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Natural Resource Stewardship and Science

Inventory of Intertidal Habitats: *Boston Harbor Islands, a national park area*

Richard Bell, Mark Chandler, Robert Buchsbaum, and Charles Roman

Technical Report NPS/NERBOST/NRTR-2004/1

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INTRODUCTION AND PROJECT OBJECTIVES

Boston Harbor Islands (BOHA) national park area, encompasses about 60 km of shoreline on over 30 islands. The intertidal zone, or the area between the reaches of high tide and low tide, includes a diversity of habitats such as bedrock outcrops, tide pools, rock, cobble and gravel beaches, small sandy barrier beaches, mud and sand flats, salt marshes, and others. Given a 3-m or more tidal range, these intertidal habitats can be quite extensive. The richness of macroalgae, vascular plants, invertebrates, fishes, birds and mammals associated with and dependent on these important intertidal habitats of New England is well-documented in the literature (e.g., Lubchenco and Menge 1978, Nixon 1982, Teal 1986, Whitlatch 1982, Bertness 1999, Roman et al. 2000).

A series of natural resource inventories are currently being conducted throughout the Boston Harbor Islands, including terrestrial, marine and estuarine ecosystems. The resource inventories will greatly enhance our appreciation for the habitats and species that occur within the Boston Harbor Islands landscape. These resource inventories will begin to provide a scientific foundation for natural resource management decisions, will assist in the design of long-term monitoring programs, and will help identify areas requiring additional inventory. Moreover, the natural resource inventories will be used to identify research needs focused on enhancing our understanding of relationships between the structure and function of ecosystems and the natural and human-induced processes that influence ecosystem change.

The Boston Harbor Islands intertidal natural resources inventory was designed with the following objectives;

<u>GIS-based Habitat Maps</u>

- Develop an intertidal zone classification scheme, specific to the Boston Harbor Islands, but capable of more wide scale applications, particularly in the Northeast. Development of this scheme was required before habitat mapping could begin.
- Provide detailed intertidal zone habitat maps for 20 islands
- Provide summary statistics on the aerial extent of discrete habitats for each of the 20 islands

The habitat maps were made from field-based delineation of habitat boundaries using a Global Positioning System, and thus, the maps provide considerable detail. In another Boston Harbor Islands inventory project, investigators are mapping wetlands, which includes intertidal resources, based on the US Fish and Wildlife Service's National Wetlands Inventory (NWI) classification scheme (Cowardin et al. 1977). Because the NWI maps are being developed from interpretation of aerial photography, they will not provide the level of detail found in the field-based mapping of the 20 islands. The field-based habitat maps are being used by the NWI photo interpreters for ground-truth verification.

<u>Species lists</u>

- Compile species lists for major taxonomic groups based on literature review and field surveys.

No published lists of species specific to the intertidal zone of Boston Harbor Islands exist. Lists from the nearby Northeastern University Marine Science Center (Nahant, MA) and Shoals Marine Laboratory (Isle of Shoals, NH) are comprehensive (based on decades of field research and surveys) and provide a guide to species that may likely occur within the Boston Harbor Islands. The purpose of this project was not to develop a comprehensive (i.e., all inclusive) species list for the Boston Harbor Islands intertidal zone and its associated habitat types, but rather, to begin the process of compiling a comprehensive list. As additional inventories are completed, monitoring initiated, and research conducted, the species list will expand. From field surveys conducted in this study, the attached and epibenthic fauna (e.g., echinoderms, gastropods, bivalves, crustaceans, and anthrozoans) was more completely covered than both benthic fauna (e.g., annelids) and vertebrates. Another research team conducted avian surveys and fish were not intensively sampled during this project. Angiosperms and macroalgae within the intertidal zone were well covered in this survey, but again, not comprehensive.

Natural Resource Management Issues

- Identify and discuss issues that may be of interest and under the control of managers charged with protecting intertidal resources

Based on our one year of surveying the intertidal habitats and our experience in similar coastal ecosystems, a discussion of management concerns will be initiated, including topics such as invasive and non-native species, rare species and habitats, identification of habitats that are particularly sensitive to human use and impacts, and other issues.

Long-term Monitoring and Research Needs

- Identify questions that could serve as the foundation of a long-term monitoring program
- Recommend additional resource inventories that would enhance our understanding of intertidal ecosystems
- Identify management-oriented research needs

Details of a long-term monitoring program or design of research projects will not be presented in this report, but based on the initial inventory findings and discussion of management concerns this report will begin to identify some monitoring, inventory and research needs that will support resource management decision-making.

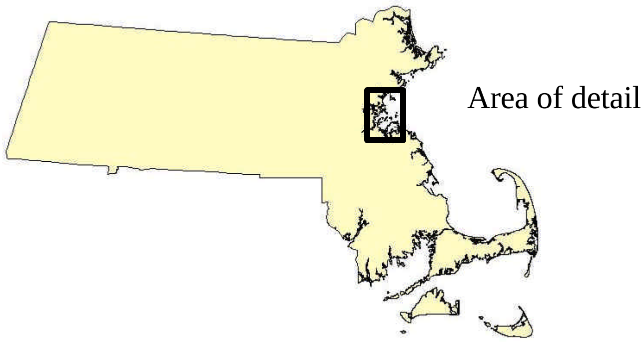
THE STUDY SITE – THE REGIONAL SETTING

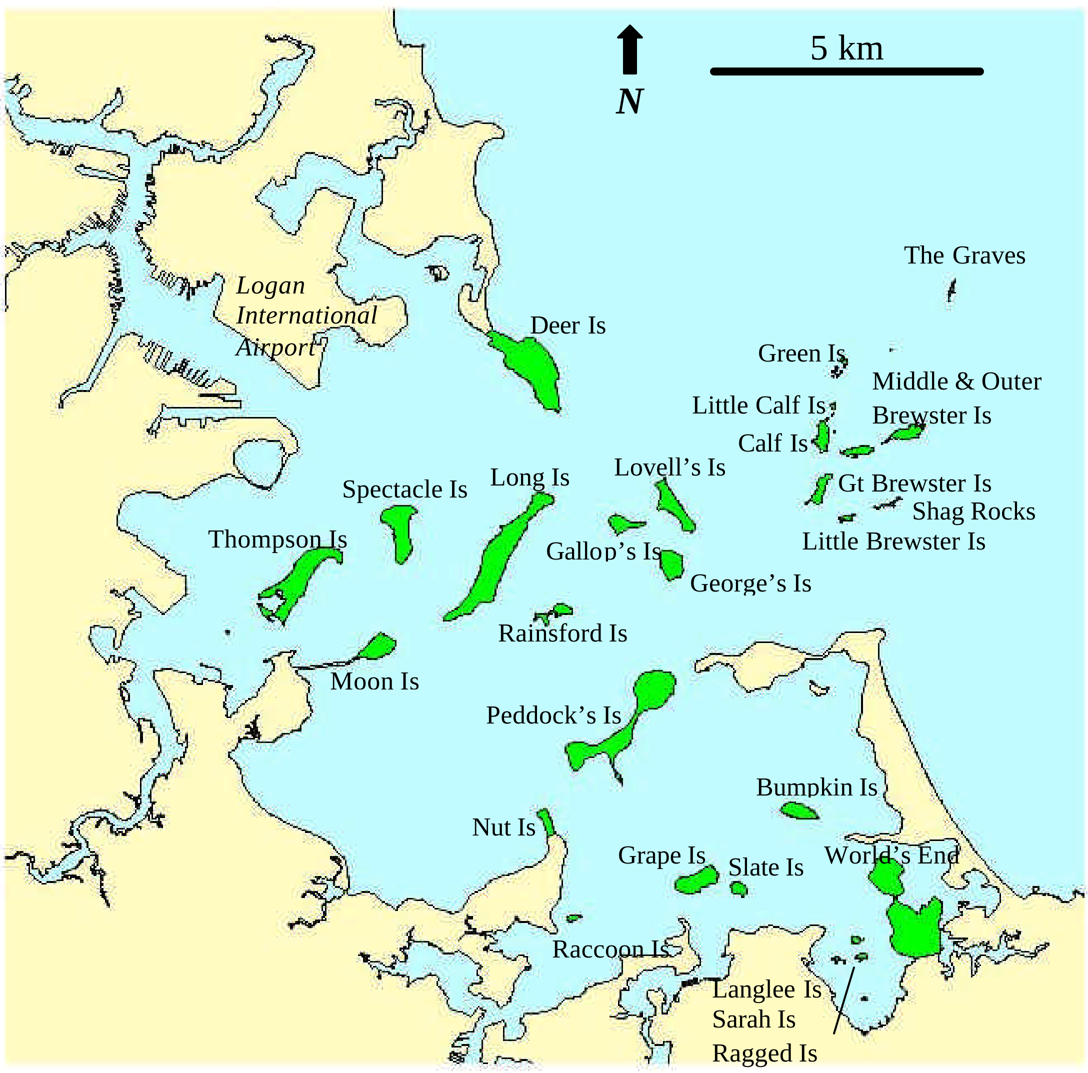
Over 30 islands within Boston Harbor make up the Boston Harbor Islands national park area. The islands contain about 650 hectares of land and are contained within an area of land and water of about 130 km^2. As part of Massachusetts Bay, the islands extend eastward (seaward) up to 18 km from downtown Boston (Fig. 1). Mean tidal range at the NOAA-Boston tide gage is 2.9 m.

