Final Programmatic Report

National Fish and Wildlife Foundation
Hurricane Sandy Coastal Resiliency Competitive Grants Program Grant ID No. 44199
Designing a plan to reuse dredged rock to protect the Boston Harbor shoreline (MA)
Updated 2/19/2018

EXECUTIVE SUMMARY

This project designed a plan to reuse dredged rock for the purpose of reducing wave energy along a section of shoreline in Boston Harbor, Massachusetts. The Army Corps will be widening and deepening parts of Boston Harbor for navigational purposes. Rock is present in the project footprint and will be dredged or blasted for removal. The default plan is to dispose of the rock material at the Massachusetts Bay Disposal Site, located 22 miles east of Boston Harbor in 200 feet of water. The project partners assessed if, how, and where this rock material could be beneficially reused for shoreline protection and provide a wave break to allow for eelgrass to be planted shoreward of the material disposal site.

An interagency steering committee that included representatives from the Massachusetts Division of Marine Fisheries, Office of Coastal Zone Management, The Nature Conservancy, Northeastern University, the City of Boston, and the U.S. Army Corps of Engineers oversaw this project. An engineering firm, Applied Coastal Research and Engineering, conducted engineering assessments. A Working Group provided guidance and feedback; the Working Group included representatives from municipal, state, and federal government, non-governmental organizations, and academia. Between October 2014 and November 2016 the project partners held five working group meetings, conducted desktop and in-water site selection work, developed conceptual plans for how to build out two sites, and began initial pre-permitting field work to characterize the sites.

Initial site selection utilized GIS analysis to exclude sites with negative characteristics for reef building such as navigation channels and existing high value habitat (e.g. eelgrass). Thirty-three potential sites identified by the Working Group and through meetings with municipalities were then ranked with a model that included feasibility variables such as utility of dredged rock use, potential suitability for eelgrass, and the relative importance of variables such as public value. We selected one site that could use dredge material, and one that would need an engineered breakwater. This was done because the Army Corps dredged rock estimate was reduced from 1 million cubic yards (cy) to 240,000 cy and perhaps as low as 10,000 cy, effectively reducing available reuse materials to allow build-out at only one site. We were also interested in learning more about potential sites where the dredge material might contribute to an engineered structure, by serving as core material for example. The final two sites, Gallops Island, Boston and Devereux Beach, Marblehead, were selected after ranking and discussions with municipalities. The reuse of dredged material for an artificial reef/nearshore berm at Gallops Island was identified as a feasible reuse option. However, Devereux Beach, due to its high energy, requires an engineered breakwater design, preventing the exclusive reuse of dredge rock as an option for this site.

Hydrodynamic modeling was used to create conceptual reef/breakwater designs that would provide some shoreline protection but not impede sediment movement along the shoreline. In order to achieve

shoreline protection value in the tide ranges at the two sites, a berm or breakwater that extends above water at low tide will be necessary at both sites.

A key limitation in determining beneficial reuse options turned out to be limited knowledge of the quantity and grain size of the dredge material. At best we could assume the dredge material would be a mix of rocky and fine grained sediment. Disposing of material nearshore introduces concerns about the fate of the dredged material. Without clear knowledge of the quantity and grain size of the material, quantifying shoreline protection benefits is impossible. Since project performance criteria cannot be defined or measured, the risk of expected and unintended consequences (including habitat burial, high organic content sediment washing ashore, widespread habitat impacts as the sediment moves around, increased turbidity at the disposal site) is generally thought to be too high. If the material is less rocky, and more appropriate for creating a subtidal nearshore berm, there will not be wave attenuation benefits on the shoreline and the risk of incompatible materials washing ashore is thought to be high. If the material is larger rock, higher elevation nearshore berms and breakwaters may achieve shoreline protection performance standards, but may also represent higher risk of instability in a high energy storm. Introducing sediment into a littoral system may have significant benefits, but may also have unintended consequences if the sediment doesn't end up where it is needed.

An important decision point was to separate this project from the Army Corps Boston Harbor Deep Draft Navigational Improvement Project. Since the permitting timelines did not coincide, and potential sites were not available while the navigation project was being developed, a regulatory subcommittee recommended permitting the reef building separately from the navigational dredging project. This introduced flexibility with respect to the timeline and allowed more time to better gauge the type of rock material needed for reef building and available from the dredge project. The reef permit applications could identify the dredged rock material or other materials to be used for reef construction.

Gallops Island was ultimately selected as the site to develop. The site characterization work identified that the Devereux Beach site is located proximal to a heavily used recreational swimming area, surfing area, lobster habitat, productive shellfish grounds, and a popular beach. Furthermore, the site will require an engineered breakwater structure, so would require significant funding resources beyond those available to beneficially use the dredge material. Gallops Island had a mixed seafloor, estimated to be similar to that of the dredge material, an unremarkable biological environment, and a low risk of unintended consequences. Gallops was deemed a better site for further consideration of beneficial reuse of dredge rock for shoreline protection via wave attenuation. A plan and timeline for permitting and developing an artificial reef at Gallops was the final product of this project.

Introduction

Geographic Context

The focus of our project is Boston Harbor, Massachusetts. Massachusetts has 1,500 miles of shoreline with 31% of its population residing in coastal municipalities. Coastal counties in Massachusetts have seen a more than 30% increase in population since 1960. Population densities for Massachusetts' coastline counties rank third highest in the nation, behind only New York and New Jersey (U.S. Census Bureau, 2008). This project will benefit communities within the Greater Boston area (Figure 1). Portions of this project have potential to influence projects throughout the entire Commonwealth of Massachusetts.

Sea level rise is projected to rise between 2 and 6 feet in Boston Harbor by the end of the century (CZM 2013), leading to increases in the extent and frequency of coastal flooding and erosion. State agencies are concerned about the future impacts of sea level rise and increased storm impact and have actively assessed coastal hazards for many years. The Massachusetts Office of Coastal Zone Management (CZM) launched a StormSmart Coasts initiative in 2008 to help address challenges arising from erosion, flooding, storms, sea level rise, and other climate change impacts. In Massachusetts, erosion and accretion rates have been measured, inundation scenarios are available, and public coastal engineering structures have been assessed and prioritized based on their condition and what they protect for all MA coastal communities (DCR 2009). The assessment of private coastal engineering structures characterizes the extent of armoring, but does not assess condition or prioritize needs. Adjacent to the large coastal population in Massachusetts are some of the most productive marine regions on the planet (Aquarone and Adams 2009). Many of the Gulf of Maine, Georges Bank, and Southern New England fish populations utilize nearshore rivers, streams, wetlands, and submerged aquatic vegetation resources as nurseries. Hard bottom structures also function as important habitats to several resident and migratory species. However, the threats to the nearshore environment due to human activities and climate change are continual. The US Fish and Wildlife Service reported that from 2004 through 2009 intertidal emergent wetlands experienced a habitat loss rate more than three times higher than the previous rate loss calculated for the period between 1998 and 2004 (Dahl 2011). Despite strict environmental regulations to stem the tide of

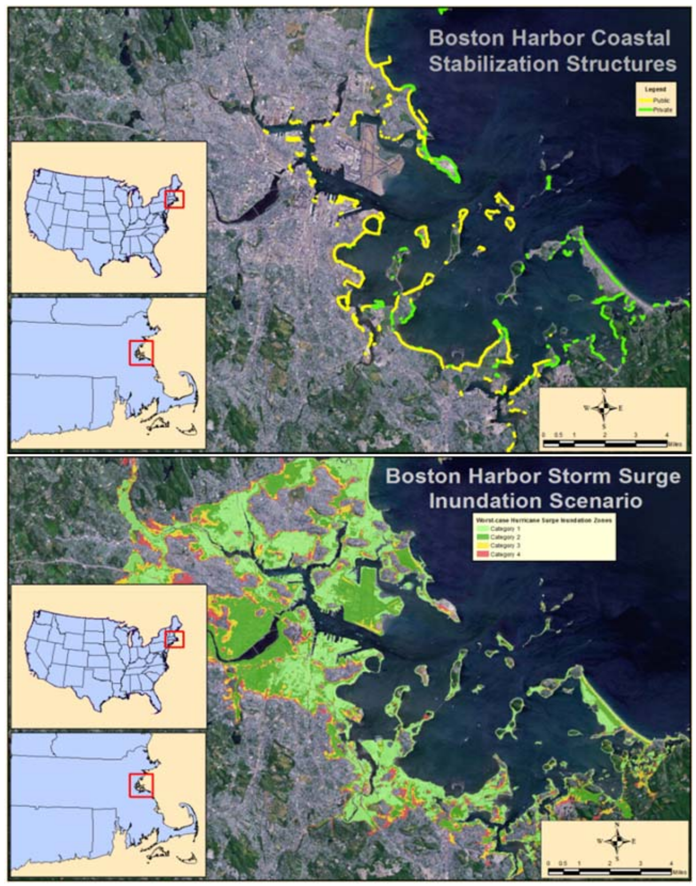

Figure 1. Maps of Boston Harbor, the project focus area, depicting coastal stabilization structure locations (top) and projected storm surge inundation scenario within the focus area (bottom). *Credits: MassCZM, DCR, USACE, FEMA, NOAA.*

wetland loss and habitat degradation, there are documented declines of several aquatic habitats including eelgrass, a critical fisheries habitat. Massachusetts lost more than 20% of its eelgrass between 1995 and 2001 in mapped embayments and coastal areas (Costello and Kenworthy 2011). The trend continues and widespread eelgrass decline is observed today. The Massachusetts Division of Marine Fisheries (DMF) has had an active eelgrass restoration program since 2004. The program targeted Boston Harbor as a primary eelgrass restoration location due to the dramatic improvement of water quality in the Harbor after improvements to wastewater management in the late 1990's. Despite improving water quality, the success of eelgrass transplants in the Harbor is somewhat checkered; the limiting factor at some sites is wave exposure (Evans pers comm).

Background

A major challenge facing Massachusetts is how to best protect vulnerable coastal areas while avoiding adverse environmental impacts. Maintenance activities for existing infrastructure traditionally involve the use of additional hard material. Seawalls, groins and breakwater systems are typically emergent structures that fundamentally alter coastal processes (Figure 2). In the face of uncertainty regarding the impacts of hardened structures on marine habitats current regulations and permitting in Massachusetts favor soft solutions for coastal protection, such as beach nourishment and bioengineering with natural fiber products and vegetation. In contrast, the creation of artificial reef habitat has been employed by many coastal states as an effective method of increasing fisheries productivity and augmenting fisheries habitats (Ditton et al. 2002; Figley 2004). There are five permitted artificial reef structures in Massachusetts that were created for fisheries benefit and research. In order to provide an operational framework for responsible siting and long term management of artificial habitats, Massachusetts developed an Artificial Reef Plan (Rousseau 2008). The Plan defines an artificial reef as an area within the marine waters of the Commonwealth in which approved structures have intentionally been placed or constructed for the purpose of enhancing benthic relief. A DMF study of an artificial reef installed in Boston Harbor in 2006 demonstrated that site selection models for determining reef material placement are successful in identifying areas with natural larval supply and settlement and that over time artificial reefs function similarly to the

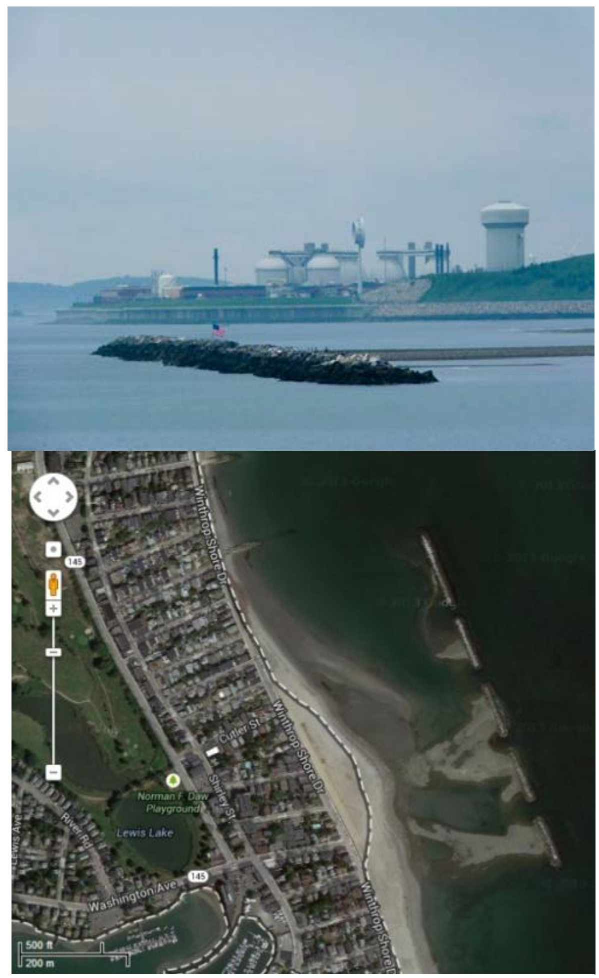

Figure 2. A traditional breakwater in Winthrop, MA (top). Below, the same breakwater shows dramatic impact on local sediment movement. *Credits: Steven James, Google Earth*

surrounding natural reef environments (Barber et al. 2009). To date the artificial reef projects in Massachusetts have occurred in deeper offshore habitats. There is interest among regulators and ENGO's in developing infrastructure solutions that can demonstrate benefits to both aquatic habitat and shoreline protection. With proper siting we predict that reefs can be placed nearshore to meet both biological and shoreline protection goals.

An estimated 240,000 cubic yards (cy) of rock will be removed from Boston Harbor in 2020 as part of a federal navigation channel dredging project conducted by the U.S. Army Corps of Engineers. The default disposal option for the dredged material is at a designated dredge disposal site 22 nautical miles off shore. If a beneficial use of the dredged rock material can be identified within 22 nautical miles of the dredging project there are cost-share options for disposing of the material at an identified beneficial use site. A multi-organization team coalesced as the Boston Harbor Dredge Material Working Group in June 2013 to discuss beneficial reuse options for the dredged material. The Working Group includes representatives from DMF, CZM, MA Department of Environmental Protection (DEP), The Nature Conservancy (TNC), US Environmental Protection Agency (EPA), the Massachusetts Port Authority (MPA), Northeastern University (NEU), US Army Corps of Engineers (USACE), and the City of Boston's Conservation Commission. The group identified that in order to examine more options for beneficial reuse we need a better understanding of how artificial reefs can be used in the nearshore environment without adverse environmental impact.

In support of the Working Group, a planning grant was received from the National Fish and Wildlife Foundation. The grant funded the initial phases of site selection and characterization which have laid the foundation for permitting. The funded project had both a steering committee of project partners (DMF, CZM, TNC, NEU, USACE, and the City of Boston) and the full Working Group to promote dialogue and feedback regarding the use of dredge materials for shoreline protection (members are listed in Appendix A).

Project Goals

This project has one primary goal: to plan a shoreline protection project designed to attenuate wave energy and protect transplanted eelgrass through the creation of complex hard bottom habitats. This planning project is intended to inform specific recommendations for the beneficial re-use of approximately 240,000 cubic yards (cy) of rock that will be dredged from the Boston Harbor federal navigation channel.

The specific deliverables for this project are a document identifying two potential locations to construct an eelgrass bed and artificial reef sited to achieve infrastructure protection, and a plan document clarifying the Boston Harbor Dredged Material Working Group's perspective on the potential beneficial re-use of dredged rock.

This project included three primary phases:

Phase 1: Site selection

Phase 2: Hydrodynamic modeling and design

Phase 3: Plan development

Phase 1 includes text and figures from DMF, Northeastern University, and Applied Coastal Research and Engineering. Phase 2 includes text and figures from Applied Coastal Research and Engineering. Phase 3 includes text and figures from DMF and The Nature Conservancy.

Definitions

Using the proper terminology for the proposed structure is a challenge since established definitions for coastal structures overlap and certain user groups may have unique preconceived notions of what the terms means. The definitions relevant to our primary project type are as follows:

> Artificial reef – structures, either natural or man-made, which have intentionally been placed or constructed for the purpose of enhancing benthic relief. This definition was taken from the Massachusetts Artificial Reef Policy (Rousseau 2009). Note that this broad definition does not assume biological enhancement, although that is commonly why artificial reefs are placed.
>
> Nearshore berm – is an "artificial berm built in shallow water using dredge material. Often, the berm is intended to renourish the adjacent and downdrift shore over time under the influence of waves and currents" (U.S. ACE 2006). These features are also called offshore berms, and their purpose "is to absorb part of the wave energy approaching a beach so that the wave climate at the beach is less severe" (PIANC 1992). An offshore berm is "generally a submerged formation" which "may gradually erode and be dispered" (PIANC 1992). A nearshore/offshore berm is distinct from a beach berm.
>
> Breakwater– "a structure employed to reflect or dissipate the energy of water and thus prevent or reduce wave action in an area it is desired to protect" (U.S. ACE 1986). In our application, we use the term to exclusively refer to a potential rubble-mound breakwater, "typically constructed with one or more stone underlayers and a cover layer composed of stone or specially shaped concrete armor units" (U.S. ACE 1986). A breakwater is also defined as "a man-made structure protecting a shore area, harbor, anchorage, or basin from waves. A harbor work" (U.S. ACE 2006). A berm breakwater is defined as a "rubble mound structure with horizontal berm of armor stones at about sea level, which is allowed to be (re)shaped by the waves" (U.S. ACE 2006). However, a manual describing the design of berm breakwaters describes wide stone-armored structures that extend well above sea level (Van der Meer and Sigurdarson 2017), suggesting that the term berm breakwater is used fairly broadly.
>
> Bar – "a submerged or emerged embankment of sand, gravel, or other unconsolidated material built on the sea floor in shallow water by waves and currents" (U.S. ACE 2006). This terminology rarely refers to built structures, so it is not used in this report.

This report primarily describes two major conceptual project types:

1. Artificial reef (nearshore berm) – this terminology refers to structures built by disposing of a mound of material on the seafloor in the nearshore environment (not on the beach). For this project, the project goal is to reduce wave energy (as opposed to providing nourishment to a nearby beach). Some material, particularly finer grain sized material, might move off of the structure, but the rock material is expected to remain largely in place.
2. Artificial reef (breakwater) – this terminology refers to structures requiring more than basic disposal of material on the seafloor. Instead, the structure would be designed specifically as a

breakwater, with no expectation that the material would move. In such a structure, the dredge material would likely serve as an underlayer core material, which would then be covered by stones of a specific (large) grain size.

In cases where either term applies, “artificial reef” or “nearshore berm/breakwater” or “artificial reef nearshore berm/breakwater” may be used.

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Phase 1A: Desktop Site Selection

Introduction

In order to determine where to place an artificial reef for shoreline protection purposes, our first step was to utilize a statewide site selection tool for artificial reefs that was developed primarily to site recreational fishing reefs. This tool was designed to consider where the placement of structure will create or enhance habitats that provide added ecological benefits to important marine species and habitats, and where the addition of structure will not inhibit existing uses. The tool was designed by DMF using ESRI ArcGIS 10.2. The initial work on this tool started in around 2010, but the tool was optimized for this project in 2014.

The GIS siting tool assembles 35 geo-referenced datasets of human uses, habitats, and areas of historical value that have relative importance to artificial reef site-selection within the waters of the Commonwealth. Using this tool, users can click on a grid cell and receive information on what underlying uses and habitats occur within that cell and the overall rank of the cell according to suitability for reef building.

Final selection of reef sites requires site-specific groundtruthing to verify the model outputs, including sediment verification, species presence, unpublished areas of historical or archaeological significance, and other parameters. All potential sites are subject to additional review by local, state, and federal resource agencies once the permitting process is initiated.

Important Qualifiers and Exclusions

Some important factors to consider when using this tool for artificial reef siting:

- This tool is specific to artificial reef siting. Users seeking instruction on suitable materials for reefing, reef permitting, or other information relevant to artificial reefs should consult the Massachusetts Marine Artificial Reef Plan (Rousseau 2008).
- This may not be a comprehensive index of all uses or habitats along the Massachusetts coast. Spatial data is constantly evolving and habitat information, existing uses, and regulations may change, requiring updates.
- Important, complex siting criteria for artificial reefs such as current regimes, sediment transport, wave action, high energy areas (sand waves) and others are important to the placement and design of structured habitats and are not included in this tool.
- This tool does not assess habitats in terms of ecological function or importance. For example, species such as cod utilize several habitat types during different life history stages.

- Natural heritage and endangered species habitats and unpublished areas of historical or archaeological importance require separate consultations through permitting and are not included here.
- This tool utilizes many different forms and scales of available spatial data, requiring additional site-specific verification.
- This tool does not consider the natural rarity of a habitat type or current habitat trends (i.e. expansion or contraction of eelgrass beds).
- Artificial reefs sited specifically to increase shellfish habitat may be subject to additional regulations by the U.S. Army Corps of Engineers (USACE), The MA Department of Environmental Protection (DEP) and municipal conservation commissions. Users seeking further guidance for activities specific to siting structures that include shellfish should consult the Massachusetts Division of Marine Fisheries Shellfish Planting Guidelines (Hickey et al. 2015).

Methods

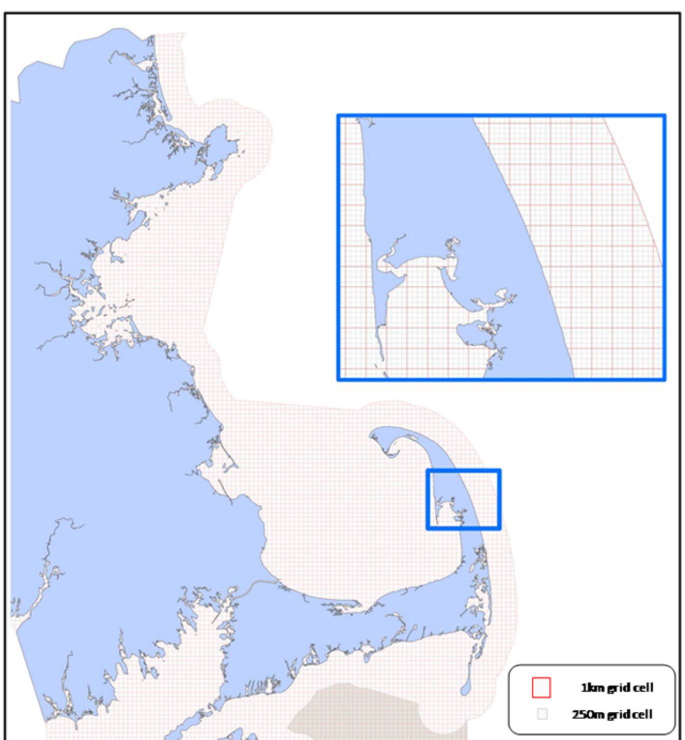
Input data layers included relevant spatially referenced data available from MassGIS, CZM's Massachusetts Ocean Resource Information System (MORIS) and DMF as of 2014. Thirty-five (35) separate GIS data sets were grouped into three separate assessment categories:

Category 1: existing use exclusions

Category 2: slope and substrate

Category 3: conditional, non-exclusionary

For each category, point, line, and polygon data were spatially joined to a 250 m x 250 m vector grid and then clipped to the MA coastline and the MA three-mile jurisdictional ocean boundary including Nantucket Sound (Figure 1A-1). Three criteria, suitable, unsuitable, or conditional, are used to calculate attribute scores within each grid cell. Any portion of a joined data layer that intersects or is contained within a grid cell generates a cell score. Cells without any joined data receive a score of 0 for that category. The total score of an individual cell is additive, meaning higher cell scores represent areas with more potential conflict, and are potentially less suitable for an artificial reef. A final layer is created using a traffic light analysis technique to delineate unsuitable (red), conditional (yellow), and suitable (green) cells by combining the final scores from the three categorical assessments.



Category 1: Exclusionary conditions

Category 1 uses presence/absence criteria to identify grid cells where exclusionary conditions may factor into reef siting. Seventeen (17) data layers were identified as having unsuitable characteristics for artificial reef siting (Table 1A-1). Data were grouped into four sub-categories; permitted infrastructure, navigation, designated uses, and mapped habitats. Presence of data occurring in any grid cell constitutes an unsuitable criteria designation and is scored as one (1), while absence is scored as zero (0). Cumulative scores resulting from multiple attributes present within the same grid cell are not calculated, as only one criterion present within a cell is sufficient for excluding an area from consideration for reef siting (Figure 1A-2).

Table 1A-1: Category 1 Exclusionary conditions

Grouping	Layer	Source
Permitted infrastructure	Tunnels	MORIS
	Pipelines	MORIS
	Cables	MORIS
	Marinas	MORIS
	Fish Weirs	DMF
	Artificial Reefs	DMF
	Public Shoreline Stabilization Structures	CZM/MassGIS
	Private Shoreline Stabilization Structures	CZM/MassGIS
Navigation	Designated Navigation Channels	MORIS/ NOAA Nautical Charts
	Ferry Routes	MORIS/ NOAA Nautical Charts
	Pilot Boarding areas	MORIS/ NOAA Nautical Charts
	Anchorage areas	MORIS/ NOAA Nautical Charts
Designated uses	Mooring areas	MORIS
	Designated Port Areas (DPA's)	MORIS
	Disposal sites	MORIS
	Publicized areas of historical significance	National Register of Historic Places
Mapped habitats	Seagrass	DEP Eelgrass Mapping Program all years

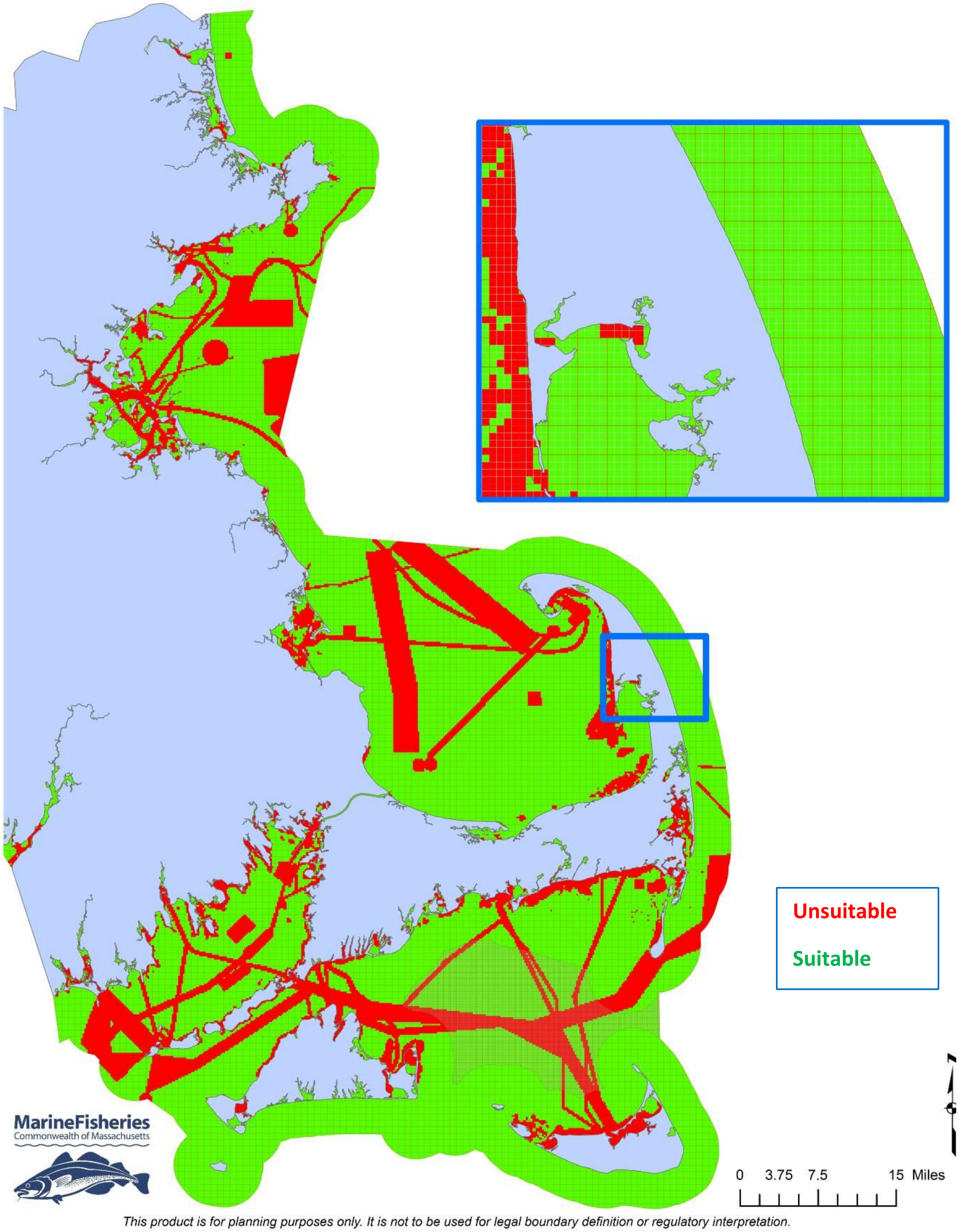


Figure 1A-2. **Results of the Category 1, exclusionary conditions, mapping.**

Category 2: Substrate and Slope

Suitable, conditional, or unsuitable substrate assessments employ four primary substrates types mapped by CZM and utilized in the 2015 Massachusetts Ocean Management Plan Baseline Assessment and Science Framework (CZM 2015). Sand (S) substrate is categorized as a most suitable for reefs, rock (R) is considered unsuitable, while mud (M) and gravel (G) are less than ideal substrate for reefs, but could be used under the right conditions. To assess slope, data were generated by converting a raster bathymetry image to point slope data change in degrees, then joining point data to the grid. Slope grid cell scores were generated based on greatest individual point value within a cell (Table 1A-2). Slope score category ranges employed work by Barber et al. (2009) to assign values >5˚ as unsuitable.

Slope and substrate cell scores were summed to generate a final score attribute for each grid cell, with final scores ranging from zero to four. Final values were adjusted into a range of 0 (suitable), 1 (conditional) or 2 (unsuitable) (Table 1A-3). Cell scores of 2 or greater were considered unsuitable when either slope or substrate data within a grid cell equaled 2. A final score equal to two (2) was adjusted to a conditional (score=1) when both substrate and slope data within a grid cell were both scored as conditional (score=1). Figure 1A-3 illustrates the category 2 assessment results.

Table 1A-2: Category 2 Substrate and Slope

Substrate (Primary)	Sand	(Score=0. Suitable)
	Mud, Gravel	(Score=1. Conditional)
	Rock	(Score=2. Unsuitable)
Slope	<1˚	(Score=0. Suitable)
	0˚- 5˚	(Score=1. Conditional)
	>5˚	(Score=2. Unsuitable)

Table 1A-3: Category 2 Adjusted Score Summary

Slope Score	**Substrate Score**	**Final Score (slope + substrate)**	**Adjusted Final Score (AFS)**	**Justification for AFS**
0	0	0	0	Suitable – all categories equal 0
0	1	1	1	Conditional - 1 category equals 1
0	2	2	2	Unsuitable – 1 category equals 2
1	0	1	1	Conditional – 1 category equals 1
1	1	2	1	Conditional – 2 categories equal 1
1	2	3	2	Unsuitable – 1 category equals 2
2	0	2	2	Unsuitable – 1 category equals 2
2	1	3	2	Unsuitable – 1 category equals 2
2	2	4	2	Unsuitable – 2 categories equal 2

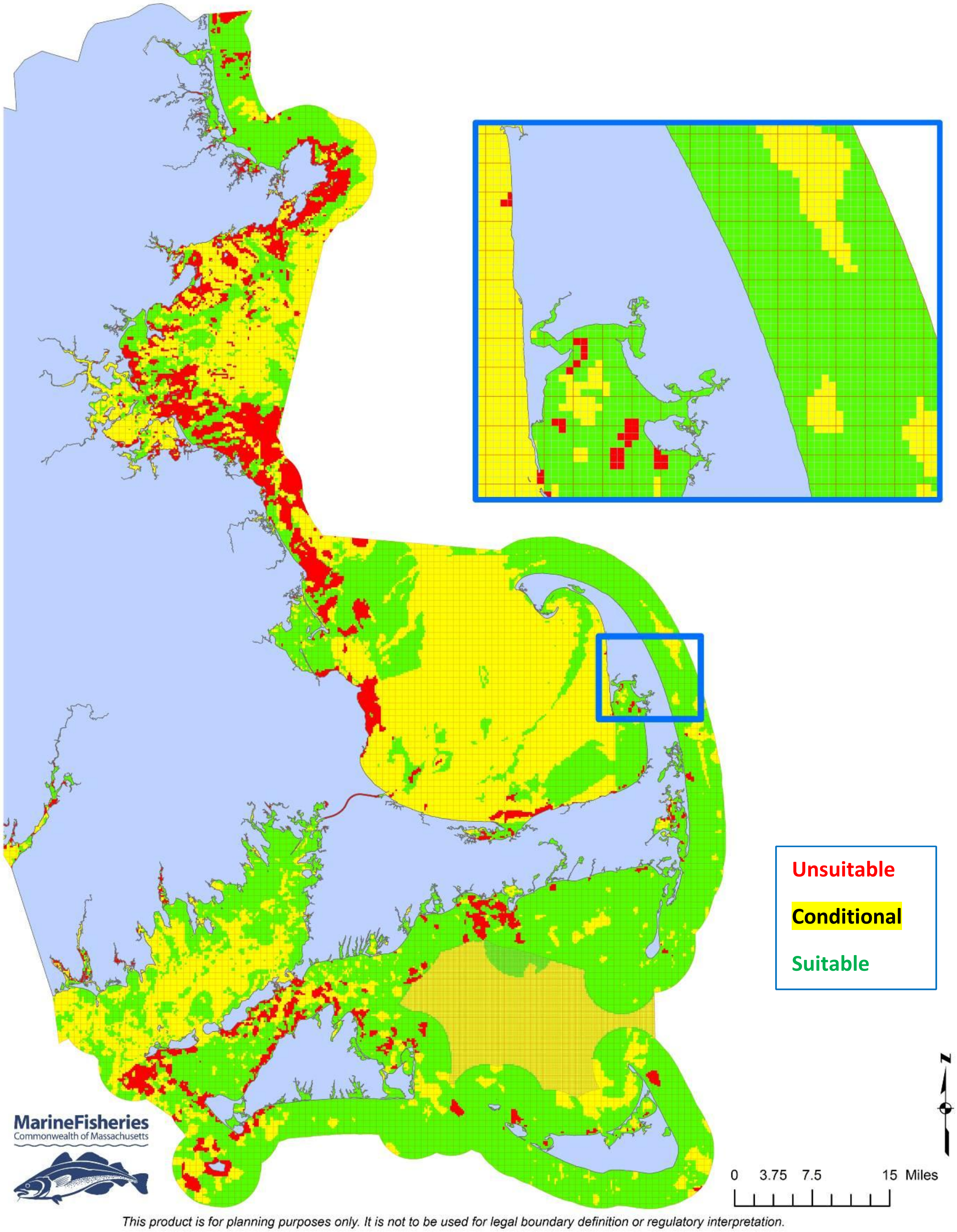


***Figure 1A-3*. Results of the Category 2, slope and substrate, mapping.**

Category 3: Non-exclusionary with conditions

Category 3 uses presence criteria to identify grid cells where non-exclusionary conditions may factor into reef siting. Eleven data layers were identified as having conditional, non-exclusionary characteristics (Table 1A-4). Data were grouped into four sub-categories; depth (<30', since recreational fishing reefs are better placed in deeper waters to avoid navigational concerns), regulated fishery closure areas, important habitat areas, and important areas/ temporary uses. Presence of any data in any grid cell constitutes a score of 1 (conditional). A final score attribute consisting of two scores, zero or one (0 or 1), were generated for mapping (Figure 1A-4). Joined attribute scores were summed to generate a final score attribute for each grid cell, with final scores ranging from zero to eleven, which were used in the combination of the three categories to make a final map.

Table 1A-4: Category 3 Non-exclusionary conditions

Depth	Bathymetry <30'	generated from bathymetry data layers
Regulated Fishery Closure Areas	Cod –spring & winter	DMF
	Winter Flounder	DMF
Important Habitat Areas	Shellfish Suitability	DMF/MassGIS
	Intertidal Flats	DEP/MassGIS
	Right Whale Critical	Ocean Plan/MORIS
	Humpback Core Habitat	Ocean Plan/MORIS
	Finback Core Habitat	Ocean Plan/MORIS
Important Areas/ Temporary Uses	Submerged Wrecks	MORIS
	Precautionary Areas	MORIS
	DMF Resource Assessment Historic Tows	DMF

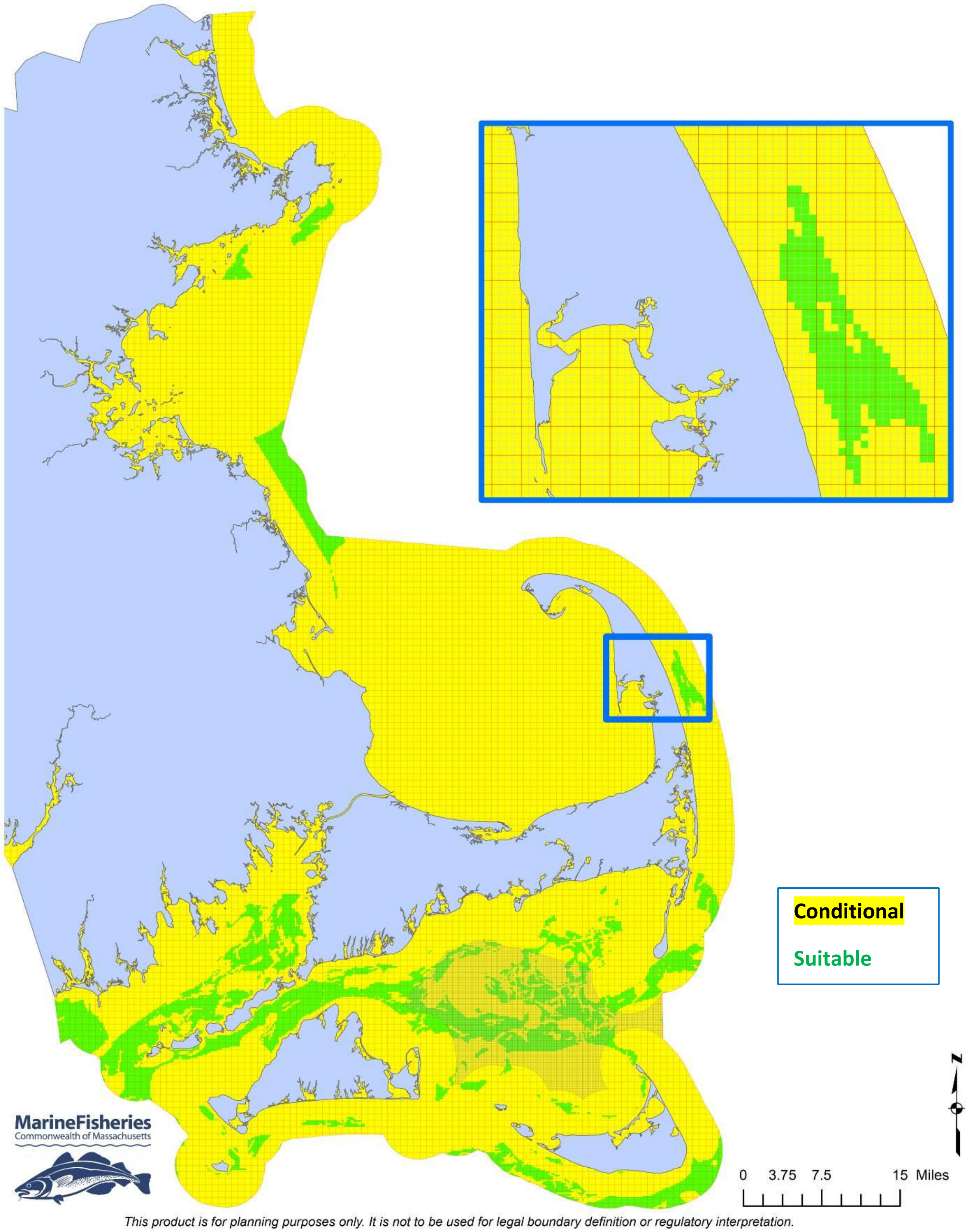


Figure 1A-4. **Results of Category 3, non-exclusionary conditions, mapping.**

Final mapping tool

The final mapping tool combines Category 1, 2, and 3 assessments into a single map. Grid cells classified as unsuitable in Category 1 or 2 assessments were re-coded to a cell value of 15 (Table 1A-5). This value is greater than the sum of all conditional criteria from category 2 and 3 combined. If a grid cell contains only conditional (non-exclusionary) data from Categories 2 and 3, the overlap was assessed by summing the number of layers occurring within that cell. These cumulative scores ranged between 1 and 13 (Table 1A-5). The final map generates the most restrictive classification for a cell by combining the scores from all three categories (Figure 1A-5). Exclusionary and conditional criteria within each grid cell could be ascertained by clicking on the "information" button in ArcGIS 10.2 (Figure 1A-6). Additional metadata is provided in Appendix B.

Table 1A-5: Artificial Reef Site Selection Matrix

Category 1. Existing use exclusions		**Criteria**			**Final Matrix Recoded Scores**		
Type	**GIS Layer**	**Suitable**	**Unsuitable**		**Suitable**	**Conditional**	**Unsuitable**
Permitted Infrastructure	Tunnels	0	1		0	NA	15
	Pipeline -Neptune LNG	0	1		0	NA	15
	Pipeline - Northeast Gateway LNG				0	NA	15
	Pipeline - Algonquin HubLine				0	NA	15
	Sewer lines	0	1		0	NA	15
	other pipelines (Pipeline Areas)	0	1		0	NA	15
	Cables	0	1		0	NA	15
	Cable Areas	0	1		0	NA	15
	Permitted Artificial Reef sites	0	1		0	NA	15
	Marinas	0	1		0	NA	15
	Private Shoreline Stabilization structures	0	1		0	NA	15
	Public Shoreline Stabilization structures	0	1		0	NA	15
	Permitted Fish Weirs	0	1		0	NA	15
Navigation	Navigation channels	0	1		0	NA	15
	Ferry Routes	0	1		0	NA	15
	Pilot Boarding Areas	0	1		0	NA	15
	Anchorage areas	0	1		0	NA	15
Designated Use	Designated Port Areas (DPA)	0	1		0	NA	15
	National register of historic places	0	1		0	NA	15
	Disposal Sites - active	0	1		0	NA	15
	Disposal Sites -inactive	0	1		0	NA	15
	Mooring Areas	0	1		0	NA	15
Mapped Habitats	Eelgrass	0	1		0	NA	15
	Category 1 Final Score (sum of scores) range	0	1-21	→	0	NA	15

Category 2. Slope and Substrate	**Criteria**

Type	GIS Layer	Suitable	Conditional	Unsuitable		Suitable	Conditional	Unsuitable
Slope	Bathymetry layer	0	1	2		0	1	15
Substrate	CZM layer	0	1	2		0	1	15
Category 2 Final Score (sum of scores) range		0	1-2	2-4	→	0	1-2	15

Category 3. Non exclusionary with conditions		Criteria				
Type	GIS Layer	Suitable	Conditional	Suitable	Conditional	Unsuitable
Depth	Bathymetry	0	1	0	1	NA
Regulated Fishery Closure Areas	Cod -spring Cod - winter	0	1	0	1	NA
	Winter Flounder	0	1	0	1	NA
Important Habitat Areas	Shellfish Suitability	0	1	0	1	NA
	Intertidal Flats	0	1	0	1	NA
	Right Whale Critical	0	1	0	1	NA
	Humpback Core Habitat	0	1	0	1	NA
	Finback Core Habitat	0	1	0	1	NA
	Submerged Wrecks	0	1	0	1	NA
Important Areas / Temporary Uses	Precautionary Areas	0	1	0	1	NA
	DMF RA Historic Tows	0	1	0	1	NA
Category 3 Final Score (sum of scores) range		0	1-11 →	0	1-11	NA

Final Matrix range of scores	Suitable	Conditional	Unsuitable
	0	1-13	15

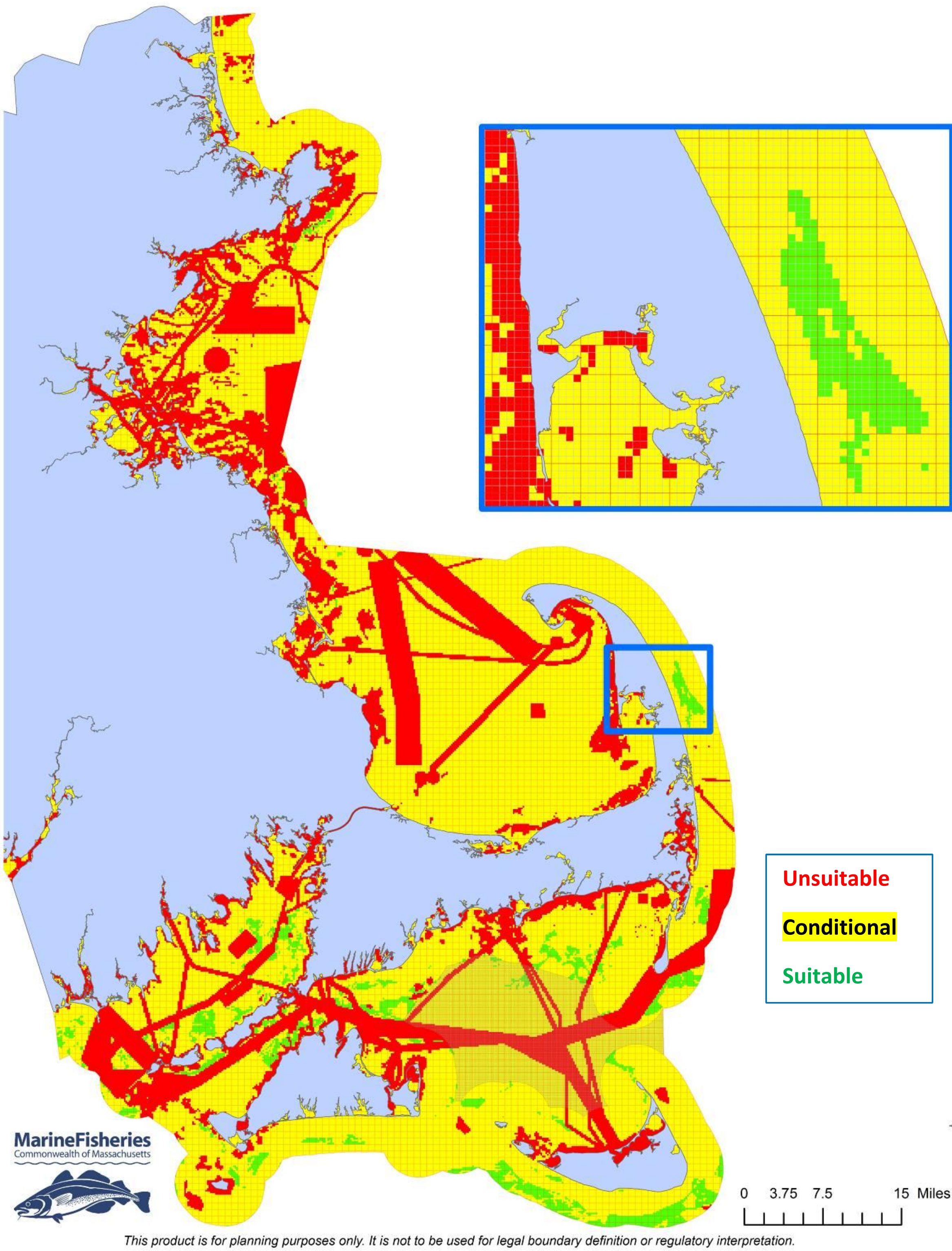


Figure 1A-5. **Final map combining all three categories.**

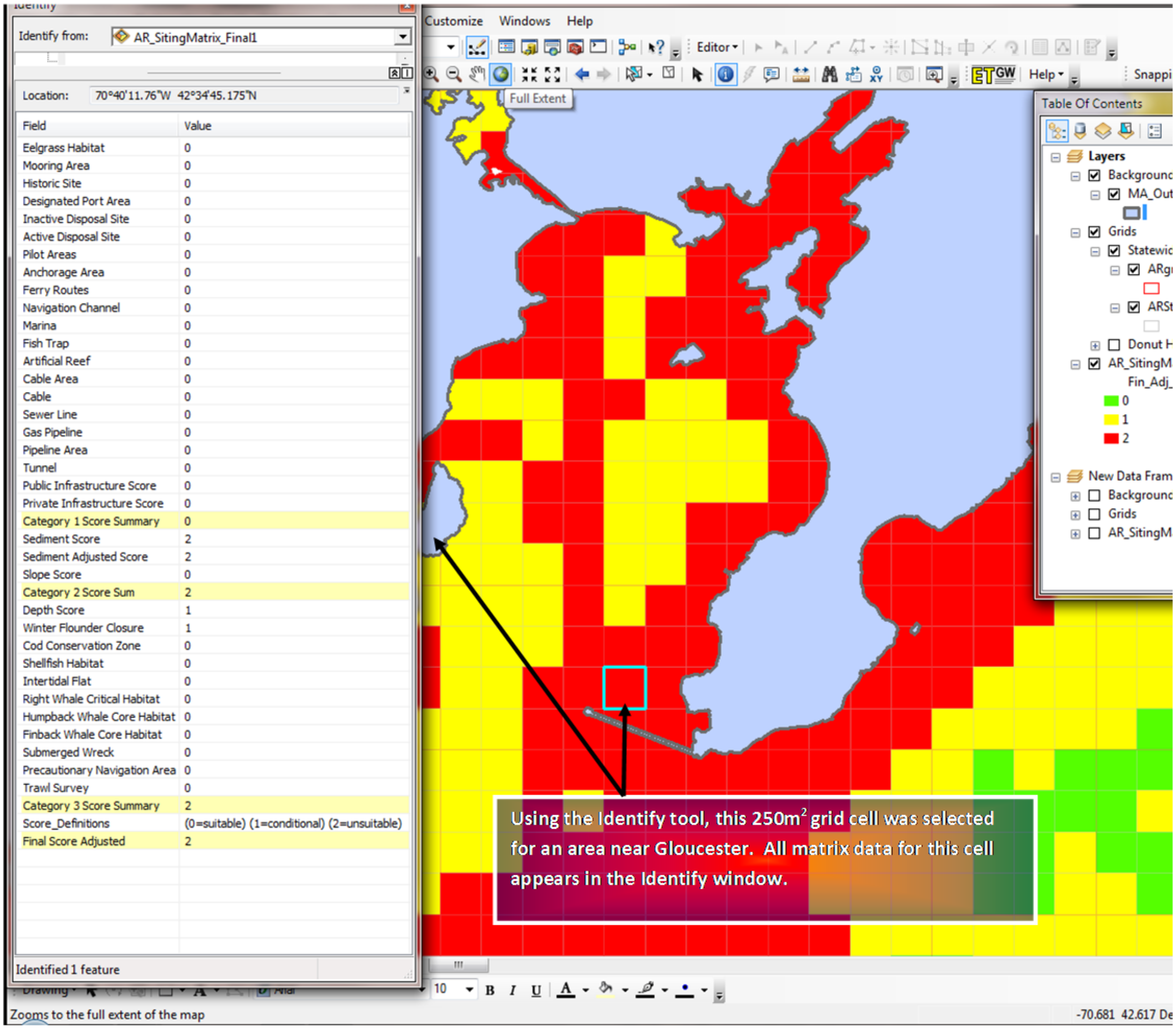


Figure 1A-6. **Clicking on a cell in the mapping tool produces a list of exclusionary and conditional criteria.**

Discussion

Our original intent was to use the tool to help identify potential sites. The primary limitation was that this approach did not connect well with identifying known shoreline protection needs. Furthermore, the existing data was coarse enough resolution that it limited our ability to truly know if a site was truly unsuitable. We ended up using the tool to identify potential conflicts and data needs for sites found by interviewing towns and shoreline protection experts, in Phase 1B, and to help with site characterization in Phase 1D.

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Phase 1B: Site Selection-Top 10 Sites

Introduction

Originally we anticipated that a desktop site selection and/or hydrodynamic modeling could identify sites needing protection. We found that those approaches were too coarse resolution and couldn't incorporate our specific project goals efficiently. It was more appropriate to use what amounts to a Delphi approach, a survey of experts, to identify potential sites. Our next step in site selection solicited local expert knowledge to specifically identify shoreline areas within a 22 mile radius of Boston that a) benefit from wave attenuation, b) feasible for reef building, c) feasible for rock material disposal, and d) feasible for eelgrass growth. This phase was completed by Applied Coastal Research and Engineering, a consulting company hired for this purpose.

A list of 33 candidate reef sites was developed through consultation with the Working Group, including input from DMF, the Department of Conservation and Recreation (DCR), and CZM. Also towns and other stakeholders (such as the regional coordinators for the Massachusetts Bays Estuary Program) were surveyed via email and phone. Additional sites were added to the list by Applied Coastal. These sites were then ranked, the ranking process tested for sensitivity, and 10 sites were identified for qualitative field assessments.

Town Surveys

Summary

As part of a project to site and design and artificial reef for shoreline protection, we assembled a working group to provide advice and feedback. At the first working group meeting, a desktop site selection model was presented. The primary feedback from the working group was to engage municipalities for the purposes of identifying sites and bringing additional expertise to the table. Through phone calls, emails, and working group meetings, 20 potential sites in 7 towns were identified. We were also able to gauge the municipality's level of interest in developing artificial reefs.

Methods & Results

Two staff members contacted municipal conservation agents, harbormasters, shellfish wardens, regional planners, and other contacts with municipal-level knowledge within the 22 nautical mile dredging radius via phone and email between February and March 2015. The following questions were used to guide the conversations:

- Are there sites with vulnerable shoreline?
- Are there sites where eelgrass could be restored?
- What sites would you target for an artificial reef or hard bottom enhancement? (With potential follow-up questions including are there spots where you would want to encourage people to fish? Are there spots where you would want to augment biological value?)
- Is there anyone else we should talk to?

Follow up calls and emails were made in May and June of 2015. A list of sites including town recommended sites and other sites identified by the working group, the steering committee, and the contracted engineering firm was presented to towns in September and October 2015 for additional feedback. The survey was concluded in October 2015. Twenty sites in 6 towns were identified (Table 1B-1, Figure 1B-1). Survey notes are provided in Appendix C.

Table 1B-1: Potential sites identified by towns

OBJECTID *	Shape *	Id	eelgrass	reef	shoreline	CityTown	Location	ContactNam
1	Point	0	unknown	unknown	yes	Salem	Salem Willows Pier	Tom Devine
2	Point	0	unknown	unknown	yes	Salem	Camp Naumkeg shoreline	Tom Devine
3	Point	0	unknown	unknown	yes	Salem	Collins Cove shoreline	Tom Devine
4	Point	0	unknown	unknown	yes	Manchester	Singing Beach	Bion Pike
5	Point	0	yes	unknown	unknown	Manchester	Manchester Harbor	Bion Pike
6	Point	0	unknown	unknown	yes	Manchester	Downtown Manchester	Bion Pike
7	Point	0	unknown	unknown	yes	Salem	Palmer Cove Yacht Club	Barbara Warren
8	Point	0	unknown	unknown	yes	Salem	Dion's Yacht Yard	Barbara Warren
9	Point	0	unknown	unknown	yes	Salem	Forest River Park	Tom Devine
10	Point	0	unknown	unknown	yes	Boston	Shaeffer Paper Mill	Rebecca Haney
11	Point	0	unknown	unknown	yes	Boston	Georges Islamd	Marc Albert
12	Point	0	yes	unknown	yes	Boston	Long Island	Phil Colarusso
13	Point	0	unknown	yes	unknown	Quincy	Long Island Bridge	Peter Fifield
14	Point	0	unknown	unknown	yes	Quincy	Nickerson Beach	Peter Fifield
15	Point	0	unknown	unknown	yes	Quincy	Edgewater Drive, Houghs Neck	Peter Fifield
16	Point	0	unknown	unknown	yes	Quincy	Wollaston beach	Peter Fifield
17	Point	0	unknown	unknown	yes	Quincy	Sea Street	Peter Fifield
18	Point	0	unknown	unknown	yes	Weymouth	Fort Point Road	Mary Ellen Schloss
19	Point	0	unknown	unknown	yes	Marshfield	North/South River	Jay Wennemer
20	Point	0	unknown	unknown	yes	Salem	Juniper Cove	Barbara Warren

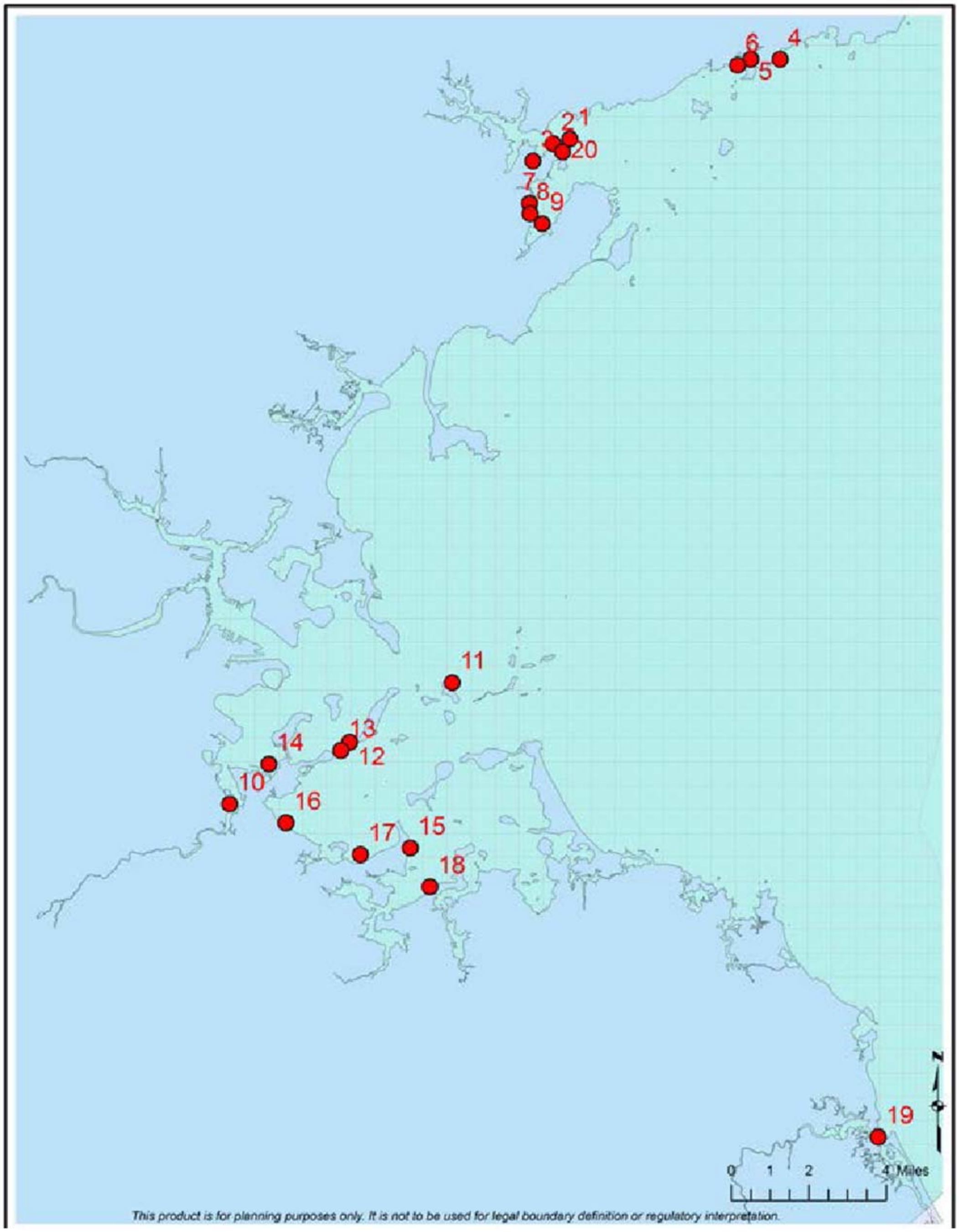

Figure 1B-1. **Locations of potential artificial reef sites cited in Table 1.**

Discussion

The questions helped to focus the conversation but our contacts did not answer them very directly and in some cases towns did not respond to our requests. However, the local knowledge was necessary to identify viable sites. Also, the town surveys allowed us to initiate outreach about this project.

