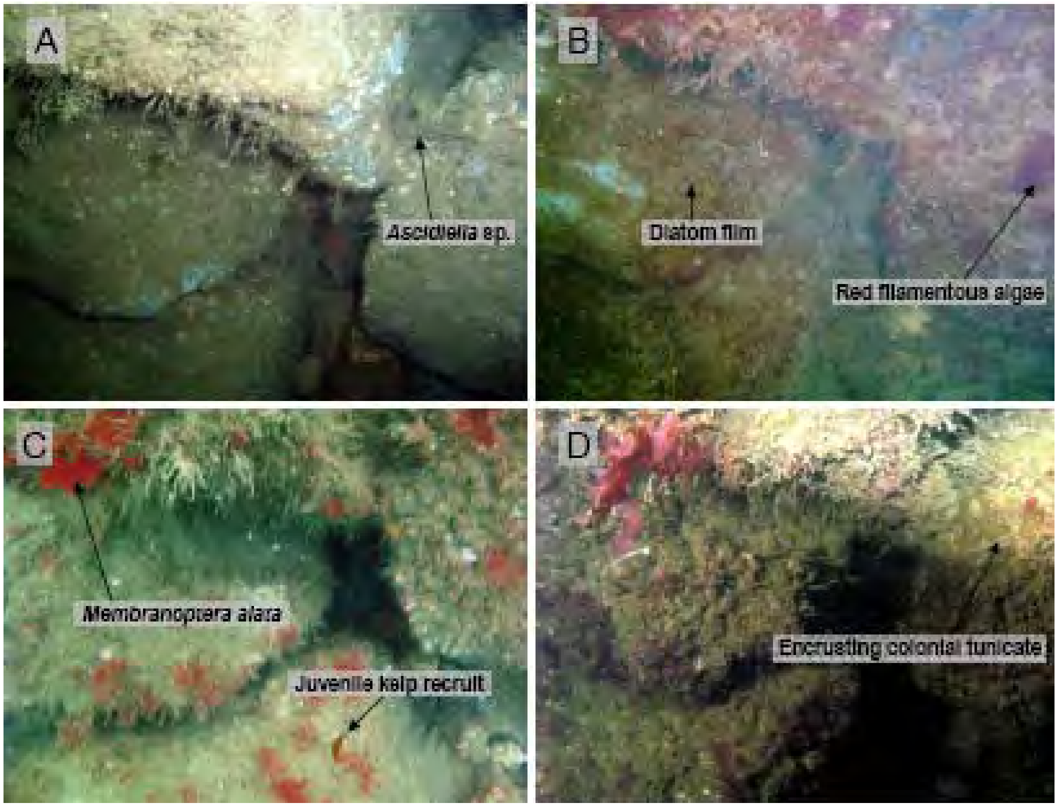


Figure IVB2.18. Photographs taken on Artificial Reef 9 on (A) 12/7/2006, (B) 3/14/2007, (C) 6/26/2007, and (D) 7/25/2007.

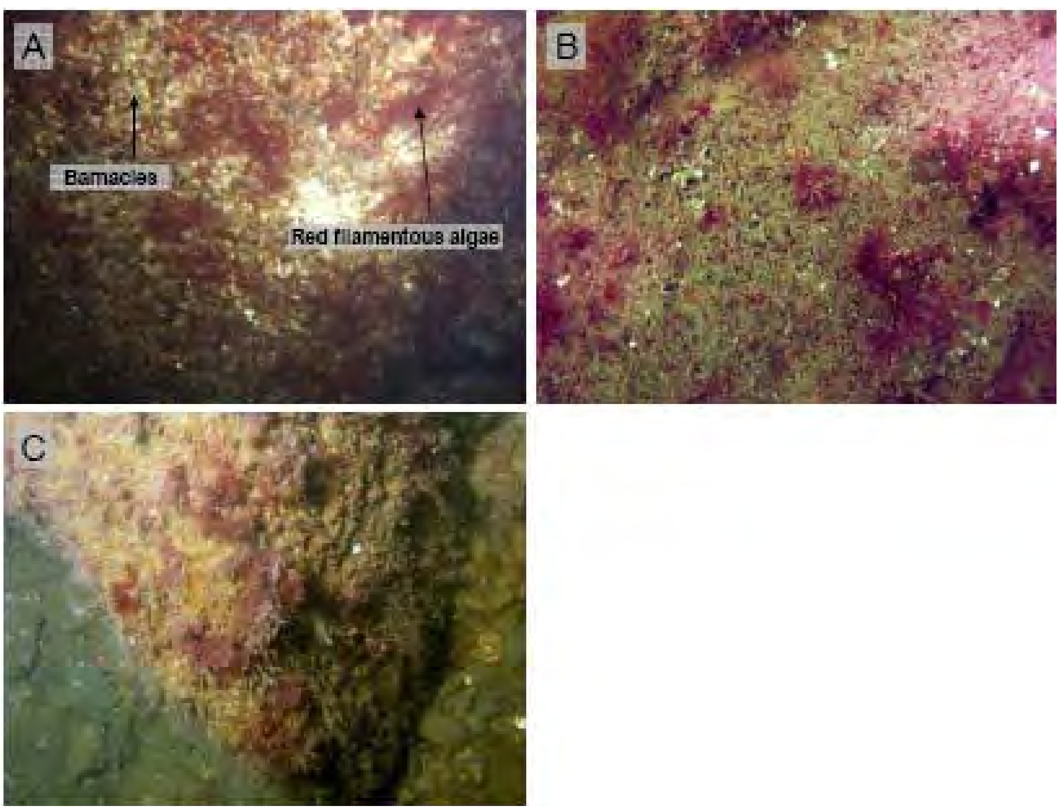


Figure IVB2.19. Photographs taken on Artificial Reef 7 on (A) 3/14/2007, (B) 6/26/2007, and (C) 7/27/2007. Note: Photograph C was taken with a wider angle lens on a new camera system.

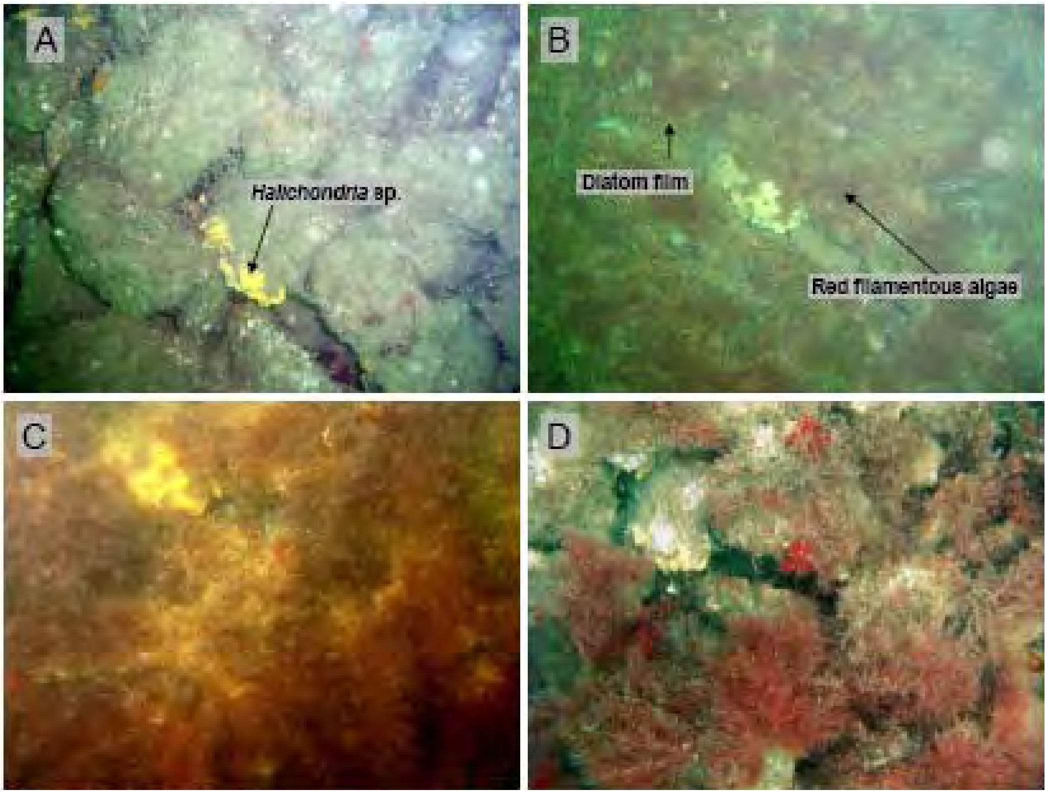


Figure IVB2.20. Photographs taken on the HubLine on (A) 12/7/2006, (B) 3/1/2007, (C) 5/23/2007, and (D) 7/12/2007.

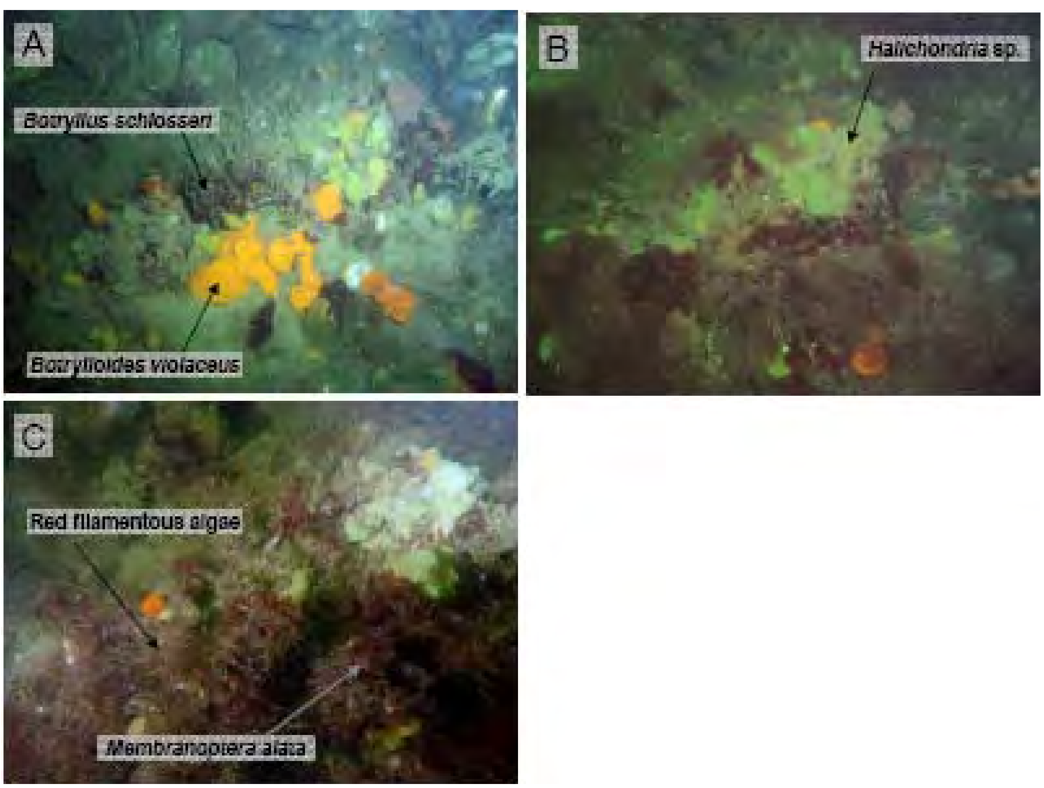


Figure IVB2.21. Photographs taken on Natural Reef 1 on (A) 12/7/2006, (B) 4/11/2007, and (C) 5/24/2007. Note: photographs were not obtained in July 2007 due to adverse diving conditions.

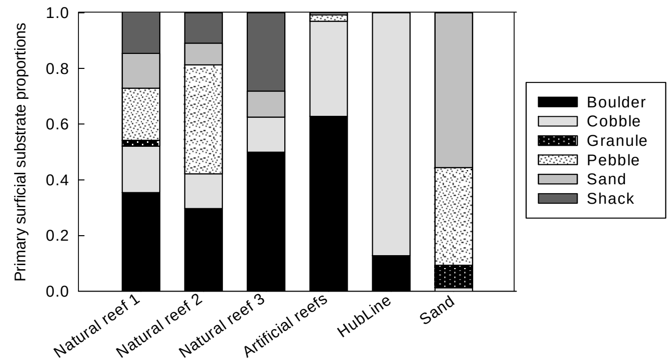


Figure IVB2.22. Proportion of primary surficial substrates (> 50% of area) among study sites.

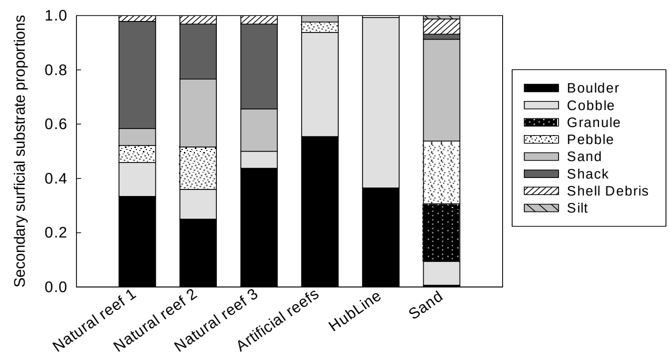


Figure IVB2.23. Proportion of secondary surficial substrates (10 - 50% of area) among study sites.

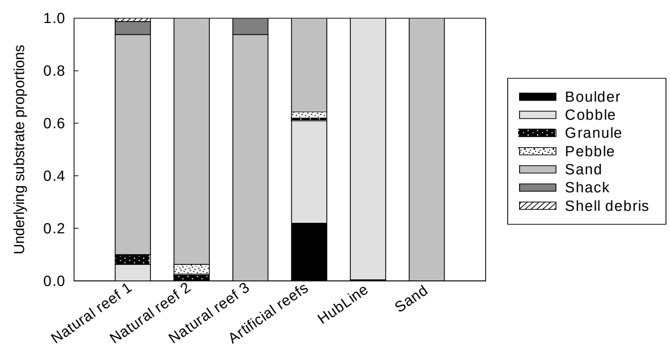


Figure IVB2.24. Proportion of substrates underlying the primary and secondary substrates among study sites.

were also obvious in December, but not easily viewed in March, May, or June 2007 due to algal coverage. A small broad-leafed red alga was present in July 2007. Also in July 2007, it appeared that some of the rocks had been disturbed, as a portion of the sponge (*Halichondria* sp.) and patches of red filamentous algae were missing from the surface of some rocks (Figure IVB2.20d). This disturbance was specific to the HubLine photo monitoring site, as we did not observed a site-wide occurrence.

