0028–8330/09/4301–0283

A systematic model for artificial reef site selection

J.S. BARBER
D.M. CHOSID
R.P. GLENN
K.A. WHITMORE
Massachusetts Division of Marine Fisheries
1213 Purchase Street
New Bedford
Massachusetts 02740 United States
email: kelly.whitmore@state.ma.us

Abstract 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 the subsequent ranking analysis, visual transect surveys, benthic air-lift sampling, and larval settlement collector deployment. American lobster (*Homarus americanus*) was selected as the target species for these investigations owing to the local commercial importance of the species. Results from each step in this process ultimately allowed us to select a site for an artificial reef 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 before reef installation. Each step in this site selection model was designed for easy adaptation to suit the needs of various artificial reef projects.

Keywords *Homarus americanus*; geographic information systems; habitat characterisation; larvae; collectors; mitigation; postlarva; settlement

M07102; Online publication date 24 February 2009
Received 30 November 2007; accepted 12 June 2008

INTRODUCTION

Despite its common use as a mitigation tool, artificial reef development is rarely subjected to a rigorous site selection process before deployment. Although many states within the United States of America have artificial reef plans with guides on site selection methods, these guidelines focus primarily on 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; Figley 2005; US Department 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 results are important for judging the effectiveness of reefs, often they do not provide managers with the data necessary to make informed decisions regarding future siting for mitigation reefs. Inadequate site selection is one of the most common causes of unsuccessful artificial reefs (Chang 1985; Mathews 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 used by managers and scientists to select sites for habitat restoration and/or artificial reef deployment (Pope et al. 1993; Gordon 1994; Tseng et al. 2001; Kennish et al. 2002; Kaiser 2006). Although this method is useful for initially eliminating areas where conflicts are likely to arise (e.g., with navigation, commercial fishing activities, oil and gas platforms), this process does not always provide managers with the 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 in the site selection process, including: currents (Nakamura 1982; Baynes & Szmant 1989), wave action (Nakamura 1982; Duzbastilar et al. 2006), proximity to natural habitat (e.g., Carter et al. 1985; Chang 1985; Spieler et al. 2001),

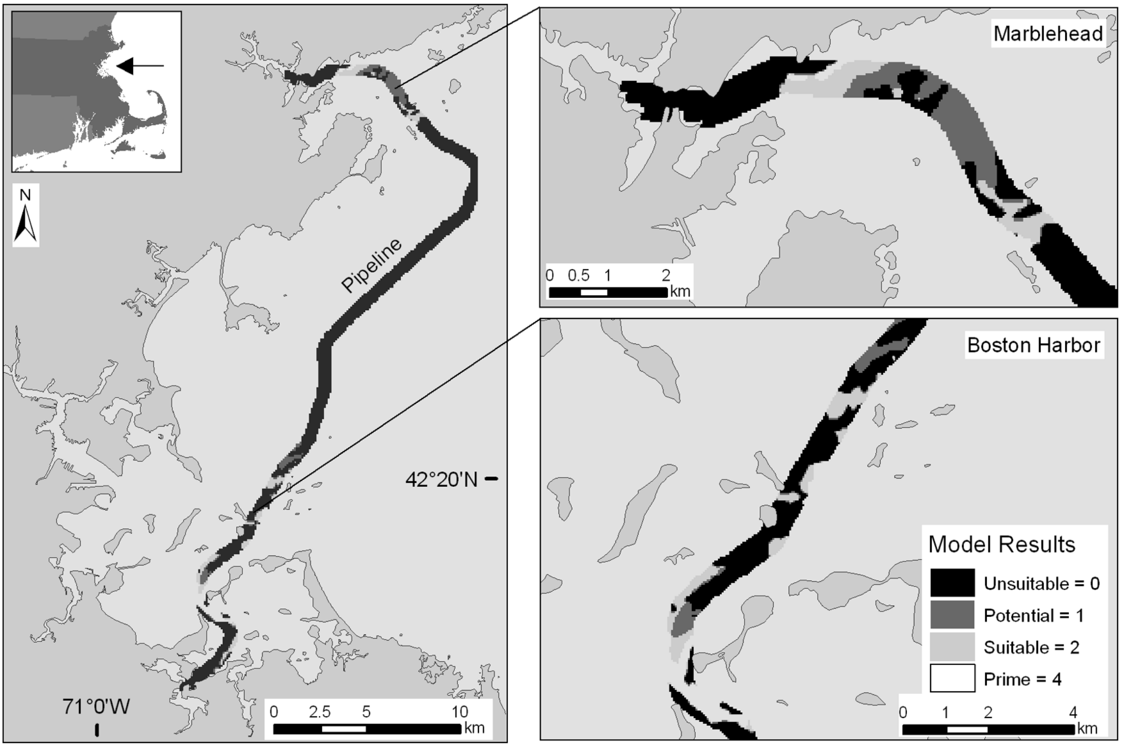

Fig. 1 Results of the initial exclusion mapping model for artificial reef deployment in Massachusetts Bay, Massachusetts, United States. Numerical values representing prime, potential, suitable, and unsuitable depth and sediment for the artificial reef were multiplied using the GIS raster calculator to produce this suitability data layer.

substrate stability (Mathews 1985), and existing benthic communities (Carter et al. 1985; Bohnsack & Sutherland 1985; Mathews 1985; Hueckel et al. 1989). Although these site selection criteria have been summarised in the literature (Yoshimuda & Masuzawa 1982; Carter et al. 1985; Ambrose 1994; Sheng 2000), there are few examples of projects that have investigated each criterion before deploying artificial reefs (but see Hueckel & 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. 1985; Pratt 1994). Although exclusion mapping could take the majority of these variables into account, there are no published examples of a study that combines exclusion mapping with physical and biological field measurements to evaluate the suitability of a site for artificial reef deployment.