Applied Coastal screening process for reef site selection

An understanding of the process for evaluating both the influences regarding eelgrass enhancement and shore protection associated with offshore reef construction is essential for ensuring that projects are sited appropriately to maximize both ecological and engineering aspects. It is understood *a priori* that construction of artificial reefs also can have potential adverse biological environmental impacts resulting from alteration of the seafloor; however, that assessment is beyond the scope of the present effort and is being evaluated separately by other members of the Working Group (Northeastern University and DMF). The screening methodology employed provides a way to systematically review and evaluate alternatives to ensure they meet the project goal to the maximum extent possible. This initial screening effort utilized available data sets as the basis for ranking the various screening criteria.

The first step in the alternative site screening analysis is formulating precise project purpose for the artificial reef project. The purpose leads to the scoping process during which a particular artificial reef project is described, reasonable alternative sites are determined, and a process is developed to objectively assess the various alternative sites. For the artificial reef, a dual project purpose was sought; shore protection to infrastructure at risk and eelgrass enhancement within the wave "shadow zone" created by the reef. Based on this project purpose, a logical evaluation process was developed to assess candidate sites as shown in (Figure 1B-2).

The primary emphasis of the site selection process is site screening. The goal of the screening process is to identify the most appropriate sites for an artificial reef project. Once exclusionary criteria are evaluated, the remaining potential sites are ranked based on a set of assessment criteria linked to the project goals. The screening process is designed to assess a wide range of potential sites, and through comparative analysis, narrow the list of sites until only the most appropriate sites remain.

Screening criteria are characterized as either exclusionary or discretionary. Exclusionary criteria reflect a situation that prevents the site from being considered because it cannot meet the project goals. For example, sites located in water that is too deep to support eelgrass would be deemed inappropriate and 'water depth' exclusionary criterion would prohibit further evaluation of the site.

Discretionary criteria are those that determine, when applied as a group, which artificial sites are least or best suited for shore protection and eelgrass enhancement. For example, the bottom sediment quality is evaluated under discretionary criteria: the presence of fine-grained substrate in a candidate site would not automatically exclude the site from further consideration, but it would identify that site as less desirable than one in which sandy substrate that was ideal for eelgrass was present. The application of discretionary criteria is the main component of the screening process, and it is the process by which sites are compared amongst themselves, using site-specific information to prioritize site appropriateness.

The screening process begins by evaluating candidate sites under the exclusionary criteria. Those that fail are excluded from further review and are not carried forward in the review. Sites that pass become potential alternatives. Potential alternatives then are reviewed using the discretionary criteria and assigned a relative ranking. Sites that have significant limitations receive low marks; sites with fewer limitations receive higher marks.

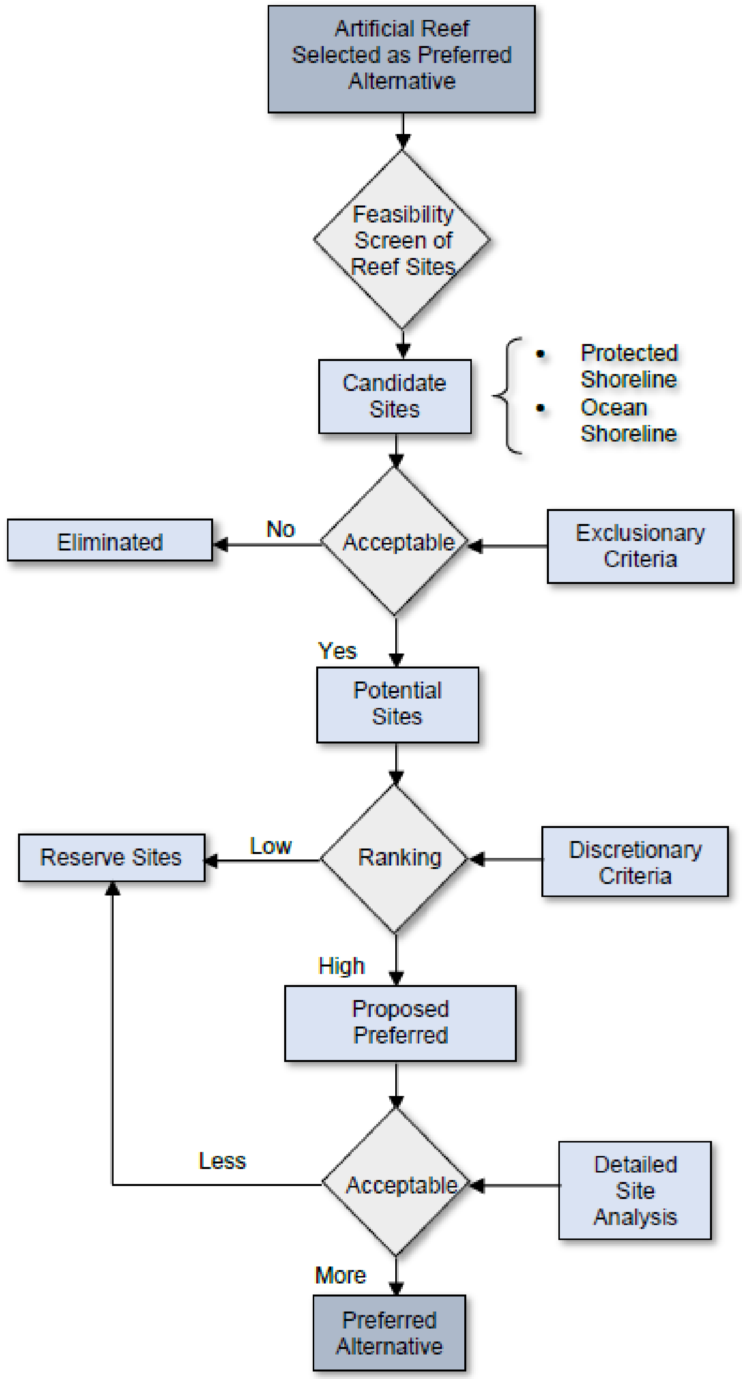

Figure 1B-2. **Screening process flowchart for the artificial reef project.**

The result is a continuum of sites, from least to most appropriate, under the criteria. Sites that are least appropriate are categorized as reserved, and, as the name implies, are carried forward in reserve but are not subject to further analysis. Sites that are more appropriate are categorized as potential alternatives. These sites are then subject to detailed, site-specific analysis. Sites that prove unacceptable under this detailed analysis are placed back in the reserved category; sites that prove acceptable are categorized as preferred alternatives and represent the sites recommended for evaluation in the Federal and State regulatory process.

Exclusionary Criteria

By definition, the proposed artificial reef project was required to be within a 22-mile radius of Boston Harbor, as this was the limit of transport distance from the Boston Harbor Deep Draft Navigation Improvement Project acceptable to the U.S. Army Corps (USACE). Greater transport distances would incur significant additional transport costs; therefore, potential sites outside this 22-mile radius were deemed unacceptable.

As one of the primary goals of the artificial reef is to enhance eelgrass resources, it is imperative that the reef be placed in a location suitable for eelgrass. One critical component for eelgrass is light penetration through the water column. While water clarity varies, eelgrass generally does not exist in the Massachusetts Bay region in water depths greater than 20-to-25 feet at low tide. An exclusionary criterion eliminated potential artificial reef sites in water depth exceeding 25 feet. An additional exclusionary criterion stipulated that the artificial reef site could not be placed within the limits of an existing eelgrass bed. During a Working Group meeting, the concept of excluding any site where eelgrass had historically been documented had been considered; however, the broad scale of anthropogenic changes within the region (specifically Boston Harbor) made this criterion too restrictive.

Finally, the proposed reef locations were not allowed to be placed within or along the border of an existing authorized navigation channel. Prior to the formal conceptual design process, it was not possible to determine the freeboard of the structures. Based on general wave attenuation literature, it was anticipated that the artificial reef structure(s) would be at or near the water surface for some tidal conditions; therefore, the reef would represent a navigation hazard which was deemed unacceptable.

Discretionary Criteria

1. Sediment Quality

A significant level of geophysical research has been performed in the Boston Harbor region, originally as part of the MWRA’s efforts for the Boston outfall and then followed by CZM-funded side-scan survey work performed by the U.S. Geological Survey. These datasets are available digitally and could be utilized to characterize the bottom sediment type including delineations between rock, gravel, sand, and mud. A numerical weighting for each candidate site was developed, where sandy substrate was determined to be most favorable to eelgrass propagation. The numerical rating system ranged from 5 for material that was predominantly sand to 1 for bottom sediments that were characterized as either mud or rock.

2. Water Clarity (Eelgrass Suitability)

Light penetration through the water column is critical to the survival of eelgrass. While it is understood that natural perturbations occur in water clarity, primarily as a result of storm activity either introducing fines through freshwater inflow or waves stirring up bottom sediments, long-term water clarity levels remain relatively stable. In open coastal areas of Massachusetts Bay, the overall water clarity is deemed excellent for eelgrass suitability. Within many of the estuarine and inner harbor areas, nutrient-laden inflow from upland development can often lead to decreased water clarity. Measurements of water clarity performed as part of MWRA’s monitoring efforts in Boston Harbor were utilized to assess sites in this water body. Other estuarine and/or harbor sites were assessed based on proximity to the open coast. The numerical rating system ranged from 5 for open coastal areas of Massachusetts and Cape Cod Bays to 1 for sites where water clarity is documented to be problematic for light penetration to the sea floor.

3. Public and Private Infrastructure

This combined category for shore protection benefits provided a potential score of 10: maximum of 7 for public infrastructure and 3 for private infrastructure. The heavier weighting towards public infrastructure protection was deemed appropriate, as the proposed artificial reef project is intended to be constructed using public funds. An acknowledgement of private shore protection benefits also is important, as shore protection is primarily a public safety benefit regardless of whether the infrastructure being protected is private or public in nature. The numerical ranking was based upon two criteria: the level of susceptibility and whether the protected infrastructure provided a critical service (e.g. protected critical utilities).

4. Community Desire

DMF contacted the various municipalities where candidate sites were located to determine the level of interest the community had towards having an artificial reef constructed within their borders. The numerical rating system ranged from 5 for communities that were favorable towards the concept to 0 for communities that did not express an interest. Unlike other discretionary criteria, community desire was an 'on-off switch', where the numerical ranking was either a 5 or 0.

5. Wave Environment

Both incident wave length and wave height can influence the amount of transmitted wave energy that the artificial reef can cause along the shoreline. In general, reef structures are most effective in relatively shallow water, where the structure can occupy a majority of the water column under all tidal conditions. The direct correlation between structure crest width and incident wave length on wave transmission make overall structure scale a concern for longer wave lengths (i.e. open ocean wave conditions). Moreover, in open ocean wave environments, wave set-up along the coast during storms can raise the ambient water level by 1-to-2 feet, making structures in these environments less effective during critical periods of storm activity. Additionally, exposure to open ocean wave conditions makes reef construction more difficult. The numerical rating system ranged from 5 for relatively sheltered shorelines that would not be exposed to any long period waves propagating to the shoreline from the ocean to 1 for sites openly exposed to east and northeast wave conditions generated in the North Atlantic Ocean.

6. Navigation Proximity

An exclusionary criterion dictated that the artificial reef structure could not be constructed within or immediately bordering an authorized navigation channel. In addition, a discretionary criterion was developed to ensure public safety related to navigation concerns, where close proximity to an authorized navigation channel and/or a mooring basin also was considered to be a detriment. The numerical rating system ranged from 4 for sites where no navigation channel exists and no mooring basin/piers/docks are in the vicinity to 1 for sites where navigation channels and other boat-related activity are a major safety concern.

7. Proximity to Loading Port

As project cost is a concern, potential transport of reef material to the candidate site was also deemed an appropriate discretionary criterion. Since many of the loading facilities within the Boston Harbor region have disappeared as the waterfront transitions away from its historic dependence on commercial shipping, the number of facilities where loading a marine barge with rock material has become a limiting factor. As detailed in an analysis for delivery of beach-compatible sediment to Winthrop Beach (Parsons Brinckerhoff, 2005), only one marine facility in the Boston Harbor region has access to rail service. Outside of Boston Harbor, few deep-draft facilities exist for loading barges with rock material for the proposed artificial reef. The numerical rating system ranged from 5 for sites where available loading facilities (including potential Boston Harbor beneficial re-use material) was in close proximity to 1 for sites where the distance from loading facilities was greatest (i.e. closer to the outer limits of the 22-mile radius from Boston Harbor).

8. Sediment Transport Impacts

As wave attenuation at the shoreline for the purpose of shore protection is a project goal, the direct influence of this wave attenuation effect on shoreline dynamics is an appropriate discretionary criterion to ensure the proposed reef does not adversely impact existing shoreline stability. Overall, offshore breakwaters create a “shadow zone” of reduced wave heights landward of the structure. Along beaches with active alongshore transport, this reduction in wave height can interrupt the natural littoral drift, potentially “robbing” downdrift beaches of sediment. In addition, appropriate placement of an offshore structure can have a positive effect by instigating accretion within a historically observed “hot spot” along a shoreline and either having a limited effect on downdrift shorelines or no effect if the downdrift shoreline is armored. The numerical rating system ranged from 4 for sites where the influence of the reef on sediment transport likely would be minimal to 2 for sites where the influence on sediment transport likely would be noticeable along the shoreline. For the lower ranked sites, site-specific analyses would be required to ensure proper reef placement and scale to avoid adverse impacts to the shoreline.

Reef Sites Ranking Process

The initial ranking (J1) didn’t adequately incorporate sites or criteria to assess the use of dredge material. The second ranking process (J2) incorporated sites most proximal to the channel (and so most likely to work as beneficial reuse options) and added 2 additional sites not previously considered. The J1 ranking analysis is presented in Table 1B-2. The J2 ranking analysis is presented in Table 1B-3. Figures 1B-3 to 1B-8 illustrate the location of potential reef sites that encompass the area described by the 22-mile radius from Boston Harbor.

Table 1B-2. Reef site ranking results, with individual discretionary criteria category scores and final sum ranking score.

Community	Site	MCZM mapped Sediment type	Sediment Quality	Water Clarity (Eel Grass suitability)	Public Infrastructure	Private Infrastructure	Comminity Desire/Willingness	Wave environment	Navigation Proximity	Proximity to Loading Port	Sediment Transport impacts	S sum ranking score
Marshfield	Green Harbor R. inlet, west jetty	S	5	5	6	3	5	4	2	1	3	27
Marshfield	Brant Rock at Webster Ave.	Rg	2	5	6	3	5	2	4	1	4	24
Scituate	Bar Rock at Glades Rd.	Rg	2	5	6	3	5	2	4	2	2	24
Weymouth	Fort Point Road	Sm/Rs	3	3	6	3	5	3	2	4	4	23
Boston	Georges Island	Rs	3	5	6	0	5	1	3	3	4	22
Nahant	Black Rock, at Wendell Rd.	Sr/Sg	5	5	0	3	5	4	3	3	4	22
Marblehead	Devereux Beach at Ocean Ave.	S/R	4	5	5	0	5	3	4	1	2	22
Manchester	Singing Beach	S	5	5	4	0	5	1	4	1	2	21
Boston	Spectacle Is., beach north of pier	Rs	3	2	7	0	5	4	2	5	4	21
Manchester	Downtown Manchester	R/S	3	5	3	2	5	4	1	1	4	21
Quincy	Sea Street	Rs	3	2	4	3	5	3	2	4	3	20
Boston	Gallops Island	Rs	3	5	3	0	5	1	3	3	4	19
Boston	Long Island	Sm/Rs	2	5	4	0	5	3	2	4	4	19
Hull	Crescent Beach	Rg/S	3	5	6	3	0	1	2	2	4	19
Quincy	Wollaston beach	Rs	3	2	6	0	5	3	2	4	2	19
Salem	Forest River Park	R	1	3	5	1	5	4	2	1	4	18
Quincy	Nickerson Beach	Ms	2	3	4	0	5	4	2	4	4	18
Quincy	Long Island Bridge	Sm/Rs	2	3	4	0	5	3	2	4	4	17
Boston	William J. Day Blvd.	Sm/S	2	2	5	0	5	3	2	5	2	17
Quincy	Edgewater Drive, Houghs Neck	Rs	3	3	1	2	5	3	2	4	2	17
Winthrop	Short Beach	Rg	2	5	6	1	0	2	4	3	2	17
Manchester	Manchester Harbor	R	1	3	4	1	5	4	1	1	4	17
Salem	Collins Cove shoreline	M	1	3	1	3	5	5	1	1	4	16
Salem	Palmer Cove Yacht Club	R/G	2	3	0	3	5	4	1	1	4	16
Salem	Juniper Cove	R/S	2	3	0	3	5	3	1	1	4	15
Salem	Camp Naumkeg shoreline	R	1	3	4	0	5	5	1	1	2	15
Salem	Salem Willows Pier	R	1	3	4	0	5	2	1	1	4	15
Winthrop	north of Five Sisters	Rg/Sr	5	5	1	1	0	1	4	3	4	15
Salem	Dion's Yacht Yard	R	1	3	0	3	5	4	1	1	4	15
Boston	Shaeffer Paper Mill	Rs/Ms	1	1	3	0	5	5	2	5	4	14
Cohasset	Atlantic Ave. Beach	Rs	3	5	3	0	0	1	4	2	2	13
Marshfield	North/South River	M/R	1	3	0	0	5	3	1	1	2	11

Table 1B-3. Second reef site ranking results.

Community	Site	MCZM mapped Sediment type	Water Depth (Constructability from Barge)	Foundation Stability	Navigation Concerns	Public Infrastructure	Private Infrastructure	Community Desire/Willingness	Σ sum ranking score
Boston	Spectacle Island	Rs	4	5	3	7	0	5	24
Boston	Georges Island	Rs	4	5	3	6	0	5	23
Weymouth	Fort Point Rd.	Sm/Rs	0	3	5	6	3	5	22
Quincy	Sea Street	Rs	0	5	5	4	3	5	22
Boston	Gallops Island	Sm/Rs	5	3	3	5	0	5	21
Quincy	Wollaston Beach	Rs	0	5	5	6	0	5	21
Boston	Long Island	Sm/Rs	4	3	3	4	0	5	19
Quincy	Edgewater Dr.	Rs	0	5	5	1	2	5	18
Quincy	Long Island	Sm/Rs	4	3	1	4	0	5	17
Boston	William J. Day Blvd	Sm/S	0	2	5	5	0	5	17
Boston	Shaeffer Paper Mill	Rs/Ms	0	3	5	3	0	5	16
Quincy	Nickerson Beach	Ms	0	1	5	4	0	5	15
Winthrop	Coughlin Park	Ms	2	1	1	4	0	0	8

Sensitivity Analysis

Rank sensitivity analysis was done to test the sensitivity of the ranking. This was done separately by two independent analysts. The processes are described below. There was broad agreement about which sites were best for further consideration across the Applied Coastal rankings (J1, and J2) and two sensitivity analyses (MRank and KRank) (Table 1B-4).

Site selection sensitivity analysis M Rousseau (M Rank)

My assessment remained focused on the site selection criteria for a reef/eelgrass project, although I know we discussed evaluating different criteria and habitats to assess potential projects for the beneficial reuse of dredged rock material from Boston Harbor at our last meeting. I did not change any of the scores, but I did look closely at how some of the scores were used in the ranking criteria. See attached spreadsheet for reference.

The process I followed to get from 31 to 10 sites:

1. Using the ranking spreadsheet, sites with unconfirmed or no community desire / willingness (Hull – Crescent Beach, Winthrop, Short Beach and North of Five Sisters, Cohasset, Atlantic Ave Beach) were removed. Four sites total. Subtotal of remaining projects = 27.

2. Removed community desire / willingness category altogether as all remaining projects were scored a equally (5). Ranked remaining 27 projects according to their total score derived from the remaining primary ranking categories ONLY (sediment quality, water quality, public and private infrastructure – green categories on the spreadsheet). Primary category scores ranged from 19 to 4. All projects scoring **8** or lower in the primary ranking category sums were removed. (Marshfield – North / South River, Boston – Shaeffer Paper Mill, Salem, Dion's Yacht Yard, Salem Willows Pier, Camp Naumkeg Shoreline, Juniper Cove, Palmer Cove, Collins Cove). Eight sites. Subtotal of remaining projects = 19.

At this point, I elected not to assess the 12 sites eliminated in steps 1 and 2 any further. I considered the 19 remaining sites to be an adequate sample size for finding 10 potentially suitable sites. Relative to the higher ranking sites, the lack of community desire / willingness and the lower rankings in the primary ranking categories indicate potential flaws in these sites ability to meet the minimum criteria outlined in the grant. The rest of this assessment focuses on the remaining 19 projects.

3. For the secondary ranking categories (wave environment, navigation proximity, port proximity, sediment transport impacts - in blue on the spreadsheet) one value was used in the ranking, derived from averaging the scores of all four categories. I assessed whether or not some of these 4 secondary categories should be equally weighted and not averaged (scores worth only ¼ of the value of the primary (green) categories) as originally assessed, and how that may change final ranking results. I also examined if certain categories might be more important than others from our ranking standpoint (Should more weight be given to wave environment vs. proximity to port, for example). There was variability in scoring using different approaches, but the top four and bottom four projects did not change in rank order. I removed the four lowest projects from the list (Boston – William J. Day Bvd, Quince – Edgewater Drive and Long Island Bridge, Manchester – Manchester harbor). Subtotal of remaining projects = 15

4. To get from 15 down to 10 was more subjective. Two projects (Boston – Georges Island and Manchester – Singing Beach) had the lowest scores in the secondary ranking categories. Both of these

sites have come up in recent steering committee meetings and phone calls as not being ideal sites for the purposes of this grant. The final three projects (Salem – Forrest River Park, Quincy – Wollaston and Nickerson Beach) all ranked lowest among the remaining projects on the list.

To summarize, the highest four or five ranked projects should definitely move to the next phase. The lowest 8-12 ranked projects should not. The middle 10 to 11 projects should be discussed in more detail by the working group to determine which 5-6 projects will be selected to move forward. We should also discuss whether or not we should advocate some more for two projects that ranked highly, but that we were unable to confirm community willingness. Hull - Crescent Beach and Winthrop - Short Beach both ranked well enough to make it into the top 10, even without the additional 5 points for community willingness.

Site selection sensitivity analysis K Ford (K Rank)

If there's no community support – then no. But we haven't fully established if there might be community support for the sites in Hull and Winthrop that currently don't have community support. So I ignored community support column.

If there's no public infrastructure – then no. We're looking to spend public dollars. It should be on public infrastructure projects. I didn't exclude projects with no public infrastructure outright, but I double checked all final projects have public infrastructure value.

Sed quality and water quality – combining into a habitat score was recommended but I chose not to since it seemed better to be able to unravel the results in the two separate categories.

For each green category (sediment, water, public infrastructure, private infrastructure) I took the top scoring sites. I looked at the top 10 scores and then added all sites with the same score as the lowest in the top 10.

Then I looked at how many categories each site achieved a top 10 score for. So the total rank score could be 4 – a site that scored in the top 10 for each category.

I did the same for the blue categories (wave environment, navigation proximity, proximity to loading port, sediment transport impacts).

Then I combined them. Top score possible is 8. A site with an 8 was in the top 10 for all 8 categories (4 environment and 4 logistics).

I selected the top 8 sites. These were sites with a ranking of 5 or higher. (Seven sites had a ranking of 4.)

Table 1B-4. Ranking sensitivity results.

Site	Town	J1 RANK (max 27)	J2 RANK (max 24)	M RANK (max 22)	K RANK (max 7)	
Green Harbor R. inlet west jetty	Marshfield	27	-	22	5	
Brant Rock at Webster Ave	Marshfield	24	-	19	6	
Bar Rock at Glades Rd.	Scituate	24	-	19	5	
Fort Point Road	Weymouth	23	22	18	4	in top 15 for K, in top 10 for M
Devereux Beach at Ocean Ave	Marblehead	22	-	17	7	
Black Rock at Wendell Road	Nahant	22	-	17	5	
Georges Island	Boston	22	23	16	5	removed from M list at step 4, assessment based on previous conversations
Spectacle Island, beach north of pier	Boston	21	24	16	5	
Downtown Manchester	Manchester	21	-	16	4	in top 15 for K, in top 10 for M
Sea Street Seawall	Quincy	20	22	15	3	in top 10 for M
Crescent Beach	Hull	19	-	19	5	removed from M list because of no community support
Long Island	Boston	19	19	14	4	in top 15 for K, in top 10 for M
Wollaston Beach	Quincy	19	21	14	4	removed from M list at step 4, assessment based on previous conversations
Gallops Island	Boston	-	21	-	-	
Coughlin Park	Winthrop	-	8	-	-	
- not ranked						
J1 Rank is first ranking from John Ramsey's group, Nov 2015						
J2 Rank is 2nd ranking from John Ramsey's group, Dec 2015						
M Rank is Mark Rousseau's site selection analysis based on J1						
K Rank is Kathryn Ford's site selection analysis based on J1						

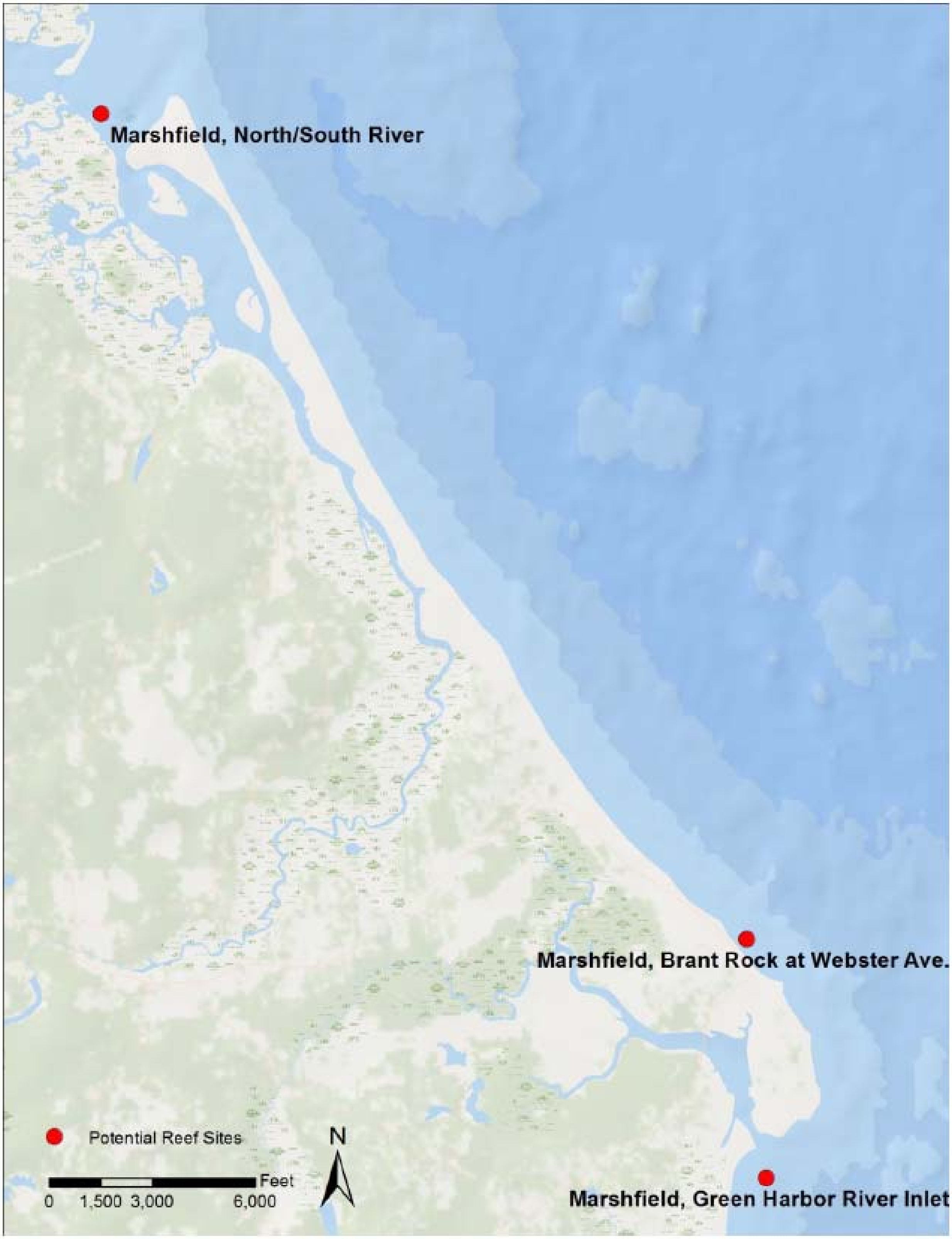

Figure 1B-3. **Location of potential artificial reef sites in Marshfield.**

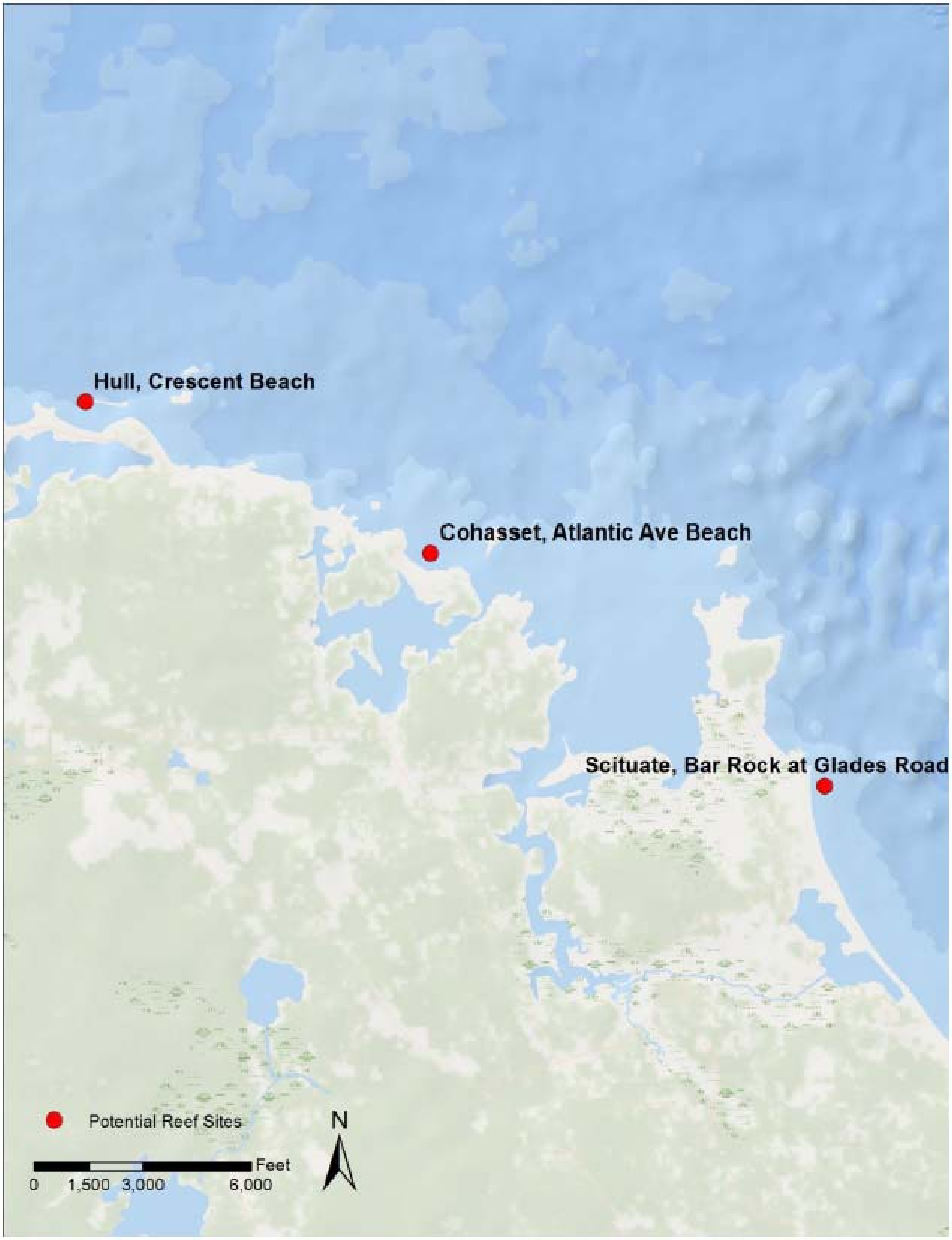

Figure 1B-4. **Location of potential artificial reef sites in Scituate, Cohasset, and Hull.**

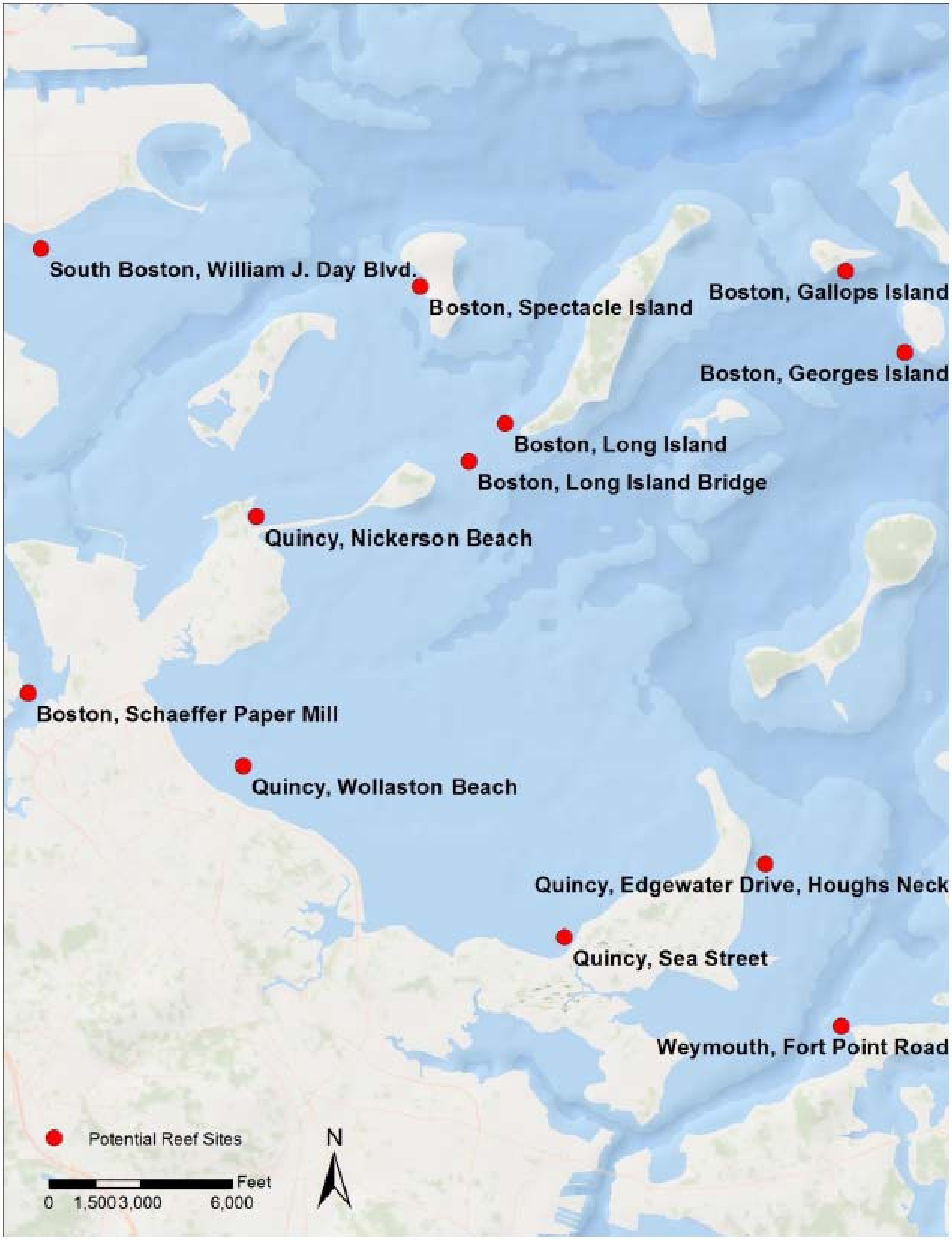

Figure 1B-5. **Location of potential artificial reef sites in Quincy and Boston.**

Figure 1B-6. **Location of potential artificial reefs sites in Winthrop and Nahant.**

Figure 1B-7. **Location of potential artificial reef sites in Marblehead and Salem.**

Figure 1B-8. **Location of potential artificial reef sites in Manchester.**

Final Selection of Top 10 Sites

At a phone conference on 12/4/2015, the Steering Committee[1] reviewed the first Applied Coastal ranking, discussed the site selection sensitivity analyses, and reviewed the second ranking of sites that Applied Coastal provided that considered more carefully which sites would be compatible with dredge material. The goal of the meeting was to reduce the 33 sites under consideration to 10. The target of 10 sites reflects the number of sites we felt reasonable to conduct additional qualitative site assessment work to ultimately identify 2 sites for quantitative site characterization and reef design development.

There was agreement that that top sites were ranked appropriately. We discussed the project goals. There has been a long-standing concern that the dredge material will not be compatible or not available (due to timing or logistics). Therefore, the committee has been committed to identifying a broad suite of sites that could benefit from a nearshore submerged breakwater. At the same time, if there are locations where we can use the dredge material, we want to continue to prioritize those sites (since, if the material is suitable and available, it will be a very low cost option). In order to balance the interest in using Boston Harbor dredge material while identifying high priority sites which may not be able to receive dredge material, the steering committee decided to select 5 sites to target for dredge material, and 5 sites where the use of dredge material was not a priority.

As the 33 sites were reviewed, only 4 were deemed low enough energy to use the mixed grain sizes expected in the dredge material, and provide shoreline protection via the placement of an artificial reef/ nearshore berm. Therefore, the final 10 sites include four that could be considered for the use of the Boston Harbor dredge material and six that may not be suitable for the dredge material, but that are worth considering for the development of a nearshore submerged breakwater.

Sites for development of a reef that can use BH dredge material.

1. Spectacle Island Boston
2. Georges Island Boston
3. Long Island Boston
4. Gallops Island Boston

Sites for development of a reef, may not use BH material

1. Sea Street Quincy – this is a very shallow site so it might cost more to work for the dredge material since it may need rehandling, pumping, and/or sorting. It is high on infrastructure protection value.
2. Fort Point Rd. Weymouth – this is a very shallow site so it might cost more to work for the dredge material since it may need rehandling, pumping, and/or sorting. It is high on infrastructure protection value.
3. Green Harbor River inlet west jetty Marshfield– needs a breakwater so material doesn’t get washed onto onto the beach.
4. Brant Rock at Webster Ave. Marshfield – needs a breakwater so material doesn’t get washed onto the beach.
5. Bar Rock at Glades Rd. Scituate– needs a breakwater so material doesn’t get washed onto the beach.

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[1] The phone call participants were John Ramsey (Applied Coastal), Mark Rousseau (DMF), Tay Evans (DMF), Randall Hughes (Northeastern), Ryan Davis (Anchor QEA), Rebecca Haney (CZM), Christy Foran (Army Corps ERDC), and Kathryn Ford (DMF)

6. Devereux Beach Marblehead– needs a breakwater so material doesn't get washed onto the beach.

This list of sites was sent out to the entire Working Group (Appendix A) for feedback. Individual outreach to municipalities and Boston Harbor Islands stakeholders occurred coincidentally with qualitative site assessment field work. A map with approximate design outlines was prepared and used for outreach and to plan the qualitative site assessment field work (Figure 1B-9).

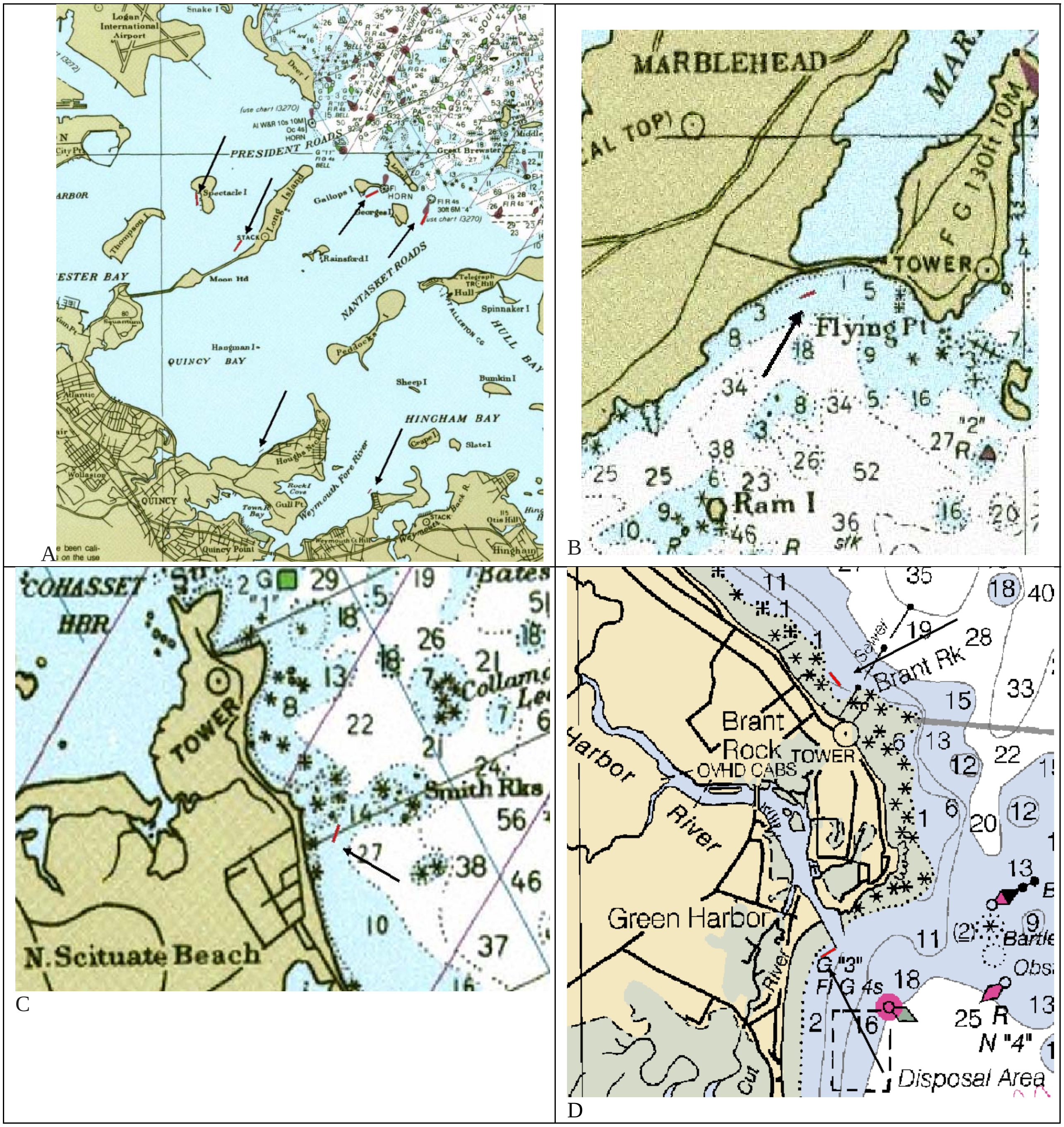


Figure 1B-9. **(A) 6 sites in Quincy, Weymouth, and Boston within Boston Harbor; (B) 1 site in Marblehead, 14 miles north of Boston Harbor; (C) 1 site in Scituate, 14 miles south of Boston Harbor; (D) 2 sites in Marshfield, 22 miles south of Boston Harbor. Red boxes are proposed site boundaries and the black arrows point to them.**

Discussion
Communicating the project goals to municipalities and the working group was challenging, suggesting that the goals are too broad or that a more thorough communication strategy was warranted. This isn't entirely unexpected since different project partners have different priorities. Also, the ability to use dredge material is still unclear in terms of timing, compatibility, and cost. Lastly, how and if to make trade-offs concerning the site's ability to support eelgrass is a discussion point. If it's a high priority shoreline protection site but can't support eelgrass, should we keep it on the list? We ultimately decided to keep it on the list, but sites that will support eelgrass will rank higher. The site selection process initiated a broader discussion of using reefs and other living shorelines for shoreline protection that is ongoing. There was full agreement of the steering committee that we have selected the right set of 10 sites within the 22 mile radius of Boston Harbor to move forward.

References
Parsons Brinckerhoff Quade and Douglas, Inc. (2005). Winthrop Shores Reservation Restoration Program. Environmental Impact Report, Three Volumes. Prepared for Massachusetts Department of Conservation and Recreation, Boston, MA.

Phase 1C: Site Selection-Top 2 Sites

Introduction
Ten candidate sites for artificial reef creation were selected through a process which included a desktop site assessment, surveys of municipalities, professional engineering site selection and ranking, site ranking sensitivity analysis, professional engineering site selection and ranking after workgroup feedback, and steering committee discussion and final site selection. The 10 sites identified are: 1) Spectacle Island Boston, 2) Georges Island Boston, 3) Long Island Boston, 4) Gallops Island Boston, 5) Sea Street Quincy, 6) Fort Point Rd. Weymouth, 7) Green Harbor River inlet west jetty Marshfield, 8) Brant Rock at Webster Ave. Marshfield, 9) Bar Rock at Glades Rd. Scituate, and 10) Devereux Beach Marblehead. These 10 sites were reviewed by a steering committee, additional meetings with municipalities were held, and the final 2 sites were selected by the project lead, DMF.

Once the ranking analysis had been completed, more in-depth discussions with some of the municipalities having top-ranked sites was conducted by DMF, including meetings with Marshfield, Boston, DCR, and Marblehead. Due to concerns expressed during the meetings, sites in Marshfield, as well as Spectacle Island in Boston Harbor, were dropped from further consideration.

Qualitative site assessment and fisheries analysis by DMF indicated that the two most appropriate sites for detailed field work, based on a combination of the ranking analysis developed for this report and independent fisheries evaluations conducted by DMF were Devereux Beach in Marblehead and Gallops Island in Boston Harbor. As discussed at Working Group meetings, one of the candidate sites was to be located in Boston Harbor and assessed utilizing blasted 'fast' rock generated from the Boston Harbor Deep Draft Navigation Improvement Project. As this site likely would be located in a more protected wave environment, the heterogeneous material generated from the dredging project potentially could function adequately with less material movement over time. The other site evaluated was an open ocean site, where significant storm waves were expected. In this case, the artificial reef breakwater would be constructed from uniform-sized large scale armor stone that would come from another source. The dredge material may serve as a core material or bedding stone and then the armor stone would be placed individually on top to form the reef/breakwater structure.

Methods & Results

The final site selection of the top two sites was accomplished in six steps.

1. Qualitative site assessment – a DMF field team visited all 10 sites and assessed basic characteristics of the site including sediment type, accessibility, shoreline protection value, and existing resources. The work ranked the sites in terms of priority for this project. The full description and results of the field assessment work is provided in Appendix D.
2. Working Group meeting – a meeting of the wider Working Group was held to discuss the qualitative site assessment and to make a final selection of the top 2 sites. Four sites easily came to the top:
    a. Spectacle and Gallops Islands, Boston. Gallops was selected based on DCR concerns of dredge material affecting a popular nearby bathing beach and marina.
    b. Green Harbor, Marshfield and Devereux Beach, Marblehead. Marshfield was selected based on presumed impact on surfers at Devereux Beach, CZM's higher ranking of Marshfield in terms of public need/value, and John Ramsey's sense that a structure in Marshfield could have more wave attenuation capacity than the slightly more exposed site in Marblehead.

    The working group selected Gallops and Marshfield, but hesitated to finalize selection without more discussion with the town of Marshfield. The working group recommended a follow up conversation with Marshfield.
3. Follow up discussion with Marshfield
    a. On April 25, 2016 a meeting was held with town representatives of Marshfield, including the Conservation Commission, the Harbormaster, the Town Administrator, the Natural Resources Committee, and the CZM South Shore Regional Coordinator. Project partners DMF (K Ford) and CZM (R Haney) were in attendance also. K Ford gave a presentation. There is great interest in the project and significant municipal support. The group had a little trouble envisioning the shoreline protection benefits of an artificial reef in the conceptual site location diagram, feeling that the structure should be further to the south to protect the publicly owned seawall protecting a neighborhood. The wall is in disrepair and protecting the wall with a wider fronting beach is of interest. The site is adjacent to an Army Corps-managed inlet which also needs maintenance; the inlet is shoaled, so boats get stuck at low tides or in storms, and the jetties are in disrepair, representing a safety hazard for the town since people walk out on them. Adding another structure nearby may result in safety concerns. Landward there are ownership challenges since accreted beach in some sections revert to the ownership of upland land owners. This is also a popular location for boaters to cross from the inlet over to the "boaters beach." Depth at low tide was a question. Some concern expressed about impact on surfers and shark attraction (a porbeagle was in the harbor recently). We do not think these structures will attract sharks more than existing rocks and structures in the water. Planting eelgrass shoreward of the site may not be a good thing since the area is used by swimmers. CZM supports this site due to previous storm damage history and efforts of the state and town to improve protection the area.
4. Steering committee meeting. A steering committee meeting was held on June 2, 2016 to discuss the four sites that originally ranked very highly. Primarily based on the complications associated with the Marshfield site, the project lead was interested in reconsidering Marblehead. Also, Marblehead represents a simpler site to study in terms of biological impact/value. Since this is a pilot study to consider artificial reefs for shoreline protection, the research logistics are relevant. In Boston, the project lead recommended "reopening" Spectacle due to its high shoreline protection priority. Also, it is a more complicated site that might benefit from this pilot project to consider options there. For example, a reef there might have

added recreational benefits. The steering committee was amenable to considering all four and supportive of further discussions with both DCR and Marblehead.

5. Follow up discussions with DCR and Marblehead
    a. Phone calls/emails to DCR (month of May). No further conversations were held due to our inability to schedule them since the beginning of the summer season is so busy. It was decided that since Gallops represents the site with the most likelihood of using dredge material, that we will indeed go ahead with Gallops as the working group recommended.
    b. Meeting with Marblehead. On June 21, 2016 a meeting was held with town representatives of Marblehead, including the Conservation Commission, the Harbormaster, the Town Administrator, the Fire and Police Departments, and the CZM North Shore Regional Coordinator. Project partners DMF (K Ford and M Rousseau) were in attendance also. K Ford gave a presentation; it was simplified based on the experience in Marshfield, where a much longer and more detailed presentation was given with no added benefit. There is great interest in the project and significant municipal support. In general the conversation focused on unintended consequences such as attracting sharks, creating a seaweed problem resulting in a stench on the beach, aesthetic impacts, and marking for navigation. Recreational surf clamming occurs in the area and adjacent to the proposed site is a bathing beach shoreward of the site. Surfing occurs up on the Neck, not in this area. Boating is unlikely to be an issue, but marking the structure would be important. Additional safety concerns don't seem to be problematic. Public input and perception will need to be carefully handled. The town supports the need and value, but anything that might affect property values could be seen as a negative. What to do if it's not working or causing problems needs to be addressed in permitting (e.g. who pays to remove it? What if there are rocks on the beach from it after a storm?). Quantifying the shoreline protection value is of great interest. Most specifically, will it reduce the number of times the beach sand ends up in the parking lot? Also, the town is required to station and staff emergency vehicles out on Marblehead Neck during large storms because of the overwashing of the Causeway leading out to the Neck. The town administrators saw value in potentially reducing this need by adding additional protection to reduce wave impacts to the causeway during storms.
6. Final decision making. Based on input from the various parties, the project lead selected Marblehead as the second site. Marblehead has equivalent shoreline protection needs (a public beach and a critical evacuation route) in a simpler setting. It has more chance of growing eelgrass. It is also a better site from the standpoint of logistics associated with conducting baseline research studies.

Discussion

Four sites rose to the top as being highly appropriate for this study. Originally we anticipated that the Working Group would make the final site selection. But the number of variables to consider was quite large, and conversations with individuals outside of the Working Group were necessary to inform final decision-making. Gallops and Spectacle are inside Boston Harbor and lower energy sites. Relatively little is known about the dredge material with respect to grain size, sorting, and ultimately how the material will be handled to build a reef or a berm, so these lower energy sites were the best two sites for considering the use of dredge material. We thoroughly considered if we should choose Spectacle Island since it has relatively higher priority shoreline protection needs than Gallops. Spectacle Island has the only lifeguarded bathing beach of the Boston Harbor islands, and is adjacent to a marina which is dredged regularly due to sediment buildup. The manager of the Spectacle Island site considers the use of dredge material too risky at the site (if the material washes up onshore, it's a problem). In contrast, Gallops Island is not currently open to the public. There is a dock that could use protecting and the island has asbestos contamination and smallpox graves, so managing erosion at this island is viewed as a priority to the National Park Service and the Massachusetts Department of Conservation and Recreation. Their goal is to reopen the island to the public. In order to have a site with the best chance of using the dredge material, we chose Gallops as our primary Boston site. Gallops Island is the only site where we might use dredge material, meeting our original project goal of exploring dredge material use options. Gallops is also a site that has been previously targeted for eelgrass restoration and it is thought that the restoration efforts failed due to ferry wake energy.

The next decision point was whether or not we should target Spectacle or an open ocean site for the design of a reef that does not rely on the dredge material (i.e. a breakwater). In December, the steering committee had identified a worthwhile objective of exploring how to manage two different energy settings with an artificial reef. Spectacle has a similar energy setting as Gallops, so it was determined that an "open ocean" site should be prioritized. This gives us a unique opportunity to explore how effective nearshore reefs might be in a different energy setting.

The top two open ocean sites were Marblehead and Marshfield. The steering committee did not achieve consensus regarding which of these two sites was optimal for this project. Marshfield has a crumbling public seawall and has worked with the state to come up with options to repair, protect, and manage that stretch of their shoreline. Therefore, Marshfield was of great interest to some steering committee members. Marblehead has a routinely overwashed public parking lot at the start of a critical evacuation route that is currently protected by a seawall. Marblehead is struggling with current and future management of this stretch of shoreline. Additionally, the Marblehead site has more likelihood of growing eelgrass shoreward of the reef and had fewer public safety concerns than Marshfield (in Marshfield, boats come out of Green Harbor and head just south to a bathing beach; the reef would likely be placed in the path of that boat traffic). Marblehead also has simpler field logistics, so our research budget can be spent more efficiently on data collection. There is also a chance that the site will receive additional field studies due to its proximity to two field stations. Therefore, the project lead agency selected the Marblehead site for the next stages of this project.

It is also worth noting that all of the sites we have considered in this project are worthy of further consideration, which they could receive over the coming years.