The natural reef photographs showed an overall decline in the percent cover of encrusting tunicates (*Botryllus schlosseri* and *Botrylloides violaceus*) and a fair amount of growth of the sponge *Halichondria panicea* from December 2006 to May 2007 (Figure IVB2.21). There was also a noticable increase in red algal coverage (filamentous and leafy red) from December 2006 to May 2007. Usable photographs were not obtained in July 2007 due to adverse diving conditions including strong currents and poor visibility.

Substrate. Primary surficial substrate, the sediment type that constituted more than 50% of the area, varied within each study site as well as across sites (Figure IVB2.22). The natural reef had a greater assortment of primary substrates including boulder, cobble, granule, pebble, sand, and shack (whole shell debris). Primary surficial substrates on the artificial reef were mainly boulder and cobble, while the HubLine was dominated by cobble. The sand site was composed largely of sand and pebble.

Secondary surficial substrate, the sediment type that constituted from 10 to 50% of the area, also varied across sites (Figure IVB2.23). The natural reef had high proportions of shack and boulder as secondary substrates. The artificial reef and HubLine were predominantly boulder and cobble. Secondary substrates on the sand included a wide range of sediment types, but primarily consisted of sand, pebble, and granule.

Underlying substrates were fairly similar across the natural reef and the sand sites, (Figure IVB2.24) consisting primarily of sand and occasionally cobble, granule, pebble, and shack. The artificial reef and HubLine, however, had more hard-bottom as their immediate underlying substrate. In other words, the substrate directly underneath the top layer of rocks was also rock. This occurred in about 50% of the artificial reef quadrats (with the other underlying substrate being primarily sand) and in all HubLine quadrats.

Species diversity. Using presence/absence species data, a total of 80 species were sighted on the artificial reef between May 2006 and July 2007

(Table IVB2.1). Seventy-seven species were observed on the natural reef from July 2006 to July 2007 (Table IVB2.2), 64 species were sighted on the HubLine from June 2006 to July 2007 (Table IVB2.3), and 53 species were sighted on the sand sites from June 2006 to July 2007 (Table IVB2.4).

Diversity analyses. The Shannon index of diversity run on enumerated species (swath surveys) indicated that diversity was higher on the artificial reef in the summers of 2006 and 2007 than any other sites or seasons (Table IVB2.5, Figure IVB2.25). On all sites, diversity was lowest in winter 2007; then rose considerably from winter to spring 2007. On the artificial reef, there was a significant decrease in diversity from summer 2006 to fall 2006 (t-stat = 3.31, $p < 0.016$) and from fall 2006 to winter 2007 (t-stat = 6.68, $p < 0.016$), then, a significant increase in diversity from winter 2007 to spring 2007 (t-stat = 7.62, $p < 0.016$), and from spring 2007 to summer 2007 (t-stat = 15.6 $p < 0.016$). A comparison of diversity among all sites in spring 2006 revealed significantly lower diversity on the artificial reef than the HubLine (t-stat = 3.86, $p < 0.008$) and sand (t-stat = 3.35, $p < 0.008$) (Table IVB2.5). There was no difference in diversity between the artificial and natural reef in spring 2006 (t-stat = -2.03, $p > 0.008$). Also, in summer 2006, fall 2006, and winter 2007 diversity on the artificial reef was not significantly different from the diversity on the other three sites ($p > 0.008$). In the following spring (2007), diversity on the artificial reef was significantly lower than on the HubLine (t-stat = 6.99, $p < 0.008$), but there was no difference in diversity between the artificial reef and natural reef or sand (t-stat = -3.46, -2.17 respectively, $p > 0.008$). In summer 2007, index values varied less than 0.4 among sites and none of the differences were significant.

The Shannon index of diversity run on species assessed by percent cover (quadrat surveys) indicated that diversity on the natural reef and the sand was higher than on the artificial reef and the HubLine (Table IVB2.6, Figure IVB2.26). On the artificial reef, diversity of sessile species generally increased over time, with the lowest value in spring 2006 and the highest value in summer 2007 (Table IVB2.6, Figure IVB2.26). Statistically, the only significant difference in diversity between the artificial reef and the other three sites was in summer 2007 between the artificial reef and the HubLine (t-stat = 5.15, $p < 0.008$). The natural reef had significantly higher diversity than the HubLine in all seasons except spring 2007 (t-stat = 4.89 $p < 0.008$). HubLine diversity was higher than the artificial reef from spring 2006 to fall 2007 but in winter 2007 artificial reef diversity was higher. Overall, the natural reef maintained higher diversity than the artificial reef and HubLine throughout the course of monitoring.

<u>Species densities</u>. Densities of red filamentous algae, common kelp (*Laminaria* sp.), sponges, solitary tunicates, blue mussels (*Mytilus edulis*), Cancer crabs, and American lobster (*Homarus americanus*) were compared among survey sites. Mean percent cover of red filamentous algae decreased from the summer months (July and August 2006) to fall (September and November/December 2006), then increased from late fall (November/ December 2006) to spring (March 2007). Densities fluctuated from May to July 2007 (Figure IVB2.27). The HubLine consistently had the highest percent cover of red filamentous algae until March 2007. Mean percent cover of red filamentous algae on the artificial reef was low (< 3%) post-installation from June to December 2006, and then rose in March 2007 to surpass the natural reef (~23%). In May and June 2007, the natural reef and HubLine had higher coverage than the artificial reef, however in July the artificial reef was again highest. The artificial reef had higher cover of red filamentous algae in 2007 than in 2006.

Common kelp (*Laminaria* sp.) mean percent cover was variable across sites especially in the summer months (Figure IVB2.28). The artificial reef was nearly void of common kelp throughout the survey period in 2006, as was the sand site. The HubLine had minimal kelp coverage in November/December and June 2006, then relatively high cover from July to August 2006 (~15%). Natural reef kelp coverage was similar to the HubLine in August. Both sites then experienced a dramatic decline in kelp coverage in September 2006 that continued through March 2007. Kelp coverage increased on all sites except the sand in June 2007, and continued to increase

Table IVB2.1. Species recorded on the artificial reef by date.

ARTIFICIAL REEF (page 1 of 2)	Date	05/31/06	06/14/06	06/19/06	06/20/06	06/29/06	07/18/06	07/25/06	07/27/06	08/02/06	08/10/06	09/18/06	09/26/06	11/20/06	11/21/06	03/14/07	05/07/07	05/24/07	06/20/07	06/26/07	06/27/07	07/09/07	07/12/07	07/17/07	07/25/07	07/27/07
Algae																										
Agarum cribrosum	Sieve kelp / shotgun kelp																									x
Brown filamentous algae	Unid. brown filamentous		x		x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Chondrus crispus	Irish moss		x				x			x							x	x	x					x		x
Desmarestia sp.	Filamentous brown algae															x										
Laminaria sp.	Kelp species		x		x		x		x	x		x				x	x	x	x	x	x	x	x	x	x	x
Membranoptera alata	Leafy red blade						x	x	x	x			x			x	x	x	x	x	x	x	x	x	x	x
Palmaria palmata	Red blade algae								x		x		x	x	x		x	x			x	x		x		x
Porphyra sp.	Thin red blade algae																			x						
Red blade algae	Unidentified blade-like sp.	x	x		x											x			x	x	x				x	
Red coralline algae	Encrusting coralline algae		x	x			x		x	x		x						x		x	x	x			x	x
Red filamentous algae	Unidentified red filamentous	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ulva lacuta	Sea lettuce, green blade																					x				
Invertebrates																										
Poriferans																										
Clathrina sp.	White tubular sponge															x	x	x	x	x	x	x	x	x	x	x
Halichondria panicea	Crumb of bread sponge		x		x			x		x			x	x	x	x	x	x	x	x	x	x	x	x	x	x
Haliclona loosanoff	Loosanoff's haliclona sponge																		x		x	x	x		x	x
Haliclona oculata	Dead man's finger sponge																			x	x			x	x	x
Isodictya sp.	Palmate sponge		x	x			x	x	x	x		x	x	x	x	x	x		x	x		x		x	x	x
Unidentified sponge	Unidentified sponge																			x						
Cnidarians																										
Cerianthus borealis	Burrowing anemone						x	x				x	x	x	x	x	x									
Metridium senile	Frilled anemone														x	x	x	x	x	x	x	x	x	x	x	x
Obelia sp.	Hydroid on kelp																x	x	x	x	x	x			x	x
Tubularia crocea	Pink hydroid							x	x		x		x			x				x	x	x	x	x	x	x
Unidentified hydroid	Unidentified hydroid																			x						
Bryozoans																										
Bugula turrita	Tree-shaped bryozoan						x	x		x		x	x	x	x		x		x	x	x	x	x	x	x	x
Cryptosula pallasiana	Red crust bryozoan											x	x	x			x			x				x		
Electra pilosa	Encrusting bryozoan																							x		
Membranipora sp.	Encrusting bryozoan							x	x	x		x	x	x				x	x				x	x	x	x
Molluscs - Gastropods																										
Crepidula fornicata	Atlantic slipper snail																x									
Crepidula plana	Eastern white slipper shell						x			x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dorid nudibranch	Family Onchidorididae															x	x									
Dendronotus sp.	Dendronoid nudibranch																x									
Flabellina pellucida	Red-gilled nudibranch															x	x	x								
Lacuna vincta	Northern Lacuna																									x
Muricidae Family	Drill whelks								x																	
Nassarius trivittata	New England dog whelk						x		x	x	x	x					x	x			x	x	x	x	x	
Unidentified snail or whelk	Unidentified snail or whelk							x																		
Molluscs - Bivalves																										
Mytilus edulis	Blue mussel				x		x	x		x	x	x	x	x	x	x	x				x	x	x	x	x	x
Modiolus modiolus	Horse mussel														x											
Placopecten magellanicus	Sea scallop	x															x		x			x				
Molluscs - Polyplacophorans																										
Tonicella sp.	Chiton																	x								
Annelids																										
Myxicola sp.	Slime worm																x									
Scale worm	Polynoidae & Sigalionidae															x										
Spirorbis borealis	Spirorbid worm																				x	x				x
Arthropods																										
Barnacles	Order Thoracica	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Cancer borealis	Jonah crab	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cancer irroratus	Rock crab	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cancer sp.	Rock and Jonah crabs					x										x										
Carcinus maenas	Green crab																			x						
Crangon sp.	Sand shrimp															x										
Homarus americanus	American lobster	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Majidae crabs	Spider crab (Hyas or Libinia)	x		x			x	x		x				x			x	x		x			x	x		x
Pagarus sp.	Large hermit crabs									x		x	x	x		x	x									
Unidentified shrimp	Unidentified shrimp																x									
Echinoderms																										
Asterias forbesi	Common sea star	x	x			x	x	x	x				x		x	x	x	x	x	x	x	x	x	x	x	x
Asterias vulgaris	Northern sea star							x			x		x		x	x	x	x	x	x	x	x	x	x	x	x
Asterias sp.	Asterid sea star species												x			x	x	x		x			x			
Henricia sp.	Blood star	x	x	x		x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x		x
Strongylocentrotus droebachiensis	Green sea urchin															x	x	x		x	x		x	x		
Chordates																										
Tunicates																										
Ascidiella aspersa	European sea squirt						x		x		x		x		x	x	x	x	x	x	x	x	x	x		x
Botrylloides violaceus	Orange sheath tunicate		x			x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Botryllus schlosseri	Star tunicate				x								x		x		x	x		x		x	x			
Ciona intestinalis	Sea vase tunicate														x	x	x	x	x	x	x	x	x	x	x	x
Didemnum albidum	White encrusting tunicate							x	x						x	x	x	x	x	x	x	x	x	x	x	x
Didemnum sp.	Gray encrusting, invasive														x	x	x		x	x	x	x	x	x	x	x
Styela clava	Club tunicate														x	x	x	x	x	x	x	x	x	x	x	x
Unidentified tunicate	Unidentified tunicate												x			x	x	x	x	x	x	x	x	x	x	x

Table IVB2.1 (cont.). Species recorded on the artificial reef by date.

ARTIFICIAL REEF (page 2 of 2)		Date	05/31/06	06/14/06	06/19/06	06/20/06	06/29/06	07/18/06	07/25/06	07/27/06	08/02/06	08/10/06	09/18/06	09/26/06	11/20/06	11/21/06	03/14/07	05/07/07	05/24/07	06/20/07	06/26/07	06/27/07	07/09/07	07/12/07	07/17/07	07/25/07	07/27/07
Fishes																											
Centropristis striata	Black sea bass																						x				
Gadus morhua	Atlantic cod									x		x				x				x			x			x	x
Hemitripterus americanus	Sea raven								x			x				x			x		x	x	x				
Macrozoarces americanus	Ocean pout				x																				x		
Myoxocephalus aenaeus	Grubby sculpin							x		x	x		x	x		x	x	x		x	x	x	x	x	x		x
Myoxocephalus scorpius	Shorthorn sculpin																x			x	x	x	x				x
Myoxocephalus sp.	Shorthorn/ grubby/ longhorn				x									x												x	x
Pholis gunnellus	Rock gunnel			x					x					x			x		x		x	x	x	x		x	x
Pollachius virens	Pollock								x			x		x		x				x		x				x	x
Pseudopleuronectes americanus	Winter flounder			x	x		x	x		x	x	x	x	x					x	x	x	x	x	x	x	x	x
Tautogo onitis	Tautog																										x
Tautogolabrus adspersus	Cunner		x	x	x		x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
Ulvaria subbifurcata	Radiated shanny							x						x		x			x			x				x	x
Urophycis chuss	Red hake													x									x				

Table IVB2.2. Species recorded on the natural reef by date.

