Technical Report

Massachusetts Division of Marine Fisheries
Technical Report TR-35

Boston Harbor Artificial Reef Site Selection & Monitoring Program

Julie S. Barber, Kelly A. Whitmore, Mark Rousseau,
David M. Chosid, and Robert P. Glenn

Massachusetts Division of Marine Fisheries
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CHAPTER 1. ARTIFICIAL REEF SITE SELECTION MODEL

Summary: Although artificial reefs are commonly used throughout the world as tools to mitigate for habitat alteration, their development is rarely subjected to a rigorous site selection process. We developed a simple site selection model using the following seven systematic steps: exclusion mapping, depth and slope verification, surficial substrate assessment, data weighting and subsequent ranking analysis, visual transect surveys, benthic air-lift sampling, and larval settlement collector deployment. Results from each step in this process ultimately allowed us to select a site for habitat enhancement at a target depth that received little wave action, had no slope, and possessed a surficial substrate type that could support the weight of a reef. The site also had the presence of a natural larval supply and low species diversity prior to reef installation. Each step in this site selection model was designed for adaptation by others interested in future artificial reef development.

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). Although 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). Although this method is useful for initially eliminating areas where obvious conflicts (e.g., with navigation, fishing activities, oil and gas platforms) are likely to arise, this process does not provide managers with the particular physical and biological data necessary 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 before deploying artificial reefs (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, United States. A substantial amount of the impacted seabed along the pipeline footprint was comprised of rocky substrate, a habitat type that is not easily restored (Auster et al. 1996, Freese et al. 1999). 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*), Atlantic sea scallops (*Placopecten magellanicus*), and other species of fish and invertebrates (Wahle and Steneck 1992; Tupper and Boutilier 1995; Packer et al. 1999). As mitigation for the assumed impacts to hard-bottom habitat, *MarineFisheries* constructed a series of cobble/boulder reefs in Massachusetts Bay designed to target different life history stages of invertebrate and vertebrate species found in Massachusetts Bay (Cobb 1971, Dixon 1987, Wahle 1992, Wahle and Steneck 1992, Dorf and Powell 1997, Tupper and Boutilier 1995, Bigelow and Schroeder 2002) (see Appendix A for reef design specifications). Rock sizes used to construct the reef reflected the size range of cobble and boulder found on nearby naturally occurring rock reefs in Massachusetts Bay (U.S. Geological Survey 2006).

In advance of reef 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*, H. Milne Edwards, 1837) was selected as the target species for these investigations due to local commercial importance of the species (ASMFC 2006). This project 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 1.1). Once these criteria were defined, 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. Before 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 B). This delineated area represented the estimated extent of impact to bottom habitat from the pipeline's construction, and the area within which the mitigation project was targeted. The clipped substrate and bathymetry data were coded to represent prime, potential, and unsuitable areas (Table 1.2). 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 1.2). Using the ArcGIS raster calculator, the numerical values from both data layers were multiplied to produce a site-suitability data layer. This data layer was used to identify prime sites for the artificial reef (Figure 1.1). Twenty-four sites that fell within areas delineated as "prime" were selected for further investigation. Five alternate sites (also located within "prime" areas) were identified as well and incorporated only if the primary sites failed to meet the selection criteria.

Depth Verification and Slope Calculation. After completing the initial selection process using exclusion mapping, bathymetry data were collected *in situ* on the 24 prime sites in

November 2004 and on one alternate site in July 2005, to verify the GIS datalayer. Based on the reef design, each potential site footprint was 140 m x 50 m in size (Appendix A). Depth data were collected using sonar within the footprint of the site (Appendix 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 deep (< 5 m or > 15.1 m) and sites that had slopes over 5º were eliminated from further consideration (Table 1.1). This process eliminated 10 potential sites leaving 14 sites in consideration (Figures 1.2 & 1.3).

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 between November 2004 and July 2005. The two parallel transects were deployed at 45º angles to the 140 m x 40 m footprint such that each transect bisected about half of the reef area

Table 1.1. 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

Table 1.2. 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

(Appendix B). Divers quantified substrate type in continuous 5 m x 2 m sections along the transect using a 2-m PVC bar. Each divers collected data on one side of the transect. Using rulers for reference, coarse surficial substrate was visually classified according to the Wentworth scale (i.e., bedrock, boulder, cobble; Wentworth 1922) whereas 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 10-50% of the area), 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 B).

Divers recorded 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 C), estimating the percent coverage of algae and encrusting invertebrate species as well as counts of mobile benthic vertebrates and invertebrates.

Although wave action was considered by following Nakamura's (1982) depth suggestions, divers ranked sand ripple presence 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.

Weighting and Ranking Analysis. A weighting and ranking system was developed to incorporate multiple aspects of the site selection

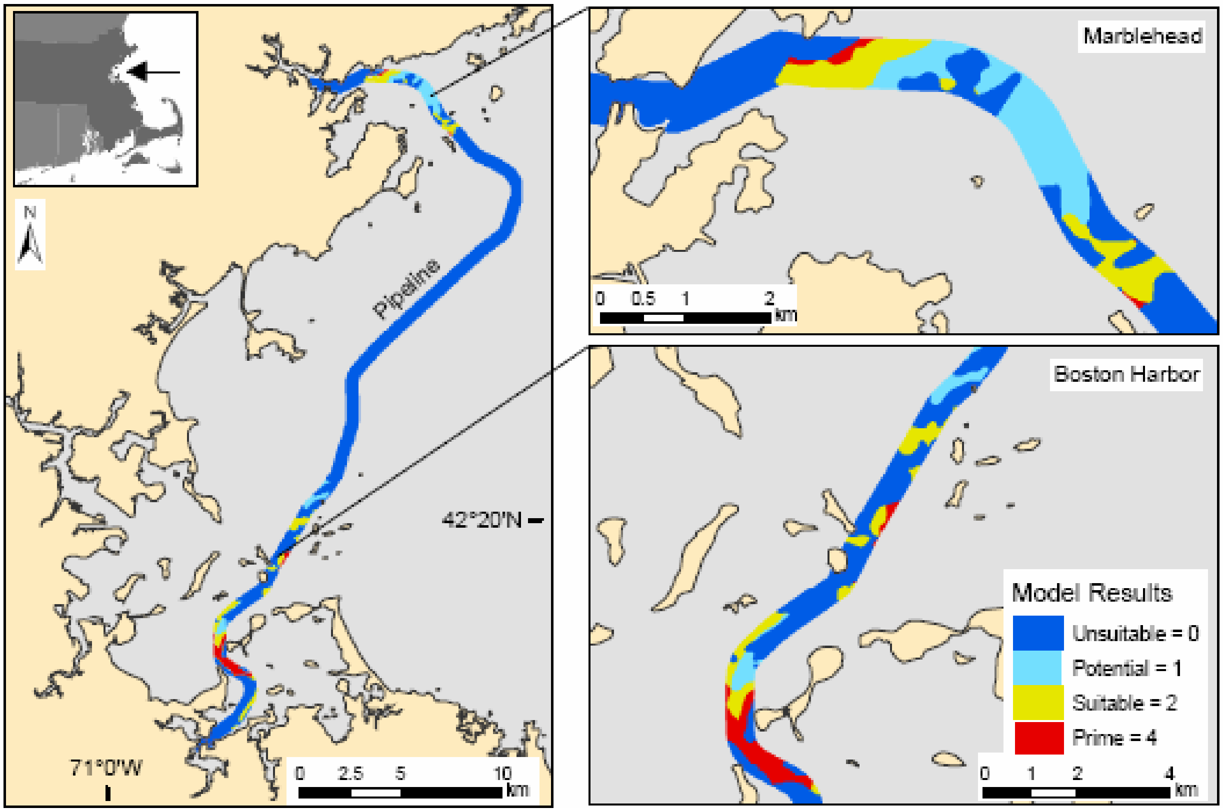

Figure 1.1. Results of the initial exclusion mapping model for habitat enhancement in Massachusetts Bay, Massachusetts, USA. Numerical values representing prime, potential, and unsuitable depth and sediment were multiplied using the GIS raster calculator to produce the suitability data layer.

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 1.3).

For each potential site, we assigned a numerical score to every data category based upon how well the site met the selection criteria (Table 1.3). 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 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 suitable substrate was necessary for reef stability 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 1.3). 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

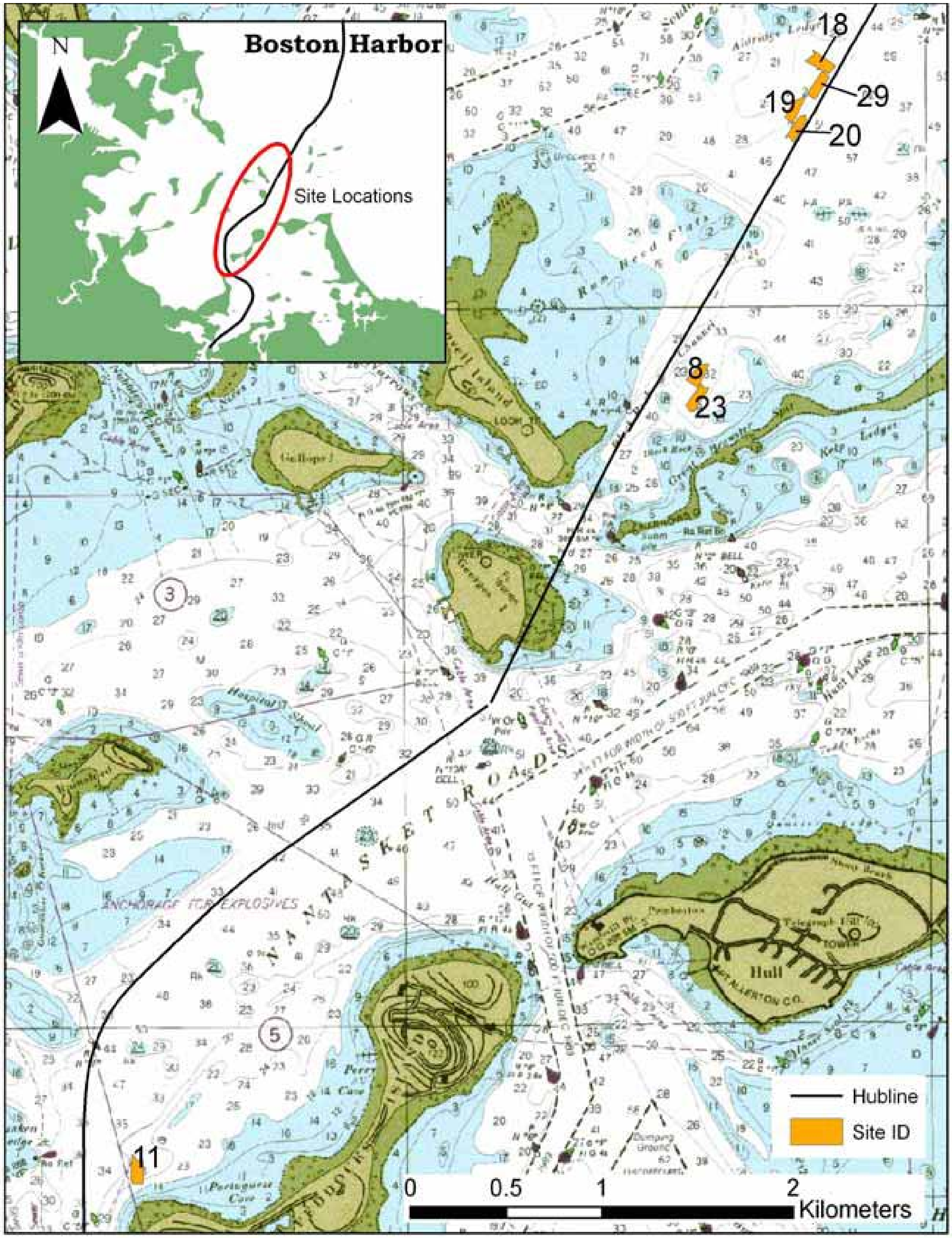

Figure 1.2. Location of potential sites in Boston and Hull following slope and depth eliminations.

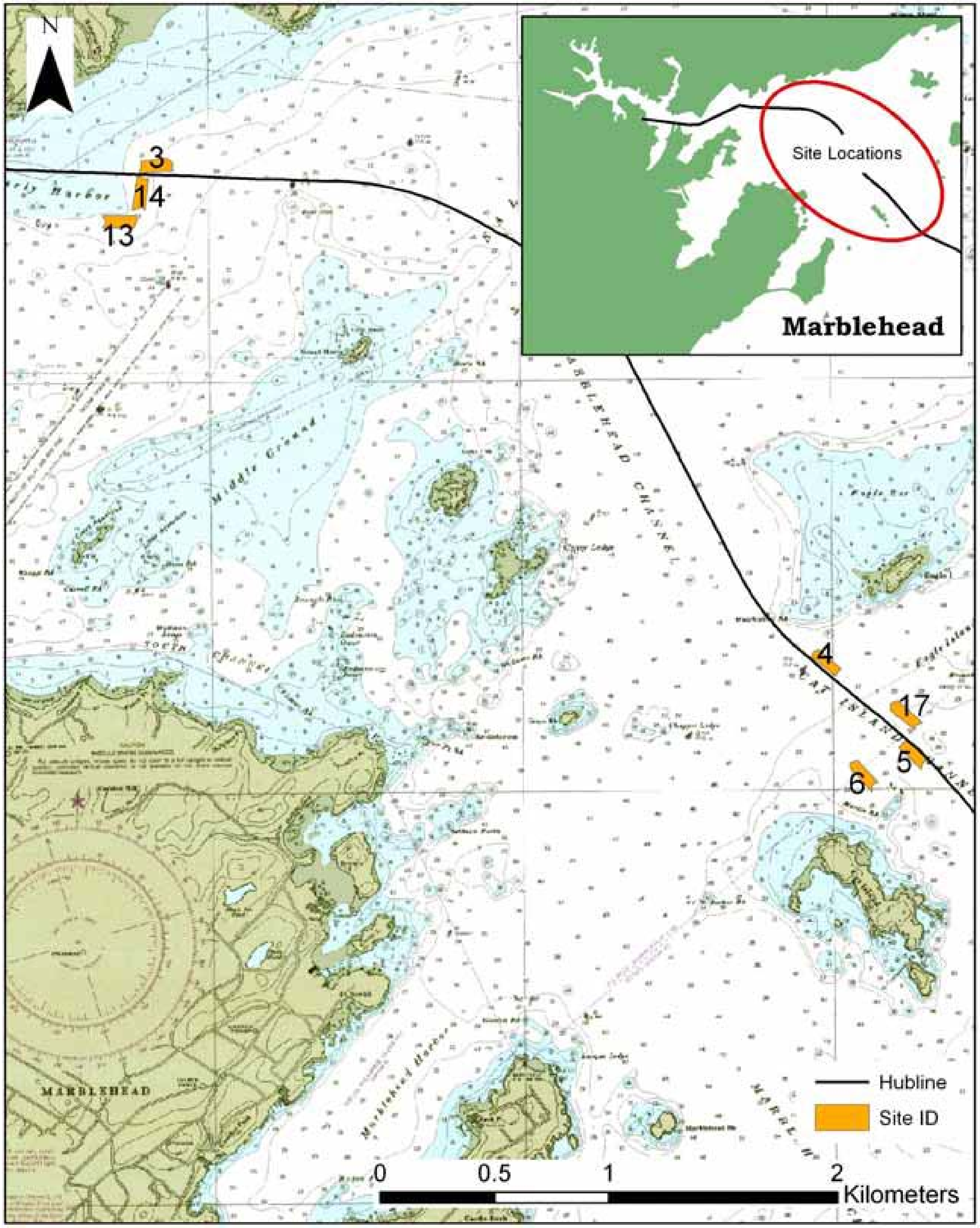

Figure 1.3. Location of potential sites in Beverly and Marblehead following slope and depth eliminations.

Table 1.3. 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 (see Wentworth, 1922 for description of substrate type)	Boulder, silt	Poor	1
	Flat cobble	Potential	2
	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 pipeline	>150 m from fill point	Poor	1
	30 – 150 m from fill point	Potential	2
	Adjacent to fill point (<30 m)	Prime	3

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. To avoid placing the reef on a naturally productive area, one site was eliminated because of observed high species abundance and diversity. At this point, the number of potential sites was narrowed to six.

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).

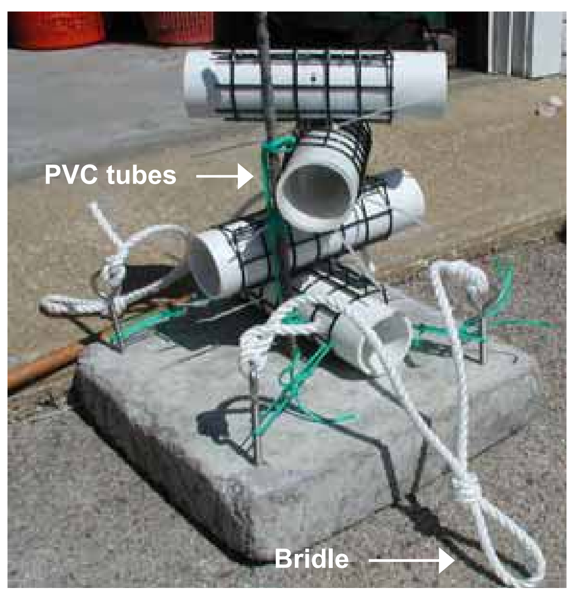

Figure 1.4. Current direction meter. Image shows position of stacked PVC tubes on a concrete base and bridles used for deployment and retrieval.

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 rings 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 stake and angled 45º from the previous tube (Figure 1.4). 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) in June and July 2005. These surveys were used to examine as much area as possible in the 0.6 ha site footprints to assess each site's overall potential for artificial reef development. 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. The results of this survey were used to narrow the number of prospective sites to three.

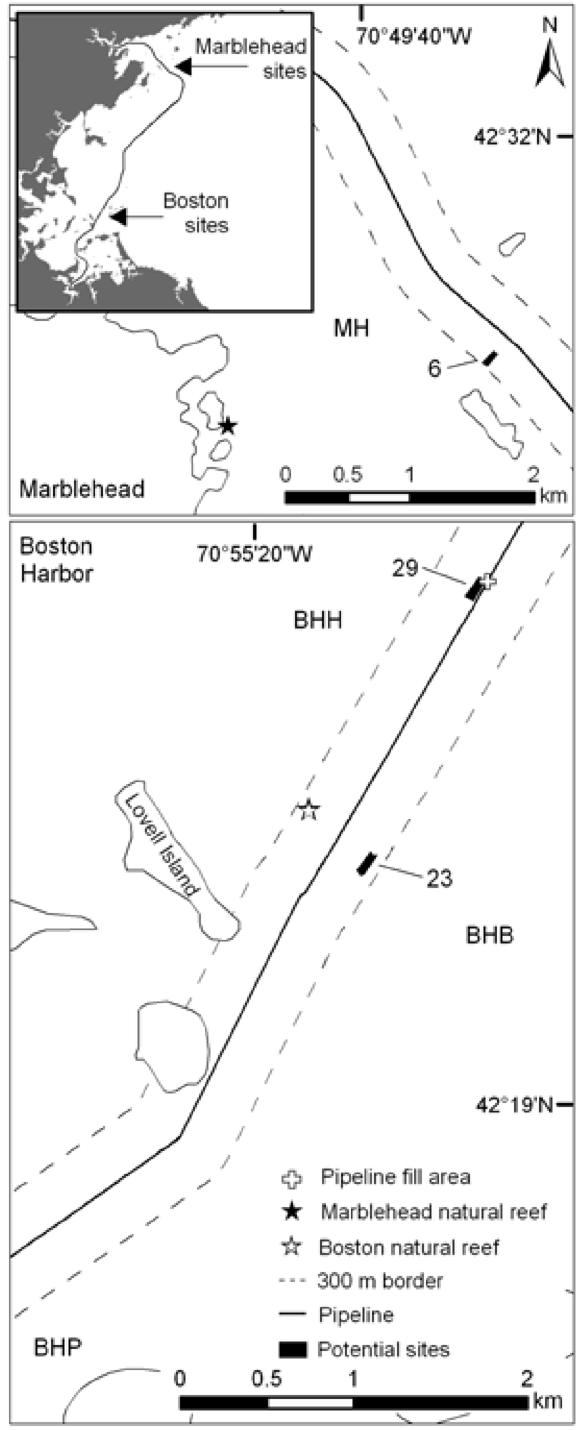

Figure 1.5. Location and orientation of final three potential sites, natural reefs, and the pipeline cobble fill point. Map also depicts general target areas for habitat enhancement: Marblehead (MH), Boston Harbor near Hypocrite Channel (BHH), Boston Harbor near the Brewster Spit (BHB), and Boston Harbor near Peddocks Island (BHP).

Benthic Air-Lift Sampling. Using methods described by Wahle and Steneck (1991), the three potential sites, the pipeline fill point, and two nearby natural rocky reefs were air-lift sampled in September 2005, to compare densities of mobile benthic macrofauna (Figure 1.5). Air-lift sampling provided two important datasets: it established baseline information on the sites ahead of 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.

At each site, 12 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. Sampling a quadrat in cobble habitat involved pushing the lift tube (fitted with a 1.5-mm nylon mesh collection bag) 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, decapods, bivalves, echinoderms, polyplacophorans, 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 (Sokal and Rohlf 1995, SPSS 9.0 statistical software). Data were $\log_{10}(x + 0.1)$ transformed to meet the assumption of homogeneity and a post hoc comparison was conducted using a Tukey HSD test (Sokal and Rohlf 1995). 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 (Sprent 1989, Zar 1999). Using all the enumerated species data, Shannon indices of diversity were calculated for 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). 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. The 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 artificial turf (short-pile synthetic grass carpeting) on the bottom (Figure 1.6). Each collector was filled with 15-25-cm diameter cobble and lowered from the boat using a built-in bridle (Appendix B). Ten collectors were placed on each of the three sites in July 2005 prior to the postlarval lobster settlement

Figure 1.6. Settlement collector loaded with rocks and ready for deployment.

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 of fauna during retrieval. Buoyed lines were tied to the collector bridle and the collector was hauled to the surface using a winch. The rocks and artificial turf in each collector were inspected and species were recorded following the air-lift sampling methods.

The larval settlement collector data were used to address our primary hypothesis; young-of-the-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 target species, American lobster, would use the reef.

A 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 conducting a one-way ANOVA and a post-hoc Tukey HSD test on the mean number of lobster per 1 m^2 by site (Sokal and Rohlf 1995). 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 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 GIS model allowed us to eliminate 80% of prospective reef area prior to field assessments (Figure 1.1).

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 (see Table 1.1 for site selection criteria). After reviewing these 16 sites, three additional sites were eliminated because of known poor larval settlement in the area (*MarineFisheries,* unpubl. data), high siltation rates, and heavy boat traffic (hazardous for divers). At this point Site 29, an alternate site, was included in the selection process to fill a gap in a prospective area where many of the primary sites had been eliminated. These steps brought the total number of potential sites to 14 (Figures 1.2 & 1.3).

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 1.1). 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 1.1).

Substrate Composition and Weighting and Ranking Analysis. Sites 3, 13, 14, and 17 (all in Marblehead = MH), the lowest ranking sites, were eliminated because of the presence of large sand ripples or silty substrate (Table 1.4, Figure 1.7). 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, unpubl. data).

The PCA analysis revealed that some of the high ranking sites (such as 11and 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 1.4). (Figure 1.8). Sites that scored poorly (3, 13, and 14) were grouped together, indicating that they had similar weaknesses.

Table 1.4. 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

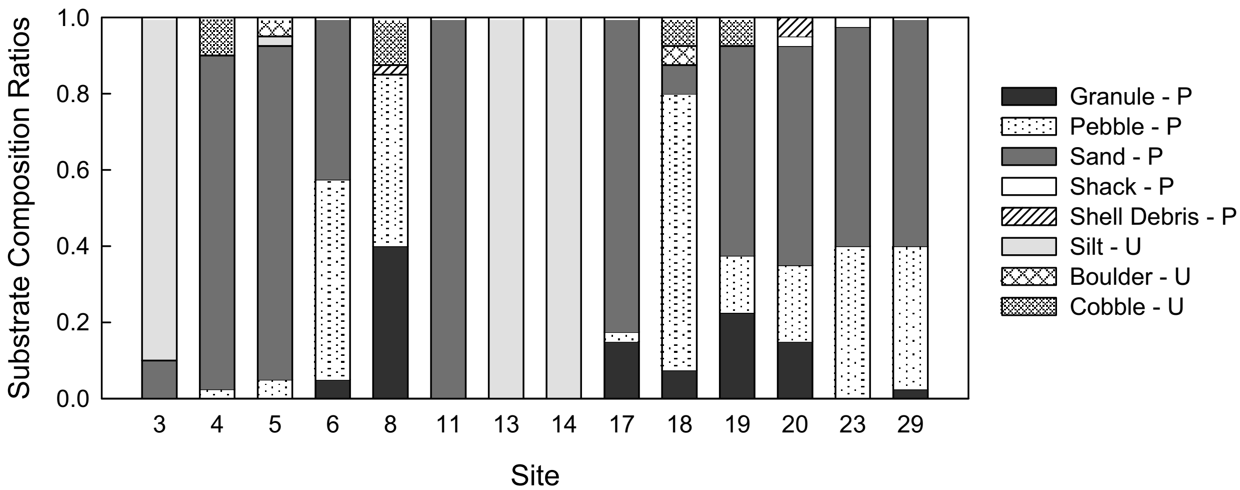

Figure 1.7. Primary surficial substrate composition of the 14 potential sites. P = prime substrate for artificial reef deployment, U = unsuitable substrate for reef deployment.

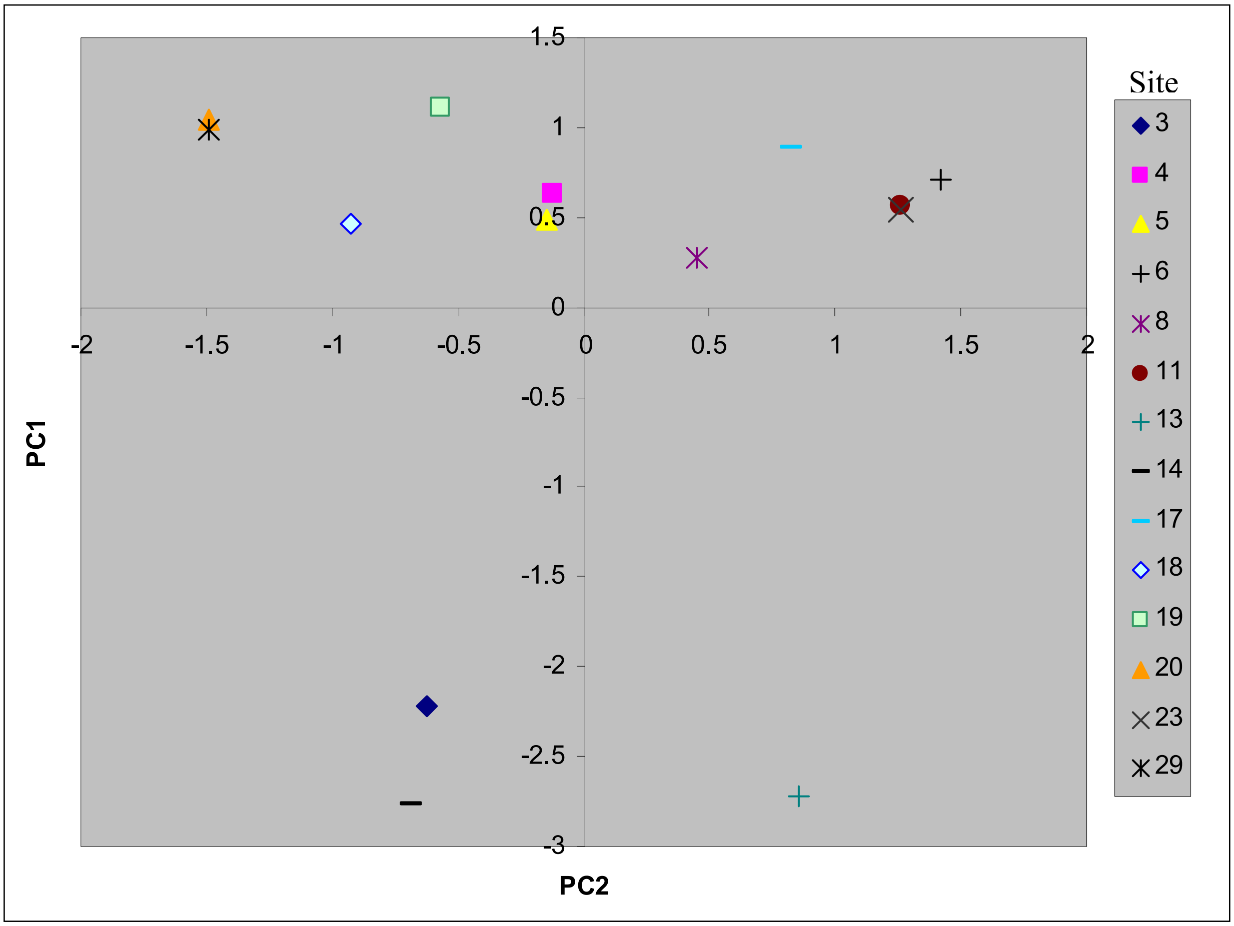

Figure 1.8. Principal component analysis comparing similarity of potential artificial reef sites (by site ID).