Phase 1D: Quantitative site characterization

Introduction

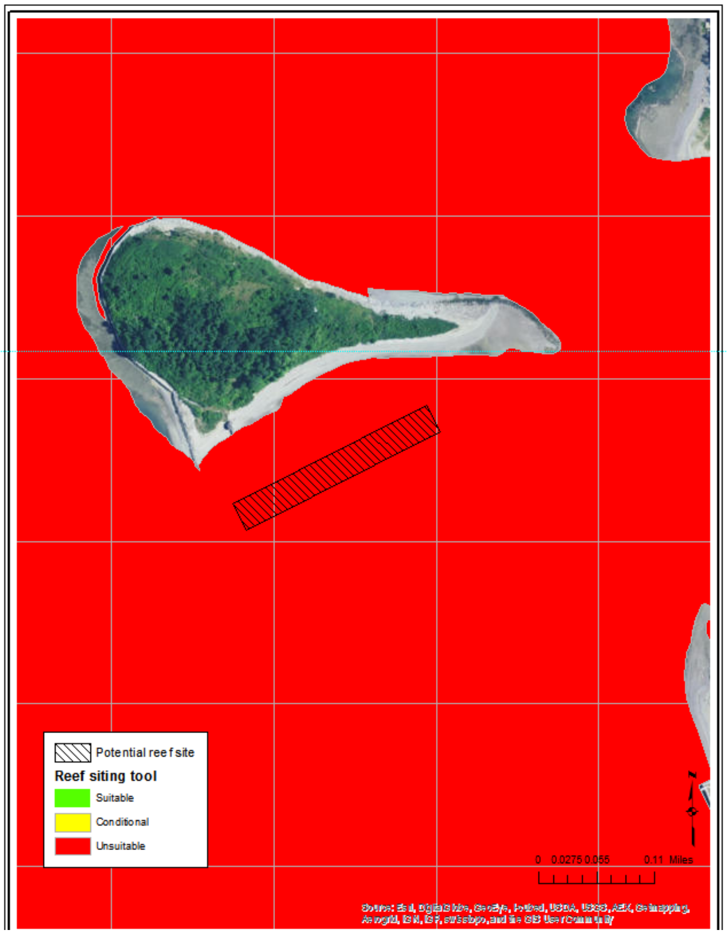
The next component necessary to prepare for permitting Gallops Island and Devereux Beach for artificial reef (berm and breakwater, respectively) building was to study the sites in more detail to determine if there were any features that might be adversely affected by reef building. The characterization study was designed to serve as baseline information in the event that a reef/breakwater is built. These data can be used to assess post-construction alterations in biology and wave energy. These studies were conducted by Northeastern University (a project partner) with vessel and staff support from DMF.

Reef siting tool

The reef siting tool was used to summarize what is known about the potential reef sites.

Gallops Island

The potential artificial reef (berm) site falls within two grid cells in the reef siting tool. Both cells are graded as "unsuitable" for reef development (Figure 1D-1) for the same reasons (i.e. the rankings for the individual criteria are identical). Ferry routes and cables were the Category 1 exclusionary criteria, but the specific reef location will avoid both. Slope and substrate (Category 2) were suitable for reef development. The grid cell contains four of eleven Category 3, non-exclusionary layers: depth (<30'), winter flounder closure area, intertidal flat, and submerged wreck. The specific site does not overlap with an intertidal flat or a submerged wreck and we are targeting relatively shallow sites with this particular project.

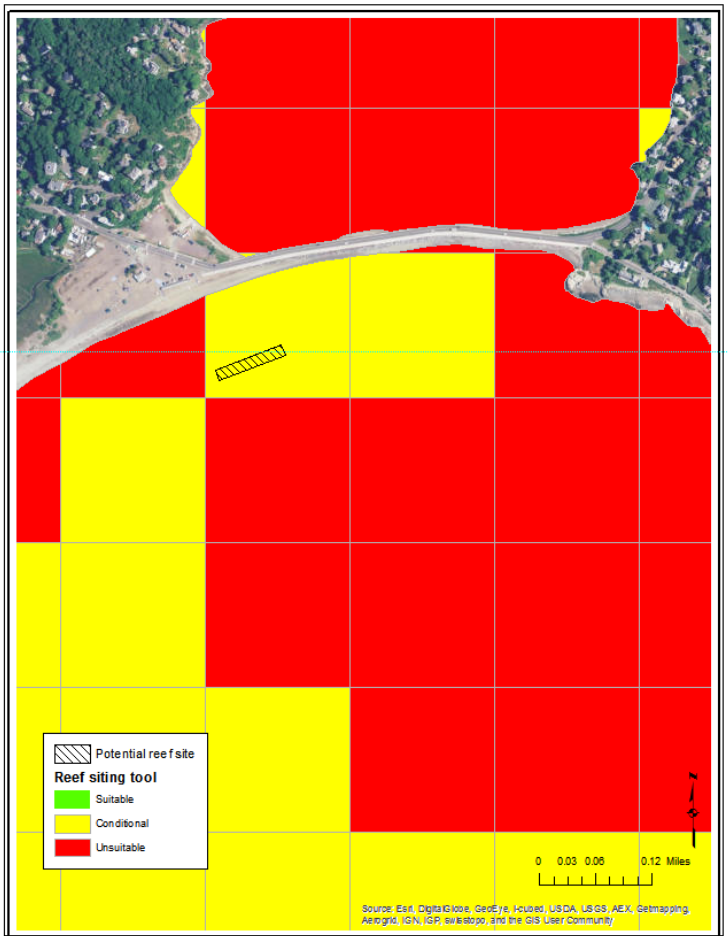


Eelgrass Habitat	0
Mooring Area	0
Historic Site	0
Designated Port Area	0
Inactive Disposal Site	0
Active Disposal Site	0
Pilot Areas	0
Anchorage Area	0
Ferry Routes	1
Navigation Channel	0
Marina	0
Fish Trap	0
Artificial Reef	0
Cable Area	1
Cable	0
Sewer Line	0
Gas Pipeline	0
Pipeline Area	0
Tunnel	0
Public Infrastructure Score	0
Private Infrastructure Score	0
Category 1 Score Summary	2
Sediment Score	0
Sediment Adjusted Score	0
Slope Score	0
Category 2 Score Sum	0
Depth Score	1
Winter Flounder Closure	1
Cod Conservation Zone	0
Shellfish Habitat	0
Intertidal Flat	1
Right Whale Critical Habitat	0
Humpback Whale Core Habitat	0
Finback Whale Core Habitat	0
Submerged Wreck	1
Precautionary Navigation Area	0
Trawl Survey	0
Category 3 Score Summary	3
Score_Definitions	(0=suitable) (1=conditional) (2=unsuitable)
Final Score Adjusted	2

Figure 1D-1. **Reef siting tool results for Gallops Island potential reef site.**

Devereux Beach

The potential artificial reef (breakwater) site falls within a single grid cell in the reef siting tool. The cell is graded as "conditional" for reef development (Figure 1D-2). There were no Category 1 exclusionary criteria found in the grid cell that contains the site and slope and substrate (Category 2) were suitable for reef development. The grid cell contains five of eleven Category 3, non-exclusionary layers: depth (<30'), winter flounder closure area, cod conservation zone, shellfish habitat, and intertidal flat. The grid cell is proximal to several cells that are deemed unsuitable for reef development due to rocky seafloor. Since we are targeting relatively shallow sites with this particular project, the depth constraint is not as relevant.



Eelgrass Habitat	0
Mooring Area	0
Historic Site	0
Designated Port Area	0
Inactive Disposal Site	0
Active Disposal Site	0
Pilot Areas	0
Anchorage Area	0
Ferry Routes	0
Navigation Channel	0
Marina	0
Fish Trap	0
Artificial Reef	0
Cable Area	0
Cable	0
Sewer Line	0
Gas Pipeline	0
Pipeline Area	0
Tunnel	0
Public Infrastructure Score	0
Private Infrastructure Score	0
Category 1 Score Summary	0
Sediment Score	0
Sediment Adjusted Score	0
Slope Score	0
Category 2 Score Sum	0
Depth Score	1
Winter Flounder Closure	1
Cod Conservation Zone	1
Shellfish Habitat	1
Intertidal Flat	1
Right Whale Critical Habitat	0
Humpback Whale Core Habitat	0
Finback Whale Core Habitat	0
Submerged Wreck	0
Precautionary Navigation Area	0
Trawl Survey	0
Category 3 Score Summary	5
Score_Definitions	(0=suitable) (1=conditional) (2=unsuitable)
Final Score Adjusted	1

Figure 1D-2. **Reef siting tool results for Devereux Beach potential reef site.**

Substrate characterization

Methods

We created side scan sonar mosaics to identify trawling impediments, confirm the presence/absence of eelgrass, and characterize the seafloor substrate types at the potential reef sites and control sites. On August 1, 2016 we used a GPS integrated Humminbird 999CI HD SI 800 kHz side scan sonar with 83/200 kHz dual beam downward-looking bathymetric sonar with a transducer mounted off the port-side of a 20' Maritime Skiff. Side scan sonar data were processed for water column removal and slant range and beam angle corrections with SonarTRX Pro and then exported as GeoTIFF mosaics. No layback corrections were needed since the sonar transducer was mounted to the gunwale a couple of feet away from the GPS antenna. The side scan sonar mosaic was groundtruthed by divers, sediment samples, and photo groundtruthing with an AquaVu camera (DMF 2016). The Devereux Beach control site (Marblehead control) was not imaged since the control was not been identified in time for the sidescan sonar imaging.

Additionally, 6 samples at each site, for a total of 24 sediment samples, were collected to process for grain size characterization. The samples were collected by divers on 9/1/2017 and 9/21/2017 using a scoop to put approximately 2 cups of sediment in a plastic bag within the top 1 foot of the seafloor. The samples were stored frozen and analyzed on June 30, 2017 by Alpha Analytical using American Society for Testing and Materials standard D6913/D7928. Results are provided in the Wentworth scale as percent grain size.

Results

At Gallops Island, the bottom was soft and smooth except for clearly identifiable rocks/debris (Figure 1D-3). At Long Island, the bottom was smooth and sandy, with no identifiable rocks/debris (Figure 1D-4). At Devereux Beach, the bottom was slightly harder than at the Boston Harbor sites, with no rocks/debris (Figure 1D-5).

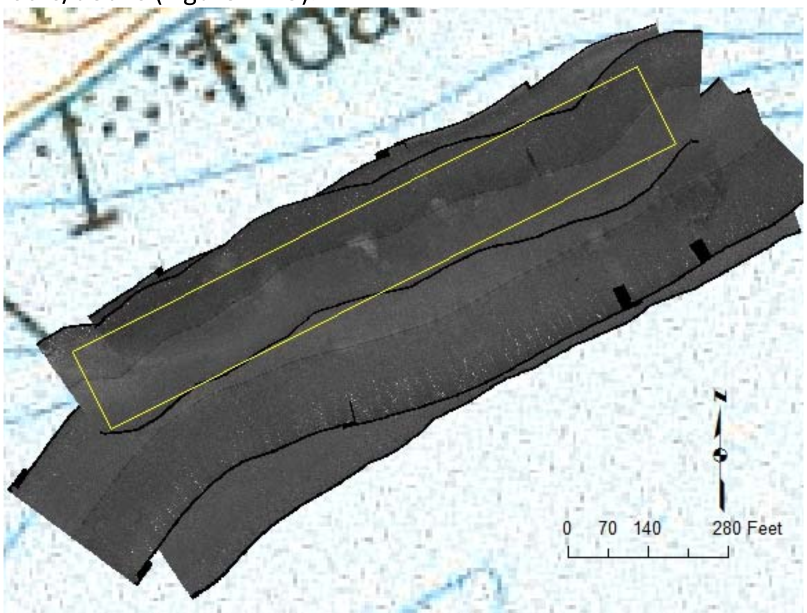


Figure 1D-3. **Sidescan sonar mosaic at Gallops Island. Yellow box identifies potential reef location.**

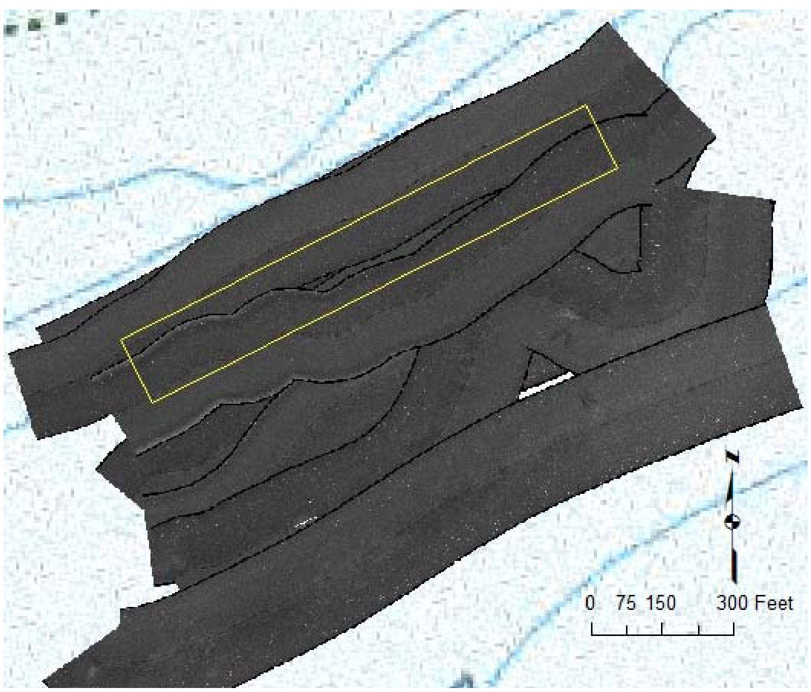


Figure 1D-4. **Sidescan sonar mosaic at Long Island (Gallops control site). Yellow box identifies target study area.**

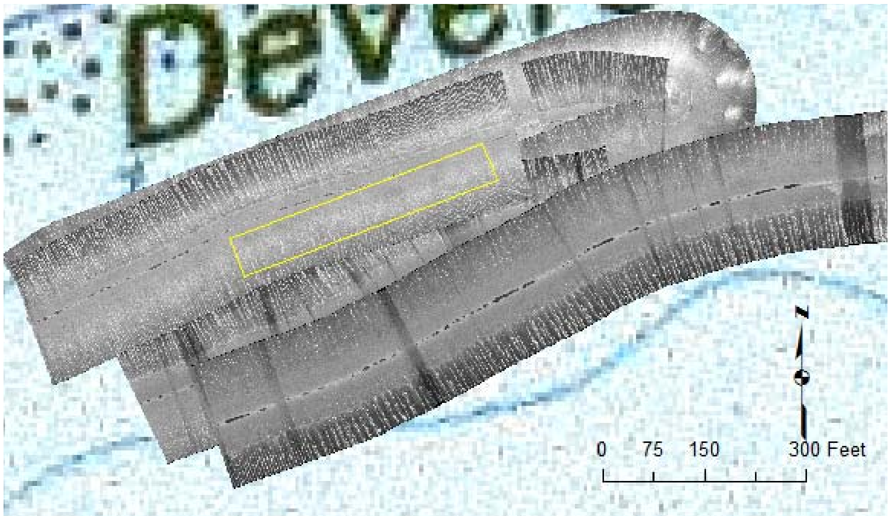


Figure 1D-5. **Sidescan sonar mosaic at Devereux Beach, Marblehead. Yellow box identifies potential reef location.**

The sediment samples were collected by divers along the diving transects (Table 1D-1).

Table 1D-1. Sediment grain size results in percent.

Location	Site	Pebbles	Granule	V. crs. sand	Coarse sand	Medium sand	Fine sand	Fines
Marblehead Reef	1	0.5	0.2	0.1	0	0.5	45	53.8
Marblehead Reef	2	0	0.4	0.1	0	0.6	46.9	52.1
Marblehead Reef	3	0	0	0	0	0.6	40.3	59.1
Marblehead Reef	4	0.1	0	0	0.1	0.7	49.7	49.6
Marblehead Reef	5	0	0.2	0.1	0.1	0.7	60.5	38.6
Marblehead Reef	6	0	0.3	0.1	0.1	0.7	62.6	36.4
Marblehead Control	1	0.4	1.2	0.8	1.6	13.8	73.6	8.6
Marblehead Control	2	0.4	0.3	0.3	0.3	6.6	75.7	16.4
Marblehead Control	3	1.1	1.7	2.2	3.4	14.9	68.9	7.8
Marblehead Control	4	2.5	1.5	1.5	2.2	10.9	71.6	9.8
Marblehead Control	5	3.5	2	0.9	1.6	11.7	69	11.3
Marblehead Control	6	0	0.4	0.5	0.8	7.1	76.6	14.6
Gallops Island	1	4.5	6	5.7	5	5.9	27.8	45.1
Gallops Island	2	3.7	2.3	2.9	3.2	4.4	20.9	62.6
Gallops Island	3	12.3	4.8	3.9	4.5	6.1	18.6	49.8
Gallops Island	4	0.7	2.7	2.4	2.1	4.1	13	75
Gallops Island	5	0.2	1.2	1.1	0.8	2.3	13.7	80.7
Gallops Island	6	1.3	1.1	1.1	1	2.5	12.4	80.6
Long Island	1	2.8	0.9	1	1.9	4.1	17.2	72.1
Long Island	2	0.5	1.5	1.5	1.3	2	7.8	85.4
Long Island	3	0.7	1.6	1.6	1.1	1.6	10.8	82.6
Long Island	4	0.5	1.1	1.4	1.3	1.8	6.3	87.6
Long Island	5	0	0.2	0.3	0.3	0.4	3.3	95.5
Long Island	6	0.3	0.6	0.4	0.5	0.8	5.4	92

Fish and invertebrate sampling

Methods

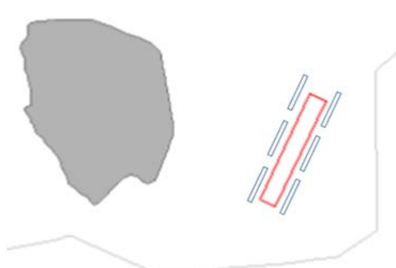
Site characteristics

During each tow, water temperature and depth were recorded using a Garmin depth finder. The start and end GPS locations of each tow were recorded by the vessel captain using the ship's GPS system. Visibility and surficial sediment/basic habitat observations (e.g. the macroalgal cover) were recorded by divers.

Trawling

Trawling was used at the Marblehead sites to determine the relative catch rates of fishes and decapod crustaceans adjacent to future reef and control sites. Unfortunately, underwater obstructions precluded us from conducting trawl sampling efforts at the Boston Harbor Island sites; however, we did conduct diver transects at all 4 sites (see next section). In September of 2016, six replicate tows were conducted at both the Marblehead reef and control sites using a 3-m otter trawl (15-m head rope, 2.0-cm body mesh, 0.6-cm cod end mesh, 0.3 m × 0.7-m doors) with a 4-seam balloon design, with floating and lead lines (Table 1D-2). One hundred meter-long tows (~2 minute duration) were conducted at a target speed of 2.5 km/h, a speed which has been shown to maintain trawl mouth diameter, optimize bottom contact and mitigate gear performance issues associated with erratic trawl flight (Figure 1D-6). Trawl performance was visually monitored during each tow, and all tows were deemed acceptable.

At the completion of each tow, the net was hand-retrieved while maintaining tension on the head ropes to avoid escapement, and the catch was shaken into the cod end as the net was hauled on board. All organisms captured were enumerated, up to 20 per species measured (total length for fish, carapace length for lobsters, and carapace width for crabs, all in cm), and released.



Site	Date	Start time	End time	High tide	Tide stage
Marblehead Reef	9/1/2016	11:00 AM	11:45 AM	12:19 PM	Flooding
Marblehead Control	9/1/2016	1:00 PM	2:00 PM	12:19 PM	Ebbing

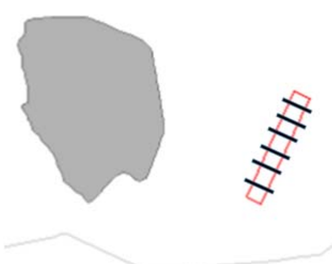
Figure 1D-6. **Trawl tow paths (blue rectangles) occurred parallel to the site (red rectangle) just landward and shoreward of the proposed control and reef sites at the Marblehead sites. The dates, start times, end times, high tide times, and tidal stages are provided for each site.**

Table 1D-2. Start and end points of trawl tows conducted at Marblehead Reef and Control Sites in September 2016. N/A = not available.

Date	Site	Position	Start GPS Point (°N,°W)	End GPS Point (°N,°W)
9/1/2016	Marblehead Reef	Shoreward	42.490455 , 70.852940	42.489867 , 70.854734
9/1/2016	Marblehead Reef	Shoreward	42.490399 , 70.852665	42.489825 , 70.854745
9/1/2016	Marblehead Reef	Shoreward	42.490312 , 70.852564	42.489669 , 70.854936
9/1/2016	Marblehead Reef	Seaward	42.489991 , 70.852459	42.489457 , 70.858501
9/1/2016	Marblehead Reef	Seaward	42.489922 , 70.852277	42.489434 , 70.854463
9/1/2016	Marblehead Reef	Seaward	42.489830 , 70.852305	42.489345 , 70.854367
9/1/2016	Marblehead Control	Shoreward	N/A	N/A
9/1/2016	Marblehead Control	Shoreward	42.478340 , 70.878460	N/A
9/1/2016	Marblehead Control	Shoreward	42.478616 , 70.877831	42.477738 , 70.879174
9/1/2016	Marblehead Control	Seaward	42.478333 , 70.877470	42.477537 , 70.879367
9/1/2016	Marblehead Control	Seaward	42.477431 , 70.879253	42.478240 , 70.877426
9/1/2016	Marblehead Control	Seaward	42.478158 , 70.877343	42.477322 , 70.879141

Diver transects

To determine the presence and abundance of fish species and lobsters at the control and impact (reef) sites, we also conducted dive transects at each location. Six 50 m x 4 m transects were established running across (i.e., perpendicular to the long axis) each site; the location of transects along the length of each site were randomly determined (Figure 1D-7). Transects consisted of a 50-m weighted transect line with cable ties attached at 5-m intervals and were anchored in place at each end by rebar marked with orange flagging tape. Two divers swam each transect once, recording visibility conditions and the abundance of each fish species and lobsters observed on their side of the transect (left or right) within 2 m of the line. When species were unable to be determined, they were identified to the lowest possible taxa. Dive transects were also conducted in September of 2016.



Site	Date	Start time	Finish time	High tide	Tide stage
Marblehead Reef	9/1/2016	10:00 AM	10:50 AM	12:19 PM	Flooding
Marblehead Control	9/1/2016	12:00 PM	12:40 PM	12:19 PM	High tide
Gallops Island	9/21/2016	10:30 AM	11:15 AM	3:30 PM	Flooding
Long Island	9/21/2016	1:00 PM	1:45 PM	3:30 PM	Flooding

Figure 1D-7. **Diver transects (black lines) ran perpendicular to shore and ran directly through the proposed control and reef sites near Marblehead and the Boston Harbor Islands. The dates, start times, end times, high tide times, and tidal stages are provided for each site.**

Quadrat sampling

To determine the density of commercially important bivalve species adjacent to (i.e., < 50 m from the proposed perimeter of each proposed control or reef) and within the footprint of future reef and control sites, we used 0.25 m^2 quadrats. In September of 2016, divers conducted a total of 15 quadrats in and around each of the 4 sites (Figure 1D-8). To ensure the independence of individual samples and maximize coverage of each site, all quadrats were separated by a minimum of 10 m. Within each quadrat, the percent cover of macroalgae and macrophytes, and the abundance of benthic invertebrates and finfish were quantified by genus. Divers then excavated each quadrat to a depth of 25 cm. Any living shellfish were retained in bags and returned to the research vessel where they were enumerated, measured, and released.

Site	Date	Start time	Finish time	High tide	Tide stage
Marblehead Reef	9/1/2016	10:00 AM	10:50 AM	12:19 PM	Flooding
Marblehead Control	9/1/2016	12:00 PM	12:40 PM	12:19 PM	High tide
Gallops Island	9/21/2016	10:30 AM	11:15 AM	3:30 PM	Flooding
Long Island	9/21/2016	1:00 PM	1:45 PM	3:30 PM	Flooding

Figure 1D-8. **Quadrat sampling (blue stars) was conducted in and around each proposed control and reef site near Marblehead and the Boston Harbor Islands. The dates, start times, end times, high tide times, and tidal stages are provided for each site.**

Vemco tags

For site monitoring, an acoustic receiver was deployed to document presence on the reef site of acoustic tagged fish, taking advantage of MarineFisheries ongoing striped bass, black sea bass, cod, and white shark acoustic tagging efforts occurring in the region. The fish tagging programs utilize tags that emit pings with identifying information, including species. These pings can be heard by the receivers and the information can be used to measure fish presence. Vemco stationary acoustic receivers (Vemco Inc.,VPS system, model VR2W) were mounted on the outer moorings (Figure 1D-8) at the two candidate reef sites in September 2016. One receiver was deployed at each site at the center of the deep edge boundary of the study area.

Results

Site characteristics

The bottom depth of the Harbor Island sites was slighter greater than those at Marblehead. Gallops Island transects averaged 7.1 m at 1-2 hrs after low tide, whereas those at Long Island were slightly shallower at 6.2 m at 1.75-2.5 hours before high tide. Meanwhile, diver transects at the Marblehead reef (4.5 m at 1-2 hrs prior to high tide) site were slightly deeper than those conducted at the Marblehead control (3.0 m at high tide) site. Average bottom temperature was consistent across all sites, and ranged from 16.7-17.2 °C. Quadrat sampling detected very little macroalgal cover, which accounted for < 5 % of cover at the Boston Harbor Island sites and was not present at the Marblehead sites. Visibility was slightly better in the Boston Harbor Islands (2-3’) than at the Marblehead sites (1-2’) when the biological sampling occurred. Quadrat sampling detected that the Boston Harbor Island sites consist of mud substrate, whereas the Marblehead sites contain sandy bottom.

Trawling

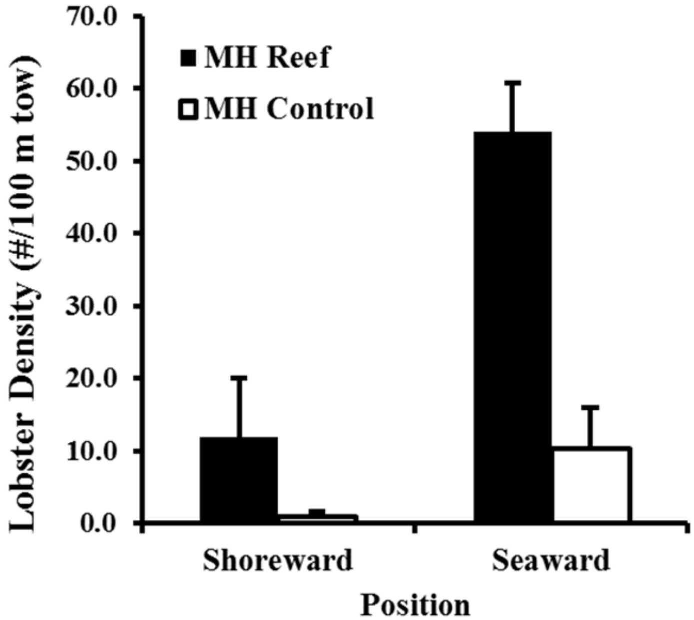
The American lobster (*Homarus americanus*) was the most abundant species captured in the trawl sampling efforts conducted at the Marblehead sites (Table 1D-3). Lobsters were more abundant at the reef than the control site, and on the seaward relative to the shoreward side of both sites (due to the lack of independence among tows within a site and lack of replicate sites, did not perform any significance testing). Lobster density peaked at 54.0 ± 6.8 lobsters/100-m tow (mean ± 1 SE) along the seaward side of the potential reef site at Marblehead (Figure 1D-9a). Meanwhile, lobster densities at the shoreward side of the Marblehead reef site were less than 25% of those along the seaward edge of the reef site, and averaged 12.0 ± 6.8/100-m tow. Meanwhile, at the Marblehead control site, lobster densities peaked at the seaward side at 10.3 ± 5.7/100-m tow, whereas they decreased to 1.0 ± 0.7/100-m tow at the shoreward edge. In addition to the American lobster, 5 Jonah crabs (Cancer borealis), 1 rock crab (*Cancer irroratus*), 1 calico crab (*Ovalipes ocellatus*), 1 longfin inshore squid (*Doryteuthis pealeii*), and 1 windowpane flounder (*Scophthalmus aquosus*) were captured at the reef site, vs. 1 longfin inshore squid at the control site.

Table 1D-3. Total abundance of fish and invertebrates captured during trawling at the Marblehead Reef and Control Sites. Three tows each were conducted along the shoreward and seaward edge of both the reef and control sites.

		Marblehead Reef		**Marblehead Control**	
Scientific Name	**Common Name**	**Shoreward**	**Seaward**	**Shoreward**	**Seaward**
Homarus americanus	American lobster	36	162	3	31
Scophthalmus aquosus	Windowpane flounder	1	0	0	0
Doryteuthis pealeii	Longfin inshore squid	1	0	0	1
Cancer borealis	Jonah crab	0	5	0	0
Cancer irroratus	Rock crab	0	1	0	0
Ovalipes ocellatus	Calico crab	1	0	0	0

The size-frequency distributions of lobsters at the control and reef sites in Marblehead were similar: lobsters at the control averaged 55.4 ± 1.3, whereas those at the reef site averaged 58.3 ± 1.5 (Figure 1D-9b). A Kolmogorov-Smirnov test confirmed that size distributions of lobsters at these two sites did not differ (D = 0.18, p-value = 0.40).

a.



b.

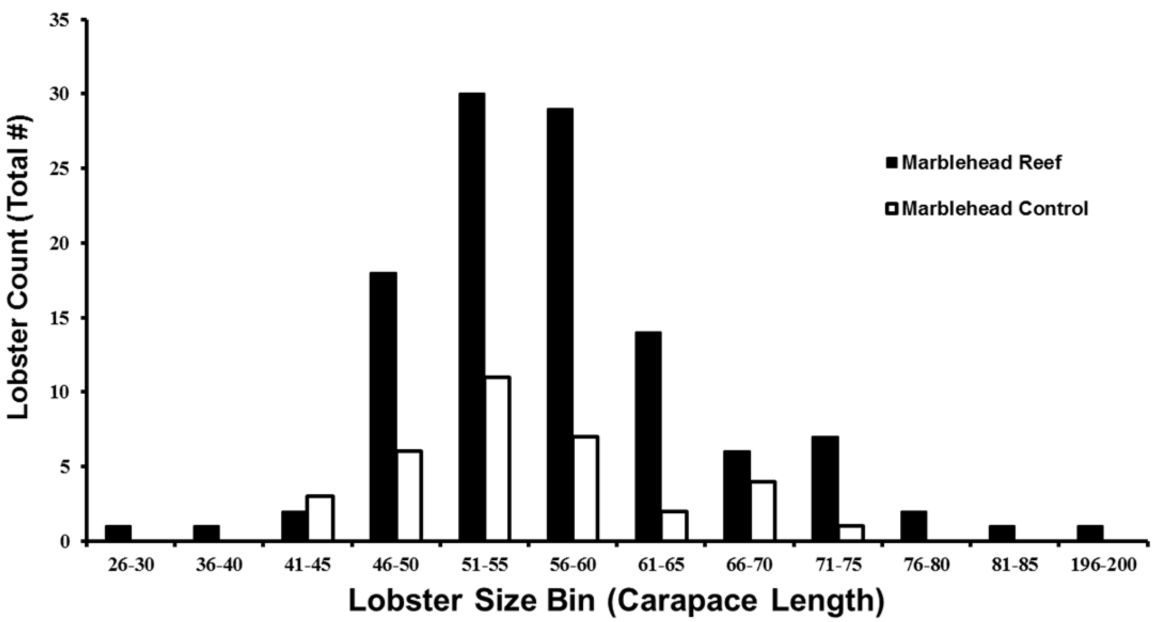


Figure 1D-9. **The (a) densities and (b) size-frequency distributions of lobsters captured via trawling at the Marblehead (MH) reef and control sites. Sampling was conducted in September 2016.**

Diver Transects

Diver transects revealed that lobsters were far more prevalent at the Marblehead sites than the Boston Harbor Island sites (Figure 1D-10, Table 1D-4). In addition, the relative increase in lobsters observed in transects conducted on the reef (24.3 ± 3.3 per transect) vs. control (1.3 ± 0.6 per transect) sites at Marblehead was even greater than what was detected in trawl tows. Meanwhile, lobsters were rare in the Boston Harbor Islands, with only 2 observed at the Gallops Island site.

Our diver transects indicated that the density of lobsters in September 2016 at the reef site in Marblehead was 0.122/m^2 vs. 0.007/m^2 at the control site. To compare our lobster densities captured in the trawl survey with those in the diver transects, we calculated the average at each site for shoreward and seaward tow samples. We pooled our shoreward and seaward tow samples because the diver transects were run perpendicular to shore, and consequently spanned from the shoreward to seaward side of the site where each was conducted. Our tow sampling efforts indicated that the density of lobsters was 0.110/m^2, which is almost identical to our estimate from dive surveys. These results suggest that the catch efficiencies of each gear type are similar for lobsters. At the control site at Marblehead, the density of lobsters caught in tows was 0.19/m^2, which was ~ 3x greater than the estimate from diver transects. This difference could be a consequence of uneven lobster distributions at this site, or that lobsters were harder to visually observe here.

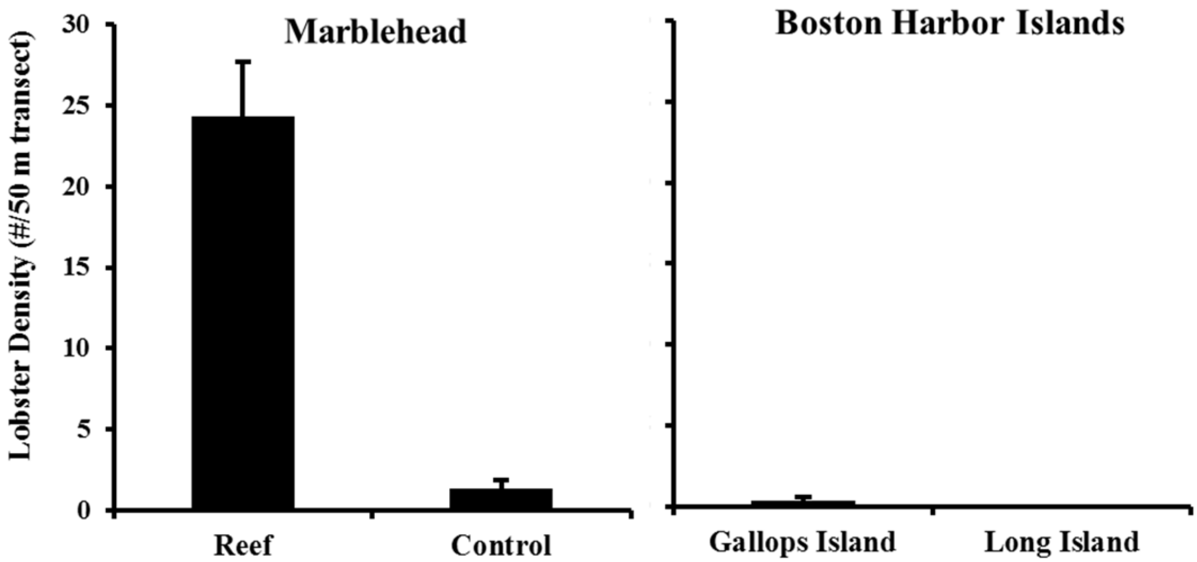


Figure 1D-10. **Lobster densities observed during 50-m diver transects conducted in September 2016 at sights in the Boston Harbor Islands and Marblehead.**

After lobsters, Jonah crabs were the most prevalent species observed during diver transect sampling (Figure 1D-11). Jonah crabs were most common at the Marblehead reef (3.5 ± 1.0/50-m transect) and Gallops Island (3.8 ± 0.6/50-m transect) sites, whereas they were less common but still present at the Marblehead control (1.0 ± 0.6/50-m transect) and Long Island (1.2 ± 0.3/50-m transect) sites. Given that the density of Jonah crabs were ~ one order of magnitude higher in diver transects (0.012/m^2) than in trawl surveys (0.001/m^2) at the Marblehead sites, diver transects were likely more effective method of quantifying the density of Jonah crabs at our sites.

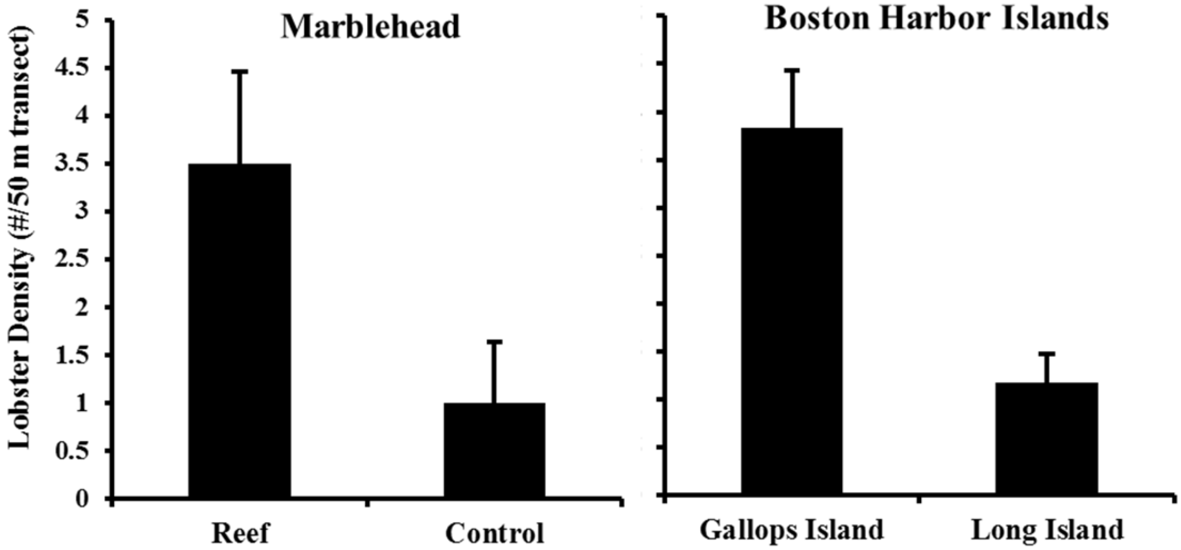


Figure 1D-11. **Jonah crab densities observed during 50-m diver transects conducted in September 2016 at sights in the Boston Harbor Islands and Marblehead.**

Several other crustacean species were observed during diver transect sampling. The green crab (*Carcinus maenas*), an invasive species that can exert strong predation pressure on commercially important bivalves in New England, was only observed in diver transect surveys conducted at Long Island (4.5 ± 2.0/50-m transect). The spider crab (*Libinia emarginata*) was also common at Long Island (3.7 ± 0.8/50-m transect), and was also observed at Gallops Island (0.3 ± 0.2/50-m transect), but not at the Marblehead sites. One Calico crab (*Ovalipes ocellatus*) each was observed at both the Gallops Island and Marblehead control sites. Finally, one Asian shore crab (*Hemigrapsus sanguineus*) was also observed at Gallops Island.

Fish were less commonly observed than crustaceans during diver transects. The tautog (*Tautogolabrus adspersus*) was the most common fish species, though it was only observed at Gallops Island (2.3 ± 1.1/50-m transect). After tautog, winter skate (*Leucoraja ocellata*) was the most common fish species and the only cartilaginous fish observed during diver transects. A winter skate was observed at the Gallops Island, Long Island, and Marblehead Reef sites. Lastly, one winter flounder (*Psuedopleuronectes americanus*) was observed at the Marblehead control site, whereas one yellowtail flounder (*LImanda ferruginea*) was observed at Gallops Island.

Table 1D-4. Total abundance of fish and invertebrates quantified in 50-m long diver transects conducted at the Marblehead and Boston Harbor Island Sites.

Species	**Gallops Island**	**Long Island**	**Marblehead Control**	**Marblehead Reef**
Leucoraja ocellata	1	1	0	1
Tautogolabrus adspersus	14	0	0	0
Limanda ferruginea	1	0	0	0
Psuedopleuronectes americanus	0	0	1	0
Homarus americanus	2	0	8	146
Ovalipes ocellatus	1	0	1	0
Libinia emarginata	2	22	0	0
Cancer borealis	23	7	6	21
Carcinus maenas	0	27	0	0
Hemigrapsus sanguineus	1	0	0	0
Neverita lewisii / Euspira heros	0	0	1	1
Environmental Characteristics				
Start depth (m)	8.2	6.6	3.9	5.1
End depth (m)	6.1	5.8	2.1	4.0
Temperature (^{o}C)	17.2	17.2	17.2	16.7
Visibility (m)	3.0	2.0	2.0	1.0

Quadrat sampling

While the purpose of quadrat sampling was to quantify the densities of economically valuable bivalve species, only one harvested bivalve species was detected: A hard clam (*Mercenaria mercenaria*) was found in 2 of the 15 quadrats conducted at the Marblehead control site (Table 1D-5). The European oyster (*Ostrea edulis*), which is an invasive invertebrate species, was the only other bivalve species that was present in a quadrat sample. Two European oysters were found in each of two quadrats conducted at Gallops Island.

The most prevalent species in the quadrat samples was the long-clawed hermit crab (*Pagurus longicarpus*). Hermit crab densities were higher at the Marblehead than the Boston Harbor Island sites. Densities were greatest at the Marblehead control (4.9 ± 4.2/0.25 m^2) site, and just slightly lower at the Marblehead reef (4.4 ± 2.3/0.25 m^2) site. Meanwhile, hermit crab densities were also similar at the two Boston Harbor Island sites: 0.75 ± 0.69/0.25 m^2 at Gallops Island vs. 0.5 ± 0.26/0.25 m^2 at Long Island. Other crustaceans that were sampled by quadrats but not common (i.e., < 1/0.25 m^2) included the sand shrimp (*Crangon septemspinosa*), the Jonah crab (*Cancer borealis*) and the lady crab (*Ovalipes ocellatus*) (Table 1D-5).

Fish species were rarely observed during quadrat sampling. One individual of the following three fish species was observed within quadrat samples: a longhorn sculpin (*Myoxocephalus octodecimspinosus*) at Gallops Island, a black seabass (*Centropristis striata*) at Long Island, and a tautog (*Tautogolabrus adsperus)* that was also at Long Island.

Table 1D-5. Total abundance of fish and invertebrates quantified in 0.25 m2 quadrat samples conducted at the Marblehead and Boston Harbor Island Sites.

	Gallops Island	Long Island	Marblehead Control	Marblehead Reef
Number of quadrats	16	16	15	15
Myoxocephalus octodecimspinosus	1	0	0	0
Centropristis striata	0	1	0	0
Tautogolabrus adspersus	0	1	0	0
Crangon septemspinosa	1	7	5	0
Crassostrea virginica	4	0	0	0
Pagurus longicarpus	12	8	73	66
Cancer borealis	0	0	3	1
Ovalipes ocellatus	0	0	1	1
Mercenaria mercenaria	0	0	2	0
Littorina littorea	0	0	77	0

Vemco tags

These data will be collected in the fall of 2017 and used for the permitting process.

Physical sampling

Methods

Wave height climate

Depth variations at field sites were monitored using small (39.4 mm x 13 mm) transducer/dataloggers manufactured by Star-Oddi, Gardabaer, Iceland.

The sensors resolve water depth with an accuracy of ±0.4% of full-scale, and a resolution of 0.03% of full-scale, for the depth range. We used loggers with a 50-m depth full-scale reading; thus, accuracy is ± 0.004 x 5000 cm = ±20 cm, with a resolution of 0.0003 x 5000 cm = 1.5 cm. These loggers are capable of measuring temperature, but to save memory, temperature was measured using Hobo pendants. Star-Oddi's sensors for pressure and temperature are calibrated by the manufacturer at the factory and calibration coefficients are available to the user. At a sampling rate of once every 30 sec., these loggers have a depolyment life in excess of one year and adequate memory capacity for the desired monitoring period of this project. The Appendices present more information on this device.

The DST milli-TD mini pressure (depth) and temperature loggers were mounted in plastic sleeve and deployed by divers at a range of depths of c. 6-8 m (MLW) at a height about 25 cm above the bottom using a cement tub mooring system (Figure 1D-12). Exact average depth placement is available in the wave spectral data section below.

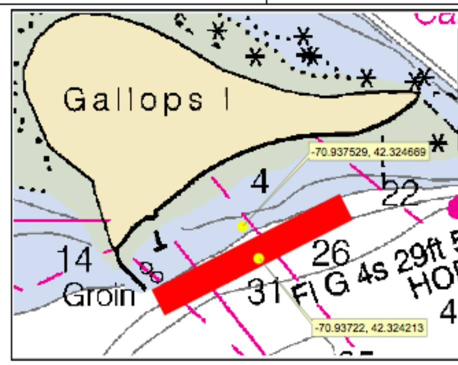
Over the initial project period (23 September 2016-12 April 2017), 8 loggers were deployed with a slower sampling period (once every 30 sec) to estimate wave heights (Figure 1D-13). One sensor set (Marblehead Control (shoreward) has not been recovered and may be either lost from a storm event, or is buried. Efforts are ongoing to attempt to relocate this logger.

Figure 1D-12. **Image of the (a) cement tub mooring system and (b) the plastic sleeve that housed the Starr-Oddi DST depth logger.**

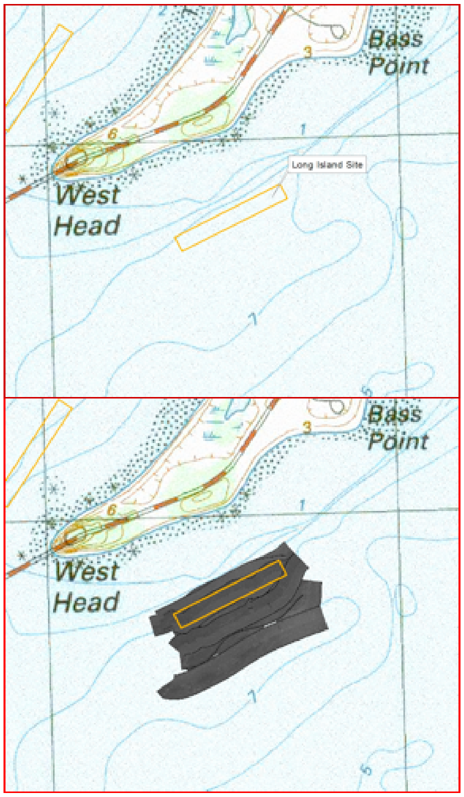
The 30-sec sampling period was selected to capture the wave height distribution, but does not allow estimation of dominant wave periods. On 12 April 2017, loggers sampling at 10 Hz to capture short-term wave data to estimate wave period were deployed, but a software configuration error prevented high frequency sampling. A new deployment is planned for late June.

a. Gallops Island

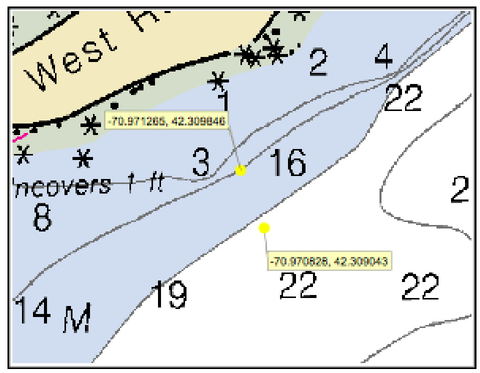
Gallops Island - Site Box Coordinates			
Corner	Lat	Lon	
NW	42 19.427	070 56.358	
NE	42 19.508	070 56.139	
SE	42 19.486	070 56.125	
SW	42 19.405	070 56.343	
Inner Mooring			
	42 19.48014	070 56.25174	Attached equipment
Time deployed: 09/21/2016, 10:30AM			wave sensor (#B1622)
			HOBO Pendant (#10350121)
Outer Mooring			
	42 19.32421	070 56.23320	Attached equipment
Time Deployed: 9/21/2016, 10:50AM			wave sensor (#B1623)
			HOBO Pendant (#10625906)
			VEMCO Receiver (#103084)



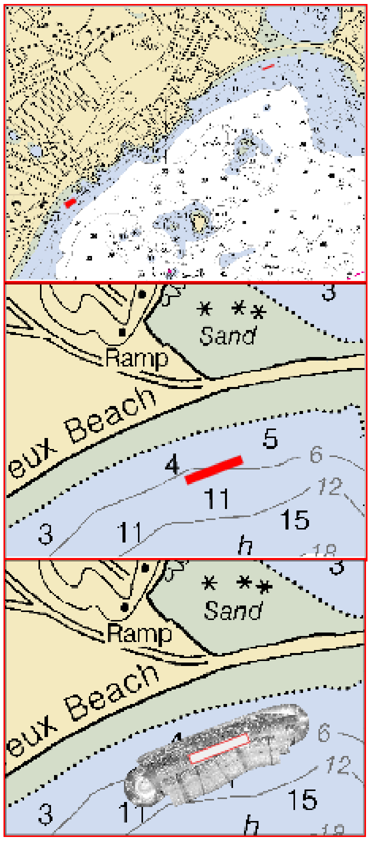
b. Long Island



Long Island - Control Site Box Coordinates			
Corner	Lat	Lon	
NW	42 18.530	070 58.374	
NE	42 18.611	070 58.155	
SE	42 18.588	070 58.141	
SW	42 18.507	070 58.359	
Inner Mooring			
	42 18.59076	070 58.27590	Attached equipment
Time deployed: 09/21/2016, 12:50AM			wave sensor (#B1625)
			HOBO Pendant (#10626933)
Outer Mooring			
	42 18.54258	070 58.24968	Attached equipment
Time Deployed: 9/21/2016, 13:00AM			wave sensor (#B1621)
			HOBO Pendant (#10350120)
			VEMCO Receiver (#109287)

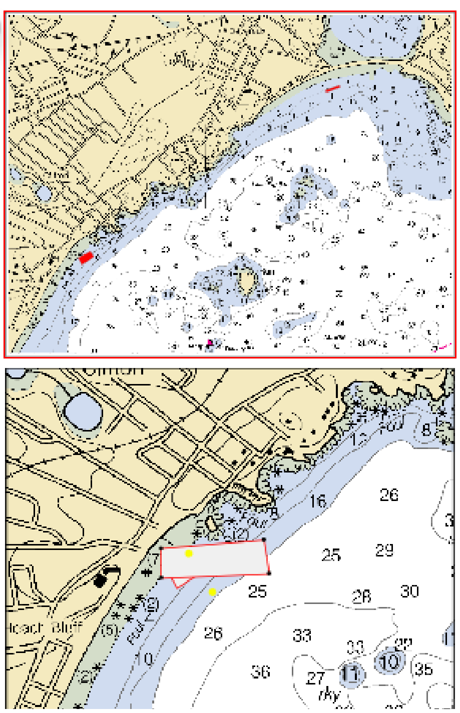


c. Marblehead Reef



Marblehead Site Box Coordinates			
Corner	Lat	Lon	
NW	42 29.3883	070 51.2826	
NE	42 29.41152	070 51.19974	
SE	42 29.40234	070 51.19500	
SW	42 29.37942	070 51.27834	
Inner Mooring			
	42 29.40114	070 51.24197	Attached equipment
		Time deployed: 10:50	wave sensor (#B1688)
			HOBO Pendant (#none)
Outer Mooring			
	42 29.38943	070 51.23404	Attached equipment
		Time Deployed: 10:45	wave sensor (#B1626)
			HOBO Pendant (#10942816)
			VEMCO Receiver (#104708)

d. Marblehead Control



Marblehead Control - Control Site Box Coordinates			(off Preston Beach)
Corner	Lat	Lon	
NW	42 28.7034	070 52.7735	
NE	42 28.7177	070 52.5268	
SE	42 28.6577	070 52.5148	
SW	42 28.6515	070 52.7735	
Inner Mooring			
	42 28.69390	070 52.7072	Attached equipment
		Time deployed: 09:55	wave sensor (#B1627)
			HOBO Pendant (#none)
Outer Mooring			
	42 28.624975	070 52.65093	Attached equipment
		Time Deployed: 09:50	wave sensor (#_B1494)
			HOBO Pendant (#10945355)
			VEMCO Receiver (#128018)

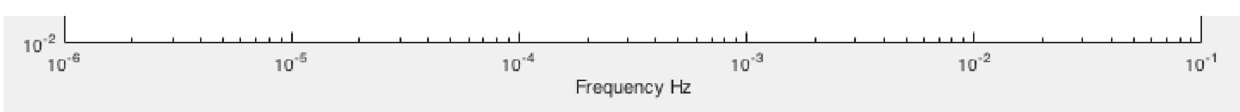
Figure 1D-13. **GPS locations of site boxes and inner and outer moorings with attached equipment at each site.**

Wave spectral parameters and associated wave statistics were estimated using MATLAB routines developed by Dr. Urs Neumeier (2003) based on best engineering practices given in Tucker and Pitt (2001). Dispersion relationships were solved using a polynomial approximation. Data were split into three periods, 23 September - 30 November 2016 (SeptNov in file nomenclature), 1 December 2016 - 28 February 2017 (DecFeb in file nomenclature), and 1 March – 12 April 2017 (MarApril in file nomenclature) for analysis. Because we anticipate continuing sampling until September 2017, the initial sampling period was split arbitrarily into three periods that to conduct preliminary analyses on potential seasonal patterns. These periods were selected to assess whether seasonal variation in wave climate occurs at these sites. During the analysis of each wave climate period, the data are further subdivided into quarter-records for computation of wave spectral characteristics and statistics, and then averaged.

Constraints on data estimation: Pressure sensors used to infer wave heights must estimate attenuation correction factors using spectral analysis of the wave field and then correcting for depth attenuation coefficients using linear wave theory by solving the wave dispersion relation. Most wind waves occur with a period of 0.5-30 sec period, while longer periods result from combined wind and storm events (Nortek 2017). Because we used longer-period sampling (0.0333 Hz = 30 sec sampling interval) to allow long-term observation of the wave climate from storms using low-cost pressure sensors, shorter-period waves (0.5-30 sec periods) are “aliased” into longer wavelengths. “Aliasing” is the process whereby fluctuations at higher frequencies bias the estimation of the spectrum. In other words, energy present at high frequencies is detected as extra variance in the energy at the lower frequencies that were sampled. During the design phase of this study, it was decided that seasonal storm wave spectra would be estimated from long-term deployments of the low-cost Star-Oddi pressure recorders, with short “snapshots” of high frequency sampling by these same recorders used to estimate the wind wave spectra.

Worldwide, a significant fraction of the arriving wave energy is contained in the range of 8-12 sec waves (0.125-0.0833 Hz) from ocean swell (Leigh et al. 1987; Denny 2006). Because of the 0.0333 Hz (30 sec interval) sampling rate used for the long-term deployment, this energy from wind waves will be folded into the highest frequency of the computed spectrum. The highest frequency we can compute from our 30-sec sampling internal is of course half the sampling frequency (0.0167 Hz = 60 sec interval waves). The aliasing from shorter period waves will thus be found at the far right-hand part of the computed spectrum (Figure 1D-14). Seasonal changes in wave climate, mediated by frequency and intensity of storm events due to passing weather systems are thus not contaminated by this aliased signal energy from shorter period swell.

In the data reported, all wave climate parameters are referred to modulation of wave heights relative to the average depth, defined as the mean of the high and low tides over the period of deployment.

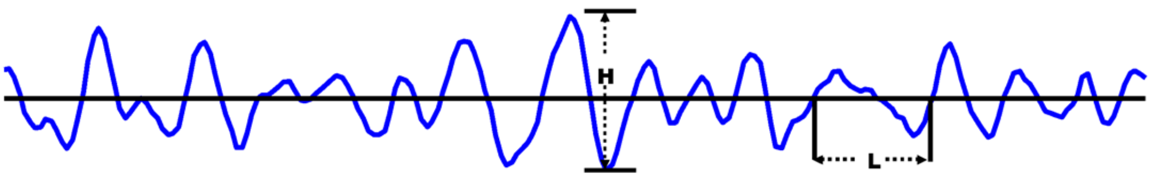


27.8 h 2.78 h 0.278 h 100 s

Figure 1D-14. **The intervals corresponding to the frequency spectrum are shown above for convenience in interpreting Figure 1D-16.**

Spectral wave parameters derived from the observed spectrum, as well as zero-crossing parameters from the individual waves, are calculated by the algorithm developed in MATLAB by Neumeier (2003). Because of the long sampling interval, all wave period estimates are irrelevant here (other than confirming that the tidal periods dominates these data). All times are in seconds, and heights in meters. The **h value** is the mean water level reference (depth) in meters. This is the average of the high and low tides over the observation period.