NATURAL REEF (page 1 of 2)	Date	07/05/06	07/26/06	08/01/06	08/03/06	09/25/06	12/05/06	12/07/06	03/12/06	04/11/07	05/24/07	06/01/07	06/18/07	07/17/07	08/01/07
Algae															
Agarum cribrosum	Sieve kelp / shotgun kelp			x						x	x		x	x	
Alaria sp.	Kelp w/ mid-rib														
Brown filamentous algae	Unid. brown filamentous	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Chondrus crispus	Irish moss	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Desmarestia sp.	Filamentous brown algae								x						
Green filamentous algae	Unid. green filamentous								x	x					x
Laminaria sp.	Kelp species	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Membranoptera alata	Leafy red blade		x	x	x	x			x	x	x	x	x	x	x
Palmaria palmata	Red blade algae	x	x	x	x	x	x		x	x	x	x	x	x	x
Porphyra sp.	Thin red blade algae											x			
Red coralline algae	Encrusting coralline algae	x	x	x	x		x	x	x	x	x	x		x	x
Red filamentous algae	Unidentified red filamentous	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ulva lactuca	Sea lettuce, green blade			x	x		x		x			x		x	x
Invertebrates															
Poriferans															
Clathrina sp.	White tubular sponge								x	x	x	x	x		
Halichondria panicea	Crumb of bread sponge	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Haliclona loosanoff	Loosanoff's haliclona sponge													x	x
Haliclona oculata	Dead man's finger sponge	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Isodictya sp.	Palmate sponge	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Suberites ficus	Fig sponge		x	x	x	x	x	x	x	x	x		x	x	x
Unidentified sponge	Unidentified sponge			x											
Cnidarians															
Cerianthus borealis	Burrowing anemone		x											x	
Haliclystus auricula	Stalked jellyfish											x		x	
Tubularia crocea	Pink hydroid					x								x	
Obelia sp.	Hydroid on kelp						x					x	x	x	x
Hydroid	Unidentified hydroid	x													
Bryozoans															
Bugula turrita	Tree-shaped bryozoan	x	x	x	x	x	x	x		x	x		x	x	x
Cryptosula pallasiana	Red crust bryozoan					x		x			x		x	x	x
Electra pilosa	Encrusting bryozoan												x	x	
Membranipora sp.	Encrusting bryozoan		x	x	x	x	x	x	x	x	x	x	x	x	
Unidentified bryozoan	Unidentified bryozoan	x			x										
Molluscs - Gastropods															
Acmaea sp.												x			
Anomia sp.	Jingle shell			x											
Crepidula fornicata	Atlantic slipper snail		x	x	x	x	x	x	x		x	x		x	x
Crepidula plana	Eastern white slipper shell	x	x			x	x	x	x	x	x		x	x	x
Dorid nudibranch	Family Onchidorididae									x					
Flabellina pellucida	Red-gilled nudibranch								x	x	x	x	x		
Metridium senile	Frilled anemone							x							
Nassarius trivittata	New England dog whelk		x	x	x				x	x	x	x	x	x	
Unidentified snail or whelk	Unidentified snail or whelk	x													
Molluscs - Bivalves															
Mytilus edulis	Blue mussel	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Placopecten magellanicus	Sea scallop		x									x		x	
Annelids															
Spirorbis borelis	Spirorbid worm			x	x	x	x	x	x	x	x	x	x	x	x
Amphipods															
Caprellid shrimp	Skeleton shrimp									x					
Arthropods															
Barnacles	Order Thoracica	x	x	x	x	x	x	x	x	x	x	x	x	x	
Cancer borealis	Jonah crab	x	x	x	x	x	x	x		x	x	x	x	x	x
Cancer irroratus	Rock crab	x	x	x	x	x	x	x			x	x	x	x	x
Cancer sp.	Unid. rock or Jonah crab								x						
Crangon sp.	Sand shrimp											x			
Homarus americanus	American lobster	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Majidae crabs	Spider crab (Hyas or Libinia)	x	x	x	x	x	x	x			x	x	x	x	x
Mysid sp.	Mysis shrimp				x			x							
Pagarus sp.	Large hermit crab		x	x				x			x	x		x	
Echinoderms															
Asterias sp.	Asterid sea star species													x	
Asterias vulgaris	Northern sea star							x							
Brittle star	Class Ophiuroidea											x	x		
Henricia sp.	Blood star					x		x			x		x	x	
Chordates															
Tunicates															
Ascidiella aspersa	European sea squirt			x		x	x	x	x	x	x	x	x	x	x
Botrylloides violaceus	Orange sheath tunicate	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Botryllus schlosseri	Star tunicate	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ciona intestinalis	Sea vase tunicate						x	x		x		x			
Didemnum albidum	White encrusting tunicate	x						x	x			x		x	x
Didemnum sp.	Gray encrusting, invasive						x				x	x		x	x
Styela clava	Club tunicate								x		x		x	x	
Unidentified tunicate	Unidentified tunicate						x	x	x	x	x	x	x		

Table IVB2.2 (cont.). Species recorded on the natural reef by date.

NATURAL REEF (page 2 of 2)		Date	07/05/06	07/26/06	08/01/06	08/03/06	09/25/06	12/05/06	12/07/06	03/12/06	04/11/07	05/24/07	06/01/07	06/18/07	07/17/07	08/01/07
Fishes																
Hemitripterus americanus	Sea raven				x											x
Liparis sp.	Snailfish			x												
Macrozoarces americanus	Ocean pout														x	x
Myoxocephalus aenaeus	Grubby sculpin		x	x	x	x	x	x	x		x	x	x	x	x	x
Myoxocephalus scorpius	Shorthorn sculpin			x			x					x				
Myoxocephalus sp.	Shorthorn/ grubby/ longhorn								x							
Pholis gunnellus	Rock gunnel		x	x	x				x		x	x	x		x	x
Pollachius virens	Pollock		x													
Pseudopleuronectes americanus	Winter flounder		x	x	x	x	x		x					x	x	
Raja sp.	Skate								x		x					
Tautogolabrus adspersus	Cunner			x	x	x	x	x	x		x	x	x	x	x	x
Ulvaria subbifurcata	Radiated shanny		x	x	x	x	x					x	x	x	x	
Unidentified fish	Unidentified fish				x								x			x

Table IVB2.3. Species recorded on the HubLine by date.

HUBLINE	Date	06/06/06	07/06/06	07/18/06	08/02/06	08/10/06	09/22/06	11/20/06	03/01/07	05/23/07	06/19/07	06/20/07	07/12/07
Algae													
Agarum cribrosum	Sieve kelp / shotgun kelp												x
Brown filamentous algae	Unid. brown filamentous	x	x	x	x	x		x		x	x		x
Chondrus crispus	Irish moss											x	
Desmarestia sp.	Filamentous brown algae								x				
Laminaria sp.	Kelp species		x	x	x	x	x	x	x	x	x	x	x
Membranoptera alata	Leafy red blade		x	x	x	x		x	x	x	x	x	x
Palmaria palmata	Red blade algae		x	x	x	x	x	x	x	x	x	x	
Red blade algae	Unidentified blade-like sp.	x											x
Red coralline algae	Encrusting coralline algae		x		x	x				x			x
Red filamentous algae	Unidentified red filamentous	x	x	x	x	x	x	x	x	x	x	x	x
Ulva lactuca	Sea lettuce, green blade	x			x								
Invertebrates													
Poriferans													
Halichondria panicea	Crumb of bread sponge		x		x	x	x	x	x	x	x	x	x
Haliclona loosanoff	Loosanoff's haliclona sponge											x	x
Haliclona oculata	Dead man's finger sponge			x		x			x	x			x
Isodictya sp.	Palmate sponge	x	x	x		x	x	x	x	x		x	x
Unidentified sponge	Unidentified sponge	x											
Cnidarians													
Obelia sp.	Hydroid on kelp			x	x	x				x	x	x	x
Hydroids	Unidentified hydroid		x	x					x				
Bryozoans													
Bugula turrita	Tree-shaped bryozoan				x			x					
Cryptosula pallasiana	Red crust bryozoan					x		x	x				x
Electra pilosa	Encrusting bryozoan										x		
Membranipora sp.	Encrusting bryozoan		x	x	x	x	x				x		x
Unidentified bryozoan	Unidentified bryozoan				x								
Molluscs - Gastropods													
Crepidula plana	Eastern white slipper shell		x	x		x	x	x	x	x	x	x	x
Nassarius trivittata	New England dog whelk								x	x	x		x
Molluscs - Bivalves													
Mytilus edulis	Blue mussel		x	x	x	x	x	x	x	x	x	x	x
Modiolus modiolus	Horse mussel			x									
Placopecten magellanicus	Sea scallop			x	x		x			x		x	x
Annelids													
Myxicola sp.	Slime worm									x			
Scale worm	Polynoidae & Sigalionidae								x				
Spirorbis borelis	Spirorbid worm					x				x	x		x
Arthropods													
Barnacles	Order Thoracica	x	x	x	x	x	x	x	x	x	x	x	x
Cancer borealis	Jonah crab	x	x	x	x	x	x	x	x	x	x	x	x
Cancer irroratus	Rock crab	x	x	x	x	x	x	x			x	x	x
Homarus americanus	American lobster	x	x	x	x	x	x	x	x	x	x	x	x
Majidae crabs	Spider crab (Hyas or Libinia)									x		x	
Pagarus sp.	Hermit crab										x		
Echinoderms													
Asterias forbesi	Common sea star	x	x	x	x	x		x	x	x	x	x	x
Asterias vulgaris	Northern sea star	x	x	x	x	x	x	x	x	x	x	x	x
Asterias sp.	Asterid sea star species								x				x
Brittle stars	Subclass Ophiuroidea								x				
Henricia sp.	Blood star	x	x	x		x	x	x	x	x	x	x	x
Stronglyocentrotus droebachiensis	Green sea urchin								x				
Chordates													
Tunicates													
Ascidiella aspersa	European sea squirt						x				x	x	x
Botrylloides violaceus	Orange sheath tunicate	x								x	x	x	x
Botryllus schlosseri	Star tunicate				x	x				x			x
Ciona intestinalis	Sea vase tunicate					x						x	
Didemnum albidum	White encrusting tunicate								x	x		x	x
Didemnum sp.	Gray encrusting, invasive						x					x	
Unidentified tunicate	Unidentified tunicate								x	x	x	x	
Fishes													
Hemitripterus americanus	Sea raven					x					x		
Liparis sp.	Snailfish		x										
Morone saxatilis	Striped bass				x								
Myoxocephalus aenaeus	Grubby sculpin		x	x	x	x	x			x	x	x	
Myoxocephalus scorpius	Shorthorn sculpin				x					x			
Myoxocephalus sp.	Shorthorn/ grubby/ longhorn								x				
Pholis gunnellus	Rock gunnel	x		x	x		x			x	x	x	
Pseudopleuronectes americanus	Winter flounder	x			x						x	x	x
Squalus acanthias	Spiny dogfish						x						x
Stichaeus punctatus	Arctic shanny					x						x	x
Tautogolabrus adspersus	Cunner		x	x	x	x	x	x		x	x	x	x
Ulvaria subbifurcata	Radiated shanny		x	x		x				x		x	
Unidentified fish	Unidentified fish		x										

Table IVB2.4. Species recorded on the sand by date.

SAND		Date	06/14/06	06/20/06	07/18/06	08/02/06	09/18/06	09/26/06	11/20/06	03/01/07	03/14/07	05/07/07	07/09/07	07/25/07
Algae														
Brown filamentous algae	Unid. brown filamentous		x	x	x	x	x		x		x	x	x	x
Chondrus crispus	Irish moss		x		x	x						x		
Laminaria sp.	Kelp species		x	x	x	x	x				x	x	x	x
Membranoptera alata	Leafy red blade				x	x					x	x	x	x
Palmaria palmata	Red blade algae								x			x		
Red blade	Red blade algae		x	x										x
Red coralline algae	Encrusting coralline algae		x		x	x	x						x	x
Red filamentous algae	Unidentified red filamentous		x	x	x	x	x		x		x	x	x	
Invertebrates														
Poriferans														
Halichondria panicea	Crumb of bread sponge		x	x		x		x	x		x	x	x	x
Isodictya sp.	Palmate sponge		x		x	x	x	x	x	x	x	x	x	x
Cnidarians														
Cerianthus borealis	Burrowing anemone				x		x	x	x	x	x	x		
Tubularia crocea	Pink hydroid													x
Bryozoans														
Bugula turrita	Tree-shaped bryozoan				x	x	x	x	x				x	x
Cryptosula pallasiana	Red crust bryozoan						x	x	x			x	x	x
Membranipora sp.	Encrusting bryozoan					x	x		x					
Molluscs - Gastropods														
Acmaea sp.								x						
Anomia sp.	Jingle shell											x		
Crepidula fornicata	Atlantic slipper snail				x		x	x				x		
Crepidula plana	Eastern white slipper shell				x	x	x	x	x				x	x
Nassarius trivittata	New England dog whelk				x	x	x				x			x
Molluscs - Bivalves														
Mytilus edulis	Blue mussel				x	x	x	x	x	x	x	x	x	x
Pandora gouldiana	Gould's pandora		x	x	x	x		x						x
Placopecten magellanicus	Sea scallop					x		x				x	x	x
Annelids														
Myxicola sp.	Slime worm					x						x		
Scale worm	Scale worm										x			
Arthropods														
Barnacles	Order Thoracica		x	x	x	x	x	x	x		x	x	x	
Cancer borealis	Jonah crab		x	x	x	x	x	x	x	x		x	x	x
Cancer irroratus	Rock crab		x	x	x	x	x	x	x	x		x	x	x
Crangon sp.	Sand shrimp									x				
Homarus americanus	American lobster		x	x	x	x	x	x	x		x	x	x	x
Majidae crabs	Spider crab (Hyas or Libinia)				x	x			x			x	x	x
Mysid sp.	Mysis shrimp									x				
Pagarus sp.	Large hermit crab					x	x	x	x			x	x	x
Unidentified shrimp												x		
Echinoderms														
Asterias forbesi	Common sea star		x		x					x				x
Asterias vulgaris	Northern sea star				x					x			x	
Henricia sp.	Blood star		x		x	x		x	x			x	x	x
Chordates														
Tunicates														
Ascidiella aspersa	European sea squirt				x						x	x		
Botrylloides violaceus	Orange sheath tunicate		x		x		x	x	x	x	x	x		x
Botryllus schlosseri	Star tunicate			x						x				
Ciona intestinalis	Sea vase tunicate											x		
Didemnum albidum	White encrusting tunicate												x	
Styela clava	Club tunicate											x		
Unidentified tunicate	Unidentified tunicate											x		
Fishes														
Myoxocephalus aenaeus	Grubby sculpin				x	x	x					x	x	x
Pholis gunnellus	Rock gunnel		x					x		x			x	
Pseudopleuronectes americanus	Winter flounder		x		x	x	x	x		x			x	x
Raja sp.	Skate								x					x
Syngnathus fuscus	pipefish								x					
Tautogolabrus adspersus	Cunner		x		x		x	x	x			x	x	x
Ulvaria subbifurcata	Radiated shanny				x									x
Urophysis sp.	hake		x											
Unidentified fish	Unidentified fish								x					

Table IVB2.5. Shannon index values of diversity on enumerated species.