There is a gradient of wave activity and exposure as one travels from the islands within the Inner Harbor near Boston proper to those of the outer harbor. The islands of the Inner Harbor are more protected and exposed to lower wave energy. Geologically, many of the islands are drumlins, i.e., glacier-formed, elongate mounds ("whaleback" hills) of unconsolidated till. After the glaciers melted, there has been considerable re-working of shorelines on drumlin islands due to rising sea level and wave action (Rosen and Leach 1987). Eroding cliffs, spits, and beaches contribute to a dynamic shoreline. Some of the Boston Harbor islands are composed of bedrock, and thus, are geomorphologically more stable.

For this study, 20 of the 34 Boston Harbor Islands within the National Park were selected for intensive intertidal habitat mapping. In selecting the study islands, we attempted to represent the diversity of geomorphologic conditions that exist. Islands with unconsolidated sediment and associated with less wave exposure include World's End, Slate, Thompson, Long, Grape, Spectacle, Rainsford, Georges, Lovell, and Peddocks islands. Exposed bedrock islands are Outer Brewster, Little Brewster, and Calf islands while Langlee is a protected bedrock island within Hingham Harbor. Great Brewster is unique in that it is in the outer harbor thus more exposed to wave action, but is comprised largely of unconsolidated sediment.

Fig. 1. Map of the Boston Harbor Islands





THE BOSTON HARBOR ISLANDS INTERTIDAL CLASSIFICATION SYSTEM

Introduction to Community Classification Systems

Understanding species distributions, abundances and interactions and the biogeochemical processes that structure communities are essential precursors to environmental management. Each element brings unique information to the understanding of a landscape, and each element brings inherent difficulties in either assessing its state, or in how the information can be used to make decisions.

Appreciating the spatial and temporal distribution of individual species is one if not the most important criterion to understanding the character and quality of a habitat. However, it would be impractical to fully assess the diversity of most ecosystems. Few taxonomists exist that can readily identify the full spectrum of taxa present, and the sampling effort required to capture the spatial and temporal variability of species is large.

Instead, the management unit that most landscape-based conservation efforts have focused on is the identification and conservation of specific communities. Communities are typically defined to be unique assemblages of organisms present within particular physical parameters that interact with one another in some predictable way. The concept of communities can be applied at multiple scales, from the intestinal parasite community of a particular host species to the community of organisms living in broad regional ecosystems such as the Atlantic coastal waters. This multi-scalar aspect of communities is beneficial in that it allows for the use of a nested hierarchical classification system. The Nature Conservancy has developed such a classification system for vegetation communities where the largest scale units (classes) represent growth form or broad structure of the vegetation (e.g., woodland). The smallest units (associations) in this system represent communities defined by specific dominant species and/or other diagnostic species (e.g., *Populus deltoides* –(*Salix amygdaloides*)/*Salix exigua* woodland)(Anderson et al. 1998; Grossman et al. 1998).

Community classification schemes have been developed by governmental organizations and non-governmental organizations alike as a practical way of understanding and managing moderate-sized ecological units. Examples include those developed by state Natural Heritage programs, the National Wetland Inventory, and The Nature Conservancy's community classification system.

Few standard classification systems exist for some ecosystems including most marine ecosystems. For aquatic ecosystems, including marine environments, one of the most commonly used classification systems is the National Wetland Classification System developed by Cowardin *et al*. (1979), currently in use as the National Wetland Inventory (NWI).

For the intertidal zone, NWI wetland maps provide boundaries and classification of general habitat types delineated from aerial photography. This broad scale classification system is based on substrate and the presence of vegetation, but includes little information about type of vegetation or information about the animals that often play an important role structuring intertidal habitats. Intertidal maps generated from aerial photography interpretation may be further limited because vegetation is delineated at the expense of substrate and the intertidal zone communities are often smaller than is typically mapped by NWI wetland mapping (e.g., minimum mappable unit of 1 acre). Another difficulty is the often-narrow width and elongate spatial layout of the intertidal zone, which makes interpretation of this community from an aerial photograph difficult.

Supplementing the continental perspective generated by the Cowardin *et al.* (1979) system are more regionally focused classification systems. Regional classification systems are intermediate in scale with potential minimum mappable units in the 10 to 100 m^2 range depending on the needs and resources available. The state of Washington created a community classification scheme that was implemented along the entire Washington coast (Dethier et al. 1990). This scheme has subsequently been used as a basis for further classification efforts of Puget Sound (Ritter et al. 1996). The state of Maine has also developed a marine community classification system (Brown 1993), similar to the one developed for Washington.

This project adapted these two regional classification schemes for use in the intertidal zone of Boston Harbor. The approach taken here should result in a classification scheme with widespread applicability, particularly throughout the northeastern US from Long Island Sound to the Gulf of Maine.

Overview of Boston Harbor Intertidal Classification System (BHICS)

Boston Harbor and its islands have had a long and significant history of human alteration. Coast lines have been modified, embayments and estuaries filled in, and many of the shorelines have been built up to prevent coastal erosion. Rip-rap, armature, jetties, piers, groins are all common features in Boston Harbor. The intertidal zone today is the result of interplay between cultural forces and features and subsequent natural processes. To account for the diversity of habitat types found throughout the Boston Harbor Islands, we have modified existing community classification systems into a more open system that can accommodate a full range of possible habitat types.

The Boston Harbor Intertidal Classification System was built upon the original wetland classification system created by Cowardin *et al.* (1979), incorporating features found in the regional schemes of Dethier et al (1990) and Brown (1993). In particular, we have attempted to incorporate important cultural features that are commonly found in this marine system heavily altered by centuries of active human use. The general framework used is that of a nested hierarchy, which will allow for greater flexibility in use (Stein et al. 2000).

The intertidal zone is structured by the intersection of physical factors such as exposure and sediment size, and biological factors such as competition for space and predation. As such, the methods used to classify marine communities have sought to reflect these dominant structuring agents by using them as axes that differentiate communities. Most marine classification systems incorporate information about sediment structure, dominant structuring organisms and exposure. How classification schemes differ is usually related to differences in how they weight these features. Some systems emphasize substrate as the primary feature, whereas others favor either biology or exposure.

At the broadest scale, marine community classification schemes start differentiating by salinity and water depth (Table 1). The two generally recognized *marine* systems are estuarine and marine, which can be further split into intertidal and subtidal (or deep water) subsystems. The BHICS mapped discrete biotic assemblages that covered both marine and estuarine systems. The salinity was not directly measured, but could be inferred based on species composition. This classification system was also restricted to the intertidal.

Table 1. Levels of Standard classification schemes and how BHICS would integrate

Classification level	Basis	Standard Classifications	BHICS
System	Salinity	Marine, estuarine	Inferred from biota
Subsystem	Water depth	Intertidal, subtidal	Restricted to the intertidal
Class	Substrate	Rock, reef, pool, gravel	Rock, reef, pool, gravel
Subclass	Wave Exposure	Exposed, protected	Inferred from biota
Biotic Community	Diagnostic or major space occupying organism	1. Aquatic Bed-Algal, Rooted vascular 2.Rocky intertidal partially exposed	*Spartina alterniflora* salt marsh assemblage, *Ascophyllum nodosum* assemblage

The next level (*class*) of BHICS follows Dethier et al's (1990) system using substrate as the critical feature reducing duplication between class and sub-class levels in the Cowardin *et al.* (1979) system. The common classes include (bed)rock, boulders, cobble, gravel, sand and mud (Dethier et al. 1990; Brown et al. 1993). Substrate definitions are based on a standard classification system of sediment size groups (Wentworth 1922). Sediment types may be combined to form one class substrate classes; for example, pebbles and granules were combined into a "gravel" class (Dethier et al 1990; Brown 1993) Furthermore, some class categories can be defined to contain mixtures of sediment sizes.

The Dethier et al. (1990) and Brown (1993) systems also incorporate information about wave exposure or energy into the "class" level as a further modifier. This was not done in BHICS. Instead, BHICS follows the National Vegetation Classification (TNC) system using the diagnostic or major-space-occupying organism(s) found to identify finer levels of classification. The use of the term alliance was avoided and the term "assemblage" was used instead to reflect the fact that animals are also included as diagnostic or major space occupying organisms

The advantages of this approach are at least two-fold. First, it creates a classification system with similar terminology to that used for other systems by state natural heritage programs, as well as the National Vegetation Classification (TNC) system. Secondly, it is easier to identify the dominant biotic community present rather than estimate the exposure. Measuring fetch along much of the Massachusetts coastline and Boston Harbor in particular is very difficult given the irregular shape and quantity of islands, as well as the vagaries of major storm events. Rather than classify using exposure generated through inference from indicator biota, it is more straight forward to classify using biota and subsequently infer exposure for that site. The drawback to the use of assemblages is that they are more temporary in nature than "exposure" conditions.

Minimum mappable community

For the purposes of this project, we have used 25 m^2 as the threshold minimum size for a community to be mapped. This should provide moderate scale resolution of broad community types, without being so small to be practically difficult to interpret. Moreover, this represents a reasonable size that matches with the resolution of photo interpretation of aerial photographs. This is comparable to the 16 m^2 used by the Puget Sound study, and is roughly equivalent to one pixel of a 1:12,000 aerial photograph. The dGPS was capable of greater accuracy and in a small number of cases assemblages smaller then this threshold were mapped. These assemblages were considered areas of management concern and potentially could be used to measure environmental health, invasive species, boat wake impacts (i.e., *Spartina alterniflora, Phragmites australis, etc*).

Classification Categories

Marine vs. Estuarine Systems

Marine and Estuarine Systems were not separated in the BHICS. Salinity was not directly measured, but could be inferred based on species composition.