Zero-crossing wave parameters are computed using the zero-crossing convention from mathematics, defined as the point at which a function crosses the horizontal axis as its value passes through zero and changes sign. In wave measurements from pressure sensors, we extract wave height (H) and period (L) on a wave-by-wave basis as shown in the following diagram.



spectral wave-parameters (computed from the distribution)

m0	Total variance
	wave energy = water-density · g · m0
Hm0	significant wave height by spectral method
Tp	Peak period
T_0_1	average period m0/m1
T_0_2	average period (m0/m2)^0.5
T_pc	calculated peak period
EPS2	spectral width parameter
EPS4	spectral width parameter

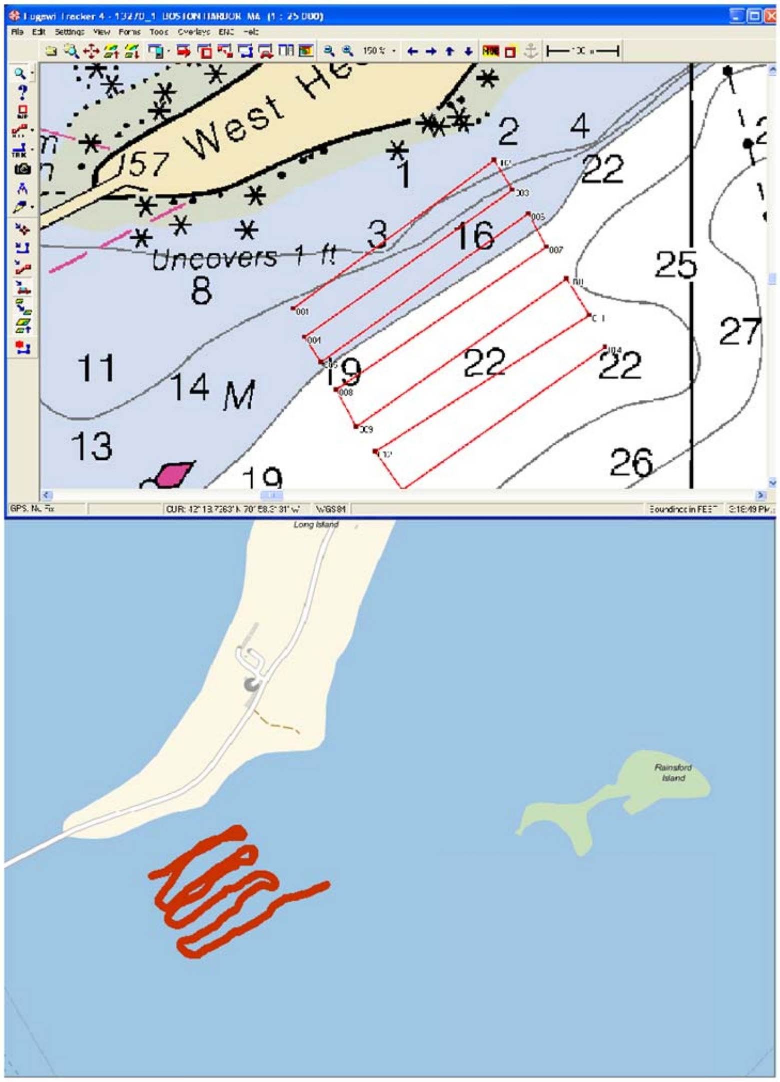
zero-crossing wave-parameters (computed from the set of all waves observed)

H_s	significant wave height
H_mean	mean wave height
H_10	height of highest 10%
H_max	maximum wave height
T_mean	mean wave period
T_significant	mean period of highest 33%

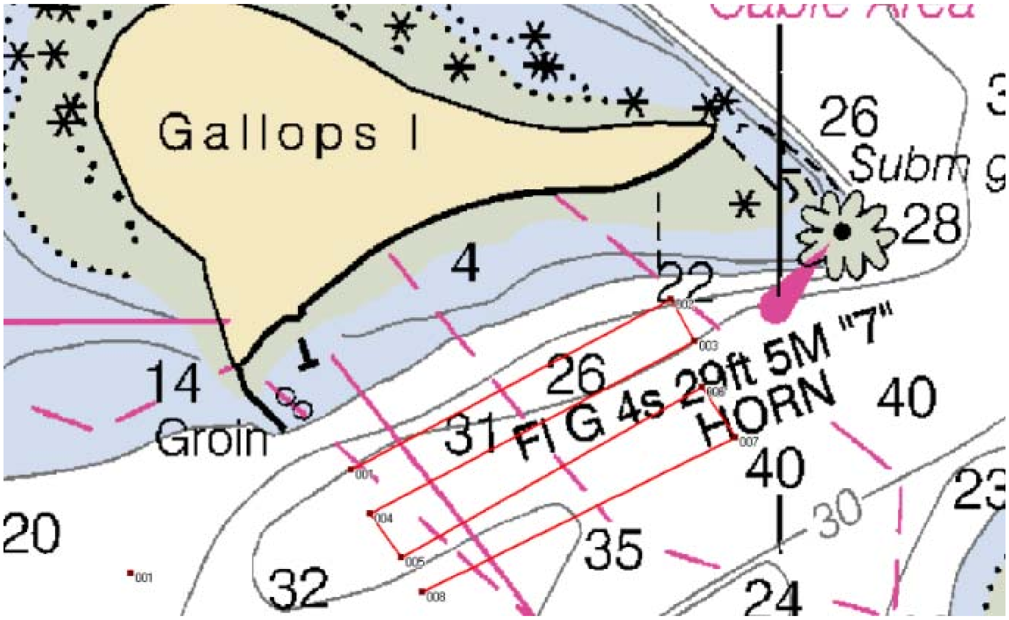
Water quality sampling

Because of technical issues involving the sensor suite on the AUV, and an unforeseen delay in the installation of a davit with winch on our research vessel, water quality sampling at all four sites was accomplished towing a YSI EcoSonde II at c. 0.5-1 m depth in lawnmower patterns, with separate water column profiles conducted from the surface to the seafloor, at the center of each lawnmower pattern (Figure 1D-15). The sonde sampled temperature (°C), salinity (practical salinity units, PSU), chlorophyll a concentration (µg/l), turbidity (formazin nephelometric units, FNU), and dissolved oxygen (mg/l) as a function of depth (m). Are sensors were calibrated following the manufacturer's recommendations in the operator's manual and are National Institute of Standards and Technology (NIST) traceable. Sampling occurred 1 December 2016 at the Harbor Islands sites, and 2 December 2016 at the Marblehead sites. It rained the night of November 30-December 1 and conditions were partly sunny with air temperatures between 39 and 57°F. Sonde data were geo-referenced using a separate Garmin GPS, WAAS-enabled, that logged NMEA position sentences. The Circular Error Probable (CEP) of GPS position estimate during the days of sampling was < 10 m. The sonde clock was synchronized with a time server a few hours before deployment so it would within < 0.1 sec of the GPS time. Sampling on the sonde was set to 1 Hz.

a. Long Island

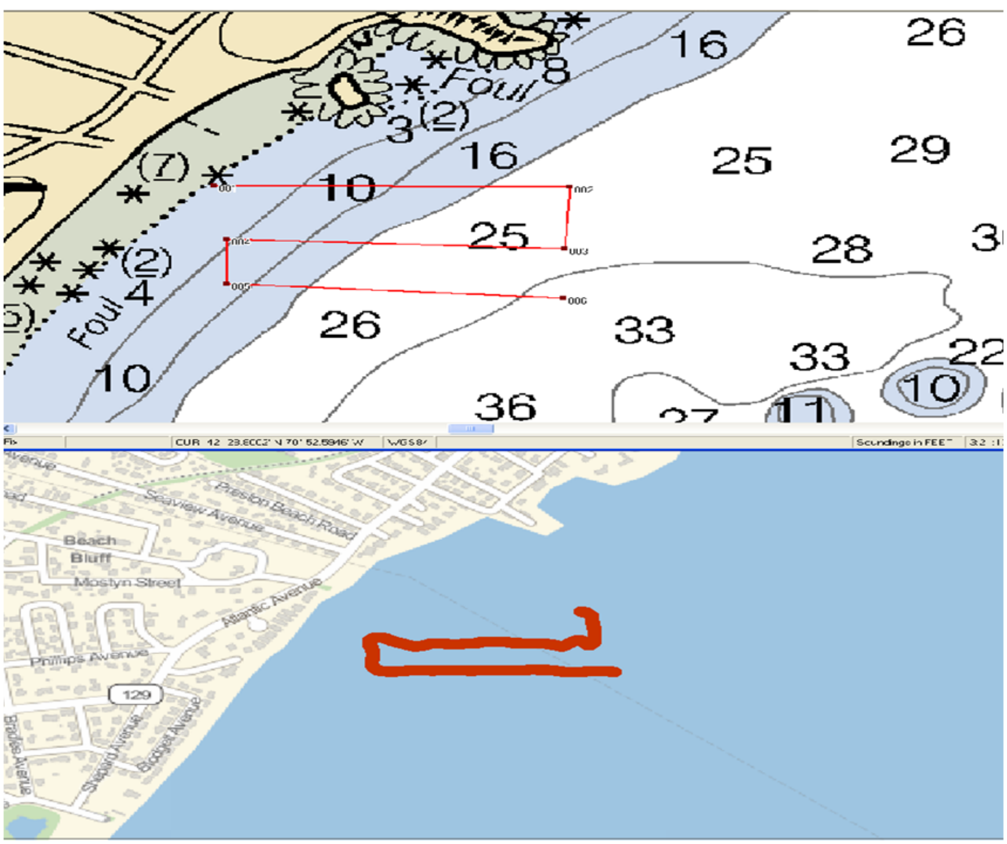


b. Gallops Island



Note: GPS tracker did not record; however, captain followed these lines in real-time on chart display very well.

c. Marblehead Control



Note: Line from waypoint 1 to waypoint 2 was completed, but GPS tracker did not start up immediately.

d. Marblehead Reef

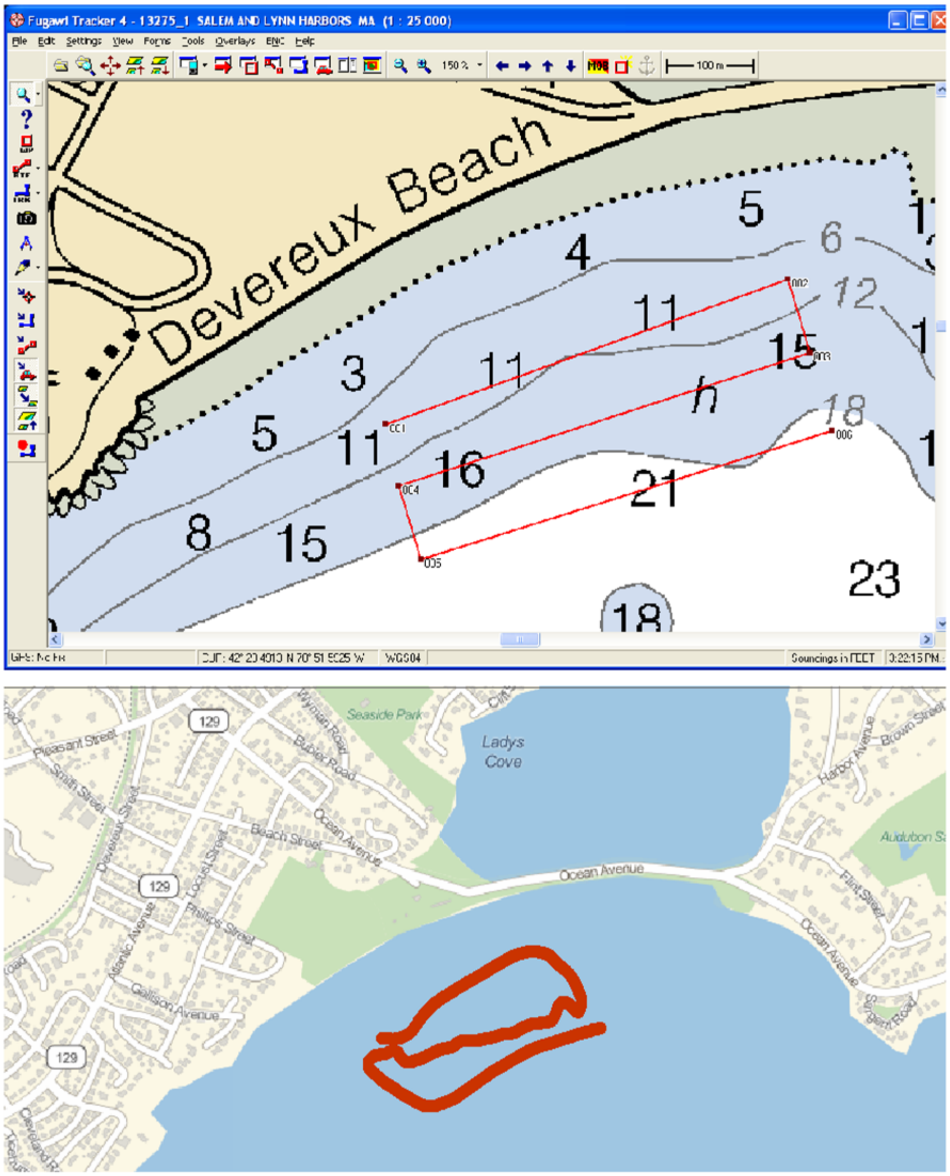


Figure 1D-15. **Planned and realized track lines for spatial surface water sampling. The velocity of the vessel was c. 2 kt (1 m/s).**

Results

Wave height climate

The spectra shown in Figure 11 give energy on the y-axis in m^2/Hz and frequency on the x-axis in Hz. The highest frequency shown (0.01667 Hz = 60 sec period) is half the sampling rate (0.0333 Hz = 30 sec period).

For the purposes of seasonal and site inter-comparisons, H_s, H_mean, and H_max, are the most informative (Table 1D-6). H_s, significant wave height, is the average height estimated by a trained observer of the largest 1/3rd of waves. For ease in comparison, values below are rounded to the nearest

0.1 m (see also the wave parameter tables in Figure 11). Note that the pressure sensor has a resolution less than the computed statistics (c. 0.015 m).

Table 1D-6. Wave Climate, Fall 2016-Spring 2017. tba = to be added; this logger has not been recovered after three attempts to locate it and is possibly buried by a storm.

Site	**H_s (m)**			**H_{mean} (m)**			**H_{max} (m)**		
	Fall	**Winter**	**Spring**	**Fall**	**Winter**	**Spring**	**Fall**	**Winter**	**Spring**
Gallops	3.2	3.2	3.5	1.8	1.9	2.1	4.0	4.0	3.9
Long Seaward (Gallops Control)	3.3	3.3	3.5	2.2	2.1	2.4	4.0	3.9	4.0
Long Island Shoreward (Gallops Control)	3.3	3.2	3.5	1.9	1.9	2.1	4.0	4.0	4.1
Marblehead Shoreward	1.2	1.3	1.1	0.6	0.7	0.6	3.9	3.6	3.1
Marblehead Seaward	1.3	1.3	1.2	0.6	0.7	0.6	3.9	3.7	3.0
Marblehead Control Shoreward	tba	tba	tba	tba	tba	tba	tba	tba	tba
Marblehead Control Seaward	1.3	1.4	1.3	0.6	0.6	0.7	3.9	3.9	3.7

As shown in Table 1D-6, the Harbor Islands show larger wave amplitudes than the North Shore sites at all times of year as measured by H_s and H_mean.

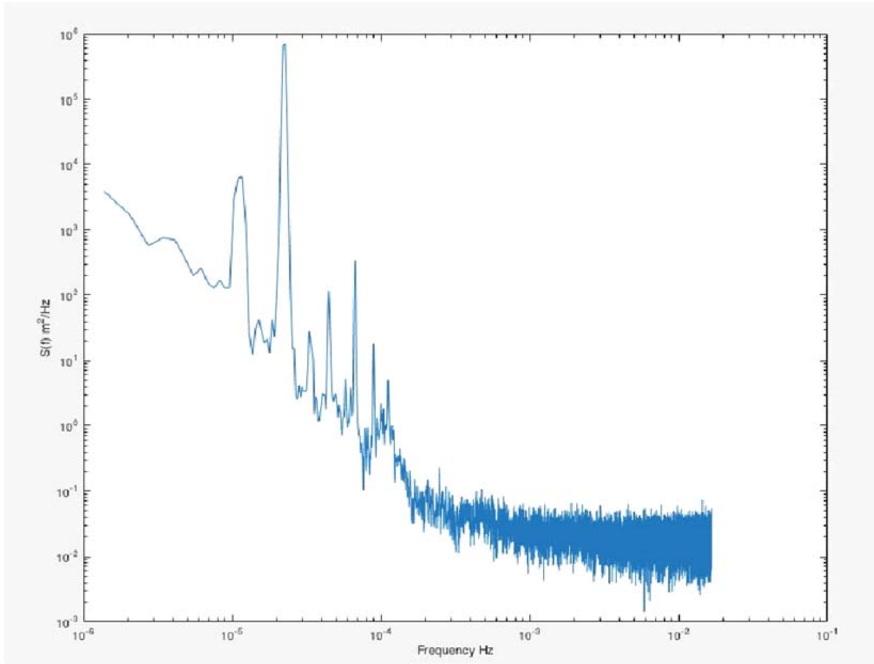
Spectral comparison:

Total wave energy as measured by spectral variance: At all sites, wave energy increased during the three periods, with March-April the most energetic period of observation when comparing m0, the total wave energy variance. The only exception to this pattern was the Marblehead Control site, where the first two observation periods, September-November and December-February, were about equal, with March-April having much more energy.

Spectral peaks: The Harbor Island sites (Gallops and Long Island) had high variation in energy at several peaks near 10^{-4} Hz (2.78 hours) that was not evident in the Marblehead records (Figure 1D-116). These may be wave energy bands associated with refraction and diffraction of waves around adjacent harbor islands. It is unlikely that these perturbations result from boat traffic as the variance is large (note the logarithmic scale on the y-axis).

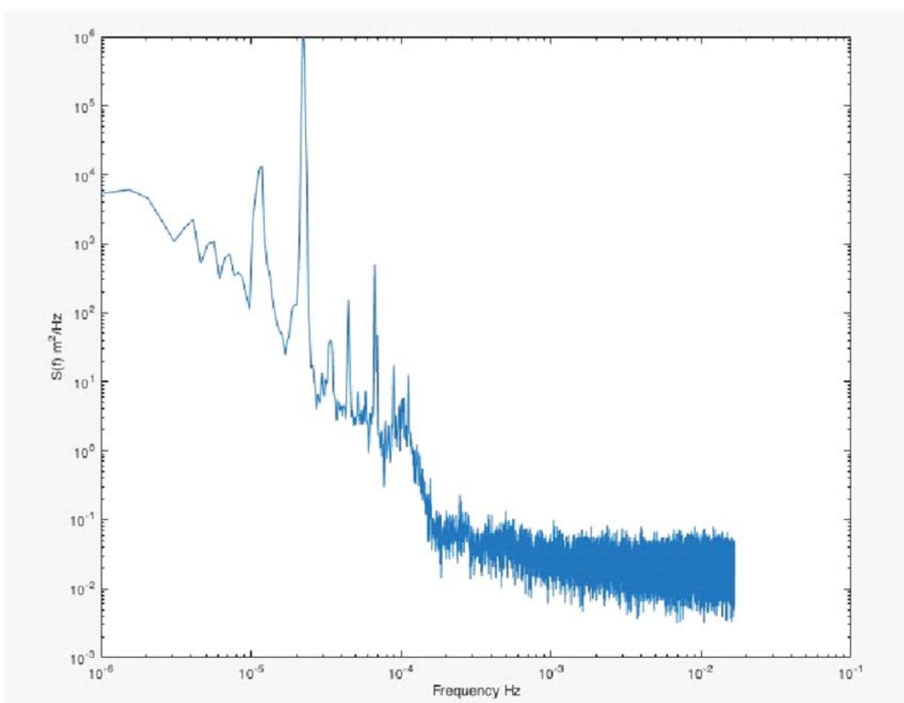
As expected, for all spectra, significant wave energy occurs at c. 24 and 12 hours, which is the influence of the tidal cycle. As the tide falls twice each lunar day, wave amplitude should increase over the wave sensor, as waves entering shallow-water feel the bottom and start peaking and subsequently break.

a. Gallops Island (shoreward side), September-November 2016



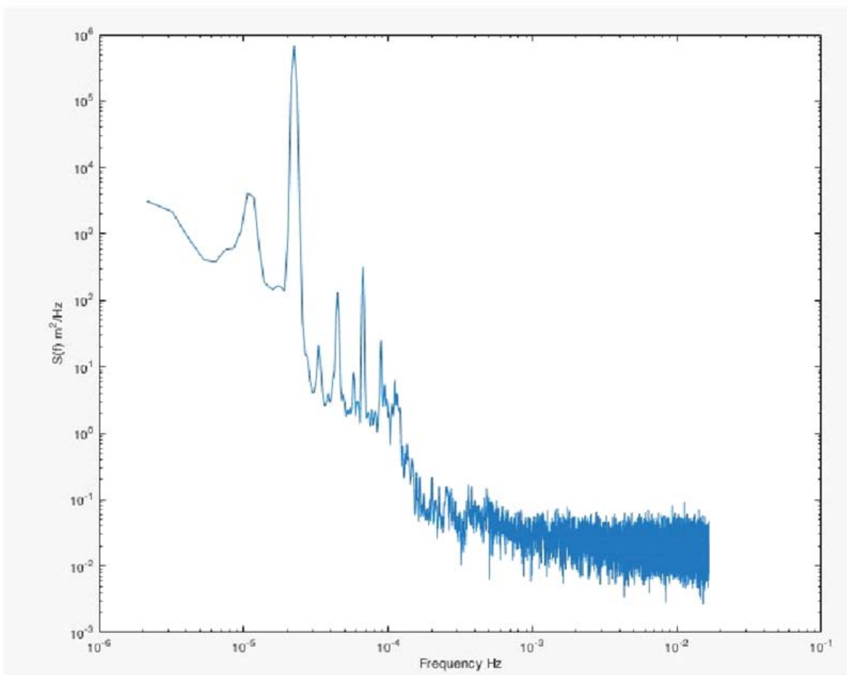
Wave Parameter Table	
h	6.89759
Hm0	4.06129
Tp	44100
m0	1.03088
T_0_1	40609.9
T_0_2	5944.92
T_pc	213325
EPS2	6.75743
EPS4	0.999913
H_significant	3.22697
H_mean	1.82374
H_10	3.78602
H_max	4.04981
T_mean	27726.7
T_s	44759.6

b. Gallops Island (shoreward side), December 2016-February 2017



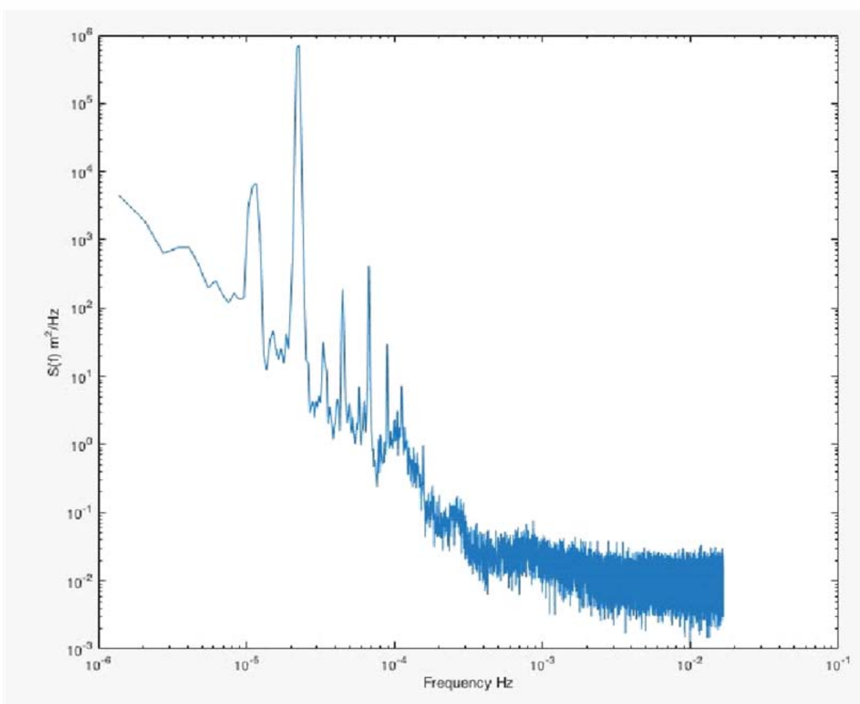
Wave Parameter Table	
h	7.00241
Hm0	4.12061
Tp	45209.3
m0	1.06121
T_0_1	40352.8
T_0_2	5587.13
T_pc	340168
EPS2	7.15289
EPS4	0.9999
H_significant	3.1793
H_mean	1.86215
H_10	3.63724
H_max	3.98972
T_mean	28123.7
T_s	44775

c. Gallops Island (shoreward side), March-April 2017



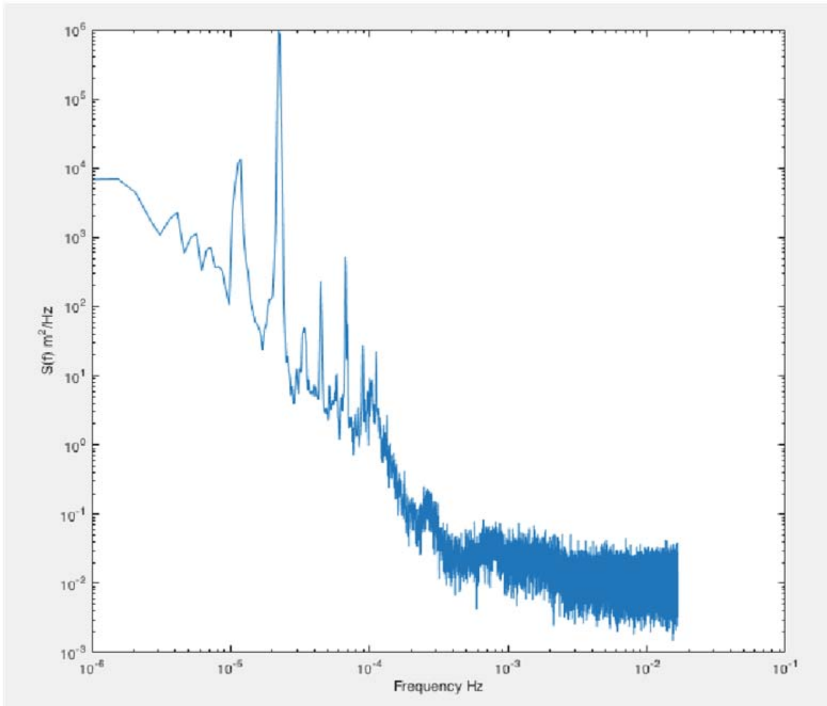
Wave Parameter Table	
h	7.02992
Hm0	4.28361
Tp	44625.7
m0	1.14683
T_0_1	40483.5
T_0_2	5877.6
T_pc	125233
EPS2	6.81479
EPS4	0.99991
H_significant	3.46335
H_mean	2.08894
H_10	3.77935
H_max	3.92857
T_mean	29670.7
T_s	44708.6

d. Long Island (seaward side), September-November 2016



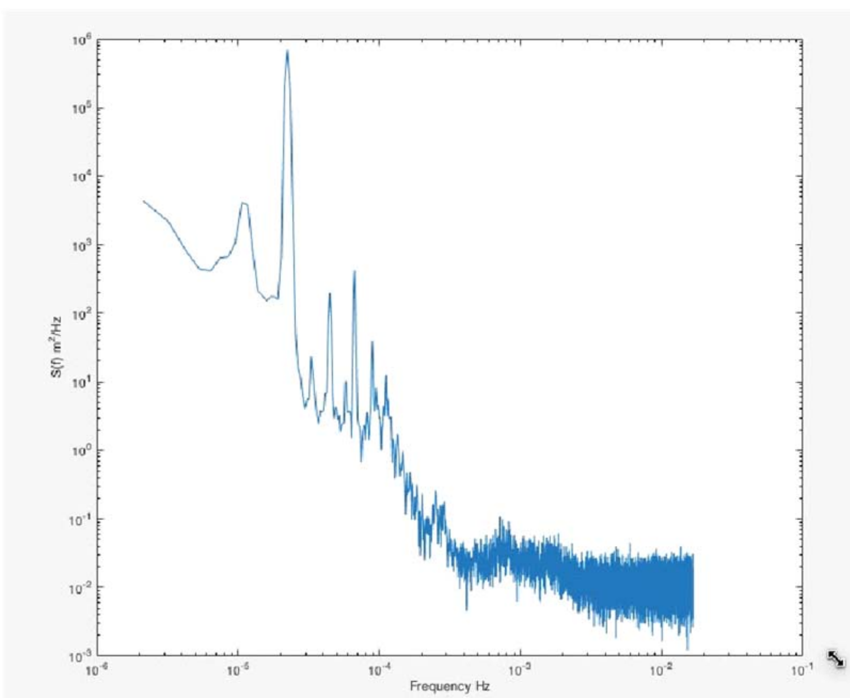
Wave Parameter Table	
h	8.20513
Hm0	4.06565
Tp	44100
m0	1.03309
T_0_1	42497.5
T_0_2	7827.35
T_pc	235439
EPS2	5.33647
EPS4	0.999949
H_significant	3.32663
H_mean	2.20444
H_10	3.84315
H_max	3.99789
T_mean	33759.1
T_s	44791.1

e. Long Island (seaward side), December 2016-February 2017



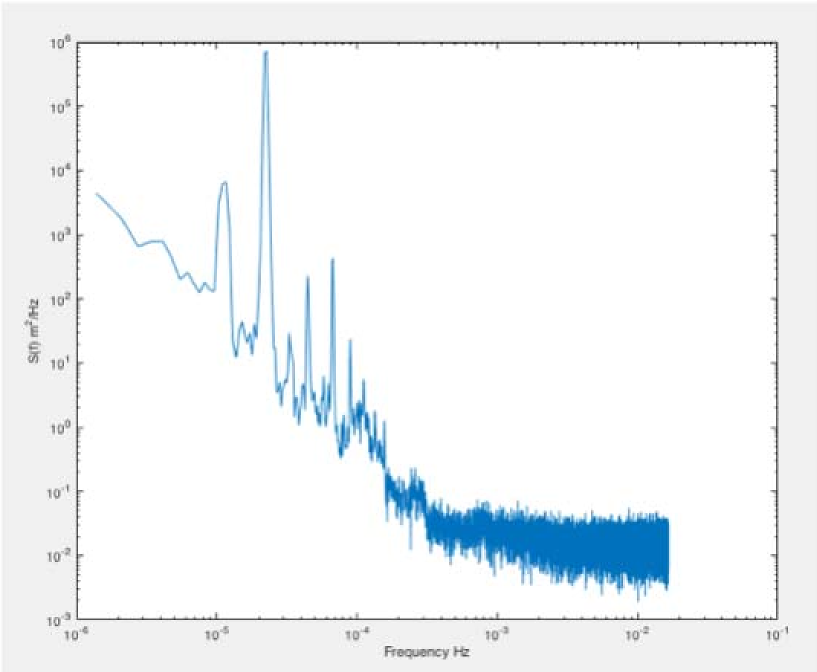
Wave Parameter Table	
h	8.77385
Hm0	4.09154
Tp	45209.3
m0	1.04629
T_0_1	42634.1
T_0_2	7482.96
T_pc	418177
EPS2	5.60905
EPS4	0.999945
H_significant	3.28376
H_mean	2.10234
H_10	3.68384
H_max	3.93925
T_mean	32224.4
T_s	44878.9

f. Long Island (seaward side), March-April 2017



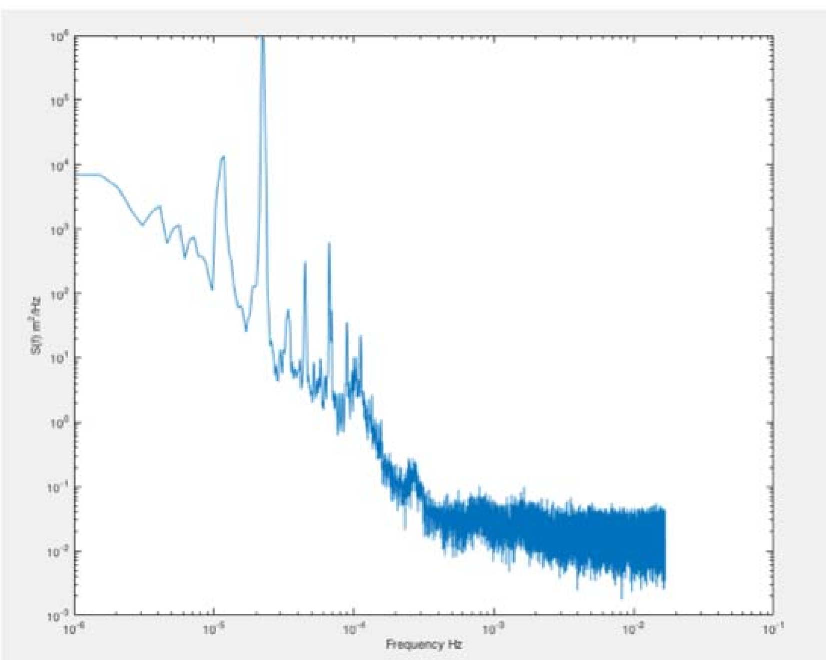
Wave Parameter Table	
h	8.825
Hm0	4.2924
Tp	44720
m0	1.15155
T_0_1	42483.2
T_0_2	7762.88
T_pc	145179
EPS2	5.38047
EPS4	0.999948
H_significant	3.5382
H_mean	2.4112
H_10	3.83938
H_max	3.95848
T_mean	34383.3
T_s	44723.3

g. Long Island (shoreward side), September-November 2016



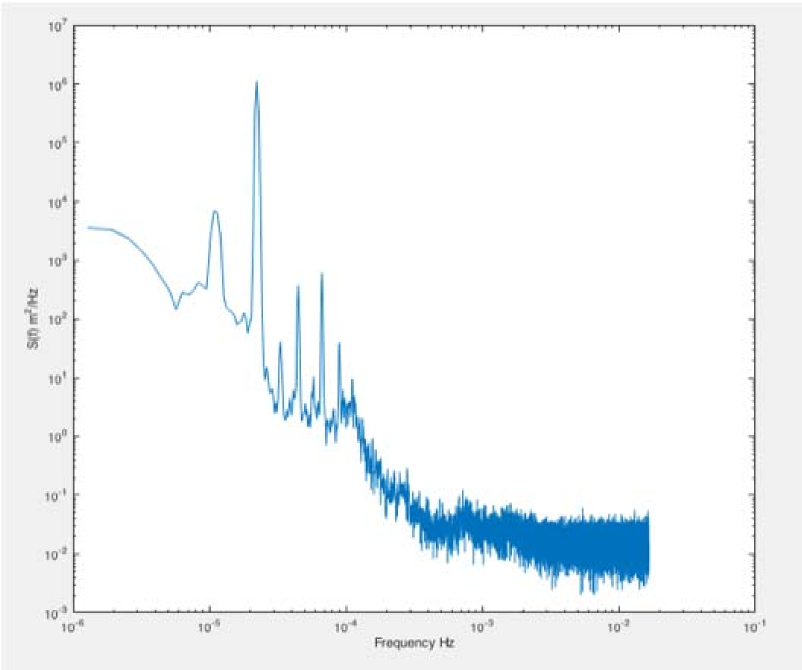
Wave Parameter Table	
h	4.93976
Hm0	4.09272
Tp	44100
m0	1.0469
T_0_1	41347.3
T_0_2	6521.79
T_pc	229634
EPS2	6.26051
EPS4	0.999928
H_significant	3.2631
H_mean	1.93607
H_10	3.8188
H_max	4.04775
T_mean	29155.2
T_s	44745.5

h. Long Island (shoreward side), December 2016-February 2017



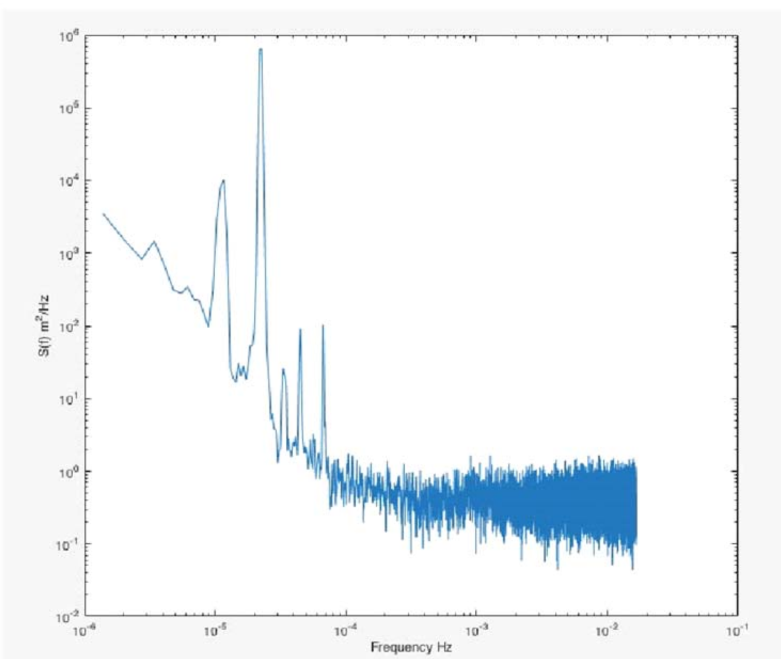
Wave Parameter Table	
h	5.48617
Hm0	4.11495
Tp	45209.3
m0	1.0583
T_0_1	41374.6
T_0_2	6231.84
T_pc	429825
EPS2	6.56348
EPS4	0.999921
H_significant	3.19527
H_mean	1.87211
H_10	3.63093
H_max	3.96941
T_mean	28225.5
T_s	44822.6

i. Long Island (shoreward side), March-May 2017



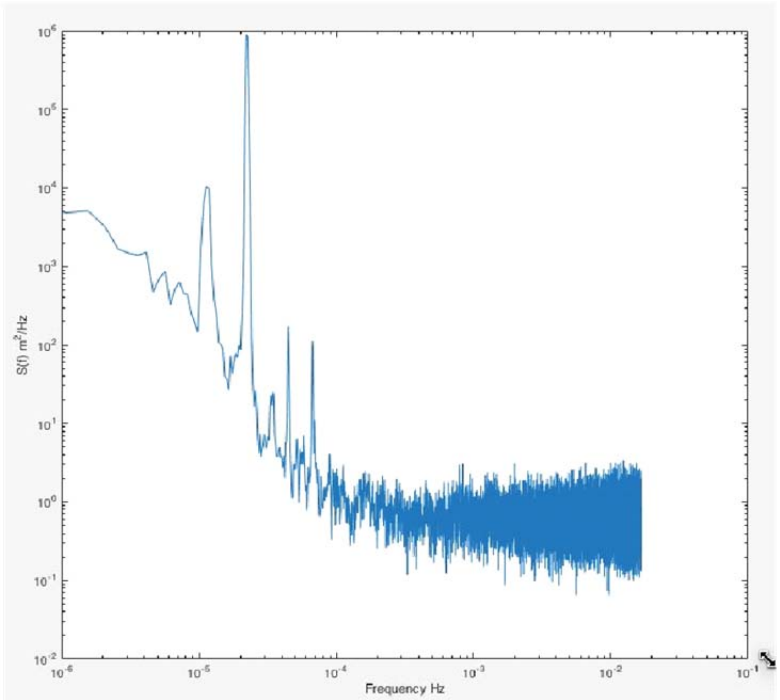
Wave Parameter Table	
h	5.35533
Hm0	4.27949
Tp	44705.1
m0	1.14463
T_0_1	41583.6
T_0_2	6768.18
T_pc	210381
EPS2	6.06206
EPS4	0.999933
H_significant	3.49826
H_mean	2.10334
H_10	3.89724
H_max	4.13156
T_mean	29867.5
T_s	44715.4

j. Marblehead Reef (shoreward side), September-November 2016



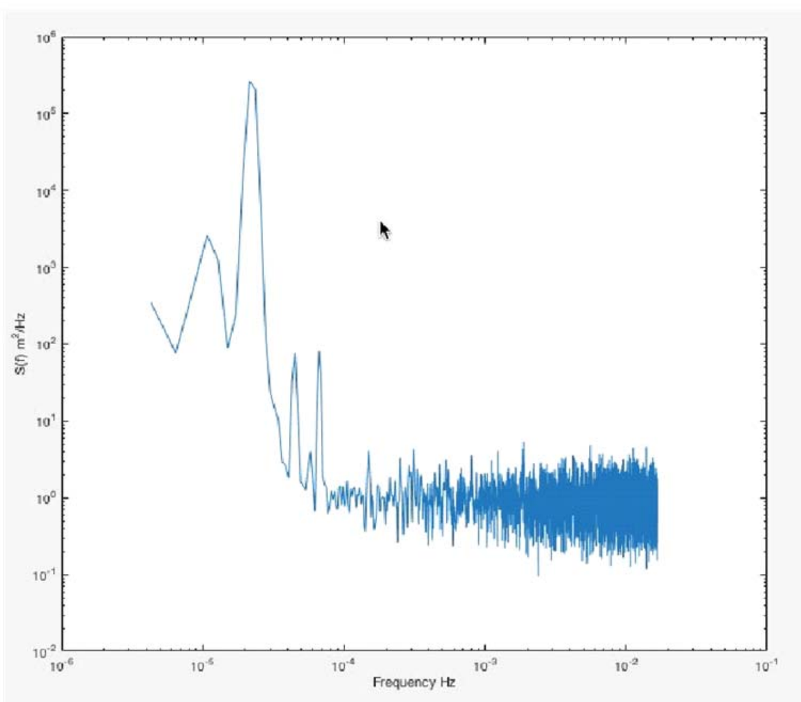
Wave Parameter Table	
h	3.54891
Hm0	3.95472
Tp	44100
m0	0.977489
T_0_1	11773.3
T_0_2	1195.32
T_pc	671002
EPS2	9.79863
EPS4	0.99788
H_significant	1.23743
H_mean	0.578279
H_10	1.98228
H_max	3.88016
T_mean	4149.76
T_s	12096.8

k. Marblehead Reef (shoreward side), December 2016-February 2017



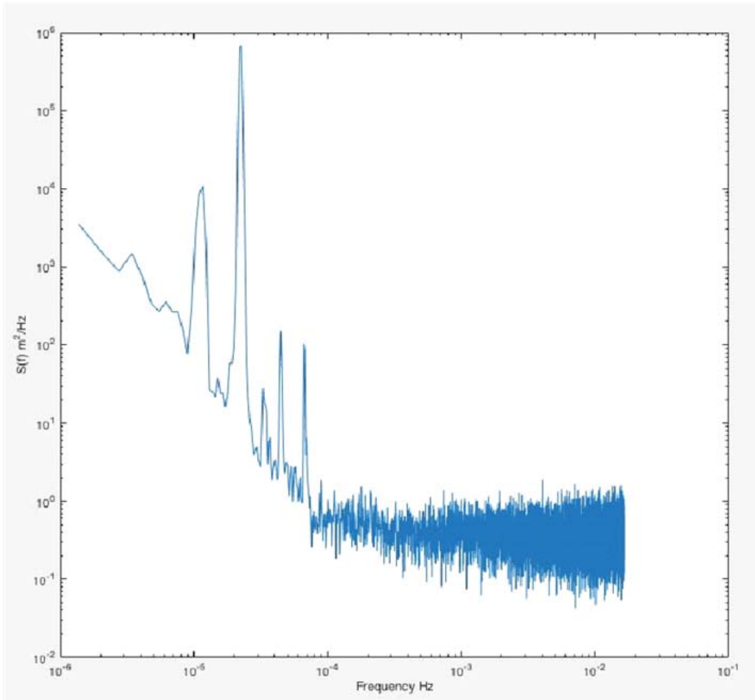
Wave Parameter Table	
h	3.52475
Hm0	4.01257
Tp	45209.3
m0	1.00629
T_0_1	7791.33
T_0_2	915.962
T_pc	1.66154e+06
EPS2	8.44719
EPS4	0.996417
H_significant	1.29718
H_mean	0.654909
H_10	1.8466
H_max	3.56013
T_mean	3268.14
T_s	9440.98

l. Marblehead Reef (shoreward side), March-April 2017



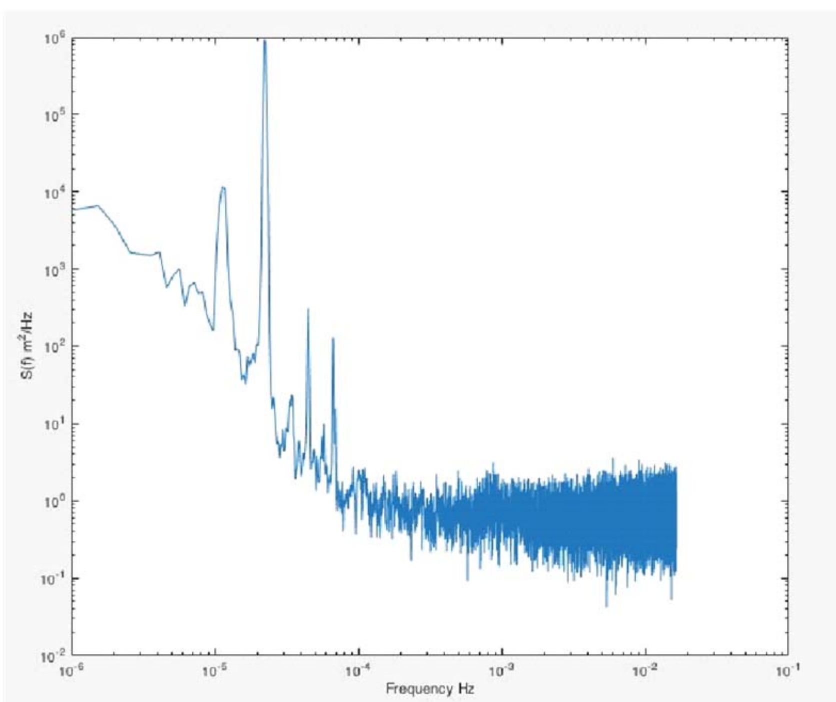
Wave Parameter Table	
h	3.59406
Hm0	4.18977
Tp	46590
m0	1.09714
T_0_1	7062.64
T_0_2	873.761
T_pc	342923
EPS2	8.02094
EPS4	0.996003
H_significant	1.14971
H_mean	0.613474
H_10	1.86418
H_max	3.08909
T_mean	2461.59
T_s	7045.71

m. Marblehead Reef (seaward side), September-November 2016



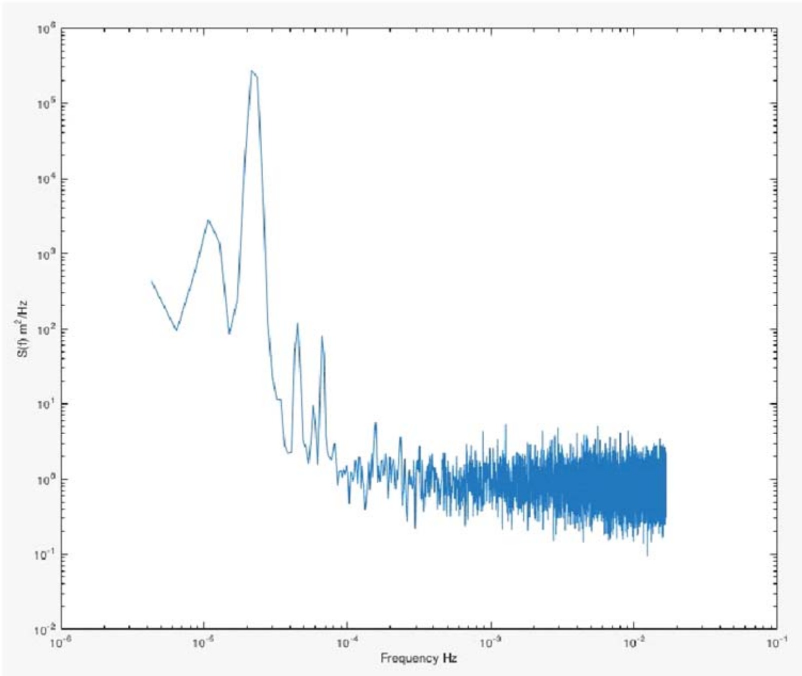
Wave Parameter Table	
h	4.48837
Hm0	4.02239
Tp	44100
m0	1.01123
T_0_1	12734.7
T_0_2	1256.98
T_pc	604260
EPS2	10.0816
EPS4	0.99811
H_significant	1.31909
H_mean	0.6131
H_10	2.0997
H_max	3.90813
T_mean	4671.02
T_s	13646.7

n. Marblehead Reef (seaward side), December 2016-February 2017



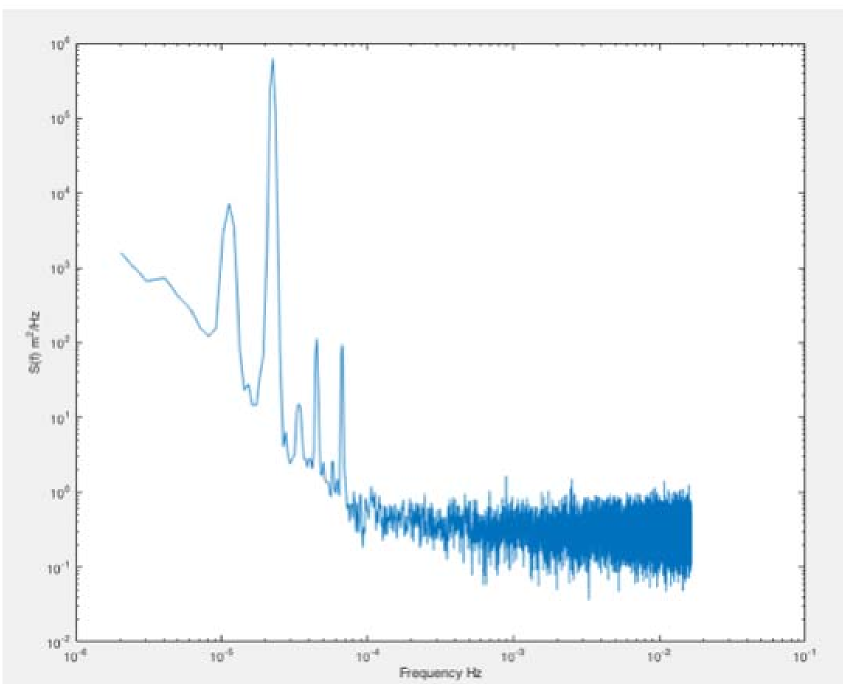
Wave Parameter Table	
h	4.84065
Hm0	4.08169
Tp	45209.3
m0	1.04126
T_0_1	8108.54
T_0_2	935.962
T_pc	1.77504e+06
EPS2	8.60542
EPS4	0.996605
H_significant	1.34379
H_mean	0.681146
H_10	1.94606
H_max	3.7095
T_mean	3406.32
T_s	9838.7

o. Marblehead Reef (seaward side), March-April 2017



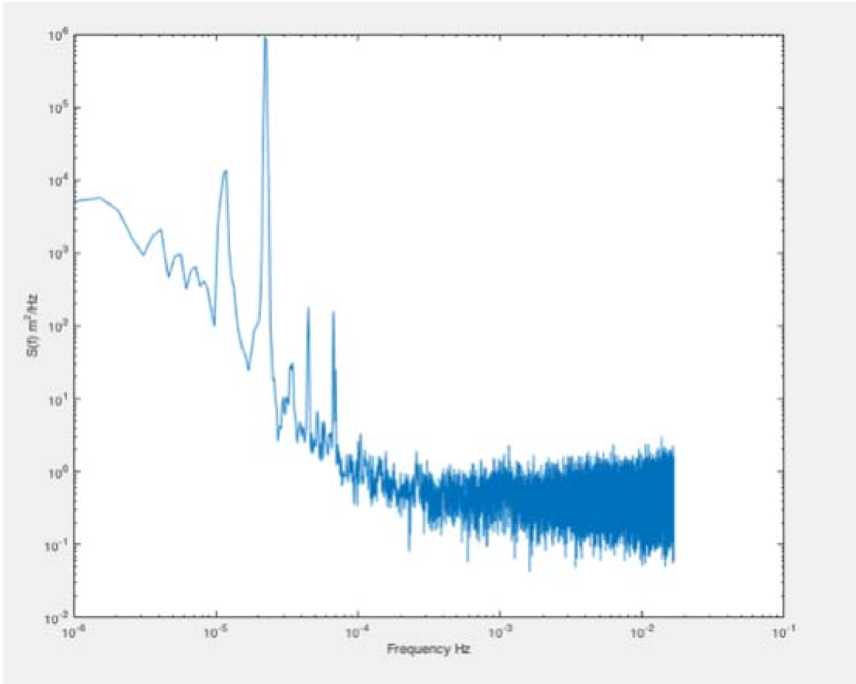
Wave Parameter Table	
h	4.96492
Hm0	4.26914
Tp	46650
m0	1.1391
T_0_1	7271.73
T_0_2	886.731
T_pc	340477
EPS2	8.13941
EPS4	0.996161
H_significant	1.16518
H_mean	0.625107
H_10	1.87783
H_max	3.03931
T_mean	2460.99
T_s	7029.25

p. Marblehead Control (seaward side), September-November 2016



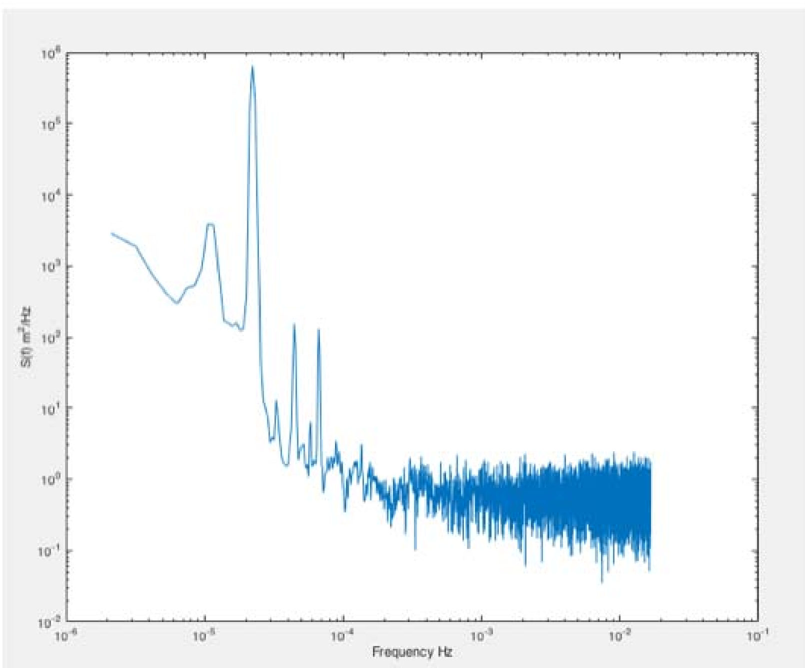
Wave Parameter Table	
h	7.27752
Hm0	4.05387
Tp	44550
m0	1.02711
T_0_1	14712.5
T_0_2	1396.86
T_pc	386703
EPS2	10.485
EPS4	0.998465
H_significant	1.34591
H_mean	0.605986
H_10	2.13119
H_max	3.85743
T_mean	5032.64
T_s	14745.5

q. Marblehead Control (seaward side), December 2016 – February 2017



Wave Parameter Table	
h	**7.67442**
Hm0	4.00487
Tp	45209.3
m0	1.00243
T_0_1	10691.5
T_0_2	1113.08
T_pc	1.26546e+06
EPS2	9.55315
EPS4	0.997607
H_significant	1.36142
H_mean	0.648477
H_10	2.07436
H_max	3.92891
T_mean	4590.73
T_s	13404.9

r. Marblehead Control (seaward side), March-April 2017



Wave Parameter Table	
h	**7.81171**
Hm0	4.16736
Tp	44868.6
m0	1.08543
T_0_1	10090.5
T_0_2	1081.13
T_pc	500617
EPS2	9.27962
EPS4	0.997421
H_significant	1.33669
H_mean	0.653744
H_10	2.08635
H_max	3.73834
T_mean	4075.8
T_s	11877.8

Figure 1D-16 (a-r). **Wave climate results for each site during each of the three seasons.**

Water quality results

Vertical structure of the water column: In December, temperatures at all sites were within seasonal norms and the water column was close to isothermal (Figure 1D-17). Salinity at the two Marblehead sites showed a distinct freshening near the surface that was not apparent at the Harbor Islands sites. Dissolved oxygen through the water column was high at all sites, but Long Island has close to 1 mg/l more dissolved oxygen than the other sites, consistently through the water column. Chlorophyll *a* concentration showed significant increase with depth at all sites, with Long Island showing a dramatic increase half-way to the bottom. Also, at both Marblehead sites, there was a distinct microlayer structure in chl *a* with two sub-surface maxima about 1/3 and 2/3rd of the way to the seafloor. Marblehead sites also exhibited a sharp increase in turbidity right near the seafloor that was not seen at the Harbor Island sites.

Spatial structure of water quality in the surface layer: Data from the surface tows were plotted using custom routines in *Mathematica 11.1.1* (Figures 1D-18-21). The tow paths were designed to capture the vast majority of each site. The data were not smoothed in these plots to prevent small-scale patchiness from being erased by a smoothing kernel. However, a first order interpolation routine using nearest neighbors is employed by the ListDensityPlot routine in *Mathematica* to fill in missing values.

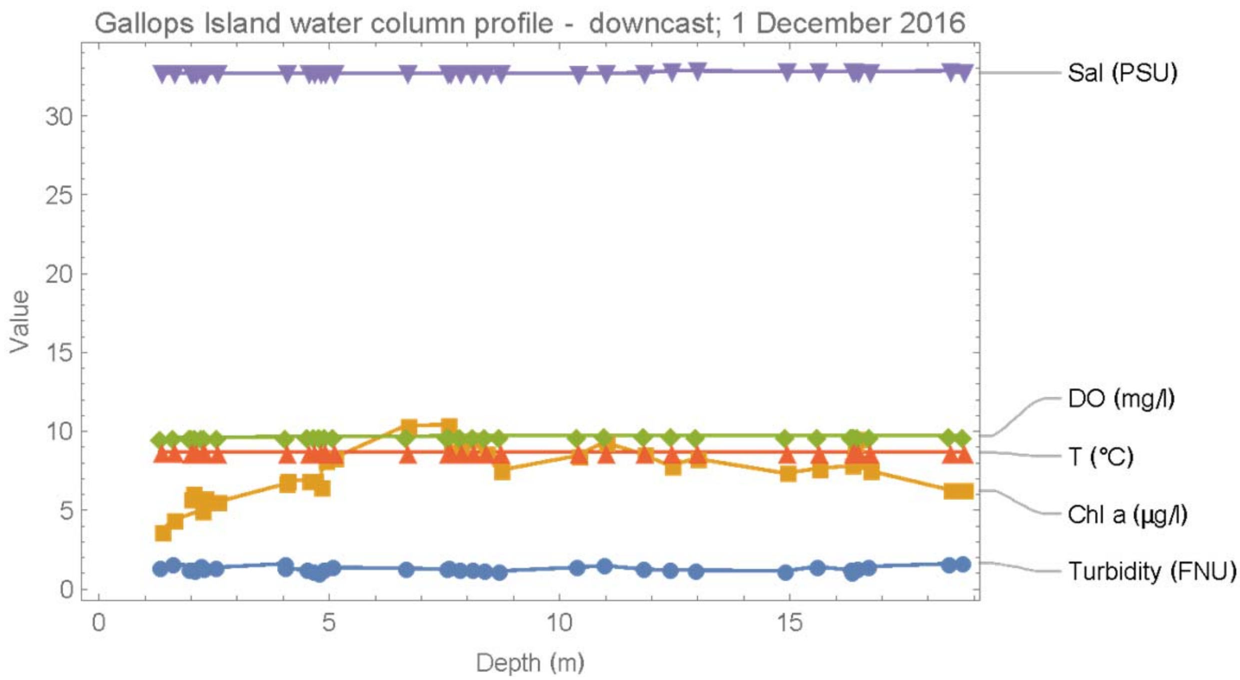
At the Marblehead Control site (south), variation in surface layer turbidity was seen, with more turbid water closer to shore. Patchiness in phytoplankton as measured by chl *a* concentration was seen at a fine scale. Interestingly, the higher chl *a* concentrations are associated with a slight elevation in dissolved oxygen in the surface layer. Salinity also showed some surface variation. Most interesting was a cold-water anomaly closer to shore that had a slight drop in salinity, which may be indicative of groundwater entering the system. A similar feature was observed in the surface sampling near the Long Island site.