In 2004, the Massachusetts Division of Marine Fisheries (MADMF) received monetary compensation from Algonquin Gas Transmission Company to provide mitigation for impacts resulting from the construction of a 48 km natural gas pipeline in Massachusetts Bay, Massachusetts, United States (Fig. 1). A substantial amount of the impacted seabed along the pipeline footprint consisted of rocky substrate, a habitat type that is not easily restored (Auster et al. 1996; Collie et al. 1997; 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 scallop (*Placopecten magellanicus*), and other species of fish and invertebrates (Wahle & Steneck 1992; Tupper & Boutilier 1995; Packer et al. 1999). As mitigation for the assumed impacts to hard-bottom habitat, MADMF constructed a series of cobble/boulder reefs (rock sizes 6–75 cm diam.) designed to target different life history stages of invertebrate and vertebrate species found in Massachusetts Bay (Cobb 1971; Dixon 1987; Wahle 1992; Wahle & Steneck 1992; Dorf & Powell 1997; Tupper & Boutilier 1995, 1997; Bigelow & Schroeder 2002). 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 (US Geological Survey 2006).

In advance of reef deployment, a thorough site selection technique was developed with the aim of promoting the future success of the reef. Our goals were to: (1) use 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; (3) create a rigorous but simple site selection process that could easily be adapted for use by others interested in artificial reef deployment; and (4) compare biological variables between the artificial reefs and reference sites following reef deployment. American lobster (*Homarus americanus*, H. Milne Edwards, 1837) was selected as the target species for these investigations owing to its local commercial importance (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 the procedures recommended by multiple investigators into one 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). 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 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. This delineated area represented the estimated extent of impact to bottom habitat from construction of the pipeline, within which the mitigation project was targeted. The clipped substrate and bathymetry data were recoded to represent prime, potential, and unsuitable areas (Table 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 2). Using the GIS 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. Twenty-four sites that fell within areas delineated as "prime" were selected for further investigation. Five alternate sites (also located within "prime" areas) were also identified 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 data layer. Based on the reef design, each potential site footprint was 140 m × 40 m in size. Each corner of a potential site was marked using buoys and depth data were collected (with sonar) within the footprint of the site. 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 (<5.0 m or >15.1 m) and sites that had slopes over 5° were eliminated from further consideration (Table 1).

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 45° angles to the 140 m × 40 m footprint such that each transect bisected about half of the reef area. Divers quantified substrate type in continuous 5 m × 2 m sections along the transect using a 2 m PVC bar. Each diver collected data on one side of the transect until the entire transect had been sampled. Using rulers for a 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 categorised 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 characterised by large areas of boulder and cobble with sand or granule underlying; consequently, data from this type of area would be classified as: primary = boulder; secondary = cobble; and underlying = sand.

Divers also recorded benthic macroinvertebrates and vertebrates seen during these dives. Although wave action was considered by establishing potential sites following Nakamura's (1982) depth suggestions, divers ranked sand ripples on sites as an indicator of wave presence. Sand ripples were classified into three categories: large (>13.1 cm height), small (2.5–13.0 cm), or none.

Weighting and ranking analysis

A weighting and ranking system was developed to integrate multiple aspects of the site selection criteria. Data used in this portion of the study included: primary and secondary surficial substrate, underlying sediment, sand ripple presence, site proximity to the pipeline, and site proximity to cobble fill points along the pipeline (areas along the pipeline armoured with rock) (Table 1).

For each potential site, we assigned a numerical score to every data category based on how well the site met the selection criteria (Table 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: $(0.70 \times 3) + (0.30 \times 1) = 2.4$.

Next, a weighting system was developed based on the relative importance of each criterion to the project goals. Substrate variables were assigned the

Table 1 Criteria for selecting a site for artificial reef deployment in Massachusetts Bay, United States.

Criterion	Description	Reference
General criteria		
Accessibility	The area selected 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 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, as well as to maintain a well-oxygenated environment. Sites needed to be oriented for maximum exposure to the current.	Nakamura 1982; Baynes & Szmant 1989
Depth and wave action	Water needed to be deep enough to protect the reef from wave action but shallow enough to promote larval settlement; our target depth range was 5.0–9.9 m, but 10.0–15.0 m was also acceptable.	Nakamura 1982; Duzbastilar et al. 2006
Established habitat and/or proximity to established habitat	Existing natural reefs were avoided to minimise further impacts to hard-bottom habitat. The artificial reef needed to be in 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 *Homarus americanus*.	This study
Substrate	The substrate needed to consist of firm sediment types that provided a stable platform for the cobble and boulder. Soft, muddy sediments, silt, and shifting fine sand were avoided to minimise reef sinking.	Yoshimuda & Masuzawa 1982; Mathews 1985
Slope	Sites with slopes over 5° were eliminated for reef stability.	Yoshimuda & 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 & 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	We targeted areas <30 m distance from the pipeline's vicinity, although we considered sites up to 300 m from the pipeline.	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 points could serve as a comparison area for mitigation research.	This study

highest weights: primary = 50%, secondary = 15%, and underlying = 15%, since suitable substrate was necessary for reef stability and existing productive 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%. 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.