Tidal Regimes

Intertidal Subsystem

The Intertidal Subsystem encompasses substrata from extreme low water of the spring tides (ELWS) to the extreme high water of the spring tides (EHWS). It includes all land that is sometimes submerged and sometimes exposed to air. ELWS is used because the desiccation experienced during the frequent tides failing below MLW appears to limit the distribution of many species (Dethier 1990). Thus, this low zone is more intertidal than subtidal.

Subtidal Subsystem

The Subtidal Subsystems includes benthic habitat below ELWS (i.e., any substratum that is continuously submerged). The subtidal was not incorporated into the BHICS since our focus was on the intertidal community.

Substrata

The substrate classes used are taken from Brown (1993) with some modifications for the Boston Harbor Islands intertidal communities (Table 2).

Table 2. A hierarchical classification scheme of the marine intertidal communities from the Boston Harbor Islands based on substrate.

rock
boulder
hardpan
cobble
mixed coarse
gravel
sand
shells
mixed coarse and fine
mud
peat
cultural
reef
seep

Full description of Substrata:

Rock: Bedrock > 3 m diameter, can be various types of consolidated rock. It constitutes a major component of New England's coastline north of Boston Harbor. Rock often has other materials overlying it or is found in conjunction with other types of substrata. Therefore, one can classify an area as rock if it has at least 50% cover of bedrock.

Boulders: Rocks > 256 mm *(*= 10"*)* to 3 m diameter-, i.e., those large enough not to be rolled by moderate wave action. Boulders are also found associated with a variety of types of substrata from bedrock to mud. Any site with at least 75% boulders can be classified as boulder. In addition, a site with at least 50% cover of boulders is classified as boulder if at least 6% bedrock is also present.

Hardpan: A hard impervious layer, composed chiefly of clay, cemented by relatively insoluble materials, does not become plastic when mixed with water. Forms a substratum firm enough to support an epibenthos and too firm to support a normal infauna (e.g., bivalves, worms), but with an unstable surface which sloughs frequently. (Not found in Boston Harbor during this project.)

Cobble: Rocks <256 mm, but >64 mm (=2.51") diameter; unstable. Cobble beaches that are >75% of particles this size. Many will have cobble, but will be mixed coarse, as they are not sufficiently dominated by cobble.

Mixed Coarse: Substrata consisting of rocks, boulders, cobbles, gravel, shell, and sand (no one substratum type exceeding 75% surface cover, less than 50% cover by rocks or boulders).

Further modification of the mixed coarse class can be made based on the proportion of different substrate types present.

Large coarse: Boulders, rocks > 5 %
Mid coarse: > 25 % gravel or cobble
Small coarse: sand > 25 %

Gravel: Small rocks or pebbles 2 to 64 mm diameter. Habitats are deemed to have gravel substratum if 75% or more of the habitat bottom is gravel. This definition combines granules (2 to 4 mm) and pebbles (4 to 64 mm).

Sand: Sediment particles ranging between 0.06-2 mm in diameter. Habitat is classified as sand if 75% or more of the surface cover is sand. This definition combines very coarse sand (1.0 to 2.0 mm), coarse sand (0.5 to 1.0 mm), medium sand (0.25 to 0.5 mm), fine sand (0.125 to 0.25 mm) and very fine sand (0. 0625 to 0. 125 mm).

Shells: Sediment consisting of >75% shells. Typically composed of *Mytilus* and *Mya* shells near reefs or mudflats

Mixed Coarse and fine: Consisting of rocks, boulders, and coarse and fine particles. No one substratum type exceeding 75% surface cover and less than 50% cover by rocks or boulders.

Mud: Fine substrata <0.06 mm, usually mixed with organic matter. If a site has at least 75% surface cover of mud, it is classified as mud. Mud includes both silt (3.9 to 62.5 micrometers) and clay (< 3.9 micrometers).

Peat (Organic in Dethier (1990) and Brown (1993)): Substrata composed primarily of organic matter such as peat, sawdust, wood chips, leaf litter, other detritus. Peat was found with such frequency that it was incorporated as its own substrate

Cultural: Tires, docks, washed up boats, bulkheads, logs, pilings (woods, or metal), oyster culture, and others. A site with at least 75% artificial materials is classified as cultural.

Reefs: (synonymous with Bioherms in Brown (1993)): Carbonate mound-like features, e.g., oyster and mussel bars.

Seep: substrate kept wet through ground-water seep.

Mixed-Fine: Used in Dethier (1990) and Brown (1993), but not in BHICS

Biotic Assemblages

A biotic assemblage is defined as an area with >30% biotic cover. The particular assemblage of a given area is defined by the major space occupying organism, or suite of organisms present where that assemblage makes up at least 75 % cover of the biota. A location with no living biota on at least 30 % of the substrate is classified as "no macrobiota".

This classification system, outlined in Table 3, is based on being able to identify the visible community and is thus most relevant to hard surface intertidal habitats. Soft-bottomed communities (e.g., mudflats) were therefore classified based on their sediment composition rather than any biota found there.

Table 3. A hierarchical classification scheme of the marine intertidal communities from the Boston Harbor Islands based on biotic assemblage

No macrobiota
Black Zone
Green Crust
Transition zone
Semibalanus
Ascophyllum
Fucus
Brown algae
Mixed brown/*Semibalanus*
Other brown algae
Mixed brown/*Semibalanus*/green algae
High intertidal green algae
Green algae
Red encrusting algae
Red foliose algae
Kelp
Mytilus edulis
Mixed zonation assemblage
Mixed C/reef: mixed assemblage
Rock/boul: mixed no zonation assemblage
Mytilus edulis reef
Mixed brown/*Mytilus* reef
Mixed brown/ *Semibalanus/* reef
Mudflat
Spartina alterniflora
Spartina patens
Salicornia
Suaeda
Juncus gerardii
Iva frutescens
Phragmites australis
High marsh
Tide pool
Creek
Other

Full description of assemblages

NO MACROBIOTA

Definition: Biota covers < 30 % of an area; remainder of substrate bare
Commonly seen: in intertidal zones with substrate sizes smaller than boulders, especially the upper intertidal zone. Also common above the high tide line on bedrock in more exposed areas.
Examples: Beaches on Lovell, Peddocks, Rainsford, and Long Island. Bedrock on Little Brewster and Outer Brewster.
Common organisms: The only fauna is usually in-fauna or species associated with the wrack line
Species of management concern: None found

BLACK ZONE ASSEMBLAGE

Definition: Biota covers >30 % of an area with Black Lichen, *Verrucaria sp.*, and blue-green bacteria cover >75% of the total biota
Commonly seen: at the upper lifeline of the intertidal on all hard substrates
Examples: Calf, Langlee, Spectacle, Little Brewster
Diagnostic species: *Verrucaria sp., Calothrix crustacea*
Common Species: *Lichinia* sp., *Lyngbya majuscula, Oscillatoria* sp.
Species of management concern: None found

GREEN CRUST ASSEMBLAGE

Definition: Biota covers >30 % of an area with Green Crust cover >75% of the total biota
Commonly seen: On Mixed coarse beaches below No Macrobiota zone.
Examples: Spit on Great Brewster
Diagnostic species: Pseudendoclonium submarinum and other crusts
Common Species: Gomontia polyhiza, Verrucaria sp., Calothrix crustacea
Species of management concern: None found

TRANSITION ZONE

Definition: The area below the No Macrobiota zone where the biota starts to take hold on mixed coarse beaches. There are no clear assemblages, but simply scattered individuals, crusts and lichen. The upper limit is defined as the point where life first begins to take hold in the upper intertidal. The lower boundary is usually defined by whatever recognizable assemblage occurs below it or if none is present, the subtidal itself.
Commonly seen: on mixed coarse beaches below the No Macrobiota zone
Examples: On most islands with mixed coarse beaches, Long, Peddocks, Thompson
Diagnostic species: Verrucaria sp., Pseudendoclonium submarinum, scattered *Semibalanus,* and *Littorina littorea*

Common Species: *Lichinia* spp., *Calothrix crustacea, Lyngbya majuscula, Oscillatoria* sp., *Prasiola stipata, Gomontia polyhiza, Mytilus edulis* and *Fucus* spp.

Species of management concern: None found

<u>*SEMIBALANUS BALANOIDES* ASSEMBLAGE</u>

Definition: Biota covers >30 % of an area with *Semibalanus* cover >75% of the total biota

Commonly seen: On hard stable substrate varying from cobble and mixed coarse beaches to bedrock in the high intertidal and occasionally very low intertidal

Examples: South east corner of Lovell, north side of Peddocks, north end of Long, and along the spit on Great Brewster

Diagnostic species: *Semibalanus balanoides*

Common species: Littorina littorea, Littorina saxatilis, Nucella lapillus, Blidingia minima, Verrucaria sp, Fucus spp., *Carcinus maenas, Pseudendoclonium submarinum*

Species of management concern: Hemigrapsus sanguineus

<u>ASCOPHYLLUM ASSEMBLAGE</u>

Definition: Biota covers >30 % of an area with *Ascophyllum nodosum* cover >75% of the total biota

Commonly seen: Mid intertidal on semi-sheltered bed rock, boulders, and occasionally on rip-rap or cobble

Examples: southern boulder community of Calf, sheltered areas on eastern side of Outer and Little Brewster and most of Langlee Island

Diagnostic species: Ascophyllum nodosum

Common organisms: Littorina obtusata, Littorina saxatilis, Littorina littorea, Nucella lapillus, Asterias forbesi, Asterias vulgaris, small Mytilus edulis, Alcyonidium sp., *Acanthodoris pilosa, Cancer irroratus, Cancer borealis, Carcinus maenas, Notoacmaea testudinalis, Polysiphonia lanosa, Polysiphonia harveyi, Semibalanus balanoides, Semibalanus balanoides, Nucella lapillus, Metridium senile, Crepidula fornicata, Crepidula plana, Halichondria sp*

Species of management concern: Hemigrapsus sanguineus, Botrylloides violaceous, Membranipora membranacea

<u>*FUCUS* ASSEMBLAGE</u>

Definition: Biota covers >30 % of an area with *Fucus sp.* cover >75% of the total biota

Commonly seen: mid intertidal along anthropogenic boulder fields or rip-rap, and semi-exposed bedrock.