Area		H' value
Artificial reefs		
	Spring 2006	1.35
	Summer 2006	2.19
	Fall 2006	1.85
	Winter 2007	1.20
	Spring 2007	1.60
	Summer 2007	2.04
Natural reef		
	Spring 2006	1.14
	Summer 2006	1.25
	Fall 2006	1.42
	Winter 2007	0.35
	Spring 2007	1.41
	Summer 2007	1.65
HubLine		
	Spring 2006	1.72
	Summer 2006	1.57
	Fall 2006	1.14
	Winter 2007	0.94
	Spring 2007	1.91
	Summer 2007	1.88
Sand		
	Spring 2006	1.73
	Summer 2006	1.93
	Fall 2006	1.73
	Winter 2007	0.34
	Spring 2007	1.38
	Summer 2007	1.66

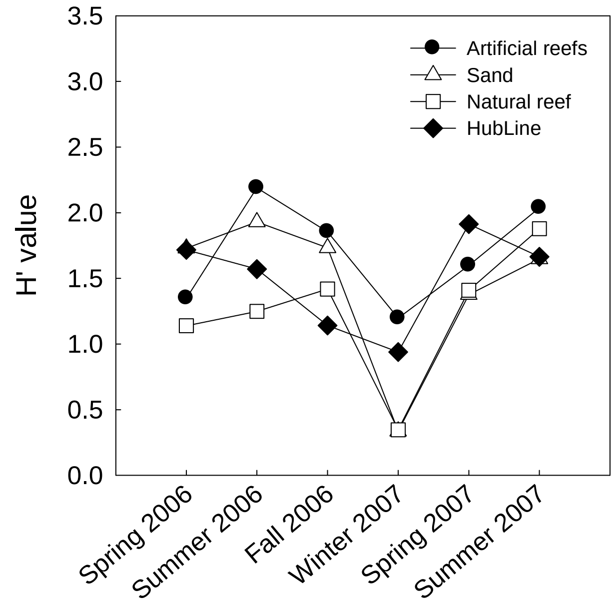


Figure IVB2.25. Temporal changes in diversity of enumerated species (diversity calculated with the Shannon index).

Table IVB2.6. Shannon index values of diversity on species assessed by percent cover.

Area		H' value
Artificial reefs		
	Spring 2006	0.45
	Summer 2006	1.22
	Fall 2006	0.74
	Winter 2007	1.40
	Spring 2007	1.59
	Summer 2007	1.76
Natural reef		
	Spring 2006	2.41
	Summer 2006	2.61
	Fall 2006	2.87
	Winter 2007	2.33
	Spring 2007	2.32
	Summer 2007	2.29
HubLine		
	Spring 2006	1.72
	Summer 2006	1.53
	Fall 2006	0.92
	Winter 2007	1.13
	Spring 2007	1.61
	Summer 2007	1.15
Sand		
	Spring 2006	2.34
	Summer 2006	2.66
	Fall 2006	2.45
	Winter 2007	1.70
	Spring 2007	1.67
	Summer 2007	2.21

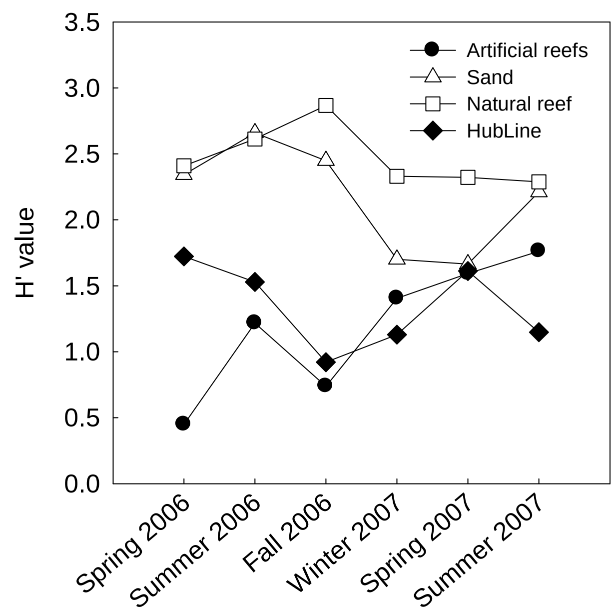


Figure IVB2.26. Temporal changes in diversity of species that were assessed by percent cover (diversity calculated with the Shannon index).

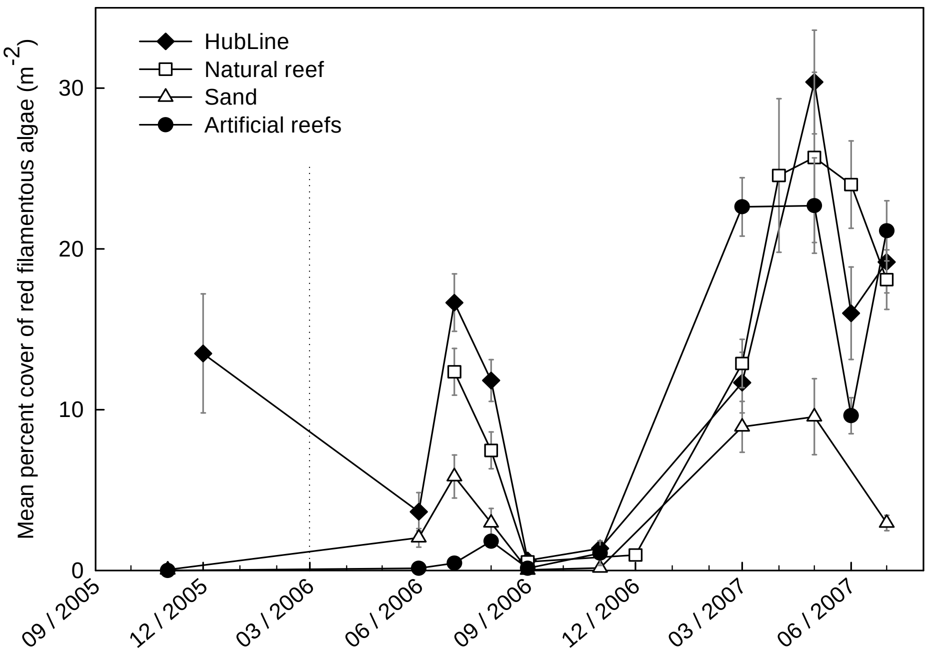


Figure IVB2.27. Temporal changes in mean percent cover of red filamentous algae on the study sites. The dotted vertical line represents the date that the artificial reef was installed.

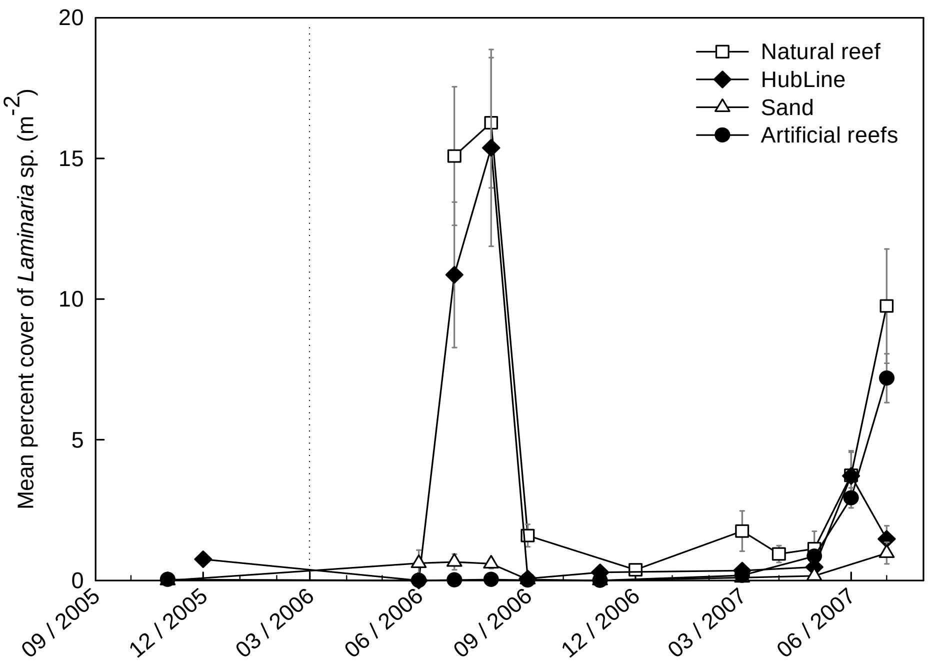


Figure IVB2.28. Temporal changes in mean percent cover of common kelp (*Laminaria* sp.) on the study sites. The dotted vertical line represents the date that the artificial reef was installed.

on the artificial and natural reefs in July 2007. The artificial reef had notably higher kelp coverage in spring 2007 than in spring 2006.

Densities of sponges (including *Clathrina* sp., *Halichondria panicea*, *Haliclona oculata*, *Haliclona loosanoff*, *Isodictya* sp., *Suberites ficus*, and an unidentified sponge) on the artificial reef, HubLine, and sand were low over the survey period compared to the sponge density on the natural reef (Figure IVB2.29). Mean sponge percent cover on the artificial reef, HubLine, and sand was less than 1.3% in all months, while mean percent cover on the natural reef varied between ~3.2 and 4.5%. From fall 2006 through summer 2007, sponge density increased slightly on the artificial reef.

Mean solitary tunicate density (including C*iona intestinalis*, *Ascidiella* sp., and *Styela clava*) was low (< 0.2 m^{-2}) on all sites from June 2006 to September 2006 (Figure IVB2.30). From September 2006 to April 2007, there was a rapid increase in the density of solitary tunicates from 0.1 to over 7 m^{-2} on the artificial reef. Densities on the natural reef, HubLine, and sand remained less than 0.3 m^{-2} during the same time period. From April 2007 through July 2007, the density of solitary tunicates decreased considerably on the artificial reef, although it was still much higher than on the other sites. There was a small increase followed by a decline in the density of tunicates on the natural reef from March to July 2007.

Mean densities of blue mussels (*Mytilus edulis*) were variable across sites (Figure IVB2.31). Mussel densities on the artificial reef and sand remained low (< 1.2 m^{-2}) throughout this study from March 2006 to July 2007. Mussel densities were much higher on the natural reef than on the HubLine from July to September 2006. However, in March 2007, natural reef mussel densities dipped below HubLine densities. From March to July 2007 mussel densities on the natural reef and HubLine fluctuated.

Mean Cancer crab density appeared to be seasonably variable for both *Cancer irroratus* (Figure IVB2.32a) and *Cancer borealis* (Figure IVB2.32b). From September 2006 to March 2007, mean densities decreased on each site to less than 0.05 m^{-2} for both species. From March 2007 through July 2007 densities of both crab species increased noticeably on all sites. In July 2007, the artificial reef had the highest density of C*ancer irroratus* and *Cancer borealis* when compared to the other sites.

Mean lobster densities varied across sites, but followed a general trend of increasing during warmer summer months and decreasing in cooler winter months (Figure 2.33). The sand site had a relatively lower lobster density (< 0.07 m^{-2}) than the three other sites. Lobster density was highest overall in June 2006 on the HubLine fill point (0.31 m^{-2}). The natural reef had the highest relative density in the summer from July to September 2006 (~0.16 m^{-2}). In June 2007 the artificial reef surpassed the natural reef in lobster density (0.14 m^{-2} versus 0.07 m^{-2}, respectively).

<u>Lobster density by rock size</u>. Mean lobster density varied depending on the habitat type (χ^2 = 66.94, p < 0.01, Figure IVB2.34). Lobster densities were the highest on the boulders (mean = 0.127 ± 0.001 s.e. per m^2, n = 302) and the boulder/cobble (BO/CO) transition areas (mean = 0.115 ± 0.011 per m^2, n = 116). The lobster densities on BO/CO transition zone were similar to the cobble mix (CO mix) (0.077 ± 0.015 s.e. per m^2, n = 54) and the cobble (CO) (0.091 ± 0.001 s.e. per m^2, n = 340, p < 0.003). The density of lobsters found on cobble was significantly higher than the density of lobsters found on sand (SA) (0.039 ± 0.001 s.e. per 10 m^2, n = 156, p < 0.003). Lobster densities were also higher on pebble (PE) (0.079 ± 0.001 s.e. per m^2, n = 136, p < 0.003) than on the sand. The density of lobsters found on the cobble mix was similar to densities on other habitat types (p > 0.003).

<u>Fish Tagging Study</u>

<u>Catch rate analysis</u>. Mean trap soak time was significantly shorter in the spring (79 hrs. ± 6.1) than in the fall (110 hrs. ± 9.7, *t*-stat = 6.94, p < 0.01) but these data were not adjusted because no relationship was found between soak time and catch rate (Figure IVB2.35). Mean cunner catches did not vary by season (Table IVB2.7, $F_{1, 288}$ = 0.45, p = 0.50), although the catch differed significantly by site (χ^2 = 135.7, p < 0.01). Pairwise comparisons revealed that the HubLine had significantly higher mean catch rates than any other site, while the artificial reef had higher mean catch rates than the

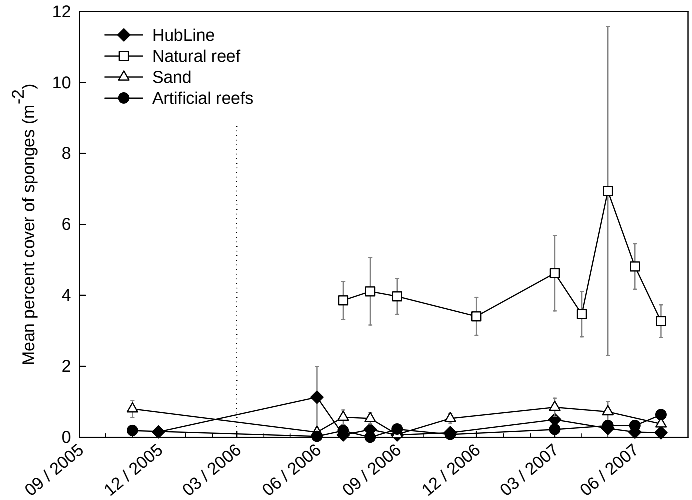


Figure IVB2.29. Temporal changes in mean sponge density on the study sites. Species included: *Clathrina* sp., *Halichondria panicea, Haliclona oculata, Haliclona loosanoff, Isodictya* sp., *Suberites ficus,* and an unidentified sponge. The dotted vertical line denotes time of artificial reef installation.