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.

Qualitative transect surveys

Comprehensive visual surveys using SCUBA were conducted along 140 m transects on each of the

Table 2 Reclassification values for bathymetry and 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
Bathymetry			
0.0–4.9 m	Unsuitable	Navigational concerns, wave action	0
5.0–9.9 m	Prime	Ideal larval settlement depth, safe SCUBA depth	2
10.0–15.0 m	Potential	Acceptable larval settlement depth, reduced bottom time for divers	1
>15.1 m	Unsuitable	Too deep for many larvae, and SCUBA	0
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

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

Data category	Description of data categories	Classification	Numerical score
Primary surficial substrate	Boulder, cobble, silt	Poor	1
	Pebble, granule, sand, shack, shell debris	Prime	3
Secondary surficial substrate	Boulder, silt	Poor	1
	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 (2.5–13.0 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

oriented sites in June and July 2005 (sites were oriented perpendicular to the predominant current; Baynes & Szmant 1989; MADMF unpubl. data). 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. We established three lengthwise transects along the sides and centre 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.

Benthic air-lift sampling

Using methods described by Wahle & Steneck (1991), the three potential sites and two nearby rocky reefs (Fig. 2) were air-lift sampled in September 2005, to compare densities of mobile benthic macrofauna. 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 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, twelve 0.5 m^2 quadrats were haphazardly placed on the substratum at least 2 m apart. Large boulders and patches of sand were avoided on the natural reefs (Wahle & Steneck 1991), whereas sand was primarily sampled on the potential reef footprints. The air-lift sampling device consisted of a PVC tube supplied with air from a SCUBA tank. Sampling a quadrat in cobble habitat involved slowly 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 moved over the area of the quadrat until the entire quadrat had been sampled. Gastropods, bivalves, polyplacophorans, decapods, echinoderms, solitary tunicates, and fish were identified to the lowest practical taxon and enumerated. We did not count polychaetes (except for scale worms) because most were destroyed in the process. Species that were not readily identifiable in the field were preserved in 90% ethanol and identified in the laboratory.

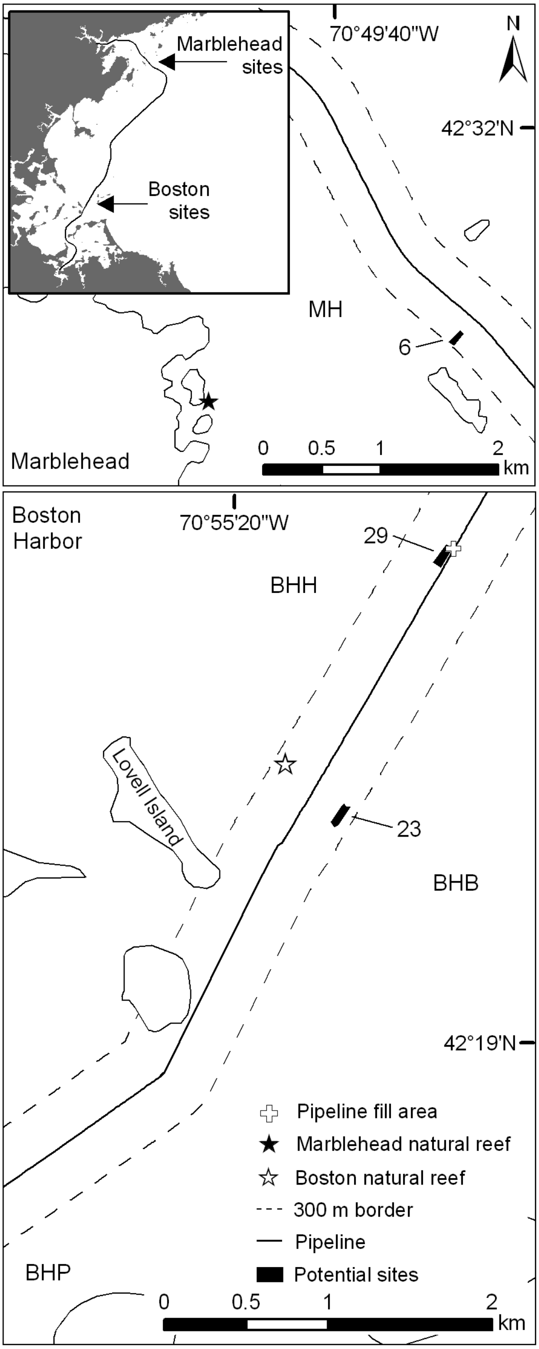

Fig. 2 Location of final three potential sites (Sites 6, 23, 29) and the natural reefs, also the location of the general target areas for the artificial reef deployment: Marblehead (MH), Boston Harbor near Hypocrite Channel (BHH), Boston Harbor near the Brewster Spit (BHB), and Boston Harbor near Peddocks Island (BHP), United States.