Examples: Rock substrate on Rainsford and rip-rap around George

Diagnostic species: *Fucus sp.*

Common organisms: Carcinus maenas, Cancer irroratus, Cancer borealis, Littorina littorea, Semibalanus balanoides, Nucella lapillus, Notoacmaea testudinalis, Asterias vulgaris, Asterias forbesi, Alcyonidium sp, Ciona intestinalis, Haliclonia, Halichondria sp., Crepidula fornicata, Crepidula plana, Mytilus edulis, Acanthodoris pilosa, Alcyonidium spp., Electra pilosa

Species of management concern: Hemigrapsus sanguineus, Botrylloides violaceous, Membranipora membranacea

BROWN ALGAE ASSEMBLAGE

Definition: Biota covers >30 % of an area with *Ascophyllum nodosum and Fucus sp.* cover >75% of the total biota, but no single species occupies > 75 % of the vegetated cover

Commonly seen: Mid intertidal on boulders, rip-rap and bedrock in medium to low exposure areas often surrounded with cobble and gravel or on slate and shale that breaks off easily.

Examples: Southwest side of Rainsford and the north side of Slate. Both areas were composed of hard substrate that was crumbling. East side on World's End and Grape in areas of boulders and bedrock surrounded by mixed coarse, and the north side of Georges on rip-rap

Diagnostic species: Ascophyllum nodosum and Fucus spp.

Common species: Carcinus maenas, Cancer irroratus, Cancer borealis, Hemigrapsus sanguineus, Littorina obtusata, Littorina saxatilis, Littorina littorea, Nucella lapillus, Semibalanus balanoides, Notoacmaea testudinalis, Asterias vulgaris, Asterias forbesi, Alcyonidium sp, Crepidula fornicata, Crepidula plana, Mytilus edulis, Acanthodoris pilosa, Electra pilosa

Species of management concern: Hemigrapsus sanguineus, Botrylloides violaceous, Membranipora membranacea

MIXED BROWN/ SEMIBALANUS ASSEMBLAGE

Definition: Biota covers >30 % of an area with *Semibalanus* and mixed brown (*Ascophyllum* and/or *Fucus)* cover >75% of the total biota, but no single species occupies > 75 % of the cover

Commonly seen: mid intertidal on large cobble and boulders in mixed coarse areas, as well as on Rip-rap and rock walls.

Examples: Rip-rap on George, Lovell and Spectacle, boulders on Grape, Worlds End, Peddocks, and Calf

Diagnostic species: Ascophyllum nodosum, Fucus spp. *and Semibalanus balanoides*

Common Species: Carcinus maenas, Littorina littorea, Nucella lapillus, Crepidula fornicata, Crepidula plana, Mytilus edulis

Species of management concern: Hemigrapsus sanguineus

OTHER BROWN ALGAE ASSEMBLAGE

Definition: Biota covers >30 % of an area with brown algae (that is not kelp, *Ascophyllum* or *Fucus)* cover >75% of the total biota. There were many different types of brown algae in Boston Harbor, but they were rarely major space occupying organisms. This assemblage represented all of them, but was seldom used. The assemblage "Other Brown Algae" could be broken up into different assemblages in future monitoring efforts.

Commonly seen: In the lower intertidal on exposed rocks; a separate community of brown filamentous grows on mud flats, shallow estuarine creeks, and groundwater seeps.

Examples: Mud on east side of Thompson in the spring, Tide pools on Lovell in the spring

Diagnostic species: *Scytosiphon lomentaria, Petalonia fascia, Ecocarpus sp. Pilayella littoralis*

Common organisms: Pagurus longicarpus, Littorina littorea

Species of management concern: None found

MIXED BROWN/ *SEMIBALANUS* AND GREEN ALGAE MIXED ASSEMBLAGE

Definition: Biota covers >30 % of an area with *Fucus, Ascophyllum, Semibalanus* and green algae (most often *Blidingia)* cover >75% of the total biota, but no single species occupies more than 75 % of the biota

Commonly seen: in the mid to upper intertidal on bedrock, rip-rap, boulders and large cobble.

Examples: Calf, Great Brewster, Spectacle, Rainsford

Diagnostic species: Fucus spp.*, Ascophyllum nodosum, Semibalanus balanoides, Blidingia minima*

Common Species: Enteromorpha sp., Littorina littorea, Ulva lactuca, Ascophyllum nodosum, Carcinus maenas, Nucella lapillus, Crepidula fornicata, Crepidula plana, Mytilus edulis

Species of management concern: None found

HIGH INTERTIDAL GREEN ASSEMBLAGE

Definition: Biota covers >30 % of an area with *Blidingia minima* or a combination of *Blidingia, Enteromorpha intestinalis,* and Black lichen cover >75% of the total biota, but no single species occupies more than 75 % of the biota

Commonly seen: Blidingia often formed carpets on mixed coarse beaches and rip-rap in the high intertidal with scattered individuals of *Porphyra purpurea.* High intertidal on rip-rap and rock walls, as well as on large cobble and boulders in mixed coarse areas

Examples: Rainsford, Lovell, Great Brewster, Long, Calf, most islands

Diagnostic species: Blidingia minima, and Porphyra purpurea

Common Species: Verrucaria sp., Carcinus maenas, Semibalanus balanoides, Littorina littorea, Fucus spp.*, Enteromorpha intestinalis, Prasiola stipitata*

Species of management concern: None found

GREEN ALGAE ASSEMBLAGE

Definition: Biota covers >30 % of an area with Green Algae that is not *Blidingia minima* cover >75% of the total biota. All the other areas of green algae were mapped under the same category though different assemblages were present. This group could be broken up into different assemblages in future monitoring efforts.
Commonly seen: In tide pools, fresh water seeps and in the upper subtidal on mixed coarse substrate.
Examples: Standing water in the north end of Lovell during the summer, Great Brewster
Diagnostic species: Ulva lactuca, Enteromorpha spp., *Monostroma* spp.
Common organisms: Carcinus maenas, Semibalanus balanoides, Scytosiphon lomentaria
Species of management concern: None found

RED ALGAE: ENCRUSTING ASSEMBLAGE

Definition: Biota covers >30 % of an area with red encrusting algae cover >75% of the total biota. Red Encrusting Algae was never mapped as its own discrete assemblage, but was present in the low intertidal of many of the islands.
Commonly seen: In the low intertidal on bedrock, *Mytilus* reef and shells or in tide pools in mixed coarse areas. Also seen in bedrock tide pools at all elevations.
Examples: lower intertidal on Little Brewster on exposed bedrock, tide pools on Lovell, Rainsford, Thompson, and Long
Diagnostic species: *Hilenbrandia rubra, Clathromorphum circumstriptum*
Common organisms: Mytilus edulis, Pagurus longicarpus, Strongylocentrotus droebachiensis, Notoacmaea testudinalis, Littorina littorea, Polysiphonia spp., *Chondrus crispus*
Species of management concern: Polysiphonia harveyii

RED ALGAE: FOLIOSE ASSEMBLAGE

Definition: Biota covers >30 % of an area with Red Foliose Algae cover >75% of the total biota. (In practice this category was used only for *Chondrus and Mastocarpus.)*
Commonly seen: In the lower intertidal on moderately exposed bedrock, boulder and *Mytilus* substrates as well as in low tide pools
Examples: lower intertidal of Little Brewster, Calf, Outer Brewster, Lovell, east side of Rainsford and George
Diagnostic species: *Chondrus crispus, Mastocarpus stellatus*
Common organisms: Stongylocentrotus droebachiensis, Notoacmaea testudinalis, Asterias vulgaris, Asterias forbesi, Electra pilosa
Species of management concern: Hemigrapsus sanguineus, Botrylloides violaceous, Membranipora membranacea, Botryllus schlosseri, Styela clava

KELP ASSEMBLAGE

Definition: Biota covers >30 % of an area with kelp cover >75% of the total biota. Kelp was never mapped as its own discrete assemblage, but was present in the extreme low intertidal of many of the islands. This assemblage was more common in the shallow subtidal.

Commonly seen: In the low intertidal / upper subtidal on bedrock, large boulders and tide pools. Occasionally present in the low intertidal / upper subtidal of *Mytilus* reefs and Larger sized mixed coarse substrates.

Examples: The low intertidal / upper subtidal of Calf, Outer Brewster, Little Brewster and the subtidal along the spit on Great Brewster. Also present at the northern edge of the Reef on Lovell

Diagnostic species: *Laminaria saccharina, Alaria esculenta*

Other potential Diagnostics: *Laminaria digitata*

Common Species: Strongylocentrotus droebachiensis, Notoacmaea testudinalis, Asterias vulgaris, Asterias forbesi, Lacuna vincta, Electra pilosa

Species of management concern: Membranipora membranacea

<u>*MYTILUS EDULIS* ASSEMBLAGE</u>:

Definition: Biota covers >30 % of an area with *Mytilus edulis* cover >75% of the total biota. This assemblage was present, but was never mapped because it failed to meet the 25m^2 minimal mappable area.