At the Marblehead reef site (Devereux Beach), surface layer turbidity was higher nearer to shore, and chl *a* was patchy, but not organized into coherent structures. Dissolved oxygen showed a slight gradient in the shore-parallel direction.

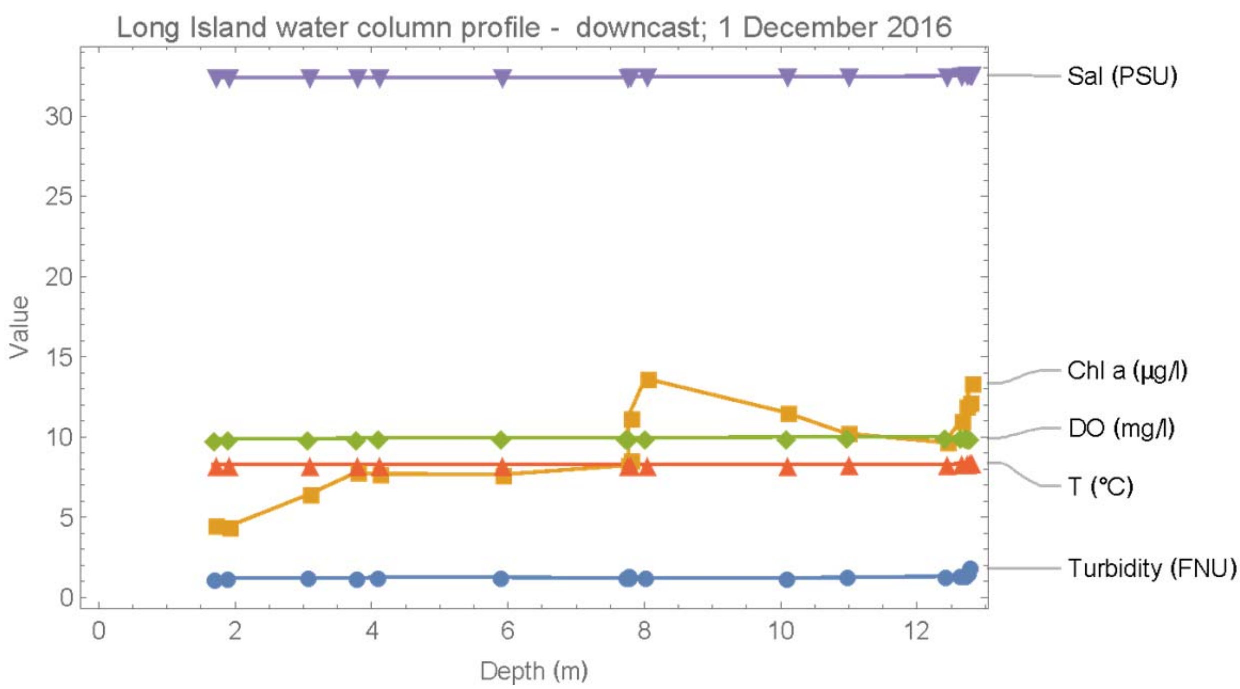
In the Harbor Islands, Long Island showed strong surface patchiness in chl *a*, and in turbidity. Filaments of high chl *a* concentration were detected normal to the shore, closer to shore. There were also very strong gradients in surface dissolved oxygen, which were not associated with surface chl *a*. At this same location, there is a very slight drop in temperature and a marked drop in salinity, so it is possible that the dissolved oxygen enhancement is related to ground water intrusion.

Gallops Island showed very patchy chl *a* and turbidity and there was an association with higher dissolved oxygen at the locations of higher surface chlorophyll that was not seen at Long Island. Salinity and temperature did not show any anomalies indicative of possible groundwater intrusion.

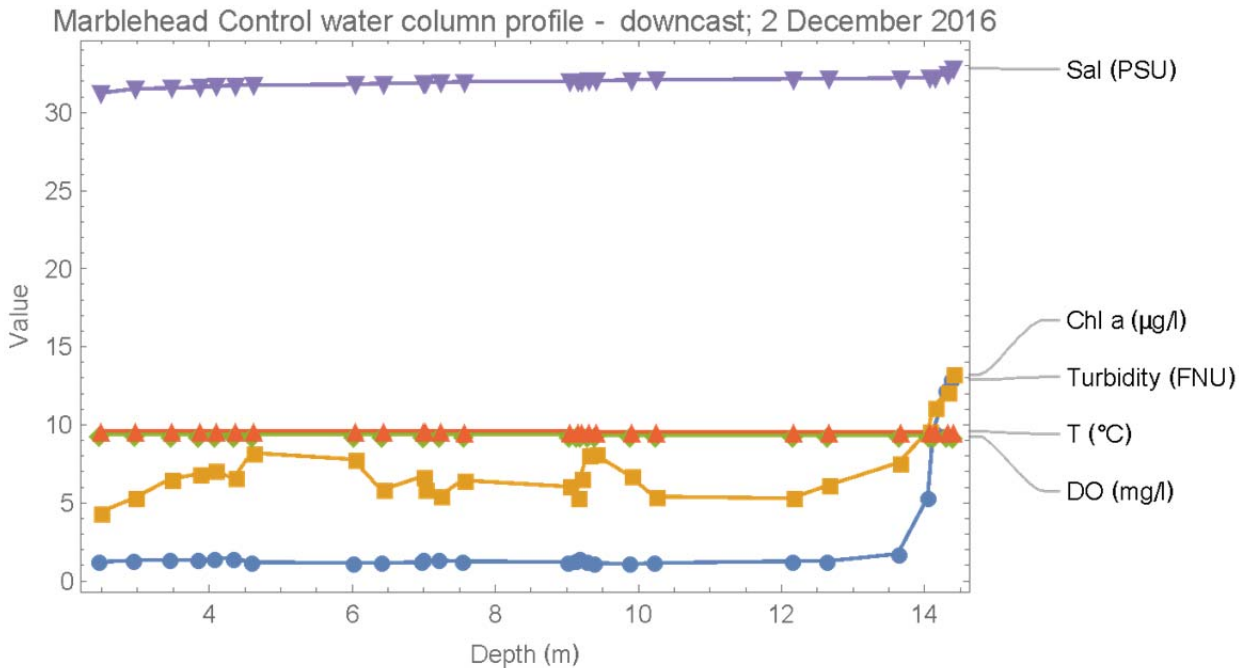
a. Gallops Island water column profile



b. Long Island water column profile



c. Marblehead control water column profile



d. Marblehead reef water column profile

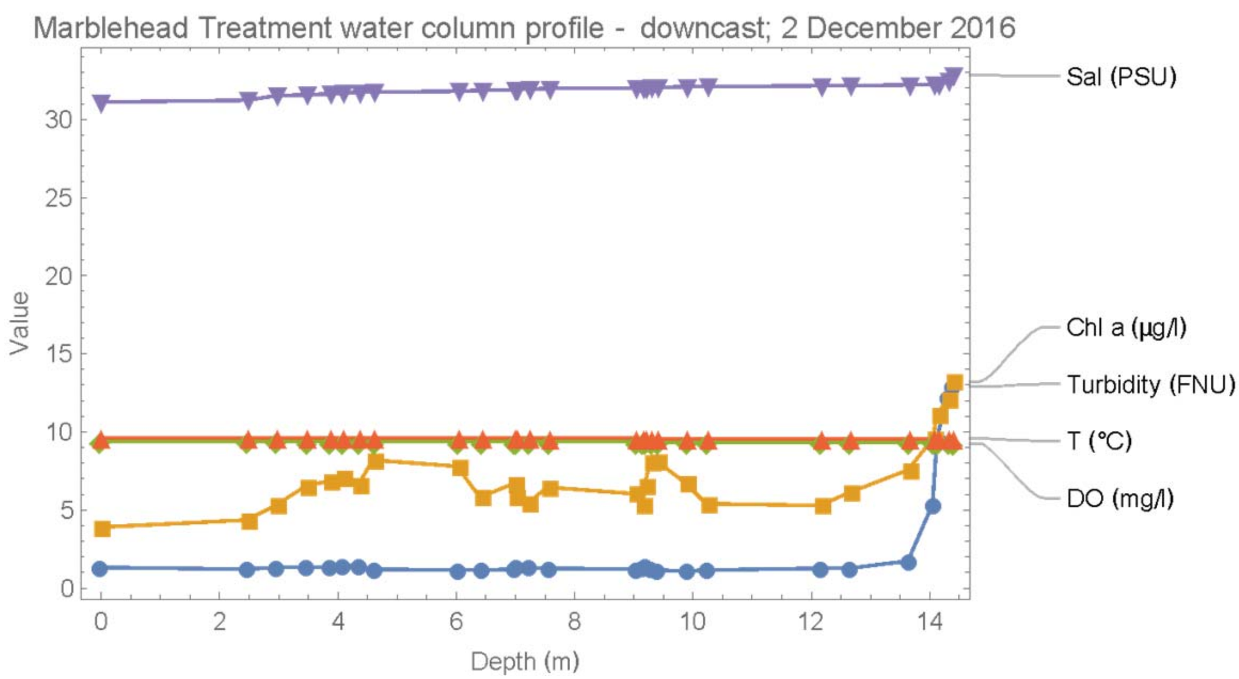
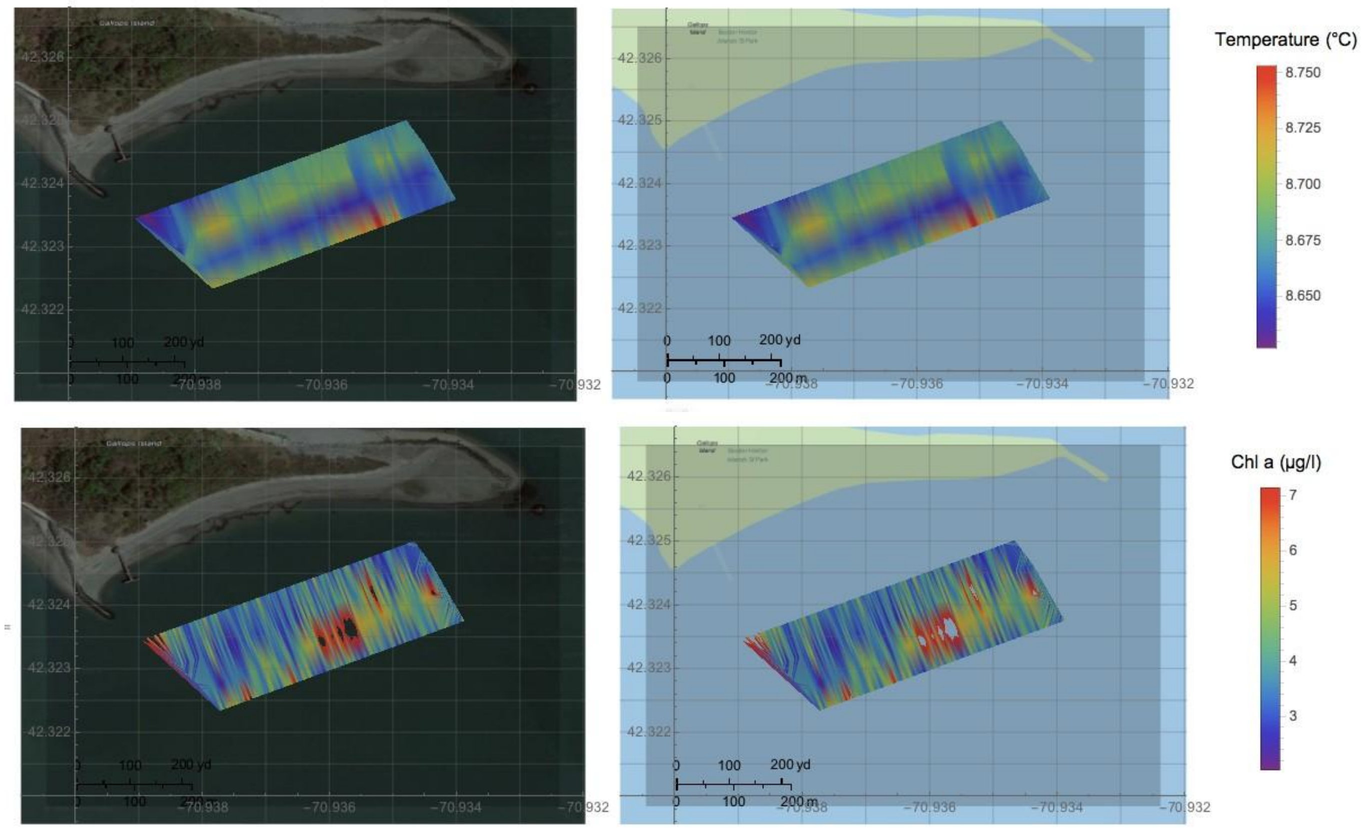


Figure 1D-17. **Water column profile results from the YSI EcoSonde II for salinity (PSU), dissolved oxygen (DO) (mg/l), temperature (°C), chlorophyll a (µg/l), and turbidity (FNU) as a function of depth (m). Profiles were conducted in December 2016.**

Figure 1D-18. **YSI EcoSonde II sampling at 1 Hz for turbidity (FNU), chlorophyll a (µg/l), dissolved oxygen (mg/l), temperature (°C), and salinity (PSU) in the surface layer (0.5-1 m depth) at Gallops Island in December, 2016. The tow paths were designed to capture the majority of each site (see Figure 1D-8 for a map and the coordinates of the proposed reef or control at each site).**



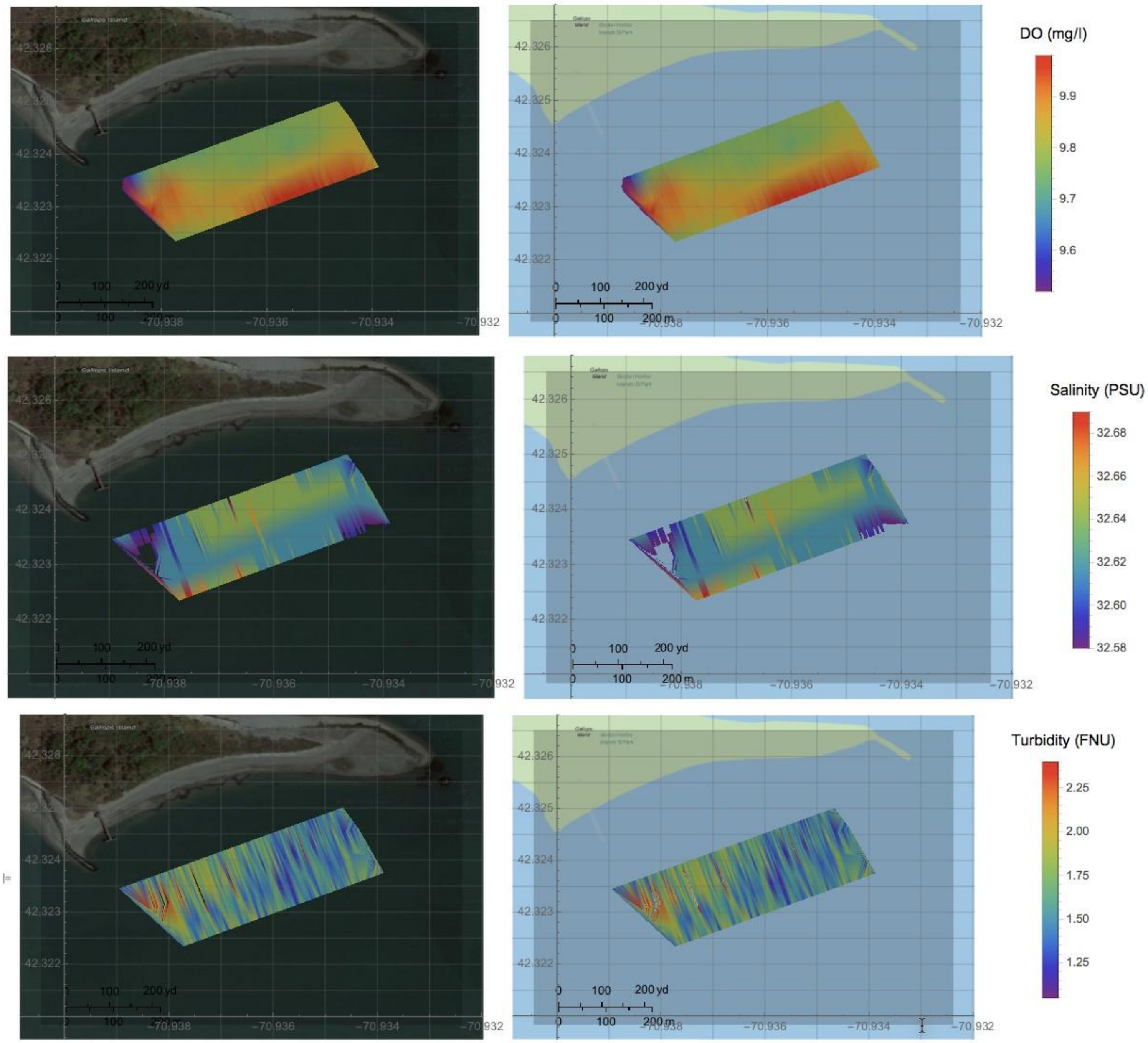
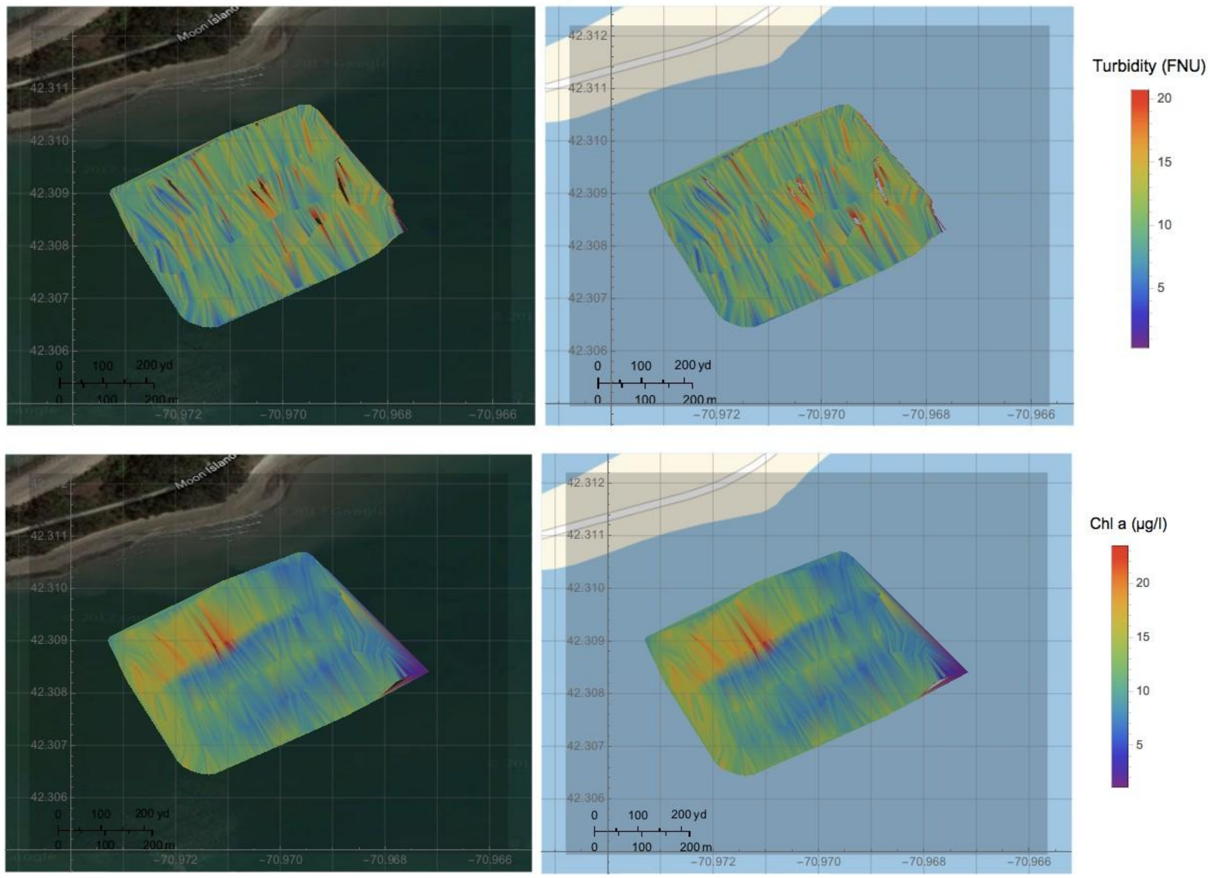
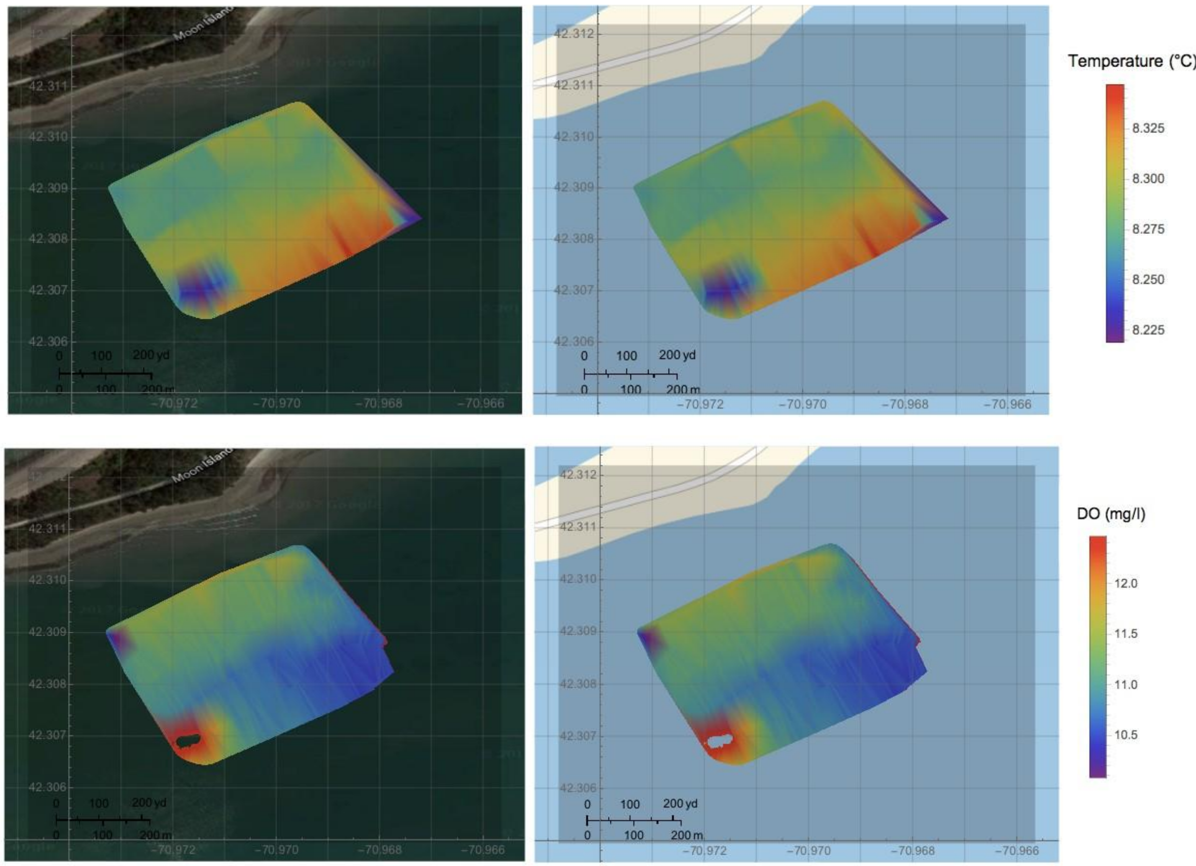

DO (mg/l)
9.9
9.8
9.7
9.6
Salinity (PSU)
32.68
32.66
32.64
32.62
32.60
32.58
Turbidity (FNU)
2.25
2.00
1.75
1.50
1.25
42.326
42.325
42.324
42.323
42.322
−70.938
−70.936
−70.934
−70.932
0 100 200 yd
0 100 200 m

Figure 1D-19. **YSI EcoSonde II sampling at 1 Hz for turbidity (FNU), chlorophyll a (μg/l), dissolved oxygen (mg/l), temperature (°C), and salinity (PSU) in the surface layer (0.5-1 m depth) at Long Island in December, 2016. The tow paths were designed to capture the majority of each site (see Figure 8 for a map and the coordinates of the proposed reef or control at each site).**




Moon Island
Temperature (°C)
8.325
8.300
8.275
8.250
8.225
DO (mg/l)
12.0
11.5
11.0
10.5
42.312
42.311
42.310
42.309
42.308
42.307
42.306
−70.972
−70.970
−70.968
−70.966
0 100 200 yd
0 100 200 m

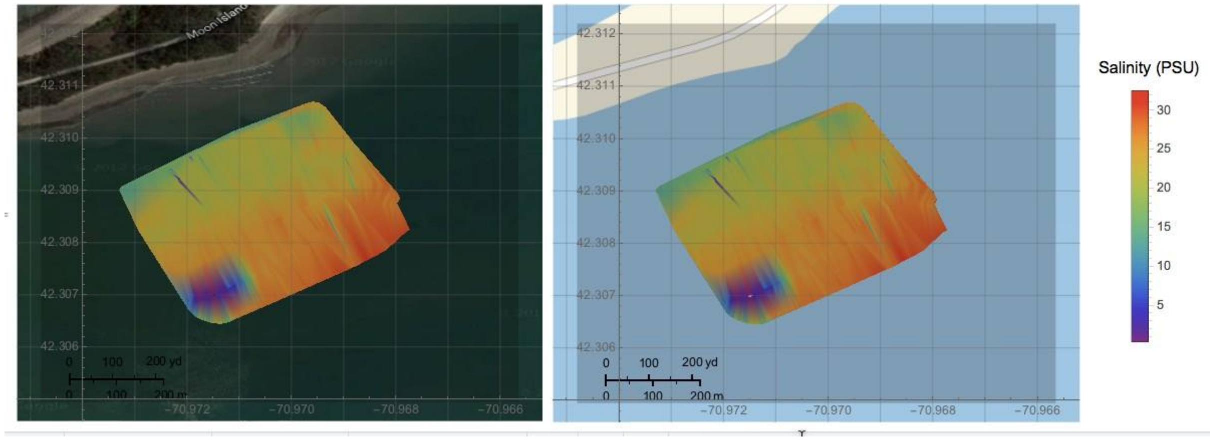
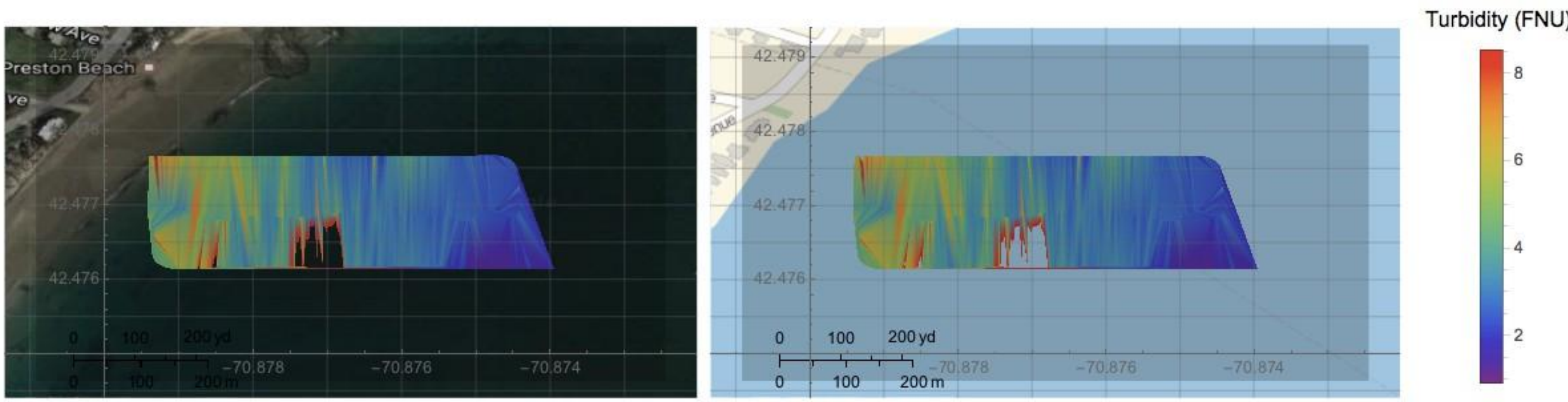
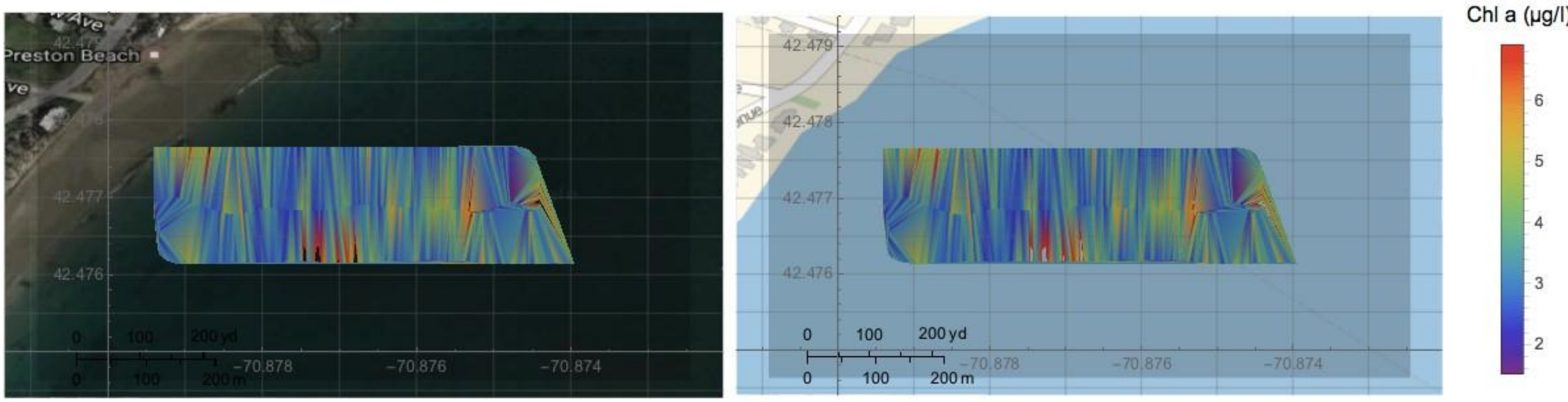
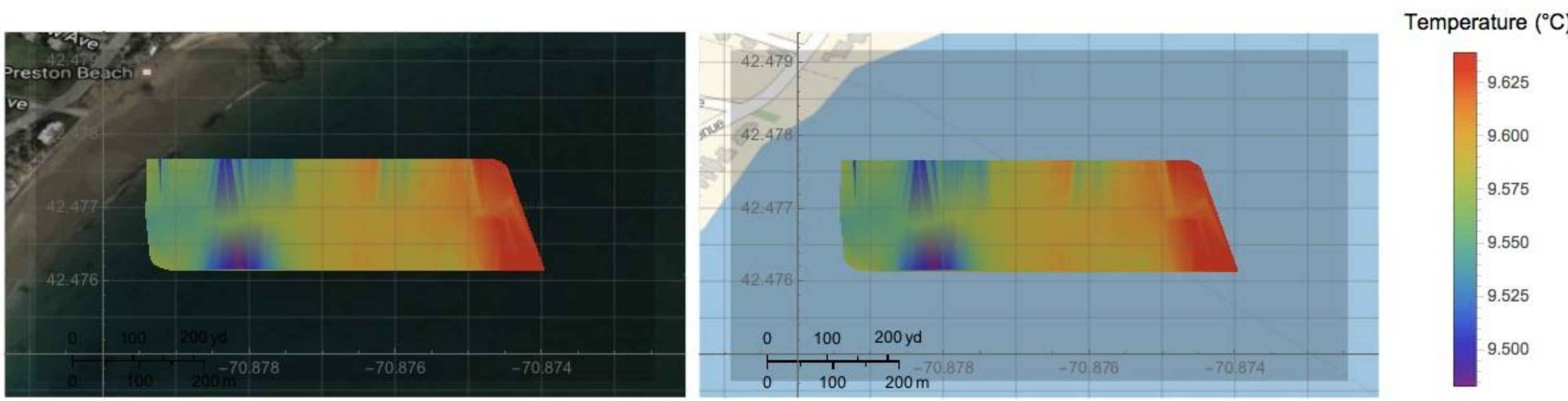


Figure 1D-20. **YSI EcoSonde II sampling at 1 Hz for turbidity (FNU), chlorophyll a (µg/l), dissolved oxygen (mg/l), temperature (°C), and salinity (PSU) in the surface layer (0.5-1 m depth) at the Marblehead control site in December, 2016. The tow paths were designed to capture the majority of each site (see Figure 8 for a map and the coordinates of the proposed reef or control at each site).**




Preston Beach
42.479
42.478
42.477
42.476
0 100 200 yd
0 100 200 m
-70.878
-70.876
-70.874
Chl a (μg/l)
6
5
4
3
2


Preston Beach
42.479
42.478
42.477
42.476
0 100 200 yd
0 100 200 m
-70.878
-70.876
-70.874
Temperature (°C)
9.625
9.600
9.575
9.550
9.525
9.500

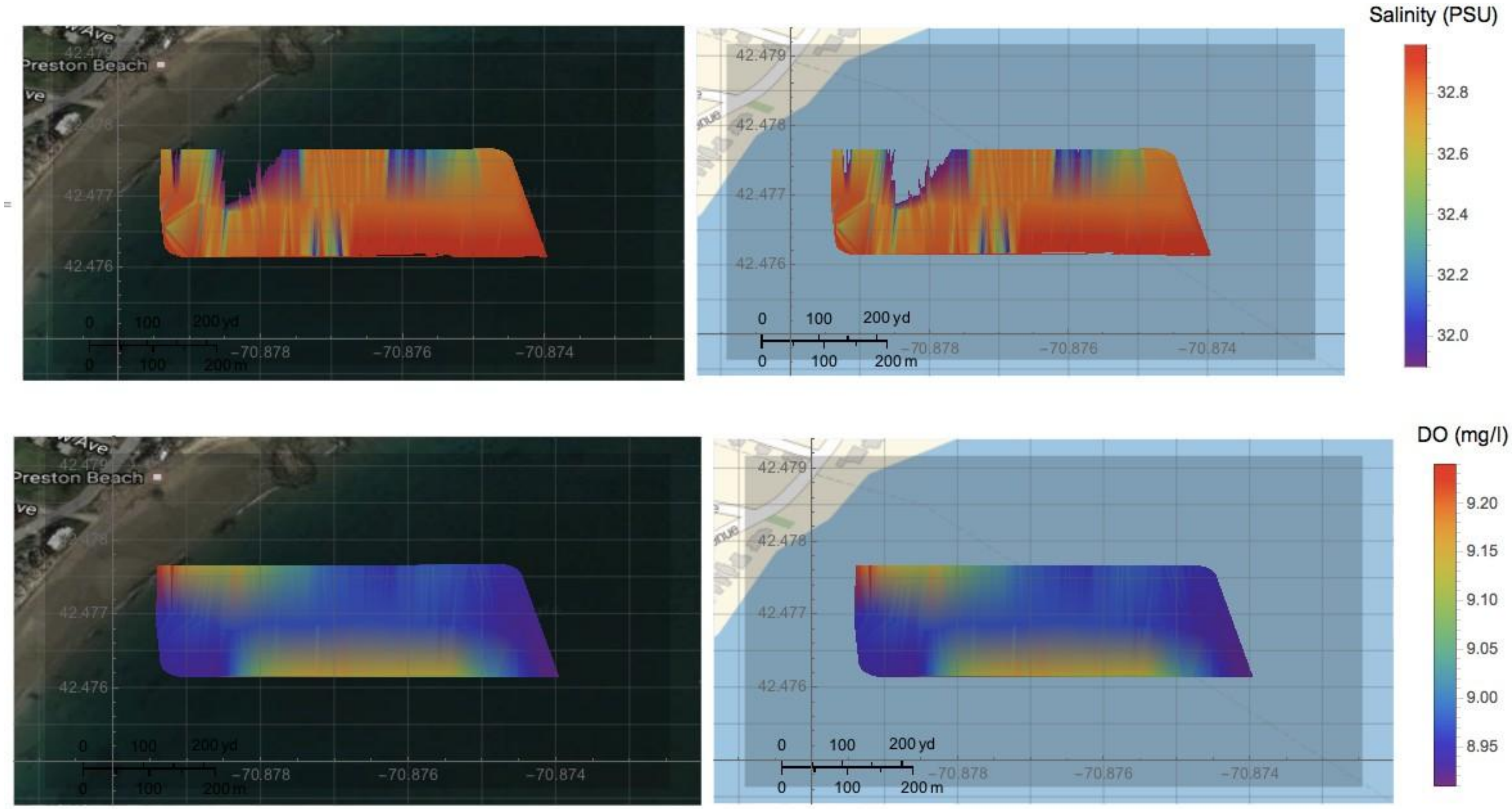
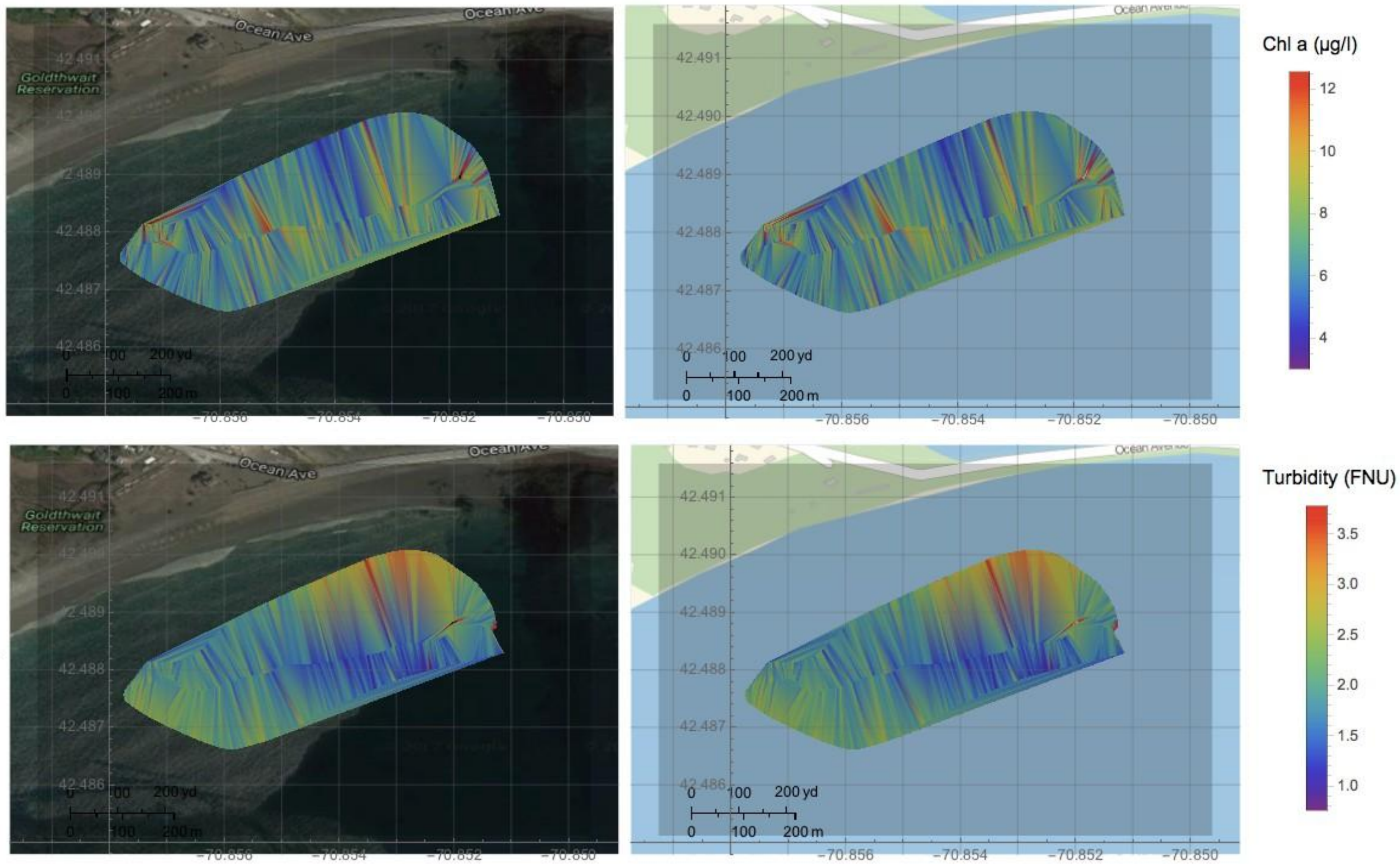
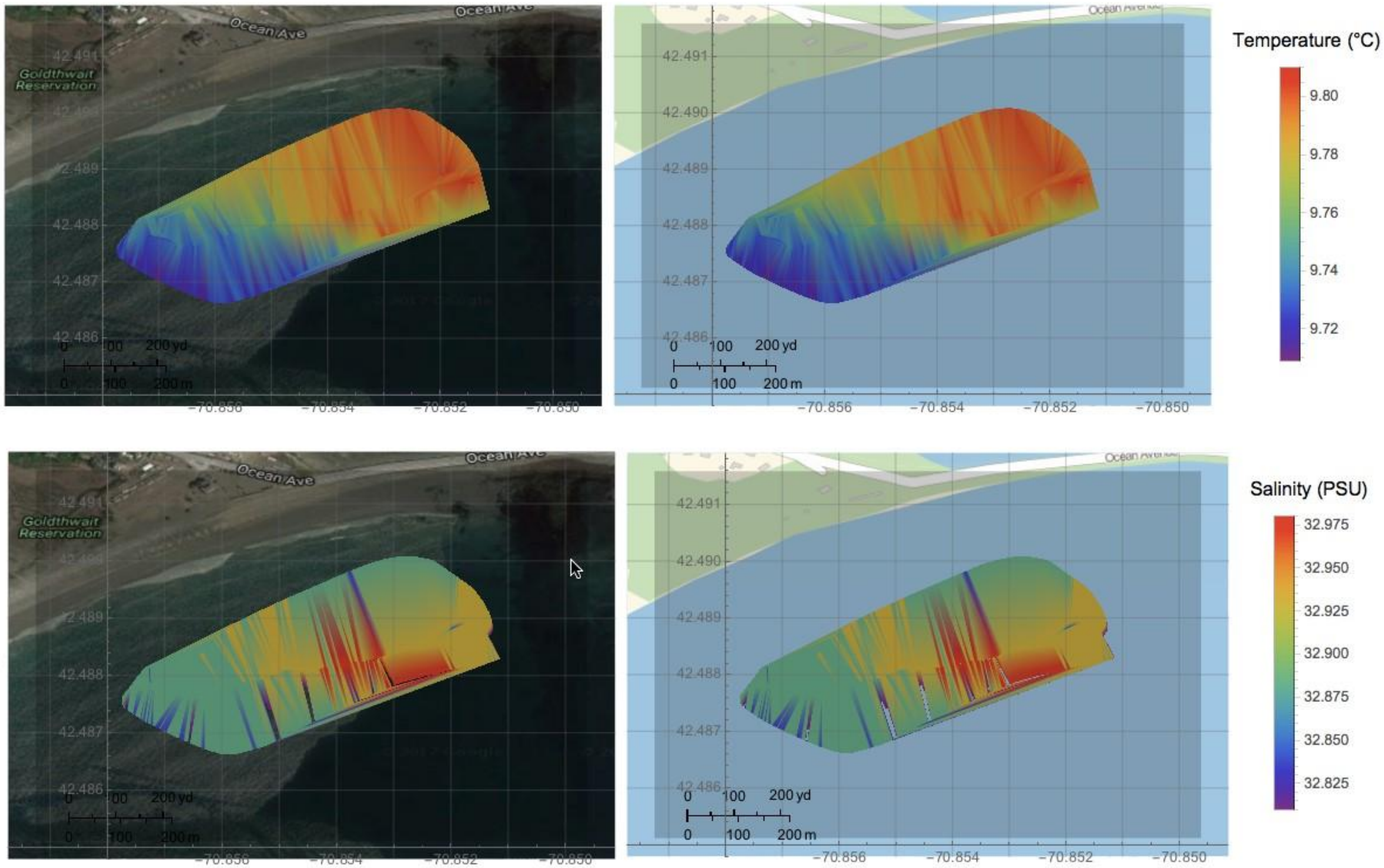
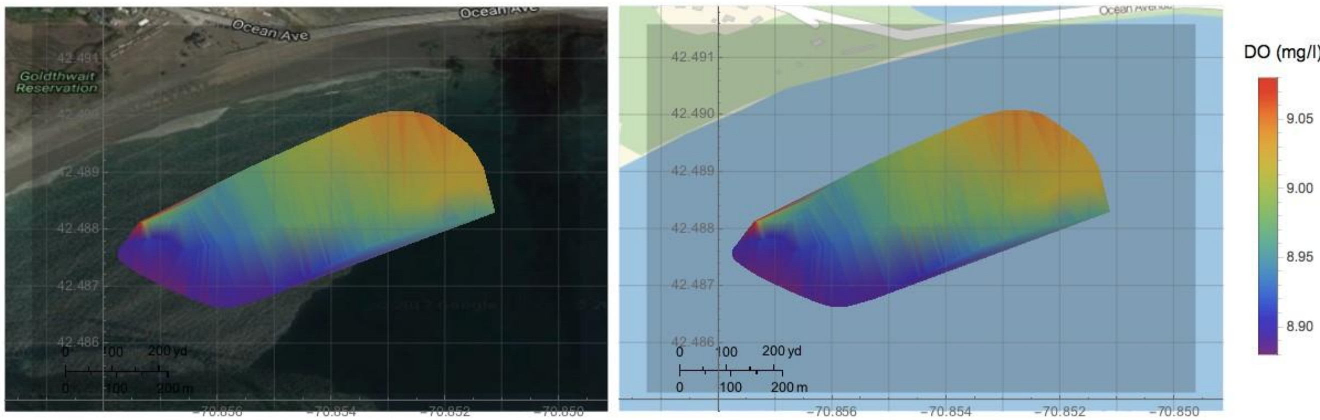


Figure 1D-21. **YSI EcoSonde II sampling at 1 Hz for turbidity (FNU), chlorophyll a (µg/l), dissolved oxygen (mg/l), temperature (°C), and salinity (PSU) in the surface layer (0.5-1 m depth) at the Marblehead reef site in December, 2016. The tow paths were designed to capture the majority of each site (see Figure 8 for a map and the coordinates of the proposed reef or control at each site).**



Ocean Ave
Goldthwait Reservation
42.491
42.490
42.489
42.488
42.487
42.486
0 100 200 yd
0 100 200 m
−70.856
−70.854
−70.852
−70.850
Chl a (µg/l)
12
10
8
6
4
Turbidity (FNU)
3.5
3.0
2.5
2.0
1.5
1.0


Ocean Ave
Goldthwait Reservation
42.491
42.490
42.489
42.488
42.487
42.486
0 100 200 yd
0 100 200 m
−70.856
−70.854
−70.852
−70.850
Temperature (°C)
9.80
9.78
9.76
9.74
9.72
Salinity (PSU)
32.975
32.950
32.925
32.900
32.875
32.850
32.825



Ocean Ave
Ocean Ave
Goldthwait Reservation
42.491
42.490
42.489
42.488
42.487
42.486
0 100 200 yd
0 100 200 m
-70.856
-70.854
-70.852
-70.850
DO (mg/l)
9.05
9.00
8.95
8.90

Discussion

Gallops Island

The site at Gallops Island has a mixed bottom with enough seafloor structure to impede trawling. A reef placed at this location will not result in substantial habitat conversion, since there is already hard structure. Biological sampling found species typical of nearshore New England and in abundances that were not remarkable. The water quality results did not find any unique water column structure or groundwater seeps. This site is located in a winter flounder fisheries closure area and is likely winter flounder spawning habitat. To avoid impacts, it may be necessary to use a time of year restriction during the winter flounder spawning season.

Devereux Beach

The site at Devereux Beach is sandy. A reef placed at this location would introduce hard substrate into the immediate area, however hard substrate is commonly found along the shoreline and near offshore of the Marblehead coast, resulting in many of the adjacent siting tool cells being flagged as unsuitable for reef development due to hard bottom. Biological sampling found species typical of nearshore New England, with a high abundance of lobster. The water quality results showed a relatively turbid seafloor and possible evidence of groundwater influence. The site is located in a winter flounder fisheries closure area, shellfish habitat, and a cod spawning area, so future site development should consider potential impacts and necessary conditions to avoid impacts. This site has relatively high natural resource value already, so a clearer picture of the spatial distribution of shellfish in the area and the timing and distribution of the lobster resource abundance in the area is needed. Some conditions might include the use of a time of year restriction during the high abundance lobster period and the winter flounder and cod spawning seasons.

Recommendations from the Working Group included using this data as a starting point to develop fuller environmental characterizations of each of the sites.

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Phase 2: Hydrodynamic Modeling and Reef Design

Overview

The engineering firm Applied Coastal Research and Engineering, Inc. was contracted to assist with site selection, as described in Phase 1, and hydrodynamic modeling to assess potential sediment transport impacts and wave attenuation associated with different reef/breakwater designs. Initially the focus was on developing subtidal reefs to eliminate aesthetic concerns associated with reefs. However, through an iterative process, different reef/breakwater heights and distances from shore were explored to reach a reef/breakwater design option that a) minimally affected sediment transport downstream, yet b) had enough height to result in wave attenuation, and c) provided enough room for an eelgrass bed to be planted shoreward of the reef/breakwater. The final recommended reef/breakwater designs for these study sites are 4 feet above mean low water, so they would be visible between slack tide and low tide but not visible at high tide.

Through consultation with the engineers, we were made aware that our approach to design was somewhat unusual, and that it is more typical to determine the wave attenuation performance criteria and then design a reef/breakwater that can achieve that amount of wave attenuation under various conditions. Our approach was driven by the interest in finding a beneficial reuse for dredged materials while balancing a multitude of other factors, so the ultimate wave attenuation benefit is for keeping the shoreside sites intact and stable, so the shoreline is better able to withstand a storm event.

Introduction

In order to evaluate the wave sheltering performance of proposed reef designs at the two selected locations, site specific computer modeling tools were developed. These tools incorporate data that represent local meteorological and wave climate conditions as well as other data that represents bathymetry and topography. The data are used to specify boundary conditions in numerical codes that simulate wave growth and propagation and sediment transport along shorelines. Analysis methods developed to quantify shoreline impacts caused by offshore wave refracting features use the output of the wave and sediment transport models to determine the performance characteristics of different proposed reef layouts. Modeling tools incorporated mean tide levels, as this represented average conditions experienced by each breakwater structure. Due to the relatively large tide range within the study region (mean tide range of approximately 9.5 feet), structures designed to attenuate a meaningful portion of the wave energy needed to be surface-piercing at low tide; however, were submerged by several feet at high tide. The final assembled system is a tool that is used at each site to iterate the reef design and provide detailed engineering guidance for design and environmental permitting of the reefs.

Wind and wave conditions developed from US Army Corps of Engineers Wave Information Study (WIS) hindcast records were applied to two-dimensional wave model grids developed for both reef study sites. The wave mode SWAN developed at the Delft Technical University in the Netherlands was used to run the various specified model cases developed for each location. Multiple model runs are made for existing conditions and each separate reef alternative.

The output from the wave model was in turn used to compute sediment transport potential along both study shorelines using a shoreline model that represents coastal processes that affect shoreline evolution. With the computation of sediment transport potential, it is possible to quantify the effect that each reef alternative would have on the adjacent shoreline. The location of the reef wave "shadow" and the resulting change in the magnitude of sediment transport for each reef alternative are determined using the shoreline model.

In order to evaluate the significance of the changes to sediment transport by each modeled reef alternative, an analysis methodology developed to assess borrow site impacts (i.e., the "spatial and temporal" method, Kelley et al. 2004) was employed for both study sites. An offshore feature, whether it is an excavated sand borrow site or an offshore reef, will tend to change the distribution of wave energy along a shoreline. Borrow sites will focus wave energy away from the up- and down-drift edges of the pit by wave refraction. Structure like reefs have a similar effect on an adjacent beach, as they block wave energy and create a wave energy "shadow" on the shoreline. For both borrow sites and structures built on the ocean bottom, the degree of the effect on sediment transport depends on the wave climate, the size of the feature and also its proximity to the shore. The "spatial and temporal" method compares the magnitude of the changes caused by the offshore feature to the natural variability of sediment transport potential. Depending on the comparison of change to natural variability, the effect can be determined to be acceptable or not.

The "spatial and temporal" method for determining the relative significance of impacts on a shoreline by an offshore reef is a straightforward procedure that relies on a statistical evaluation of sediment transport along a shoreline.

The key advantages of this method are 1) it is based upon a site-specific analysis of waves and sediment transport, 2) shoreline impacts by the reef are directly compared against an allowable limit determined in the analysis, so the changes are easily determined to be acceptable or not.

In the application of this method, first sediment transport potential is computed for several individual years. The WIS wave records available for the coastal United States provide data records of sufficient length on which to base the transport calculations. Using a WIS dataset, average sediment transport potential can be computed along the shoreline of interest for 35 separate years.

The standard deviation of transport potential then is computed using the individual annual means. The significance envelope for the shoreline is then determined as one-half a standard deviation (0.5σ). The $\pm 0.5\sigma$ envelope about the mean transport potential computed for the entire duration of the available wave data record incorporates 38% of the variability. Mean transport computed for any single year has a greater than 50% chance of falling outside this envelope. If the alterations in sediment transport potential caused by an offshore reef are within the significance envelope, it is likely the changes due to the structure would not be distinguishable in the observed shoreline record from change due to the natural variability in the wave climate. Since the proposed reefs are intended to provide some level of shore protection, it is desirable for each reef to have a sheltering effect that influences the shore. The reef design should therefore cause shoreline impacts to sediment transport that exceed the significance envelope in order to ensure that it provides a positive sheltering influence on the shoreline.

Wave Modeling

In this study, a three-part procedure was followed for the generation of wave input for the sediment transport analysis. First, a long-term wave and wind data record was collected and processed. Second, the processed wave and wind data were used as inputs into the two-dimensional wave transformation model SWAN. Third, output from this program was then used to generate the wave input record used in the sediment transport calculations.

The sediment transport analysis depends upon a long-term (20-years or more) wave data record, in order to accurately depict the average coastal process at work at the beach. Ideally, this wave record would come from a data buoy stationed offshore of the site being modeled. In the absence of such a physical measurement record, there are few other options for retrieving wave data. For sites located on the open coast, simulated long-term wave records are available through the Wave Information Study (WIS) program conducted by the US Army Engineer Waterways Experiment Station (WES). The WIS program has generated hindcast wave data for waves propagating from the open ocean, through the use of computer simulations, for the entire US coast at stations placed about every 6 nautical miles.

Wave and Wind Cases

For this study, wave conditions were generated using the wind and wave data available from the WIS hindcast database (wis.usace.army.mil), at station 63052 and 63053 located in Massachusetts Bay (Figure 2-1). The WIS data were used to develop offshore wave boundary conditions as well as the winds applied to the surface of Massachusetts Bay and Boston Harbor. Though other sources of wind and wave data are available from stations in the general study area (e.g., Logan Airport and NOAA Massachusetts Bay wave buoy station), WIS hindcasts provide continuous and concurrent wind and directional wave data for the entire span of the record. The other sources of wave data in Massachusetts Bay either do not provide directional wave data or do not provide a record that is long enough to be useful.

The WIS station 63052 is located 9.3 NM ESE of Devereux Beach while WIS station 63053 is 13.5 nautical miles east of Point Allerton, at the entrance to Boston Harbor (Figure 2-1). Both stations have a record spans the 33-year period between January 1980 through December 2012, and provide hourly records of winds and waves at hourly intervals for the length of the record.