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 & Rohlf 1995). Data were $\log_{10}$- (x + 0.1) transformed to meet the assumptions of ANOVA and a post hoc comparison was conducted using a Tukey HSD test (Sokal & 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-Wiener diversity indices 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 & Steneck 1991, 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 × 70.6 cm width × 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. Each collector was filled with 15–25 cm cobble and lowered from the boat using a built-in bridle. Ten collectors were placed on each of the three sites in July 2005 before the postlarval lobster settlement season (Lawton & Lavalli 1995). Collectors remained on the bottom for 2 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 from each collector were inspected and species were recorded following the air-lift sampling methods.

The larval settlement survey was used to address our primary hypothesis; YOY lobster or larvae of other species settle at these sites when provided with their preferred habitat. Two additional hypotheses were investigated using data from the collectors: (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 colonise the artificial reef and how the target species, American lobster (*H. americanus*), would use the reef.

A present/absent rule was used to address our primary hypothesis, whereby if YOY lobster or 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 of postlarval settlement. The second hypothesis was investigated by conducting a one-way ANOVA and a post-hoc Tukey HSD test (Sokal & Rohlf 1995) on the mean number of lobster per 1 m^2 by site. Shannon-Wiener diversity indices were calculated for each potential reef site (Krebs 1999).

Post-deployment assessment

The artificial reefs were installed in February and March 2006. Following deployment of the artificial reefs, a multi-faceted research programme was initiated 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 pipeline fill point (Fig. 2). Two components of the programme were benthic air-lift sampling and permanent transect sampling. Air-lift sampling was conducted on the above sites in September 2006 and 2007, according to the methods described above for benthic air-lift sampling. A non-parametric Kruskal-Wallis test was used with follow-up pairwise comparisons (Mann-Whitney test) to test for differences in YOY lobster density by site. A Bonferroni-adjusted α value of 0.008 was used to account for the possibility of increased Type I error associated with multiple pairwise comparisons (Sokal & Rohlf 1995).

Permanent 40 m transects were also established at each site and were sampled in the spring, summer, and autumn of 2006, and winter and spring of 2007. Divers quantified all mobile macroinvertebrates (e.g., echinoderms, crustaceans, whelks), some sessile macroinvertebrates (e.g., solitary tunicates, anemones), and fish in continuous 5 m × 2 m sections along the transect using a 2 m PVC bar. Each diver collected data on one side of the transect. Rocks were not lifted, but interstitial spaces were carefully inspected for organisms. Quadrats, 1 m^2 PVC frames, were used to visually quantify algal coverage and encrusting/sessile invertebrate coverage (e.g., colonial tunicates or sponges). Eight randomly-selected quadrats were sampled on each side of the 40 m transect, for a total of 16 quadrats sampled per site per season. Percentages of cover of algae, sponges, and encrusting tunicates were visually estimated within the 1 m^2 quadrat. Shannon-Wiener indices of diversity were generated for each site by season of survey for: 1) enumerated species; and 2) species assessed by percentage of cover. Before calculating diversity indices, abundances of enumerated species and percentages of cover of algae and encrusting species were averaged across transects per site per season.

RESULTS

The GIS model results indicated general areas that had the most potential for artificial reef deployment; 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 (Fig. 1).

Eight sites were eliminated because of unsuitable depth or slope; the remaining 16 sites had slopes ranging from 0° to 5° (see Table 1 for site selection criteria). After reviewing these 16 sites, three additional sites were eliminated because of known poor larval settlement in the area (MADMF 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.

All 14 remaining sites were within 11 km to the nearest harbour, and in the 6–15 m mean low water depth range, therefore meeting the accessibility criteria (Table 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 because of shellfish closures and shallow, undesirable depths for mobile gear fishing practices such as trawling (Table 1).

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 substrates (Tables 3 and 4, Fig. 3). Site 4 (MH) was eliminated because it had the highest relative species abundance and diversity of all potential sites. Site 11 (Boston Harbor near Peddocks Island) was eliminated because of heavy boat traffic and poor larval settlement (MADMF unpubl. data). 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) (Fig. 2). The top two

Table 4 Weighted scores by data category and final ranking analysis results. (All sediments were surficial substrates.) Low scores indicate poor ability to meet site selection criteria. Ranks with lowest values indicate the best sites.

Site ID	Primary sediment	Secondary sediment	Underlying sediments	Wave action	Proximity to pipeline	Proximity to cobble fill	Total	Ranking within area	Overall rank
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
Boston Harbor near 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
29[a]	1.50	0.44	0.45	0.30	0.15	0.15	2.985	2	2
Boston Harbor near 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
Boston Harbor near Peddocks Island									
11	1.50	0.45	0.45	0.30	0.05	0.05	2.800	1	3

[a], Alternate site.

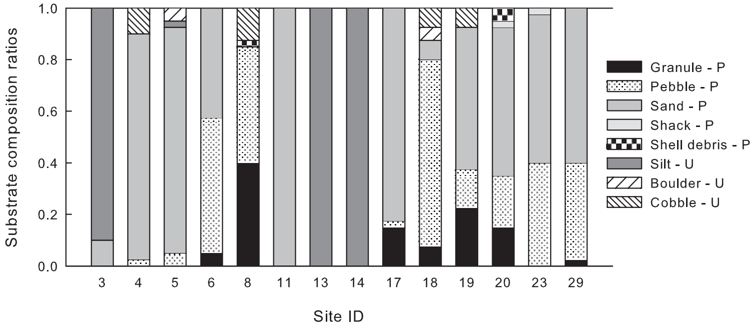

Fig. 3 Primary surficial substrate composition of the 14 potential sites (P, prime substrate for artificial reef deployment; U, unsuitable substrate for reef deployment).