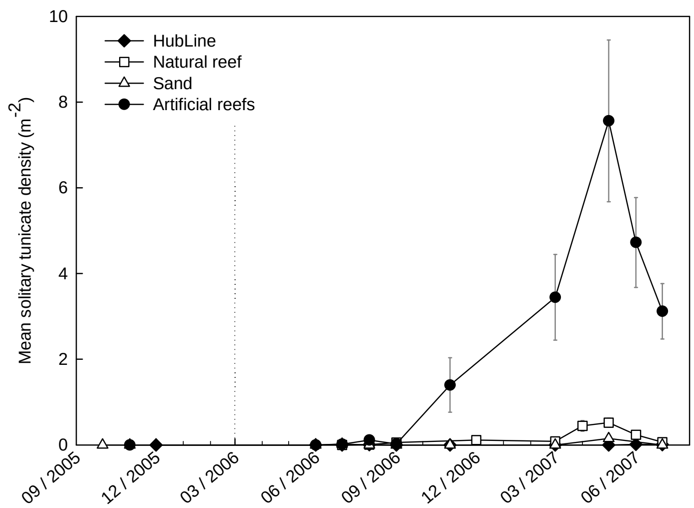


Figure IVB2.30. Temporal changes in mean solitary tunicate density on the study sites. Species included: *Ciona intestinalis, Ascidiella* sp., and *Styela clava*. The dotted vertical line denotes artificial reef installation.

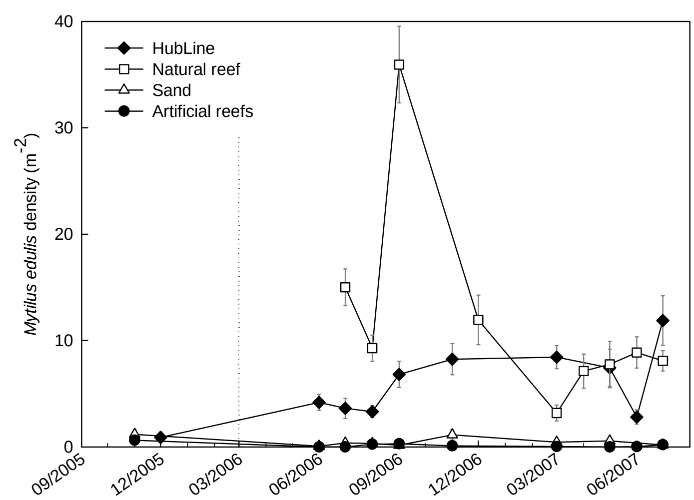


Figure IVB2.31. Temporal changes in mean blue mussel (*Mytilus edulis*) density on the study sites. The dotted vertical line denotes time of artificial reef installation.

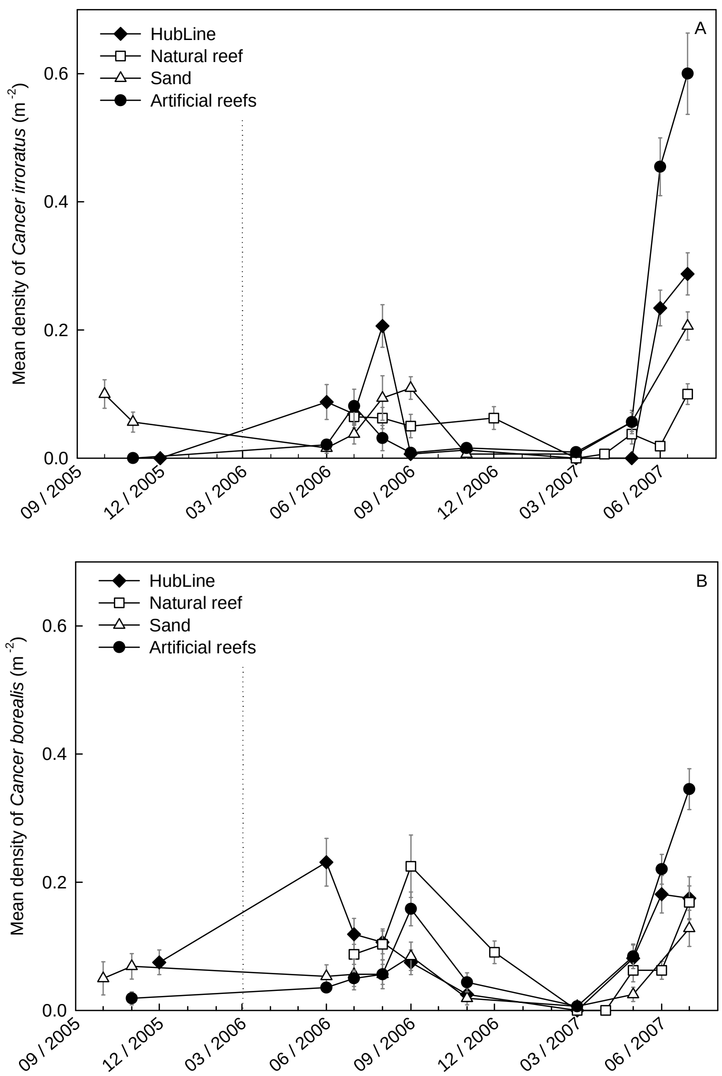


Figure IVB2.32. Temporal changes in mean (A) *Cancer irroratus* and (B) *C. borealis* densities on the study sites. The dotted vertical line denotes time of artificial reef installation.

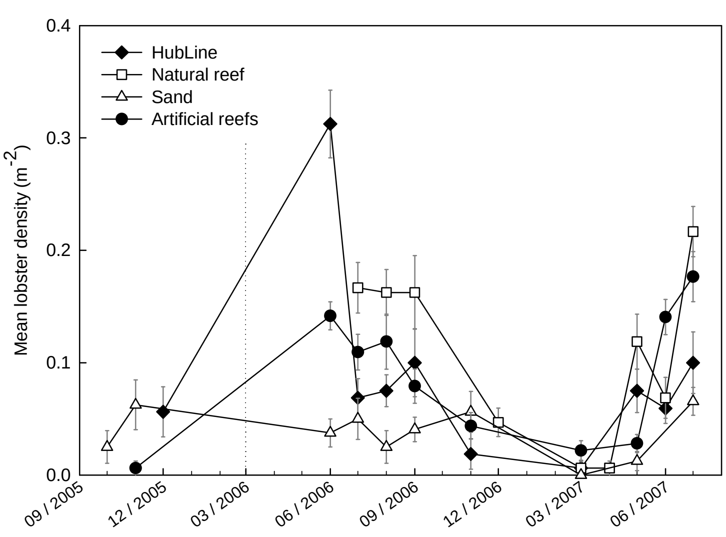


Figure IVB2.33. Temporal changes in mean American lobster (*Homarus americanus*) density on the study sites. The dotted vertical line denotes time of artificial reef installation.

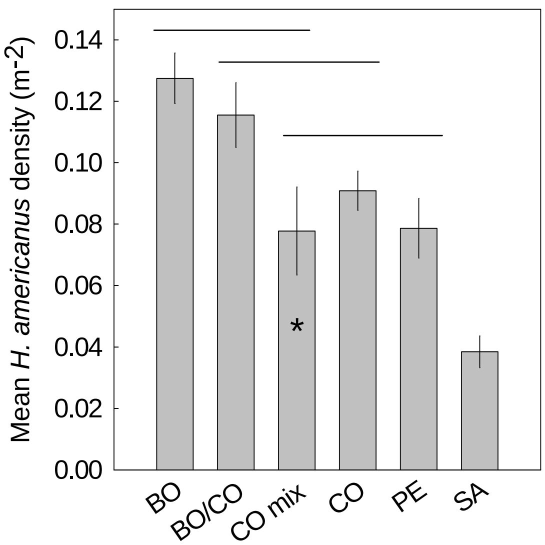


Figure IVB2.34. Mean density of lobsters by primary (> 50% of area) surficial substrate type. BO = boulder (n = 302), BO/CO = area where size transitions from boulder to cobble (n = 116), CO mix = mix of small and large cobble (n = 54), CO = cobble (n = 340), PE = pebble (n = 136), and SA = sand (n = 156).
(* Note: CO mix was also similar to PE and SA lobster densities. This result was not depicted because lobster densities on CO and PE were significantly higher than on SA.)

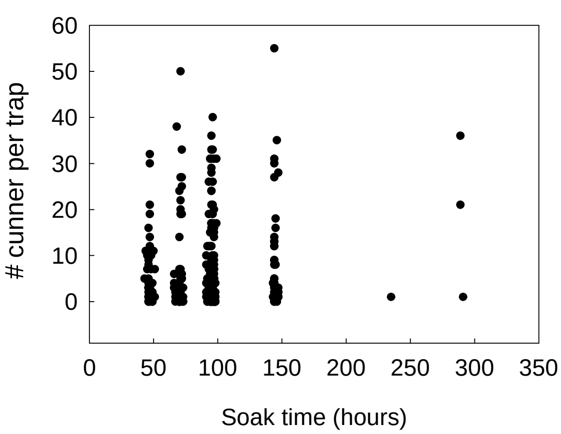


Figure IVB2.35. Number of cunner (*Tautogolabrus adspersus*) caught per trap by trap soak time (spring and fall data combined).

natural reef and the sand ($p < 0.008$, Table IVB2.7, Figure IVB2.36). Finally, the natural reef had significantly higher mean catch rates than the sand area ($p < 0.008$, Table IVB2.7, Figure IVB2.36). There was a difference in mean catch rates by individual reef units ($F_{5, 61} = 4.92$, $p < 0.01$). Reef 3 had a significantly higher catch rate than Reef 4, 8, and 9 (Table IVB2.7, Figure IVB2.36). All other reef units had similar mean catch rates. Looking at only the HubLine traps, no difference in catch rate was found along the north to south gradient ($F_{6, 61} = 1.983$, $p > 0.05$). There was no interaction of mean HubLine catch rate and season ($F_{6, 61} = 0.840$, $p > 0.05$). No lobsters tagged were recaptured.

Cunner length-frequency. Captured cunner ranged in size from 3.5 – 23.5 cm total length. Cunner were significantly larger in the fall than in the spring (Table IVB2.8). Cumulative percent frequency of cunner total length demonstrated that cunner on the natural reef (in both spring and fall) had a larger and broader distribution than cunner on other sites ($p < 0.008$, Figures IVB2.37 & IVB2.38). The natural reef had a significantly different length distribution in the fall than in the spring ($p < 0.008$). Length distributions in the fall and spring on the HubLine and artificial reef were similar ($p > 0.008$, Figures IVB2.37 & IVB2.38).

Cunner growth. Mean growth was 1.8 cm ± 0.15 over an average of 132.3 ± 1.1 days at large (n = 43).

Cunner movement. Cunner exhibited high site fidelity (Figure IVB2.39). Of the 130 recaptures on the HubLine, 112 (86%) were originally tagged and released on the HubLine, compared to 18 fish (13.8%) tagged on the HubLine that were recaptured elsewhere. On Reef 3, 16 of the 28 recaptured fish (57%) were tagged there, and on Reef 7, six of the eight fish (75%) recaptured there were originally tagged on Reef 7. Although cunner showed high site fidelity, some did move within and among sites. There was one recorded incident of a cunner moving from the HubLine to the natural reef, a minimum distance of ~700 m. All other fish recaptured on the natural reef had been tagged and released on the natural reef. Thirteen tagged fish moved from hard-bottom habitat such as the HubLine or artificial reef to the sand, while eight fish that were tagged

Table IVB2.7. Mean catch of cunner (*Tautogolabrus adspersus*) per trap and descriptive statistics by (A) season, (B) site, and (C) reef unit. Note: Catch rates from spring and fall were combined for (B) site data and (C) reef unit data because there was no significant difference in catch rate by season.

	Mean # cunner per trap			Total #	Total #	# Unique	Total #
	Mean	s.e.	n	caught	tagged	recaptures	recaptured
(A) Season							
Spring	7.64	0.68	166	1268	1068	131	147
Fall	8.46	1.03	124	1049	447	34	61
(B) Site							
Artificial reefs	10.87	1.32	73	794	553	49	54
HubLine	15.89	1.24	75	1192	709	98	130
Natural reef	3.01	0.39	76	229	189	9	12
Sand	1.55	0.32	66	102	64	9	12
(C) Specific reefs							
Reef 1	14.73	3.64	11	162	99	8	7
Reef 3	20.55	4.59	11	226	134	22	28
Reef 4	6.09	1.9	11	67	58	3	3
Reef 7	11.55	2.61	20	231	173	8	8
Reef 8	3.73	0.96	11	41	32	3	3
Reef 9	7.44	1.78	9	67	57	5	5

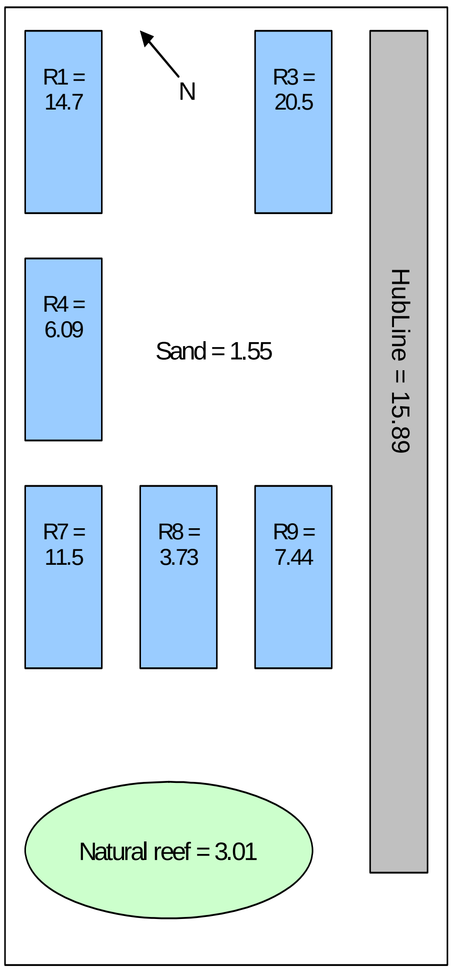


Figure IVB2.36. Mean cunner catch per trap represented spatially (error and sample size in Table 6). R# = unit ID number. Note: Image not drawn to scale.