Representations of the entire wave record from the WIS hindcasts are presented in Figures 2-2 and 2-3, for stations 63052 and 63053 respectively, as compass rose plots which show magnitude and percent occurrence as a function of compass sector. At station 63052, the predominant wave direction is the east, from where 35% of the waves in the record propagate from. The second most occurring wave direction is the ESE, with an occurrence of 29%. The largest wave in the record occurred during the October 1991 “no-name storm”, with a height of 23.3 feet, a period of 16.7 seconds, propagating from the ENE. The wave statistics of station 63053 are similar, with the east being the predominant wave sector, with a percent occurrence of 37%. The max wave height at this station is slightly larger, at 23.9 feet.

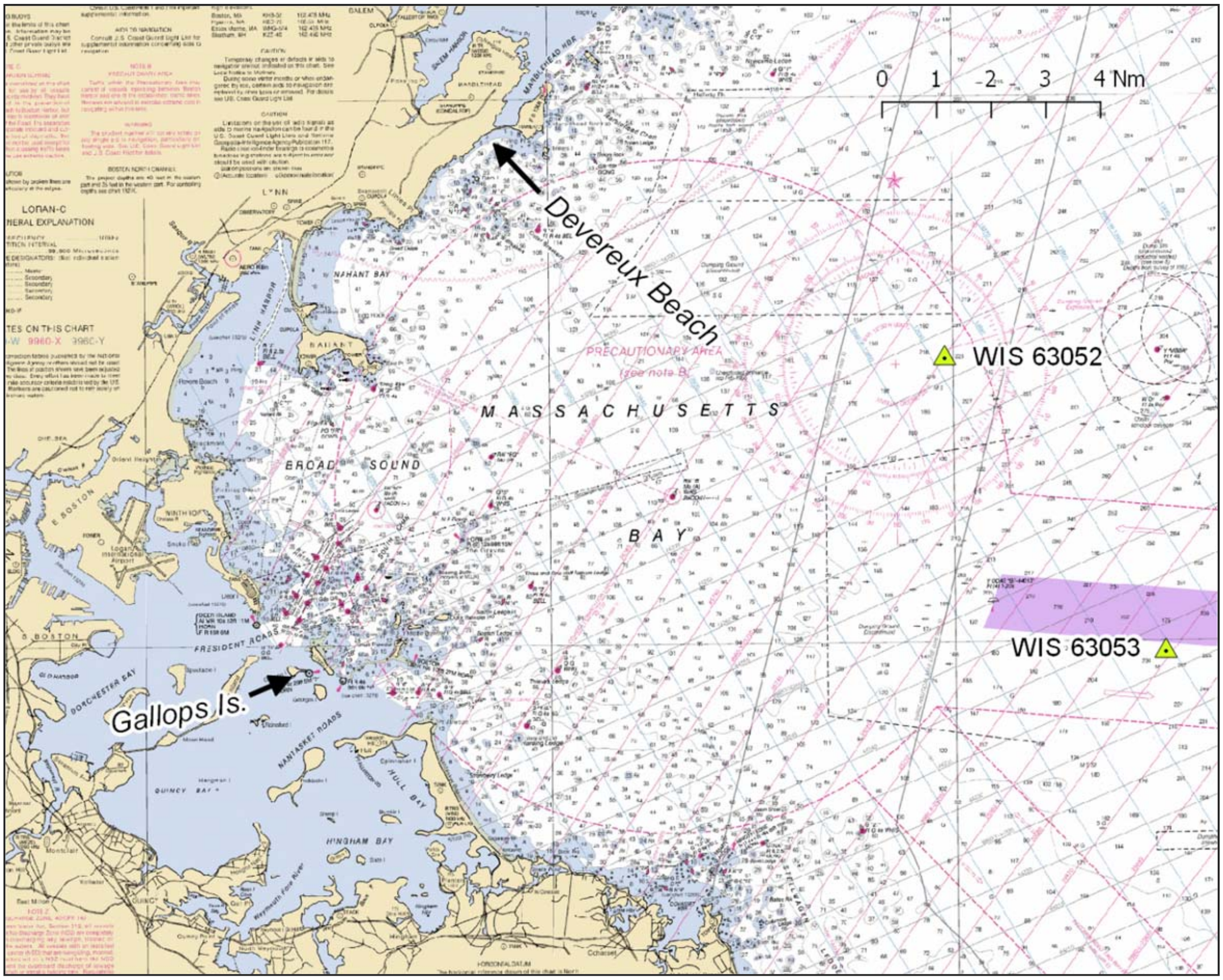

Figure 2-1. **Detail of the nautical chart of Massachusetts Bay, showing the location of the Gallops Island and Devereux Beach study sites, and the WIS wave hindcast stations used to develop wind and offshore wave conditions for each site.**

Similar to the rose plots for waves from the two WIS station records, wind roses are provided in Figure 2-4. As plotted, data from both stations have a similar distribution by direction and speed. At both stations, there is no single compass sector that is the clear predominate wind direction. The west sector has the highest percent occurrence in both records (8.9%) but is only more frequently occurring by 0.1% over the SSW sector. The sectors with the most frequently occurring strongest winds are the west, NNW and NW, where winds greater than 25 knots occur 2.3% of the entire record. The greatest wind speed occurs in both records during Hurricane Bob of August 1991. At station 63053 the greatest wind speed is 51.5 kts from the east, and it is slightly lower at station 63052, at 47.4 kts, also from due east.

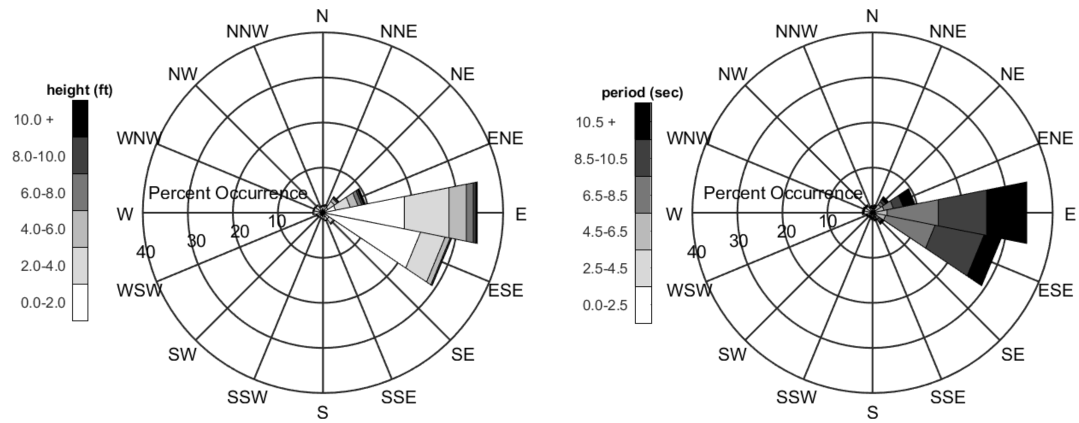

Figure 2-2. **Rose plot of WIS station 63052, used as the source of offshore waves for the Devereux Beach wave model.**

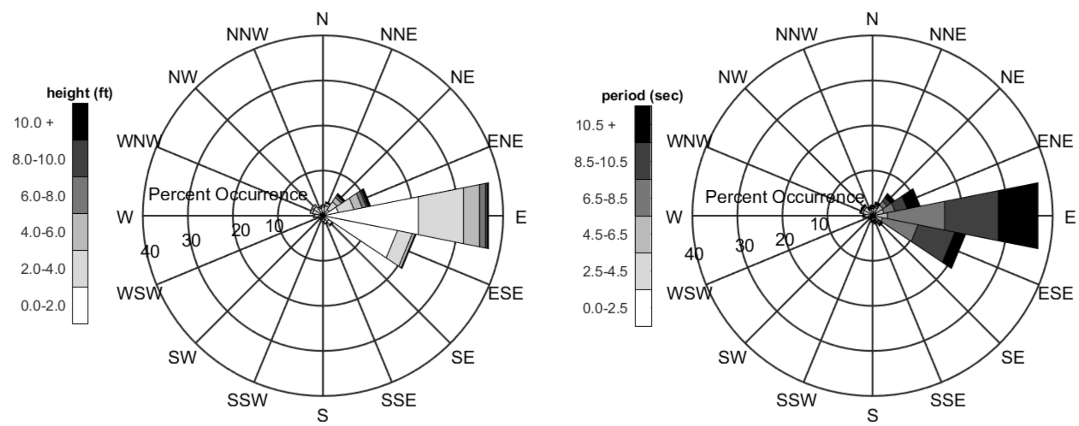

Figure 2-3. **Rose plot of WIS station 63053, used as the source of offshore waves for the Gallops Island wave model.**

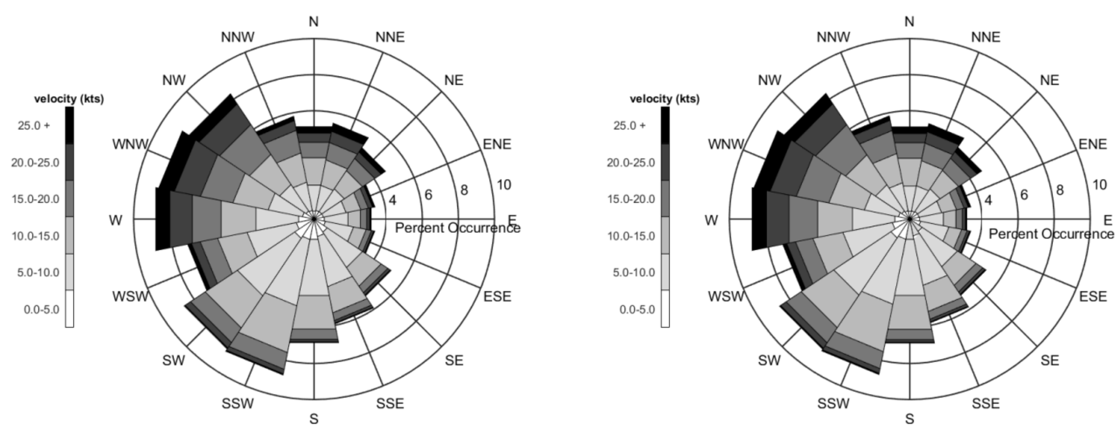

Figure 2-4. **Wind rose plots for WIS hindcast stations 63052 (left) and 63053 (right), used as the source of wind data for the Gallops Is. and Devereux Beach models, respectively.**

To determine the offshore wave input conditions for the wave models, the wave parameters from the WIS hindcasts were binned based on the speed and direction of the wind of each hourly record. After sorting by direction, wind records in each compass sector was split into two bins (bottom and top bins) that represent winds that are greater or less than one-half of the maximum wind speed occurring for each direction bin. The records in each direction and speed bin were then averaged. The cases from the top bin of the direction sectors with winds that blow onshore (azimuths -90 to+90 degrees from shore normal) were selected to run in the wave model (Table 2-1 for Gallops Is. And Table 2-2 for Devereux Beach). These top bin cases represent less frequent (with each sector occurring in about 1% of the span of the record, with a cumulative occurrence of about 8% for all modeled sectors), higher energy events that have the greatest influence on shoreline sediment transport. These model cases are the most useful in determining the benefit to the shoreline from the modeled breakwater alternatives during higher energy wave conditions.

Wave model runs used to determine the significance envelope where also initially binned by year, which is required in order to determine the inter-annual variability of the wave climate at each site.

Table 2-1. Gallops Island modeled wave cases using the entire 33-year WIS wave hindcast record. Listed cases represent average conditions for the entire length of the record, for each sector.

Sector	Wind dir.	Wind vel.	Wave dir.	Wave Hs	Wave Tp	% occr.
E	89.5	21.7	87.9	5.9	7.0	0.7
ESE	112.6	21.5	97.7	5.2	7.0	0.6
SE	136.2	20.4	107.0	4.6	7.1	0.8
SSE	156.8	19.7	113.9	3.9	7.2	0.9
S	180.9	19.2	124.1	3.3	6.9	1.1
SSW	203.1	19.9	143.7	3.0	6.7	1.7
SW	224.5	20.4	170.1	3.0	6.5	1.8

Table 2-2. Devereux Beach modeled wave cases using the entire 33-year WIS wave hindcast record. Listed cases represent average conditions for the entire length of the record, for each sector.

Sector	Wind dir.	Wind vel.	Wave dir.	Wave Hs	Wave Tp	% occr.
NE	43.7	25.7	70.0	7.2	7.3	1.2
ENE	66.7	23.5	80.7	6.9	6.9	0.8
E	89.5	21.5	91.0	5.9	7.0	0.7
ESE	112.7	21.3	100.2	4.9	7.2	0.6
SE	136.2	20.1	108.4	4.3	7.2	0.9
SSE	156.8	19.7	114.8	3.9	7.3	0.9
S	180.9	19.0	124.0	3.3	7.2	1.2

SWAN Model Development

Land and seafloor elevation data used to create the wave model grids and determine shoreline positions were derived from existing public archives available from state and federal agencies. LiDAR elevation data at Devereux Beach are available from a 2010 survey flight by the US Army Corps of Engineers (USACE). This dataset provides high resolution measurements on land and to depths greater than -50 feet NAVD (North American Vertical Datum of 1988). At Gallops Island, a 2011 USGS LiDAR flight is available, though the lowest elevations reported in this survey are above MLW. LiDAR data are available through the NOAA Office for Coastal Management website (https://coast.noaa.gov/dataviewer).

In offshore areas that do not have available recent LiDAR elevation data, NOAA single-point sensor bathymetry data were used. NOAA makes these data available through their National Centers for Environmental Information web site (https://www.ngdc.noaa.gov/mgg/geodas/trackline.html).

Gallops Island For Gallops Island, winds and offshore waves are applied to a coarse grid with a 131.2-foot (40-meter) mesh (Figure 2-5) of the whole of Boston Harbor, including the offshore area of western Massachusetts Bay. A smaller fine 16.4-foot (5-meter) mesh at Gallops Island (Figure 2-6) is nested within the coarse grid in order to provide detailed wave information along the study shoreline. The coarse grid is made up of 193,600 total computational cells, with 440 mesh rows along both the x- and y-axes. The minimum elevation of the coarse mesh is -103.2 feet NAVD, located along its offshore edge.

The fine mesh is made up of 222,525 total cells, with 345 rows along the y-axis if the grid and 645 rows along its shore-parallel x-axis. The grid's x-axis is oriented to the northeast (45-degrees true north). The minimum elevations is -43.7 feet NAVD. The highest elevation in the grid is +39.2 feet, on the upland area of the island.

Devereux Beach At Devereux Beach, wave and wind boundary conditions are initially applied to a coarse grid that covers the western areas of Massachusetts Bay between Marblehead to the north and Scituate to the south. Two grids with increasing finer meshed are nested within the coarse grid in order to include the area shoals and islands south of the beach and to provide detailed wave information along the study shoreline. The coarse grid (Figure 2-7) has a 393.7-foot (120-meter) mesh and 57,596 total cells, with 242 rows along the x-axis and 238 rows along the y-axis. The minimum elevation is 226.9 feet NAVD along the eastern edge of the grid.

The mid-scale grid (Figure 2-8) has a mesh size of 131.2 feet (40 meters) and total of 29,143 cells, with 193 rows along the x-axis and 151 along the y-axis. By using a mid-scale mesh, the complex bathymetry of the area offshore of Devereux Beach is efficiently represented in the model. The lowest offshore elevation is -127 feet NAVD in the southeast corner of the grid.

The fine 5-meter grid (Figure 2-9) is nested within the mid-scale grid in order to provide detailed wave output at the study shoreline. It has 59,682 total cells, arranged in 343 cross-shore columns and 174 alongshore rows. The x-axis is oriented to 80 degrees true north. Elevations in the grid range between -40.1 feet NAVD offshore and +55.7 feet in the included inland area.

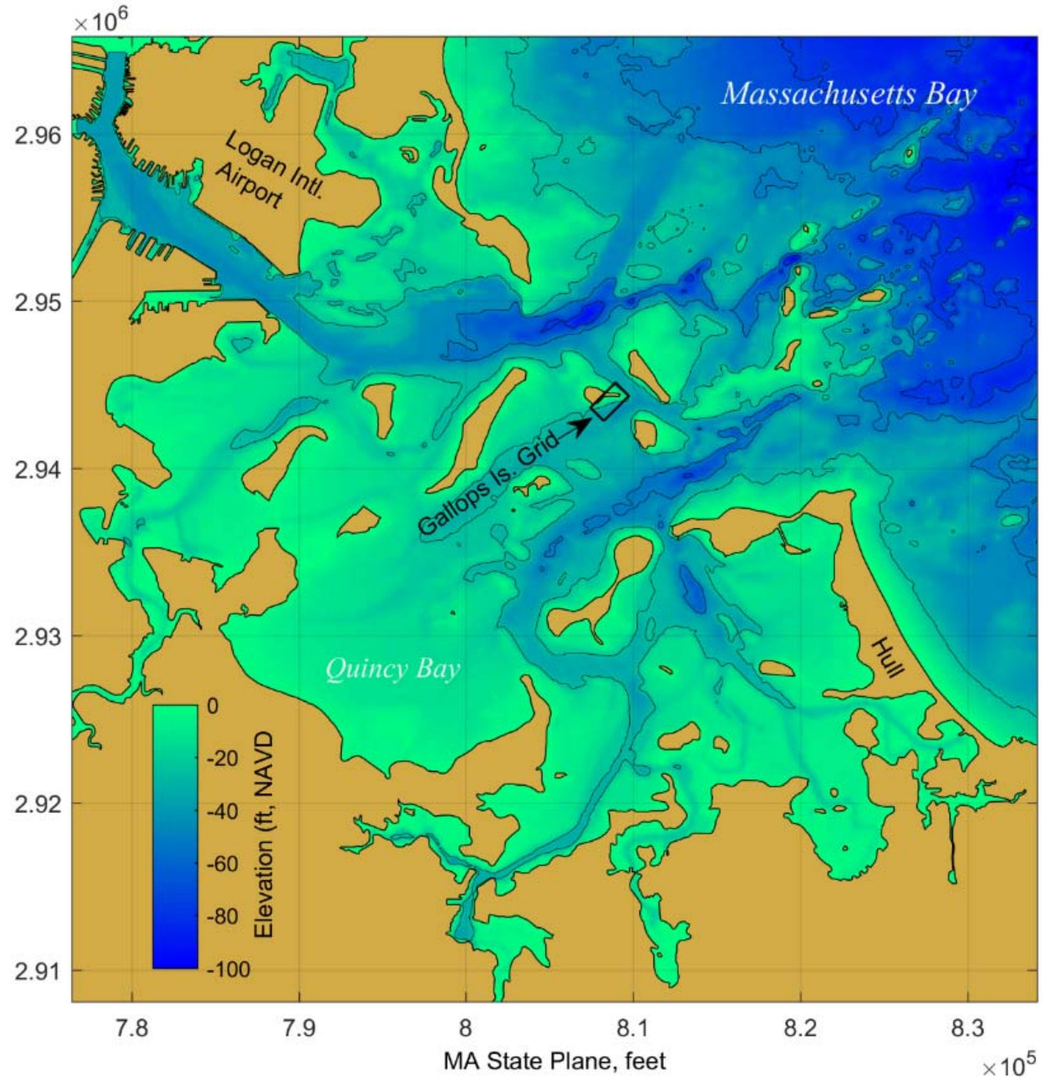

Figure 2-5. **Coarse grid mesh of Boston Harbor used to simulate waves at Gallops Island. The extent of the nested Gallops Island fine-scale mesh is indicated. Contour lines are also provided at 25-foot intervals.**

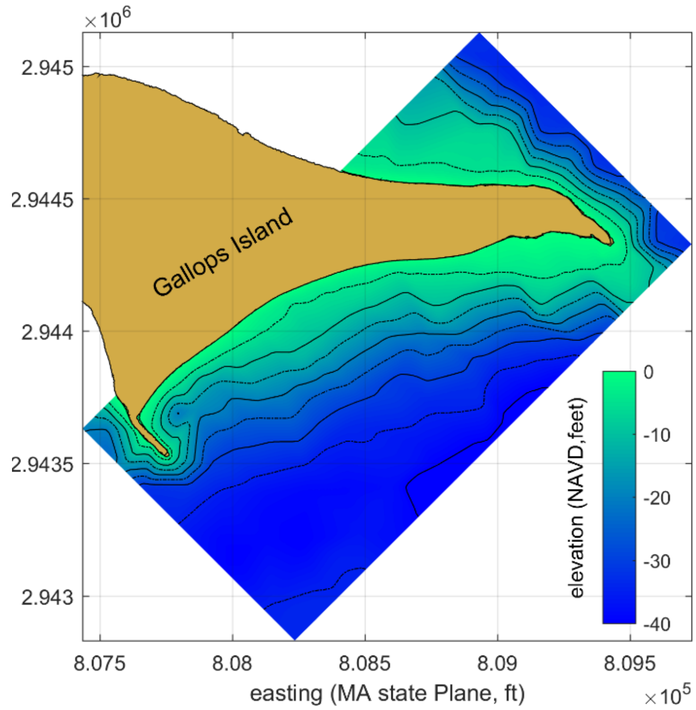

Figure 2-6. **Extent and elevations of the five-meter mesh used to compute waves along the south-facing shoreline at the Gallops Island study site. The island 0 NGVD shoreline was developed using 2011 LiDAR data.**

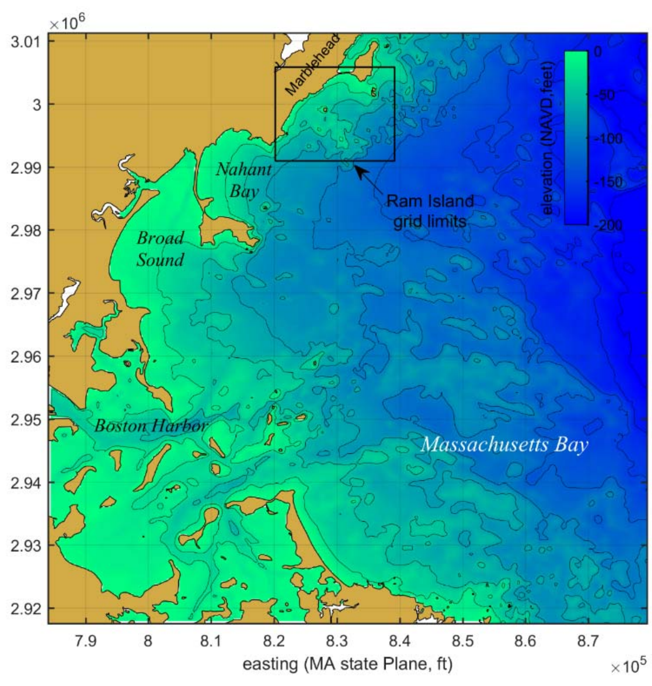

Figure 2-7. **Coarse grid mesh of Massachusetts Bay used to simulate waves at Devereux Beach. The extent of the nested mid-scale mesh of the Marblehead shoreline is indicated. Contour lines are also provided at 25-foot intervals.**

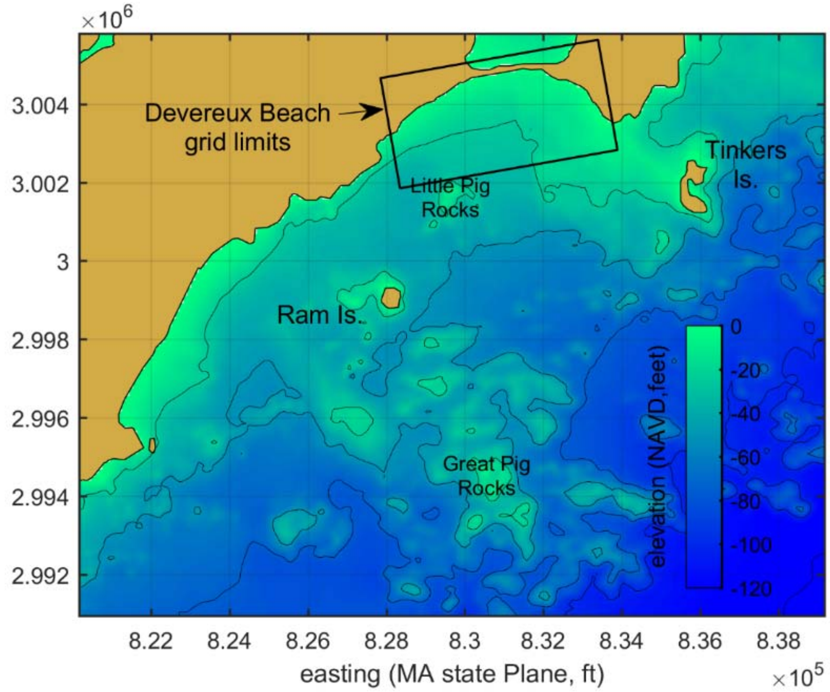

Figure 2-8. **Intermediate-scale (30-meter) grid mesh of the southern Marblehead shoreline used to simulate waves at Devereux Beach. The extent of the nested fine-scale mesh covering the Devereux Beach study shoreline is indicated. Contour lines are also provided at 25-foot intervals.**

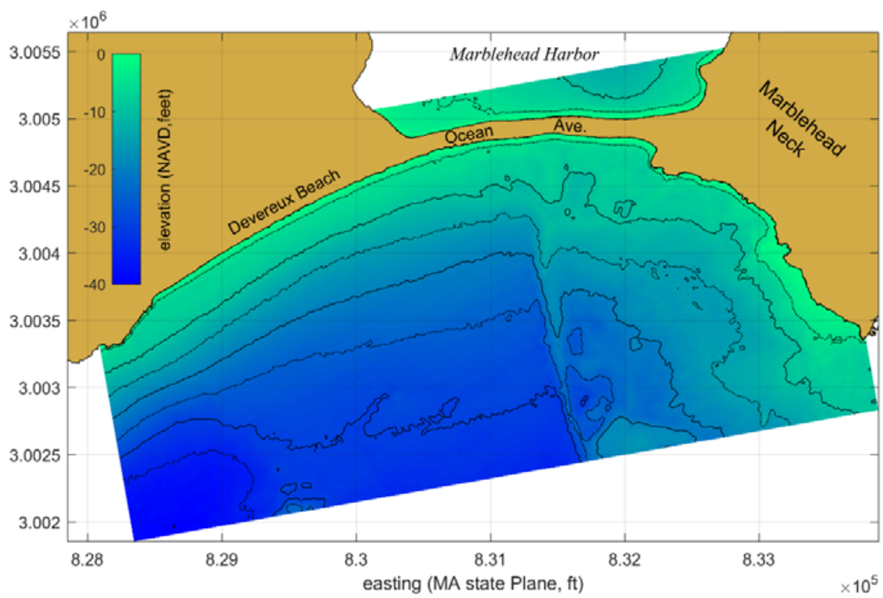

Figure 2-9. **Extent and elevations of the fine-scale five-meter mesh used to compute waves along the Devereux Beach study site. The mainland 0 NGVD shoreline was developed using 2010 LiDAR data. Contour lines are shown at 5-foot intervals.**

Wave Model Results

The wave model for each reef site was run to compute the wind case from Tables 2-1 and 2-2 (upper half of winds for each compass sector), averaged over entire 33-year span of the WIS record, and also for each year individually. The model cases for winds averaged over the entire 33-year span of the record (seven total model runs for each study site, and each reef alternative) are used to determine change in sediment transport potential caused by the different reef options. The individual yearly averaged model cases (231 total model cases run for each study site) are used to compute the transport potential significance envelope that provides the indication whether the presence of the proposed reef options is able to influence sand movement at the shoreline.

Gallops Island Results of the east wave case for Gallops Island are shown in Figures 2-10 and 2-11. A 6-foot, 7-second wave propagates toward the harbor entrance from the model open boundary. The many islands at the harbor entrance and the peninsula that comprises most of the Town of Hull act to block wave energy from entering the harbor. The combination of wave refraction and blocking reduces wave heights to about one foot in the lee of Georges and Lovell Island. Waves approaching Gallops Island (Figure 2-11) refract in the presence of the shallower bathymetry of the islands nearshore. Even with a 22-mph wind blowing from the East, wave heights remain about one foot through the nearshore, with little change in height due to shoaling.

Wave model output for all average cases at a single station located 300-feet offshore of the study shoreline at Gallops Island is presented in Table 2-3. From these results, it can be seen that the area is on average relatively well sheltered, with wave heights of about 1 foot for all onshore compass sectors.

Devereux Beach The results of the southeast wave case for Massachusetts Bay are shown in Figures 2-12, 2-13 and 2-14. There is little change in wave heights along the offshore approach of the study shoreline on the southern coast of Marblehead. The plot of waves from the mid-scale 30-meter grid shows the wave shoaling and sheltering effects of the highly variable bathymetry, intertidal ledge reefs and fully emergent islands that are present in the area immediately south of Devereux Beach. The fine grid (5-meter) output at the beach shows further shoaling and refraction of wave energy caused by the nearshore bathymetry of the area. The effect of the shore-perpendicular ridge that extends from the Ocean Avenue causeway (Figure 2-9) can be seen in the wave model output. The ridge acts to focus wave energy along its axis. Wave heights increase over the ridge, while areas of reduced wave heights on either side of the ridge occur, due to this focusing.

As before for Gallops Island, model output for all modeled average wind cases are presented in Table 2-3 for a single station located 640 feet offshore of Devereux Beach. The model cases that represent the top half of wind speeds result in slightly larger waves from the ESE through SSE sectors.

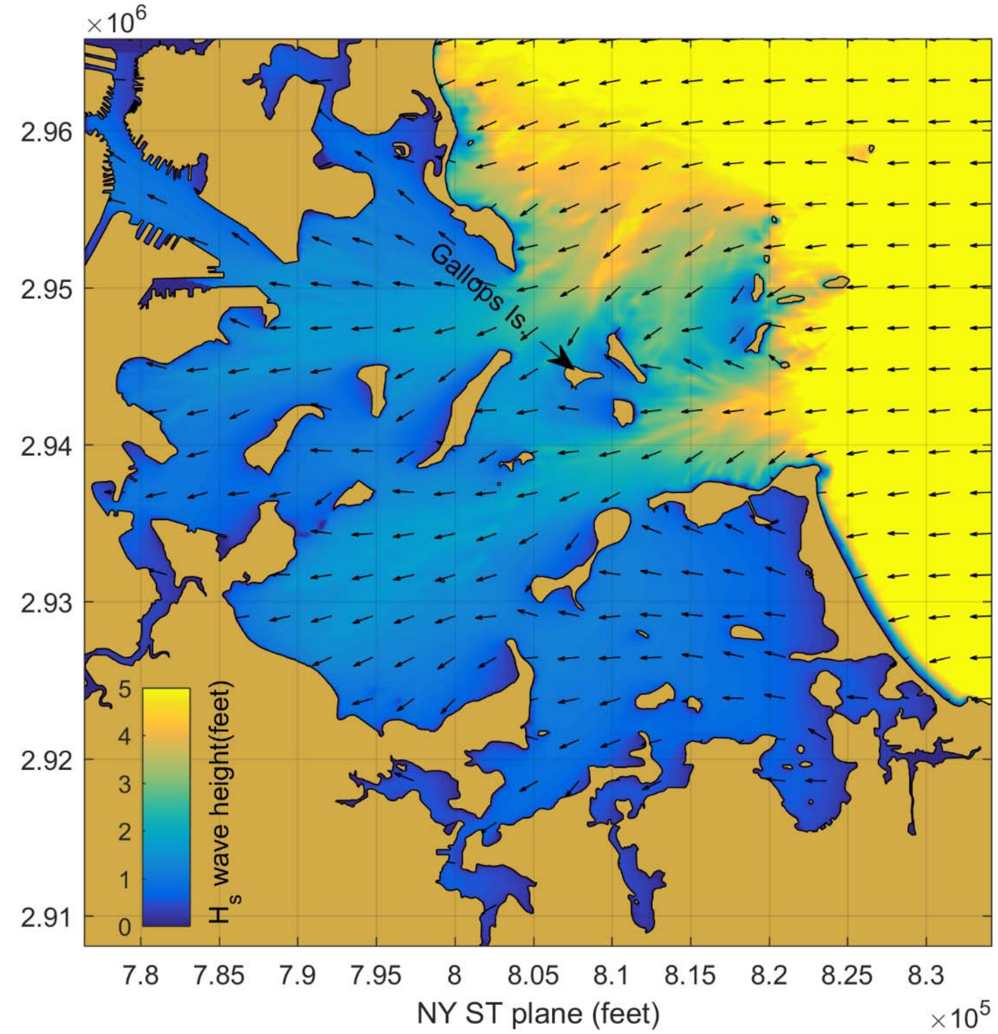

Figure 2-10. **Plot of East wave model case for Boston Harbor. Color contours indicate wave height, while vectors show the wave propagation direction.**

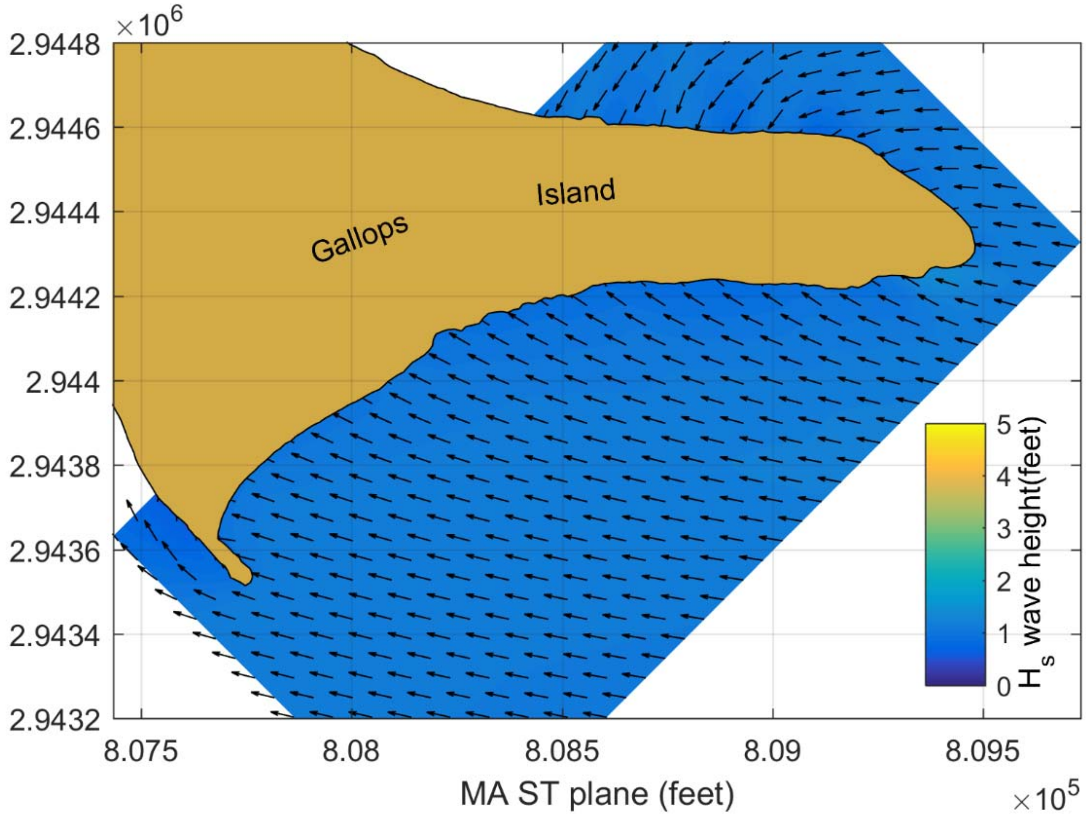

Figure 2-11. **Plot of East wave model case for the fine grid (5-meter mesh) of Gallops Island. Color contours indicate wave height, while vectors show the wave propagation direction.**

Table 2-3. Wave model output (H_s significant wave height and T_p peak period) taken from a nearshore station within each fine grid (300 feet offshore at Gallops Island and 640 feet offshore at Devereux Beach).

Gallops Island			Devereux Beach		
Sector	H_s	T_p	Sector	H_s	T_p
E	1	2.2	NE	2.4	6.3
ESE	1.1	2.1	ENE	2.6	5.9
SE	1.1	2	E	2.8	5.8
SSE	1.1	2.2	ESE	3	5.8
S	1.1	2.2	SE	3	5.8
SSW	1	2.4	SSE	3	5.8
SW	1	2.5	S	2.7	5.8

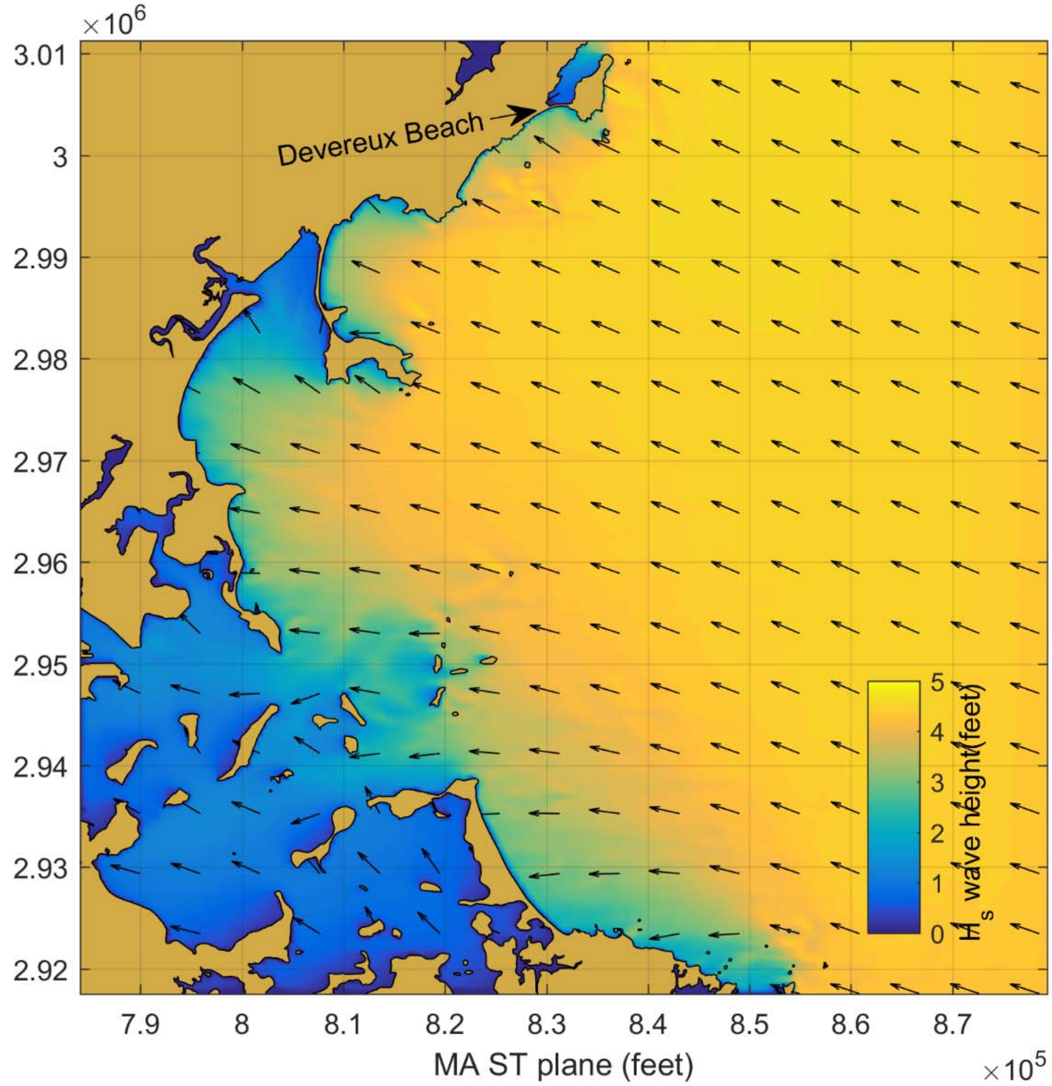

Figure 2-12. **Plot of SE wave model case for Massachusetts Bay. Color contours indicate wave height, while vectors show the wave propagation direction.**

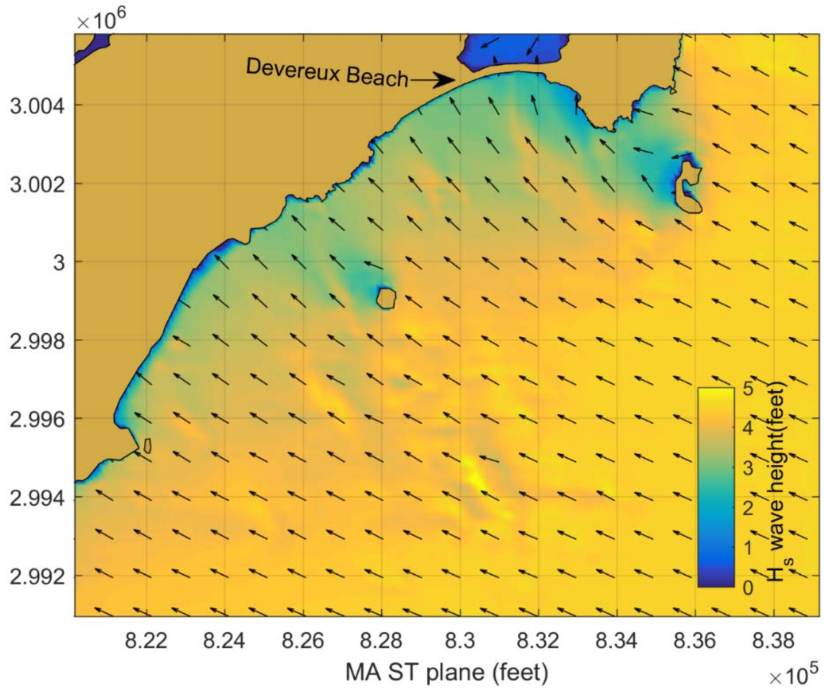

Figure 2-13. **Mid-scale (30-meter mesh) wave model output for SE wave case for the offshore area south of Marblehead. Color contours indicate wave height, while vectors show the wave propagation direction.**

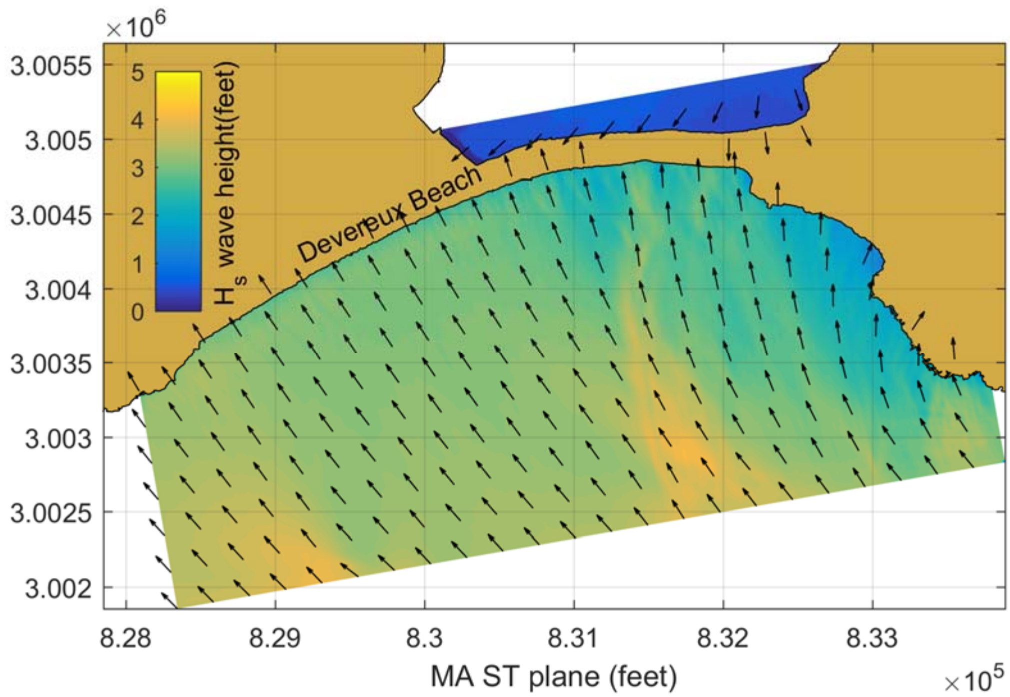

Figure 2-14. **Plot of SE wave model case for the fine grid (5-meter mesh) of Gallops Island. Color contours indicate wave height, while vectors show the wave propagation direction.**

Coastal Processes Modeling

A quantitative analysis was performed based on regionally available data that the physical, meteorological and oceanographic attributes of the modeled sites to assist in the determination of reef attributes that will provide desirable levels of protection at each study site. These data were used in the development of numerical models that determine wave and longshore sediment transport processes that influence sand movement along the beach at both sites.

The transport of sediments along a beach is induced by complex wave patterns and can be determined using empirical relationships that describe sediment transport potential. Coded as a computer model, these empirical methods can be used to obtain an understanding of existing coastal processes, and are verified through comparison to field measurements and other sources of data. Establishing a model of existing conditions allows for subsequent analyses of proposed structural alternatives for a shoreline.

Sediment Transport

As an integral part to the understanding of the coastal processes that are at work at each study shoreline, an evaluation of sediment transport along the shoreline is necessary. Results from the spectral wave model formed the basis computed sediment transport rates along the modeled beach segments since wave-induced transport is a function of various parameters (e.g., wave breaking height, wave period, and wave direction). Longshore transport depends on long-term fluctuations in incident wave energy and the resulting longshore current; therefore, annual transport rates were calculated from the long-term average wave conditions developed and described in the previous section.

The sediment transport equation employed for the longshore analyses is based on the work of the U.S. Army Corps of Engineers (1984). In general, the longshore sediment transport rate is proportional to the longshore wave energy flux at the breaker line, which is dependent on wave height and direction. Since the transport equation was calibrated in sediment-rich environments, it typically over-predicts sediment transport rates. However, it provides a useful technique for comparing erosion/accretion trends along the shoreline of interest.

In the method described by the Army Corps, the volumetric longshore transport, *Q*, past a point on a shoreline is computed using the relationship:

$$Q = \frac{I}{(s-1)\rho g a'}$$

where *I* is the immersed weight longshore sediment transport rate, *s* is the specific gravity of the sediment, *a'* is the void ratio of the sediment, and *ρ* is the density of seawater.

For this study, immersed weight longshore sediment transport, *I*, was computed using a method based on the so-called "CERC formula",

$$I = KP_{\lambda s}$$

where K is a dimensionless coefficient and P_{ls} is the longshore energy flux factor computed using the following relationship:

$$P_{\lambda s} = \frac{\rho g^{3/2}}{16\sqrt{\gamma}} H_{sb}^{5/2} \sin 2\alpha_b$$

where H_{sb} is the significant wave height at breaking, γ is the coefficient for the inception of wave breaking ($\gamma = H_b/h_b$), and α_b is the breaking wave angle. A value of K=0.39 is designated for use with significant wave heights (as output from SWAN).

The actual method used to compute immersed weight longshore sediment transport for this study was described by Kamphuis (1990). This method is basically a modification to the original CERC formula, and adds a dependency on the median grain diameter of the beach sediment, and also the surf similarity parameter, ξ_b, which is expressed as

$$\xi_b = \frac{m}{(H_b / L_0)^{0.5}}$$

where m is the bottom slope and L_o is the incident wave period. The complete expression of Kamphuis is written as:

$$I = K^* \rho g \left(\frac{g}{2\pi}\right)^{0.75} \xi_b T^{0.5} (m d_{50})^{-0.25} H_s^{2.5} \sin^{0.6}(2\theta_b)$$

where the coefficient K^* = 0.0013. The value of transport potential derived using this method represents the maximum possible at a particular location, given a rich sediment supply, and no structures (e.g., seawalls and groins) to modify the movement of sediment along the shoreline.

Using these empirical expressions of sediment transport potential, a computer code was developed which computed sediment transport potential along the Gallops Island and Devereux Beach shorelines. Values of sediment transport are computed at evenly spaced grid cells, with positions that correspond to alongshore grid cells of the wave transformation model grid. For this application, transport potential calculations were performed using a 16.4 ft (5 meter) grid spacing, which corresponds to the grid spacing of the fine wave grid. 2011 USGS LiDAR data were used to develop the modeled shoreline for Gallops Island, and 2010 USACE LiDAR was used at Devereux Beach. The modeled shore segment is approximately 1,600 feet long for Gallops Island and 3,600 feet-long for Devereux Beach.

Inputs into the sediment transport potential calculations include beach slope and sediment grain size. A 0.4-0.3 mm representative grain size was determined based on past sediment samples collected in the area. Beach slope was set to 0.1 (1:10 v:h) for the both shorelines based on approximations of typical cross-shore profiles using the available LiDAR data.

Results of the long-term average sediment transport potential computations based on the model cases listed in Table 2-1 and 2-2 are presented graphically in Figures 2-15 and 2-16 for Gallops Island and Devereux Beach. In each plot, the net transport of the modeled wave cases is plotted together with the separate east- and west-directed components of transport. The net is simply the sum of the east and west components.

Gallops Island Along the Gallops Island shoreline, transport is predominantly eastward driven, with a mean rate of 1,500 cubic yards per year for the whole shoreline segment. The mean eastward component of transport is 2,800 cubic yards per year, which means that the net transport is a little more than half of the east component, or 37% of the combined gross east and west transport magnitude. Apart from a reversal in net transport direction located at the eastern and of the shoreline (around station 15+00), transport is directed to the east on average.

Devereux Beach For Devereux Beach, the east- and west-directed components of transport along the sandy portion of the modeled shoreline (between station 0+00 and 21+00) are more balanced, resulting in a net transport that is a smaller percentage of the total gross transport. In this case, the average net transport is 5,600 cubic yards to the west, and the east- and west-directed components are 29,500 and 35,100 cubic yards per year, respectively. Therefore, the net magnitude is only 9% of the total gross east and west transport magnitudes along the sandy portion of the shoreline. This small value of the net transport compared to the large total gross transport indicates that the sandy portion of the beach is in a state of equilibrium characteristic of stable pocket beaches. Along the Ocean Avenue causeway, net transport rates are predominantly to the west, which is an indication that orientation of this hardened shoreline segment is out of equilibrium with the wave climate. The influence of the shore-perpendicular ridge that intersects the shoreline around station 32+00 can be seen by the highly variable net and west-directed transport values at the east end of the modeled shoreline. The ridge acts to refract and re-focus wave energy along the shore which causes large swings in potential transport rates.

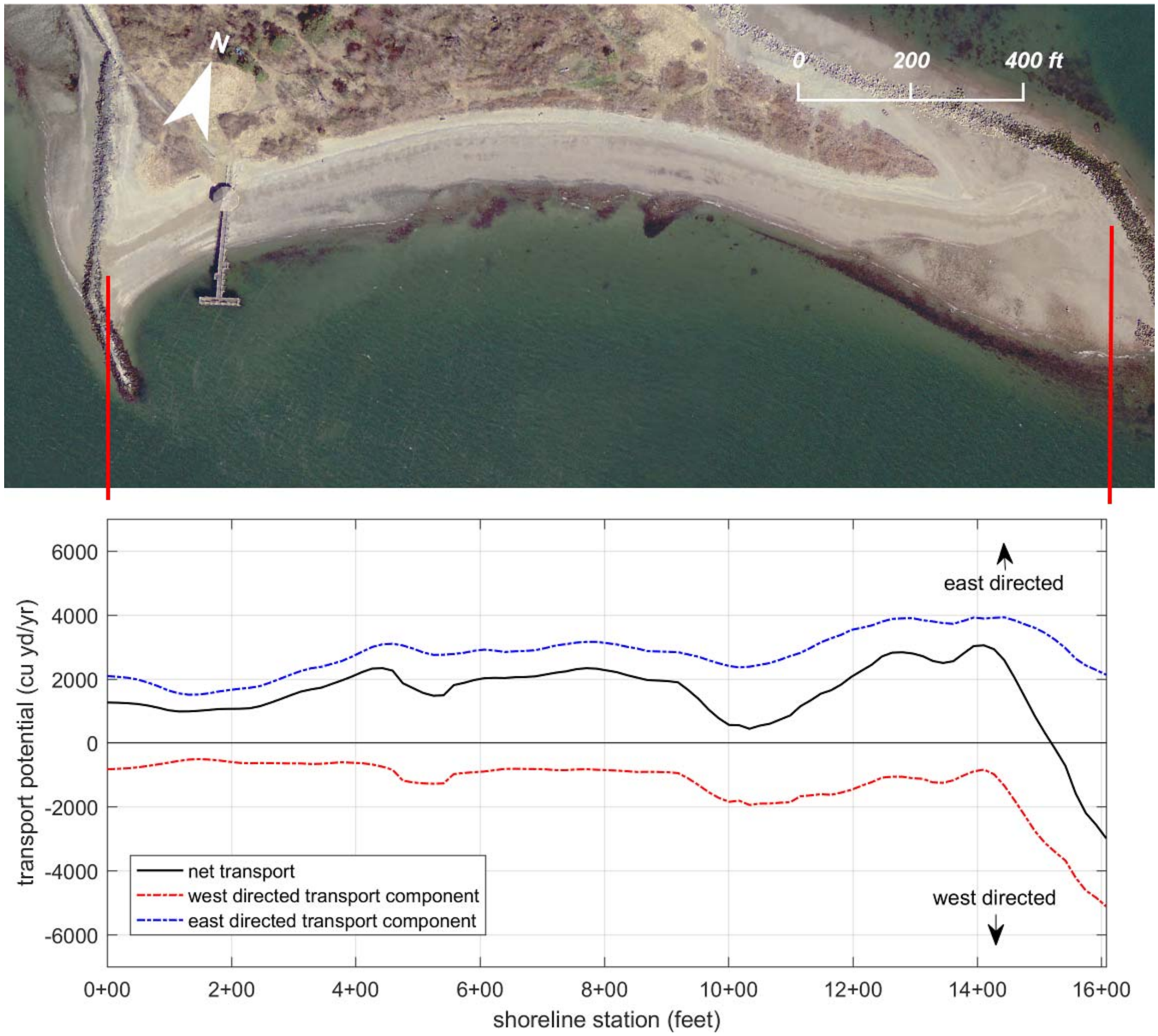

Figure 2-15. **Mean transport potential for Gallops Island, computed for the 33-year span of the WIS hindcast. East and west components of the net transport are also shown. Positive rates are east-directed, while negative rates are west-directed The 2013 aerial of the island shoreline is provided for reference (USGS 2013).**

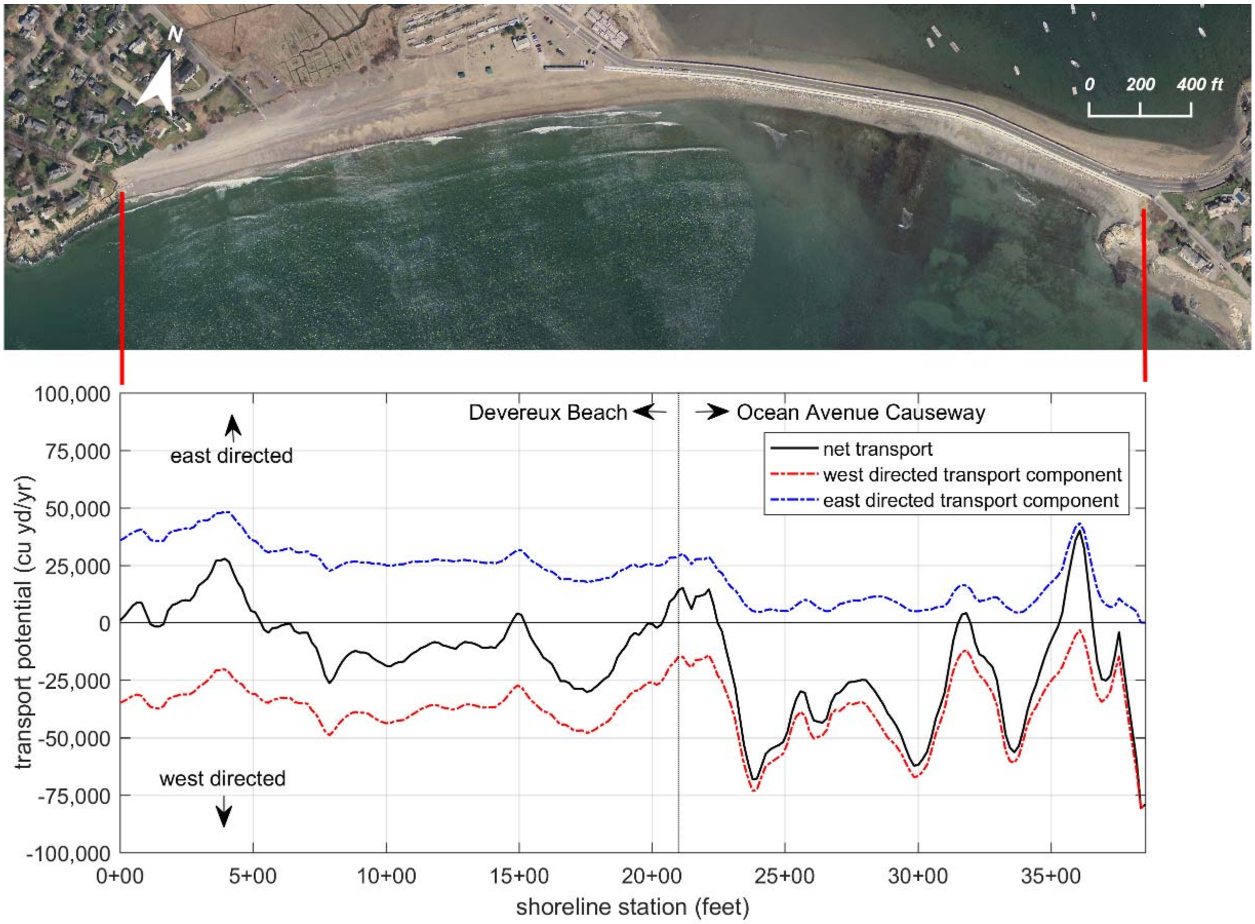

Figure 2-16. **Mean transport potential for Devereux Island, computed for the 33-year span of the WIS hindcast. East and west components of the net transport are also shown. The 2013 aerial of the island shoreline is provided for reference (USGS 2013). The line plotted at station 22+00 indicates the approximate boundary between the sandy beach and the hardened shoreline of the causeway.**

Quantifying Natural Variability

For this study, the capability of the modeled reef structures to protect the shoreline was determined by comparing the change in sediment transport potential caused by each structure along the two study shorelines to the naturally occurring variability of transport potential. When a nearshore reef structure is constructed, it will modify how waves approach the shoreline by refracting, diffracting and blocking wave energy. These modifications to nearshore waves in turn change how sediment moves along the shoreline. If the change in sediment movement patterns is large compared to the natural variability of sediment transport, then it is likely that the presence of the reef will lead to observable impacts to the shoreline position.