After these initial eliminations, we selected two final sites within each of the three areas we considered for placing the reef: (1) MH, (2) Boston Harbor near Hypocrite Channel (BHH), and (3) Boston Harbor near Brewster Spit (BHB) (Figure 1.5). 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 1.4).

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 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.

Sites 5, 8, and 18 were eliminated after qualitative transect surveys revealed existing hard-bottom habitat at those sites. Comparison of sampled species diversity among sites indicated that Site 6 (MH), Site 20 (BHH), and Site 23 (BHB) had relatively lower existing species diversity than the other sites and thus were selected as the three final sites for further consideration. As Site 20 was located within the buffer zone of an area of archeological concern (V. Mastone, Massachusetts Board of Underwater Archaeological Resources, pers. comm.), an alternate site, Site 29 (the second highest ranking site within the BHH region), was substituted for Site 20 (Fig 1.2).

Final Three Site Descriptions. Site 6 in Marblehead (MH) was located adjacent to Cat Island outside of the shipping channel (Figures 1.3 and 1.5). The primary substrates at this site were pebble, granule and sand (Figure 1.9). 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

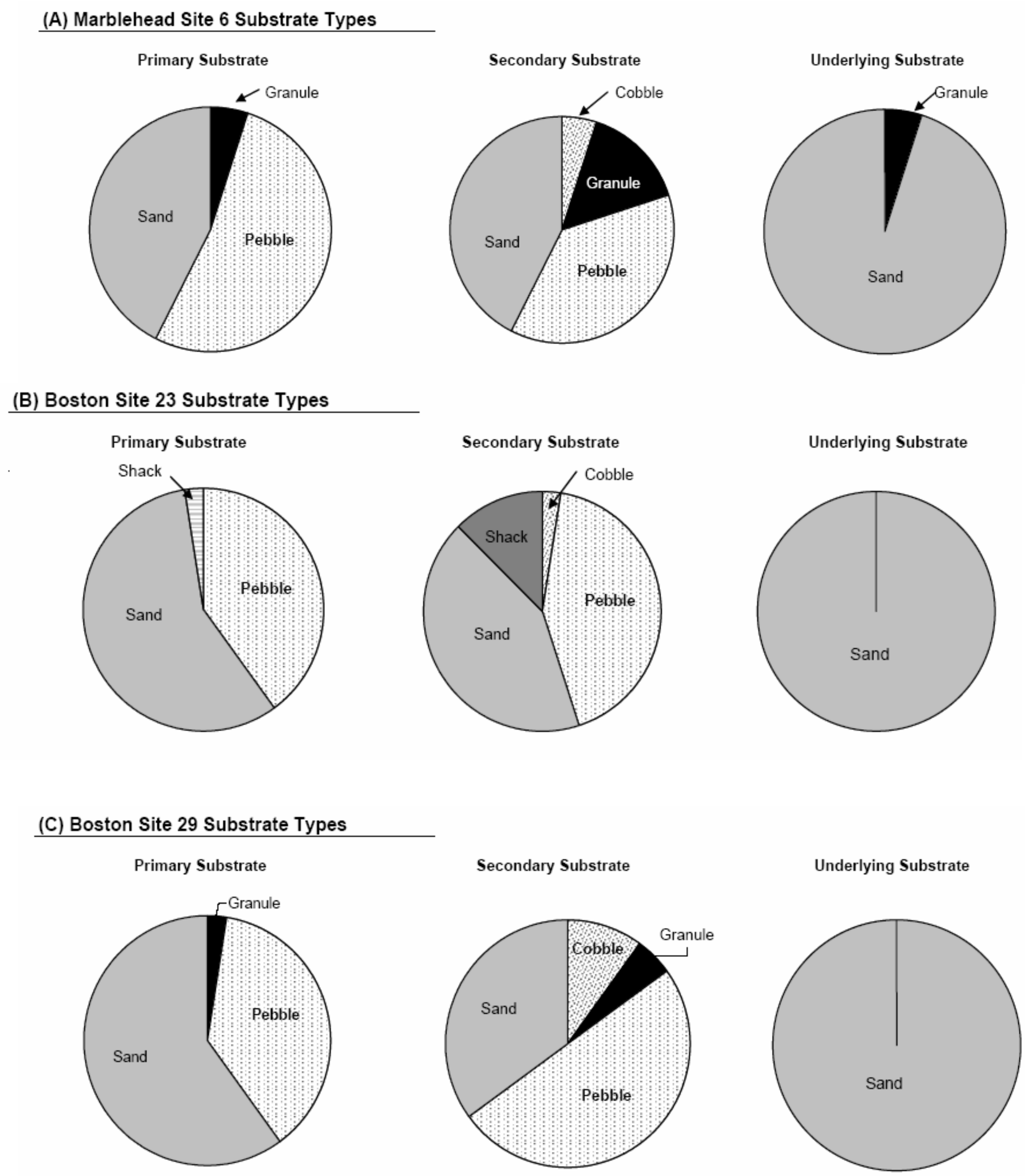

Figure 1.9. Primary, secondary, and underlying sediment proportions of the final three potential sites.

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 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 1.2 and 1.5). The primary substrates at this site were pebble and sand with a small percentage of shell shack (Figure 1.9). 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 (Rajidae), 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 Hypocrite Channel in Boston (BHH) (Figures 1.2 and 1.5). The primary substrates were sand and pebble and a small amount of granule (Figure 1.9). 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 individuals per 140-m transect) included lobster (*H. americanus*), sea stars (*Henricia* sp.), grubby sculpin (*M. aenaeus*), skates (Rajidae), and northern cerianthid anemones (*Cerianthus 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.

<u>Benthic Air-Lift Sampling</u>. Significantly more decapod crustaceans were found on the two natural reef sites (Marblehead = 52.33 individuals m^{-2} ± 4.52 SE, n = 12; Boston = 41.83 individuals m^{-2} ± 6.58 SE, n = 12) than the three potential reef sites (Site 23 (BHP) = 14.67 individuals m^{-2} ± 2.12 SE, n =12; Site 29 (BHH) = 14.17 individuals m^{-2} ± 2.25 SE, n = 12; Site 6 (MH) = 14.00 individuals m^{-2} ± 3.50 SE, n = 12), ($F_{5, 66}$ = 12.85, p <0.05; Tukey HSD, p <0.05, Figure 1.10). The pipeline cobble fill point (mean = 25.50 m^{-2} ± 3.61 SE, n = 12) was similar to the Boston natural reef, as well as the potential reef sites (Tukey HSD, p >0.05, Figure 1.10a). However, the pipeline had a significantly lower crustacean density than the Marblehead natural reef (Tukey HSD, p <0.05, Figure 1.10a). No significant differences were detected between the two natural reef sites or among the three potential reef sites (Tukey HSD, p >0.05, Figure 1.10a).

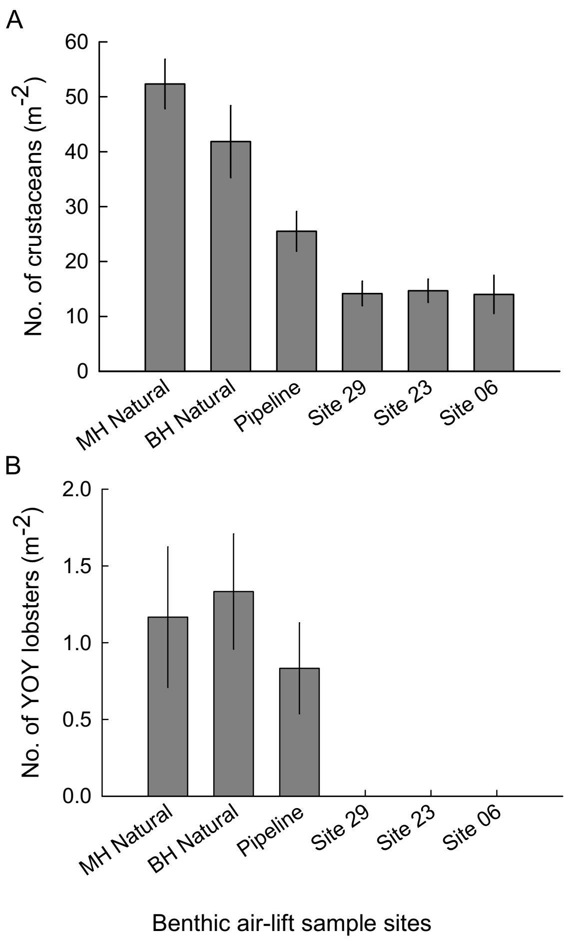

Figure 1.10. Mean (A) decapod crustacean density and (B) young-of-the-year (YOY) lobster density (+SE) by site as determined by air-lift sampling (n = 12 for each site). MH = Marblehead, BH = Boston Harbor. Horizontal bars indicate statistical similarity based on a post-hoc Tukey test (α = 0.05) (A) and permutation testing at 1000 iterations (α = 0.05) (B).

Young-of-the-year (YOY) lobster density, as sampled by benthic air-lift, was significantly lower on the potential reef sites (all three sites = 0.00 individuals m^{-2}, n = 12) than the natural reef sites (Marblehead = 1.17 individuals m^{-2} ± 0.46 SE, n = 12; Boston = 1.33 individuals m^{-2} ± 0.38 SE, n = 12) (Kruskal-Wallis test, H = 11.5, 4 d.f., p <0.05; permutation tests, p <0.05, Figure 1.10b). YOY lobster density on the pipeline (mean = 0.83 individuals m^{-2} ± 0.30 SE, n = 12) was similar to all other sites (permutation tests, p >0.05, Figure 1.10b). There was no significant difference in YOY lobster density on the two natural reefs; the three potential reefs were also similar in that they had no larval lobster settlement (permutation tests, p >0.05, Figure 1.10b). As expected, the two natural reef sites had higher sampled species diversity than the potential reef sites (Table 1.5). Of the three potential reef sites, Site 6 (MH) had the highest species diversity and Site 23 (BHP) had the lowest diversity (Table 1.5).

Table 1.5. Species diversity values (Shannon index).

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

Larval Settlement Collectors. Site 23 was the only site where YOY lobsters were found in larval settlement collectors; however, all three sites experienced settlement of other species of decapod crustaceans and fish. Site 23 had significantly more juvenile and adult lobster in the collectors (mean = 6.75 individuals m^{-2} ± 1.00 SE, n = 8) than the other two potential reef sites (Site 29 = 2.40 individuals m^{-2} ± 0.40 SE, n = 10; Site 6 = 2.67 individuals m^{-2} ± 0.47 SE, n = 9) ($F_{2,\ 24}$ =

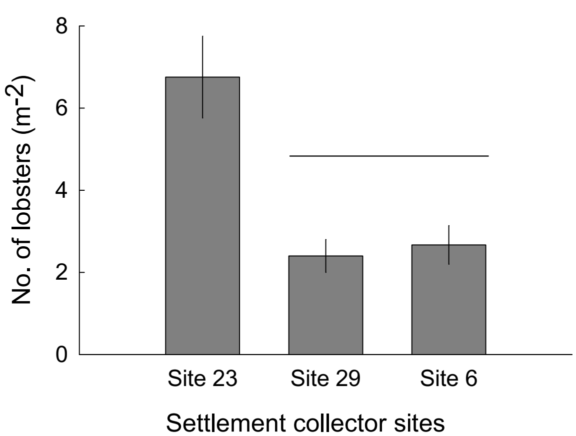

Figure 1.11. Mean juvenile and adult lobster density (+SE) in settlement collectors by potential reef site (Site 23, n = 8; Site 29, n = 10; Site 6, n = 9). Horizontal bars indicate statistical similarity based on a post-hoc Tukey test (α = 0.05).

14.08, $p < 0.05$; Tukey HSD, $p < 0.05$, Figure 1.11). Site 29 and Site 6 had similar densities of lobster (Tukey HSD, $p > 0.05$, Figure 1.11). Site 23 had the highest sampled species diversity in the settlement collectors, whereas the diversity at Site 6 was the lowest (Table 1.5).

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 a 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 lobster settlement. However, during the two-month period the collectors were deployed on Site 23, the rocks and artificial turf 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 young-of-the-year (YOY) lobster because of the additional shelter it offered. The sand and silt could also explain why collectors at Site 23 had the highest sampled species diversity when compared to the other two sites, which did not experience high sedimentation rates. Despite the positive species diversity, partial burial of the cobble in two months indicated that there was high potential for siltation and reef burial at Site 23. With no anomalous weather events during the study period, sedimentation driven by rapid tidal exchange in outer Boston Harbor (Signell and Butman 1992) was not likely to be temporary; therefore Site 23 was eliminated from consideration.

Site 29 in Boston Harbor near Hypocrite Channel and Site 6 in Marblehead were the two sites remaining in the selection process. Although neither site had YOY lobster present in the settlement collectors, many other decapod crustacean and fish species were recorded at the sites. Air-lift sampling the adjacent natural reefs also demonstrated that YOY lobster and larvae and/or juveniles of other benthic species were present near the prospective reef sites. Thus, the air-lift sampling and settlement collector work indicated that adequate levels of larval settlement would occur at either of these sites.

The species diversity indices and weighting and ranking analysis were used to determine the best site for reef development out of the final two sites. Air-lift sampling results demonstrated that Site 29 had naturally lower sampled species diversity than Site 6, whereas 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.

Throughout this year-long process, areas where improvements and adaptations to our seven-step model could be made were noted. The first of the seven steps, exclusion mapping, targeted prime areas for artificial reef deployment before 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 data sets 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, provided verification of the substrate data layer for portions of Massachusetts Bay. This verification proved to be important because several of the sites (3, 13, and 14) were located in "prime" areas for reef deployment according to the GIS model, yet *in situ* verification revealed that the substrates at these sites were too soft to support the weight of a reef. The hand burial method did not provide us with additional information to the quantitative substrate surveys, 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 and 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 an influential step in the site selection process. Maintaining three separate geographic regions in the analysis provided the flexibility needed if one of the areas did not meet all the selection criteria. This decision was crucial because high siltation rates were recorded at Site 23 during the final weeks of site selection, eliminating the use of that area. 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 better verified 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, the qualitative transect-survey, visually confirmed the suitability of each site and narrowed the number of potential sites to three. This method does not require any major alterations to improve future site selection models.

Results from the two final steps, the 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 YOY lobster because none were recorded on these sites. A comparison of sampled species diversity from air-lift sampling resulted in the elimination of 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 artificial turf to more closely approximate preferred habitat and reflect natural conditions. However, the trade off to this approach is the loss of the ability to gauge relative siltation rates among sites, which would have been masked if sand was added to the collectors. Information on larval settlement, species diversity, and siltation rates on the remaining two sites were important factors in the final site selection process.

Acknowledgements

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CHAPTER 2. ARTIFICIAL REEF MONITORING PROGRAM

Summary: In March and April of 2006, the Massachusetts Division of Marine Fisheries (*MarineFisheries*) installed a six-unit cobble/boulder reef in Boston Harbor, Massachusetts. An intensive, long-term monitoring program was implemented to measure ecological variation on the artificial reef and to determine how well the artificial reef met certain goals. Two primary questions are being addressed with this monitoring program: (1) can a cobble/boulder artificial reef establish similar levels of species abundance and diversity as a nearby natural reef, and (2) if so, in what timeframe? *MarineFisheries* is also investigating smaller scale questions such as: does the artificial reef augment post-larval lobster settlement and the settlement of other fish and invertebrates; does the artificial reef provide mitigation for the hard-bottom encrusting community; and does the artificial reef provide shelter for multiple life stages of various marine organisms?

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

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

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 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 2.1). Throughout the remainder of this report, the reef and sand units are referred to using their unique numbers.

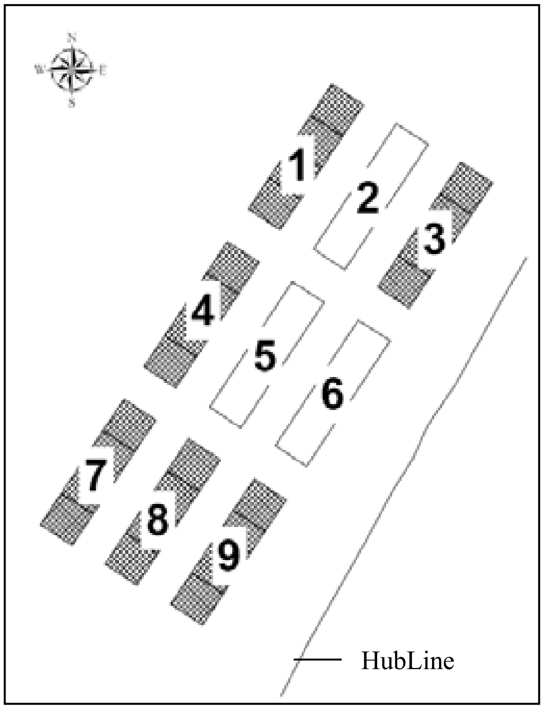


Figure 2.1. Assigned identification numbers for artificial reef units and sand areas. Sand = white, artificial reef unit = gray.

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 2.2). 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 2.3 & 2.4). 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 2.5).

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 2.5). 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

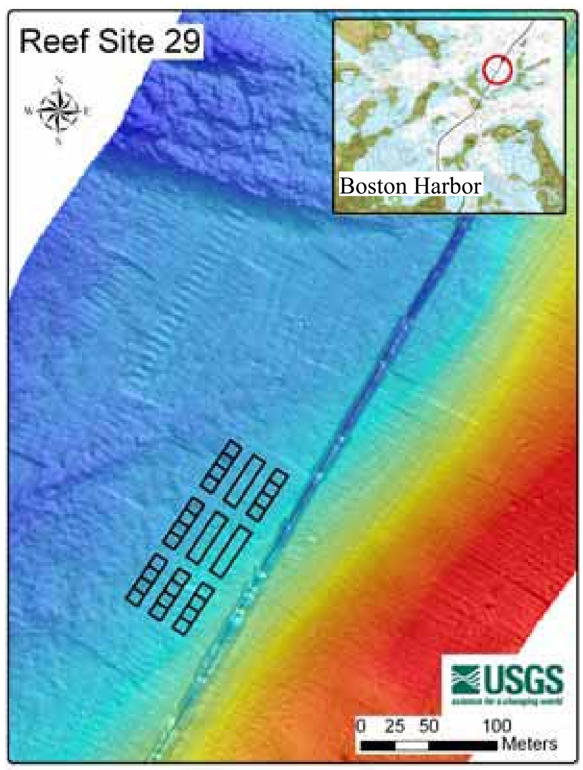


Figure 2.2. Multibeam and side-scan sonar survey results from a pre-construction survey in January 2006. Location of the planned reef area (Site 29) is shown over the sonar image; hashed areas depict areas where reef units were to be constructed, open bars depict sand sites.

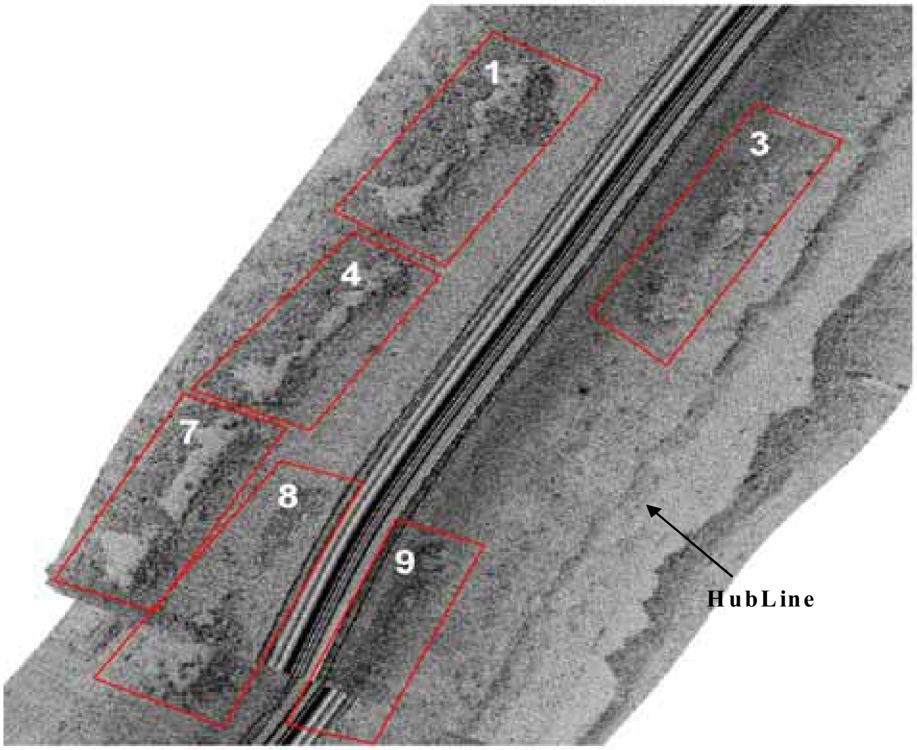


Figure 2.3. Side-scan sonar survey, conducted in May 2006, of the artificial reef units (outlined with their unique ID numbers) and the HubLine cobble fill point.

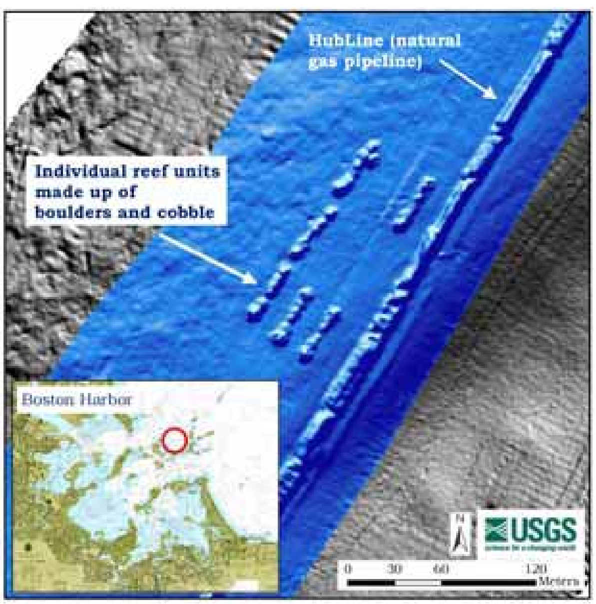


Figure 2.4. Results from the multibeam survey, conducted post-construction in July 2006, showing the location of the artificial reef units in relation to the HubLine cobble fill area.

which was more similar to that of the artificial reef (Figure 2.5).

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 least similar of the three transects in substrate

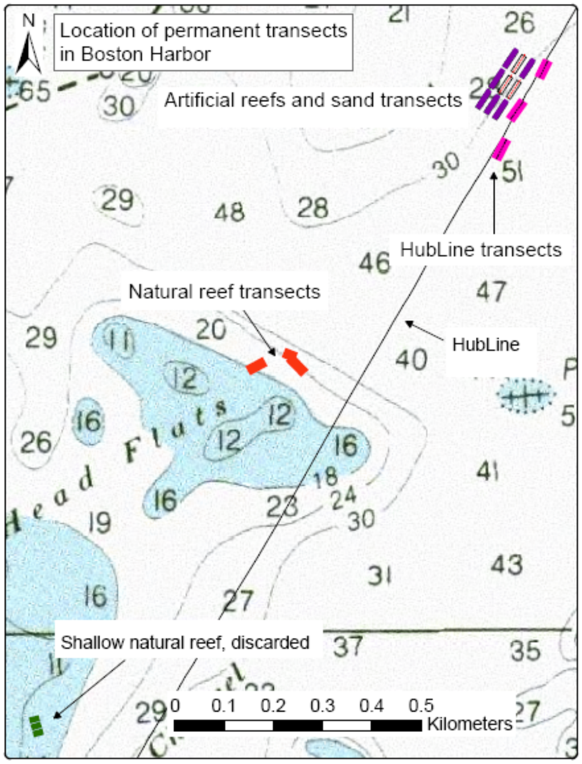


Figure 2.5. Location of permanent transects deployed on the artificial reef, sand, HubLine, and natural reef.

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 2.1).

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 2.6). 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 2.7). 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 2.6. Diver collecting data on the artificial reef using a swath bar.

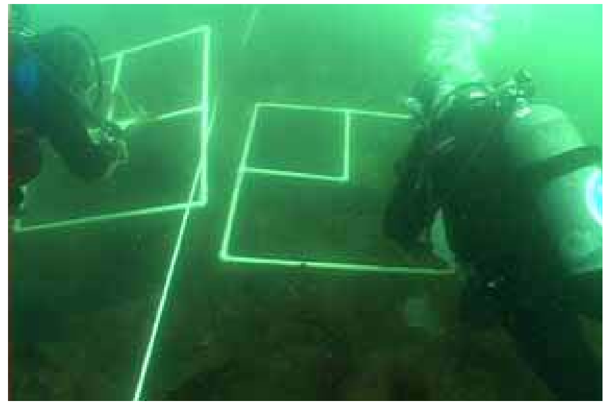


Figure 2.7. Diver collecting data on the artificial reef using quadrats.

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 tally 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.

<u>Species densities.</u> 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.

<u>Lobster density by rock size</u>. 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.

<u>Fish Tagging Study</u>

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 2.8) 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 2.9). Each trap was placed at least 12 m apart from other traps, 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 2.9).

Figure 2.8. 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 cm 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 2.10). For all fish species, total length was measured to the nearest 0.1 cm using a measuring board. Cunner with a total length of 7.5 cm or greater (spring) or 8.0 cm or greater (fall), were tagged with Floy Fingerling tags (Figure 2.11). 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.

Catch rate analysis. 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 and separate analyses were run to determine if catch

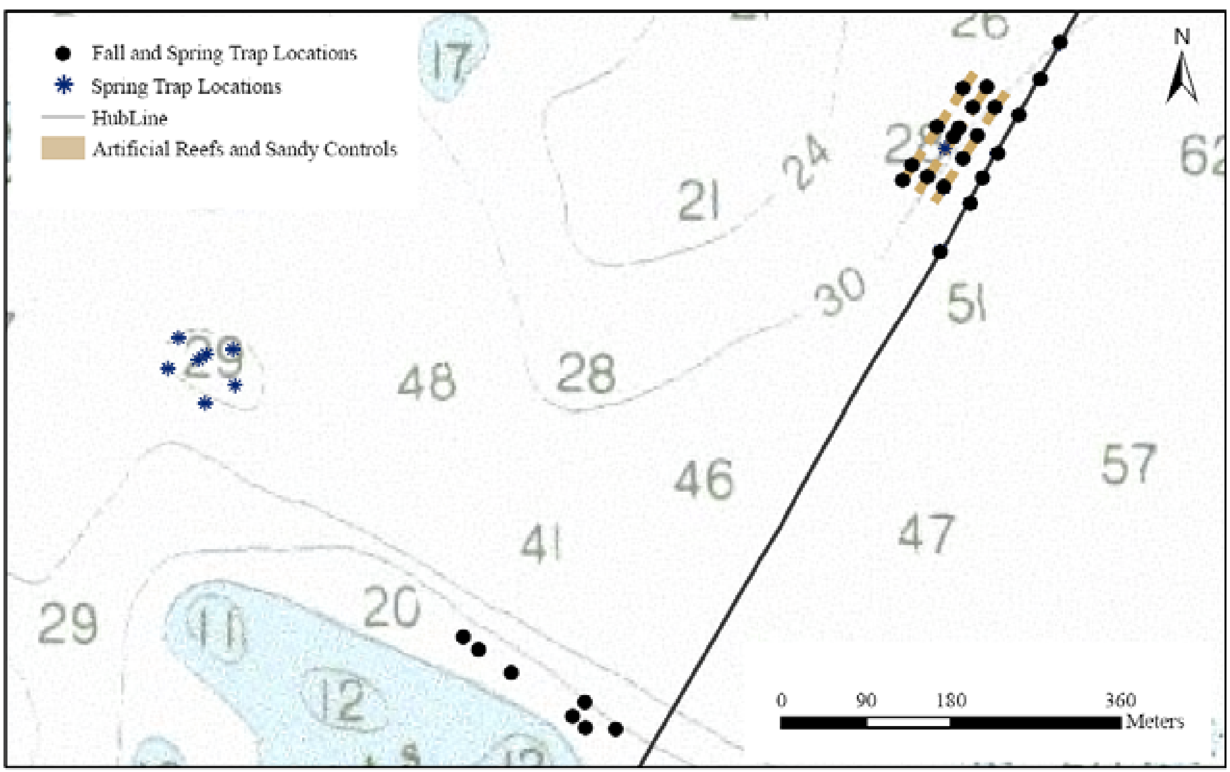


Figure 2.9. Locations of fish traps set in the spring and fall of 2006. Note: Spring locations represented by the stars were not resampled in the fall.