Table IVB2.8. Mean cunner length by (A) season and (B) site.

	Length (cm)	s.e.	n
(A) Season			
Spring	10.39	0.07	1268
Fall	10.86	0.08	1049
(B) Site			
Spring			
Artificial reefs	10.05	0.12	387
HubLine	10.43	0.09	650
Natural reef	11.48	0.24	154
Sand	9.6	0.28	77
Fall			
Artificial reefs	10.73	0.13	407
HubLine	10.81	0.11	542
Natural reef	11.97	0.38	75
Sand	10.6	0.56	25

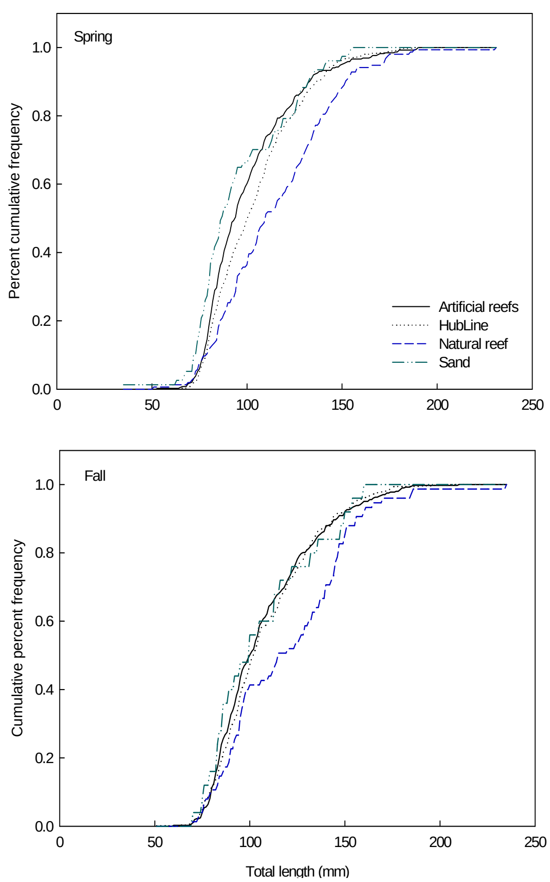


Figure IVB2.37. Cumulative percent frequency distribution of cunner total length by site and season (spring – top, fall – bottom).

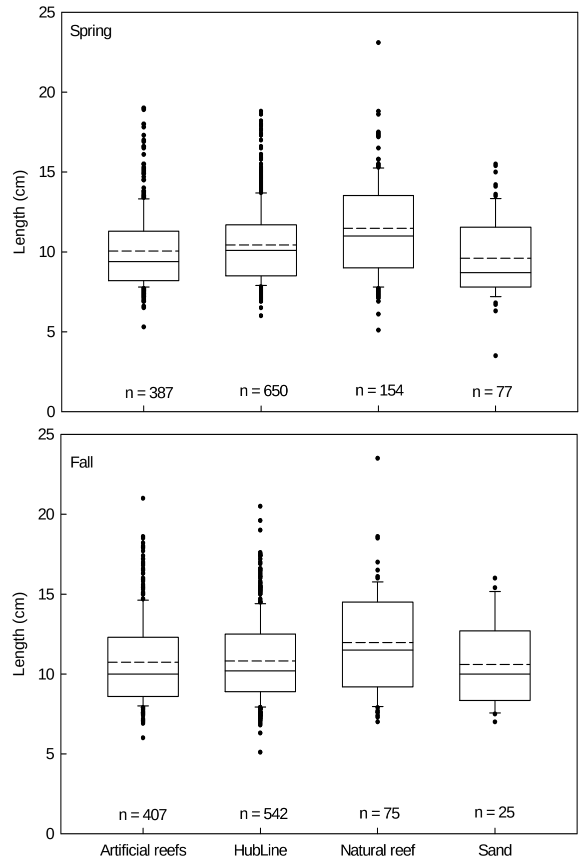


Figure IVB2.38. Length-frequency distributions of cunner by season and site. Dashed line represents the mean, solid line represents the median.

on the sand moved to hard-bottom areas. Of cunner that moved from their original tagging location, the distance traveled ranged from ~23 m to ~76 m (excluding one fish that moved from the HubLine to the natural reef). There were no occurrences of recaptured fish moving from the sand area to the HubLine or to the natural reef.

Length distributions of cunner that moved from their original tagging location versus fish that were recaptured at their original tagging location (i.e. fish that moved versus fish that did not move) were compared using the KS test. Fish that moved were significantly larger (total length) than fish that did not move from their original tagging location ($Z = 1.504$, $p = 0.02$, $n = 214$). Cumulative length-frequency distributions of these fish were similar in shape but larger for cunner that moved (Figure IVB2.40).

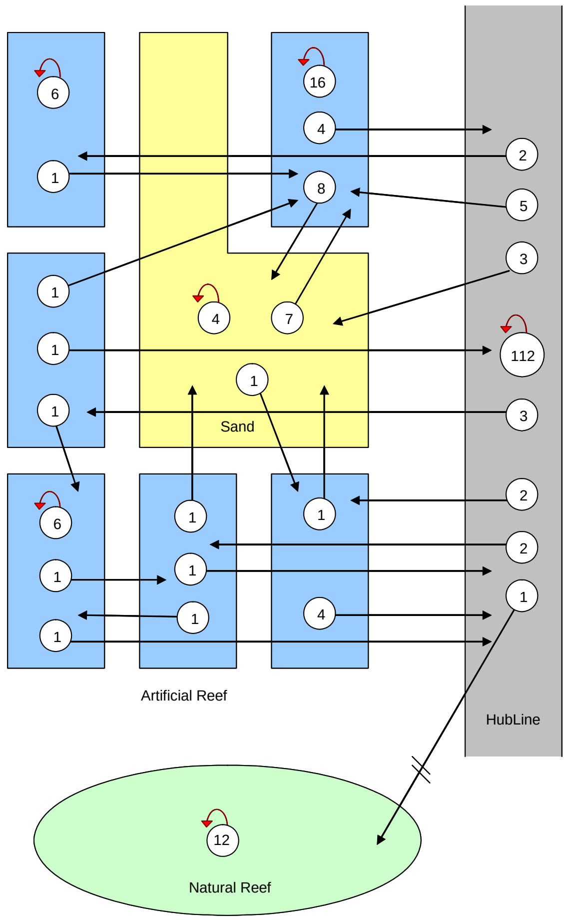


Figure IVB2.39. Cunner movements among sites. Curved arrows indicate recaptures at the same site; straight arrows show direction of movement of recaptured fish (includes multiple recaptures). Image not drawn to scale; circles do not represent trap locations.

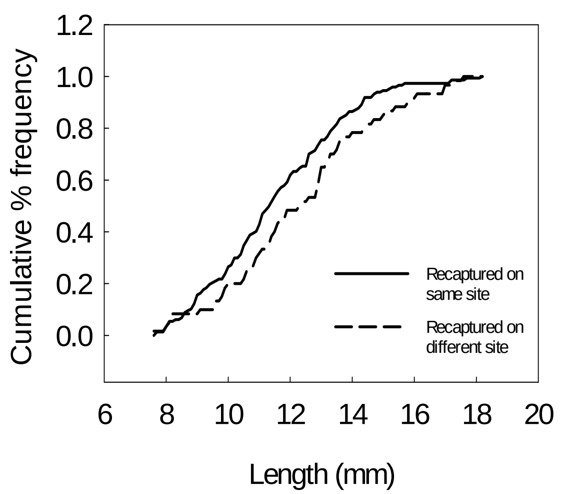


Figure IVB2.40. Cumulative length-frequencies of cunner that were recaptured on the same site that they were tagged versus cunner that were recaptured on a site other than their original tagging location.

Air-lift Sampling

Species diversity. Of the species collected through air-lift sampling, the natural reef had higher species diversity than the HubLine (*t*-stat = 3.93, $p < 0.008$) and the sand (*t*-stat = 8.08, $p < 0.008$, Table IVB2.9 & IVB2.10). The artificial reef, however, was similar in diversity to the natural reef (*t*-stat = -0.518, $p > 0.008$, Tables IVB2.9 & IVB2.10). The artificial reef had significantly higher diversity than the HubLine and the sand. The HubLine had higher species diversity than the sand.

Lobster density by site. The Kruskal-Wallis test showed that there was a significant difference in lobster density by site ($\chi^2 = 36.80$, $p < 0.01$). Pairwise comparisons (Bonferroni adjusted $\alpha = 0.008$) showed that lobster density was higher on the artificial reef (mean = 0.92 $m^{-2} \pm 0.19$, n = 48) than on the sand (mean = 0 m^{-2}, n = 24, $p < 0.01$), and lower on the artificial reef than on the natural reef (mean = 3.08 $m^{-2} \pm 0.54$, n = 24, $p < 0.01$) (Figure IVB2.41). Lobster densities on the artificial reef and HubLine (mean = 2.0 $m^{-2} \pm$ 0.47, n = 24), were similar ($p > 0.01$). Also, the natural reef and HubLine had significantly higher lobster densities than the sand ($p < 0.01$) (Figure 2.41).

Table IVB2.9. Shannon index of diversity values from air-lift sampling data.

Area	H' value
Artificial reefs	1.78
Natural reef	1.80
HubLine	1.58
Sand	1.29

Table IVB2.10. Results of Student's *t*-test conducted on Shannon index values. Note: Critical value of Student's *t* distribution for all comparisons = 2.80, α = 0.008. A = Artificial reef, H = HubLine, S = Sand, and N = Natural reef.

Comparison	*t*-stat	df	Difference?
A to H	3.382	1303	yes
A to S	7.553	1147	yes
A to N	-0.518	1470	no
H to S	4.389	1216	yes
H to N	3.931	1437	yes
S to N	8.088	1185	yes

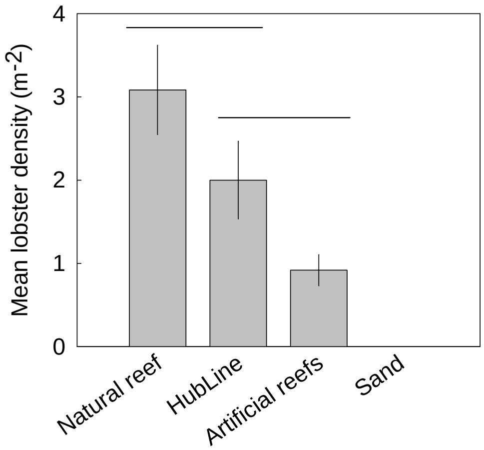


Figure IVB2.41. Mean number of lobsters (m^{-2}) by site (n = 24 for natural reef, HubLine, and sand; n = 48 for artificial reef).

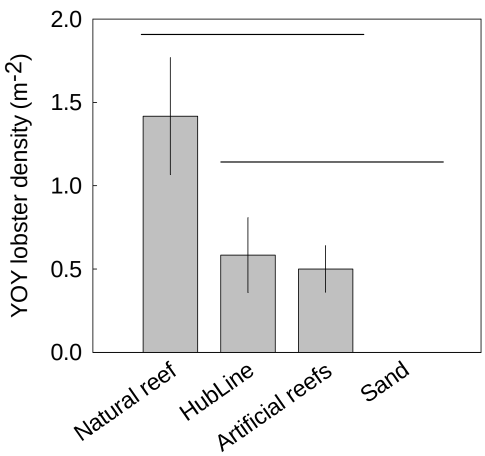


Figure IVB2.42. Mean number of young-of-the-year lobsters (m^{-2}) by site (n = 24 for natural reef, HubLine, and sand; n = 48 for artificial reef).

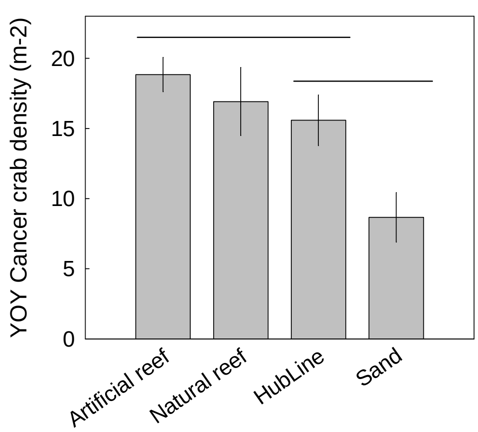


Figure IVB2.43. Mean number of young-of-the-year Cancer crabs (m^{-2}) by site (n = 24 for natural reef, HubLine, and sand; n = 48 for artificial reef).

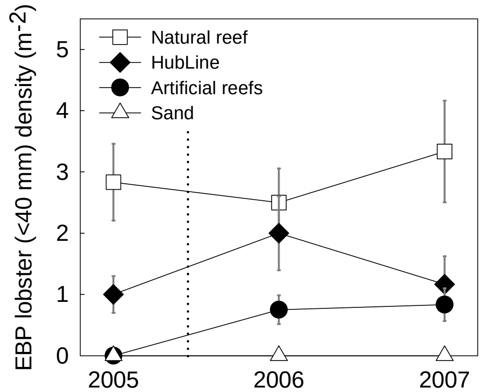


Figure IVB2.44. Temporal changes in the mean number of early benthic phase lobsters (m^{-2}) by site (n = 24 for natural reef, HubLine, and sand; n = 48 for artificial reef). Dotted line denotes artificial reef installation.

Young-of-the-year lobster density by site. The Kruskal-Wallis test indicated that young-of-the year (YOY) lobster density varied significantly by site ($\chi^2 = 17.24$, $p < 0.01$). Pairwise comparisons (Bonferroni adjusted $\alpha = 0.008$) revealed that the natural reef (mean = 1.42 ± 0.35, n = 24) had a higher YOY lobster density than the sand (mean = 0.0, n = 24, $p < 0.008$) (Figure IVB2.42). All other sites had similar YOY lobster densities.

Young-of-the-year Cancer crab density by site. The ANOVA revealed a significant difference in YOY Cancer crab density among the sites ($F_{3, 116} = 6.44$, $p < 0.05$). A follow-up Tukey test showed that the artificial reef had a similar density (mean = 18.8 m^{-2} ± 1.23, n = 48) as the natural reef (mean = 16.9 m^{-2} ± 2.42, n = 24) and the HubLine (mean = 15.6 m^{-2} ± 1.81, n = 24, all $p > 0.05$). However, YOY Cancer crab density on the sand (mean = 8.7 m^{-2} ± 1.77, n = 24) was significantly lower than densities on the artificial reef ($p < 0.001$) and the natural reef ($p = 0.015$) (Figure IVB2.43). The HubLine had a similar density of YOY Cancer crabs as the sand ($p = 0.056$).