Commonly seen on: Bedrock in exposed areas tending to be on non-vertical faces

Examples: Very small areas in the most exposed sites on Outer and Little Brewster

Diagnostic species: Small *Mytilus edulis*

Common organisms: most other organisms are out competed leaving only *Mytilus. Semibalanus balanoides* and occasionally the stunted form of *Chondrus crispus* and *Fucus* spp. can also be found.

Species of management concern: None found

<u>MIXED ASSEMBLAGE</u>

Areas, which we were not able to divide into discrete assemblages, were labeled as Mixed Assemblage. This often occurred because boundaries were not clear, there were many small patches of different assemblages or because of extreme terrain. Mixed Assemblage was separated into two categories with the second category further divided into sub assemblages.

The species composition of these groups was relatively similar, but differences arose in the morphology and organization of the intertidal species. Certain algae and invertebrates showed stunted growth forms in areas of high wave exposure and certain combinations of biotic and abiotic factors resulted in zonation patterns as described in classical intertidal ecology (Bertness 1999).

MIXED ZONATION ASSEMBLAGE

Definition: Biota covers > 30 % of an area, and is organized with clear vertical zonation (i.e., with barnacles, followed by brown algae, followed by red algae) forming distinct vertical striations, typically along rock and boulder faces, but no single taxa covers >75% of the total biota. In most cases this assemblage covered the complete intertidal from the upper black zone to the lowest limit that could be safely attained

Commonly seen on: Semi-exposed (semi) vertical rock wall faces and large boulders.

Examples: north-west rock faces on Little Brewster and Calf, and on the eastern exposed rock faces of Little Brewster and Outer Brewster.

Common organisms: Upper intertidal is dominated by a thin strip of *Semibalanus* barnacles, followed by a strip of *Fucus*, along the mid intertidal, and *Chondrus crispus* dominating the low intertidal. Kelp often found in the low intertidal / upper subtidal. *Littorina saxatilis, Littorina obtusata, Littorina littorea, Ulva lactuca, Ascophyllum nodosum, Fucus* spp.*, Chondrus crispus, Scytosyphion lomentaria, Polysiphonia,* Kelps, *Carcinus maenas, Cancer irroratus, Cancer borealis, Nucella lapillus, Lacuna vincta, Semibalanus balanoides, Notoacmaea testudinalis, Metridium senile, Strongylocentrotus droebachiensis, Asterias vulgaris, Asterias forbesi, Ophiopholis aculeata, Alcyonidium spp, Ciona intestinalis, Haliclonia* spp.*, Halichondria* spp.*, Crepidula fornicata, Crepidula plana, Mytilus edulis, Acanthodoris pilosa, Electra pilosa*

Species of management concern: Hemigrapsus sanguineus, Botrylloides violaceous, Membranipora membranacea, Botryllus schlosseri, Styela clava, Harbor Seal *(Phoca vitulina)*

SUB-ASSEMBLAGES

The following two assemblages have similar species composition, but are considered sub assemblages. The difference between them is an observed difference in the morphology of certain intertidal organisms (i.e., *Mytilus, Chondrus, Fucus, etc.).* Further studies are needed to determine if these morphological differences on the scale of Boston Harbor reflect actual habitat differences. Because these two sub assemblages were highly correlated with their physical setting, substrate was included in the assemblage title.

MIXED COARSE/REEF: MIXED ASSEMBLAGE

Definition: Biota covers > 30 % of an area, but no single taxa covers >75% of the total biota. An area that contains two or more of the assemblages listed above: brown, red, green algae, *Semibalanus, Mytilus*, etc…; with distinct patches (mosaic) but no zonation and no clear boundaries between patches. Typically there is a great variety of algal species.

Commonly seen: In the low intertidal in areas with slopes of less then 15 degrees on mixed coarse or reef substrate. Tide pools are often present.

Examples: North side of Lovell, north and south side of Great Brewster, west side of Thompson

Common organisms: Large *Mytilus edulis, Littorina littorea, Ulva lactuca, Ascophyllum nodosum, Fucus* spp.*, Chondrus crispus, Scytosyphion lomentaria, Polysiphonia sp., Dumontia contorta,* kelps, *Carcinus maenas, Cancer irroratus, Cancer borealis, Nucella lapillus, Lacuna vincta Semibalanus balanoides, Notoacmaea testudinalis, Metridium senile, Strongylocentrotus droebachiensis, Asterias vulgaris, Asterias forbesi, Ophiopholis aculeata, Alcyonidium sp, Ciona intestinalis, Haliclonia, Halichondria sp., Crepidula fornicata, Crepidula plana, Mytilus edulis, Acanthodoris pilosa, Pagurus longicarpus, Electra pilosa, Pholis gunnellus* (Rock gunnel).

Species of management concern: Hemigrapsus sanguineus, Botrylloides violaceous, Membranipora membranacea, Botryllus schlosseri, Styela clava, Haematopus palliatus (American oystercatcher)

ROCK/BOULDER: MIXED NO ZONATION ASSEMBLAGE

Definition: Biota covers > 30 % of an area, but no single taxa covers >75% of the total biota and the area lacks vertical zonation. The intertidal is a mosaic of different organisms growing in patches that were often stunted in form. In most cases this Assemblage covered the complete intertidal from the upper black zone to the lowest limit that could be safely attained.

Commonly seen: In areas with varied topography such as on rip-rap that has its lower edge in standing water and its upper edge in the high intertidal and boulders on top of bedrock, or in the middle of *Mytilus* reefs. This Assemblage tends to be found in more exposed areas on bedrock and boulders where there are large amounts of microhabitats that enable many assemblages to proliferate, but which were so small as to be unmappable.

Examples: Outer Brewster, South side of Little Brewster, North side of Calf,

Common organisms: Littorina saxatilis, Littorina obtusata, Littorina littorea, Ulva lactuca, Ascophyllum nodosum, Fucus sp., Chondrus crispus, Scytosiphon lomentaria, Polysiphonia sp., kelps, *Carcinus maenas, Cancer irroratus, Cancer borealis, Nucella lapillus, Lacuna vincta Semibalanus balanoides, Notoacmaea testudinalis, Metridium senile, Strongylocentrotus droebachiensis, Asterias vulgaris, Asterias forbesi, Ophiopholis aculeata, Alcyonidium* sp, *Ciona intestinalis, Haliclonia, Halichondria* sp.*, Crepidula fornicata, Crepidula plana, Mytilus edulis, Acanthodoris pilosa, Electra pilosa*

Species of management concern: Hemigrapsus sanguineus, Botrylloides violaceous, Membranipora membranacea, Botryllus schlosseri, Styela clava, Harbor Seal *(Phoca vitulina)*

REEF ASSEMBLAGES

Reefs in the Boston Harbor intertidal occurred in a number of different forms. We separated them into the following categories.

MYTILUS EDULIS REEF ASSEMBLAGE

Definition: Solid substrate formed by *Mytilus edulis* and their shells creating a mounded structure on unconsolidated bottoms

Commonly seen: In the low intertidal, particularly on Mixed coarse or mixed coarse and fine sediments

Examples: Thompson, Langlee, George, Lovell, Great Brewster. Not found on the outer islands that tend to be bedrock and drop off quickly

Diagnostic species: Large *Mytilus edulis*

Common organisms: Fucus spp., *Chondrus crispus, Scytosiphon, Polysiphonia,* Kelps, *Fucus vesiculosus forma mytilii, Carcinus maenas, Cancer irroratus, Cancer borealis, Hemigrapsus sanguineus, Littorina littorea, Nucella lapillus, Lacuna vincta, Semibalanus balanoides, Notoacmaea testudinalis, Metridium senile, Strongylocentrotus droebachiensis, Asterias vulgaris, Asterias forbesi, Ophiopholis aculeata, Alcyonidium sp, Ciona intestinalis, Haliclonia, Halichondria* sp., *Crepidula fornicata, Crepidula plana, Acanthodoris pilosa, Electra pilosa*

Species of management concern: Hemigrapsus sanguineus, Botrylloides violaceous, Membranipora membranacea, Botryllus schlosseri, Styela clava

MIXED COARSE/ MIXED COARSE AND FINE *MYTILUS* REEF ASSEMBLAGE

Definition: Areas in which *Mytilus edulis* was intermixed with cobble, gravel and boulders forming a solid bar or berm (unmoved by moderate wave action) held together with byssal threads.

Commonly seen: In the low intertidal on mixed coarse and mixed coarse and fine substrates

Examples: Found on almost all the inner islands. Thompson, Long, Peddocks, George, Lovell, Spectacle, Great Brewster, and World's End.