Figure 2.10. Juvenile lobster tagged with a knuckle tag.

rate differed by season, site and individual artificial reef units. To investigate catch rate by season, data from all sites were combined and a one-way ANOVA was conducted on mean catch rate by season. Seasonal catch data were ln (x +1) transformed to meet the assumptions of the ANOVA. With no difference in catch rate between seasons, seasonal data were combined by site. To assess differences in catch rates by site, a non-parametric test (Kruskal-Wallis) with follow-up pairwise comparisons (Mann-Whitney test) was performed. A Bonferroni adjusted alpha of 0.008 was used in the site comparisons. Next, to compare differences in catch rate among individual reef units, we conducted a one-way ANOVA and a follow-up Tukey test using cunner catch rates among the reef units. A one-way ANOVA was also run on the HubLine traps to determine if there was a difference in catch rate along a north-south gradient. These analyses were not run on lobsters or crabs because catch rates were minimal.

<u>Cunner length-frequency</u>. 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.

<u>Cunner growth</u>. 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.

<u>Cunner movement</u>. 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.

Figure 2.11. Tagged cunner. Note: Thread on the fish on right was trimmed prior to release.

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 compared to cunner that were recaptured on the site 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 2.12). 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

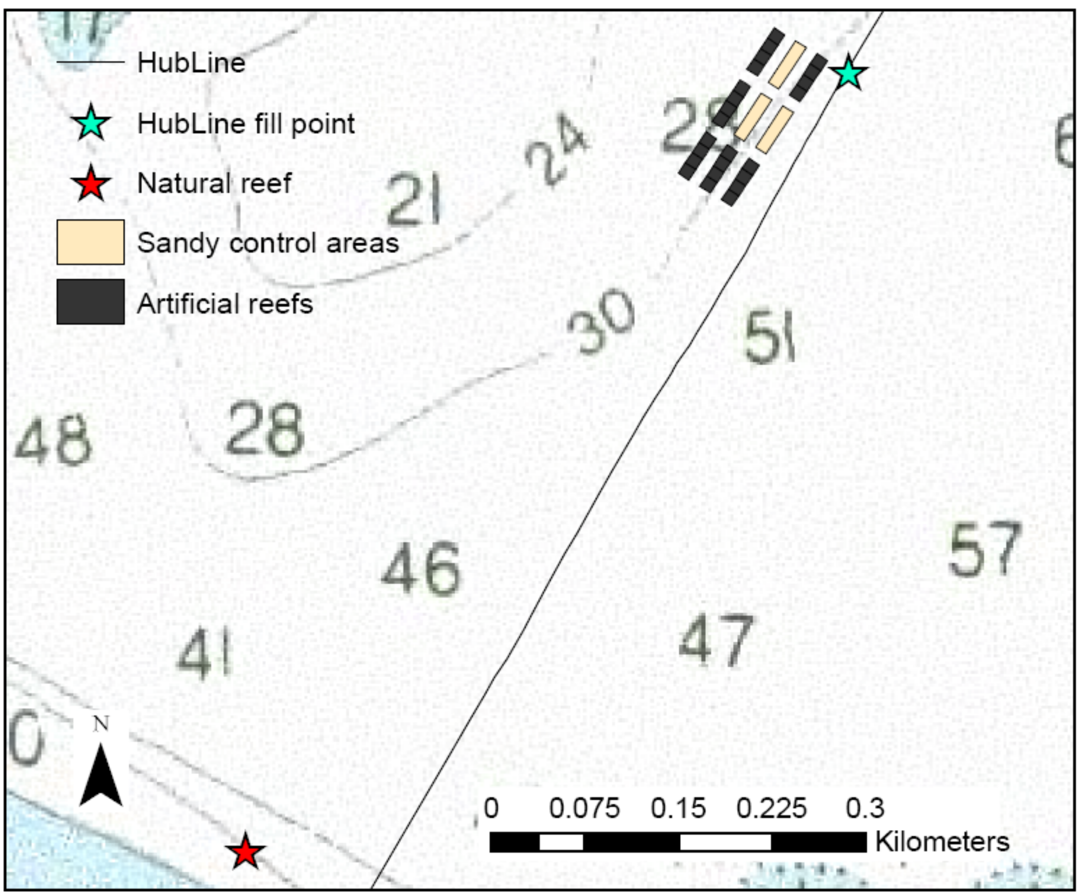


Figure 2.12. Location of 2006 air-lift sampling sites.

samples were taken. This routine was used on the natural reef site (large boulder and patches of sand 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) 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 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 2.14). Light data from July 18, 2007 to August 1, 2007 indicated that the artificial reef had slightly more light than the natural reef (Figure 2.15). 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 2.16).

Water transparency ranged from the 1.7 – 3.1m category to the 9.2 – 10.6 m category over the course of survey from May 2006 to August 2007 (Figure 2.17). 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 2.18b). Yet, by June 2007 much of the red filamentous algae had declined and there was

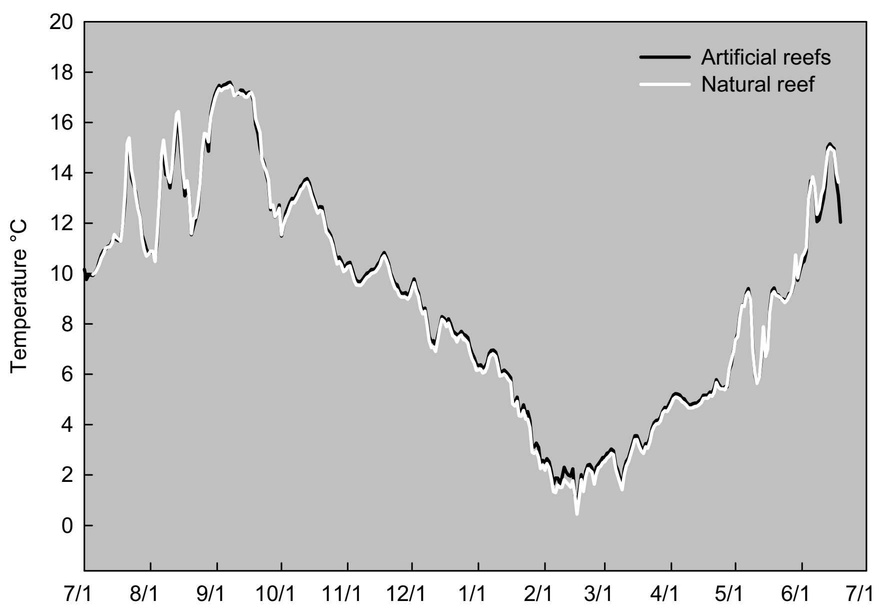


Figure 2.13. Temporal changes in bottom temperature on the artificial and natural reefs from July 1, 2006 to July 1, 2007.

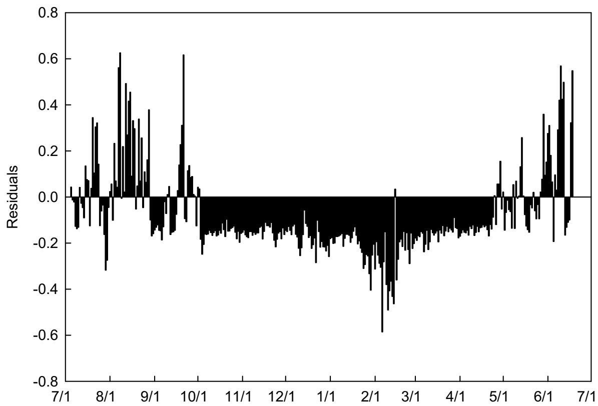


Figure 2.14. Temperature residuals between the artificial and natural reefs from July 1, 2006 to July 1, 2007. Negative values indicate when the natural reef was colder than the artificial reef.

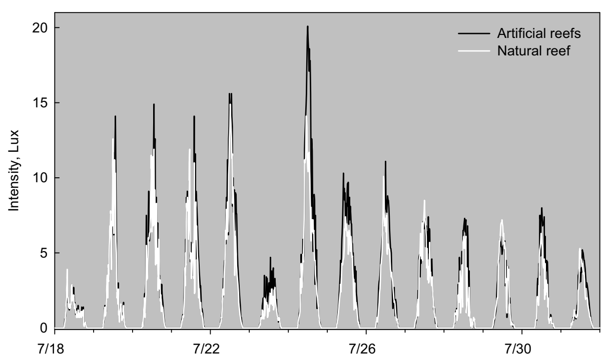


Figure 2.15. Daily changes in light intensity (lux) on the artificial and natural reefs in July 2007.

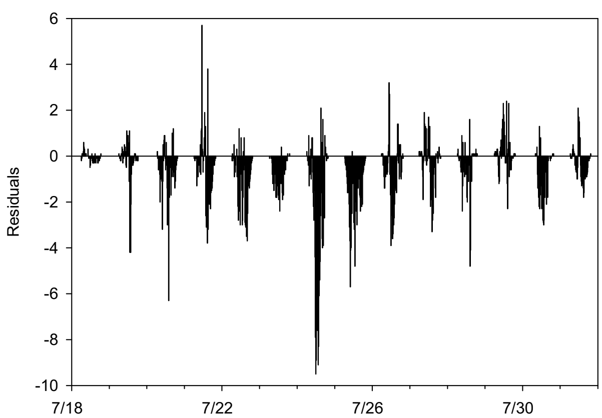


Figure 2.16. Light intensity residuals between the artificial and natural reefs in July 2007. Negative values indicate when the natural reef had less light than the artificial reef.

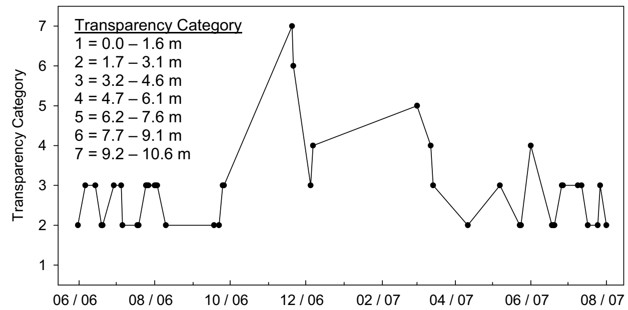


Figure 2.17. Water transparency estimated by divers at the start of each permanent transect survey.

evidence that a broad, leafy red algae (*Membranoptera alata*) had recruited to the reef (Figure 2.18c). A juvenile kelp recruit, most likely *Laminaria* sp., was also noted in the spring (Figure 2.18c). 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 2.18d).

The second photograph station on the artificial reef (Reef 7) was not constructed until March 2007, therefore only three seasons of photographs exist (Figure 2.19). 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 2.19a). Coverage of the red filamentous algae decreased noticably between March and June 2007 (Figures 2.19a & b) but increased from June to July 2007 (Figures 2.19b & 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 2.20a - c) and a slight decline from May to July 2007 (Figures 2.20c & d). Small encrusting tunicates (orange dots in Figure 2.20a), 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

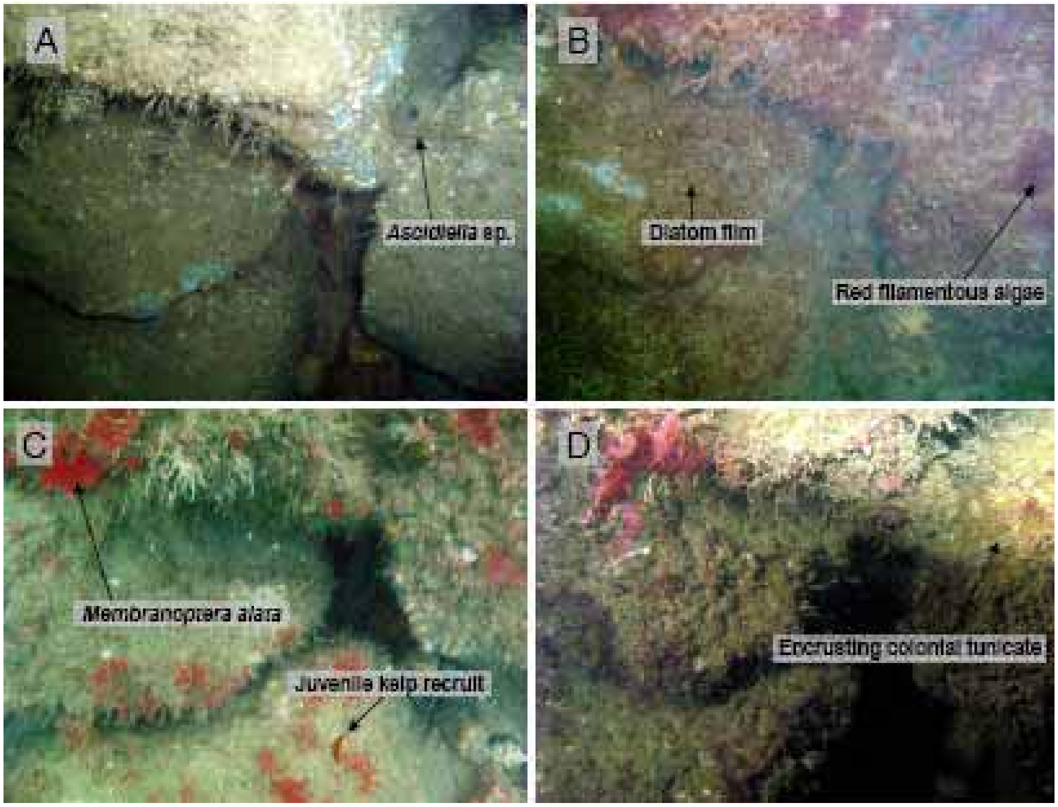


Figure 2.18. Photographs taken on Artificial Reef 9 on (A) 12/7/2006, (B) 3/14/2007, (C) 6/26/2007, and (D) 7/25/2007.

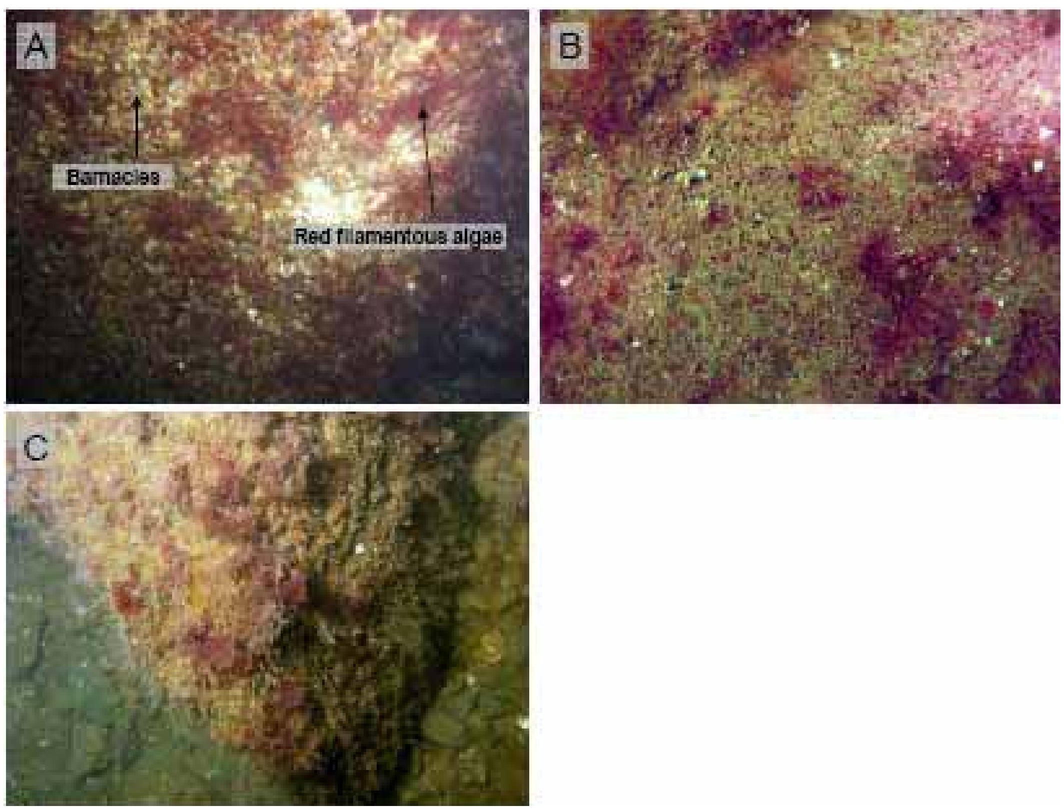


Figure 2.19. Photographs taken on Artificial Reef 7 on (A) 3/14/2007, (B) 6/26/2007, and (C) 7/27/2007. Note: Photograph C was taken with a wider angle lens on a new camera system.

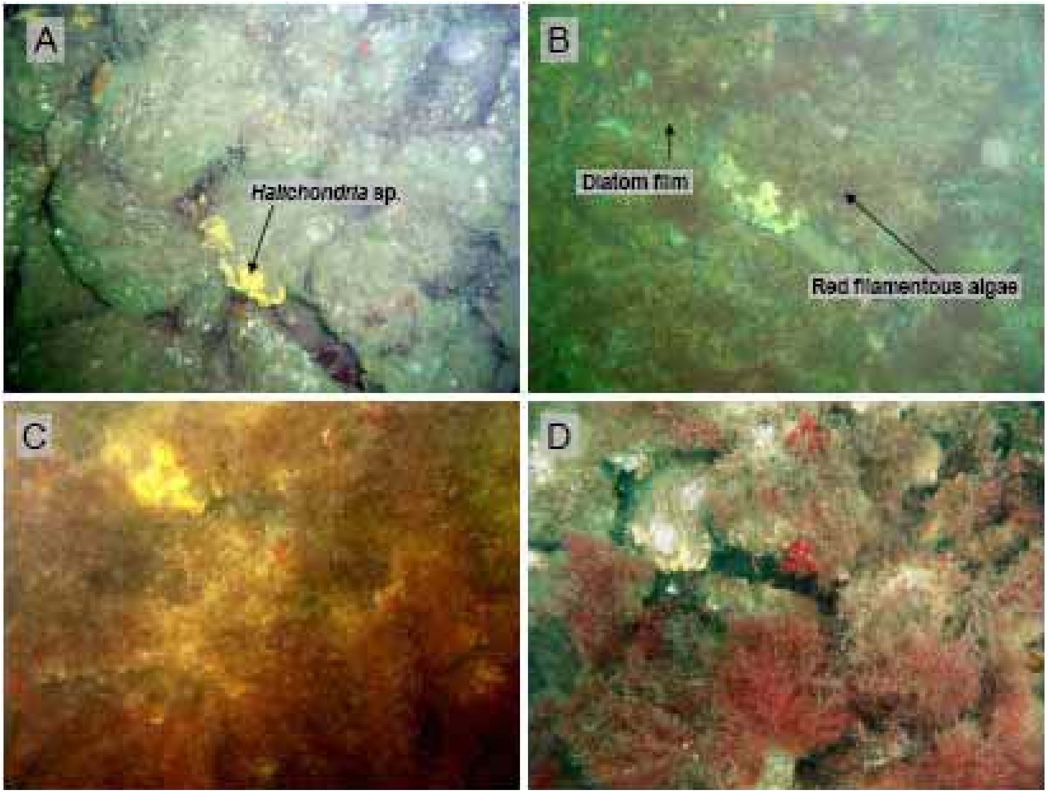


Figure 2.20. Photographs taken on the HubLine on (A) 12/7/2006, (B) 3/1/2007, (C) 5/23/2007, and (D) 7/12/2007.

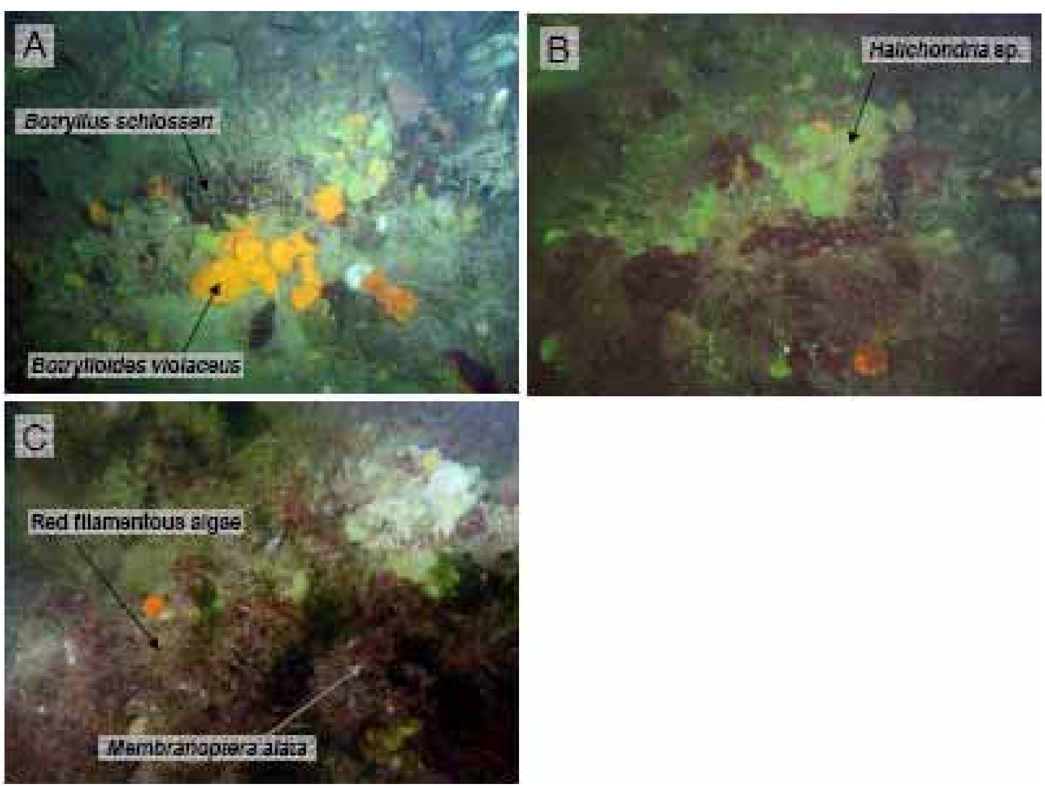


Figure 2.21. Photographs taken on Natural Reef 1 on (A) 12/7/2006, (B) 4/11/2007, and (C) 5/24/2007. Note: photographs were not obtained in July 2007 due to adverse diving conditions.

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 2.20d). 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 2.21). 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.

<u>Substrate</u>. 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 2.22). 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 2.23). 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 2.24) consisting primarily of sand and occasionally cobble, granule, pebble, and shack. The artificial reef and HubLine, however, had

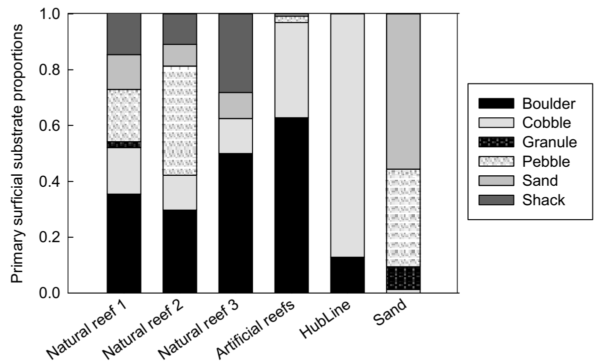


Figure 2.22. Proportion of primary surficial substrates (> 50% of area) among study sites.

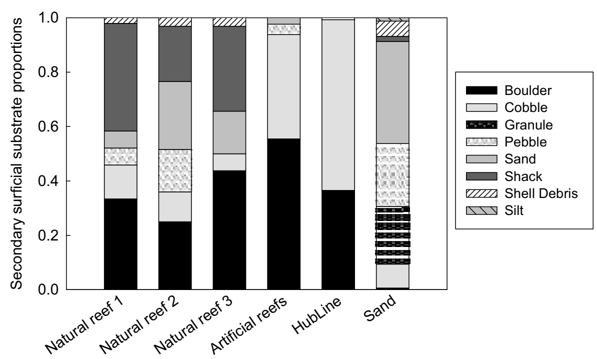


Figure 2.23. Proportion of secondary surficial substrates (10 - 50% of area) among study sites.

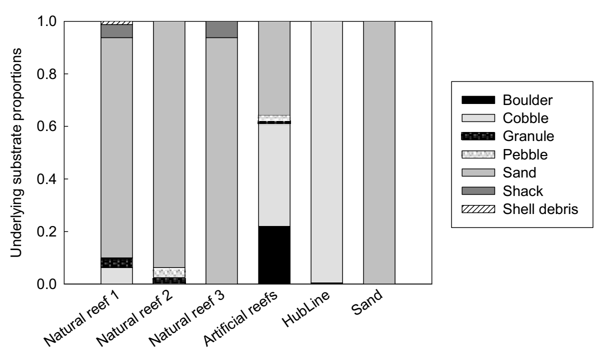


Figure 2.24. Proportion of substrates underlying the primary and secondary substrates among study sites.

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.

<u>Species diversity</u>. Using presence/absence species data, a total of 80 species were sighted on

the artificial reef between May 2006 and July 2007 (Table 2.1). Seventy-seven species were observed on the natural reef from July 2006 to July 2007 (Table 2.2), 64 species were sighted on the HubLine from June 2006 to July 2007 (Table 2.3), and 53 species were sighted on the sand sites from June 2006 to July 2007 (Table 2.4).

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 2.5, Figure 2.25). 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 2.5). 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 2.6, Figure 2.26). 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 2.6, Figure 2.26). 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 2.27). The HubLine consistently had the highest percent cover of red filamentous algae until March 2007. Mean percent cover of red filamentous 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 it did in 2006.

Common kelp (*Laminaria* sp.) mean percent cover was variable across sites especially in the summer months (Figure 2.28). 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 2.1. 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 2.1 (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 2.2. 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 2.2 (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	
Rajidae	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 2.3. 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 2.4. 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
Rajidae	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 2.5. 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

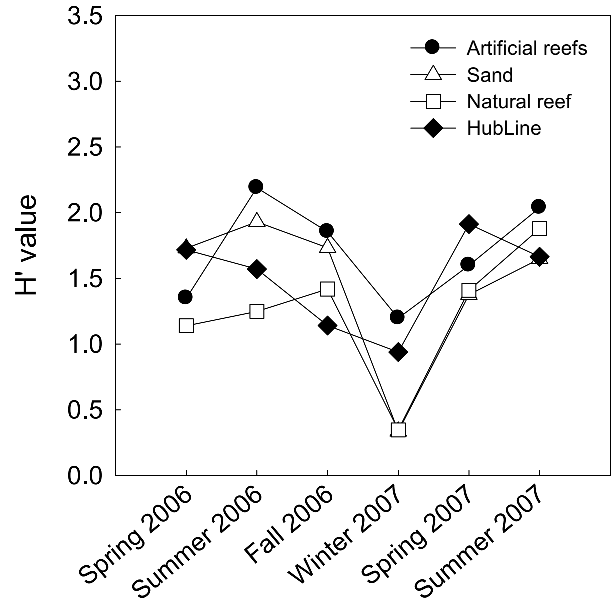


Figure 2.25. Temporal changes in diversity of enumerated species, as calculated using the Shannon index of diversity.

Table 2.6. 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

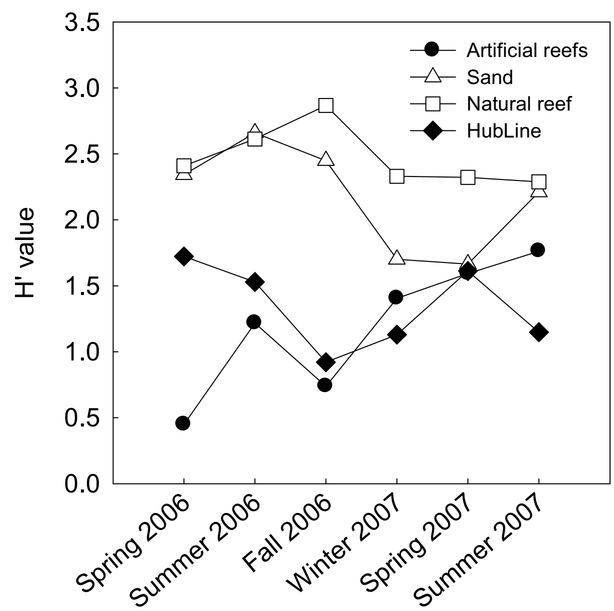


Figure 2.26. Temporal changes in diversity of species that were assessed by percent cover, as calculated using the Shannon index of diversity.