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 4).

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 archaeological 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. 2).

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 = 14.67 individuals m^{-2} ± 2.12 SE, n =12; Site 29 = 14.17 individuals m^{-2} ± 2.25 SE, n = 12; Site 6 = 14.00 m^{-2} individuals ± 3.50 SE, n = 12) ($F_{5,66}$ = 12.85, $P < 0.05$; Tukey HSD, $P < 0.05$, Fig. 4A). No significant differences were detected between the two natural reef sites or among the three potential reef sites (Tukey HSD, $P > 0.05$, Fig. 4A).

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 on 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, H = 11.5, d.f. = 4, $P < 0.05$; permutation tests, $P < 0.05$, Fig. 4B). There was no significant difference between YOY lobster densities on the two natural reefs; the three potential reefs were also similar in that they had no larval lobster settlement (permutation tests, $P > 0.05$, Fig. 4B).

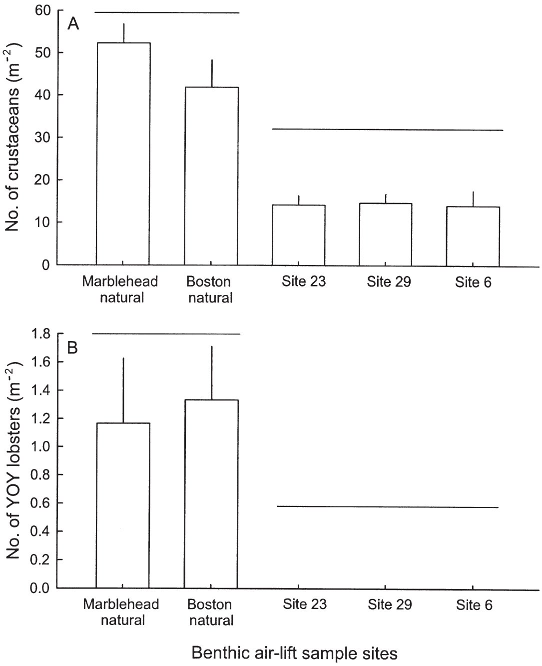

Fig. 4 Mean (+ SE) **A**, crustacean and **B**, young-of-the-year (YOY) lobster density by site as determined by air-lift sampling (n = 12 for each site). Horizontal bars indicate statistical similarity based on a post-hoc Tukey HSD test ($\alpha = 0.05$) (A) and permutation testing at 1000 iterations ($\alpha = 0.05$) (B).

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

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 settlement 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) ($F_{2, 24} = 14.08$, $P < 0.05$; Tukey HSD, $P < 0.05$, Fig. 5). Site 29 and Site 6 had similar densities of lobster (Tukey HSD, $P > 0.05$, Fig. 5). Site 23 had the highest sampled species diversity in the settlement collectors, whereas the diversity at Site 6 was the lowest (Table 5).

YOY lobster density varied significantly by site (Kruskal-Wallis, $H = 17.24$, d.f. = 3, $P < 0.01$). Pairwise comparisons revealed that the natural reef had higher YOY densities (mean = 1.42 individuals ± 0.35 SE, n = 24) than the sand (mean = 0.00 individuals, n = 24, $P < 0.008$) (Fig. 6). The artificial reef, pipeline, and sand had similar YOY lobster densities (Fig. 6).

Diversity indices of enumerated species revealed that diversity was higher on the artificial reefs than the natural reefs in all seasons surveyed, from spring 2006 through spring 2007 (Fig. 7A). Seasonally, diversity decreased on all sites from autumn 2006 to winter 2007 and then rose again in spring 2007. For three of the five seasons surveyed (summer 2006 to winter 2007), the artificial reefs had the highest diversity for enumerated species. Of all sites, diversity was highest on the artificial reefs in the summer of 2006.

Diversity of sessile species assessed by percentage of cover exhibited different site and seasonal trends than that of enumerated species. Diversity was lower on the artificial reefs than on the natural reef in all seasons surveyed (Fig. 7B). Of all sites surveyed, diversity was lowest on the artificial reefs in spring 2006, immediately following reef deployment. One year later (spring 2007), diversity on the artificial

Table 5 Shannon-Wiener diversity index results.

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

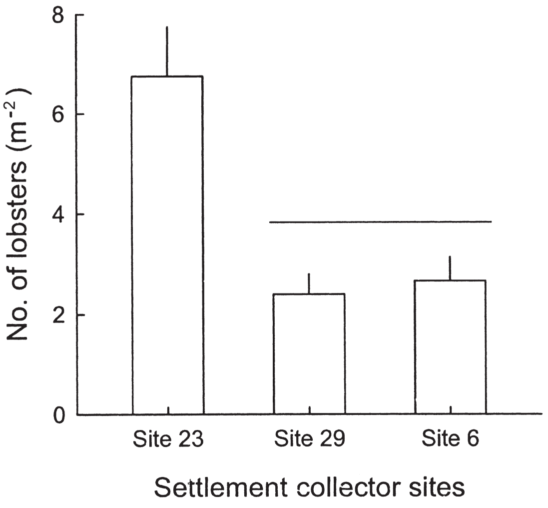

Fig. 5 Mean lobster density (+ SE) in settlement collectors by potential reef site (Site 23, n = 8; Site 29, n = 10; Site 6, n = 9). Horizontal bars indicate statistical similarity based on a post-hoc Tukey HSD test (α = 0.05).