The “spatial and temporal” method (Kelley et al. 2004) was developed to assess the significance of offshore bathymetry changes to a given shoreline, and further verified by Kelley and Ramsey (2006) as a technique to quantify potential impacts to the shoreline associated with nearshore bathymetric alterations. The method is a site-specific analysis of waves and sediment transport potential wherein the offshore bathymetry impacts are compared against an allowable limit. This allows the user to easily determine whether the bathymetry changes are acceptable to the shoreline or not. While the “spatial and temporal” method was developed for offshore bathymetry changes caused by excavating borrow sites, the method is equally appropriate to evaluate the impact of breakwater/reef designs with respect to sediment transport. The method and its applications are described below.

The methodology developed to compare changes in sediment transport due to a structure and the natural variability is called the “spatial and temporal method”. This method for determining the relative significance of borrow site impacts on a shoreline is a straightforward procedure that relies on a statistical evaluation of sediment transport along a shoreline.

Quantifying the natural variability of sediment transport along both study shorelines is done by evaluating transport potential annually over a time span that covers many years (20 or more years). If transport potential varies by a small amount between years, then the variability is low for that shoreline, and it would be more sensitive to changes in wave climate affected by the construction of a nearshore reef. Alternately, if transport potential changes by a large amount between years (e.g., due to the influence of storms), the variability would be high and it would be more difficult to differentiate changes that resulted from inter-annual variability of the offshore wave climate and changes that resulted directly from the influence of the reef structure.

Using 20-year wave records, offshore waves are transformed to the nearshore region using a spectral wave model. STWAVE (e.g., Smith, *et al*., 1999) was used in Kelley et al (2004) and Kelley and Ramsey (2006). Sediment transport potential along the shoreline is computed using a modification of the CERC (Bodge and Krause 1991) formula by Kamphuis (1990). Mean sediment transport potential is calculated for the 20 separate years and the standard deviation, σ, of the individual annual means are computed along the given shoreline. With the assumption that the wave energy approaching the shoreline is normally distributed, a significance envelope of $\pm 0.5\sigma$ is determined. The significance envelope encompasses 38% of the variability of the incident wave climate. If the change in sediment transport potential caused by a borrow site is within the significance envelope, the associated influences to the shoreline are not likely to be distinguishable from the natural variability of the wave climate. Conversely, if the change in sediment transport potential exceeds the significance envelope, the shoreline will likely be noticeably impacted.

With the Gallops Island and Devereux Beach applications of the “spatial and temporal method”, first sediment transport potential is computed for several individual years. The WIS wave records available for the coastal United States provide data records of sufficient length on which to base the transport calculations. Using a WIS dataset, average sediment transport potential can be computed along the shoreline of interest for 33 separate years.

The standard deviation of transport potential then is computed using the individual annual means. The significance envelope for the shoreline is then determined as one-half a standard deviation (0.5σ) at each separate along-shoreline grid point. The $\pm 0.5\sigma$ envelope about the mean transport potential computed for the entire duration of the available wave data record incorporates 38% of the variability. Mean transport computed for any single year has a greater than 50% chance of falling outside this envelope. Therefore, if the alterations in sediment transport potential caused by a reef structure are greater than the significance envelope, it is likely that the reef would have an observable influence on the shoreline. While this influence on the shoreline does not necessarily indicate an adverse impact, it does provide insight regarding the influence of the offshore structure on alongshore sediment transport patterns that need to be considered as part of the design process.

The key advantages of this method are 1) it is based upon a site-specific analysis of waves and sediment transport, 2) the shoreline impacts of the constructed reefs are directly compared against a quantitative metric determined by the analysis, so the changes are easily determined to be useful or not with regard to maintaining the beach.

Gallops Island The ±0.5σ transport significance envelope for Gallops Island is presented in Figure 2-17, along with the results of the 33 individual modeled years. The year with the greatest east-directed net transport is 1982, which has a mean value of 4,500 cubic yards per year for the whole modeled shoreline. The year with the greatest west-directed transport is the next year (1983), with a net transport of 1,100 cubic yards per year, averaged over the whole beach. The resulting ±0.5σ envelope varies between 300 and 1500 cubic yard per year about the net transport and has a mean value of ±630 cubic yards per year. Compared to the average net transport of the shoreline (1500 cu yd/yr) it represents a range of ±42 percent.

Devreux Beach At Devereux Beach, the ±0.5σ transport potential envelope is an order of magnitude larger than the envelope calculated along the Gallops Island study shoreline. Along the sandy portion of the beach (west of the Ocean Avenue causeway) the mean value of the ±0.5σ envelope is 8,200 cubic yards per year about the mean net transport (Figure 2-18). In this case, the magnitude of the significance envelope is 146% of the mean transport along the sandy portion of the shoreline. Along the sandy beach, the magnitude of the envelop varies less than it does at Gallops Island.

The single year with the largest east-directed mean transport is 1982, with a mean transport of 17,800 cubic yards per year along the sandy beach. 2010 has the greatest west-directed mean transport, with an average rate of 36,400 cubic yards per year to the west.

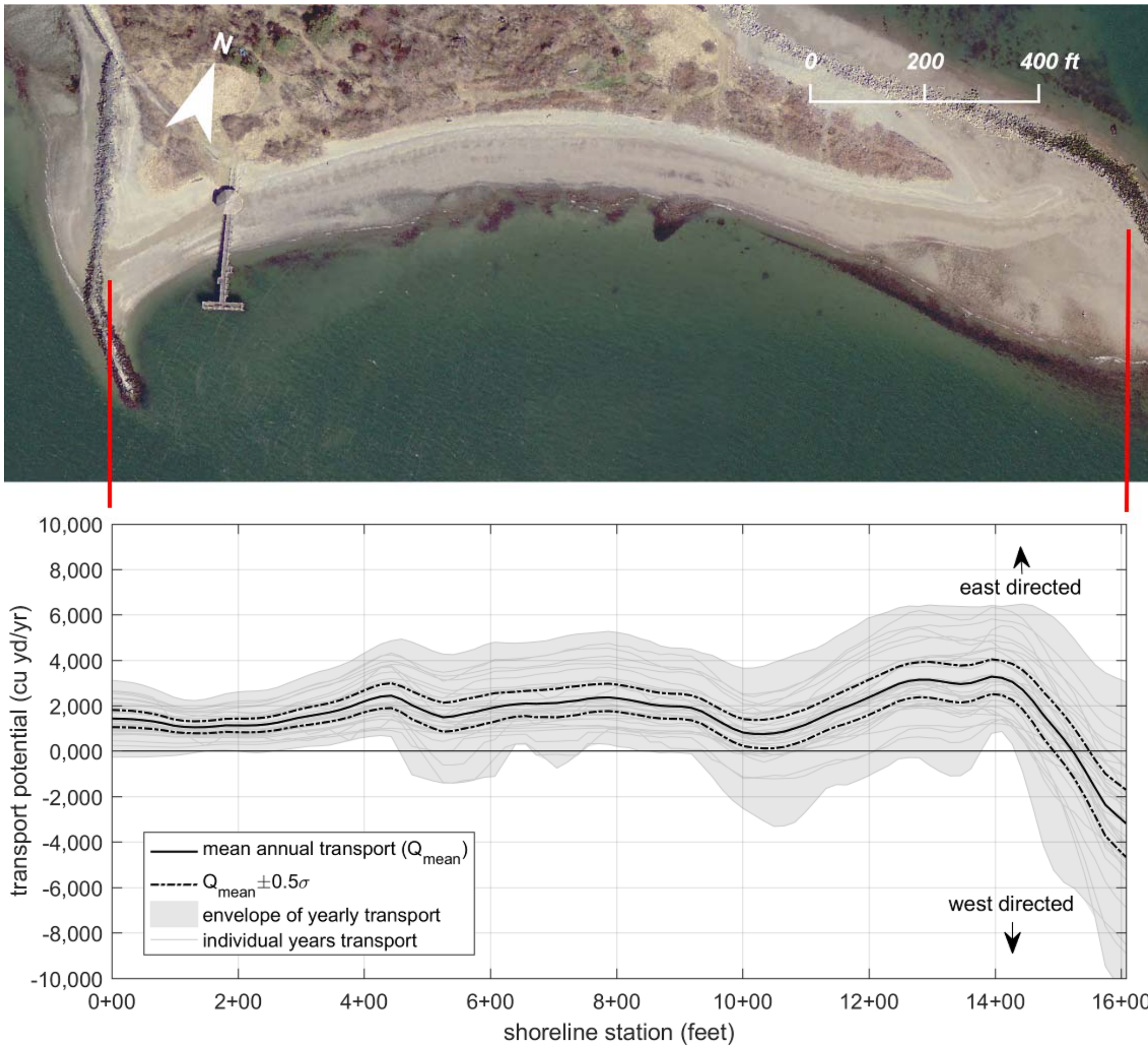

Figure 2-17. **Plot showing the maximum range of transport potential computed for Gallops Islland. Average annual transport rates determined for each separate year included the WIS record is indicated by a gray area. The mean transport potential of the entire 33-year period is plotted as a solid black line. The ±0.5σ significance envelope this plotted as a black dash-dot line.**

Modeled Reef Options

With the determination of the significance envelopes for the two study shorelines, is it possible to run different offshore reef options in the wave model, compute how transport is changed along the shoreline by the placement of the reef, and to judge whether the changes will influence sand movement in a way that will enhance the sustainability of the beach.

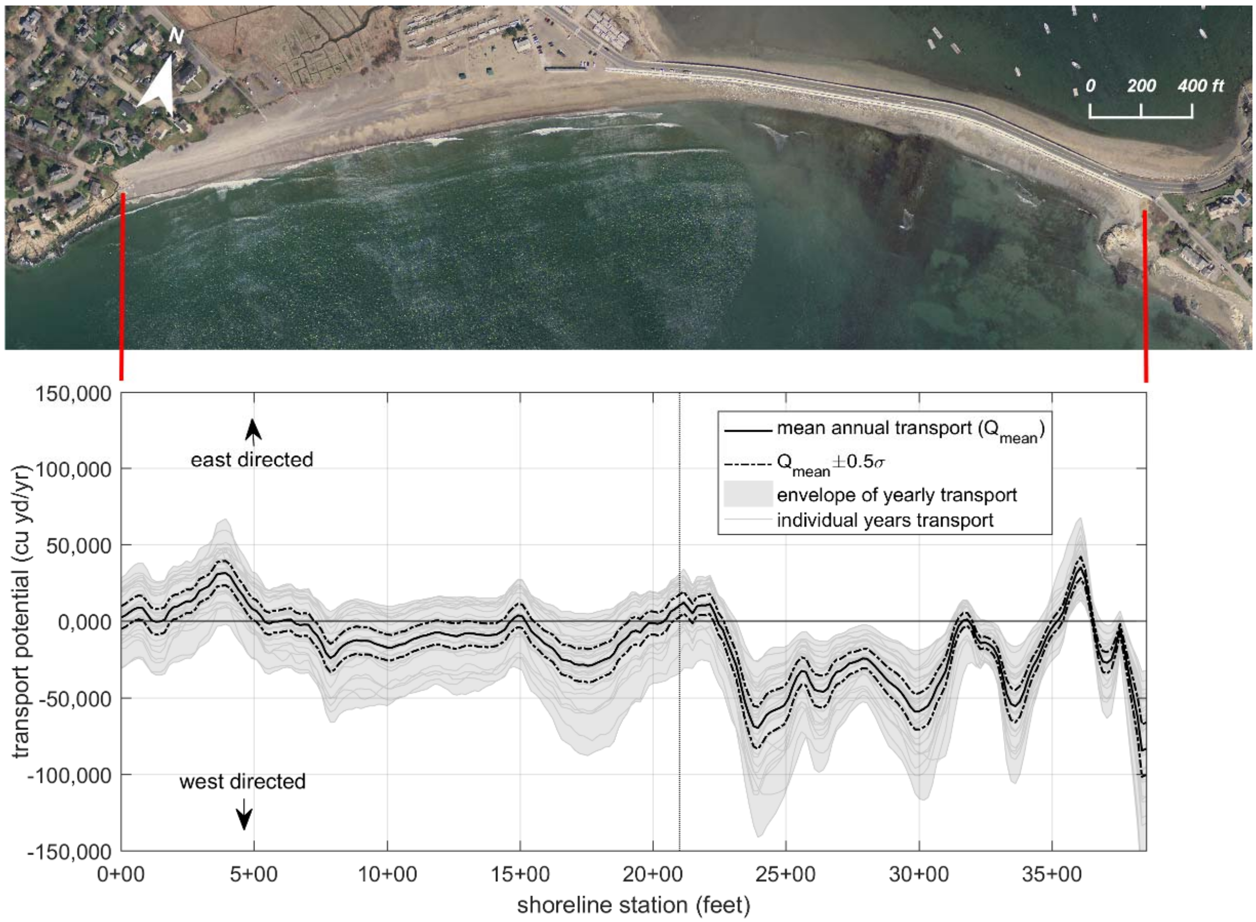

Figure 2-18. **Plot showing the maximum range of transport potential computed for Devereux Beach. Average annual transport rates determined for each separate year included the WIS record is indicated by a gray area. The mean potential of the entire 33-year period is plotted as a solid black line. The ±0.5σ significance envelope this plotted as a black dash-dot line.**

The selected reef options presented in in this study were developed through an initial screening evaluation which included the determination of the wave damping characteristics of several potential designs at each site. As the initial design effort focused on submerged breakwaters for the project, where a screening analysis was performed with model iterations with reef crest elevations varying between -4 feet and zero feet MLW. Due to the crest elevation of thes structures relative to typical water level conditions, wave energy attenuation landward of the structure was minor-to-negligible for all cases. Based on the initial wave model results and feedback from the DMF working group of these initial designs, higher crest elevations were evaluated, including tidally-emergent alternatives. Through this iterative design process, the final crest elevation of +4-ft MLW was determined, as this elevation represented the lowest crest height that could achieve meaningful wave attenuation at each site.

The initial distance offshore for the reef sites was based on water depth alone, where regionally, seagrass typically grows at depths between approximately -12 ft to -22 ft NAVD. The landward edge of each reef was located initially along the approximate -17 ft NAVD contour. However, due to the location of this contour relative to the pier at the Gallops Island site, the DMF working group recommended that the structure be located seaward to facilitate safe navigation and provide a sheltered area in the lee of the proposed breakwater. At the Gallops Island site, the reef was positioned along the approximate -20 ft NAVD contour.

The location of the final selected options are shown in Figures 2-19 and 2-20 for the Gallops Island and Devereux Beach study sites. At Gallops Island, the two selected alternatives include 400-foot long nearshore berm sections with a 15-foot wide crest at +4 MLW (-1.2 feet NAVD). These reef sections would likely be constructed of heterogeneous material sourced from the Boston Harbor navigation channel expansion. The side slopes of the reefs are 3:1 (v:h), and they are placed along the -20 ft NAVD contour. Option 1 includes two separate 400-foot-long reef sections centered along the islands south shoreline. Option 2 has only one 400-foot reef placed to the west of the shoreline's center. The reefs are placed between 300- and 400-feet offshore of the beach, where the crest width and side slopes were determined based on the proposed placement technique for the dumped stone.

At Devereux Beach, the two selected options are a 400-ft-long breakwater placed in a water depth of -17 ft NAVD (Option 1) and a second option that simply doubles the length to 800 feet (Option 2). As described earlier, it is anticipated that the Devereux Beach site would consist of individually placed large-scale armor stone; therefore, based on cost assumptions related to the specific project, the scale of this structure was limited to the 400-ft length. In contrast, the Gallops Island site was designed using the 'fast' rock available from the Boston Harbor Deep Draft Navigation Improvement Project; therefore, the cost would be relatively minor for this beneficial re-use alternative and the size of the reef likely would be limited by the volume of high quality rock available. Both options have a crest width of 15 feet at +4 MLW, with side slopes of 2.5:1 (h:v) for Devereux Beach and 3:1 (h:v) for Gallops Island. The Devereux Beach reef sections would be positioned about 700 feet offshore of the beach and could be constructed using angular armor stone derived from an upland source. The crest width of 15 feet and side slopes of 2.5:1 (h:v) are consistent with a crest two armor stones wide and uniformly sized armor stone placed to form the breakwater.

Figure 2-19. **Position of modeled Gallops Island reef options. Both reef sections have a crest elevation of +4 ft MLW and are 400 feet long.**

Figure 2-20. **Position of modeled Devereux Beach reef options. Both reef sections have a crest elevation of +4 ft MLW and are 400 feet long.**

<u>Gallops Island</u> Plots representing the changes resulting from the options modeled for Gallops Island are presented in Figure 2-21. The middle plot of this figure shows how transport potential along the shoreline changes for each reef option. Option 1 has two 400-foot-long segments and impacts transport rates along the entire length of the southern shoreline of island, from jetty to jetty. The changes for this option fall outside of ±0.5σ significance envelope at three spots, indicating that the changes in these areas would lead to observable changes in the shoreline orientation.

The bottom plot of Figure 2-21 shows an estimate of relative shoreline change that would result from the transport changes in the middle plot. The plotted lines indicate the shoreline response to the presence of each reef option by showing where accretion and erosion would occur. These lines are calculated as the derivative of the transport change plotted in the middle plot. Shoreline change is related to the gradient in sediment transport using the relationship

$$\frac{\partial y}{\partial t}+\left(\frac{\partial Q}{\partial x}+q\right)\bigg/\left(D_B+D_c\right)=0$$

where Q is sediment transport at a particular shoreline transect, x is alongshore width of a computational cell, y is the cross-shore position of the shoreline, t is time, q is a source term, D_B is the berm elevation of the beach, and D_C is the depth of closure. $\partial Q/\partial x$ is the gradient of transport potential determined by the change plotted in the middle figure, and is directly proportional to the change in shoreline position over time. The estimate of shoreline change developed from the $\partial Q/\partial x$ gradient of transport is not intended to be an exact predictor of shoreline response, but it is useful as a qualitative indicator of shoreline change caused by the presence of on offshore reef.

From the plot of relative shoreline change, it is seen that the change in transport caused by either reef option results in areas of accretion and erosion. The integral of both lines in the bottom plot is zero, which indicates that the volume of sand that is moved to the areas of accretion equal the sand lost from the areas where erosion occurs. This is the expected result for a shoreline segment that is a self-contained littoral cell, where sediment neither enters or exits the cell at either end of the shoreline.

For Option 1, with two 400ft-long segments, areas of accretion occur at points centered at station 5+00 and 11+00. These would be the areas where tombolo features eventually would grow behind the reef segments. Erosional areas occur at both ends of the shoreline and in the area between the two reef sections, centered around station 9+50.

For Option 2, with a single 400-foot-long breakwater, the shoreline change effect is not as large. The area of maximum accretion is centered behind the single reef section, and areas of erosion occur at both ends. It should be noted that the anticipated areas of erosion are either adjacent to the existing groin at the west end of the beach (where a wide beach exists) or within the coarse-grained east end of the beach that likely is erosion resistant. Therefore, the overall adverse impacts of a reef project at this site are anticipated to be minor.

Devereux Beach Changes to transport potential and relative shoreline position for the two Devereux Beach reef options are presented in Figure 2-22. The changes are larger compared to the Gallops Island site because the wave climate is more energetic at this shoreline. In the middle plot of transport change it is seen that Option 2 has a much larger impact to transport rates, since it is twice as long as the Option 1 reef. The transport change for both reef options fall well outside of the ±0.5 significance envelope, indicating that they would both result in readily distinguishable changes to the shoreline position.

The bottom plot of Figure 2-22 shows the estimate of relative shoreline position change resulting from the transport change cause by either reef. For both options, the area of greatest accretion occurs directly behind the reef, with areas of potential erosion occurring at both ends. Similar to the results for the Gallops Island reef options, the integral of relative shoreline change for both Devereux Beach options shown in the bottom plot is zero, indicating that the accretional areas are filled with sand that is moved from the areas where erosion occurs. The volume of sand in the accretional areas equal the sand volume lost in the areas where erosion occurs. In this case, accretion occurs along the area where shore protection is needed to protect the western end of the causeway. However, care should be taken during final design to ensure potential impacts to the beach system further west do not create additional shore protection concerns.

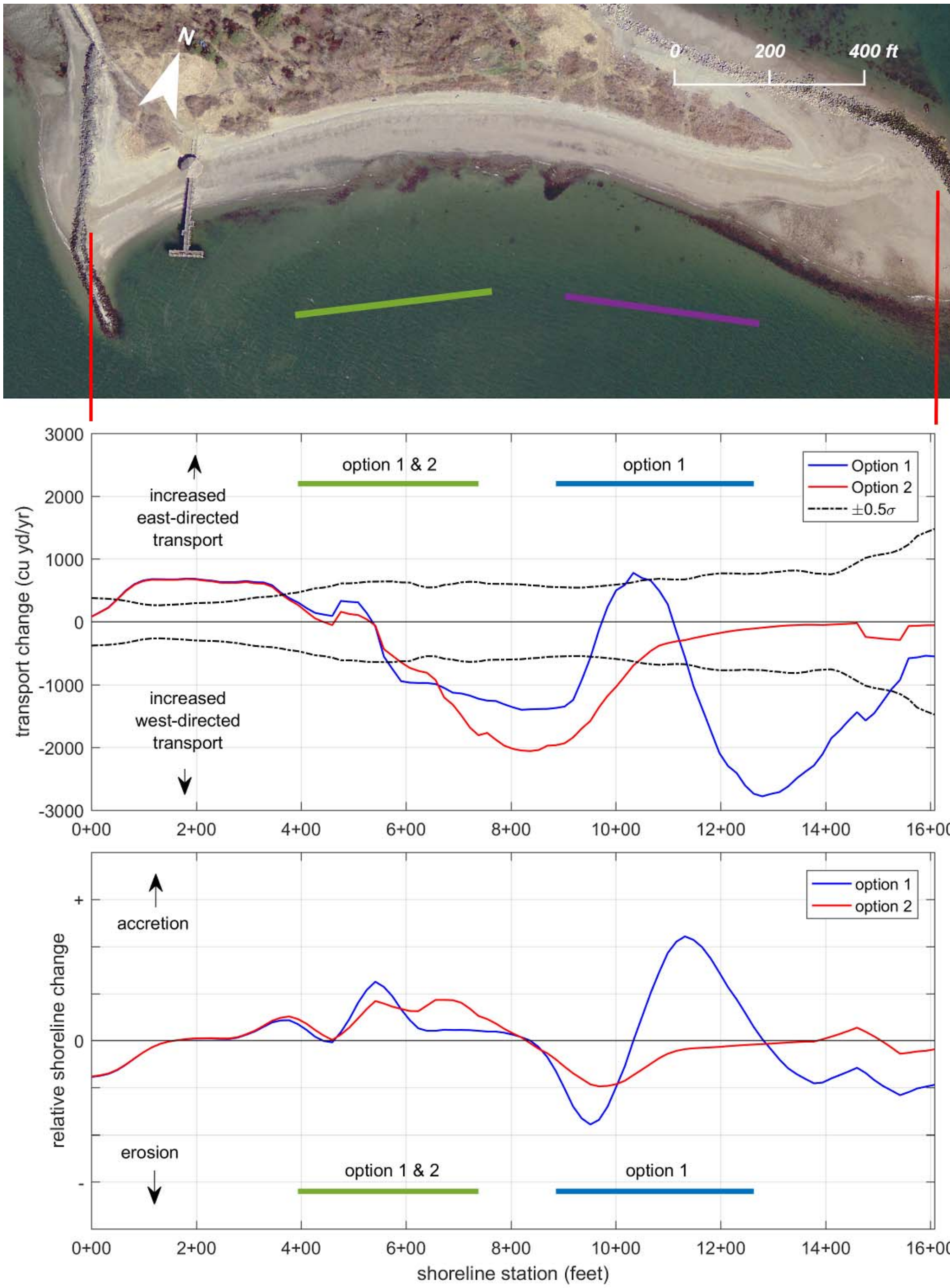

Figure 2-21. **Plot of transport potential change and relative shoreline change resulting from the two modeled reef scenarios for Gallops Island. An aerial photograph of shoreline and reef alignments is provided for reference. The ±0.5σ transport significance envelope is plotted with transport change in the middle plot. The bottom plot indicates areas that would experience accretion versus erosion as a result of the presence of either reef option.**

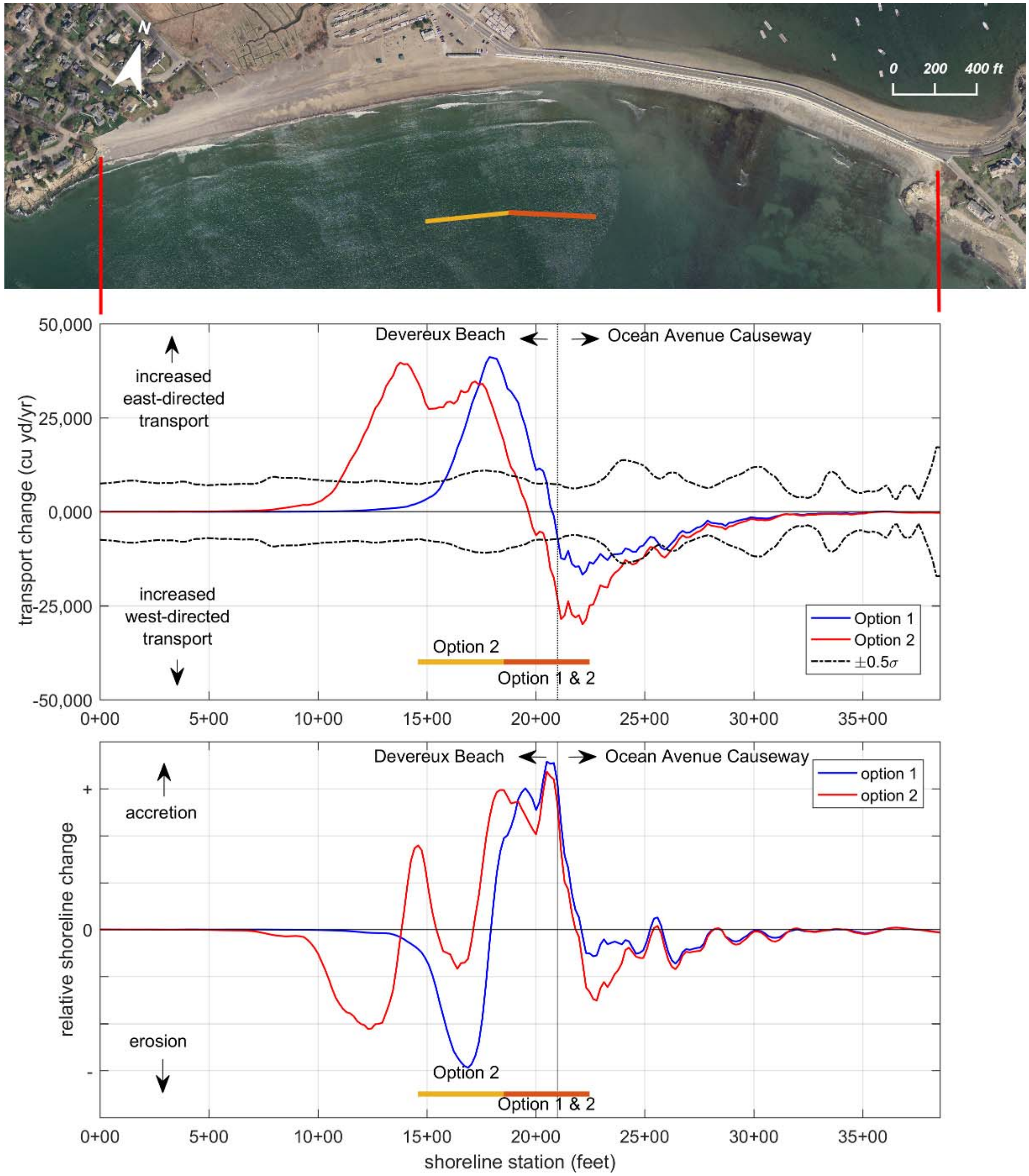

Figure 2-22. **Plot of transport potential change and relative shoreline change resulting from the two modeled reef scenarios for Devereux Beach. An aerial photograph of shoreline and reef alignments is provided for reference. The ±0.5σ transport significance envelope is plotted with transport change in the middle plot. The bottom plot indicates areas that would experience accretion versus erosion as a result of the presence of either reef option.**

Assessment of Potential Salient Formation

The previous analysis indicates the relative impact to sediment transport that would occur as a result of artificial reef construction at both the Gallops Island and Devereux Beach sites. Depending on the location along the beach, areas can either experience erosion or accretion. It is well-documented that the accretional influence of offshore breakwaters/reefs can create salients that reach the structure over time. These salients that connect a breakwater to the shoreline are called tombolos and can act as a complete barrier to alongshore drift. At both sites, tombolo formation is not the goal. Instead, some modest beach accretion in the form of a salient could be viewed favorably, as added beach width would be a benefit to shore protection. To determine the extent of salient formation, relevant literature related to salient and tombolo formation was evaluated in context with the proposed artificial reefs at the two candidate sites.

The Army Corps of Engineers provides a summary of different empirical methods that can be used to qualitatively assess shoreline impacts caused by a particular offshore breakwater configuration (Chasten, M.A, et al., 1993). These methods are used to predict whether the presence of an offshore structure will tend to modify alongshore transport to a minor degree and cause a slight offshore excursion of the shoreline (called a salient) or interrupt shoreline sediment transport to the point where the shoreline transport behind the structure is essentially blocked, causing the shoreline to accrete to the point where it comes in contact with the structure (called a tombolo). A schematic representation of tombolos and salients that can form by the influence on wave propagation by an offshore structure is presented in Figure 2-23.

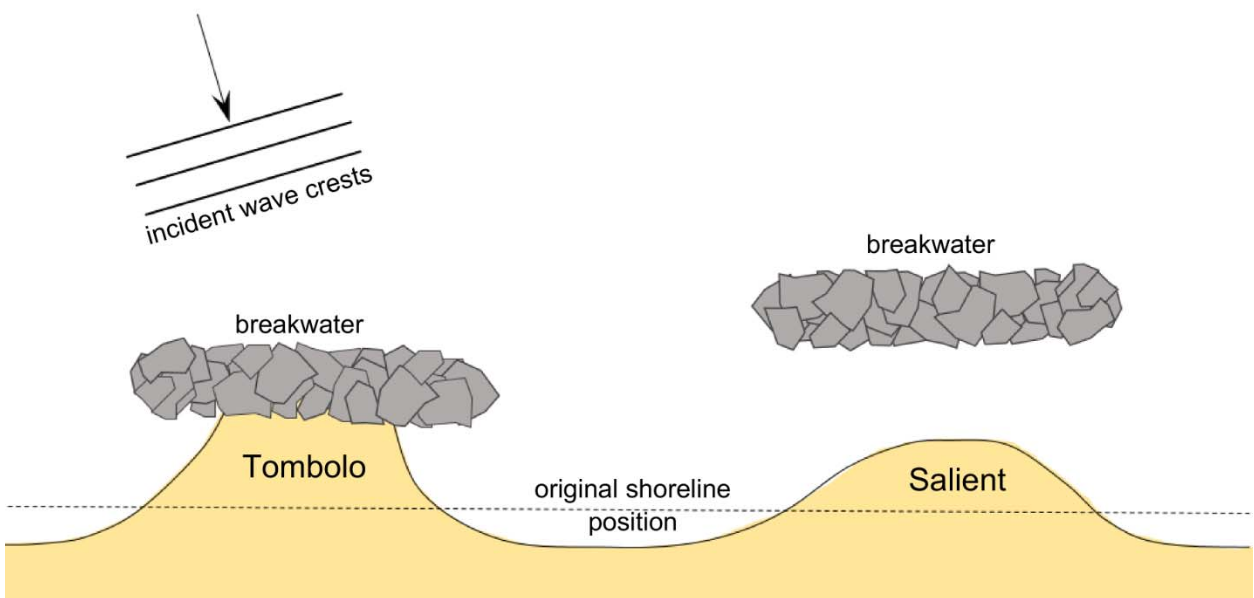

Figure 2-23. **Schematic of shoreline response to the presence of offshore, shore parallel breakwaters. A tombolo forms when the shoreline comes in contact with the structure, which blocks alongshore movement of sediment. A salient is a similar offshore excursion of the shoreline, which does not form a complete block to sediment transport.**

Methods that predict salient and tombolo formation generally rely on the ratio of structure length (L_s) to structure distance offshore (X) as a first-approximation indicator of to the shoreline response. The method of Dally and Pope (1986) represents the simplest form of the available methods, where threshold values of L_s/X are used to indicate the likelihood of tombolo or salient formation behind emergent (crest elevation above the water surface) structures. For tomobolo formation L_s/X is in the range of 1.5 to 2.0. For salient formation, L_s/X is in the range of 0.5 to 0.67.

The method of Ahrens and Cox (1990) similarly includes L_s/X for emergent structures, but in the form of an exponential function. A response index (I_s) is determined using the equation

$$I_s = e^{(1.72 - 0.41 L_s/X)}.$$

Five categories of shoreline response are provided, based on the computed value of the index (I_s values of 5 or greater indicate no shoreline impact, I_s = 4 indicate a subdued salient, I_s = 3 indicates a well-developed salient, I_s = 2 indicates a periodic (transient) tombolo, and I_s values less than 1 indicate permanent tombolo formation).

Some research attempts to account for the subdued effect of non-emergent structures, where the trunk of the breakwater is not a complete block to wave propagation since it allows some wave energy to pass over its submerged crest. The method developed by Pilarczyk and Zeidler (1996) uses the same L_s/X ratio of Dally and Pope (1986), but adds the wave transmission coefficient K_t to include wave transmission across the structure. In this method, tombolo formation is indicated when

$$(1 - K_t)L_s/X > 1 \text{ to } 1.5$$

and salient formation occurs for

$$(1 - K_t)L_s/X < 1.$$

The wave transmission coefficient is simply the ratio of transmitted wave height to the total incident wave height ($K_t = H_t/H_i$). Values of the wave transmission coefficient for rough low-crested dams can be calculated using the model developed by d'Angremond, et al. (1996) which calculates K_t as a function of structural characteristics,

$$K_t = -0.4\frac{F}{H_i} + 0.64\left(\frac{B_k}{H_i}\right)^{-0.31}\left(1 - e^{-0.5\xi_p}\right).$$

In this equation, F is the structure's freeboard (a negative value when the crest is submerged), B_k is the crest width, ξ_p is the surf similarity parameter defined as

$$\xi_p \equiv \tan\alpha / \sqrt{H_i/L_{0p}}.$$

For the surf similarity parameter, α is the structure side-slope and L_{0p} is the offshore wavelength associated with the peak period T_p, determined using

$$L_{0p} = gT_p^2/2\pi,$$

and g is the gravitational constant. This method is encoded as an option in the SWAN wave model.

A more quantitative estimate of shoreline impacts is provided by Black and Andrew (2001), which computes the shoreline excursion for submerged offshore reefs. The method is formulated as

$$\frac{X_{off}}{L_s} = 0.50\left(\frac{L_s}{X}\right)^{-1.27}$$

where X_{off} is the distance between the structure and the salient tip. The salient magnitude would be then determined as $X\text{-}X_{off}$.

For the Gallops Island and Devereux Beach sites, the Pilarczyk and Zeidler (1996), Ahrens and Cox (1990) and Black and Andrews (2001) methods were utilized to provide an estimate of the magnitude of the shoreline impacts of the different proposed reef options. Since Ahrens and Cox (1990) is based on emergent structures, it is used to provide a conservative estimate of shoreline response.

These methods were used to compare selected reef options for the Gallops Island and Devereux Beach sites. Results for the Gallops Island site are provided in Table 2-4, and for Devereux Beach in Table 2-5. Given the inputs of L_s, X and K_t, values of $(1\text{-}K_t)L_s/X$, I_s and salient magnitude are calculated.

For the Gallops Island reef options the results are the same since with the applied methods, the behavior of breakwaters made up of multiple separate units with gaps in between individual sections is not differentiated from a single breakwater with the same dimensions of the units that make up the multi-section breakwater. A small difference in K_t results from the gap between the two sections of Option 1, but it not enough to cause a significant difference in the results shown in table 2-4. $(1\text{-}K_t)L_s/X$ is less than 1, indicating that a tombolo is not likely to form. I_s indicates salient formation. For both cases it should be recalled that I_s values represent emergent structures that completely block waves and therefore it is not likely that these structure would have the strong influence on the shoreline as would be indicated by the computed value of I_s.

At Devereux Beach, values of $(1\text{-}K_t)L_s/X$ also are less than 1 for both options, a result that indicates tombolo formation is not likely. Option 1 has the largest resulting value of I_s, which indicates that a subdued salient is possible. The computed salient magnitudes for the Devereux Beach reef options are much larger than would be suggested by the values of $(1\text{-}K_t)L_s/X$ and I_s determined for each case. It is appropriate to interpret the computed salient magnitude using the values of K_t, I_s, and $(1\text{-}K_t)L_s/X$ for each configuration. Base on this comparison, it is not likely that even for Option 2, which has a smaller value of I_s, that the actual salient would be as large as what is indicated by Black and Andrew (2001). Similar to the Gallops Island site, no tombolo likely will form at the Devereux Beach site; however, the magnitude of salient accretion likely will be larger than Gallops Island, but also minor.

Table 2-4. Estimated shoreline impacts for Gallops Island reef options. Inputs are structure length L_s, reef offshore distance X, and wave transmission coefficient K_t. Results are shown for Pilarczyk and Zeidler (1996) $(1-K_t)L_s/X$, Ahrens and Cox (1990) I_s, and Black and Andrews (2001) for salient magnitude.						
Option	L_s (feet)	X (feet)	K_t	$(1-K_t)L_s/X$	I_s	Salient (feet)
Option 1	2X400	350	0.6	0.5	3.5	181
Option 2	400	350	0.6	0.5	3.5	181

Table 2-5. Estimated shoreline impacts for Devereux Beach reef options. Inputs are structure length L_s, reef offshore distance X, and wave transmission coefficient K_t. Results are shown for Pilarczyk and Zeidler (1996) $(1-K_t)L_s/X$, Ahrens and Cox (1990) I_s, and Black and Andrew (2001) for salient magnitude.						
Option	L_s (feet)	X (feet)	K_t	$(1-K_t)L_s/X$	I_s	Salient (feet)
Option 1	400	700	0.5	0.3	4.4	293
Option 2	800	710	0.5	0.5	3.6	366

Summary and Recommendations for Future Work

After completing the work of site selection and determining reef attributes, there is future work that can be performed that further builds on the results of this study as more detailed information is made available regarding the quality and quantity of material that would be available from the Boston Harbor dredging project.

Model Validation

The results of this study provide both a simple estimate of performance based on existing methods used to determine tombolo and salient formation, and a more detailed assessment of reef performance based on sediment transport potential changes along the study shorelines. A possible additional step to further develop the modeling analysis would be to take steps to validate model performance. While model validation is often an important consideration to develop confidence in the model's predictions, it is not always the case that the additional fine-tuning of the model results would lead to meaningful alterations of how the reef design would meet project goals.

If it was desired, model validation would involve the development of a shoreline change model, built using the inputs to the sediment transport potential analysis. This modeling effort would also incorporate more detailed information regarding beach grain size information, as well as more site-specific information regarding sediment availability (i.e. what regionally available alongshore sediment sources exist and whether any portions of the shoreline are erosion-resistant). The shoreline change model would be run over a period of time where actual measured shoreline positions are available, typically from either aerial orthophotographs or LiDAR datasets.

Final Reef Design

From this study, very general attributes of the proposed reef units were developed. It was determined that a crest elevation of approximately +4 feet MLW is necessary for the reef to influence the nearshore wave climate to the level needed to significantly affect sand transport patterns along each study shoreline. The crest length and distance offshore of the proposed reefs where also determined in this study. Conceptual plans of the reefs at both locations are shown in Figures 2-24 (Gallops Island Option 1) and 2-25 (Devereux Beach Option 1). These conceptual plans represent the reef structures as curved features that more closely follow the bathymetric contours. While the numerical modeling effort simulated 'straight' reef sections (Figure 2-19 and 2-20), the difference in wave attenuation between the 'curved' and 'straight' representations is negligible. As the final design likely will be constructed along a bathymetric contour based upon updated survey results, the conceptual plans provided in Figures 2-24 and 2-25 are more representative of the final reef designs.

The attributes of the reef options developed in this study provide a starting point for the final design, but more specific details of the reefs' construction and siting will need to be developed for the review by the several permitting/licensing agencies.

Details of the final reef designs are also necessary for the development of construction specifications and engineering plans. Sourcing material for the construction of the reefs is important to all aspects of the construction and performance of the structures. It would be simpler to develop construction specifications based on a single armor stone size, rather than the mixed-size material generated by the Boston Harbor dredging project. However, the utilization of rock sources other than the Boston Harbor dredging would require additional effort for the evaluation of availability (quantity, production rates and transport) and engineering properties.

Other details that would be worked out in the final design include the evaluation of the potential for scour around the reef and the assessment of the stability of the material that the reef is constructed of during appropriate storm conditions. The geotechnical attributes of the ocean bottom where the reef sections would be placed also would be assessed in order to evaluate the potential for differential settlement and any additional need for placement of some sort of foundation, such as marine mattresses.

The characteristics of the reef construction material strongly influence all aspects of the completed structure, including footprint, stability, and habitat quality. During discussions as part of the Working Group, the USACE indicated that it would be willing to develop a methodology that would be used to estimate the performance characteristics of a reef structure constructed of heterogenous material from the Boston Harbor dredging project. Performance characteristics would include mobility of the material and confirmation of the wave attenuating capability of the reefs for the purposes of seagrass habitat establishment and shoreline protection. The footprint of each reef is more easily controlled in the case where uniform armor stones are individually placed. In contrast, there would be much less control of the reef footprint with the dumping of heterogeneous material dredged from Boston Harbor. The dredged material would form a structure with a wider footprint and shallower side slope. The dredged material would also create less interstitial space within the reef itself, since the poorly sorted distribution of rock sizes likely available from the harbor dredging would form a more densely packed mound, with smaller void spaces.

Specific design and engineering tasks that would be performed in support of the final design process include, but not limited to:

- Multi-beam baseline survey to establish engineering control for the actual reef site.
- Borings (assume spacing of approximately every 100 feet) along the main axis of the proposed reef structure alignment to assess soil stability and potential settling issues.
- Engineering design of reef structure(s) including proposed dredged rock separation, foundation concerns, rock stability, and placement methods.
- Develop permit level plans (NOI, USACE, DEP Waterways).
- Final engineering plans with draft specifications for construction.

Environmental Permitting

In addition to the tasks associated with the final reef design, further effort is necessary for the development of environmental permit documentation. As the Massachusetts DMF is a co-proponent of the project, it is anticipated that all marine environmental assessments required for the environmental permitting process would be completed by the project proponents.

The main permit, certification, license and other fillings that generally would be required include:

- Massachusetts Environmental Policy Act filing of an Environmental Notification Form (ENF) and Environmental Impact Report (if required)
- Notice of Intent (NOI) filled with the local Conservation Commission
- 401 Water Quality Certification (possible requirement based on the source of material)
- Army Corps individual permit
- MCZM Consistency
- Chapter 91 Waterways License
- Massachusetts Endangered Species Act (MESA) filing

The actual filing of the regulatory permits would likely be performed by an engineering consultant under contract to DMF, who also would be responsible for the development of the expanded ENF used in filing with the Massachusetts Environmental Policy Act (MEPA) and appropriate local, state, and federal permit applications. Prior to consultation with MEPA, it remains unclear whether this project would require filing of an Environmental Impact Report subsequent to the Expanded ENF filing. The overall permitting effort will require input and assessments provided by others that will address marine environmental impacts associated with the proposed project.

The necessity of the 401 Water Quality Certification depends on the source of the material used for the construction of the reef, and depending on the interpretation of the 314 CMR 9.00 regulations by the permitting authorities. The interpretation would depend on whether the project purpose was classified as environmental restoration. The source of the material is important since a reef constructed of dredged material would likely trigger the requirement for 401 Water Quality Certification regardless of the project purpose.

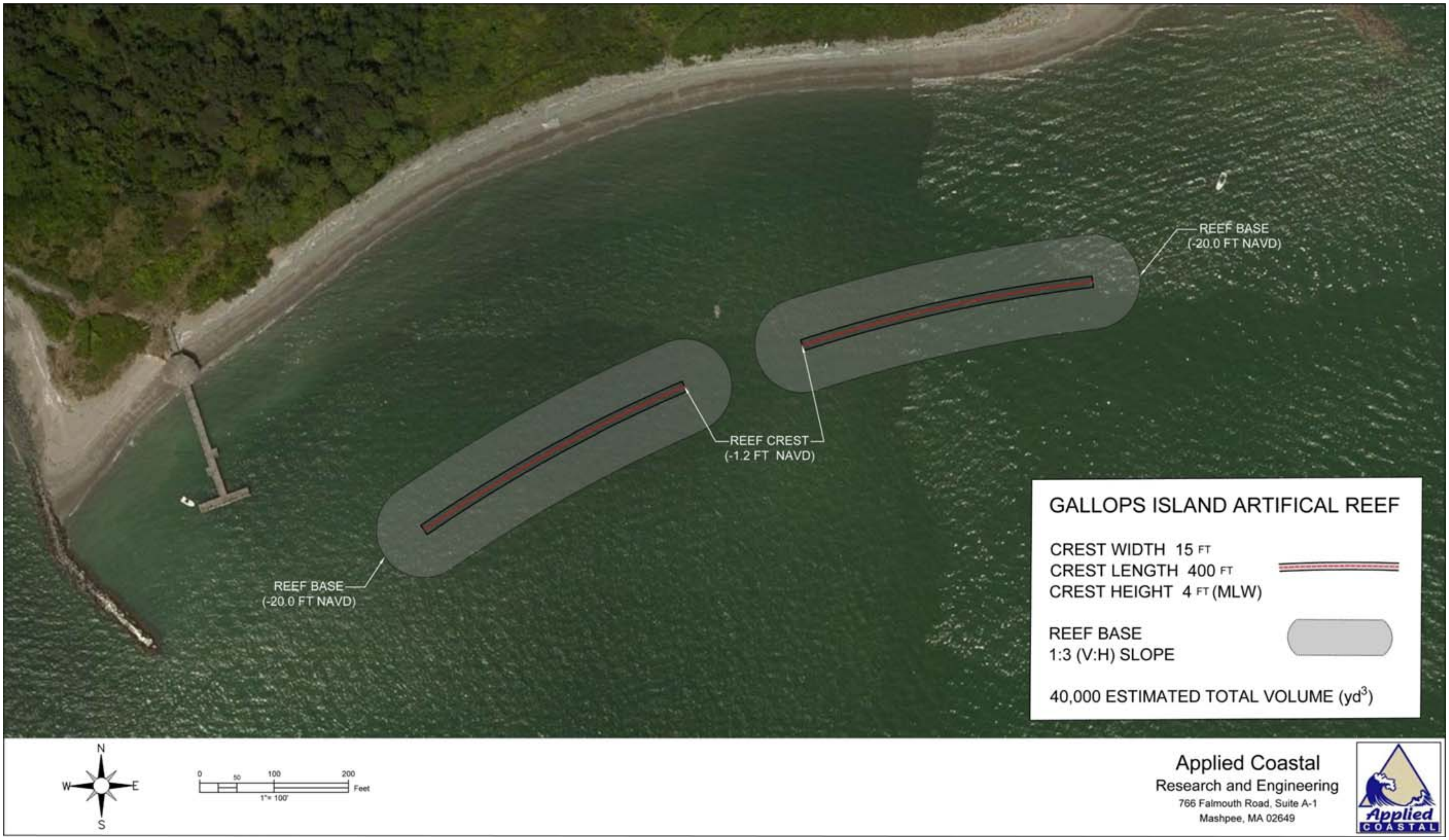

Figure 2-24. **Conceptual plan of the preferred reef alternative for Gallops Island.**

Figure 2-25. **Conceptual plan of the preferred reef alternative for Devereux Beach.**

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Phase 3: Plan development

Overview

A goal of the overall project was to enable communication across regulatory agencies regarding how to best utilize the rocky dredge materials from the Army Corps' Boston Harbor Deepening project. We achieved this goal through holding five workgroup meetings and a regulatory subcommittee meeting. We drafted a document that was agreed upon by the working group as a path forward for the development of this project.

A key limitation in determining beneficial reuse options turned out to be limited knowledge of the quantity and grain size of the dredge material. At best we could assume the dredge material would be a mix of rocky and fine grained sediment. Disposing of material nearshore introduces concerns about the fate of the dredged material. Without clear knowledge of the quantity and grain size of the material, quantifying shoreline protection benefits is impossible. Since project performance criteria cannot be defined or measured, the risk of expected and unintended consequences (including habitat burial, high organic content sediment washing ashore, widespread habitat impacts as the sediment moves around, increased turbidity at the disposal site) is generally thought to be too high. If the material is less rocky, and more appropriate for creating a nearshore berm, there will not be wave attenuation benefits on the shoreline and the risk of incompatible materials washing ashore is thought to be high. If the material is larger rock, larger nearshore berms and breakwaters may achieve shoreline protection performance standards, but may also represent higher risk of instability in a high energy storm. Introducing sediment into a littoral system may have significant benefits, but may also have unintended consequences if the sediment doesn't end up where it is needed.

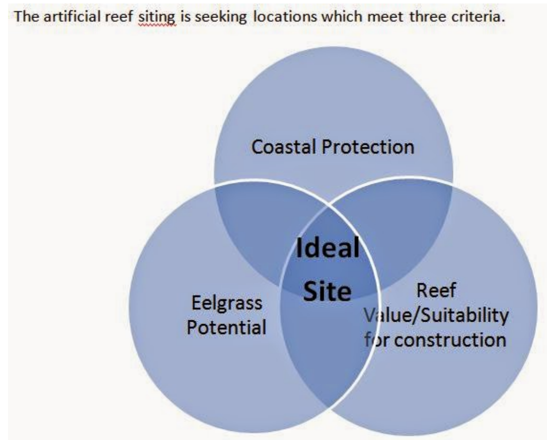
Another limitation was the lack of pre-determined sites and project ideas. Selecting appropriate sites was time consuming and required a large group of people familiar with the coast. We had 12 steering committee members and we spoke with approximately 21 additional people for town-specific information. We also had a working group which met approximately every 6 months. A total of 46 working group members received email updates and meeting invitations, and approximately 40 members provided active feedback at some stage of the project.

Our project ended up running parallel to the dredging project, instead of being engulfed within it. Since the dredging project timeline continued to be delayed, we had the flexibility to do so. This also allowed us to treat the dredged material as a potential material resource for our proposed reefs, but not the only one. Instead of trying to permit the site and reef design within the Army Corps dredging project, the working group encouraged us to simply use the traditional local, state, and federal permitting pathways. Even with the uncertainty of the dredge material grain size, it was generally thought that permits can be developed to allow deployment of dredge material fitting certain conditions. However there are outstanding concerns particularly about the fate of any fine grained material that might be in the mix.

A specific product from our grant proposal was the drafting of recommendations for the beneficial use of Boston Harbor dredged (rock) materials. The following pages include the standalone document drafted to outline the potential path forward to further developing this project. This document was reviewed by the steering committee and working group in the spring of 2017.

Beneficial Reuse Options for Building a Coastal Resilience Demonstration Reef

WORKING GROUP BACKGROUND



The Boston Harbor Beneficial Reuse Working Group has formally met five times (10/31/14, 6/22/15, 11/12/15, 3/28/16, and 11/22/16) under the larger project titled Reusing Dredged Rock to Protect the Boston Harbor Shoreline. This project, funded by the National Fish and Wildlife Foundation, includes site suitability, siting and conceptual designs for in- water reef structures to protect shoreline and add biological value. The goal is to identify sites that could utilize the rock materials from the pending Boston Harbor Navigation Improvement Project for shoreline protection, and develop a project sponsor and process for implementing at least one project as a demonstration. The ideal site location will provide public benefits for coastal protection against storm waves, bottom enhancement for complex rocky reef habitat, and the necessary conditions for potential eelgrass recruitment behind the reef (see diagram).

OPTIONS FOR REUSE OF FAST ROCK MATERIALS

The primary focus of the proposed project is to demonstrate wave attenuation for shoreline protection (and, ultimately, public benefit) as well as ecological enhancement. In Massachusetts, private and public shoreline stabilization structures are documented in statewide databases which include seawalls, groins, beach nourishment areas, and other shoreline stabilization infrastructure. In March 2017 it was estimated there is ~50,000 cubic yards of fast rock associated with the Boston Harbor federal channel deepening dredging that will need to be removed from the outer and lower harbor areas to ensure safe passage of vessels. This first phase of the larger improvement project will deepen the harbor's navigation features between deep water in Massachusetts Bay and the Conley Terminal in South Boston. Fast rock is defined as rock which will require treatment (typically drilling and blasting) before it can be removed by dredging. The first phase of the Improvement Project is currently in the design stage, with estimates of 2019 or 2020 for work (pending availability of funding). The default disposal area is the Massachusetts Bay Disposal Site in offshore ocean waters about 22 miles from Boston Harbor. Discussions have been held over the past decade regarding potential beneficial reuse options.

OPTIONS FOR REUSE OF ROCK MATERIALS

The following beneficial reuse options were discussed by the working group as possible alternatives for the unconsolidated rock materials from the Boston Harbor dredge.

1. Investigate Shaffer Paper Mill, Dorchester—Reuse of contaminated industrial upland site. Fall 2015 implementation start was scheduled and the project was completed in 2016 or 2017. Since pumping material upland was outside the scope of the Boston Harbor dredge material project, this site was not considered.
2. Moon Island, Quincy—Remediation of sewer pits and potential restoration of salt marsh. Pumping material upland was considered outside the scope of this project and there may regulatory concerns associated with existing salt marsh resources at the site.
3. Thin-layer deposition on marshes (for sands and silts). Massachusetts is still investigating the regulatory feasibility of this type of sea level rise mitigation. Our focus in this project is the rock material, so this possibility was not pursued.
4. Offshore and nearshore reefs (for rock material). Initial proposals to site offshore reefs were in conflict with existing natural reef areas, so they were not pursued. Siting was conducted to determine if a nearshore site could be used for rock material disposal.

REACHING AGREEMENT ON SELECTING REEF ALTERNATIVESSITE SELECTION

The rock material is removed from the seafloor using different methods. Weathered and fractured rock mixed with hard tills can typically be removed with a mechanical dredge using a heavy toothed bucket. Fast rock typically requires treatment, such as drilling and blasting before it can be removed by mechanical dredge. In both cases the dredged rocky material is placed in a scow for transport to the disposal site. The weathered and fractured rock material removed without treatment will likely be a mix of Argillite rock and finer grained sediments. Therefore, that mixed rocky material will either need to be used in an unconsolidated manner or be sorted or screened to achieve a certain minimum grain size. We anticipate that screening may be feasible, but sorting will be too time consuming and costly. Fast rock would likely have some component of finer materials, but would be mainly rock of sizes varying from a few inches to several feet in size.

Ideally, the material will be loaded onto the scow and transported to a location limited only by the constraints of the draft of the scow. A bottom dump scow with its doors open to discharge material would require water depths of 12 or more feet to safely operate. The intent of the demonstration project is to place the rock materials in a location with the best possibility of attenuating wave energy to protect the shoreline, enhancing biological productivity through adding structural complexity to an area, and providing for eelgrass propagation shoreward of the structure. This location would also need to have minimal impact on existing complex bottom habitat, eelgrass beds, or other known habitats with unique characteristics or function.

Work to date by the working group has focused on consideration of options for utilizing the anticipated rock materials from the dredge to build a reef somewhere within a 22-mile radius of the Boston Harbor deepening project to meet cost/benefit considerations. There are limited known opportunities for reef building in areas that require wave attenuation benefits and would also benefit habitat enhancement including eelgrass cultivation in addition to complex rocky habitat enhancement. There were two phases of site suitability analysis. In phase one, the Division of Marine Fisheries conducted a desktop site assessment to determine ecological feasibility of site locations. In phase two, Applied Coastal Research & Engineering consultants added wave attenuation and logistical feasibility constraints to the site suitability model. In June 2016, the working group selected the final two locations for further exploration. The two sites are 1) along the southerly shore of Gallops Island in Boston Harbor, and 2) along the south facing shore adjacent to Devereux Beach in Marblehead. The two sites selected represent different reef-building scenarios with the Boston Harbor site having some storm protection from other islands, and the Marblehead site being an open ocean location with no other storm protection besides the proposed reef. The current focus for utilizing the Boston Harbor dredge materials is for the Boston Harbor site offshore of Gallops Island. Gallops Island is co-managed by National Park Service and Massachusetts Department of Conservation and Recreation.