Early benthic phase lobster by site. There was no significant difference in early benthic phase (EBP) lobster density by year (2005 mean = 1.27 m^{-2} ± 0.30, n = 36; 2006 mean = 1.5 m^{-2} ± 0.26, n = 48; 2007 mean 1.54 m^{-2} ± 0.30, n = 48; Kruskal-Wallis, $\chi^2 = 0.646$, $p > 0.05$) (Figure IVB2.44). Thus, data were combined across years and analyzed by site. Each site had a significantly different EBP lobster density (χ^2 = 30.98, p < 0.05). Pairwise comparisons (Bonferroni adjusted α = 0.017) indicated that the natural reef had more EPB lobsters (mean = 2.89 ± 0.39, n = 36) than the HubLine (mean = 1.39 ± 0.20, n = 36) and the artificial reef (mean = 0.633 ± 0.15, n = 60). The HubLine also had more EBP lobsters than the artificial reef (Figure IVB2.44).

Lobster density by rock size. No significant differences existed in lobster density by rock size ($F_{3, 44}$ = 1.89, p > 0.05). The large cobble (mean = 1.67 m^{-2} ± 0.48, n = 12), however, did appear to have a slightly higher density of lobster than the small boulder (mean = 0.5 m^{-2} ± 0.26, n = 12), the small cobble (mean = 0.5 m^{-2} ± 0.26, n = 12), and the small rock mix (mean = 0.83 m^{-2} ± 0.38, n = 12) (Figure IVB2.45).

YOY lobster density by rock size. YOY lobster preferred one rock size over the other (χ^2 = 8.07, p < 0.05). Nevertheless, follow-up pairwise comparisons failed to detect where this difference existed. Large cobble had the highest mean density (mean = 1.16 m^{-2} ± 0.37, n = 12) compared to small cobble (mean = 0.5 m^{-2} ± 0.26, n = 12), small boulder (mean = 0.17 m^{-2} ± 0.17, n = 12), and the small rock mix (mean = 0.58 m^{-2} ± 0.17, n = 12) (Figure IVB2.46).

Young-of-the-year lobster density by east or west. YOY lobster density was higher on the west side (mean = 0.75 m^{-2}± 0.18, n = 37) than on the east side (mean = 0.29 m^{-2}± 0.15, n = 35) (Mann Whitney U = 498.5, p = 0.02) (Figure IVB2.47).

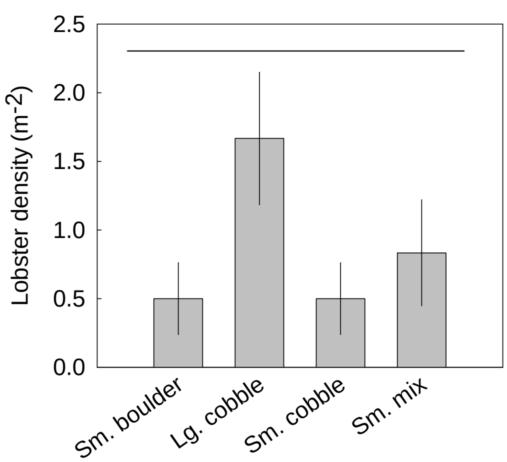


Figure IVB2.45. Mean number of lobsters (m^{-2}) by rock size (n = 12 for each rock size). Sm. = small, Lg. = large.

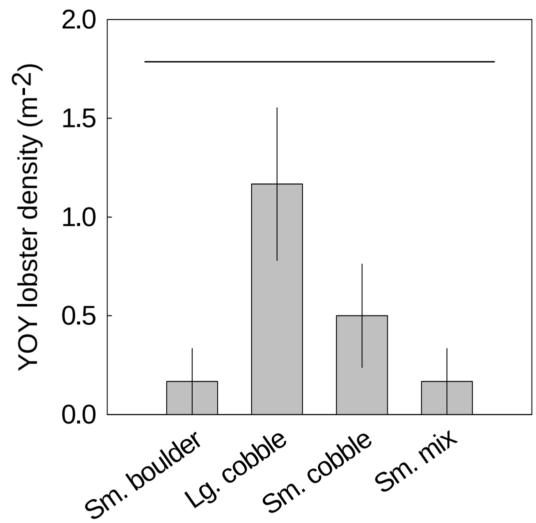


Figure IVB2.46. Mean number of young-of-the-year (YOY) lobsters (m^{-2}) by rock size (n = 12 for each rock size). Sm. = small, Lg. = large.

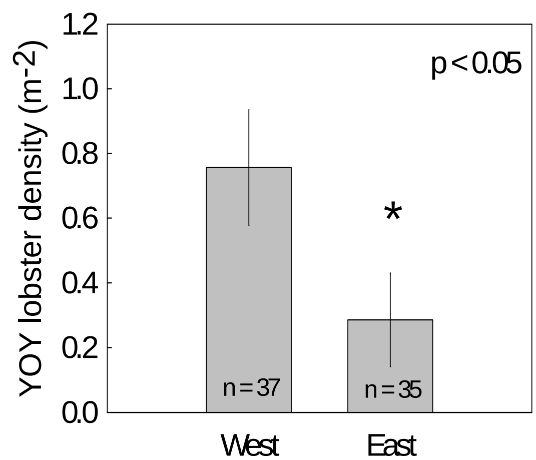


Figure IVB2.47. Mean number of young-of-the-year (YOY) lobsters (m^{-2}) by side (west or east) of the artificial reefs/HubLine. Star indicates a significant difference between sides.

Discussion

Permanent Transect Surveys

Data collected on two physical parameters, temperature and light, on the artificial reef and the natural reef indicated slight differences between the sites. The average temperature on the natural reef was ~0.2 ºC cooler than the artificial reef in the winter months (Figures IVB2.13 and IVB2.14). This small difference in bottom temperature probably did not affect species composition between the two sites, but if consistent over time, could affect growth and reproduction of certain species on the sites. Light intensity on the artificial reef was an average ~4 lux higher than on the natural reef (Figures IVB2.15 and IVB2.16). This result was unexpected given that the natural reef transect locations were slightly shallower (by ~ 1 m) than those on the artificial reef.

Although the monitoring photographs were not used in a quantitative analysis, the photos provided qualitative information when compared across seasons and visually confirmed some of the biological changes recorded in our permanent transects. For example, from November of 2006 through May 2007 a dramatic increase in the percent cover of red filamentous algae was recorded on the HubLine, followed by a sharp decline in June 2007 (Figure IVB2.27). This pattern was also readily visible in the permanent station photographs taken on the HubLine (Figure IVB2.20). The photographs confirmed and illustrated changes in species composition identified through other more intensive surveys.

The artificial reef and natural reef were composed of similar substrates but had some important differences. Primary and secondary substrates on the artificial reef were mostly cobble and boulder, not unlike the HubLine. Both of these substrate types were also present on the natural reef (Figures IVB2.22 and IVB2.23). In addition to cobble and boulder, the natural reef had relatively high proportions of shack (whole empty shells), sand, and pebble. These additional substrate types offer greater habitat complexity than the two man-made structures, possibly allowing for greater diversity of species. Alternatively, the artificial reef had greater vertical relief and more interstitial space than the natural reef, which are important factors when considering the potential for diversity and abundance of species. Furthermore, about half of the underlying substrate on the artificial reef was boulder or cobble; the natural reef did not have such a deep rock layer, and its underlying substrate consisted primarily of sand (Figure IVB2.24). This indicates that the artificial reef probably had more interstitial space than the natural reef because of the nature of the artificial reef design. This habitat difference could explain variations in species densities by site. For example, *Cancer irroratus* density may have been higher on the artificial reef and HubLine than on the natural reef (Figure IVB2.31) because the man-made sites offered more shelter. Observations in the field supported this hypothesis, as many juvenile *C. irroratus* were seen in interstitial spaces formed by cobble on the artificial reef and HubLine, yet juvenile Cancer crabs were rarely seen on the natural reef (J. Barber and K. Whitmore, personal observations).

The Shannon index of diversity conducted on enumerated species including mobile macroinvertebrates, solitary tunicates, bivalves, and fish indicated that diversities on the artificial reef and natural reef were not significantly different throughout the survey period (Figure IVB2.25). Although this result was surprising, mobile macroinvertebrates, fish, and solitary tunicates are able to utilize new habitat rapidly, minimizing differences in their abundances on old and new habitat. They are also easily detectable on substrates that lack much algal or other encrusting growth. These reasons may explain how the artificial reef had the highest diversity index values of all sites for three out of the five sampled seasons, from summer 2006 to winter 2007, although these differences were not statistically significant.

The Shannon index of diversity conducted on species assessed by percent cover (i.e. encrusting tunicates, sponges, barnacles, and macroalgae) indicated that the artificial reef and HubLine had similar species diversities and relatively lower index values than the natural reef and the sand (Figure IVB2.26). Diversity was significantly higher on the natural reef than on the HubLine from spring 2006 to winter 2007. Although diversities on the artificial and natural reef were not significantly different, artificial reef diversity was lower and more similar to the HubLine than to the natural reef (Figure IVB2.26). The lowest diversity index value overall was on the artificial reef in spring 2006, immediately following reef deployment when the rocks were barren. Diversity of species assessed by percent cover on the artificial reef rose to its highest level in summer 2007, when the reef was approximately 1.5 years old. In summer 2007, the sand, HubLine, and artificial reef had similar diversity values, all below that of the natural reef.

In spring of 2006, the artificial reef had been in place for about two months. Two months was enough time for fast recruiting invertebrates and mobile species to colonize the reef (as seen in Figure IVB2.25), but not enough time for algae, sponges, and other slower growing species to recruit. As the age of the artificial reef increased, the diversity of species assessed by percent cover also increased (Figure IVB2.26).

One of the objectives of the habitat enhancement project was to determine when and if the artificial reef would resemble the natural reef in appearance and function. Although this question will require a longer time series to answer, observations from the first year and a half of monitoring on the artificial reef, natural reef, sand, and HubLine cobble fill revealed some interesting trends in species composition. One of the most striking aspects of the natural reef is its sponge diversity and abundance. We recorded six species of sponge on the natural reef (plus an unidentified sponge), one of which, the fig sponge *Suberites ficus*, was unique to the natural reef (Table IVB2.2). Although five of the six species of sponge were also present on the artificial reef and HubLine, there was a substantial difference in density on these sites compared to the natural reef. Mean cover of sponge (m^{-2}) was generally less than 1% on the artificial reef and HubLine, yet ranged from about 4 to 7% on the natural reef throughout the year (Figure IVB2.29). Even though the HubLine is approximately two years older than the artificial reef, the presence of sponge on the HubLine is minimal. These initial results indicate that it may take many years for sponge density on the new substrate to be similar to that found on a natural reef, assuming that the artificial reef habitat is appropriate for sponge growth. In turn, species that are commonly associated with sponges (such as decorator crabs) will likely take longer to establish themselves on the artificial reef as well.

Trends in algal cover suggest that the artificial reef is beginning to resemble natural habitat. In July and August 2006, cover of red filamentous algae and common kelp (*Laminaria* sp.) was high on the natural reef and HubLine, yet minimal on the artificial reef. In the winter, algal cover on all sites diminished but in March 2007 cover of red filamentous was higher on the artificial reef than on all other sites (Figure 2.27). After March 2007, coverage on the HubLine, natural reef, and artificial reef increased, and then sequentially decreased. In July 2007 the three sites had similar coverages. These trends were also seen in the monitoring photographs, where red algal coverage on all sites was minimal in December 2006 and high in March 2007 (Figures IVB2.18 - IVB2.21). The dramatic increase in coverage of red algae most likely occurred because of an increase in water clarity (eg. Figure IVB2.17), allowing more light to penetrate and promote algal growth. Although kelp recruitment was limited on the artificial reef until June 2007 (Figure IVB2.28), kelp on the artificial reef appears to be following similar seasonal trends in percent coverage as the natural reef and HubLine. This suggests that trends in algal cover will be fairly consistent among the three sites within a short period of time.

The density of solitary tunicates changed dramatically from spring/summer 2006 to spring 2007 on the artificial reef (Figure IVB2.30). Mean density on the artificial reef was less than 0.2 m^{-2} from June to September 2006. In the following six months, the solitary tunicate density rose to almost 8 m^{-2}. This change was not observed on the HubLine or natural reef, where the solitary tunicate densities remained below 0.3 m^{-2}. On the artificial reef, the solitary tunicates settled on a range of rock sizes and in various locations but the densest patches were seen on vertically-oriented faces of large boulders. Favorable water currents around these large boulders and limited competition with other encrusting and/or sessile species, with the exception of barnacles, on the artificial reef rocks might have contributed to the population expansion. The HubLine and natural reef do not have as much vertically-oriented surface area as the artificial reef and they also had greater coverage of kelp and other algae in summer months than the artificial reef which might have limited solitary tunicate growth on these sites.

Blue mussel (*Mytilus edulis*) densities varied on each of our survey sites (Figure 2.31). Blue mussels were nearly absent from the artificial reef throughout the survey period. A few patches of juvenile blue mussels were observed on the artificial reef in the summer and fall 2006 but were not observed again until spring 2007, when the mussels were roughly 1 to 2 cm in length. The lack of immediate colonization of blue mussels on the reef was surprising to us knowing that the reef offers a great deal of hard surface area and interstitial space for settlement and that there were adult mussel beds nearby on the HubLine and natural reef. It is possible that the surface of the originally barren rock must first go through certain physical and biological changes (i.e. deposition of silt/biofilm or changes in pH, etc.) to provide suitable habitat for significant mussel settlement and growth. Or, the artificial reef may have been deployed during a recruitment pulse of barnacles, rather than mussels; thus the barnacles may have out-competed the blue mussels. In addition to competitive displacement, local current cycles and the length of the blue mussels' motile larval veliger stage (up to 35 days) (Bayne 1965) may have affected the ability of nearby mussel beds to contribute mussel colonization on the artificial reef during the study period. If the barnacles experience a die-off (there was some evidence for this in summer 2007), mussels may be able to recruit to the newly-opened space.