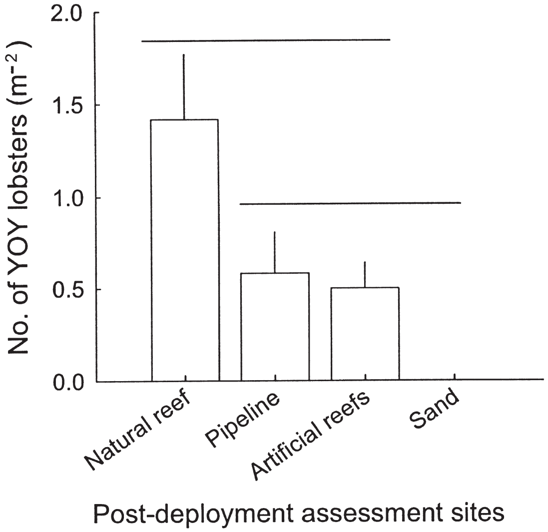

Fig. 6 Mean (+SE) density of young-of-the-year (YOY) lobster by site sampled by benthic air-lift, following the deployment of the artificial reefs (n = 24 for the natural reef, pipeline, and sand; n = 48 for artificial reefs). Horizontal bars indicate statistical similarity based on a post-hoc Tukey HSD test (α = 0.05).

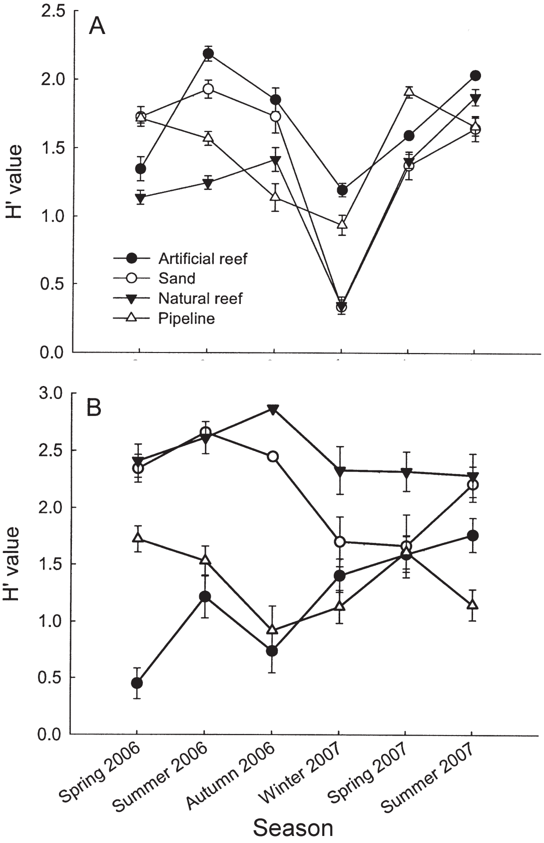

Fig. 7 Temporal changes in mean diversity (+SD) by site of **A**, enumerated species and **B**, species that were assessed by percentage of cover, following the deployment of the artificial reefs, as calculated using the Shannon-Wiener index of diversity. (n = 16 quadrats per site per season.)

reefs was similar to diversity on the pipeline and sand, but still slightly below that on the natural reef. From winter to spring 2007, diversity on the artificial reefs and pipeline increased slightly while diversity on the natural reef and sand decreased slightly.

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 final goal of selecting a site. The majority of these steps led us to three final sites; data gathered from the settlement collectors and air-lift sampling were then considered to select Site 29.

Of the three final prospective sites, Site 23 experienced the highest level of lobster settlement. However, during the 2-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 typically excavate burrows underneath cobble for shelter (Lawton & Lavalli 1995). This layer of fine substrate may have made the collectors at Site 23 more suitable for settling 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 in the collectors when compared with the other two sites, which did not experience high sedimentation rates. Despite the positive species diversity, partial burial of the cobble in 2 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 & 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 both 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 data 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 deployment 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 the 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 the 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 the 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 data sets 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 incorrect information. Although sites were eliminated because of unsuitable slope or depth, it was also necessary to discard sites with highly variable depths. Uneven depths could 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 (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. During dive surveys, the relative abundance of species on each site was qualitatively noted to avoid placing the reef on naturally productive areas. Although these observations were informative, quantitative data would have been more instructive and could have been incorporated into the weighting and ranking analysis, 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. This method could be easily adapted for future use to include project specific criteria, or by changing the weighting scheme to suit the project's goals. Maintaining three separate regions in the analysis provided the flexibility needed if one of these 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 the site selection process, eliminating the use of that area. The fifth step, final qualitative transect surveys, 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 final site selection process.

Observed decapod crustacean densities, 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 & Micheli 2001; Whitman & 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.

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 & Adriano 2001; Montgomery & 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 surveys of larval settlement would benefit from adding a layer of find sand on top of the artificial turf to more closely approximate preferred habitat and natural conditions. However, the trade-off to this approach is the loss of 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.