Diagnostic species: Large *Mytilus edulis*

Common Species: Fucus sp., Chondrus crispus, Scytosiphon, Polysiphonia, Kelps, Fucus vesiculosus forma mytilii, Carcinus maenas, Cancer irroratus, Cancer borealis, Littorina littorea, Nucella lapillus, Lacuna vincta, Semibalanus balanoides, Notoacmaea testudinalis, Metridium senile, Strongylocentrotus droebachiensis, Asterias vulgaris, Asterias forbesi, Ophiopholis aculeata, Alcyonidium sp, Ciona intestinalis, Haliclonia, Halichondria sp., Crepidula fornicata, Crepidula plana, Acanthodoris pilosa, Electra pilosa, Rock gunnel (Pholis gunnellus)

Species of management concern: Hemigrapsus sanguineus, Botrylloides violaceous, Styela clava, Styela partita, Botryllus schlosseri, American

Oystercatcher (*Haematopus palliates*), Semipalmated Plover (*Charadrius semipalmatus*)

MIXED BROWN/MYTILUS REEF ASSEMBLAGE

Definition: Mytilus reef (see above) with >50% of reef covered with *Fucus vesiculosus forma mytilii*
Commonly seen: On mixed coarse and mixed coarse and fine substrates
Examples: Great Brewster, north side of the middle drumlin on Peddocks, southwest corner of Rainsford, and southeast side of Thompson
Diagnostic species: Fucus vesiculosus forma mytilii, Mytilus edulis
Common Species: Fucus sp.*, Chondrus crispus, Scytosiphon, Polysiphonia, Kelps, Carcinus maenas, Cancer irroratus, Cancer borealis, Littorina littorea, Nucella lapillus, Lacuna vincta, Semibalanus balanoides*, *Notoacmaea testudinalis, Metridium senile, Strongylocentrotus droebachiensis, Asterias vulgaris, Asterias forbesi, Ophiopholis aculeata, Alcyonidium* sp, *Ciona intestinalis, Haliclonia, Halichondria sp., Crepidula fornicata, Crepidula plana, Acanthodoris pilosa, Electra pilosa,* Rock gunnel *(Pholis gunnellus)*
Species of management concern: Hemigrapsus sanguineus, *Botrylloides violaceous, Styela clava, Styela partita, Botryllus schlosseri, (*American oystercatcher) *Haematopus palliates*,(semipalmated plover) *Charadrius semipalmatus*

MIXED BROWN/ SEMIBALANUS MYTILUS REEF ASSEMBLAGE

Definition: Biota covers > 30 % of an area, but no single taxa covers >75% of the total biota. Mixed Brown/*Semibalanus* Assemblage interspersed throughout a mixed Coarse *Mytilus* reef.
Commonly seen: On mixed coarse reefs where boulders and large cobble stick up through the reef into the mid intertidal.
Examples: Northern side of Lovell, the east side of Great Brewster, Peddocks, Grape
Diagnostic species: Fucus spp.*, Ascophyllum nodosum, Semibalanus balanoides and Mytilus edulis*
Common Species: Fucus sp.*, Chondrus crispus, Scytosiphon, Polysiphonia,* Kelps, *Fucus vesiculosus forma mytilii, Carcinus maenas, Cancer irroratus, Cancer borealis, Littorina littorea, Nucella lapillus, Lacuna vincta, Semibalanus balanoides, Notoacmaea testudinalis, Metridium senile, Strongylocentrotus droebachiensis, Asterias vulgaris, Asterias forbesi, Ophiopholis aculeata, Alcyonidium sp, Ciona intestinalis, Haliclonia, Halichondria sp., Crepidula fornicata, Crepidula plana, Acanthodoris pilosa, Electra pilosa,* Rock gunnel *(Pholis gunnellus)*
Species of management concern: Hemigrapsus sanguineus, *Botrylloides violaceous, Styela clava, Styela partita, Botryllus schlosseri,* American oystercatcher *(Haematopus palliates*).

MUDFLAT ASSEMBLAGE

Definition: Fine sediments were the least covered in this overview. This assemblage covers all areas classified as Mud or Mixed Coarse and Fine. Below is a partial sampling of the infaunal community of fine sediments from three locations in the Harbor.

Commonly seen: In protected areas with low flow rates such as small bays, coves and estuaries.

Examples: The southern end of Thompson, Slate Grape and World's End

Diagnostic species:

Common Species in a mix of mud and gravel*: Ilyanassa obsoleta, Littorina littorea, Pagurus longicarpus, Ulva lactuca, Mytilus edulis, Mya arenaria, Leitoscoloplos fragilis, Hediste diversicolor, Sio setosa, Pectnaria gouldi, Lineus ruber, Chaetozone setosa, Polydora cornuta, Streblospio benedicti, Corophium volutator, Peloscoles benedeni*

Common Species in a mix of sand and mud*: Phascolopsis gouldi, Hediste diversicolor, Spio setosa, Chaetozone setosa, Polydora cornuta, Streblospio benedicti, Pectinaria gouldi, Clymenlla torquata, Capitella capitata, Polycirrus sp., Eteone longa, Leitoscoloplos robustus, Corophium volutator, Microdeutropus gryllotalpa, Gammarus mucronatus, Melita nitida, Peloscolex benedeni, Phallodrilus monospermathecus, Marionina southerni*

Species of management concern: Mytilus edulis, Mya arenaria, species of worm taken for bait may be important as well.

SPARTINA ALTERNIFLORA ASSEMBLAGE

Definition: Biota covers >30 % of an area with *Spartina alterniflora* cover >75% of the total biota

Commonly seen on: The upper intertidal of mixed coarse beaches in sheltered areas. These were called fringe marshes; also present in fully enclosed Salt Marshes in the low marsh on peat. Very often these occur where freshwater (river or runoff) met the marine environment.

Examples: fringe salt marshes were found on Calf, Worlds End, Slate, Grape, Rainsford. Enclosed slat marshes were found on Peddocks*;* Thompson, Calf, World's End

Diagnostic species: *Spartina alterniflora*

Common organisms: Littorina littorea, Ulva lactuca, Fucus spp.*, Ascophyllum nodosum, Carcinus maenas, Fundulus heteroclitus*

Species of management concern: Spartina alterniflora is an important producer of organic material and habitat for juvenile fish

SPARTINA PATENS ASSEMBLAGE

Definition: Biota covers >30 % of an area with *Spartina patens* cover >75% of the total biota

Commonly seen on: Protected shores in the high salt marsh on peat or in the very upper intertidal on mixed Coarse.
Examples: Peddocks, Thompson, World's End, Slate, and Calf
Diagnostic species: *Spartina patens*
Common organisms: Limonium carolinianum, Suaeda linearis, Salicornia europaea, Atriplex patula, Distichlis spicata, Juncus gerardii, Spartina alterniflora
Species of management concern: Spartina patens is an important producer of organic material and *Phragmites australis* invasions are a possibility.

<u>*SALICORNIA* ASSEMBLAGE</u>

Definition: Biota covers >30 % of an area with *Salicornia* cover >75% of the total biota
Commonly seen: On peat or mud in the upper intertidal of salt marshes often in areas previously laid bare by wrack accumulation.
Examples: Thompson, World's End in the salt marsh
Diagnostic species: Salicornia europaea
Common Species: Spartina alterniflora, Spartina patens, Suaeda linearis,
Species of management concern: None found

<u>*SUAEDA* ASSEMBLAGE</u>

Definition: Biota covers >30 % of an area with *Suaeda linearis* cover >75% of the total biota
Commonly seen: In the high marsh on peat or on mixed coarse, upper areas, that are irregularly flooded.
Examples: Above *Spartina patens* on Slate, Thompson and World's End
Diagnostic species: Suaeda linearis
Common organisms: Limonium carolinianum, Salicornia europaea, Atriplex patula, Distichlis spicata, Juncus gerardii, Spartina patens, Spartina alterniflora
Species of management concern: None found

<u>*JUNCUS* ASSEMBLAGE</u>

Definition: Biota covers >30 % of an area with *Juncus gerardii* cover >75% of the total biota. Never mapped as its own discrete assemblage, but present in the high marsh.
Commonly seen: in the upper intertidal edge of the high marsh on peat mixed with *Spartina patens*.
Examples: Thompson, World's End
Diagnostic species: Juncus gerardii
Common organisms: Limonium carolinianum, Suaeda linearis, Salicornia europaea, Atriplex patula, Distichlis spicata, Juncus gerardii, Spartina patens, Spartina alterniflora
Species of management concern: Phragmites australis

IVA ASSEMBLAGE

Definition: Biota covers >30 % of an area with *Iva* cover >75% of the total biota
Commonly seen: In the high marsh at the spring high water mark
Examples: A few small areas on World's End
Diagnostic species: Iva frutescens
Common organisms: Limonium carolinianum, Salicornia europaea, Atriplex patula, Distichlis spicata, Juncus gerardii, Spartina patens, Spartina alterniflora
Species of management concern: Phragmites australis

PHRAGMITES ASSEMBLAGE

Definition: Biota covers >30 % of an area with *Phragmites australis* cover >75% of the total biota
Commonly seen: In the high marsh in areas with a fresh water influence or limited exposure to salt water.
Examples: World's End, Calf and a number of wetlands areas on the islands that were not mapped in this survey
Diagnostic species: Phragmites australis
Common organisms:
Species of management concern: Phragmites australis, Lythrum salicaria

HIGH MARSH ASSEMBLAGE

Definition: Biota covers >30 % of an area with two or more of the following: *Limonium carolinianum, Suaeda linearis, Salicornia europaea, Atriplex patula, Distichlis spicata, Juncus gerardii, Spartina patens, Spartina alterniflora, Phragmites australis* covering >75% of the total biota, but no single species >75%.
Commonly seen: On peat usually above *Spartina alterniflora* in salt marshes or on smaller grained mixed coarse on the intertidal / terrestrial line on Protected shores.
Examples: Slate, Thompson, World's End
Diagnostic species: Limonium carolinianum, Suaeda linearis, Salicornia europaea, Atriplex patula, Distichlis spicata, Juncus gerardii, Spartina patens, Spartina alterniflora, Phragmites australis
Common Species: Solidago sempervirens, Iva frutescens
Species of management concern: Phragmites australis

TIDE POOL ASSEMBLAGE

Areas of persistent standing water were mapped as tide pools. This assemblage included a large range of organisms and could be broken up into different assemblages in future monitoring efforts.

CREEK

Creeks were mapped on a few islands. These were defined as areas with continuous running water that drains the tidal waters of coastal salt marshes or wetlands – bottom of creek is permanently flooded, banks are exposed at low tide.