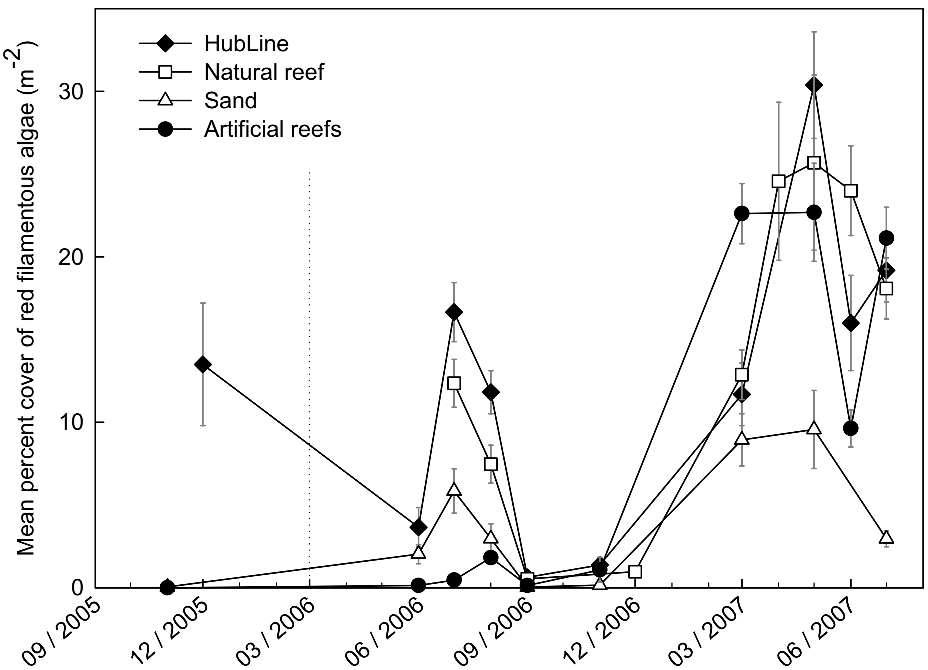


Figure 2.27. Temporal changes in percent cover of red filamentous algae (+SE) on the study sites. The dotted vertical line represents the date that the artificial reef was installed.

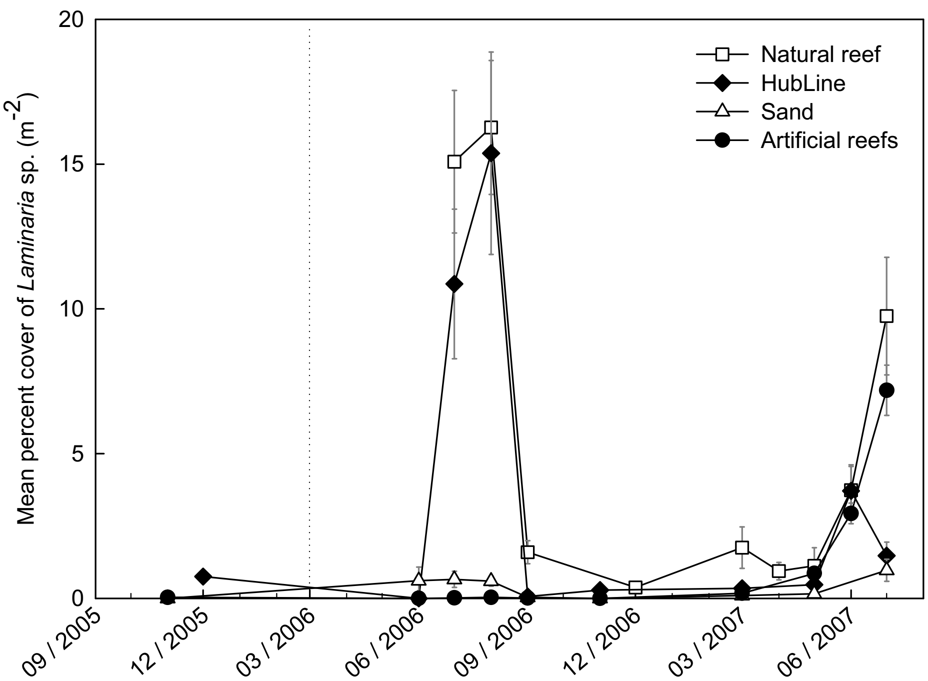


Figure 2.28. Temporal changes in percent cover of common kelp (*Laminaria* sp.) (+SE) on the study sites. The dotted vertical line represents the date that the artificial reef was installed.

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 2.29). 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 *Ciona intestinalis*, *Ascidiella* sp., and *Styela clava*) was low (<0.2 m^{-2}) on all sites from June 2006 to September 2006 (Figure 2.30). 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 2.31). 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 2.32a) and *Cancer borealis* (Figure 2.32b). 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 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 2.34). Lobster densities were the highest on the boulders (mean = 0.127 ± 0.001 SE per m^2, n = 302) and the boulder/cobble (BO/CO) transition areas (mean = 0.115 ± 0.011 SE 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 SE per m^2, n = 54) and the cobble (CO) (0.091 ± 0.001 SE 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 SE per 10 m^2, n = 156, p <0.003). Lobster densities were also higher on pebble (PE) (0.079 ± 0.001 SE 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 2.35). Mean cunner catches did not vary by season (Table 2.7, $F_{1, 288}$ = 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

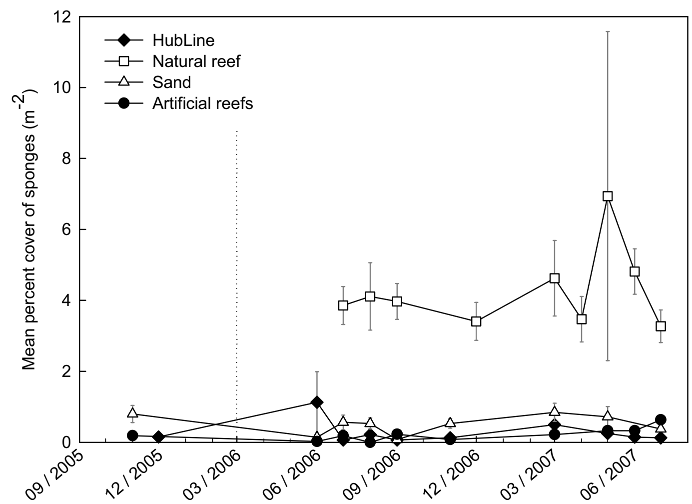


Figure 2.29. Temporal changes in sponge density (+SE) on the study sites. Species included: *Clathrina* sp., *Halichondria panicea, Haliclona oculata, Haliclona loosanoff, Isodictya* sp., *Suberites ficus*, and an unidentified sponge. The dotted vertical line denotes artificial reef installation.

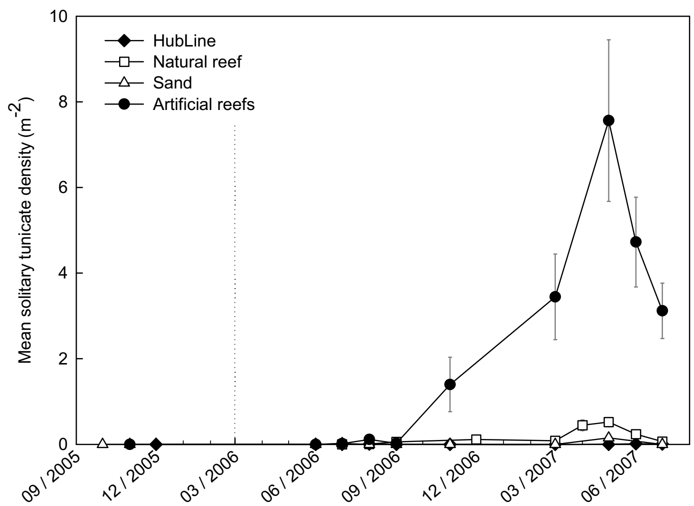


Figure 2.30. Temporal changes in solitary tunicate density (+SE) on the study sites. Species included: *Ciona intestinalis, Ascidiella* sp., and *Styela clava*. The dotted vertical line denotes artificial reef installation.

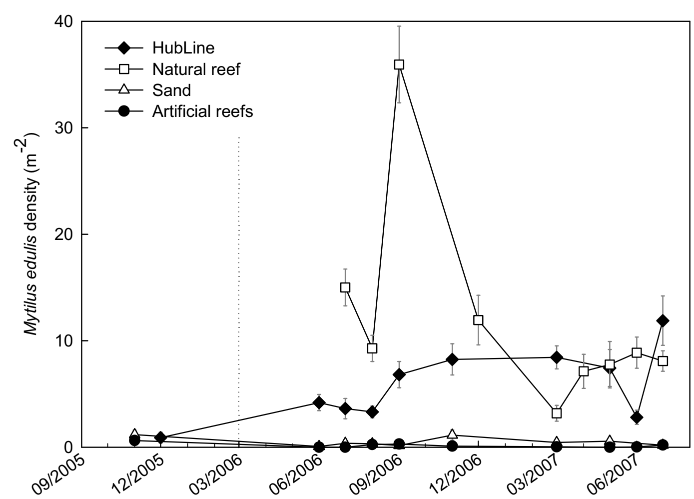
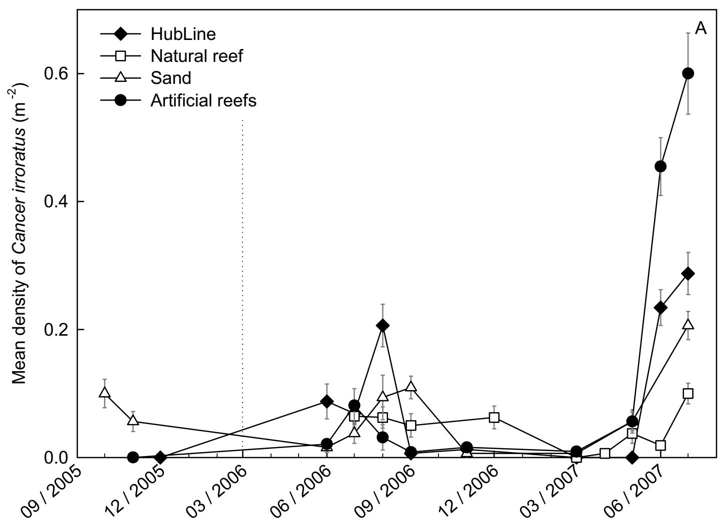


Figure 2.31. Temporal changes in blue mussel (*Mytilus edulis*) density (+SE) on the study sites. The dotted vertical line denotes artificial reef installation.



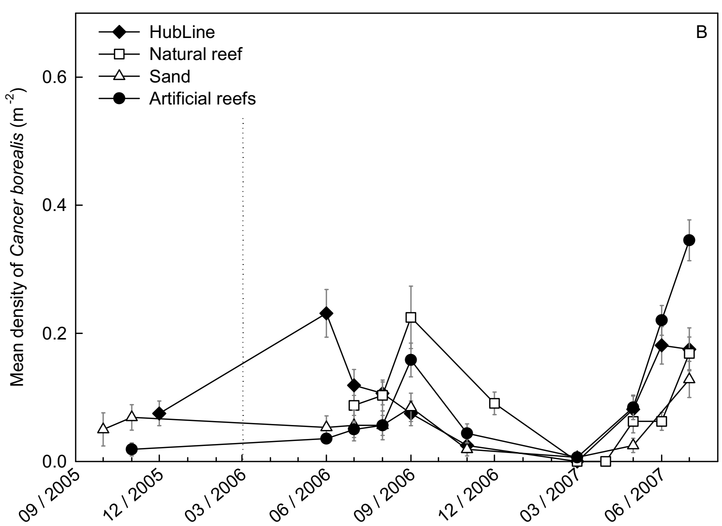


Figure 2.32. Temporal changes in (A) *Cancer irroratus* and (B) *C. borealis* densities (+SE) on the study sites. The dotted vertical line denotes artificial reef installation.

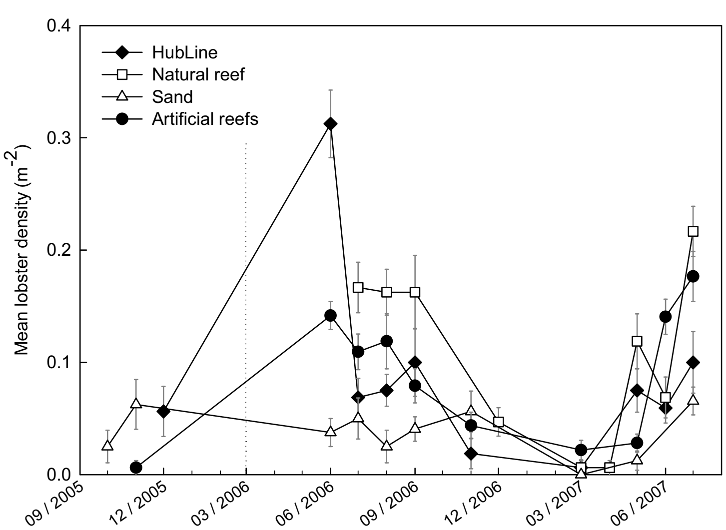


Figure 2.33. Temporal changes in American lobster (*Homarus americanus*) density (+SE) on the study sites. The dotted vertical line denotes artificial reef installation.

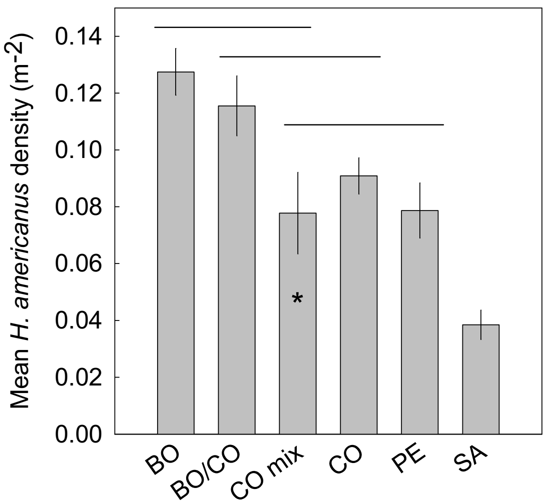


Figure 2.34. Lobster density (+SE) by primary (> 50% of area) surficial substrate type. BO = boulder (*n* = 302), BO/CO = area where size transitions from boulder to cobble (*n* = 116), CO mix = mix of small and large cobble (*n* = 54), CO = cobble (*n* = 340), PE = pebble (*n* = 136), and SA = sand (*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

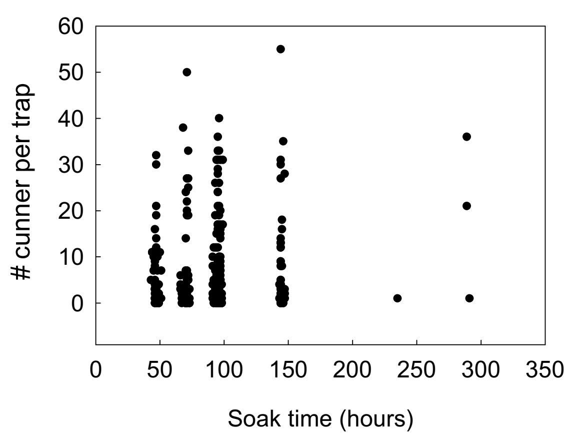


Figure 2.35. Catch of cunner (*Tautogolabrus adspersus*) per trap by trap soak time (spring and fall data combined).

natural reef and the sand (p <0.008, Table 2.7, Figure 2.36). Finally, the natural reef had significantly higher mean catch rates than the sand area (p <0.008, Table 2.7, Figure 2.36). 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 2.7, Figure 2.36). 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.

<u>Cunner length-frequency.</u> 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 2.8). 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 2.37 & 2.38). 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 2.37 & 2.38).

<u>Cunner growth.</u> Mean growth was 1.8 cm ± 0.15 SE over an average of 132.3 days ± 1.1 SE at large (*n* = 43).

<u>Cunner movement.</u> Cunner exhibited high site fidelity (Figure 2.39). 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 2.7. Catch of cunner (*Tautogolabrus adspersus*) per trap (+SE) 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

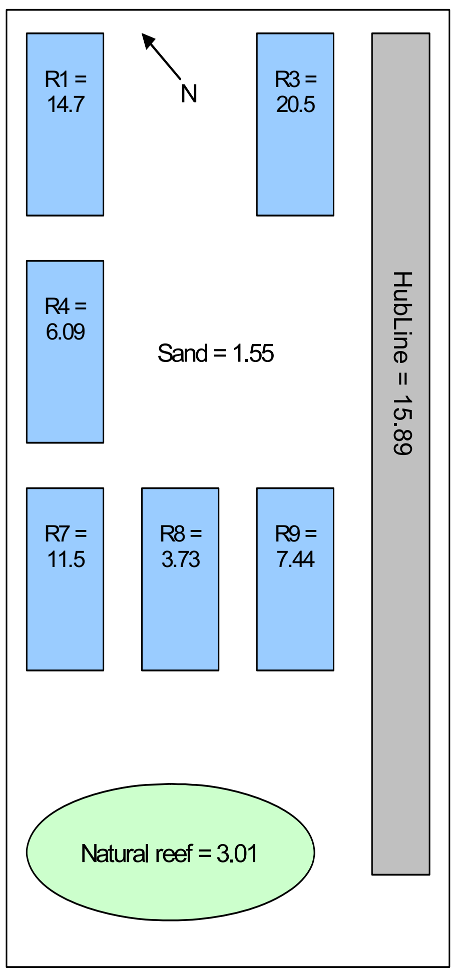


Figure 2.36. Mean cunner catch per trap represented spatially (SE and sample size in Table 6). R# = unit ID number. Note: Image not drawn to scale.

Table 2.8. 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

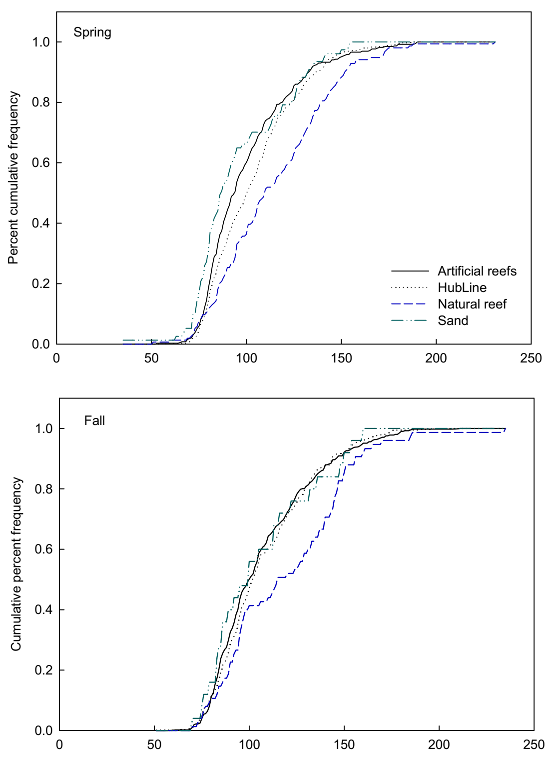


Figure 2.37. Cumulative percent frequency distribution of cunner total length by site and season (spring – top, fall – bottom).

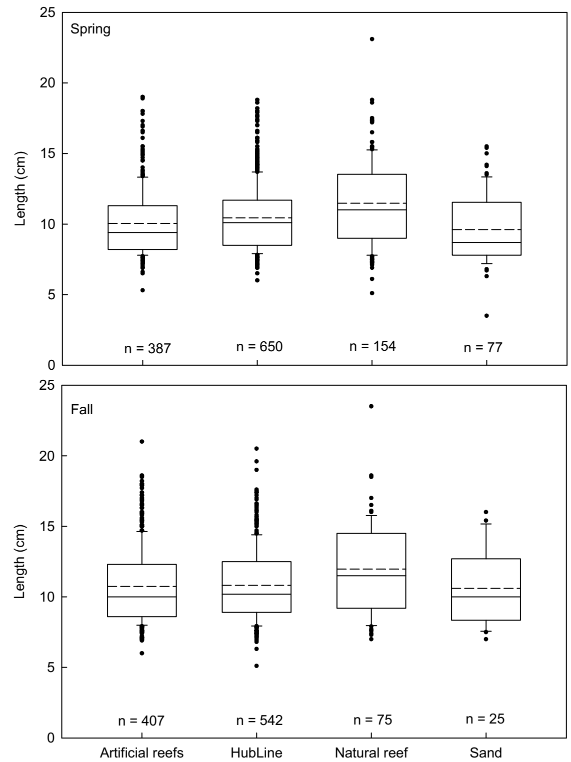


Figure 2.38. Length-frequency distributions of cunner by season and site. Dashed line represents the mean, solid line represents the median.

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 2.40).

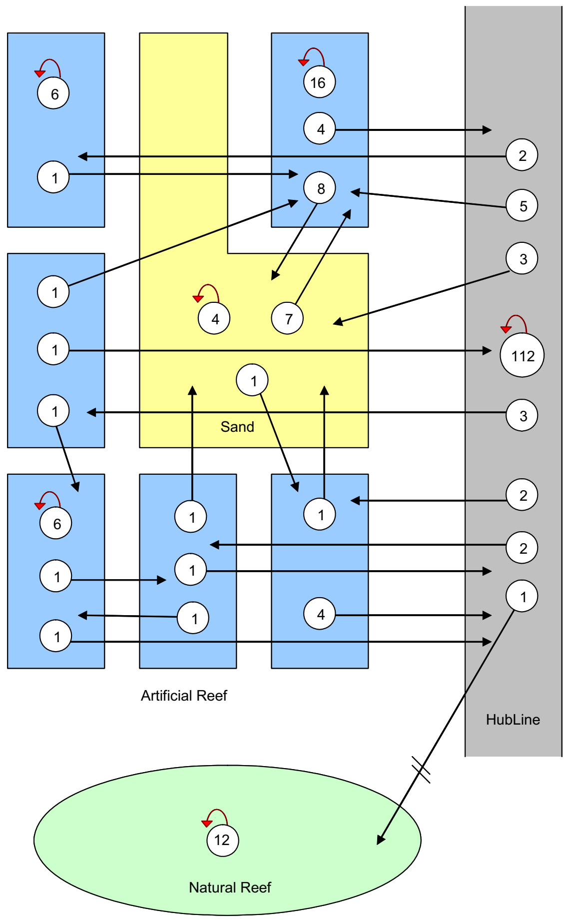


Figure 2.39. Cunner movements among sites. Curved arrows indicate recaptures at the same site; straight arrows show direction of movement of recaptured fish (includes multiple recaptures). Image not drawn to scale; circles do not represent trap locations.

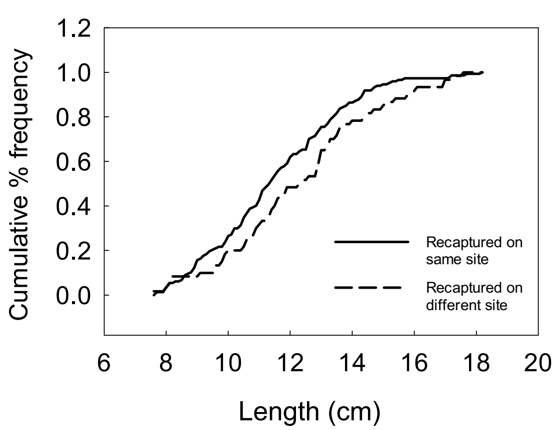


Figure 2.40. Cumulative length-frequencies of cunner that were recaptured on the same site that they were tagged versus cunner that were recaptured on a site other than their original tagging location.

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 2.9 & 2.10). The artificial reef, however, was similar in diversity to the natural reef (t-stat = -0.518, p >0.008, Tables 2.9 & 2.10). 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 (χ^2 = 36.80, p <0.01). Pairwise comparisons (Bonferroni adjusted α = 0.008) showed that lobster density was higher on the artificial reef (mean = 0.92 m^{-2} ± 0.19 SE, 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} ± 0.54 SE, n = 24, p <0.01) (Figure 2.41). Lobster densities on the artificial reef and HubLine (mean = 2.0 m^{-2} ± 0.47 SE, 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 2.9. 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 2.10. 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

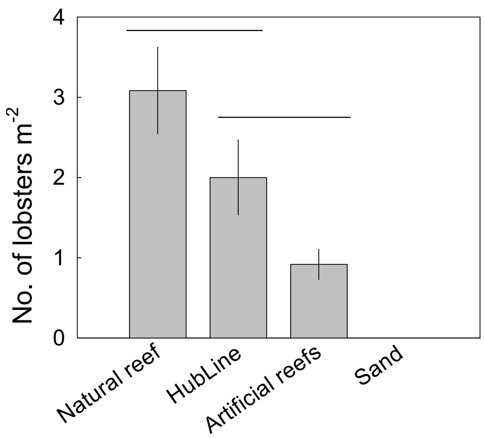


Figure 2.41. Mean lobster density (+SE) by site (*n* = 24 for natural reef, HubLine, and sand; *n* = 48 for artificial reef).

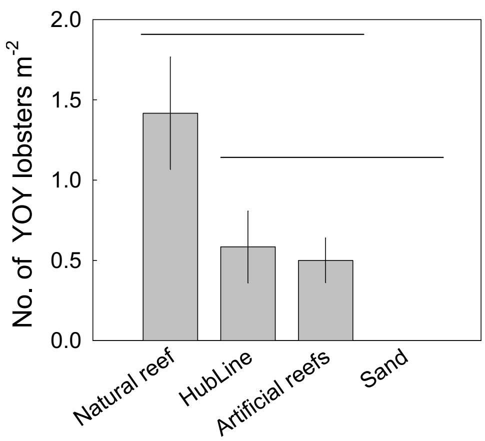


Figure 2.42. Mean density of young-of-the-year (YOY) lobsters (+SE) by site (*n* = 24 natural reef, HubLine, and sand; *n* = 48 artificial reef).

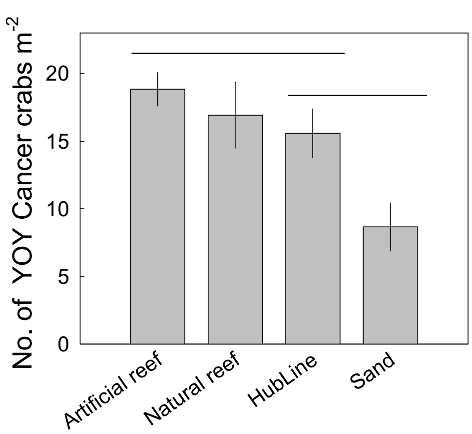


Figure 2.43. Mean density of young-of-the-year (YOY) Cancer crabs (+SE) by site (*n* = 24 natural reef, HubLine, and sand; *n* = 48 artificial reef).

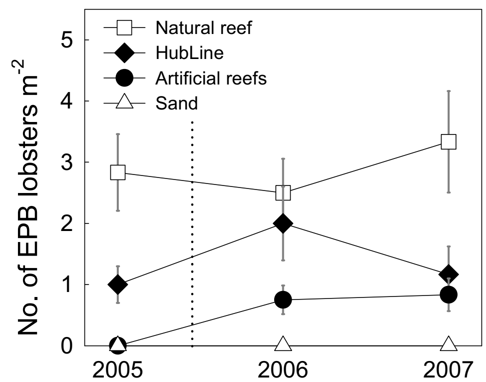


Figure 2.44. Mean density of early benthic phase (EBP) lobsters (+SE) by site (*n* = 24 natural reef, HubLine, and sand; *n* = 48 artificial reef) over time. Dotted line denotes artificial reef installation.

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 (χ^2 = 17.24, p <0.01). Pairwise comparisons (Bonferroni adjusted α = 0.008) revealed that the natural reef (mean = 1.42 ± 0.35 SE, *n* = 24) had a higher YOY lobster density than the sand (mean = 0.0, *n* = 24, p <0.008) (Figure 2.42). 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 SE, *n* = 48) as the natural reef (mean = 16.9 m^{-2} ± 2.42 SE, *n* = 24) and the HubLine (mean = 15.6 m^{-2} ± 1.81 SE, *n* = 24, all p >0.05). However, YOY Cancer crab density on the sand (mean = 8.7 m^{-2} ± 1.77 SE, *n* = 24) was significantly lower than densities on the artificial reef (p <0.001) and the natural reef (p = 0.015) (Figure 2.43). 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 SE, *n* = 36; 2006 mean = 1.5 m^{-2} ± 0.26 SE, *n* = 48; 2007 mean 1.54 m^{-2} ± 0.30 SE, *n* = 48; Kruskal-Wallis, χ^2 = 0.646, p >0.05) (Figure 2.44). 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 SE, *n* = 36) than the HubLine (mean = 1.39 ± 0.20 SE, *n* = 36) and the artificial reef (mean = 0.633 ± 0.15 SE, *n* = 60). The HubLine also had more EBP lobsters than the artificial reef (Figure 2.44).

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 SE, n = 12), however, did appear to have a slightly higher density of lobster than the small boulder (mean = 0.5 m^{-2} ± 0.26 SE, *n* = 12), the small cobble (mean = 0.5 m^{-2} ± 0.26 SE, *n* = 12), and the small rock mix (mean = 0.83 m^{-2} ± 0.38 SE, *n* = 12) (Figure 2.45).

Young-of-the-year lobster density by rock size. YOY lobster preferred one rock size over the other ($\chi^2 = 8.07$, $p < 0.05$). 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 SE, *n* = 12) compared to small cobble (mean = 0.5 m^{-2} ± 0.26 SE, *n* = 12), small boulder (mean = 0.17 m^{-2} ± 0.17 SE, *n* = 12), and the small rock mix (mean = 0.58 m^{-2} ± 0.17 SE, *n* = 12) (Figure 2.46).