The natural reef exhibited the most variability in mussel density. The mussel beds tended to be very patchy on the natural reef (J. Barber, personal observation), thus it is possible that the high density recorded in September 2006 was a random factor of the quadrats falling on large beds of mussel rather than an actual increase in the density of a slower-growing animal like the blue mussel. Understanding this, the blue mussel may not serve as a good indicator species for a timeline of species development comparing the artificial and natural reef.

As mentioned in the diversity comparisons, mobile macroinvertebrates, including Cancer crabs (*Cancer irroratus* and *C. borealis*) and American lobster (*Homarus americanus*) appeared on the artificial reef within weeks after its installation (Figures IVB2.32 & IVB2.33). In June 2007, crab and lobster densities were actually highest on the artificial reef. The large number of interstitial spaces available on the artificial reef for these shelter-seeking species may be a factor contributing to these higher densities. Cancer crab and lobster densities also exhibited a general increasing trend during the warmer summer months and decreasing in the cooler winter months on all the sites. This was expected, as it is well-known that these species exhibit seasonal movement from colder, deep water to warmer, shallow water (Lawton and Lavalli 1995).

In addition to investigating differences in relative abundance of lobster on each site, we also assessed lobster abundance on each substrate type across sites by compiling densities for all seasons. Larger rock sizes (boulder and boulder/cobble transition) supported significantly higher lobster densities than smaller, more featureless substrate types (pebble and sand) (Figure IVB2.34). Lobster densities on the cobble mix were not significantly different from the lobster densities on either the large rock or small substrate types. However, the cobble mix had a much smaller sample size than the other habitat types and the power to detect differences in densities between the substrate types might have been compromised. It should also be noted that although the method used to collect these data (i.e. visual swath surveys) does not detect all the lobsters present in a particular substrate, it provides a comparison of relative lobster densities among sites. It is likely that smaller lobsters were not sighted because no rocks were disturbed during the survey. Larger lobsters may have also been missed due to sheltering behavior. Thus, it is likely that lobster densities were higher across all substrate types.

<u>Fish Tagging Study</u>

The fish tagging study was designed to compare cunner populations on the artificial reef to the natural reef, the HubLine fill point, and the sand. The results from the catch rate analysis indicated that the HubLine fill point had a higher relative abundance of cunner than the other study areas. The artificial reef, however, also had a high overall abundance of cunner, although abundance of each reef unit was not uniform. The natural reef had a very low mean catch rate, but significantly more cunner were captured there than on the sand site (Table IVB2.7). The sand site, which had the lowest mean catch rate, most likely provided little refuge from predators and minimal foraging opportunities. Our observations from working underwater on the reef confirmed these results. Most cunner were observed on the HubLine, although the artificial reef also had large numbers of fish. We saw few cunner on the natural reef or the sand. The HubLine and the artificial reef may have supported larger cunner abundances because the rocky reefs provide the fish with more interstitial space and surface area than the natural reef and the sand. Although the HubLine and artificial reef are similar habitat types, the HubLine likely supported a slightly larger abundance than the artificial reef because the rocks on the pipeline were deployed a few years prior to the artificial reef. Those rocks had a higher percent cover of algae than the artificial reef, providing cunner with better-quality habitat than the artificial reef.

It is important to note that only fish larger than 3.5 cm (total length) were sampled due to trap selectivity. The smallest cobble on the artificial reef provided appropriately-sized interstitial spaces for smaller cunner (< 3.5 cm), while the HubLine had only larger cobble. There may have been differences in abundance of cunner less than 3.5 cm on the sites due to rock size but this was not investigated.

Mean cunner catch rates varied among reef units in the artificial reef complex. Reef 3 had significantly higher catch rates than Reefs 4, 8, and 9 (Table IVB2.7). Reef 3 also had a relatively higher mean catch rate than the HubLine (Figure 2.36). It is difficult to determine why this particular unit had more cunner than other artificial reef units. The entire reef complex (six reef units and three sandy sites) is only about 1.5 acres in size; therefore, it was unlikely that Reef 3 experienced more favorable physical conditions (temperature, current, etc.) than the other reef units. On the other hand, Reef 3 is isolated (by sand) from the other reef units, although it is the same distance away (20 m) from the HubLine as Reef 9 (Figure IVB2.1). There was no difference in catch rates from north to south along the HubLine, indicating an even distribution of fish that could move from the HubLine to Reef 3 or Reef 9. Yet, Reef 3 had higher overall cunner abundance, and movement trends indicated that there were more exchanges between the HubLine and Reef 3 than between the HubLine and Reef 9, or between other reef units (Figure IVB2.39). Cunner may have been more concentrated on Reef 3 than Reef 9 because Reef 3 is isolated from other hard-bottom habitat on all sides except the HubLine. Fish traveling to Reef 9 from the HubLine could easily move from Reef 9 to other reef units (Figure IVB2.39). Once on Reef 3, fish would have to cross a greater distance over featureless habitat (sand) to get to other reef units.

Catch rates, length-frequencies, and movements were analyzed by site. In addition to having significantly less cunner on the natural reef than on the artificial reef, the length distribution of cunner on the natural reef was statistically different (broader and larger) than cunner on the artificial reef, HubLine, and sand in both the spring and the fall (Table IVB2.8, Figures IVB2.37 & IVB2.38). These differences may have been due to the natural reef having less interstitial space than the artificial reef and HubLine. Smaller fish may have preferred the artificial reef and the HubLine because they could more easily take refuge from predators on those sites. The artificial reef and the HubLine were similar in their length-frequency distributions. Both areas provided the same type of habitat (high relief and many interstitial spaces); therefore, they likely attracted the same life history stages of cunner. The length-frequency distribution of cunner on the sand site was statistically different from the other sites, however, the number of fish sampled on the sand was small (Table IVB2.8). Fish caught on the sand had lower site fidelity than fish at the other sites. The low recapture rate suggests that the few fish recaptured here may have been attracted to the traps for structure and/or food when transitioning from one reef to another.

Because of the proximity of the artificial reef and sand sites, it is possible that trap independence was compromised, particularly with the use of bait. Currents, temperature, and other environmental conditions could have caused overlap in bait odor plumes across the artificial reef and sand sites, attracting cunner from an optimal habitat type to a less-optimal one (eg. the artificial reef to the sand). This could have inflated capture rates on the sand, although traps with the strongest scent of bait would have been on the fish's original location. Recapture rates suggested that sites were reasonably independent, as cunner showed high site fidelity on the HubLine, artificial reef units, and the natural reef, while relatively fewer fish were recaptured on the sand.

The differences in catch rates, length-frequencies, and movements observed indicate that cunner abundance on the HubLine and artificial reef may remain disparate from cunner abundance on the natural reef. This is an important determination, because one of the goals of the reef project was to determine how long, if ever, it will take for an artificial reef to reach similar levels of species abundance and diversity as a natural reef. Cunner, which are the most abundant fish on the HubLine and the artificial reef, utilize the high relief of these structures, as well as the large number of variably-sized interstitial spaces. Conversely, the natural reef, a more low-profile reef with mostly large boulders surrounded by sand and pebbles, has less available interstitial space. This type of habitat is fitting for many other species, such as lobster, but not as ideal for a structure-oriented fish like cunner. Thus, the HubLine and artificial reef will likely continue supporting more cunner than the natural reef or sand.

Our research findings suggest that if the goal of an artificial reef is to mimic species abundance and diversity on nearby natural reefs, then the relief and rugosity (i.e., surface complexity) of the natural environment needs to be duplicated, in addition to replicating the same substrate type (e.g., rocks). As found in the tropics, the degree of resemblance of structural features between artificial and natural reefs may dictate how similar the benthic communities will become over time (Perkol-Finkel et al. 2006). In the case of our artificial reef, it will most likely continue supporting more cunner than nearby natural reef in the future because of differences in relief. This introduces implications in understanding the ecology of the artificial reef system. For example, differences in larval settlement or algal percent cover on the artificial reef and the natural reef may be due to disproportionate depredation by cunner. Although it is unlikely that cunner will considerably alter the ecology of the reef, it is important to recognize the influences that these differences may have on species assemblages.

<u>Air-lift Sampling</u>

The most important result from comparing air-lift sampling data from the four sites was that within one year larval settlement on the artificial reef appeared to have reached comparable levels to that of the nearby natural reef. The artificial reef also reached similar levels of species diversity for air-lift sampled species as the natural reef within five months of its deployment. This species diversity analysis took a particular set of invertebrates and fish into account, those sampled by air-lift methods, rather than the species seen during permanent transect surveys. Air-lift techniques are better at sampling post-larval fish and crustacean diversity than visual methods, and thus are an important component in the monitoring program. Using air-lift data, the artificial reef and the natural reef supported significantly higher species diversities than the HubLine or the sand. We are not certain why the artificial reef reached significantly higher levels of diversity than the HubLine, which is similar in composition. It is possible that the variable rock sizes on the artificial reef (the HubLine rocks are fairly uniform) created a more diverse habitat which could support multiple species. The variable rock sizes on the artificial reef may also have been the reason that species diversity levels were similar to the natural reef.

The natural reef had higher densities of lobsters of all life history stages (Figure IVB2.41) and of early benthic phase (EBP) lobsters (Figure IVB2.44) when compared to the artificial reef. However, settlement of both young-of-the-year lobsters and Cancer crabs was similar between the natural reef and the artificial reef. It is encouraging that within a short period of existence, the artificial reefs supported comparable levels of larval settlement as the natural reef, as this was one of the goals of our project. In terms of the overall lobster density, however, these data demonstrated that the natural reef had a higher density of lobsters (all life history stages) than the artificial reef (Figures IVB2.21 and IVB2.44). This result is consistent because the natural reef had more edge habitat, with large boulders interspersed through sand and pebbles. This type of habitat allows all life history phases of lobster to easily dig burrows under rocks and modify the habitat to their preference. Although the artificial reef has a fair amount of edge habitat, it consists mostly of rocks piled on top of each other with less opportunity for habitat modification.

Statistically, our analyses demonstrated that rock size did not play an important role in larval settlement. An alternative to this is that the efficiency of the sampling gear differed on the various rock sizes. Although there was no statistical difference in larval settlement, there was a trend in lobster density by rock size, which suggested that large cobble was preferred by lobster (of all life history phases) over the other rock sizes (Figures IVB2.45 and IVB2.46). Since post-larval lobsters settle preferentially on large cobble (Wahle and Steneck 1991 & 1992), it is likely that additional years of survey will show differences in lobster settlement by rock size on the artificial reef, specifically, more young-of-the-year lobsters on the large cobble.

Wahle and Incze (1997) demonstrated that post-larval lobster settlement can be driven by dominant current and wind directions. We found that YOY lobsters settled out more often on the west side of the reef (Figure IVB2.47). Whether this is due to current patterns or other aspects of post-larval habitat selection (Cobb and Wahle 1994) is unknown. Boston Harbor frequently experiences alternating currents and wind directions. Temperature and nutrient delivery also may vary from one side of the reef to the other due to differences in the waters leaving inner Boston Harbor versus the waters entering the harbor from Massachusetts Bay. Further examination of settlement patterns may be warranted if preference for the western side remains evident in successive surveys.

Conclusions

In addition to addressing the broad goal of developing a timeframe of reef succession, we were also interested in investigating smaller scale questions including whether the artificial reef augments post-larval lobster settlement and settlement of other fish and invertebrates, whether the artificial reef provides mitigation to the hard-bottom encrusting community, and whether the artificial reef provides shelter to multiple life stages of various marine organisms. The artificial reef has met the goal of enhancing opportunities for larval settlement. Within months of its deployment, the density of newly settled Cancer crab larvae on the artificial reef was similar to that on the natural reef. Although the density of young-of-the-year lobster was slightly lower on the artificial reef than on the HubLine or the natural reef, we expect that densities will increase as the rocks become increasingly fouled with encrusting organisms and algae and provide more optimal habitat.

To address whether the artificial reef has provided mitigation for the hard-bottom encrusting community it is important to define the term “mitigation” in the context of the particular goal. If mitigation is only defined as providing new habitat for encrusting/benthic organisms, then the artificial reefs have succeeded at meeting this goal. Within weeks of the installment of the artificial reef, barnacles had recruited to the rocks. Shortly following, hydroids, tunicates (both solitary and encrusting), and algae were recorded on the rocks. Other encrusting species were observed for the first time on each consecutive research dive. Thus, the artificial reef units clearly provide habitat for the benthic hard-bottom community. However, if “mitigation” is defined as providing new habitat for encrusting/benthic organisms such that the community resembles that of similar naturally existing hard-bottom habitat, we have not yet met this goal with the reef.

Fish and invertebrates in most life history phases (young-of-the-year through adult) were recorded on the artificial reef throughout this year and a half of sampling. Thus, the artificial reef has met the goal of providing habitat for different life history phases of various marine species. A larger sample size, however, is needed before we can establish which habitat types (i.e. rock size) are preferred by particular species' life history phases. Observations from the field include small juvenile cunner (< 3.5 cm) inhabiting the smallest cobble and larger adult cunner (~10 - 15 cm) utilizing the larger boulders. We also recorded adult lobster within the larger interstitial spaces of the boulders and juvenile lobster inside the spaces of the large and small cobble.

Because one of the main goals of this study was to determine how long, if ever, it takes for an artificial reef to mimic the species abundance and diversity seen on natural reefs, it is important to consider our three monitoring programs together. The permanent transects surveys illustrated how drastic some differences were between the artificial reef and the natural reef, while the air-lift sampling data demonstrated that some aspects of the artificial reef quickly mimicked the natural reef. Finally, the fish tagging study showed that the abundances of certain fauna on the artificial and natural reefs may remain disparate due to structural dissimilarity between the sites. Thus, it is clear that the artificial reef does not currently resemble existing natural hard-bottom habitat in species composition, within a year and a half of deployment. This result was not surprising, as succession in the marine environment is variable, and it can take 20 or more years for species assemblages on artificial reefs to resemble those on natural reefs (Perkol-Finkel and Benayahu 2004b, Perkol-Finkel et al. 2005). Continued monitoring will allow us to track the reef's progress, detecting changes in species abundance and diversity through time, and provide the information needed to construct a timeframe on species succession. By tracking these ecological changes, *MarineFisheries* will ultimately be able to determine whether reef development is an effective technique for hard-bottom habitat mitigation in New England coastal waters. If the benthic community on the artificial reef never resembles the benthic community on natural cobble habitat, or if it requires five, ten, or more years to approach a comparable state, the efficacy of reef construction as mitigation is limited. Rigorous site selection and judicious reef design provide the framework for successful reef development, yet only long-term monitoring will determine the extent of benthic community reparation.

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