Although the post-deployment assessment programme is only 2 years into developing a long-term time series on the biological development of the artificial reefs, these data have already demonstrated that the site selection model was successful in allowing us to place the artificial reefs in an area with a natural larval supply. Within months of the artificial reef deployment, larval settlement of various invertebrate species on the artificial reefs was statistically similar to that on the nearby natural reef (J. Barber, R. Glenn, K. Whitmore unpubl. data). YOY lobster were also recorded in similar densities between the artificial reefs and the natural reefs in both 2006 and 2007.

The artificial reefs had the highest relative species diversity index of all the sites when considering only enumerated species. However, the diversity index values were the lowest on the artificial reefs, and the highest on the natural reef, when considering trends in species data on species assessed using percentage cover estimates. These differences are intuitive because one would expect the artificial reefs to quickly attract mobile invertebrates (or fast recruiting sessile invertebrates) and fish species that prefer complex habitat with high relief, whereas sessile, slower-growing species take longer to settle and establish, explaining why their diversity levels were relatively lower on the artificial reefs in comparison with the natural reef. For both analyses, however, artificial reef diversity is becoming more similar through time to that of the natural reef, perhaps indicating that the artificial reefs are reaching an established state similar to that of the natural reefs.

ACKNOWLEDGMENTS

We thank the following colleagues for their assistance with this project: B. Estrella, R. Kessler, A. Leschen, V. Malkoski, D. Perry, T. Pugh, M. Rousseau, S. Stielow, S. Voss, and S. Wilcox. Capts. J. Barrett, J. Carver, and W. Kelley provided invaluable assistance with the settlement collector portion of this study. K. Castro and J. DeAlteris offered advice that contributed to the initial development of the site selection process. J. Dimond provided discerning guidance throughout this process. This paper is contribution no. 22 of the Massachusetts Division of Marine Fisheries.

REFERENCES

Ambrose RF 1994. Mitigating the effects of a coastal power plant on a kelp forest community: rationale and requirements for an artificial reef. Bulletin of Marine Science 55: 694–708.

Ardizzone GD, Gravina MF, Belluscio A 1989. Temporal development of epibenthic communities on artificial reefs in the central Mediterranean Sea. Bulletin of Marine Science 44: 592–608.

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

Auster PJ, Malatesta RJ, Langton RW, Watling L, Valentine PC, Donaldson CLS, Langton EW, Shepard AN, Babb IG 1996. The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (Northwest Atlantic): implications for conservation of fish populations. Reviews in Fisheries Science 4: 185–202.

Baynes TW, Szmant AM 1989. Effect of current on the sessile benthic community structure of an artificial reef. Bulletin of Marine Science 44: 545–566.

Bigelow HB, Schroeder WC 2002. The fishes of the Gulf of Maine. 3rd ed. In: Collette BB, Klein-MacPhee G ed. Washington, Smithsonian Institution Press. 748 p.

Bohnsack JA, Sutherland DL 1985. Artificial reef research: a review with recommendations for future priorities. Bulletin of Marine Science 37: 11–39.

Carter JW, Jessee WN, Foster MS, Carpenter AL 1985. Management of artificial reefs designed to support natural communities. Bulletin of Marine Science 37: 114–128.

Chang KH 1985. Review of artificial reefs in Taiwan: emphasizing site selection and effectiveness. Bulletin of Marine Science 37: 143–150.

Cobb JS 1971. The shelter-related behavior of the lobster *Homarus americanus*. Ecology 52: 108–115.

Collie JS, Escanero GA, Valentine PC 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. Marine Ecology Progress Series 155: 159–172.

Cruz R, Adriano R 2001. Regional and seasonal prediction of the Caribbean lobster (*Panulirus argus*) commercial catch in Cuba. Marine and Freshwater Research 52: 1633–1640.

Dixon MS 1987. Habitat selection in juvenile tautog, *Tautoga onitis,* and juvenile cunner, *Tautogolabrus adspersus*. Unpublished MSc thesis, University of Connecticut, United States. 77 p.

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

Duzbasilar FO, Lok A, Ulas A, Metin C 2006. Recent developments on artificial reef applications in Turkey: hydraulic experiments. Bulletin of Marine Science 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 p.

Freese L, Auster PJ, Heifetz J, Wing BL 1999. Effects of trawling on seafloor habitat and associated invertebrate taxa in the Gulf of Alaska. Marine Ecology Progress Series 182: 119–126.

Gordon Jr. WR 1994. A role for comprehensive planning, geographical information system (GIS) technologies and program evaluation in aquatic habitat development. Bulletin of Marine Science 55: 995–1013.

Hueckel GJ, Buckley RM 1982. Site selection procedures for marine habitat enhancement in Puget Sound, Washington. Washington Department of Fisheries Technical Report No. 67. 82 p.

Hueckel GJ, Buckley RM, BL Benson 1989. Mitigating rocky habitat loss using artificial reefs. Bulletin of Marine Science 44: 913–922.

Incze LS, Wahle RA, Cobb JS 1997. Quantitative relationships between postlarval production and benthic recruitment in lobsters, *Homarus americanus*. Marine and Freshwater Research 48: 729–743.

Kaiser MJ 2006. The Louisiana artificial reef program. Marine Policy 30: 605–623.

Kennish R, Wilson KDP, Lo J, Clarke SC, Laister S 2002. Selecting sites for large-scale deployment of artificial reefs in Hong Kong: constraint mapping and prioritization techniques. ICES Journal of Marine Science 59: S164–S170.