Young-of-the-year lobster density by east or west. YOY lobster density was higher on the western side of the reef and HubLine (mean = 0.75 m^{-2} ± 0.18 SE, *n* = 37) than on the eastern side (mean = 0.29 m^{-2} ± 0.15 SE, *n* = 35) (Mann Whitney U = 498.5, *p* = 0.02) (Figure 2.47).

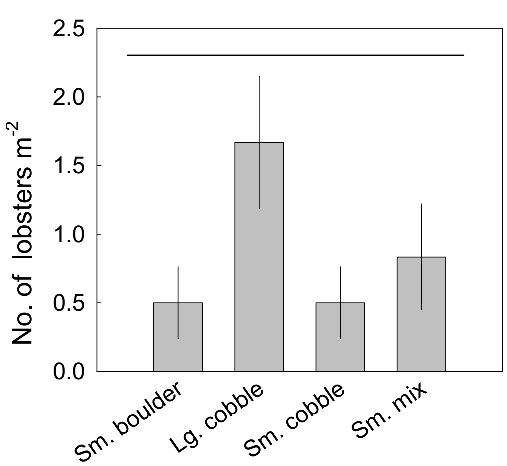


Figure 2.45. Mean lobster density (+SE) by rock size (*n* = 12 for each rock size). Sm. = small, Lg. = large.

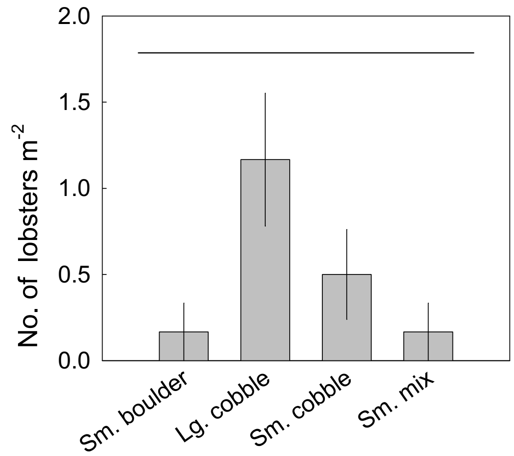


Figure 2.46. Mean density of young-of-the-year (YOY) lobsters (+SE) by rock size (*n* = 12 for each rock size). Sm. = small, Lg. = large.

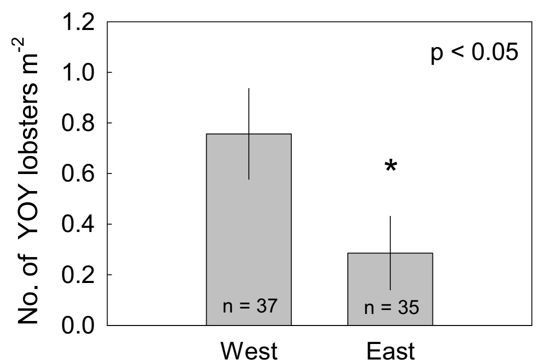


Figure 2.47. Mean density of young-of-the-year (YOY) lobsters (+SE) by side (west or east) of the artificial reefs/HubLine. Star indicates a significant difference between sides.

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 2.13 and 2.14). 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 2.15 and 2.16). 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 2.27). This pattern was also readily visible in the permanent station photographs taken on the HubLine (Figure 2.20). 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 2.22 and 2.23). 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 2.24). 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 2.31) because the man-made sites offered more shelter than the natural. 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 2.25). 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 2.26). 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 2.26). 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 colonize the reef (as seen in Figure 2.25), 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 2.26).

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 2.2). 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 2.29). 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 has 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 2.18 - 2.21). The dramatic increase in coverage of red algae most likely occurred because of an increase in water clarity (eg. Figure 2.17), allowing more light to penetrate and promote algal growth. Although kelp recruitment was limited on the artificial reef until June 2007 (Figure 2.28), 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 2.30). 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 more a random factor of the quadrats falling on large beds of mussel 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 2.32 & 2.33). 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 trend of increasing 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 2.34). 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 2.7). 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 2.7). 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 2.1). 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 2.39). 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 2.39). 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 2.8, Figures 2.37 & 2.38). 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 2.8). Fish caught on the sand had lower site fidelity than fish at the other sites, as more fish then moved to the artificial reef than stayed on the sand. The low recapture rate also 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.

Air-lift Sampling

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 2.41) and of early benthic phase (EBP) lobsters (Figure 2.44) 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 2.21and 2.44). 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 2.45 and 2.46). 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 2.47). 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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Literature Cited

Ambrose, R. F. and S. L. Swarbrick. 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of southern California. Bull. Mar. Sci. 44: 718-733.

Ambrose, R. F. 1994. Mitigating the effects of a coastal power plant on a kelp forest community: rationale and requirements for an artificial reef. Bull. of Mar. Sci. 55: 694-708.

Ardizzone, G. D., M. F. Gravina, and A. Belluscio. 1989. Temporal development of epibenthic communities on artificial reefs in the central Mediterranean Sea. Bull. of Mar. Sci. 44: 592-608.

ASMFC. 2006. American lobster stock assessment. Atlantic States Marine Fisheries Commission Report No. 06-03. 352 p.

Auster, P. J., R. J. Malatesta, R. W. Langton, L. Watling, P. C. Valentine, C. L. S. Donaldson, E. W. Langston, A. N. Shepard, and I. G. Babb. 1996. The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (Northwest Atlantic): implications for conservation of fish populations. Rev. Fisheries Sci. 4:185-202.

Badalamenti, F., R. Chemello, G. D'Anna, P. Henriquez Ramos, and S. Riggio. 2002. Are artificial reefs comparable to neighbouring natural rocky areas? A mollusc case study in the Gulf of Castellammare (NW Sicily). ICES J. Mar. Sci. 59: S127-131.

Bayne, B. L. 1965. Growth and the delay of metamorphosis of the larvae of *Mytilus edulis* L. Ophelia 2: 1-47.

Baynes, T. W. and A. M. Szmant. 1989. Effect of current on the sessile benthic community structure of an artificial reef. Bull. of Mar. Sci. 44: 545-566.

Bigelow, H. B. and W. C. Schroeder. 2002. The Fishes of the Gulf of Maine. Editors: B.B. Collette and G. Klein-MacPhee. 3rd edition. Smithsonian Institute Press, Washington.

Bohnsack, J. A. and D. L. Sutherland. 1985. Artificial reef research: a review with recommendations for future priorities. Bull. of Mar. Sci. 37: 11-39.

Burton, W. H., J. S. Farrar, F. Steimle, and B. Conlin. 2002. Assessment of out-of-kind mitigation success of an artificial reef deployed in Delaware Bay, USA. ICES J. Mar. Sci. 59: S106-110.

Carr, M. H. and M. A. Hixon. 1997. Artificial reefs: the importance of comparisons with natural reefs. Fisheries 22: 28-33.

Carter, J. W., A. L. Carpenter, M. S. Foster, and W. N. Jessee. 1985a. Benthic succession on an artificial reef designed to support a kelp-reef community. Bull. Mar. Sci. 37: 86-113.

Carter, J. W., W. N. Jessee, M. S. Foster, and A. L. Carpenter. 1985b. Management of artificial reefs designed to support natural communities. Bull. of Mar. Sci. 37: 114-128.

Castro, K. M., J. S. Cobb, R. A. Wahle, J. Catena. 2001. Habitat addition and stock enhancement for American lobsters, *Homarus americanus*. Mar. & Fresh. Res. 52:1253-1261.

Chang, K. H. 1985. Review of artificial reefs in Taiwan: emphasizing site selection and effectiveness. Bull. of Mar. Sci. 37: 143-150.

Cobb, J. S. 1971. The shelter-related behavior of the lobster *Homarus americanus*. Ecology 52: 108-115.

Cobb, J. S. and R. A. Wahle. 1994. Early life history and recruitment processes of clawed lobsters. Crustaceana 67: 1-25.

Connell, J. H. 1978. Diversity in tropical rain forests and coral reefs. Science 199 (4335): 1302-1310.

Cruz, R. and R. Adriano. 2001. Regional and seasonal prediction of the Caribbean lobster (*Panulirus* argus) commercial catch in Cuba. Mar. Freshwat. Res. 52: 1633-1640.

Davis, G. E. 1985. Artificial structures to mitigate marina construction impacts on spiny lobster, *Panulirus argus*. Bull. Mar. Sci. 37: 151-156.

DeMartini, E. E., D. A. Roberts, and T. W. Anderson. 1989. Contrasting patterns of fish density and abundance at an artificial rock reef and a cobble-bottom kelp forest. Bull. Mar. Sci. 44: 881-892.

Dixon, M. S. 1987. Habitat selection in juvenile tautog, *Tautoga onitis,* and juvenile cunner, *Tautogolabrus adspersus*. M.S. Thesis, University of Connecticut. 77 p.

Dorf, B. A. and J. C. Powell. 1997. Distribution, abundance, and habitat characteristics of juvenile tautog (*Tautoga onitis*, Family Labridae) in Narragansett Bay, Rhode Island, 1998-1992. Estuaries 20: 589-600.

Doty, M. S. 1971. Measurement of water movement in reference to benthic algal growth. Bot. Mar. 14: 32-35.

Duzbasilar, F. O., A. Lok, A. Ulas, and C. Metin. 2006. Recent developments on artificial reef applications in Turkey: hydraulic experiments. Bull. of Mar. Sci. 78: 195-202.

Figley, B. 2005. Artificial Reef Management Plan for New Jersey. New Jersey Department of Environmental Protection, Division of Fish and Wildlife. 130 pp.

Foster, K. L., F. W. Steimle, W. C. Muir, R. K. Kropp, and B. E. Conlin. 1994. Mitigation potential of habitat replacement: concrete artificial reef in Delaware Bay – preliminary results. Bull. Mar. Sci. 55: 783-795.

Freese, L., P. J. Auster, J. Heifetz, and B. L Wing. 1999. Effects of trawling on seafloor habitat and associated invertebrate taxa in the Gulf of Alaska. Mar. Ecol. Prog. Ser. 182:119-126.

Glenn, R., T. Pugh, J. Barber, and D. Chosid. 2007. 2005 Massachusetts lobster monitoring and stock status report. Massachusetts Division of Marins Fisheries Tech. Rpt. TR-29.

Gordon Jr., W. R. 1994. A role for comprehensive planning, geographical information system (GIS) technologies and program evaluation in aquatic habitat development. Bull. of Mar. Sci. 55: 995-1013.

Hueckel, G. J. and R. M. Buckley. 1982. Site selection procedures for marine habitat enhancement in Puget Sound, Washington. Wash. Dept. Fish. Tech. Rep. No. 67. 82 pp.

Hueckel, G. J., R. M. Buckley, and B. L. Benson. 1989. Mitigating rocky habitat loss using artificial reefs. Bull. of Mar. Sci. 44: 913-922.

Incze, L. S., R. A. Wahle, and J. S. Cobb. 1997. Quantitative relationships between postlarval production and benthic recruitment in lobsters, *Homarus americanus*. Mar. Fresh. Res. 48: 729-743.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration – stochastic model. Biometrika 52: 225-247.

Kaiser, M. J. 2006. The Louisiana artificial reef program. Mar. Pol. 30: 605-623.

Kennish, R., K. D. P. Wilson, J. Lo, S. C. Clarke, and S. Laister. 2002. Selecting sites for large-scale deployment of artificial reefs in Hong Kong: constraint mapping and prioritization techniques. ICES J. of Mar. Sci. 59: S164–S170.

Knebel, H. J. 1993. Sedimentary environments within a glaciated estuarine-inner shelf system: Boston Harbor and Massachusetts Bay. Mar. Geol. 110: 7-30.

Krebs, C. J. 1989. Ecological methodology. Harper Collins Publishers, NY, USA. 654 pp.

Krebs, C. J. 1999. Ecological Methodology. 2nd Edn. Addison-Welsey Educational Publishers, Inc., New York. 624 p.

Lawton, P. and K. L. Lavalli. 1995. Postlarval, juvenile, adolescent, and adult ecology. Pages 47-88 *in* J.R. Factor, ed. Biology of the lobster *Homarus americanus*. Academic Press, Inc., San Diego, California.

Lenihan, H. S. and F. Micheli. 2001. Soft-sediment communities. Pages 253-287 *in* M. D. Bertness, S. D. Gaines and M. E. Hay, eds. Marine community ecology. Sinauer Associates, Inc., Sunderland, Massachusetts.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, NJ. pp. 179.

Maida, M., J. C. Coll, and P. W. Sammarco. 1993. A simple current direction meter and its applicability to marine ecological studies. J. Exp. Mar. Biol. Ecol. 17: 115-119.

Mathews, H. 1985. Physical and geological aspects of artificial reef site selection. Pages 141-148 *in* F.M. D'Itri, ed. Artificial reefs: marine and freshwater applications. Lewis Publishers, Inc., Michigan.

Montgomery, S. S. and J. R. Craig. 2003. Effects of moon phase and soak time on catches of *Jasus* (Sagmariasus) *verreauxi* recruits on collectors. Mar. Freshwat. Res. 54: 847-851.

Nakamura, M. 1982. The planning and design of artificial reefs and tsukiiso. Pages 49-66 *in* S.F. Vik, ed. Japanese artificial reef technology. Aquabio, Inc., Bellair Bluffs, Florida. Tech. Rep. 604.

Packer, D. B., L. M. Cargnelli, S. J. Griesbach, and S. E. Shumway. 1999. Sea scallop, *Placopecten magellanicus*, life history and habitat characteristics. Essential Fish Habitat Source Document, NOAA Tech. Mem. NMFS-NE-134. 30 p.

Pappal, A., R. Rountree, and D. MacDonald. 2004. Habitat use by juvenile winter flounder, *Pseudopleuronectes americanus*, a laboratory study. Poster presentation. Ninth Flatfish Biology Conference. Dec. 1-2, 2004. Northeast Fisheries Science Center Reference Document 04-13.

Perkol-Finkel, S. and Y. Benayahu. 2004a. Community structure of stony and soft corals on vertical unplanned artificial reefs in Eilat (Red Sea): comparison to natural reefs. Coral Reefs 23: 195-205.

Perkol-Finkel, S. and Y. Benayahu. 2004b. Recruitment of benthic organisms onto a planned artificial reef: shifts in community structure one decade post-deployment. Mar. Env. Res. 59:79-99.

Perkol-Finkel, S., N. Shashar, O. Barneah, R. Ben-David-Zaslow, U. Oren, T. Reichart, T. Yacobovich, G. Yahel, R. Yahel, and Y. Benayahu. 2005. Fouling reefal communities on artificial reefs: Does age matter? Biofouling 21:127-140.

Perkol-Finkel, S., N. Shashar, and Y. Benayahu. 2006. Can artificial reefs mimic natural reef communities? The roles of structural features and age. Mar. Env. Res. 61: 121-135.

Perkol-Finkel, S. and Y. Benayahu. 2007. Differential recruitment of benthic communities on neighboring artificial and natural reefs. J. Exp. Mar. Biol. Ecol. 340: 25-39.

Pratt, J. R. 1994. Artificial habitats and ecosystem restoration: managing for the future. Bull. of Mar. Sci. 55: 268-275.

Pope, D. L., T. F. Moslow, and J. B. Wagner. 1993. Geological and technological assessment of artificial reef sites, Louisiana Outer Continental Shelf. Ocean Coast. Manag. 20: 121-145.

Reed, D. C., S. C. Schroeter, D. Huang, T. W. Andersen, and R. F. Ambrose. 2006. Quantitative assessment of different artificial reef designs in mitigating losses to kelp forest fishes. Bull. of Mar. Sci. 78: 133-150.

Rilov, G. and Y. Benayahu. 2000. Fish assemblage on natural versus vertical artificial reefs: the rehabilitation perspective. Mar. Biol. 136: 931-942.

Seber, G. A. F. 1965. A note on the multiple-recapture census. Biometrika 52:249-259.

Sheng, Y. P. 2000. Physical characteristics and engineering at reef sites. Pages 51-94 *in* W. Seaman, ed. Artificial Reef Evaluation with Application to Natural Marine Habitats, CRC Press, New York.

Signell, R. P. and B. Butman. 1992. Modeling tidal exchange and dispersion in Boston Harbor. J. of Geophysical Research 97:15591-15606.

Sokal, R. R. and F. J. Rohlf. 1995. Biometry. W.H. Freeman and Company, NY, USA. 887 pp.

Sousa, W. P. 1979. Experimental investigations of disturbance and ecological succession in a rocky intertidal algal community. Ecol. Mono. 49: 227-254.

Sprent, P. 1989. Applied nonparametric statistical methods. Chapman and Hall, New York. 259 p.

Spieler, R. E., D. S. Gilliam, and R. L. Sherman. 2001. Artificial substrate and coral reef restoration: what do we need to know to know what we need. Bull. of Mar. Sci. 69: 1013-1030.

Steimle, F. W. and W. Figley. 1996. The importance of artificial reef epifauna to black sea bass diets in the Middle Atlantic Bight. N. Amer. J. of Fish. Management 16:433-439.

Stephan, C. D., B. G. Dansby, H. R. Osburn, G. C. Matlock, R. K. Riechers, R. Rayburn. 1990. Texas Artificial Reef Fishery Management Plan. Texas Parks and Wildlife Department, Coastal Fisheries Branch. 28 pp.

Thanner, S. E., T. L. McInosh, and S. M. Blair. 2006. Development of benthic and fish assemblages on artificial reef materials compared to adjacent natural reef assemblages in Miami-Dade County, Florida. Bull. of Mar. Sci. 78: 57-70.

Tseng, C., S. Chen, C. Huang, and C. Liu. 2001. GIS-assisted site selection for artificial reefs. Fish. Sci. 67: 1015-1022.

Tupper, M. and R. G. Boutilier. 1995. Effects of habitat on settlement, growth, and postsettlement survival of Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci. 52: 1834-1841.

Tupper, M. and R. G. Boutilier. 1997. Effects of habitat on settlement, growth, predation risk and survival of a temperate reef fish. Mar. Ecol. Prog. Ser. 151: 225-236.

U.S. Department of Commerce. 2007. National Artificial Reef Plan (as Amended): Guidelines for siting, construction, development, and assessment of artificial reefs. NOAA, National Marine Fisheries Service, Washington D.C. 61 pp.

U.S. Geological Survey. 2006. High resolution geologic mapping of the inner continental shelf: Boston Harbor and approaches, Massachusetts. U.S. Geological Survey Open File Report 2006-1008. 5 p.

Wahle, R. 1992. Substratum constraints on body size and the behavioral scope of shelter use in American lobster. J. Exp. Mar. Biol. Ecol. 159: 59-75.

Wahle, R. A. and R. S. Steneck. 1991. Recruitment habitats and nursery grounds of the American lobster Homarus americanus: a demographic bottleneck? Mar. Ecol. Prog. Ser. 69: 231-243.

Wahle, R. A. and R. S. Steneck. 1992. Habitat restriction in early benthic life: experiments on habitat selection and in situ predation with the American lobster. J. Exp. Mar. Biol. Ecol. 157: 91-114.

Wahle, R. and L. S. Incze. 1997. Pre- and post-settlement processes in recruitment of the American lobster. J. Exp. Mar. Biol. Ecol. 217: 179-207.

Wentworth, C. K. 1922. A scale of grade and class terms for clastic sediments. J. Geol. 30: 377-392.

Whitman, J. D. and P. K. Dayton. 2001. Rocky subtidal communities. Pages 339-366 *in* M. D. Bertness, S. D. Gaines and M. E. Hay, eds. Marine community ecology. Sinauer Associates, Inc., Sunderland, Massachusetts.

Wilson, C. A., V. R. VanSickle, D. L. Pope. 1987. Louisiana Artificial Reef Plan. Louisiana Sea Grant College Program, Louisiana State University, Baton Rouge, Louisiana. Louisiana Department of Wildlife and Fisheries Technical Bulletin No. 41. 143 pp.

Yoshimuda, N. and H. Masuzawa. 1982. Discussion of installation planning. Pages 137-146 *in* S.F. Vik, ed. Japanese artificial reef technology. Aquabio, Inc., Bellair Bluffs, Florida. Tech. Rep. 604.

Zar, J. H. 1999. Biostatistical analysis. New Jersey, Prentice Hall. Pp. 196-200.

Appendix A. Artificial Reef Design

Reef Design Characteristics

Six rectangular 400-m^2 plots (10 m x 40 m) arranged in three parallel arrays and three rectangular 400-m^2 (10 m x 40 m) control plots without reefs were planned within the reef footprint (Figure A1). The actual reef substrate encompassed a total area of 2400 m^2, while 1200 m^2 remained undisturbed as designated control areas. Reef and control plots were separated by 10 m on all dimensions to minimize the total footprint necessary for reef installation and to facilitate ease of sampling. The entire footprint (including spacing, reef and control areas) was 7000 m^2 in size. The size of the cobble/boulder area (2400 m^2) is twice that of successful cobble reefs deployed in Boston Harbor (Sculpin Ledge) and in Narragansett Bay, Rhode Island. The reef arrays were situated perpendicular to the prevailing current to promote larval transportation and food delivery to other reef dwellers.

Four rock sizes were used to construct the reef: 6 - 11 cm cobble, 12 - 25 cm cobble, 30 - 45 cm boulders and 50 - 75 cm boulders (lengths refer to diameter of individual rocks). Rock sizes were assigned to target different phases of lobster and fish (Cobb 1971; Dixon 1987; Wahle 1992; Wahle and Steneck 1992; Dorf and Powell 1997; Tupper and Boutilier 1995 and 1997; Bigelow and Schroeder 2002; Pappal et. al. 2004). Rocks were separated by size, and arranged in a graduated fashion within each plot (Figure A1). Each rock size was represented equally within the total placement area.

Locations of individual reef unit and control area within the total reef footprint were determined by random number assignment. The design of the reef allows for hypothesis testing among reef units and between reef and control units. In addition, the separation of rock sizes within each reef unit permits hypothesis testing based on rock size. This experimental design will provide researchers with the ability to compare species densities and diversity among reef units and reference sites and among rock sizes.

Reef Construction

Upon completion of the site selection process, *MarineFisheries* solicited bids from independent contractors for reef construction. After meeting with RDA Construction to discuss methods and costs, we selected RDA Construction Corp. as our general contractor.

In the contract, RDA was responsible for obtaining clean reef materials from local quarries. The quarry rocks were blasted cobble and boulder. All rocks were cleaned of silt and sediment outside of coastal resource areas prior to transportation and installation. *MarineFisheries* expected at least 95% of the cobble and boulder material to be within one of six specified size categories. *MarineFisheries* independently inspected reef materials to ensure adherence to rock size specifications prior to deployment on the site. In addition to deploying the reef units accurately and according to the contracted dimensions, RDA Construction Corp. was also responsible for transporting all materials to the site and coordinating a post-construction side-scan sonar survey. According to the contract, *MarineFisheries* was responsible for obtaining all necessary permits and conducting independent surveys to verify correct reef placement.

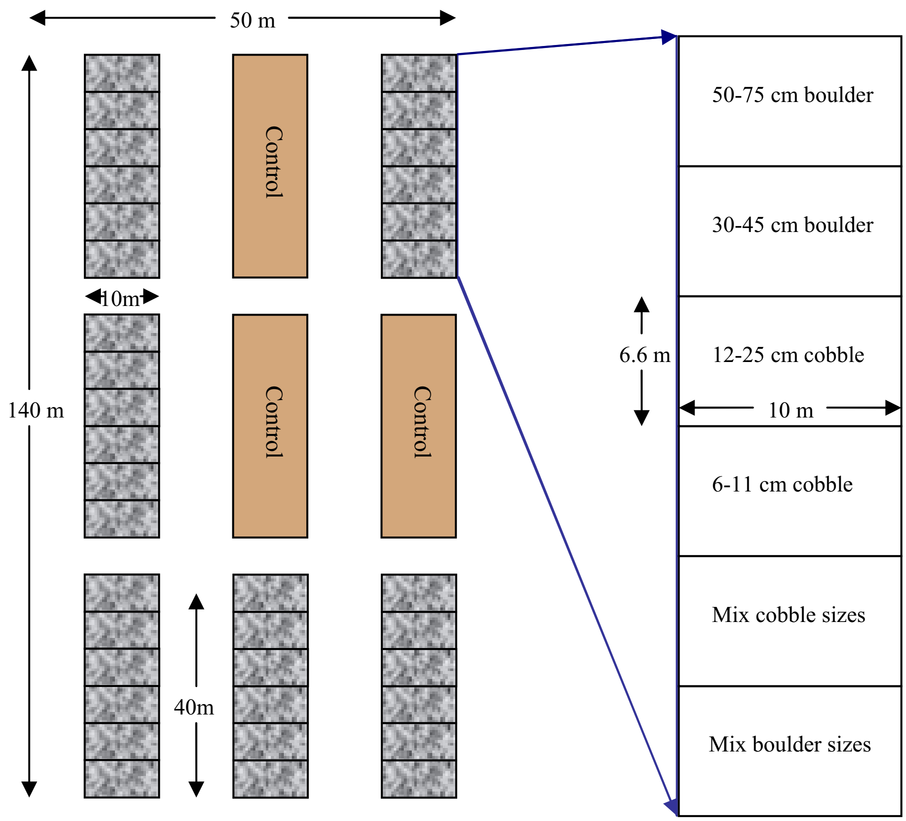


Figure A1. Artificial reef design.

MarineFisheries required that construction start by March 1, 2006 and be complete by April 15, 2006 in order to comply with time-of-year (TOY) construction limits that are normally assigned to marine construction projects in Massachusetts Bay. These TOY limits were not assigned to *MarineFisheries* in the permitting process; however, because we are a state environmental agency, we self-imposed these TOY work windows in order to avoid impacting aquatic resources and habitat. Winter construction also minimized user conflicts because lobstermen generally fish less intensively in the winter. Construction in March and April allowed for the reef to develop significant invertebrate and algal growth during the spring of 2006, which could encourage larval lobster and finfish settlement on the reef during its first year of deployment. Another advantage of winter construction was that it minimized impacts to spawning migrations of finfish and periods of shellfish and lobster spawning activity.

Construction required the precise placement of rocks by size within each reef footprint. The rocks were separated by size, and arranged in a graduated fashion within each plot so that each rock size contributed equally to the total placement area. RDA construction used a dump scow to build the reef according to the desired dimensions (40 m x 10 m for each reef unit). The dump scow had six pockets and due to loading safety requirements, each of the six pockets was filled with stone so that the rock weight would be evenly distributed throughout the barge. The following rock sizes (estimated diameter lengths) were assigned to each of the six sections: (1) 50 - 75 cm boulder, (2) 30 - 45 cm boulder, (3) 12 - 25 cm cobble, (4) 6 - 11 cm cobble, (5) mix of 6 - 11 cm and 12 - 25 cm cobble, and (6) mix of 30 - 45 cm and 50 - 75 cm boulder (Figure 17). Thus, each reef unit was composed of six smaller sections of individual rock sizes (Figure 17). The six 6.6 m x 10 m pockets of rock were dropped at the same time alongside one another to create each 40 m x 10 m reef unit. The total volume of rock used to construct the reef was 1153 m^3 (192 m^3 per reef unit).

Construction began in early March 2006. *MarineFisheries* employees monitored all construction activities to ensure compliance with permit requirements. We conducted site visits to RDA Construction's staging area to measure the rocks and check the cleanliness of rocks. RDA met the contracted rock dimension requirements for all rock sizes but the largest boulders. Diameters of the largest boulders exceeded the planned maximum size. To prevent additional delays to a project already behind schedule due to various problems that RDA encountered, the larger rocks were approved. *MarineFisheries* concluded that the larger boulders would not compromise the value or function of the reef. The larger rocks will create more relief and potentially attract more fish to the reef area than the rock sizes originally planned and were not a navigation hazard. All rocks met the required cleanliness prior to construction.

The first reef unit was constructed on March 23, 2006, and the five remaining reef units were built in the following weeks. The last reef unit was dropped on April 11, 2006. Construction was considered to be complete at this point. Throughout the construction period, *MarineFisheries* divers inspected each reef after it was dropped on site. All dimensions were within 25% of the original specifications and the reef units were positioned according to the contracted coordinates for each.

Appendix B. Site Selection and Monitoring Protocols

Introduction

The purpose of this appendix is to provide a detailed supplement to the methods described in Chapters 1 and 2. These protocols are intended to provide the reader with sufficient detail as to directly replicate our site selection and field monitoring methods.