OTHER

OTHER covered all areas that were mapped, but were not in the initial classification system.

i.e., Large areas of Wrack that persisted for long periods of time were mapped as Other and then typed into the notes field.

Definitions of Terms

Macrobiota: organisms whose two dimensional coverage is > 2 mm of the surface.

Diagnostic species: The diagnostic species are listed for all assemblages and are defined as the organism or combination of organisms that are the major space occupiers in the intertidal. The term diagnostic is used instead of dominant because an organism may be the major space occupier in an area, but may or may not be the dominant or controlling element in a particular assemblage. The term is also avoided because it often takes more then a single species to define an assemblage. This definition is different then the definitions laid out in both Dethier (1993) and Brown (1993) due to the different techniques used in classifying and mapping. The diagnostic species in some cases can also be the dominant species, but this system is designed such that the assemblages/diagnostic species are indicators of the different communities that exist in the intertidal.

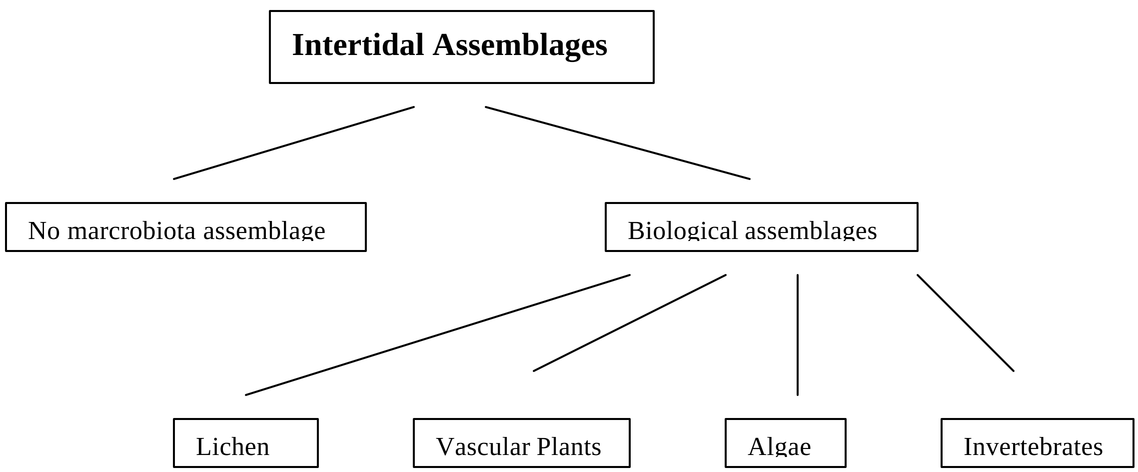
Common Species: These species are listed in addition to diagnostic species. Organisms smaller than 2-3 mm long not listed, except where strikingly abundant. Standardized common names are used for fish, but Latin binomial nomenclature is used for invertebrates and plants to avoid ambiguity. Common names, when used, are taken largely from Gosner (1978). Gleason and Cronquist (1991) is the authority used for vascular plant nomenclature.

Modifying BHICS for Use in Other Locations

The BHICS was designed for the Boston Harbor Islands, but was constructed with a nested hierarchy so as to have widespread applications with minor modifications. The substrate types were taken almost directly from Dethier (1990) and Brown (1993) who used the Wentworth Scale (1922) in order to keep terminology and sizes consistent. These substrates should be applicable in almost all locations with minor or no alterations. The assemblages were designed based on the diagnostic or major space-occupying organisms found in Boston Harbor. The major space-occupying organisms fell into four broad categories, lichen, vascular plants, algae, invertebrates and combinations of these categories. These categories are the major space-occupying organisms in most areas and could be used as an outline to tailor the assemblage types to specific locations (figure 2).

The BHICS was an effective classification system for Boston Harbor that could be used in a variety of areas, particularly in the Northeast.

Figure 2.



METHODS OF DELINEATING AND CHARACTERIZING POLYGONS IN THE FIELD

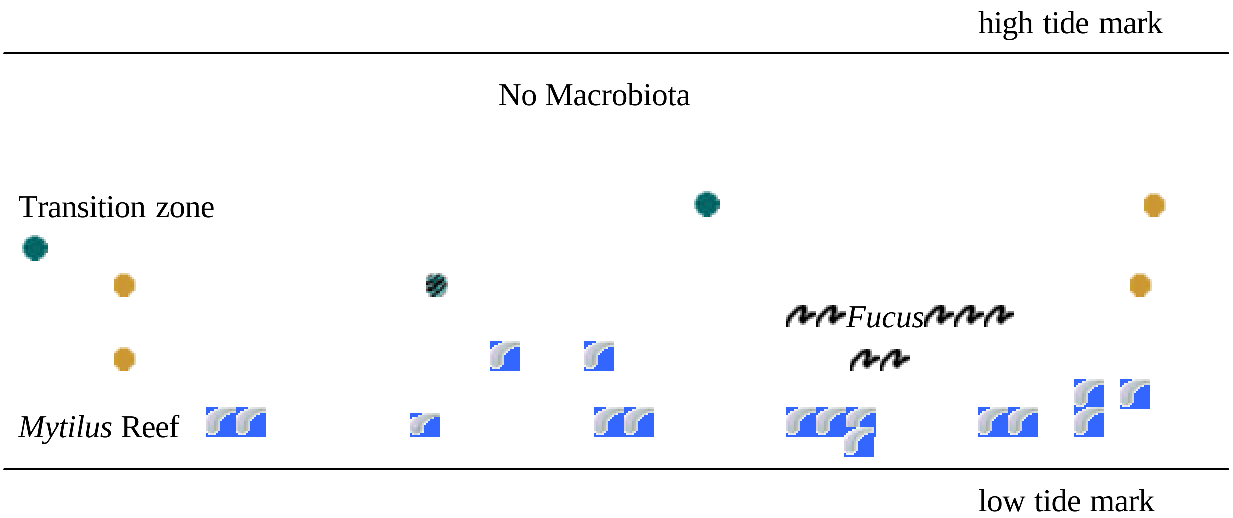
How to Use the Boston Harbor Intertidal Classification System

Twenty islands in Boston Harbor were classified using the Boston Harbor Intertidal Classification System (BHICS). On each island the entire intertidal zone was delineated by substrate and assemblage using a Trimble GeoExplorer III GPS unit. A given area ($25m^2$ or greater) was mapped by walking the perimeter with the GPS unit and creating a unique polygon. Each polygon represented an area that was composed of a single assemblage type and a single substrate type as defined in the BHICS.

The intertidal zone for this survey was defined as the area between the extreme high and low spring tides. In the field, the high tide mark on bedrock and boulders was the top of the black zone (band of lichen and cyanobacteria present in the upper most intertidal). On unconsolidated substrates (cobble, gravel, sand, mixed coarse) the high tide mark was the highest wrack line that was not in upland vegetation. Mapping was begun at the high intertidal approximately three hours before low tide and continued down the intertidal with the ebbing tide.

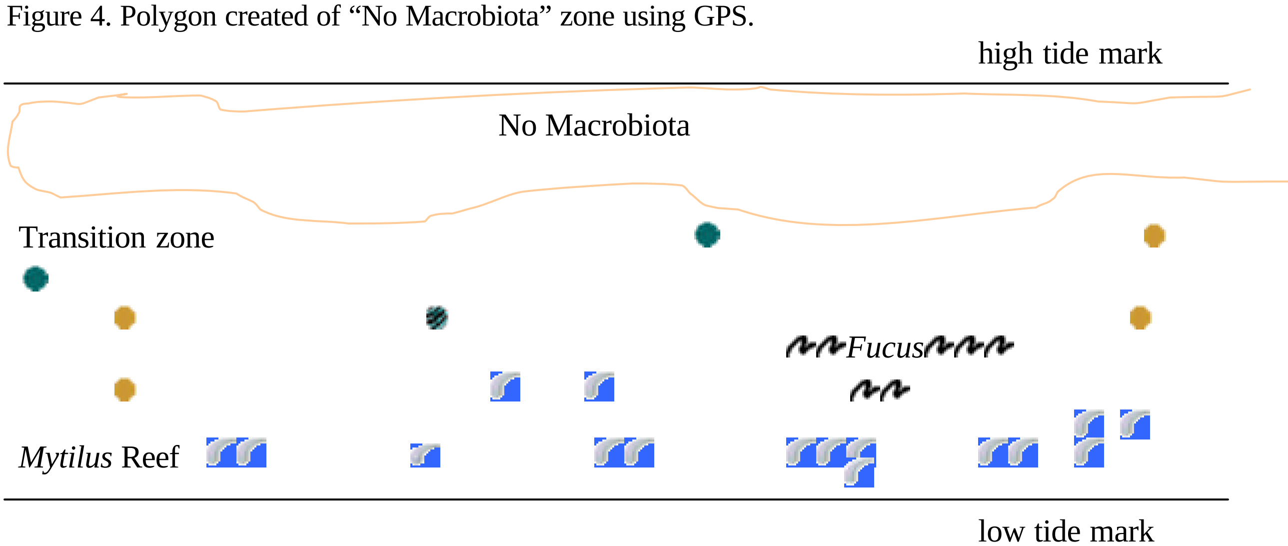
The organisms were rarely in a textbook zonation pattern, however there were clear breaks in the biota. Certain types of algae or sessile invertebrates were usually present on particular types of substrates or at different tidal heights. The different types of algae and sessile invertebrates correspond to the assemblages listed in the BHICS. On a Mixed Coarse beach, as shown in Fig. 3, the high intertidal was devoid of almost all life and was labeled a No Macrobiota assemblage. This assemblage was typically the first area mapped as it was the first area exposed during the ebbing tide.