Knebel HJ 1993. Sedimentary environments within a glaciated estuarine-inner shelf system: Boston Harbor and Massachusetts Bay. Marine Geology 110: 7–30.

Krebs CJ 1999. Ecological methodology. 2nd ed. New York, Addison-Welsey Educational Publishers. 624 p.

Lawton P, Lavalli KL 1995. Postlarval, juvenile, adolescent, and adult ecology. In: Factor JR ed. Biology of the lobster *Homarus americanus*. San Diego, California, Academic Press. Pp. 47–88.

Lenihan HS, Micheli F 2001. Soft-sediment communities. In: Bertness MD, Gaines SD, Hay ME ed. Marine community ecology. Sunderland, Massachusetts, Sinauer Associates. Pp. 253–287.

Mathews H 1985. Physical and geological aspects of artificial reef site selection. In: D'Itri FM ed. Artificial reefs: marine and freshwater applications. Michigan, Lewis Publishers. Pp. 141–148.

Montgomery SS, Craig JR 2003. Effects of moon phase and soak time on catches of *Jasus* (Sagmariasus) *verreauxi* recruits on collectors. Marine and Freshwater Research 54: 847–851.

Nakamura M 1982. The planning and design of artificial reefs and tsukiiso. In: Vik SF ed. Japanese artificial reef technology, Technical Report 604. Bellair Bluffs, Florida, Aquabio. Pp. 49–66.

Packer DB, Cargnelli LM, Griesbach SJ, Shumway SE 1999. Sea scallop, *Placopecten magellanicus*, life history and habitat characteristics. Essential fish habitat source document, NOAA Technical Memorandum NMFS-NE-134. 30 p.

Pratt JR 1994. Artificial habitats and ecosystem restoration: managing for the future. Bulletin of Marine Science 55: 268–275.

Pope DL, Moslow TF, Wagner JB 1993. Geological and technological assessment of artificial reef sites, Louisiana Outer Continental Shelf. Ocean and Coastal Management 20: 121–145.

Reed DC, Schroeter SC, Huang D, Andersen TW, Ambrose RF 2006. Quantitative assessment of different artificial reef designs in mitigating losses to kelp forest fishes. Bulletin of Marine Science 78: 133–150.

Sheng YP 2000. Physical characteristics and engineering at reef sites. In: Seaman W ed. Artificial reef evaluation with application to natural marine habitats. New York, CRC Press. Pp. 51–94.

Signel RP, Butman B 1992. Modeling tidal exchange and dispersion in Boston Harbor. Journal of Geophysical Research 97: 15591–15606.

Sokal RR, Rohlf FJ 1995. Biometry. New York, WH Freeman & Company. 887 p.

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

Spieler RE, Gilliam DS, Sherman RL 2001. Artificial substrate and coral reef restoration: what do we need to know to know what we need. Bulletin of Marine Science 69: 1013–1030.

Stephan CD, Dansby BG, Osburn HR, Matlock GC, Riechers RK, Rayburn R 1990. Texas artificial reef fishery management plan. Texas Parks and Wildlife Department, Coastal Fisheries Branch. 28 p.

Thanner SE, McInosh TL, Blair SM 2006. Development of benthic and fish assemblages on artificial reef materials compared to adjacent natural reef assemblages in Miami-Dade County, Florida. Bulletin of Marine Science 78: 57–70.

Tseng C, Chen S, Huang C, Liu C 2001. GIS-assisted site selection for artificial reefs. Fisheries Science 67: 1015–1022.

Tupper M, Boutilier RG 1995. Effects of habitat on settlement, growth, and postsettlement survival of Atlantic cod (*Gadus morhua*). Canadian Journal of Fisheries and Aquatic Sciences 52: 1834–1841.

Tupper M, Boutilier RG 1997. Effects of habitat on settlement, growth, predation risk and survival of a temperate reef fish. Marine Ecology Progress Series 151: 225–236.

US 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. 61 p.

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

Wahle RA 1992. Substratum constraints on body size and the behavioral scope of shelter use in American lobster. Journal of Experimental Marine Biology and Ecology 159: 59–75.

Wahle RA, Steneck RS 1991. Recruitment habitats and nursery grounds of the American lobster *Homarus americanus*: a demographic bottleneck? Marine Ecology Progress Series 69: 231–243.

Wahle RA, Steneck RS 1992. Habitat restriction in early benthic life: experiments on habitat selection and *in situ* predation with the American lobster. Journal of Experimental Marine Biology and Ecology 157: 91–114.

Wentworth CK 1922. A scale of grade and class terms for clastic sediments. Journal of Geology 30: 377–392.

Whitman JD, Dayton PK 2001. Rocky subtidal communities. In: Bertness MD, Gaines SD, Hay ME ed. Marine community ecology. Sunderland, Massachusetts, Sinauer Associates. Pp. 339–366.

Wilson CA, Van Sickle VR, Pope DL 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 p.

Yoshimuda N, Masuzawa H 1982. Discussion of installation planning. In: Vik SF ed. Japanese artificial reef technology, Technical Report 604. Bellair Bluffs, Florida, Aquabio. Pp. 137–146.

Zar JH 1999. Biostatistical analysis. 4th ed. New Jersey, Prentice Hall. Pp. 196–200.