SITE SELECTION PROTOCOLS

Identifying Potential Site Locations Using GIS

Initial GIS Analysis

Prior to beginning field work, a simple model was developed to select potential sites for habitat enhancement using ESRI's ArcGIS 9.0 mapping software. Three parameters were selected for use in our model: substrate, bathymetry, and proximity to the pipeline. These data layers were coded to represent prime, potential, and unsuitable areas for habitat enhancement and multiplied together to create a single layer map. The commands used to reach the final product of the map are included below:

Sequence of Commands Used to Reach the Final Analysis:

1. Buffered the HubLine by 22.7 m and 304 m to create a "nearby" buffer zone and a "maximum width" buffer zone.
2. Dissolved the HubLine to create one solid polygon for both buffered layers.
3. Created a new field in the substrate data layer called "ReefSubstrateSelection."
4. Used "symbol" in substrate to create new attributes: PoorSediment (combined the Erosion Nondeposition 4 with Deposition), PrimeSediment (Erosion Nondeposition 3), OKSediment (Sediment Reworking), Islands, Water/Other (Figure B1).
5. Dissolved on these new attributes.
6. Clipped bathymetry polygon with both new HubLine polygons.
7. Clipped sediment polygon with both new HubLine polygons.
8. Converted new clipped polygons to raster dataset with 10-m^2 cells – the bathymetry data was converted on "depthrange" and the substrate data was converted on "reef substrateselection."
9. Used the "reclassify" command in spatial analyst to reclassify the grid substrate types into the following numbers:

   PoorSediment = 0
   Islands = 0
   Water/Other = 0
   OK Sediment = 1
   PrimeSediment = 2
10. Used "reclassify" command in spatial analyst to reclassify the grid bathymetry types into the following numbers:

    5 through -10 m = 2
    10 through -15 m = 1
    all other depths = 0
11. Used raster calculator to multiply the two grids and their new classifications together to obtain a final output of areas for potential habitat enhancement sites.

    Final output:
    0 = unsuitable
    1= potential
    2 = suitable
    4 = prime

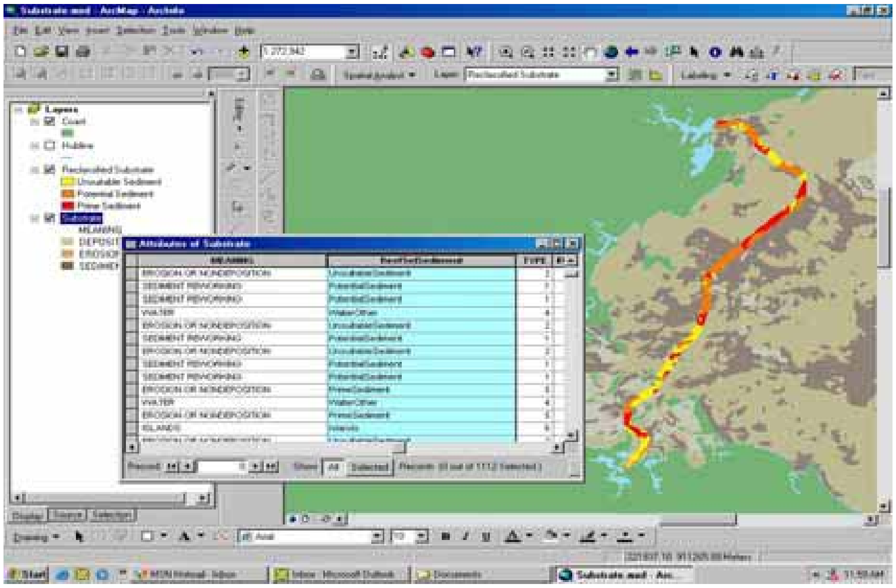


Figure B1. Image of the sediment reclassification process in ArcGIS 9.0.

The results of this model allowed us to identify four prime locations for potential reef sites (29.6 acres total prime area) off of Boston, Hull, Marblehead, and Beverly, Massachusetts. Within these areas we selected a total of 24 sites (and five alternate sites) that occurred within 304 m of the HubLine pathway. The 24 potential site polygons and five alternate site polygons were drawn in GIS, and waypoints corresponding to these polygons were gathered. Through the use of GIS, we were able to eliminate 80% of potential reef area prior to field assessments.

Field Assessments of Potential Site Locations

Depth and Slope Data

After completing the initial selection process using ArcGIS, *MarineFisheries* collected bathymetry data in the field at each of the 24 potential sites. These data were used to verify the GIS model and calculate slope. Four buoys, each with 21 m of line and a weight, were used to mark the corners of each 50 x 140-m reef footprint. The following steps describe the methods used to collect depth data:

1. Boat started at one corner of a footprint, marked with a buoy (Figure B2).
2. While keeping a constant rpm, boat operator headed towards the next corner marked with a buoy.
3. Using a stopwatch, depth (as read on the sounder) was recorded every 10 seconds until the next corner was reached.
4. This process was repeated for each corner and once down the center length of the footprint. The boat was always driven lengthwise in the same direction when data were being collected.

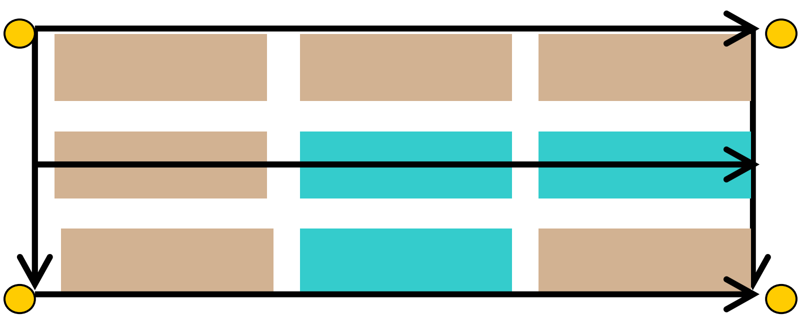


Figure B2. Example of the boat's movement over a potential site footprint while depth data were collected.

The depth data were analyzed using the following methods:

1. Depth was adjusted to account for tidal stage.
2. Slope (or the angle of inclination) was determined by calculating the difference between depths of measured points and the distance between those points (a right triangle), then taking the arctangent of the lengths to determine the angle.
3. Sites that were too deep or shallow (< 5 m or > 15.1 m) (according to our criteria) and sites that had slopes over 5º were eliminated from further consideration.

Substrate Data

Underwater surveys were conducted to determine the stability of the substrate at each site, as well as to classify and quantify the substrate at a finer scale. We qualitatively collected data on species abundance and diversity during these dives. These data allowed us to avoid placing the reef on pre-existing productive habitat and ensured that the reef would be placed on substrate that was expected to be strong enough to prevent the reef from descending into the sediment. GIS was used to determine our start and end waypoints for deploying 50-m transects for data collection on each site. We deployed two transects (A and B) from the boat at each potential reef site (Figure B3). Transects were placed across the potential reef footprint on a 45º angle to cover as much area as possible in two dives. Duration of the transect dives ranged from 15 - 40 minutes depending on the complexity of the habitat. A third diver videotaped the substrate along the transects. The following sections outline the steps necessary to collect these data on the potential sites.

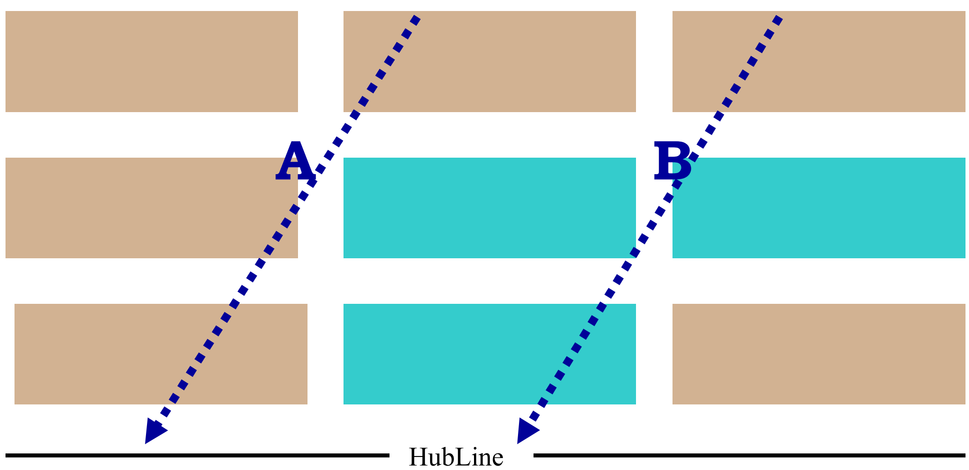


Figure B3. General transect direction and placement on a potential reef site.

Deploying the Transect

1. Required equipment: one 50-m sinking line marked every 5-m with flagging tape labeled with the meter mark, two 9-kg weights, and two surface buoys with enough line to reach from the surface to the bottom. The buoys and their surface lines were attached to the 9-kg weights. The weights were then attached to either end of the transect. Once the gear was attached, the surface lines and transect line were one continuous line, with weights at the start and end of the transect.
2. Using the GPS unit on the boat, we navigated to the starting waypoint for the transect.
3. Once on the waypoint, we dropped the 9-kg weight (with the surface buoy and transect tape attached) to mark the start of the dive/transect.
4. The transect line was fed out of the boat as we headed on the bearing that was necessary to set the transect on a 45º angle over the potential reef site (Figure B3). This bearing took us directly toward the end waypoint of the transect.

5. Once the transect line was taught, the other attached 9-kg weight (and surface buoy) was thrown in, marking the end of the transect. The waypoint where the weight was dropped was recorded in case there was discrepancy between the planned and actual ending waypoints.

50-m Transect Surveys

1. Divers descended on the origin buoy of the transect line to begin collecting data at the 0-m mark. If the current direction required it, divers would go down the buoy marking the end of the transect and work backwards. Before starting the data collection, divers usually set up current-assessment devices (see section below for this methodology). Once these instruments were arranged, divers began the transect dive. Equipment needed for the dive:
    a. Underwater slates
    b. "Substrate Swath Datasheet" (Appendix C)
    c. 2-m long PVC bar called the "swath bar"
2. Following the datasheet, divers would collect the starting depth and conduct the "hand burial test" at the 0-m mark
    a. *Depth*: Divers recorded depth from their dive computer. This depth was corrected for the tide MLW (date and time of dive was recorded on datasheet.
    b. *Hand Burial Test*: The diver made a fist and attempted to press their hand deep into the substrate. This method allowed us to obtaining a general idea of the strength of the substrate and whether or not the reef would sink into the sediment. Hand burial depth was coded as such:

        1 = Hand remains on surface
        2 = Half or whole hand buried
        3 = Hand and full wrist buried
3. From the 0-m mark, divers swam along the transect, with one diver on each side of the transect. Data were collected in 5-m swaths (essentially a 2 x 5-m quadrat). The first "swath" began at the 0-m mark and ended at the 5-m mark. Divers swam slowly along the transect holding the swath bar out in front of them to provide a 2-m width reference point and at the end of each 5-m section, record the substrate observed. Substrate data was coded by the following categories:
    a. *Primary substrate* = > 50% coverage. The primary substrate was the most common surficial substrate type, NOT the underlying substrate. Divers recorded the primary substrate as the rock type that covered more than 50% of the area. Underlying sand was recorded in the underlying substrate category (below).
    b. *Secondary substrate* = 10 - 50% coverage. This could be the same as the primary if the majority of the substrate was all the same type. For example, if a 2 x 5-m swath consisted of 95% sand and 5% shell litter - both the primary and secondary substrates were recorded as sand, while the shell litter was recorded as tertiary.
    c. *Tertiary substrate* = < 10% coverage. This category represented everything EXCEPT the primary and the secondary. For example, if one cobble was in a swath – it was recorded as a "tertiary" because it made up < 1% of the area.
    d. *Underlying substrate* = This was the type of substrate found underneath the surficial substrates. Rocks were lifted up or we shallowly dug underneath the sand or shell litter to identify the substrate below.

Substrate types were defined by the Wentworth Scale (Wentworth, 1922) as the following:

Sediment Key
BE = Bedrock
BO = Boulder (> 25.1 cm) head size or greater
CO = Cobble (6.1 – 25 cm) billiard ball to head size
PE = Pebble (0.5 – 6 cm) pea size to billiard ball
GR = Granule (0.2 – 0.4 cm) bee-bee size to pea size

SA = Coarse sand and find sand (bee-bee size to salt/sugar grain)
SD = Shell debris (broken-up shell fragments)
SH = Shack (whole or half shells)
CL = Clay
SI = Silt
Underlying = sediment underneath other substrate

4. In addition to collecting substrate, depth, and hand burial data, divers collected information on species sighted along the transect. Lobsters and other macrofauna were counted to qualitatively assess marine life on these transects. Divers also mentally noted all species (plant and animal) seen on the transect and recorded their presence/absence after completing the dive.
5. If wave ripples in the sand were present, they were noted on the datasheet as an indicator of wave action. Divers attempted to assess the height of the sand ripples.
6. Video data was collected whenever possible by a third diver over the entire length of the transect.
7. Upon completion of the dive, divers would complete a "Site Selection Presence/Absence Datasheet" (Appendix C). For algae, percent coverage across the entire transect was estimated. If algae were drift, divers recorded the percent coverage but made a note that the algae was drifting. For animals, divers estimated the count of all individuals of a particular species observed. Any species that were not listed on the datasheet but seen were written in on the datasheet.

Site Scoring and Weighting

In order to rank the remaining potential sites, *MarineFisheries* developed a weighting system to incorporate multiple aspects of the site selection criteria. Data used in this portion of the analysis included: primary and secondary surficial substrate, underlying substrate, sand ripple presence (an indicator of wave action), site proximity to the HubLine, and site proximity to cobble fill points along the HubLine. Although tertiary substrate data was collected, it was not used in these analyses due to their low percent coverage on the potential sites.

A six step approach was followed for this analysis:

1. For each potential site, a numerical score was assigned to every data category based upon how well the site met the selection criteria. The numerical scores ranged from 1 (poor site potential) to 3 (prime site potential). 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.
2. An objective weighting system was developed where a percentage value was assigned to each data category based upon the relative importance of each criterion to the project objectives.
3. The numerical scores were "weighted" by multiplying the final score for each data category by the category's assigned percentage.
4. Final weighted scores from were summed for each site.
5. Sites were ranked, where sites with the highest scores had the majority of the required physical attributes for site selection.
6. Species presence/absence data were taken into account following the ranking analysis. These data could not be included in the ranking analysis because they were qualitative.

<u>Site Scoring</u>

For each site, a numerical score was assigned to every data category based upon how well the site met the selection criteria. Numerical values were used to represent prime (3), potential (2), or poor (1) suitability for reef placement. The following methods were used to assign these scores to the data:

Sediment data

Each site was classified by the primary, secondary, and underlying sediment types recorded in the area. Sediment types included boulder, cobble, pebble, granule, sand, shack (whole shells), shell debris, and silt. Sites with pebble, granule, sand, shack, or shell debris were preferred because these substrate types are more capable of supporting the weight of a reef and naturally tend to have lower species diversity than cobble or boulder.

Primary sediment data - Primary sediment types were assigned the following numerical categories based on their ability to support the weight of a reef and expected species abundance and diversity:

Category rating levels:

1 = Poor: boulder, cobble and silt
2 = Potential: mixed flat cobble
3 = Prime: pebble, granule, sand, shack, and shell debris

Secondary sediment data - Secondary sediment types were assigned the following numerical categories based on their suitability for reef placement:

Category rating levels:

1 = Poor: boulder and silt
2 = Potential: cobble
3 = Prime: pebble, granule, sand, shack, shell debris, and hard clay

Underlying sediment data - Underlying sediments included hard clay, soft clay, granule, sand, and silt. Underlying sediment types were assigned the following numerical categories based on their suitability for reef placement:

Category rating levels:

1 = Poor: soft clay and silt
3 = Prime: hard clay, granule, and sand

Each sediment proportion was multiplied by the assigned category rating of 1, 2, or 3. These values were then summed to provide a final underlying sediment rating for that site.

Sand ripple / wave action

The presence of sand ripples on a site was presumed to indicate areas of high wave energy which may be detrimental to reef placement. Therefore, sites were classified as either (3) low energy = no sand ripples, (2) moderate energy = small sand ripples (2.5 – 13 cm height) or (1) high energy = large sand ripples (> 13.1 cm height).

Proximity to HubLine

Sites that were closer to the HubLine were preferred. Therefore, sites were classified as either (3) adjacent to the HubLine pathway (< 30 m), (2) near the HubLine (30 – 152 m), or (1) far from the HubLine (152.1 – 304 m).

Proximity to fill points

Sites that were closer to fill points were preferred. These cobble fill points along the HubLine provided an area to compare the settlement and succession of species on cobble deployed two to three years prior to the artificial reef. Sites were classified as either (3) adjacent to a fill point (< 30 m), (2) near a fill point (30 – 152 m), or (1) far from a fill point (> 152 m).

<u>Assigning the Scale</u>

Each variable described above was weighted on a percentage scale according to its relative importance to the project objectives (Table B1). The primary substrate variable was assigned the largest weight at 50% because this substrate would need to support the majority of the reef's weight and would have the most impact on existing species. If the potential site had a high percentage of poor reef substrate this weighting category would automatically rank the site much lower than a site with mostly prime reef substrate. The other two substrate categories were assigned weights of 15% to represent their importance in supporting the weight of the reef, as well as avoiding productive habitat. A weight of 10% was assigned to the presence of sand ripples as an indicator of wave action in the area. Although this variable was not as crucial as substrate type, it was important to take wave action into account in terms of its ability to dislodge or bury the reef. It should be noted that wave action was previously taken into account by ensuring that the potential reef sites were located at depths > 5 m. Finally, proximity to the HubLine and fill points received 5% weighting to account for our goal to place the reef near these areas if all other site selection criteria were met.

Table B1: Weighting categories

Variables	Weight
Primary substrate	50%
Secondary substrate	15%
Underlying substrate	15%
Wave action	10%
HubLine proximity	5%
Fill point proximity	5%

Weighting and Summing the Scores

Numerical scores from each potential site's data categories were "weighted" by multiplying the score by the category's assigned percentage. Final weighted scores were then summed for each site.

Ranking the Sites

Scores of all 14 sites were ranked (Table 1.4 in Chap. 1). Sites with the highest scores best exhibited the physical attributes targeted for reef development Prior to making another round of site eliminations based on the ranking analysis, species presence and absence were taken into account.

Species Presence/Absence

Upon completion of the weighted ranking analysis, biological factors at the potential reef areas were considered. Species presence/absence data collected on each transect dive were reviewed. The number of species present on each site were standardized by the number of transects completed per site. This information was used to determine which sites to eliminate based on concerns of impacts to sites with relatively high species abundance or diversity.

Water Flow and Current Direction

Two underwater methods were used to evaluate current with respect to strength and direction. We constructed a current-direction meter to identify the predominant current direction at each of the potential sites. The predominant current direction was then compared to the site's orientation. If a site's rectangular footprint was not already perpendicular to the predominant current, it was shifted to be perpendicular. A flowmeter (General Oceanics) was also used to collect data on the water flow at the site.

Assessing Current Direction

We designed a simplistic low-cost instrument to evaluate current direction. The instrument assessed current direction in the north/south, east/west, northeast/southwest, and northwest/southeast directions.

1. Specifications of the Predominant Current Direction Indicator (PCDI)
    a. A thick cement base (43 x 43 x 12 cm) was set with a central vertical rebar stake attached to an internal rebar frame and a vertical eye bolt in each corner (Figure 1.4 in Chap. 1).
    b. Four 7.6-cm wide PVC pipes were cut to 30 cm long. Two small holes were drilled halfway down the length of the pipe on the top and bottom of each pipe (these were eventually used to suspend the plaster blocks inside the tube). The pipes were fastened, with the holes easily accessible, to the rebar stake with plastic-coated wire mesh, similar to what is used to make lobster traps. Each pipe faced a different direction: north/south, east/west, northeast/southwest, and northwest/southeast.
    c. In order to deploy and retrieve the PCDI, a rope bridle was attached to the eye bolts, which was long enough to avoid the PVC pipes.

d. Plaster of Paris was poured into ice-cube trays with a wire penetrating the centers through the tray (a small hole was made in the bottom of each "cube mold") (Figure B4). The plaster was allowed to dry for four days. These blocks are commonly used by biologists to obtain a relative estimate of water motion by measuring the starting and ending weight of the blocks once they have been exposed to water (Doty, 1971).
e. Dry blocks were weighed and filed to a weight between 30-33 grams. Final weights were recorded to the nearest tenth of a gram.

Figure B4. Making the plaster blocks for the predominant current direction meter.

2. Deploying the Predominant Current Direction Indicator
    a. Prior to deployment, blocks were suspended in each pipe on the PCDI (through the holes that were drilled in the PVC) using the wire in each cube, secured so that the blocks did not touch the sides of the tubes. Starting weights of each block and compass directions of each tube were recorded on the "Current Datasheet" (Appendix C).
    b. The PCDI was deployed along with two cinder blocks. One cinder block was used to suspend the flowmeter (explained below) and the other block weighted a surface buoy. The surface buoy marked the location of the equipment for easy retrieval.
    c. To deploy the PCDI, two 4.5-m lines (to be used as search lines) were attached to the eye bolts on opposite corners. Separate from the PCDI, the two cinder blocks were tied together for deployment with a short line and a surface line was attached to one cinder block. One of these cinder blocks had a small subsurface buoy on a 1-m long line attached to it. The PCDI was lowered on a separate surface line. A waypoint was recorded when the equipment reached the bottom.
    d. Divers positioned the PCDI on the bottom so that the uppermost PVC tube faced north/south and the compass-direction of each tube was recorded (on the "Current Datasheet"). The flowmeter was suspended between the cinder block and a subsurface buoy (floating about 1 m off the bottom). The bottom "search lines" were used to help locate the equipment during retrieval dives. Equipment needed to be placed far enough away from one another to avoid entanglement of lines during strong currents or storms.
    e. Two to three days later, divers collected the equipment. Waiting longer to retrieve the PCDI could have resulted in the complete dissolving of the block and loss of data.
3. Analysis of Current Direction
    a. Blocks were weighed pre- and post-deployment to determine relative dissolving rates. Blocks were weighed only after they had been given sufficient time to dry out in the same place where there were originally weighed (for similar humidity, etc). It usually took about four days to completely dry the blocks before weighing them. The block with the greatest dissolving rate indicated which tube was facing the predominant water current.

Upon completion of this analysis only one of our potential site footprints (Site 6 in Marblehead) had to be rotated in order for the reef to be oriented perpendicular to the predominant current. This orientation was preferred to optimize larval settlement. This site footprint was altered and further analyses on Site 6 were conducted using the new orientation.

Measuring Flow

Due to a defective flowmeter, data collected were not used but the methods are described below:

a. The flowmeter was attached to a cinder block with brass swivel-clips such that it could rotate in both the clockwise and counter-clockwise directions to face the current.
b. A subsurface buoy was attached to the dorsal surface of the meter and was used to suspend the flowmeter in the water column.
c. Start number was recorded after set-up; end number was recorded upon retrieval.

Larval Settlement Collectors

Larval Settlement Collector Specifications

1. A lobster trap building company was contracted to build 30 ½-m^2 collectors. Collectors were made from 3.8-cm coated wire and had open tops. They had the following dimensions: 0.7 m length x 0.7 m width x 0.3 m height (Figure B5).
2. Sides of the collectors were reinforced with a wooden frames secured with rubber strips (screwed into the wood with stainless steel screws) (Figure B5).
3. The bottom of the collectors were lined with Astroturf as an impermeable "substrate" that also provided some relief.
4. Collectors and Astroturf were left outside in a parking lot exposed to weather for one month in June, prior to deployment to reduce chemical residues and scents that lobsterman believe can decrease lobster catches.
5. Just prior to deployment, approximately 68 kg of cobble (5 – 25-cm diameter pieces) was placed into each collector. Rocks had been previously sorted (haphazardly) into 68-kg piles in fish totes, such that one fish tote carried the amount of rocks needed for one collector. This allowed us to easily move the rocks onto the vessel for collector deployment and placed most of the weight strain on fish totes, rather than the collectors.

Figure B5. Settlement collector ready to be filled with cobble and deployed

Collector deployment – A lobsterman was contracted to assist us in deployment and retrieval of the collectors because the weight of each collector (about 68 kg) required a heavy, stable platform and davit. The lobster boat provided deck space needed to conduct diving operations in addition to collector deployment and retrieval. Collectors were deployed in July to capture lobster settlement which was likely to occur in August. We expected that the extra few weeks soak time would allow the rocks to become slightly fouled and the collector habitat to be more desirable to larvae. In the future, we suggest placing a unique ID on each collector prior to deployment and recorded that ID along with the collector's deployment waypoint. The IDs would have made it easier upon retrieval, to determine which collectors had been recovered and which required search dives.

When the collectors were deployed, search lines were laid out between each collector such that during the retrieval work divers could follow search lines from one collector to another. Laying line on the seafloor in this area was problematic because of the concentrated lobster fishery in Massachusetts Bay. We did not want our lines to be directly attached to the collectors, in case a fisherman grappled in the area for a lost trawl. If he/she caught the search lines attached to the collectors, there was potential for the collectors to be flipped or moved. Therefore, the system we developed allowed us to set unattached search lines on the bottom. If a search line was lost under this system, the collector presumably would not be moved and divers could conduct a search dive on the collector's waypoint. Surface buoys were not used because of the likelihood that they would be moved or lost.

1. Equipment needed for settlement collector deployment at each site:
    a. 10 settlement collectors
    b. 10 surface lines about 18 m in length with an attached white buoy – each buoy had a unique number written clearly on it (1-10)
    c. 10 subsurface buoys
    d. 10 screw anchors or sand augers
    e. 3 coils of 160 m sinking line
    f. 14 plastic garden stakes
    g. 3 mesh gear bags
    h. 1 "Pendant Hobo" temp/light logger (Onset Corp.)
2. Surface preparation:
    a. Collectors were set in three long rows along the length of the 50 x 140 m reef footprint. The two outside rows had three collectors, while the inside row had four collectors (Figure B6). One row was set at a time on the waypoints that were selected (using GIS).
    b. Rocks were loaded into the collectors from the fish totes and the 10 loaded collectors were laid out on the deck of the vessel.
    c. Surface lines with their numbered buoys were tied onto the collector's bridles in a manner that set the collectors in order of their deployment (collectors #1, 2, 3 for the first line; 4, 5, 6, 7 for the middle line and; 8, 9, 10 for the last line).
    d. The "Pendant Hobo" temp/light logger was attached to one collector per site and the unique number of the collector carrying the logger was noted.
    e. One subsurface buoy was tied to the side of each collector with a bowline knot.
    f. A gear bag was attached to collector #1 containing three sand anchors, four garden stakes, and a rubber mallet for pounding stakes into the substrate. One gear bag was placed on each collector that started off the three-collector lines. For example, using Figure B6, collectors #1, 4, and 8 had gear bags attached to them before being deployed. For the line consisting of four collectors (starting with collector #4) the gear bag was packed with four sand anchors and six garden stakes.
    g. Collectors were carefully lowered one at a time on the designated waypoint.
    h. A waypoint was recorded for each collector when it reached the bottom in case the boat had drifted off the original waypoint. Exact coordinates were essential for reducing dive time if a search dive was needed to find a collector.

3. Setting-up collectors and search lines underwater (Figure B6)
    a. Divers found the gear bag containing the screw anchors, rubber mallet, and the garden stakes and screwed in a sand anchor next to the collector. The subsurface buoy was detached from the collector and retied to the sand anchor. The subsurface buoys were a search tool because they were easier to spot on dives than the low-lying collectors that blended in with the substrate.
    b. The surface line was detached from the bridles and bridles were placed underneath the collector to keep the line from interfering with the open surface of the collector.
    c. A series of search lines were deployed to aid in the east of settlement collector retrieval. Sinking search lines were attached to the seafloor between each collector (Figure B6). A garden stake was placed close to the first collector and the search line was attached. At the next collector another stake was placed and the line leading from the first collector was attached. The diver then went to the other side of the collector and drove another stake in, and repeated the process (Figure B6).

Settlement collector retrieval – Retrieval took place in mid-to late-September, after the majority of lobster settlement had occurred in Massachusetts Bay.

1. Equipment needed for retrieval:
    b. 10 lines with attached surface buoys.
    c. Mesh coverings large enough to wrap around the collectors completely without interfering with the bridle lines (Figure B7). Mesh coverings were used to prevent escapement of plants and animals in the collector during recovery.
    d. Eight bungee cords (two per collector). Each cord long to wrap around half the collector.
    e. Gear bags to retrieve line and sand anchors off the bottom.

Retrieving the collectors worked the best with two dive teams. One dive team started on one side of the reef footprint (aiming to find collectors #1, 2, and 3) and the other team started on the other side of the footprint (aiming to find collectors #8, 9, and 10). If all the search lines were intact underwater, it was possible to find all the collectors in one dive with two dive teams.

2. Lines with surface marker buoys were deployed at two collector waypoints.
3. Divers teams deployed, carrying multiple lines with surface marker buoys.
4. A line (with buoy) was attached to each collector.
5. Mesh coverings were secured around the collectors using bungee cords.
6. Search lines, garden stakes, sand anchors, subsurface buoys, and any collector-marking items were removed and brought to the surface.
7. Meshed collectors were then hauled.