IMPLEMENTING THE REEF DEMONSTRATION

In working group discussions, there was cautious support for utilizing dredge material to build a nearshore breakwater or berm to attenuate wave energy. However, there are many key considerations that the working group discussed, summarized below:

- The purpose of undertaking a demonstration project is to explore potential alternatives for beneficial reuse of dredge materials in Massachusetts waters as well as protecting shorelines with nearshore breakwaters. **Monitoring must be undertaken to determine overall success creating a reef using dredged rock materials.** Monitoring should measure both wave attenuation resulting from the built structure as well as ecological values or impacts both on the structure itself and behind the structure in what is anticipated to become a back-barrier environment with reduced wave action.

- A project sponsor for the demonstration project must be finalized. It is recommended that the MA Department of Fish and Game (DFG), more specifically the Division of Marine Fisheries within DFG, and the MA Department of Conservation and Recreation (DCR) develop an interagency agreement to jointly manage the reef building demonstration project. It is further recommended that the proposed interagency agreement define the frequency of meetings, develop meeting agendas, and define the planning, implementation and monitoring of the reef demonstration project.

- The demonstration project and monitoring project should continue to be overseen by the working group, which includes municipal, state, federal, academic, and ENGO stakeholders. It may be worthwhile to rename the working group the Boston Harbor Reef Team.

- The permitting pathway is unclear, particularly if the material disposed nearshore has potential to move. A subcommittee of the Boston Harbor Beneficial Reuse Working Group is the Boston Harbor Regulatory Caucus which includes municipal, state, and federal agency members. **It is recommended the project sponsor engage with the agencies that participated in the caucus as a deliberate component of meeting permitting requirements.**
    - **Municipal: City of Boston Conservation Commission. State Agencies:** MA DEP, MA DCR, MA DMF, MA CZM, and MassPort. **Federal Agencies:** USACOE, NMFS, USCG, and NPS. It is recommended that the project sponsor plan a pre-application meeting as well as routine meetings thereafter to receive feedback from the permitting agencies regarding the planning, permitting and implementation of the demonstration reef; and reporting on progress related to the demonstration project in Boston Harbor and its applicability to broader efforts to build nature-based infrastructure to reduce the impacts of storm surge and sea level rise in the Commonwealth.
    - The regulatory agencies will assist in defining the permitting path, including the criteria to be met and specific monitoring requirements expected to measure the impacts, related to sediment movement and biological impacts, of the proposed demonstration reef.
- **It is recommended the demonstration reef project be submitted for permitting separately from the Boston Harbor dredge improvement work.** The project sponsor should work with assistance from the regulatory agencies, Reef Team and a consultant. This will require consideration of local, state and federal permitting requirements and would result in a permit for placement of materials independent of the permitting for the federal dredge project. Using the federal dredge project material should be an alternative considered in the permitting process for the demonstration reef project. The Federal harbor deepening

project currently has all necessary permits and approvals to proceed with construction using the Massachusetts Bay Disposal Site as the Federal base plan for placement of the dredged materials, including rock.

PROJECT TIMELINE AND TASKS

The proposed reef building project is designed to be implemented simultaneously with the federal dredge that is now estimated to begin in late fall 2018 and end in 2019 or 2020. The intent is to demonstrate implementation and monitoring of a nature-like reef building project, and separately permit the demonstration reef prior to implementation of the federal dredge rock removal. The following is an estimated timeline of activity starting with permitting through building and monitoring the demonstration reef.

Task	Who	Outcome	Date
1. Select a project sponsor	Mass EEA	A lead agency to move the project forward	June 30, 2017
2. Reef final design and permitting	Project sponsor, Regulatory Caucus, Reef Team, and consultant	Approved final design and permitting in-hand to coincide with dredge project	Completed by: December 30, 2018
3. Coordination with Boston Harbor Dredge Technical Working Group	Regulatory Caucus and Reef Team	Approved plan to use some portion of the rock materials for the federal dredge to build the demonstration reef	Starts: December 30, 2017 until completion of the dredge and reef building work estimated to be December 30, 2019
4. Secure funding for project implementation and monitoring	Reef Team (both public and private sources) oversight; project sponsor	Secured funding commitments for building and monitoring the reef ($100k is current in-hand)	Completed by: December 30, 2018 for implementation and pre-monitoring; December 30, 2019 for post monitoring
5. Implementing reef demonstration project	Reef Team/Boston Harbor Dredge Technical Working Group	Demonstration reef in place in the water and post-monitoring plan in place	Completed by: December 30, 2019
6. Post Monitoring demonstration reef	Reef Team oversight	Measure of project success attenuating waves and enhancing habitat	Completed by: December 30, 2022

Appendix A: Working Group Members

This list identifies the working group members who received email updates and meeting invitations. There were varying levels of involvement; approximately 40 members provided active feedback at some stage of the project.

Members	Affiliation
Alison Verkade	NOAA
Robert Boeri*	CZM
Patricia Bowie	EEA
Candace Leong	NFWF
Carl Spector	City of Boston
Charlotte Moffat*	City of Boston
Chet Myers	*Massport*
Ken Chin	DEP
Duncan Fitzgerald	*Boston University*
Lisa Berry Engler	CZM
Erin Berry	DMF
Tay Evans*	DMF
Christy Foran*	ACE
Tom French	DFW
Jon Grabowski*	Northeastern
Rebecca Haney*	CZM
Randall Hughes*	Northeastern
James Hoar	City of Boston
Jon Kachmar*	Nature Conservancy
Susan Kane	*DCR*
Kathleen Judge	City of Boston
Kathryn Ford	DMF
Michael Keegan	ACE
Lealdon Langley	DEP
Marc Albert	*NPS*
Martin McHugh	NFWF
Carole McCauley	MassBays/Northeastern
Meghan Quinn	ACE
Mike Johnson	NOAA
Kevin Mooney	DCR
Chris Morris	Massport
Adrienne Pappal	CZM
Peter Rosen	*Northeastern*
Phil Colarusso	EPA
Todd Randall	ACE
Robbin Peach	Massport
Mark Rousseau*	DMF
Dan Sampson	CZM
Juliet Simpson	MIT
Stefano Brizzolara	MIT

Members	Affiliation
Stephen Potts	ACE
Stewart Dalzell	Massport
Michael Stroman	DEP
Burton Suedel	ACE
Brad Washburn	CZM
Steve Wolf	ACE

Members in italics were added to the working group in January.
**Steering committee members*

Appendix B: Desktop Site Selection Metadata

Category 1 Metadata

	Attribute Name	Attribute Description	Data origin
Layer Attributes	FID	(hidden)	
	Object ID – unique ID	(hidden)	
	Shape_Area	(hidden)	
	Shape_Leng	(hidden)	
	ET_ID	corresponding grid cell unique ID (hidden)	
	ET_Index	Grid index reference number (hidden)	
Mapped Habitats	HABITAT_1	DEP Eelgrass (rupia, no eelgrass, eelgrass) (hidden)	MA GIS – DEP Eelgrass Mapping Project
	EelGr_Scr	eelgrass score (presence=1)	
	SASHaB_Scr	sum score of SAS habitats	
Designated Uses	MoorAr_Scr	mooring area score (presence =1)	CZM MORIS – Mooring Fields
	HistPL_Nam	Historic site name (Join to NAME_1 in data set) (hidden)	MA Cultural Resource Information System (MACR
	HistPl_Scr	historic places score (presence = 1)	
	DPA_Scr	designated p[ort area score (presence =1)	CZM MORIS – Designated Port Areas (DPA)
	InDisp_ID	Inactive Disposal site ID code (join with SORDAT) (hidden)	CZM MORIS – Inactive Disposal Sites
	InDisp_Scr	Inactive Disposal site score (presence=1)	
	DS_Name	active disposal site name (hidden)	CZM MORIS – Active Disposal Sites
	ADspSt_Scr	active disposal site score (presence=1)	
	DesUse_Scr	sum score of all designated uses	
Navigation	Plt_Ar_Nam	description of pilot boarding areas (hidden)	CZM MORIS – Pilot Boarding and Anchorage areas
	Pilot_Scr	pilot boarding area score (presence=1)	
	AncNOAA_Ch	Anchorage area NOAA Chart classification (presence=1) (hidden)	MA GIS – nautical .arc (NOAA chart data)
	AncAr_Desc	Anchorage area location (presence=1) (hidden)	MA GIS – nautical .arc (NOAA chart data)
	AncArea_Sc	Anchorage area score (from A presence =1)	MA GIS - AncNOAA_CH + AncAr_NAM
	FerRt_DESC	Ferry route name (Joint to ROUTE) (hidden)	MA GIS – ferryroutes.arc
	FerRt_Scr	ferry route score (presence=1)	
	Navig_Scr	federal navigation channel (presence=1)	MA GIS – nautical.arc (NOAA chart data)
	NavAll_Scr	sum of Navigation subcategory scores	
Permitted	Marina_Nam	Marina site name	CZM MORIS - Marinas

Infrastructure	Marina_Scr	marina score (presence =1)	
	FTrap_Scr	fish weirs (presence=1)	MA GIS – Fish Traps (Weirs)
	Areef_NAME	artificial reef location name	CZM MORIS – Artificial Reefs
	ArtRf_Scr	artificial reef score (presence=1)	
	CblLoc_Cod	cable area location code	MA GIS – nautical.arc (NOAA chart data)
	CblArea_Sc	Cable area score (presence=1)	
	Cable_Desc	Cable line description	CZM MORIS – cable locations
	Cable_Scr	cable line score (presence=1)	
	SL_Desc	sewer line description	CZM MORIS – SewerLines
	SLine_Scr	sewer line score (Presence=1)	
	GPipe_Desc	gas pipeline description	CZM MORIS – gas pipelines
	GasP_Scr	gas pipeline score (presence=1)	
	PLArea_Des	pipeline area description	CZM MORIS – pipeline areas
	PlnArea_Sc	pipeline area score (presence=1)	
	Tunn_Scr	tunnel score (presence=1)	CZM MORIS - tunnels
	PUBINF_ID	Public Shoreline Stabilization Infrastructure ID	CZM MORIS
	PRIMTYPpub	Public Shoreline Stabilization Infrastructure description	CZM MORIS
	PubInf_Scr	Public Shoreline Stabilization Infrastructure score (presence =1)	
	PVTINF_ID	Private Shoreline Stabilization Infrastructure ID	CZM MORIS
	PRIMTYPpvt	Private Shoreline Stabilization Infrastructure description	
	PrivInf_Scr	Private Shoreline Stabilization Infrastructure score (presence =1)	
	PIAll Score	sum of Permitted Infrastructure subcategory scores	
	CAT1_Scr	sum of all category scores (presence i f >0)	

Presence data and one descriptive variable is included in the layer

Category 2 metadata

	Attribute Name	Description	Data origin	Cross reference attribute
Sediment	BARN_	Barnhardt Classification Code assigned to area based on CZM's surficial sediment analysis. R – rock, G – gravel, S – sand, M – mud	CZM – MOP Baseline Assessment Surficial sediment data	BARN_

	CONF_	CZM's confidence level scale (Very high (4) to Low (1). (not used in matrix, but included in GIS files for future use).	CZM – MA Ocean Management Plan Baseline Assessment Surficial sediment data layer	CONF_
	SOURCE	data source, CZM sediment surficial composition dataset		SOURCE
	Sed_Rnk	not currently used for matrix – see table for breakdown (4 = Primarily rock, 3= donut hole area(no data) SedAdj_scr recoded to =1(potential), 2=rock present as secondary substrate, 1=Sand, mud, or gravel dominant or low data confidence,Sand dominant and high data confidence		
	Sed_Scr	Sediment ranking – see methods section	2 = unsuitable, 1 = potential, 0 = prime	
	SedAdj_Scr	Not used – placeholder for sediment analysis w/ high confidence data		
Slope	POINTID	bathymetry raster to point value		
	GRID_CODE	raster to point grid value		
	RASTERVALU	raster slope point value		
	Slope_Scr		RASTERVALU > 1 – Slope_Scr = 2 = unsuitable, RASTERVALU<1 to >0 – Slope_Scr = 1 = potential, RASTERVALU – Slope_Scr = 0 = prime	
	Tier2_Scr	sum of Slope_Scr + Sed_Scr		
	Tr2Adj_Scr	sum of SedAdj_Scr + Slope_Scr		
Category 3 metadata				
	Attribute Name	Description	Data origin	Cross reference attribute
Depth	DEPTHRANGE	depth range from BATHMGM_POLY, in meters		
	DEPTHCODE	numeric code assigned to each DEPTHRANGE		
	DEPTH_Scr	depth score (=1 if DEPTHCODE <3)		
Regulated Fishery Closure Areas	CMR_link	winter flounder closure CMR		
	WF_Scr	winter flounder closure area score (presence=1)		
	CCZ_Scr	DMF spring and winter Cod Conservation Zones (presence=1)		
	RegFish_Sc	sum of regulated fishery closure area scores (presence>0)		

Important Habitat Areas	HABITAT	shellfish suitability habitat type		
	ShSuit_Scr	shellfish habitat score (presence =1)		
	InterT_Typ	intertidal flat description (join to SYM_COM in original layer)		
	InterT_Scr	Intertidal flat score (presence=1)		
	RW_Hab_Des	Right whale critical habitat area		
	RW_Scr	right whale habitat score (presence=1)		
	HB_Hab_Des	Humpback whale critical habitat area		
	HB_Scr	Humpback whale habitat score (presence=1)		
	FW_Hab_Des	Finback whale critical habitat area		
	FW_Scr	Finback whale habitat score (presence=1)		
	Wreck_Code	Submerged wreck ID code (join to RECRD in Wreck layer)		
	Wreck_Scr	Submerged wreck score (presence =1)		
	ImpHab_Scr	sum of important habitat score		
Important Temporary Uses	PreAr_DSNM	precautionary area dataset name		
	Precau_Scr	precautionary area score (presence =1)		
	CRUISE	DMF Resource Assessment cruise code		
	Trawl_Scr	Resource assessment tow score (presence =1)		
	ImpTem_Scr	sum of important temp uses score		

Appendix C: Town Survey Results

Boston

Rebecca Haney identified the Shaeffer Paper Mill site for shoreline protection. Marc Albert from NPS identified Georges Island for shoreline protection. Phil Colarusso recommended Long Island for shoreline protection and eelgrass restoration.

Cohasset

Paul Shea commented on how Cohasset a granite rocky coastline, the only one south of Boston. That area south of Hull is also known for good lobster habitat- (as also pointed out by Bob Glenn). Paul mentioned the Gulf River/Hunter's Pond system as a productive spawning site for diadromous fish populations.

Cohasset indicated they could not support our project "Atlantic Ave Beach" because there was concern that successful eelgrass restoration efforts there could impede future beach nourishment efforts at that location (potential problems running pipes to shore through eelgrass). According to the town engineer, this beach is renourished about every 10 years.

Hingham

Abby Piersall is very interested in this project but did not identify any sites. No sites were identified by the workgroup or Applied Coastal.

Hull

Ann Herbst and Kurt Bornheim did not identify any sites. Crescent Beach was identified by Applied Coastal and we did not receive town feedback regarding the site.

Manchester

Bion Pike identified Singing Beach and Downtown Manchester as needing shoreline protection. He also recommended Manchester Harbor for eelgrass restoration.

Marblehead

Provided positive feedback in support of our project and indicated a strong community desire / willingness.

Marshfield

Jay Wennemer and Sara Grady identified a site in the North/South River to protect a marsh.

Nahant

Jeff Chelgren, Town Administrator did not identify any sites (no response).

When contacted about the sites on our list (Black Rock at Wendell Road) no response was received.

Quincy

Peter Fifield identified Long Island Bridge for artificial reef location. He identified Nickerson Beach, Edgewater Drive/Hough's Neck, Wollaston Beach, and Sea Street as needing shoreline protection.

Quincy is very interested in our project and in support of the listed projects. They also noted that Wollaston Beach is not City owned property.

Revere

Did not identify any sites (no response).

No sites were identified by the workgroup or Applied Coastal.

Salem

Tom Devine identified Salem Willows Pier, Camp Naumkeg shoreline, Forest River Park, and Collins Cove shoreline. All were identified as needing shoreline protection.

Barbara Warren identified Juniper Cove, Palmer Cove Yacht Club, and Dion's Yacht Yard. All were identified as needing shoreline protection.

Scituate

Patrick Gallivan and Nancy Durfee did not identify any sites but provided positive feedback in support of our project and indicated a strong community desire / willingness.

Swampscott

Peter Kane is concerned that eelgrass is impeding other projects the town wants to complete. No specific sites were identified.

Weymouth

Mary Ellen Schloss highlighted the Fort Point Road corner/seawall concerns for shoreline protection.

Winthrop

Steven Calla did not identify any sites (no response).

When contacted about the sites on our list (Black Rock at Wendell Road) no response was received.

Appendix D: Site Assessment for NFWF Sandy Grant Boston Harbor Beneficial Re-use Project

Site Assessment Summary

Boston Harbor Beneficial Reuse sites (Spectacle Island, Georges Island, Long Island, Gallops Island) were assessed to determine the feasibility of installing a proposed 50,000 cubic yard structure with a footprint of 1100' x 150'. Six other sites (Sea Street Quincy, Fort Pt. road Weymouth, Green Harbor Marshfield, Brant Rock Marshfield, Bar Rock Scituate, Devereux Beach Marblehead) were assessed to determine the feasibility of installing a 60' x 400' structure. This smaller size is based on cost assumptions.

For collecting data on-site we placed buoys at the corner coordinates of the proposed structure location and collected video, position and depth data at each end. Using a boat we ran a transect lengthwise through the location of the proposed structure and collected video and depth data at the ends and in the center. We monitored the boat's depth sounder when moving from station to station to observe any unexpected bottom features or changes to depth or composition. If we noticed any anomalies on the sounder we conducted additional camera drops at that location. We also ran three transects perpendicular to the proposed structure, one at each end and one through the center, collecting data at points inside and outside. Inside stations were as close to shore as possible and for outside stations we chose nearby channels, or deeper areas appearing featureless on NOAA charts.

This document contains notes, images, and data collected by DMF from six site visits conduced between January 13 and March 10, 2016 to ten sites selected by the working group. The purpose is to inform the selection of two of these sites for further assessment.

Site Visits

On February 2nd, DMF visited Spectacle Island, Gallops Island, Long Island, and Georges Island by boat and assessed each site using a drop camera (Snake Mate Deep Water Pro).

On January 13th, DMF conducted a shoreline survey during low tide to assess the beach/coastline at the Marblehead / Devereux Beach site.

On January 14th, DMF Conducted a shoreline survey during low tide to assess the beach/coastline at the Marshfield/Green Harbor, Scituate/Bar Rock, and Marshfield/Brant Rock sites.

On January 21st, DMF Conducted a shoreline survey during low tide to assess the beach/coastline at the Quincy/Sea Street, and Weymouth Fort Point Road sites.

On March 3rd, DMF revisited the Marblehead site via boat and ran transects along the proposed reef site, utilizing a drop camera and Hummingbird sonar unit.

On March 10th, DMF visited the Marshfield – Green Harbor and Scituate/ Bar Rock sites via boat and ran transects along the proposed reef site, utilizing a drop camera and our Hummingbird equipment.

Spectacle Island

The shoreline and intertidal area consists of primarily small cobble and sand. There were pilings remaining from an old pier near shore. The bottom sediment along the proposed site is a mix of sand/ soft sediment. On either end of the site where the structure is proposed, the bottom is bare/featureless with soft sediment. As you head toward the middle there were small amounts of gravel/cobble and drift and/or rooted algae was observed. Closer to shore/east of the site is more featureless soft bottom. Further from shore/west of the site was featureless soft bottom with a thin layer of dark sediment on top. This was consistent from all the way out to the channel.

We noted this site had high eelgrass restoration potential. The proximity of the proposed structure location relative to observable shoreline erosion was noted. These were both factors we considered when ranking this site higher relative to other sites in the BH Islands group.

Spectacle Island Shoreline. Note erosion area along the shore.

Spectacle Island Reef Deployment Bottom Type. Soft sandy bottom with algae.

Spectacle Island Reef Deployment Location.

Spectacle Island Site Assessment Data Sheet.

Site:	**SPECTACLE ISLAND**
Date:	2/2/2016
Tide:	Hull Low Tide 12:09 (+1.4)
Crew:	Ostrikis, Carr, Rousseau
Activity:	Boat survey, drop camera
Gear:	r/v Alosa, snakemate drop camera
Time on Site:	11:11

TRANSECT COORDINATES

wpt	**Lat**	**Lon**	**video files**
SPI--1 to SPI--2	get wpts off alosa		1,2,3,4
quick points, not stored	42 19.414	70 59.319	5
quick points, not stored	42 19.393	70 59.501	6
quick points, not stored	42 19.383	70 59.627	7

TRANSECT/VIDEO DESCRIPTIONS

Video File	Description
SPEC V1	short test
SPEC V2	started at SPI--1
SPEC V3	started at midpoint between buoys. Featureless sandy
SPEC V4	started at SPI--2, featureless sandy with low lying (dead?) brown algae
SPEC V5	perpendicular to transect, shallow end
SPEC V6	perpendicular to transect, deep end near no wake zone marks
SPEC V7	western way channel halfway btwn spectacle and thompson

LANDSIDE OBSERVATIONS

erosion	cobble on beach, strong current seen
public infrastructure	new dock and building. Some old dock footings
existing armoring	rip rap and cobble all around island, with much less along beach at proposed reef area, a portion of which has no armoring (closest to dock).
other	reef footprint goes very close to corner of dock - any conflicts? Commuter ferry route close by, experienced wave energy

UNDERWATER OBSERVATIONS

bottom type	soft sand with some gravel
eelgrass presence	none seen in transect
obstructions	none seen in transect
biota	ulva, laminaria, other large gr/br algae, some sand dollar
fixed gear	none seen above or below water
other	shallow, intertidal zone? Variability in depth along transect; 4-11' during transects strong current; black anoxic mud on drop buoys when

NEXT STEPS

- Dive work not needed, feel confident we characterized the site
- potential site for material reuse and eelgrass restoration
- determine distance to nearest mapped DEP grass

Gallops Island

Site is primarily featureless/bare sand with some areas of gravel and shell hash along the west end. East portion of site has some small sand mounds. Substrate surrounding the site varies. Shoreward of site between jetty and pier changes from primarily sandy to thick cobble as you move shoreward. At mid point is very rocky with dense algae coverage.
Shoreward of east end is sand with sand waves, some algae. Deeper areas further out from the site consisted of primarily sand with patches of filamentous red algae throughout the western end and some gravel cobble patches along the eastern end.

This site was previously investigated for eelgrass restoration potential for another project. Current "Closed to the Public" status was a factor in ranking this site lower relative to other sites in the BH Islands group.

Gallops Island Shoreline. Mixed sandy and gravel beach with erosion inland.

Gallops Island Reef Deployment Bottom Type. As shown in the top pictures, the site is primarily featureless sandy bottom. Bottom left picture shows the west end of the site where there is some gravel and shell hash. Bottom right picture shows area located between the jetty and pier where the bottom changes from soft sand to a cobble ledge.

Gallops Island Reef Deployment Location.

Gallops Island Site Assessment Data Sheet.

Site:	**GALLOPS ISLAND**
Date:	2/2/2016
Tide:	Hull Low Tide 12:09 (+1.4)
Crew:	Ostrikis, Carr, Rousseau
Activity:	Boat survey, drop camera
Gear:	r/v Alosa, snakemate drop camera
Time on Site:	13:30 PM - 14:20 PM

TRANSECT COORDINATES

wpt	start lat	start lon	stop lat	stop lon	video files
GP1--1 to GP1--2	42 19.417	70 56.350	42 19.497	70 56.132	1, 5, 8
quickpoint, not stored	42 19.454	70 56.373	sml survey area, shoreward of GP1--1		2
quickpoint, not stored	42 19.387	70 56.316	sml survey area, seaward of GP1--1		3
quickpoint, not stored	42 19.496	70 56.287	sml survey area, center shallow		4
quickpoint, not stored	42 19.449	70 56.247	mid point		5
quickpoint, not stored	42 19.396	70 56.219	sml survey area, mid point deep		6
quickpoint, not stored	42 19.431	70 56.124	sml survey area, off GP2 deep		7
quickpoint, not stored	42 19.5313	70 56.136	sml survey area, shoreward of gp1--2		9

TRANSECT/VIDEO DESCRIPTIONS

Video File	Description
GP V1	sandy with some gravel and hash 27'
GP V2	perpendicular betweeen jetty and pier, shoreward of GP1--1. 9' deep. Sandy deeper, changes to thick cobble around 8' deep
GP V3	perpendicular, seaward of GP1--1. Sandy bottom at 35', patches of fil. Red. Algae throughout
GP V4	perpendicular to center, shallow at 7'. Sandy/rocky with dense algae coverage
GP V5	Midpoint between GP1and2. soft sand, featureless with minimal algae at 28' deep. Some bottom
GP V6	perpendicular to center, sandy @ 36', some current
GP V7	perpendicular to gp1--2, seaward 39' sandy
GP V8	at GP1--2 end, Soft sand, featureless 21' deep
GP V9	Perpendicular landward of GP1--2, sandy w/SAND WAVES at 6.2'. Clumps of green algae

LANDSIDE OBSERVATIONS

erosion	armoring crumbling on north end of island (not reef area), erosion behind armoring. No armoring at reef location, just very low profile beach
public infrastructure	public pier, channel marker, existing jetty at either end of reef footprint
existing armoring	granite wall around most of island, crumbling in spots
other	very close to existing jetty

UNDERWATER OBSERVATIONS

bottom type	sandy with some gravel. Sand waves in shallows
eelgrass presence	none seen
obstructions	none seen

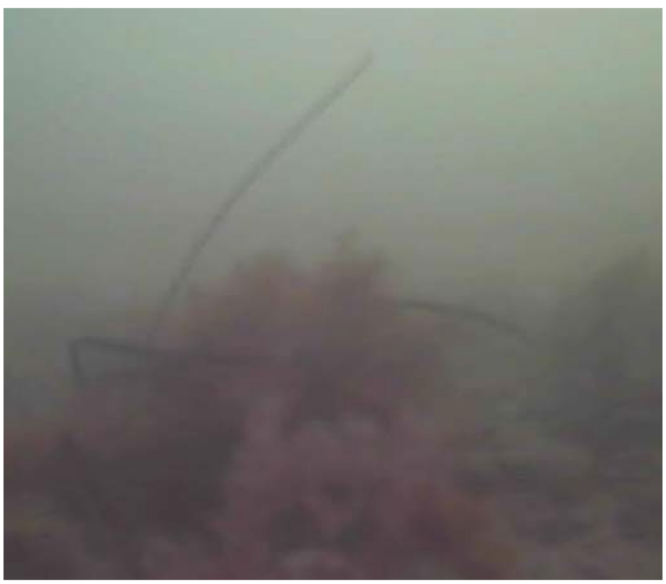
biota	chondrus, fil. Brown, fil. Red
fixed gear	none seen
other	deeper site, 20-30'
Next Steps	
• Good potential for material reuse and eelgrass • check eelgrass notes - DMF has investigated this site in the past (possibly eliminated it due to sand waves or ferry route?)	

Long Island

Recently the city deconstructed the Long Island Bridge, connecting Long Island to Quincy, MA. Piers still remain. Utility cables are being installed or have been installed near proposed site. The shoreline consists of a steep slope of sand/dirt with placed granite boulders along the bottom. The bottom along the proposed site is a mix of small cobble and shell hash covered by algae. Areas surrounding the site consisted of sandy, featureless bottom with no silt, especially in the channel. Dense areas of algae (*Laminaria, Ulva, Chondrus, Ascophilium,* unidentified red filamentous algae) dominated the shallows.

Complex subtidal habitat was a factor in ranking this site lower relative to other sites in the BH Islands group.

Long Island Shoreline. Sandy/cobble intertidal lined with riprap to support eroding slope



Long Island Reef Deployment Bottom Type. Complex substrate along bottom with mix of shell hash, cobble covered by algae. Also noted some eelgrass.

Long Island Reef Deployment Location.

Long Island Site Assessment Data Sheet.

Site:	**LONG ISLAND**
Date:	2/2/2016
Tide:	Hull Low Tide 12:09 (+1.4)
Crew:	Ostrikis, Carr, Rousseau
Activity:	Boat survey, drop camera
Gear:	r/v Alosa, snakemate drop camera
Time on Site:	12:17 - 13:06 pm

TRANSECT COORDINATES

wpt	**start lat**	**start lon**	**stop lat**	**stop lon**	**video files**
LI1--1 to LI1--2	42 18.853	70 58.597	42 18.702	70 58.731	1,2
quickpoint, not stored	42 18.699	70 58.832			3
quickpoint, not stored	42 18.729	70 58.642			4
quickpoint, not stored	42 18.744	70 58.527			5
quickpoint, not stored	42 18.816	70 58.676			6
quickpoint, not stored	42 18.896	70 58.651			7
quickpoint, not stored	42 18.803	70 58.437			8,9

TRANSECT/VIDEO DESCRIPTIONS

Video File	**Description**	note: date/time stamp reset, incorrect.
No video	LI--1 end: featureless sandy bottom, no silt. Very little algae.	
LI V1	mid point between LI1 and LI2; sandy with pebbles and shell hash; abundant and diverse	
LI V2	LI--2 end; shallower; harder bottom and very dense algae coverage	
LI V3	perpendicular to reef, deep end toward channel. Featureless soft sandy bottom at 14'.	
LI V4	perpendicular to reef, shallow end toward beach. Sandy, pebbly shell hash bottom at 5'. Very dense algae, mult spp.	
LI V5	perpendicular to reef, mid-point shallow. Sandy bottom, much less algae	
LI V6	perpendicular to reef, mid-point deep. 15.3', in channel. Featureless and sandy	
LI V7	perpendicular to reef, end point (LI1)deep. 15.5', in channel. Featureless and sandy	
LI V8,9	perpendicular to reef, shoreware of LI1. Sandy bottom at 3.8', occasional shell hash. Not	

LANDSIDE OBSERVATIONS

erosion	Massive eroded cliff on land near bridge. Beach is sandy with cobble higher in the intertidal. Some large boulders in intertidal
public infrastructure	old bridge footings, underwater utilities. Farther from reef area is above ground utilities and buildings
existing armoring	small area of rip rap only around old bridge footings

UNDERWATER OBSERVATIONS

bottom type	sandy bottom, shell hash, numerous anchored algae spp.
eelgrass presence	none seen in transect but suitable conditions and difficult to ID some vegetation w/drop
obstructions	none seen in transect, but large emergent boulders nearby
biota	laminaria, ulva, chondrus, ascophilium?, fil. Red, aleria (red blade?)
fixed gear	none seen
other	depth range along transect 13.6' - 10.6' - 7'

NEXT STEPS
• Dive work is needed to better characterized the site • potential site for material reuse, but eelgrass suitability questionable…good bottom but extremely dense algae in the shallows. • Look into Li bridge removal videos to get a feel for summer conditions and algae community

Georges Island

The shoreline consists of a granite seawall with extreme deterioration along sections and erosion behind the seawall. Bottom along the proposed site is sandy covered by gravel and pebbles and contained mixed cobble sizes. Dense algae (*Laminaria, Ulva, Chondrus, Ascophilium,* unidentified red filamentous algae) was present throughout. The island appeared to be eroding offshore towards proposed reef site. There was a well defined sloped edge leading into channel. The dredged channel contains sandy bottom with some gravel. Some shell hash sections were located shoreward of site. Bottom seaward of site was sandier with less large cobble/algae.

Complex subtidal habitat, proximity to navigation channel and highest exposure to the east were factors in ranking this site <u>lower</u> relative to other sites in the BH Islands group and overall.

Georges Island Shoreline. Granite Seawall with extreme deterioration in sections with erosion behind seawall as well.

Georges Island Reef Deployment Bottom Type. Complex hard substrate along bottom covered by algae.

George's Island Reef Deployment Location.

George’s Island Site Assessment Data Sheet.

Site:	**GEORGES ISLAND**
Date:	2/2/2016
Tide:	Hull Low Tide 12:09 (+1.4)
Crew:	Ostrikis, Carr, Rousseau
Activity:	Boat survey, drop camera
Gear:	r/v Alosa, snakemate drop camera
Time on Site:	14:30 - 15:15

TRANSECT COORDINATES

wpt	**start lat**	**start lon**	**stop lat**	**stop lon**	**video files**
GG1--1 to GG1--2	42 19.209	70 55.248	42 19.045	70 55.350	1,2,5
quickpoint, not stored	42 19.132	70 55.299	sml survey area		2
quickpoint, not stored	42 19.152	70 55.295	sml survey area		3
quickpoint, not stored	42 19.092	70 55.322	sml survey area		4
quickpoint, not stored	42 19.064	70 55.451	sml survey area		6
quickpoint, not stored	42 19.035	70 55.201	sml survey area		7
quickpoint, not stored	42 19.103	70 55.242	sml survey area		8
quickpoint, not stored	42 19.132	70 55.404	sml survey area		9
quickpoint, not stored	42 19.238	70 55.407	sml survey area		10
quickpoint, not stored	42 19.203	70 55.179	sml survey area		11

TRANSECT/VIDEO DESCRIPTIONS

Video File	Description
GG V1	between GG1-1andGG1-2, closer to 1. Gravelly with pebbles and abundant algae spp
GG V2	midpoint between GG1-1and GG1-2, 16'. Gravelly with low relief cobble
GG V3	between GG1--1 and midpoint. Gravelly, a lot of laminaria. 15'
GG V4	between midpoint and gg1-2, 14'. Gravelly with variable sized cobble, red and brown algae
GG V5	GG1-2: 18' gravelly with dense kelp
GG V6	perpendicular, shoreward of GG1-2. larger cobble 8' and dense algae
GG V7	perpendicular, seaward of GG1-2, 25'. Gravelly sand and patches of algae
GG V8	perpendicular to mid point, seaward. 20' deep, gravelly sand
GG V9	perpendicular to mid point, shoreward. Gravelly with dense laminaria and fil. Red, 7' deep.
GG V10	perpendicular, shoreward of GG1-1. Gravelly shell hash, dense laminaria and fil red. 8'
GG V11	perpendicular, seaward of GG1-1. 34' soft sand, featureless. In dredged channel

LANDSIDE OBSERVATIONS

erosion	granite wall in front of fort is crumbling extensively in several places, erosion behind
public infrastructure	historic structures/fort
existing armoring	high granite seawall and rip rap

UNDERWATER OBSERVATIONS

bottom type	gravelly with variable sized pebbles and cobble
eelgrass presence	none seen
obstructions	none seen, but variable sounder images - maybe bigger rocks not seen in video

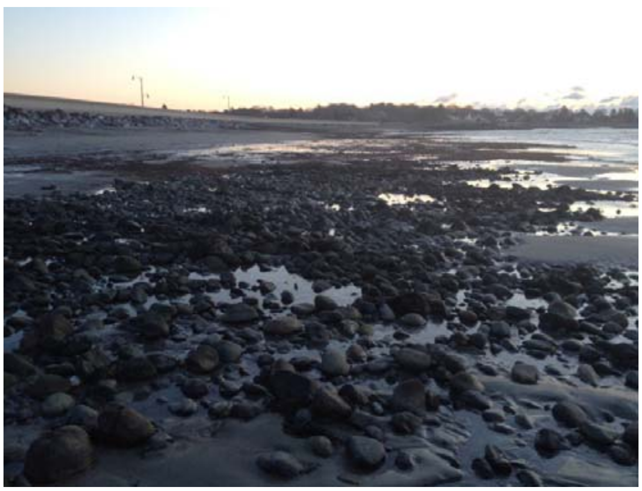
biota	very dense beds of laminaria, fil. Red and greens, red blade
fixed gear	none seen
other	depth along transect 11' - 18' but GG1-1 is right along deep channel, 30'
	channel is dredged, may not want to install a reef structure on the bank. May collapse in.

Marblehead – Devereux Beach

The beach at this site contained a mix of hard packed sand, granule, pebble, and cobble. There is a 75' wide cobble berm along the west end. We noted a large amount of cobble with dead algae along the east end of the beach. Species present included *Fucus, Laminaria*, Sea Collander, and *Ulva*. Even further east along a large rock outcrop, we noted eelgrass shoots that had washed up along the shore. We are interested in the source of this eelgrass. Although the site is mapped blue mussel and surf clam habitat, we found no blue mussel shells but surf clam shells were present. During low tide waves could be seen breaking over a small offshore rock outcrop.

During our boat survey visit we assessed the subtidal area at and around the location proposed for a structure. The site was noticeably shallow so we ran some deep transects as well. The entire site was uniformly sandy with small sand waves throughout. Seaward of proposed site along 20' depth, bottom is similar sandy bottom but covered with sand dollars and less noticeable sand waves. We identified this site as being potentially suitable for eelgrass restoration. At low tide the site is between 3' and 15' depth. East of the proposed site we noted a mix of sandy bottom with cobble and large amounts of algae, similar to what we found along the beach. Shoreward of site contained more drift algae.

This site ranked high among the smaller proposed sized reef sites. Uniform subtidal substrate, location of proposed structure relative to beach erosion and threats to and importance of public infrastructure at this location were factors ranking this site high relative to other sites in the Outer Coastal group and overall.



Marblehead Devereux Beach Shoreline. Top left picture shows transition between sandy intertidal to pebble beach. Top right picture shows cobble along the east end of the beach. Bottom picture shows exposed beach pavilion where seawall ends that would benefit from more shoreline protection.

Marblehead Devereux Beach Reef Deployment Bottom Type. Entire site is uniformly sandy with small sand waves.

Marblehead Devereux Beach Reef Deployment Location.

Marblehead Devereux Site Assessment Data Sheet

Site:	**Marblehead off Devereaux Beach**
Date:	3/3/2016
Tide:	12:17 low
Crew:	MR KO JC SV
Activity:	site assessment, drop camera and humminbird sidescan (dive if necessary)
Gear:	snakemate drop cam, humminbird sidescan
Time on	10:20 - 13:24

TRANSECT COORDINATES

wpt	start lat	start lon	stop lat	stop lon	video files
quickpoint	42 29.419	70 51.058			1,2,3
quick point	42 29.3828	70 51.2717			4
Waypoint	42 29.3939	70 51.2270			5
quick point	42 29.4065	70 51.1937			6
quick point	42 29.4287	70 51.1143			7
quick point	42 29.40	70 51.7933			8
quick point	42 29.3672	70 51.2647			9
quick point	42 29.3015	70 51.2228			10
quickpoint	42 29.2444	70 51.2068			11
quickpoint	42 29.2331	70 51.1413			12
quickpoint	42 29.3189	70 51.1685			13
quickpoint	42 29.3749	70 51.2098			14
quickpoint	42 29.4153	70 51.2332			15
quickpoint	42 29.4184	70 51.2036			16
quickpoint	42 29.2487	70 51.0943			17

TRANSECT/VIDEO DESCRIPTIONS

Video File	**Description**
v1,2,3	dark area seen in aerials southeast of causeway. Cobble bottom with dense codium, ulva, laminaria, red fil, drift. Needs more survey for eelgrass presence bc shoots were seen in beach
no video	across the middle, horizontally bottom: mini sand waves, small amount of drift algae *transect 1: west to east along mid point between 10:40 and 10:50
v4	western edge, middle; bare sand and mini sand waves 10:40
v5	mid mid line; bare sand and mini sand waves 10:42; 8' depth
v6	east edge mid line; bare sand and mini sand waves, some drift fil red algae; 10:45; 8'
v7	east of mid line (outside box); algae covered cobble and sand bottom; 10:49 4.5'
** final drop east of reef site - dark spot on aerial - hard bottom and dense codium and ulva fil red algae mixed with some sand bottom	
v8	western edge, shallow; bare sand and mini sand waves; 10:58; 4.5' transect 2: west edge, shallow to deep.
v9	western edge, deep; bare sand and mini sand waves; 11:00; 10'
v10	western edge deeper, outside of square bare sand mini sand waves, (poss sand dollars??) red fil;

v11	western edge deepest, south of plot; bare sand mini sand waves; 11:07; 20'
v12	center line, deepest; bare sand mini sand waves (poss sand dollars); 11:10; 21' transect 3: mid section, deep to shallow. Between 11:10-
v13	center line, deeper, still outside site; bare sand mini sand waves; 11:14; 15'
v14	center line deep edge of plot – same; 11:17; 10'
v15	center line, shallow edge; more drift algae, small pieces, sandy bottom still; 11:19; 5'
v16	east edge shallow; bare sand mini sand waves; 11:21; 5' transect 4: east edge, shallow to deep. Between 11:21-11:29
*not recording anymore, all uniform bottom. Shallow to deep along east edge: bare sand mini sand waves small amount of algae,	
v17	east edge deepest site; bare sand but no sand waves, sand dollars; 11:27; 20'
LANDSIDE OBSERVATIONS	
beach gradient from sand to cobble going south along beach. 90% of shingles blown off of pavilion	
public infrastructure	beach pavilion, evacuation route, playground, beach
rip rap and seawall along causeway, naturally occurring (?) rocks to S along houses	
UNDERWATER OBSERVATIONS	
featureless, uniform sandy bottom with small sand waves and occasional attached algae. No rocks or cobble anywhere.	
none in footprint, shallower or deeper. Also checked dark area south of causeway, cobble with dense algae but no grass.	
none	
no fish, algae listed above	
none, but survey done in winter. May be a lobster or recreational fishing spot in the summer.	
10 sidescan survey transects done w/Humminbird, see files	

Marshfield – Green Harbor

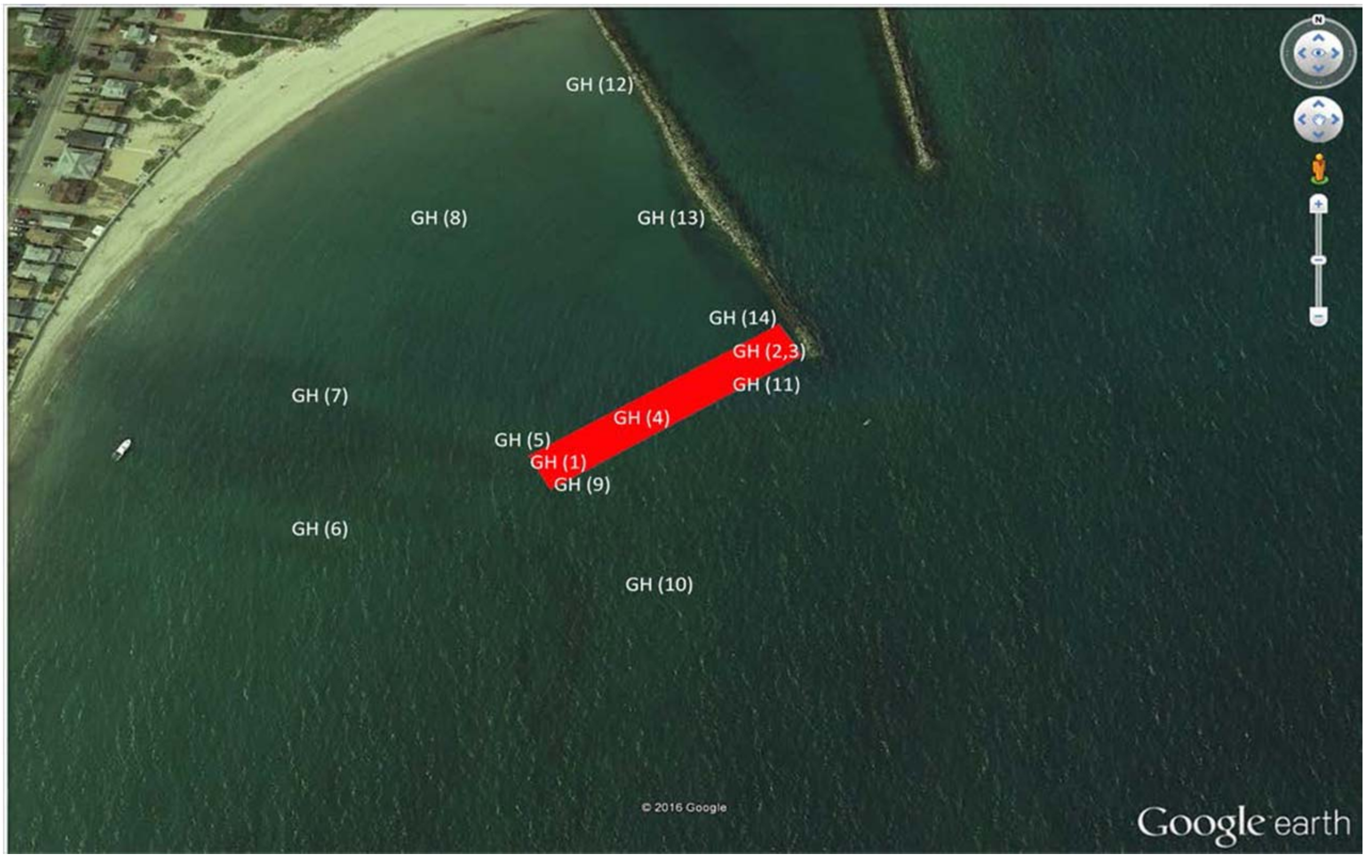
A large seawall was constructed along the shoreward side of this beach. The seawall has some sections of major wear. The majority of seawall has no beach at high tide. The beach along this site consisted of a gradual hard packed sand slope with a section of medium sized cobble covered in green algae and *fucus* along intertidal of the northern end/ south jetty. We noted random subtidal cobble patches. We noted that this site appeared to potentially be suitable for eelgrass. Subtidally, the site contained a mix of sand with visible sand waves and included areas covered with small to medium cobble with red, green and brown algae present. Sand waves here were larger than those observed at the Marblehead site. Blue mussels were seen along the west edge of the proposed reef site. This site appears to be a good candidate site to target for protection. It was noted that this site may have been used as a dredge disposal area for the Green Harbor Inlet and the spoils may be covering cobble bottom, but this was not confirmed.

Eelgrass potential elevated rank. Subtidal cobble patches and possible dredge spoil deposit area over cobble (not confirmed) were factors in ranking this site lower than the Marblehead location.

Ariel photo shows large plume leaving Green Harbor Inlet.

Top photo shows Marshfield Green Harbor Beach. Bottom photo shows cobble patch with mix of algae along beach.

Marshfield Green Harbor Reef Deployment Bottom Type. Note sandy bottom with mix of sand waves and cobble with algae.



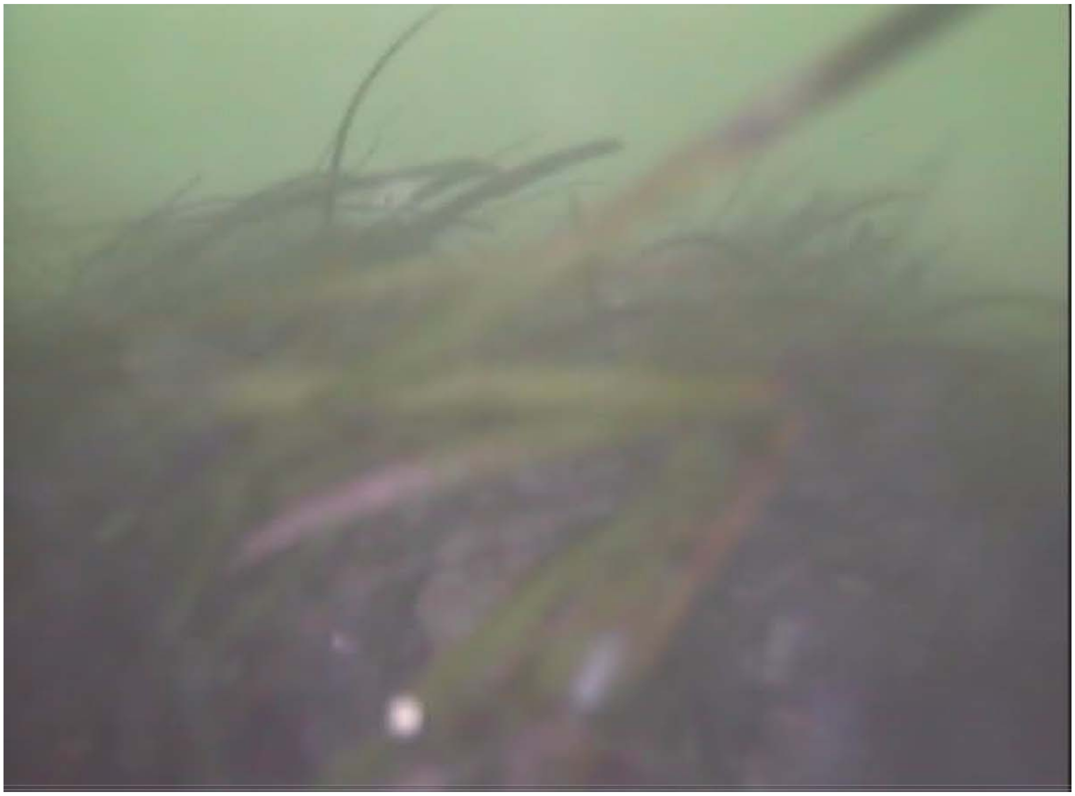
Marshfield Green Harbor Reef Deployment Location.

Scituate – Bar Rock

This site contained a large seawall and other offshore island/reef structures including Smith Rocks and Sunken Ledge. Subtidally, this site is primarily hard bottom that consists of mixed sized cobble. We noted the presence of blue mussels and dense algae including *laminaria, chondrus, ascophyllum*, and other species. Just south of the proposed site we noted sandy areas with sand waves. During a camera transect survey approximately 100' shoreward of the proposed structure we photographed eelgrass. Eelgrass presence was verified using divers and the bed extent was mapped. This area has not been previously mapped as eelgrass habitat.

Eelgrass presence near proposed structure, complex subtidal habitat and easterly exposure were factors ranking this site lower relative to other sites in the Outer Coastal group and overall.

Scituate Bar Rock Shoreline. Note person in front of seawall for reference of size of seawall. Sandy beach in front of riprap and high seawall.



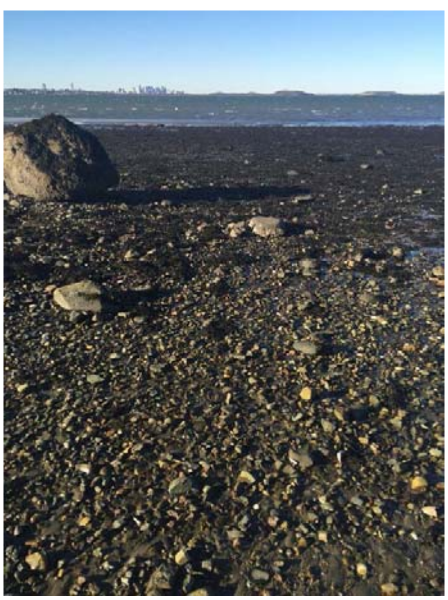
Scituate Bar Rock Reef Deployment Bottom Type. Dense eelgrass patches found nearby.

Scituate Bar Rock Reef Deployment Location.

Quincy - Sea Street

This site consisted primarily of sandy intertidal habitat with a few small cobble/gravel outcrops. A seawall behind riprap and several jetties separates the beach from Sea Street, which is lined with private residences. Red drift algae and *fucus* covered some areas of the intertidal. There was a very gradual slope and the subtidal area appears to be very shallow. There was a substantial amount of exposed intertidal flat at low tide.

DMF was unable to assess further with video or hummingbird. Uniform substrate and public Infrastructure protection potential were factors ranking this site higher than the Fort Point Road Site. Depth and importance of area as an active commercial shellfish location were factors ranking this site lower overall.



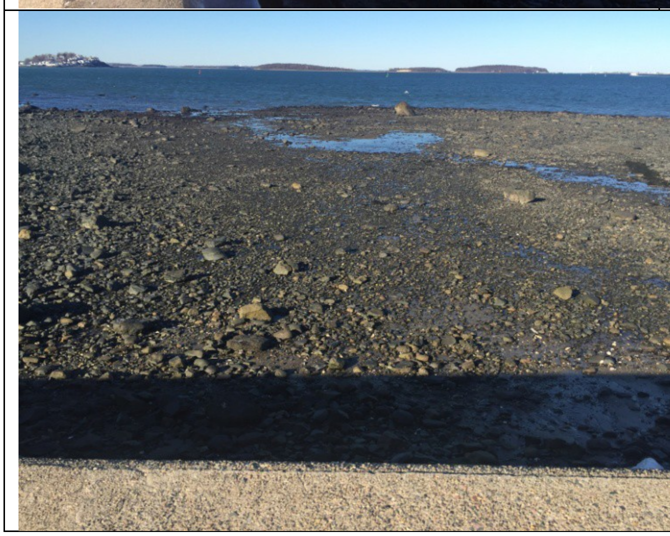
Quincy Sea Street Shoreline. Note seawall and rocky intertidal covered with algae. Sandier bottom further offshore.

Quincy Sea Street Reef Deployment Location. Did not return to assess with drop camera.

Weymouth – Fort point Road

We noted the shoreline consisted of rocky intertidal with a mix of small cobble/gravel. The site has more cobble/gravel cover than Sea Street in Quincy. A seawall is situated behind a slopped riprap wall that protects Ft. Pt. Road and private residence. A small patch of salt marsh is also present within the intertidal. The proposed reef site would be located next to the channel.

DMF did not assess with video or hummingbird. Complex subtidal substrate, depth and proximity to navigation channel were factors ranking this site low relative to the Sea Street Inner Boston Harbor site and overall.



Weymouth Fort Point Road Shoreline. Note seawall and rocky intertidal. Small patch of salt marsh can be seen in top left picture.

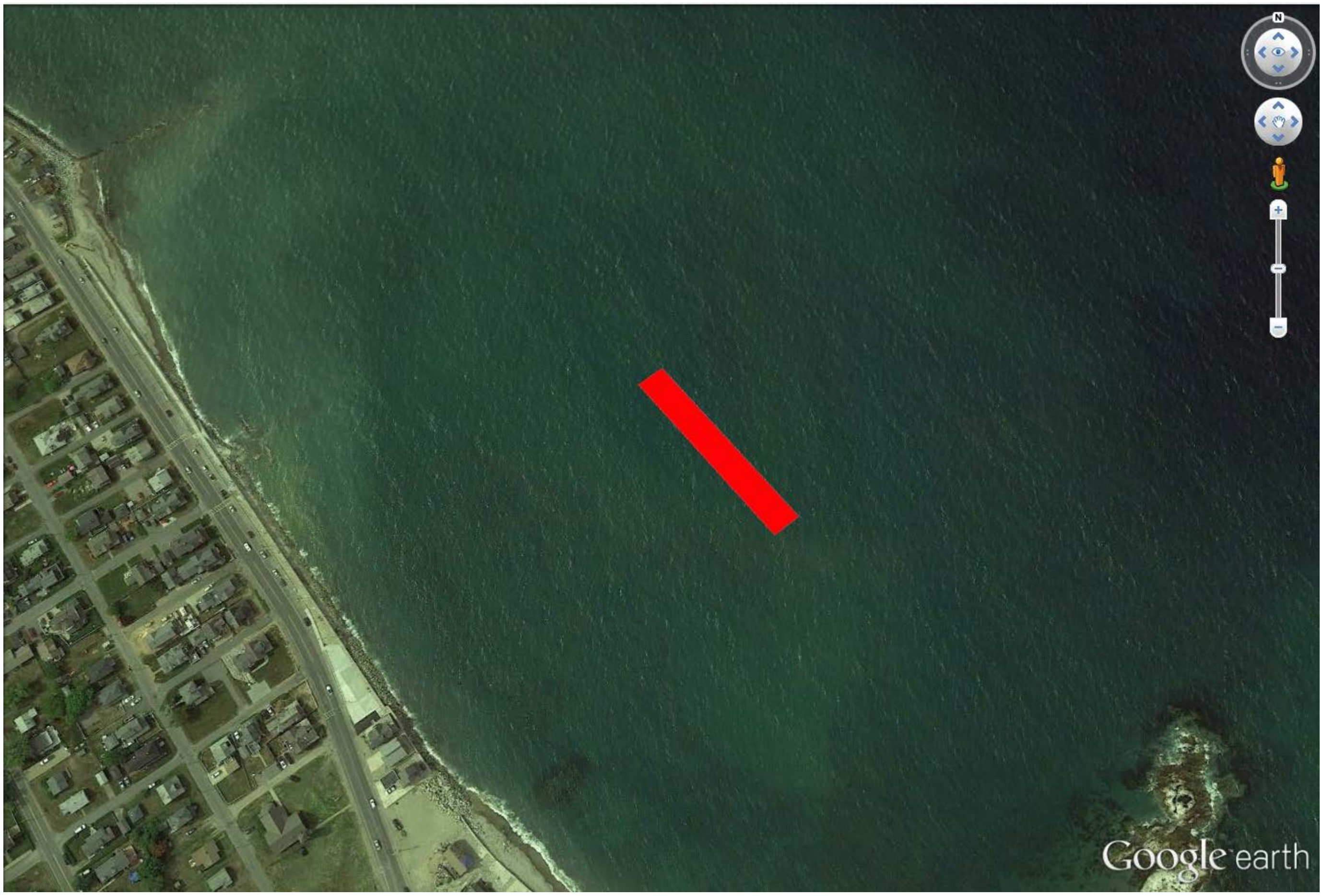
Weymouth Fort Point Road Reef Deployment Location. Did not return to assess with drop camera.

Marshfield – Brant Rock

This site did not appear to be suitable for additional shoreline protection. The site already has a large seawall and multiple manmade rock jetties. An existing 20' seawall provides protection for Ocean St./ Route 139 and a line of private properties. Various size cobble (softball to basketball) makes up most of the shoreline here, with no sand patches below the mean low water line. This site does not appear suitable for eelgrass.

Complex subtidal and intertidal habitat, poor eelgrass potential and easterly exposure were factors ranking this site <u>low</u> relative to other sites in the Outer Coastal group and overall.

Marshfield Brant Rock Shoreline. Note large seawall and rocky intertidal.



Marshfield Brant Rock Reef Deployment Location. Did not return to assess with drop camera.