Sample Processing - Astroturf and rocks in the collector were carefully inspected, and all flora and fauna found were counted and recorded on a suction sampling datasheet (Appendix C). Encrusting species and algae were recorded in the presence/absence section, while individuals of a species were enumerated. To remain consistent with the suction sampling data collection, we did not collect data on species of polychaetes except for scale worms. Species that were not readily identifiable in the field, usually small whelks or bivalves, were preserved in alcohol in small glass vials labeled with unique ID's on the lid. These ID's were recorded on the datasheets to track which site and collector the sample was found. These species were keyed out in the office following their collection.

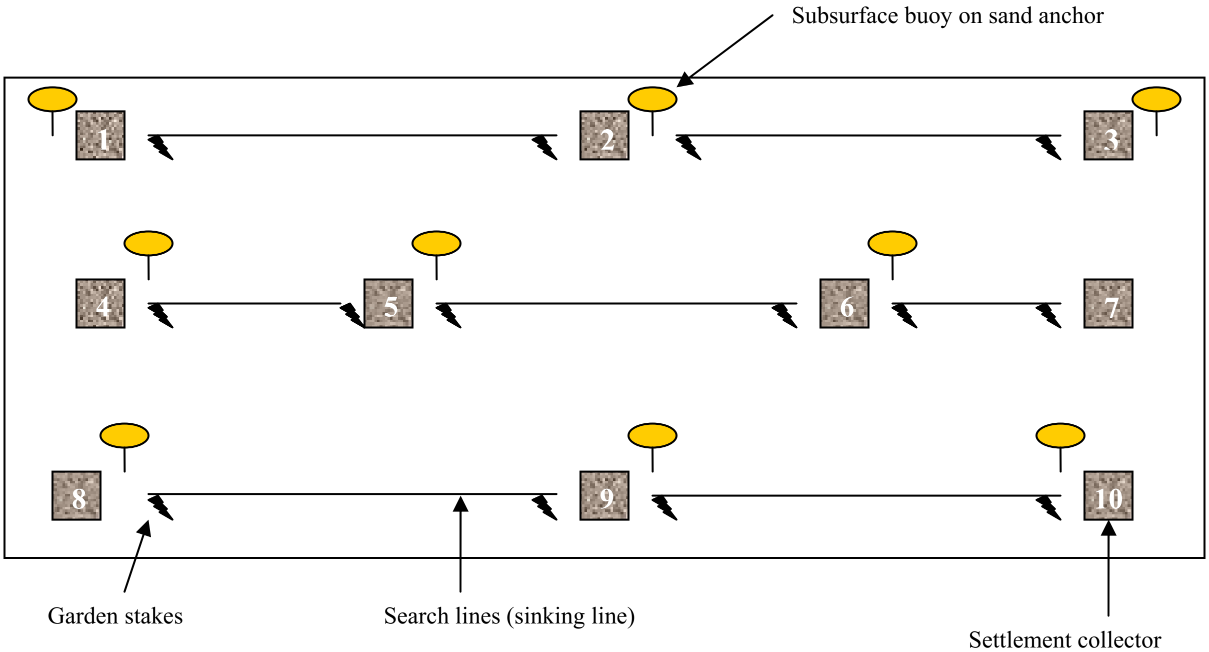


Figure B6. Arrangement of settlement collectors and search lines on a reef site footprint once divers completed equipment set-up.

Figure B7. Settlement collector retrieval.

Pre-Construction Site Survey

Prior to the start of construction, *MarineFisheries* collaborated with the United States Geological Survey (USGS) to collect georeferenced multibeam data on Site 29 and the surrounding area. The results of the survey confirmed our substrate dive survey results and showed that Site 29 was a non-descript flat area with little to no hard bottom habitat. The survey also confirmed the location of the HubLine and the cobble fill point near Site 29. Additionally, the survey verified that the reef would be near naturally occurring hard bottom areas (Figures 2.2 in Chap. 2). We assumed that naturally occurring hard bottom areas could provide the artificial reef with new juvenile settlers and potentially attract adults. *MarineFisheries* also planned to use these surrounding natural reefs for comparisons with our artificial reef during future monitoring.

REEF MONITORING PROTOCOLS

MarineFisheries initiated a monitoring program as soon as the artificial reef construction was complete. To evaluate the success of the reef project, we designed a structured monitoring program to characterize and track larval settlement, as well as the development of invertebrate and finfish populations on the reef. This program included seasonal visual dive surveys along permanent transects, semi-annual small fish trapping, annual larval suction sampling, and some monitoring of reef structure with multibeam technology. Each reef and sandy control unit will be referred to using its unique identification number assigned post-construction (Figure 2.1 in Chap. 2).

Temperature Monitors

Two permanent bottom temperature monitors were installed in the spring of 2006: one at the origin of Natural Reef transect #1 and one just east of the transect origin on artificial reef #8. A concrete base was constructed with an internal mesh wire frame and a central eye bolt for lowering the block to the seafloor. Two large bolt heads (with the threads exposed) were also installed into the concrete to allow for the permanent attachment of a large PVC tube (about 7.6 cm diameter, 45 cm long) to the base (Figure B8). The PVC tube had two holes, spaced about 15 cm apart and centered, drilled completely through both sides of the tube for running long bolts (with nuts attached to hold them in place) through. The temperature monitor (Pendant Hobo, Onset Corp.) was placed in a waterproof plastic housing and put inside the tube between the two bolts. The bolts secured the temperature logger in place. Divers switched the loggers out annually.

Figure B8. Permanent temperature monitoring station ready for deployment.
Note: buoys and dive weight were only used for deployment.

Permanent Transect Sampling

Installing Permanent Transects

1. Equipment needed to install one 40-m transect:
    a. GPS unit
    b. 40-m transect tape (Keson double-sided, Forestry Suppliers) with a 5-m leader line (sinking line) and brass clips on the leader line and the transect reel, or a 40-m transect tape without a leader line. The leader line gave the divers some distance before starting the transect, where they could disturb the bottom without disturbing the transect when setting up survey equipment. This was important on the natural reef sites where sponges and other fragile species could be inadvertently damaged. The leader line was not necessary for the artificial reefs however, because divers could easily avoid disturbing the reef by staying off the reef on the surrounding sandy edge.
    c. Five sand augers or cinder blocks for the natural reefs and sandy controls, and two sand augers for the HubLine fill points and artificial reefs. Note: sand augers are difficult to find – we purchased them from:
    http://www.shadeusa.com/beach_umbrella_holders.htm#EARTH%20ANCHORS.
    d. A short rebar stake (used for installing the sand augers into the substrate).
    e. Two subsurface buoys (we used half of a lobster buoy for each subsurface buoy) with 1.5 m of line tied to each buoy, the line ended in a loop large enough to fit the subsurface buoy through
    f. Flagging tape with the site name/number written on it - tied to the subsurface buoys
    g. 15 m of sinking line (for a search line) marked in the center (7.5-m mark) of the line with a cable tie used to mark the natural reefs and sandy controls
    h. Two to three mesh gear bags
    i. Pelican buoy (small yellow buoy and line that can be easily carried by divers and deployed to the surface to mark the end point of the 40-m transect)
    j. Waypoint for start of transect
    k. Pre-determined bearing
2. Field preparation on the surface to set-up a permanent transect:
    a. A 15-kg weight (drop weight) and a surface line with a buoy on it was set up to mark the start of the transect (marker buoy).
    b. Gear bags containing the following items were attached to the drop weight:
        i. Equipment for ORIGIN of the transect: four sand augers, short rebar stake, 15-m search line, subsurface buoy, and 40-m transect tape with or without leader line depending on the site
        ii. Equipment for FAR END of transect: sand auger, subsurface buoy, pelican buoy
        iii. If divers were collecting data on these dives, we attached the swath bars and the quadrats to the weight using loops in the line and brass clips.
    c. The weight and surface line with attached gear bags and were dropped on the waypoint.
3. Establishing the permanent transects underwater (Figure B9):
    a. A team of divers followed the marker buoy down to the origin.
    b. Divers used the "origin" gear bag containing all the equipment necessary to set-up the origin of the transect. If we were installing sites on the natural or sandy areas, the auger was installed directly next to where the drop weight fell. For the HubLine fill point, all sand augers were installed on the west side of the pipeline in a sandy area at the bottom of the cobble fill. Divers swam to the top of the mound parallel to the auger to begin transects. For the artificial reefs, the augers were centered at the northern edge of the reef. The sand augers are expected to remain in position for at least the next few years of monitoring. If the substrate type did not allow (i.e. too rocky) for installation of augers, cinder blocks were used to mark the start and end of the transects.

c. The subsurface buoy was attached to the auger or the cinder block by running the buoy through the loop at the end of the buoy's line.
d. A search line was then installed at the start of each natural reef and sandy control transect (no search line was necessary for the artificial reefs or the HubLine because they were not difficult to locate underwater):
    i. An auger was installed into the substrate near the subsurface buoy.
    ii. The 15-m search line was run through this auger until we found the cable tie marking the middle of the line. A knot was tied in the line with the cable tie.
    iii. Each diver took an auger and one end of the search line and swam out on a bearing perpendicular to the bearing of the transect. Divers placed the augers in the substrate and tied a knot to attach the line to the auger (Figure B9).
e. Divers opened the far end gear bag and set out the transect tape along the designated bearing. (For the HubLine, sandy controls, and the artificial reefs a southwest bearing around 240º was usually used). The short rebar stake and the gear bag were carried.
f. Divers verified that depth did not vary drastically on a site (usually remained at the designated depth +/- 2 m).
g. Once at the 40-m mark, divers swam one more meter out to install the last sand auger.
h. The far end subsurface buoy was attached to the auger.
i. Divers clipped the transect line onto the auger and pulled slack out of the line.
j. The pelican buoy line was tied to the transect tape reel (not the auger) and the buoy was released to the surface. This allowed us to obtain a waypoint for the end of the transect from the boat (recorded on the Surface Datasheet, Appendix C).
k. Depending on air supply, divers began surveying the site using swath bars.

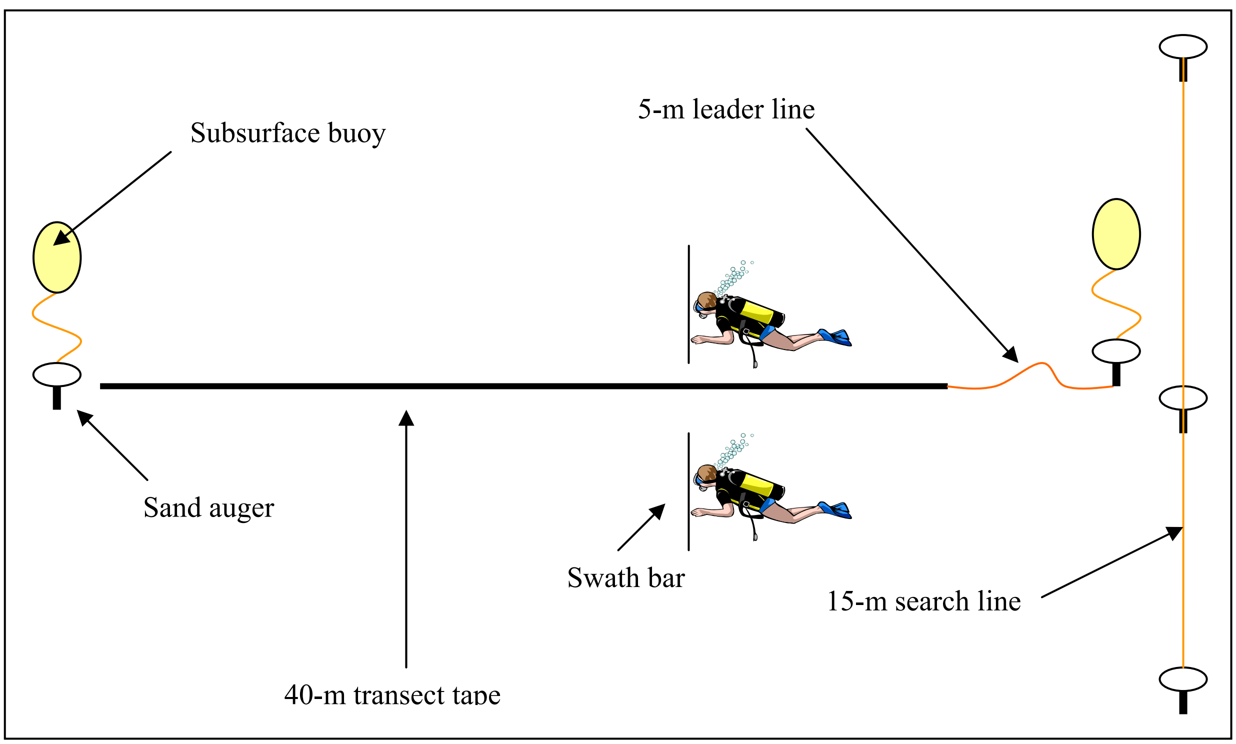


Figure B9. Permanent transect set-up and divers surveying the transect using swath bars.

4. Resampling of the permanent transects (not installing gear):
    a. Divers threw a drop weight and marker buoy on the waypoint marking the origin of the transect. Attached to the weight were the following: one gear bag holding the transect tape and a pelican buoy, quadrats, and swaths.
    b. Divers swam down the line and looked for the search lines if they were on a natural reef or a sandy control. The search lines lead divers to the origin subsurface buoy. If divers were resampling the HubLine or the artificial reefs, divers searched for the rock structures and swam to the subsurface buoy location. The drop weight was moved to the origin sand auger so we had an easy line to follow to the surface at the end of the dive.
    c. Fouling organisms were cleaned off of search lines and subsurface buoys.
    d. The transect tape was clipped onto the marker buoy line, which was positioned at the start of the transect. Divers swam out the 40-m transect tape on the recorded bearing.
    e. After reaching the 40-m mark, divers conducted a sweeping search to find the far end subsurface buoy and the far end of the transect tape was secured.
    f. If we needed to surface from the far end of the transect, we tied the pelican buoy onto the transect tape reel and deployed to the surface. This provided divers with a line to follow back to the surface from the 40-m mark.

Swath Data Collection (Swath Monitoring Datasheet, Appendix C)

Macroinvertebrates and fishes were quantified in 2 x 5 m sections along the transect using 2-m long PVC "swath" bars once transect lines were laid out:

1. One diver ran out the transect tape while the other diver swam alongside holding two swath bars. Once the transect tape was in place, divers collected data from the 40-m mark to the 0-m mark.
2. One diver collected data on the right side, the other collected data on the left side of the transect Figure 2.6 in Chap. 2).
3. Holding a swath bar, each diver swam slowly along the transect, counting macroinvertebrates and vertebrates listed on the datasheet in 5-m increments (see swath datasheet Appendix C).
4. When sighted, pelagic fish were recorded. If the fish were schooling, their count was estimated. The majority of fishes sighted were benthic such as sculpin (*Myoxocephalus* sp.) or cunner (*Tautogolabrus adspersus*). Cunner were so numerous over the artificial reefs and the HubLine (in 2006) that we estimated the count within each 5-m swath.
5. On occasion some macroinvertebrates, such as solitary tunicates, were so numerous on the artificial reefs that it was not feasible to count them (i.e. *Ascidiella aspersa, Ciona* sp.). When necessary the number of individuals within the swath section were estimated.
6. Divers did *not* lift or turn over rocks but did look into interstitial spaces when possible.
7. Divers gently moved algae to check for benthic invertebrates or fishes underneath the algae.
8. At the end of the swath survey divers filled in any blanks on the datasheet with "0" to demonstrate that we looked for that species and found none.
9. Collecting these data took about 20 minutes on the sandy controls, and 35 – 50 minutes on the artificial reefs, natural reefs, and HubLine fill point.
10. On the surface, divers tallied their "tick marks" and circled the final count for a particular species in the swath section. Circling the final count allowed for easier data entry.

Quadrat Data Collection (Quadrat Monitoring Datasheet, Appendix C)

Divers used 1-m^2 quadrats with a ¼-m^2 inset quadrat to sample small invertebrates typically found in high densities (e.g. *Mytilus edilus*), substrate type, algal coverage, and encrusting or sessile invertebrate coverage (e.g. colonial tunicates or sponges). To obtain unbiased data yet avoid sampling the entire transect, we used systematic random sampling along the 40-m transect length. Each diver collected data in two quadrats every 10 meters, for a total of eight quadrats per diver and 16 quadrats per transect.

1. Prior to the dive, the meter mark of the quadrats that were to be sampled were filled in on the datasheet. Quadrat numbers were assigned using a random number table with numbers from zero to nine, and filled in the "sampling start mark" on the datasheet, labeled by columns Q1-Q5 (i.e. "Quadrat 1") (Figure B10). The space outside the parentheses was filled in with the quadrat number the diver was to collect data from, while the number inside the parentheses was their buddy's location [e.g. ___(___)]. The first two random numbers from the table, for example 8 and 3, were re-ordered so that divers could swim in a constant direction [e.g. _3_(___) and _8_(___)]. The next two random numbers, for example 6 and 0, were filled in the blanks inside the parentheses [e.g. _3_(_0_) and _8_(_6_)]. On the dive buddy's datasheet, the numbers were reversed: _0_(_3_) and _6_(_8_). As we continued to assign quadrats, 10, 20, or 30 was added to the random number to move along the transect in 10-m increments (e.g. for 3 and 5 – the quadrats would be 13 and 15, and the next numbers 0 and 6 would be 20 and 26) (Figure B10).

Bearing ______Hour______ Left / Right Visit #__________Vis_____

Only count 1m quads if the abundance is very low

Quadrat (1/4 / 1meter^2)	Q1	Q2	Q3	Q4	Q5
Sampling Start Mark	3__(0)	__8_(6)	13 (16)	15 (19)	20 (24)
Modiolus modiolus	/	/	/	/	/
# clam siphons	/	/	/	/	/

Figure B10. Completed random number section on the quadrat datasheet.

2. Datasheets were photocopied as double-sided and flipped underwater collect data on all quadrats.
3. The datasheets also provided space for two extra quadrats, which was useful if one diver was faster at collecting data than the other. In this case, the faster diver would complete their buddy's last quadrat for them without having to obtain the slower diver's datasheet.
4. Divers usually started at the 0-m mark and worked to the 40-m mark, after having completed the swath data collection. Depending on time, this was done on the same or on a second dive.
5. One diver collected data on the right side, while the other diver collected data on the left side, as with the swaths. The side the diver was on was recorded as if the diver was swimming from the 0-m mark to the 40-m mark.
6. Correct quadrat use:
    a. 1-m^2 PVC quadrats were built with a ¼ m^2 corner inside the larger quadrat (Figure B11).
    b. When collecting data, divers placed the ¼ m^2 corner of the quadrat at the assigned quadrat number on their side of the transect (Figure B11).
    c. If a large boulder prevented the quadrat from lying flat on the substrate, divers did not move the quadrat. Data collection took place on an angle but in a method consistent with all other quadrats.

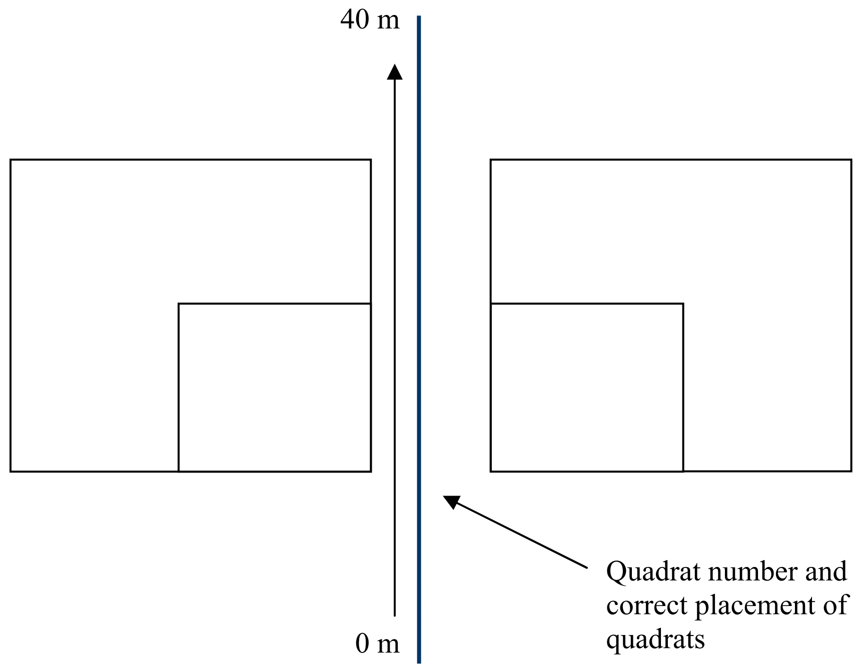


Figure B11. Transect line showing the correct placement of the quadrats next to the assigned quadrat numbers

Small Fish Trap-Sampling and Tagging Study

Trap Design and Preparation

1. Commercially-purchased 30.5 cm length x 30.5 cm width x 58.4 cm height eel pots with 1.3 x 1.3 cm vinyl-clad wire mesh were used (Figure 2.8 in Chap.2). The door folded around the trap body on three edges so that small fish could not escape and was secured with a bungee-cord. The entry passage was a long funnel design.
2. Each trap was weighted with a brick secured inside the trap and rigged with 20 m of line and a surface buoy. Surface buoys were standard lobster-pot buoys that were halved and marked with a unique ID (1 through 30).
3. Traps were fitted with lobster trap identification plates listing ownership. These tags were also marked with a unique ID for each trap that matched its buoy ID. We also added flagging tape with the trap ID to each pot. The numbers were used to track trap deployment and hauls.
4. Herring was used to bait the traps. Whole frozen fish were quartered and separated into portions each weighting around 100-150 grams. Portions were placed into containers and re-frozen.
5. Prior to deploying each trap, one portion of fish was placed in a plastic mesh bait bag and suspended inside the trap by closing the door against the open end of the bag.

Trap Placement

1. GIS was used to select seven waypoints on each of the four areas: artificial reef, sandy control, natural reef, and HubLine (Figure 2.9 in Chap. 2).
    a. One trap was placed in the center of each artificial reef (areas #1, 3, 4, 7, 8, and 9) with the exception of reef #7, which had two traps set 19 m apart along the reef's center-line.
    b. Two traps were placed in each of the sandy control sites (areas #2, 5, and 6), with the exception of area #5, which had three traps. Each trap was at least 12 m apart, but most were 30 m apart.

c. Seven traps were set in the natural reef area found during the site selection process at a depth similar to that of the artificial reefs. Traps were deployed immediately after structure/relief was detected on a bottom sounder to ensure the presence of hard substrate.
    i. In the fall, the location of the natural reef traps was changed because the site we used in the spring had limited hard substrate at depths similar to the artificial reefs. The spring site was also not the site that we eventually used for our permanent transect sampling. Additionally, the natural reef we used for our monitoring surveys had large amounts of cobble and boulder, whereas, we had not surveyed the area we set the traps in the spring. Therefore, in the fall we sampled the area we monitored. The natural reef used in the fall had a larger area at a similar depth to the reefs. Traps were spaced between 18 m and 84 m apart.

d. Seven traps were deployed on the HubLine pathway on top of the cobble fill about 30 m apart from one another. We deployed each trap only if we saw the mound appear on the bottom sounder, which ensured proper placement.

2. Traps were deployed when the GPS indicated that we were within 3 m of the waypoint.
3. As the baited trap was released, its deployment location was marked on the GPS if it varied from the original waypoint. The label of the GPS point, ID of the trap, and time deployed were recorded (on the "Fish Pot Setting Datasheet," Appendix C).
4. Traps were soaked for two to six days.

Processing the Catch and Tagging Cunner

1. Traps were hauled by hand or with the assistance of a davit.
2. Captured fishes and crustaceans from one trap were emptied immediately into a cooler with habitat water and processed. The following data were recorded on waterproof paper (on the "Fish Pot Length Frequency Datasheet," Appendix C):
    a. Lobsters (*Homarus americanus*) – Carapace length was measured to the nearest 0.1 mm using vernier calipers. The lobster was then sexed and released. When tags were available, lobster were tagged with cinch tags (containing unique ID numbers) placed around the knuckle (Figure 2.10 in Chap. 2). If the lobster were tagged, they were released over the waypoint where they were originally caught
    b. Cancer crabs (*C. irroratus* and *C. borealis*) – Carapace width measured, then released.
    c. Species other than cunner – Grubby sculpin *(Myoxocephalus aenaeus*), pollock (*Pollachius virens*), rock gunnel (*Pholis gunnellus*), and radiated shanny (*Ulvaria subbifurcata*) were occasionally captured. For these species, total length was measured to the nearest 0.1 mm using a measuring board and the fish was released.
    d. Cunner (*Tautogolabrus adspersus*) – Total length (TL) was measured to the nearest 0.1 mm using a measuring board, then Floy® Fingerling tags were applied to each cunner with a TL of 7.5 mm or greater (we increased the minimum TL from 7.5 in the spring to 8.0 in the fall because cunner less than 8.0 mm had reduced survivorship compared with the larger individuals immediately following the tagging event).
        i. Floy Fingerling tags were pre-printed with unique three-character codes and came attached to elastic line which was threaded on a needle. We used the needle to pierce the fish's flesh a few mm below the anterior end of the dorsal fin. The elastic line was then threaded through the fish's flesh and the needle was removed. We secured the tag close to the fish's body with a surgeon's knot. Dangling thread was trimmed to reduce drag.
        ii. We released the live tagged fish over the waypoint where they were originally captured. A freshly-baited trap was also released on the site. Released cunner were observed and any that did not swim down were recovered and recorded.

Air-lift Sampling

Sampling and sample analysis was performed according to the procedures described previously under the "Benthic Air-lift Sampling." One major difference between air-lift sampling the artificial reefs and the annual coastal stations was the amount of time required to complete the procedure because (1) the greater depth caused divers and the suction pipe to expend air at a faster rate than at the shallow sites, which required more tank changes, and (2) divers had to swim farther along the bottom to arrive at sampling destinations. Techniques unique to each sample site were:

Artificial Reefs

1. Twenty-four samples were taken on the artificial reef. On each reef unit, a ½ m^2 quadrat was used to sample the four rock sizes (small cobble, large cobble, small boulder, and small boulder/small cobble mix). The two larger rock sizes (large boulder and large cobble/large boulder mix) were not sampled due to the impracticality of turning those rocks over.
    a. The quadrat was placed on either the western or eastern edge of the different size rock sections. Sampling side (east or west) was randomly assigned to later analyze variations in settlement due to prevailing east/west currents. We followed the "Underwater Reef Suction Protocol Datasheet" (Appendix C) while diving, which designated what locations to sample and also listed bearings to navigate from one reef to another. Samples in 2007 were taken from the opposite side of each rock size sampled in 2006. The break between years allowed for recovery of flora and fauna that were disturbed by air-lift sampling.
    b. Water-proof identification tags were placed in each sample bag underwater, immediately following the collection to identify which reef, rock size, and side of the reef (east/west) the sample was taken (e.g. Label = Site 1, 1W; interpretation = Site 1, small boulders on the west). One diver carried these tags on a looped cable tie. Tags had holes punched in the top corner so the diver could easily rip the tag off the cable tie and place it into the collection bag before closing the bag.
    c. Overturned rocks were replaced immediately after suctioning ceased at each quadrat.
2. In a single dive, we sampled between one and two reefs (four to eight samples), depending on tides and currents. Reefs were easy to locate underwater in the east-west direction but more difficult to find in the north-south direction, where the reefs have a shorter profile.
3. This task required three divers. For most of the annual air-lift sampling, the third diver replaced bags on the suction pipe. On the artificial reef dives, the third diver acted as the lead diver, instructing others on which quadrat to complete next and keeping track of the ID tags for each collection bag. The third diver used the underwater datasheet to mark which quadrats were complete and which needed to be sampled.
4. Bringing down two suction tanks fitted with first stages eliminated the need for divers to surface to switch out tanks but the added gear made swimming from one reef to another difficult.

Sand Controls

Twelve samples were taken on a sandy control site. We randomly chose to sample site #5 but any of the three sandy controls (areas numbered 2, 5, and 6 in Figure 2.1 Chap 2) could be used.

HubLine Fill Point

Twelve samples were taken on the HubLine (centered between the origin and far end of Transect 1). For each, the quadrat was placed on the edge of the rock mound and cobbles were turned out toward the sand. Six quadrats were sampled on the eastern edge of the HubLine and six on the western edge.

Natural Reef

Twelve samples were taken on the natural reef at a location past the far end of Natural Reef Transect 3 (Figure 2.5 Chap. 2). Quadrats were chosen using the routine suction sampling protocol.

Appendix C. Artificial Reef Site Selection and Monitoring Datasheets

Site Name ____________ TimeStart______________
Date (yyyymmdd) ____________ RPM__________________
Recorder ____________

Time (seconds)	Depth	Direction of vessel movement

LatNW	
LonNW	
LatNE	
LonNE	
LatSW	
LonSW	
LatSE	
LonSE	
LatMN	
LonMN	
LatMS	
LonMS	

Time (cont)	Depth (cont.)	Direction of vessel movement

Figure C1. Depth survey datasheet used during site-selection.

Date(yyyymmdd)________________ Site ID ________________ Vis._____ **Transect Letter A / B (circle one)** Diver____________

Time (Hour)__________ Bearing____________ Left / Right (circle one) Buddy____________

	Start	0-5m	5-10m	10-15m	15-20m	20-25m	25-30m	30-35m	35-40m	40-45m	45-50m
Depth											
Hand burial test											
Substrate											
Primary (>50%)											
Secondary (10-50%)											
Tertiary (<10%)											
Tertiary (<10%)											
Tertiary (<10%)											
Tertiary (<10%)											
Underlying											
Homarus americanus **(count if seen)**											

Additional notes:

Sediment Key

***BE* =** Bedrock

***BO* =** Boulder (>25.1cm) head size or greater

***CO* =** Cobble (6.1-25cm) billiard ball to head size

***PE* =** Pebble (0.5-6cm) pea size to billiard ball

***GR* =** Granule (0.2-0.4cm) beebee size to pea size

***SA* =** Coarse Sand and Fine Sand (beebee size to salt/sugar grain)

***SD* =** Shell Debris (broken-up shell fragments)

***SH* =** Shack (whole or half shells)

CL = Clay

***SI* =** Silt

Underlying =sediment underneath other substrate

Hand burial codes:
1 = Remains on surface
2 = Half or whole hand buried
3 = Hand and full wrist buried

Figure C2. Datasheet for substrate surveys of prospective sites, using swath bars.

Date (yyyymmdd) ________________ Swath Divers ____

Site ID________________________ Video Diver ____

Transect **A / B** (circle one)

Algae	**Percent Cover** 0	<1	1-5	6-10	11-25	26-50	51-100
Kelp (*Laminaria sp., Agarum sp., Alaria sp*.)							
Filamentous browns and reds (*Desmarestia*)							
Red blades (*Palmaria sp.,* etc.)							
Encrusting coralline algae							
Drift algae - green							
Drift algae - browns							
Drift algae - reds							

INVERTEBRATES	**Estimated Count** 0	1	2-5	6-10	11-50	51-100	101-500	501-1000	1001+
Homarus americanus									
Libinia emarginata (Spider crabs)									
Cancer sp. (Rock and Jonah crabs)									
Neopanope sp. (Mud crabs)									
Large whelks (*Busycon, Buccinum*)									
S. droebachiensis									
Asterid sea stars (*Asterias, Leptasterias*)									
Hermit crabs - *Pagarus sp., etc.*									
Anemones (*Metridium sp.*)									
Bivalves (specify)									
Other bivalves (specify)									
Tunicates (specify)									

FISH									
Tautogolabrus sp. (Cunner)									
Myoxocephalus sp. (Sculpin)									
Tautoga onitis (tautog)									
Gadus Mohua (Atlantic cod)									
Policius veins (Pollack)									
Winter flounder									
Skates									

Figure C3. Datasheet for presence/absence of species sighted during site-selection dive surveys.

Site ID: ______________________________

Placed near what (Reef? Sandy control?)____________________

Placed near **origin** (0m mark) or **far end** (50m mark) (circle one)

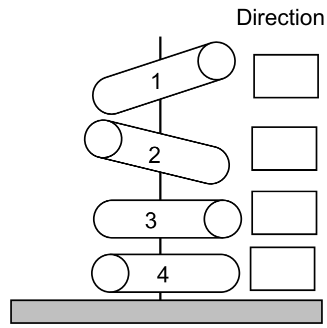
Lat: ______________________________ **Lon:** ______________________________

Divers: ______________________________

Dimond Design

Start Date	End Date	Start Time	End Time

	Start Weight	End Weight	Direction
Block 1			
Block 2			
Block 3			
Block 4			



Flowmeter

Start Date	End Date	Start Time	End Time

Start Read: ______________________________

End Read: ______________________________

Additional Notes:

FigureC4. Current-direction meter datasheet.

Date (yyyymmdd)		**Surface Observer1**	
SiteID		**Surface Observer2**	

Transect (circle one) 1 2 3		**Transect (circle one) 1 2 3**	
Bearing (dive direction)		Bearing (dive direction)	
Average Depth (from boat data)		Average Depth (from boat data)	
0m depth		0m depth	
50m depth		50m depth	
Time Divers In		Time Divers In	
Time Divers Out		Time Divers Out	

Surface Conditions:		**Surface Conditions:**	
Surface Current Direction		Surface Current Direction	
Estimated speed (if possible)		Estimated speed (if possible)	
Wind Speed		Wind Speed	
Wind direction		Wind direction	
Cloud cover		Cloud cover	

Lat West end 0 / 140m?		Lat West end 0 / 140m?	
Lon W end		Lon W end	

Lat East end 0 / 140m?		Lat East end 0 / 140m?	
Lon E end		Lon E end	

Additional Notes:	Additional Notes:

Figure C5. Site-selection surface datasheet for 140-m transect diver surveys.

Site # Diver Transect # Bearing

Date Buddy Visibility Time

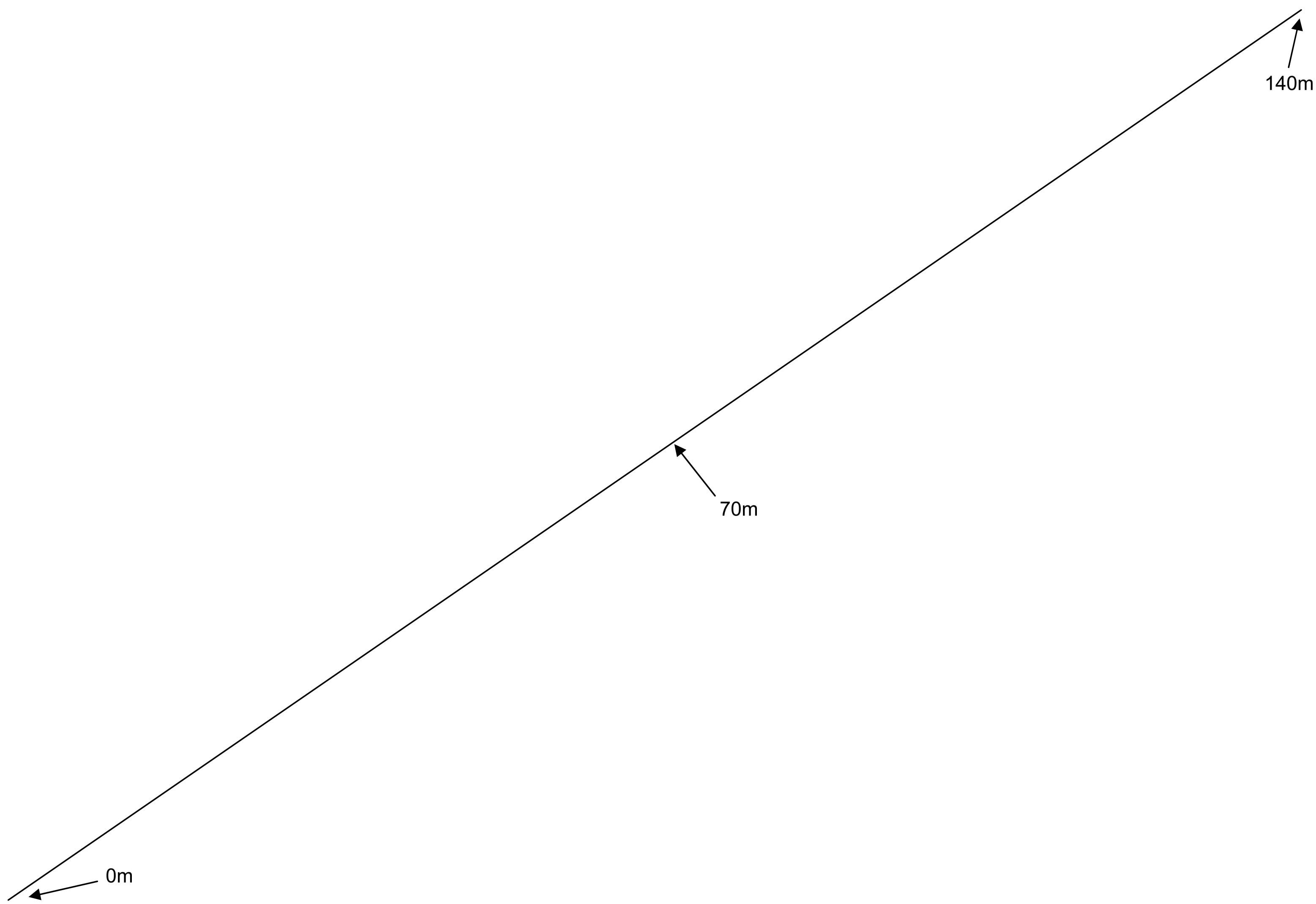


Figure C6. Datasheet for 140-m transect observations during site-selection.

Site ID ____________ Divers ____________

Date ____________ Reef or Sample ID ____________

Species ID - closest ID as possible / notes & descriptions	**Count**

Presence / Absence (for sp. in #s logistically too high to count or questionable in sampling) **Circle if present or write in!**

Algae
Codium fragile
Ulva lactuca
Chaetomorpha linum
Fucus sp.
Chondrus crispus
Membranoptera alata
Palmaria palmata
RedFilamentous
Red Blades
Red coralline algae
Lamanaria sp.
BrownFilamentous
Brown Blades

Sponges
Halichondria panicea
Isodictya sp.
Haliclona oculata
UnidSponge

Bryozoans
Membranipora sp.
Bugula turrita
Cryptosula pallasiana (red encrusting)

Hydroids
Tubularia
Obelia

Annelids
Spirorbis borelis
Family Capitellidae
Pectinaria gouldi (ice cream cone worm)

Tunicates
Botryllus schlosseri
Botrylloides

Other Inverts
Barnacles
Crepidula plana
Crepidula fornicata
Crepidula sp.

Attempt to ID and count all anemones, worms, molluscs, crustaceans, echinoderms, tunicates, and vertebrates found in samples. If their names are listed in presence/absence - do NOT attempt to count these species. If you encounter a species that is too numerous to count or is not sampled well by suction sampling, add the species ID to the presence/absence list.

Figure C7. Air-lift sampling datasheet for artificial reefs, natural reef, and HubLine.

Date (yyyymmdd) **Surface Observer1**

SiteID **Surface Observer2**

Visit #

Transect ID:

Bearing (from 0m mark to 40m mark)

Corrected Depth of Site

Tide Description Dive #1 Ebb / Flood High Slack / Low Slack What type of data was collected on this dive?

Tide Description Dive #2 Ebb / Flood High Slack / Low Slack What type of data was collected on this dive?

Tide Description Dive #3 Ebb / Flood High Slack / Low Slack What type of data was collected on this dive?

Average visibility on dives

Longitude Start (0m) --

Latitude Start (0m)

Longitude End (40m) --

Latitude End (40m)

Additional Notes (site gear and biological notes)

Figure C8. Dive survey surface datasheet.

Date(yyyymmdd)______________________ Site ID______________________ Diver_______________ Bearing_________

Hour_____________ Depth__________________ Left / Right Vis._________ Buddy______________

Group	Visit #____________ Transect# ___________	0-5m	5-10m	10-15m	15-20m	20-25m	25-30m	30-35m	35-40m
Arthropods	Homarus americanus (American lobster)								
	Cancer irroratus (Rock crab - sharp point carapace)								
	Cancer borealis (Jonah crab)								
	Family Majidae (Libina/Hyas - spider crabs)								
	Large hermit crabs (width of large chelae >1.5 cm)								
Cnidarian/Tunicates	Metridium senile (frilled anemone)								
	Northern cerianthid (Cerianthus borealis)								
	Molgula sp. (sea grape)								
	Ciona intestinalis (sea squirt with yellow rim)								
	Styela sp. (warty, knobby sea squirt)								
Echinoderms	Stronglyocentrotus droebachiensis (green urchin)								
	Henricia sp. (Blood star)								
	Asterias forbesi (orange madreporite)								
	Asterias vulgaris (white madreporite, row spines down arms)								
Gastropods	Lunatia heros (Moon snail)								
	Buccinum undatum (waved whelk)								
	Sea scallop (Placopecten magellanicus)								
Fish	Cunner (estimate)								
	Myoxocephalus sp.(shorthorn, grubby & longhorn)								
	Winter flounder (*P. americanus*)								
	Radiated shanny								

Other species to count: Crangon sp. (sand shrimp - dorsally flattened), Pandalus sp. (shrimp), nudibranchs, sea cucumbers, Solaster endeca (Sunstar), Crossaster papposus (Spiny sunstar), Neptunea lyrata (ten-ridged whelk), Colus stimpsoni (slender whelk), Razor clams, Quahogs, Surf clams, sand dollars, Goulds pandora clam, all solitary tunicates, summer flounder, spiny dogfish, other flatfish, Lumpfish, Cod, Tautog, Sea raven, Raja (skate)

Figure C9. Swath survey datasheet for mobile macroinvertebrates and solitary tunicates used during monitoring dives.

Date(yyyymmdd)__________________ Site ID ________ Transect ID________ Diver__________________ Depth________

Bearing ______Hour______ Left / Right Visit #_________Vis_____ Buddy__________________

Only count 1m quads if the abundance is very low

Quadrat (**1/4 / 1**meter^2)	Q1	Q2	Q3	Q4	Q5
Sampling Start Mark	___( )	___( )	___( )	___( )	___( )
Modiolus modiolus	/	/	/	/	/
Mytilus edilus Blue mussel	/	/	/	/	/
# of clam siphons	/	/	/	/	/
	/	/	/	/	/
	/	/	/	/	/
	/	/	/	/	/

Substrate

Quadrat (**1** meter^2)	Q1	Q2	Q3	Q4	Q5
Sampling Start Mark	___( )	___( )	___( )	___( )	___( )
Primary (>50%)					
Secondary (10-50%)					
Tertiary (<10%)					
Tertiary (<10%)					
Tertiary (<10%)					
Tertiary (<10%)					
Underlying (what you can see)					

BE drock

BO ulder (>25cm) head size or greater

CO bble (6-25cm) billiard ball to head size

PE bble (0.4-6cm) pea size to billiard ball

GR anule (0.2-0.4cm) bb size to pea size

***SA* =** Coarse and Fine Sand (beebee size to salt/sugar)

***SH* =** Shack (whole or half shells)

CL = Clay

***SI* =** Silt

***SD* =** Shell Debris (broken-up shell fragment)

Notes:

Quadrat (**1** meter^2)	Q1	Q2	Q3	Q4	Q5
Sampling Start Mark	___( )	___( )	___( )	___( )	___( )

Remember - if it is **drift algae,** no stipe count is recorded - only % cover with a "D" next to it. Count dead kelp stipes separately.

Brown Algae (#stipes/percent cover w/in 1 meter^2)

Agarum cribrosum (kelp with holes)	/	/	/	/	/
Laminaria sp. (thick blade)	/	/	/	/	/
Alaria sp. (mid-rib)	/	/	/	/	/
Unid filamentous browns					

Reds (if you can ID *Chondrus* separately, please estimate % cover separately)

RedFilamentous/Foliose					
Red Blade (*Palmaria)*					
Red Coralline Crust					
Chondrus crispus					
Membranoptera alata (leafy red blade)					

Greens

Ulva lactuca (green blade -prob. drift)					
Fucus sp. (branching green, prob. drift)					

Sessile Inverts (count / percent cover) No slash = only percent cover

Bugula (Tufted bryozoan)					
Palmate sponge *(Isodictya sp.)*	/	/	/	/	/
Crumb Bread Sponge (*Halichondria sp.*)					
Botrylloides violaceus (orange, white tunicate)					
Botryllus schlosseri (star tunicate)					
Barnacles					
Haliclona oculata (deadmans fingers)	/	/	/	/	/
Tubularia (hydroid with pink)					
Didemnum sp. (snotty gray tunicate)					

Other stuff to count: Encrusting Tunicates, Sea pork (white blob tunicate), Cryptosula sp. (red encrusting bryozoan) Membranipora (encrusting bryoz) or Electra pilosa (lacy bryoz), Broken kelp stipe, Green filamentous algae, Codium *sp*., Didemnum albidum (white, non-invasive), Clathrina sp. (white stringy sponge) other encrusting species, Haliclona

Figure C10. Quadrat survey datasheet for bivalves, substrate, and species assessed by percent cover used during monitoring dives.

Presence/Absence Date (yyyymmdd) ______________ Visit # ______

Site ______________

Transect ID ______________

ALGAE **P=Percent Cover**	0	<1	1-5	6-10	11-25	26-50	51-100	100-500	501-1000	1000+	**Drift?**
Brown											
Laminaria sp. (thick blade)											
Alaria sp. (mid-rib)											
Agarum cribrosum (seive kelp, w/ holes)											
Brown filamentous (wiry)											
Other											
Red											
Chondrus crispus (foliose)											
Palmaria palmata (red blade)											
Red coralline crust											
Membranoptera alata (flattened leafy red blade)											
Corallina officinalis (branching corraline red alga)											
Red filamentous											
Green											
Ulva lactuca (blade)											
Codium fragile (branching)											
Fucus sp. (drift, rockweed)											
Chaetomorpha linum (filamentous green, wiry)											
Ascophyllum nodosum (drift, knotted wrack)											
Green filamentous algae											
Zostera sp. (eelgrass)											

INVERTEBRATES - ***P = Percent Cover*** **and** ***C=Count***

Porifera **= P**										
Isodictya sp. (palmate, conspicuous oscula)										
Halichondria panicea (crumb of bread)										
Haliclona oculata (deadman's fingers, narrow stalk, our "purple sponge")										
Suberites ficus (fig sponge, smooth, yellowish, ball-like)										
Microciona prolifera (red beard, tiny oscula)										
Clathrina sp. (stringy white sponge)										
Other (describe)										
Cnidarians = **P or C**										
P =*Tubularia crocea* (pink tubularian hydroid)										
P =*Obelia geniculata* (threadlike runner, stalked)										
C =*Metridium senile* (frilled anemone)										
C =*Cerianthus borealis* (northern cerianthid)										
Other										

Figure C11. Datasheet for presence/absence of species sighted on the artificial reefs, natural reef, and HubLine sighted during monitoring dives, filled out post-dive.

Site ID ______________________ Transect ID _____ Visit # ______

	0	<1	1-5	6-10	11-25	26-50	51-100	100-500	501-1000	1000+
Bryozoans **= P**										
Membranipora membranacea (sea lace)										
Bugula turrita (sprial tufted bryozoan)										
Cryptosula pallasiana (red crust)										
Molluscs - Gastropods										
P = *Crepidula plana* (flat, whitish slipper shell)										
P = *Crepidula fornicata* (slipper shell, more mottled and raised)										
C = *Lunatia heros* (moon snail)										
C = *Euspira triseriata* (spotted moon snail)										
C = *Anomia* sp. (jingle shell)										
C = *Cerostoderma pinnulatum* (northern dwarf cockle)										
C = *Acmaea testudinalis* (limpet)										
C = *Buccinum undatum* (waved whelk, aperture shining white, short canal)										
C = *Neptunea lyrata decemcostata* (ten-ridged whelk)										
C = *Colus stimpsoni* (slender whelk, long siphonal canal)										
C = *Nassarius trivattata* (New England dog whelk)										
C = *Lacuna vincta* (northern lacuna snail)										
C = *Mitrella lunata* (lunar dove snail)										
C = *Flabellina pellucida* (red-gilled nudibranch)										
C = Dorid nudibranch										
C = *Dendronotus sp.* (Dendronid nudibranch)										
C = *Tonicella* sp. (chiton)										
Other										
Molluscs - Bivalvia **= C**										
Modiolus modiolous (northern horse mussel)										
Mytilus edulis (blue mussel)										
Placopecten magellanicus (sea scallop)										
Mercenaria mercenaria (northern quahog)										
Pitar morrhuanus (false quahog)										
Spisula solidissima (surf clam)										
Ensis directus (common razor clam)										
Astarte undata (wavy astarte clam)										
Petricola pholadiformis (false angel wing)										
Pandora gouldiana (Gould pandora, saddle-shaped flat shell)										
Annelids **= C**										
Spirorbis borealis (sinistral spiral tube worm, on seaweed)										
Myxicola infundibulum (slime fan worm)										
Scale worm										
Arthropods - Crustaceans										
P = Barnacles - Order Thoracica										

Figure C11. continued.

Site ID ______________________ Transect ID _____ Visit # ______

Arthropods - Crustaceans	0	<1	1-5	6-10	11-25	26-50	51-100	100-500	501-1000	1000+
C = *Homarus americanus* (American lobster)										
C = *Cancer irroratus* (rock)										
C = *Cancer borealis* (Jonah)										
C = *Mysid* sp. (mysid shrimp, dorsoventrally flattened)										
C = *Crangon septemspinosa* (sand shrimp, short rostrum, clear w/ blk spots)										
C = *Pandalus montagui* (Montague's shrimp, pink to red or red stripes)										
C = *Lebbeus polaris* (reddish-brown to red, transparent)										
C = Caprellid shrimp (skeleton shrimp)										
C = *Upogebia affinis* (ghost shrimp)										
C = *Pagurus sp.* (hermit crabs)										
C = *Libinia emarginata* (common spider crab)										
C = *Hyas* sp. (toad crab, decorator)										
C = *Neopanope* sp. (mud crab)										

Enchinoderms **= C**	0	<1	1-5	6-10	11-25	26-50	51-100	100-500	501-1000	1000+
Henricia sanguinolenta (blood sea star)										
Asterias vulgaris (northern sea star, yellow/white madreporite, row spines)										
Asterias forbesi (Forbes sea star, orange madreporite)										
Asterias sp.										
Subclass Ophiuroidea (brittle star)										
Cucumaria frondosa (orange-footed cucumber)										
Chiridota laevis (silky sea cucumber, pink/whitish)										
Stronglyocentrotus droenbachiensis (green urchin)										
Echinarachnius parma (common sand dollar)										
Solaster endeca (smooth sunstar)										
Crossaster papposus (spiny sunstar, bristles)										

CHORDATES

Tunicates	0	<1	1-5	6-10	11-25	26-50	51-100	100-500	501-1000	1000+
P = *Botryllus schlosseri* (golden star tunicate)										
C = *Molgula* sp. (sea grape)										
P = *Botrylloides violaceus* (orange/maroon/white sheath tunicate, colonial)										
P = *Didemnum albidum* (northern white crust)										
C = *Boltenia ovifera* (stalked tunicate, orange/yellow)										
C = *Halocynthia* sp. (sea peach tunicate)										
C = *Ciona intestinalis* (sea vase tunicate)										
C = *Styela clava* (club tunicate)										
P = Didemnum sp. (invasive tunicate)										
P = Unidtunicate, "white blob" possibly sea pork?										
Other tunicate species										

Figure C11. continued.

Site ID ______________________ Transect ID _____ Visit # ______

	0	<1	1-5	6-10	11-25	26-50	100	500	1000	1000+
Fishes - continuous dorsal (cont) **= C**										
Pholis gunnellus (rock gunnel)										
Ulvaria subbifurcata (radiated shanny)										
Macrozoarces americanus (ocean pout)										
Pseudopleuronectes americanus (winter flounder)										
Paralichthys denatus (summer flounder)										
Tautogolabrus adspersus (cunner)										
Tautoga onitis (tautog)										
Cyclopterus lumpus (lumpfish)										
Liparis sp. (snailfishes)										
Raja sp. (skates)										
Fishes - two dorsals **= C**										
Myoxocephalus aenaeus (grubby sculpin)										
Myoxocephalus octodecemspinosus (longhorn sculpin)										
Myoxocephalus scorpius (shorthorn scuplin)										
Myoxocephalus sp.										
Hemitripterus americanus (sea raven)										
Morone saxatilis (striped bass)										
Urophycis chuss (red hake, red-brown, feeler w/yellow, long dorsal thread)										
Urophycis tenuis (white hake, grey/purplish, short dorsal thread)										
Squalus acanthias (spiny dogfish)										
Fishes - three dorsals **= C**										
Melanogrammus aeglefinus (haddock)										
Pollachius virens (pollock)										
Gadus morhua (atlantic cod)										
Unid fish (describe)										

Figure C11. continued.

Date:
Observers:
Bait:

(only take a new waypoint if the trap is set far off it's intended waypoint)

FishPotID	Lon	Lat	Waypoint Set #	Trap Buoy ID #	Time Deployed
FFred1	-70.90680	42.34390			
FMrS2A	-70.90649	42.34391			
FMrS2B	-70.90668	42.34371			
FBarney3	-70.90639	42.34371			
FWilma4	-70.90714	42.34353			
FDino5A	-70.90686	42.34352			
FDino5B	-70.90704	42.34332			
FDino5C	-70.90693	42.34343			
FGazoo6A	-70.90662	42.34344			
FGazoo6B	-70.90681	42.34322			
FPeble7A	-70.90759	42.34302			
FPebble7B	-70.90747	42.34316			
FBetty8	-70.90727	42.34305			
FBamm9	-70.90706	42.34295			
FHub1	-70.90555	42.34433			
FHub2	-70.90580	42.34398			
FHub3	-70.90608	42.34363			
FHub4	-70.90636	42.34327			
FHub5	-70.90672	42.34279			
FHub6	-70.90711	42.34233			
FHub7	-70.90656	42.34303			
FNat1	-70.91173	42.33779			
FNat2	-70.91173	42.33804			
FNat3	-70.91134	42.33777			
FNat4	-70.91268	42.33832			
FNat5	-70.91310	42.33854			
FNat6	-70.91189	42.33790			
FNat7	-70.91330	42.33867			

Notes:

Figure C12. Small fish tagging study datasheet for recording location and time of fish pot sets.

Fish Potting Length Frequency / Tagging Datasheet

Site or Plot: ________________ Pot #:: ____________________

Date Pot Placed: ________________ Time Pot Placed: ____________________

Date Pot Removed: ________________ Time Pot Removed: ____________________

CUNNER		RECAPTURED CUNNER		Other
Tag # / Color	Measurement	Tag # / Color	Measurement	SPECIES
/		/		
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Do not tag fish smaller than 8.0 cm

Tag color code: P = Pink, B = Blue, Gr = Green, W = White, Y = Yellow, R = Red, I = Ivory, Go = Gold

Figure C13. Small fish tagging study datasheet for tagged and recaptured fishes and lobster.

Methods for Suction Sampling Boston Harbor Artificial Reefs

Sample all 6 artificial reefs, 3 sandy controls, 1 hubline, and 1 natural reef

- Artificial Reefs:
  - Sample one quadrat in each of four rock sizes:
    - Small cobble, large cobble, small boulder, small boulder/cobble mix
  - Place quadrat on right or left edge of rock type section according to plan (see figure below), L/R assigned randomly and recorded
    - Next year, sample opposite side (L/R) of each section
- Sandy Controls:
  - Sample with 12 quadrats
- Hubline:
  - Sample with 12 quadrats - place six on western edge/ six on eastern edge
- Natural Reef:
  - Sample with 12 quadrats – place all past far end point of "Natural Reef 3" transect (N 42.33814 W 070.9119)

Lg Boulder →	Site 1	X	Site 2 – Sand	Site 3	X
Sm Boulder →	**1 W**			**1 W**	
Lg Cobble →	**2 W**			**2 W**	
Sm Cobble →		**3 E**			**3 E**
Sm Mix →	**4 W**				**4 E**
Lg Mix →	X	X		X	X

Lg Boulder →	Site 4	X	Site 5 – Sand	Site 6 – Sand
Sm Boulder →		**1 E**		
Lg Cobble →		**2 E**		
Sm Cobble →		**3 E**		
Sm Mix →	**4 W**			
Lg Mix →	X	X		

Lg Boulder →	Site 7	X	Site 8	X	Site 9	X
Sm Boulder →		**1 E**		**1 E**		**1 E**
Lg Cobble →	**2 W**			**2 E**	**2 W**	
Sm Cobble →	**3 W**			**3 E**	**3 W**	
Sm Mix →		**4 E**	**4 W**		**4 W**	
Lg Mix →	X	X	X	X	X	X

Figure C14. Schematic of artificial reef air-lift sampling locations on each reef used to direct divers while underwater.

Site ID:
Transect ID:
Logger ID:
Date Logger Placed:
Time Logger Placed:
Time Logger Retrieved:
Date Logger Retrieved:

Site ID:
Transect ID:
Logger ID:
Date Logger Placed:
Time Logger Placed:
Time Logger Retrieved:
Date Logger Retrieved:

Site ID:
Transect ID:
Logger ID:
Date Logger Placed:
Time Logger Placed:
Time Logger Retrieved:
Date Logger Retrieved:

Site ID:
Transect ID:
Logger ID:
Date Logger Placed:
Time Logger Placed:
Time Logger Retrieved:
Date Logger Retrieved:

Site ID:
Transect ID:
Logger ID:
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Logger ID:
Date Logger Placed:
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Time Logger Retrieved:
Date Logger Retrieved:

Figure C15. Temperature monitor datasheet.