Figure 3. Typical intertidal zone on a Mixed Coarse beach. The top of the figure represents the approximate maximum high tide line, bottom the low tide line. Moving from the high to low tide zones within the intertidal, one proceeds from a zone of no macrobiota near the high tide mark through a transition zone, then into a *Fucus* sp.(rockweed)-dominated zone and finally to a zone dominated by blue mussels (*Mytilus edulis*). Colored shapes represent the distribution of organisms.



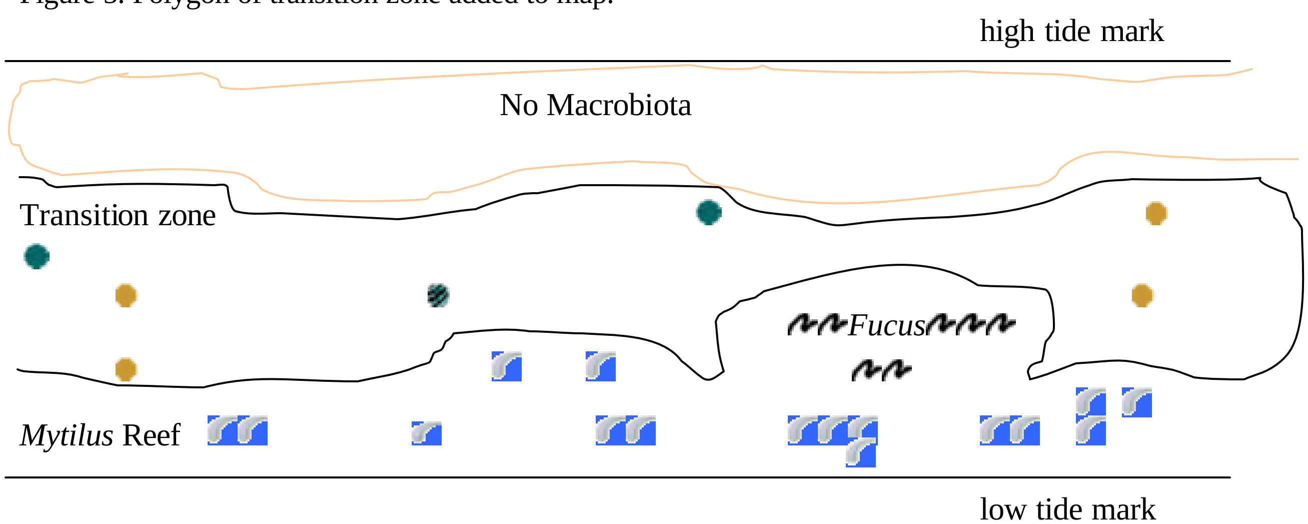
An individual with GPS in hand would begin making a polygon by first walking the upper boundary, most often the wrack line, of the assemblage. The polygon continued until there was a change in substrate or biota. The individual would then walk the remaining border of the "No Macrobiota" polygon (Fig. 4).

Figure 4. Polygon created of "No Macrobiota" zone using GPS.



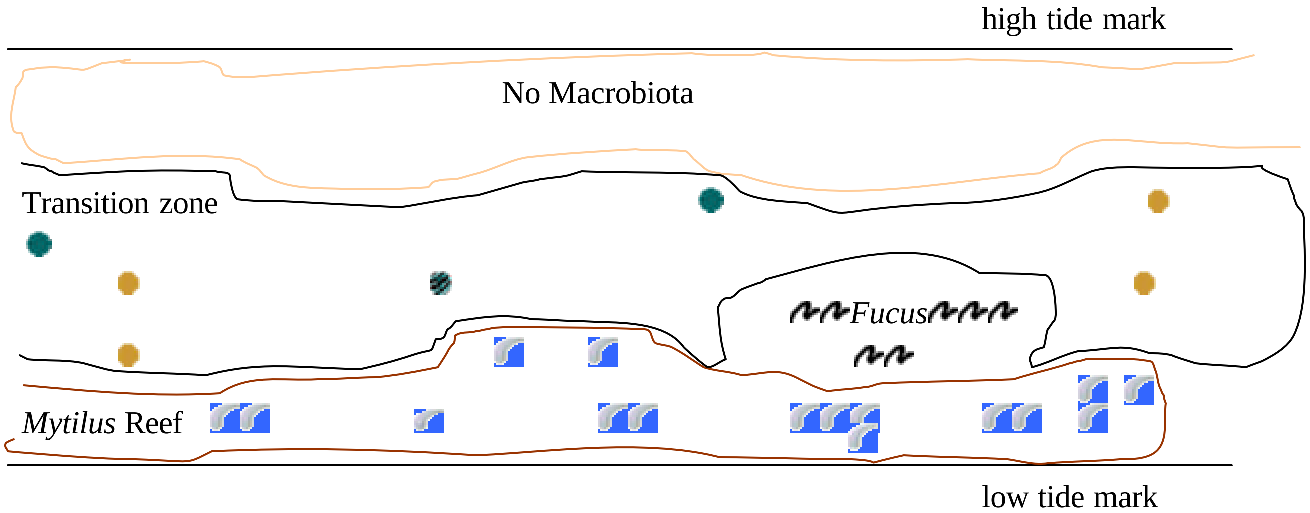
After walking the entire perimeter of a polygon a substrate and assemblage type was assigned to it and the rest of the data dictionary was completed. (See the data dictionary section.) This process was then repeated over the entire intertidal. As more area became exposed an individual would move down the intertidal and delineate another polygon. Note that the lower boundary of the No Macrobiota zone was re-walked while mapping the upper boundary of the Transition zone (Fig. 5). Due to limitations in the GPS and GIS technology, in almost all cases it was not possible to simply walk the lower boundary and use the boundary of the other polygon. The entire perimeter had to be walked for each polygon.

Figure 5. Polygon of transition zone added to map.



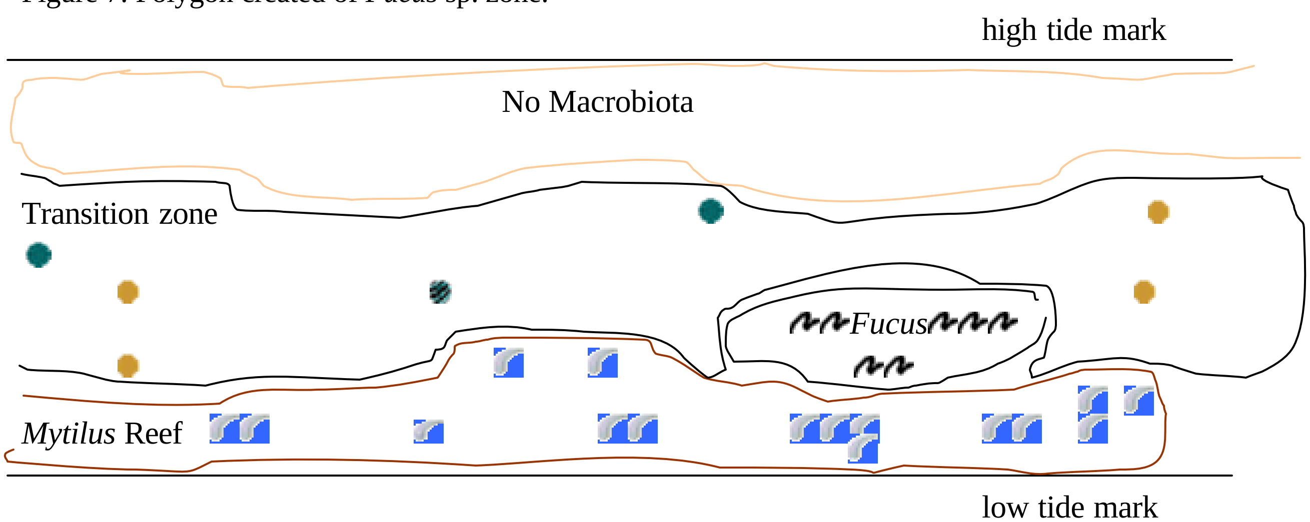
The lower boundary of the assemblage that defined the bottom of the intertidal (*Mytilus* reef in Fig. 6) was usually started forty-five minutes before low tide and was continued until 45 minutes after low tide. When a clear boundary was present near the low tide mark that edge was the lower boundary of the intertidal. When assemblages continued into the subtidal the individual with the GPS would walk as deep as was possible (waist to chest deep) in the water while still able to see the assemblage through the water. Almost all lower boundaries were mapped on mean or spring tide phases when much of the lower boundary would be exposed or in shallow water.

Figure 6. Mapping of the *Mytilus edulis* reef.



It was often necessary to stop mapping the mid intertidal at low tide and then return after delineating the lowest assemblage (*Fucus* is mapped after the reef in Fig. 7).

Figure 7. Polygon created of *Fucus* sp. zone.



Data Dictionary

After walking a specific polygon, the information about that area was recorded in the data dictionary. The data dictionary was simply an electronic data sheet within the Trimble GeoExplorer III GPS unit. It had four main sections, substrate, assemblage, percent cover menu, and other features.

The first section was a substrate menu that identified the polygon as a specific substrate (Table 4a). A given polygon had to have >75% cover of a specific substrate as defined in the BHICS to be labeled as that substrate. The second section was an assemblage menu that identified the polygon as a specific assemblage (Table 4b). A given polygon had to have >30% biotic cover to be labeled as a biotic assemblage, otherwise it would be labeled as "no macrobiota.". A specific assemblage then had to be >75% of the biotic coverage to be labeled as that specific assemblage type. (All definitions are found in the BHICS.)

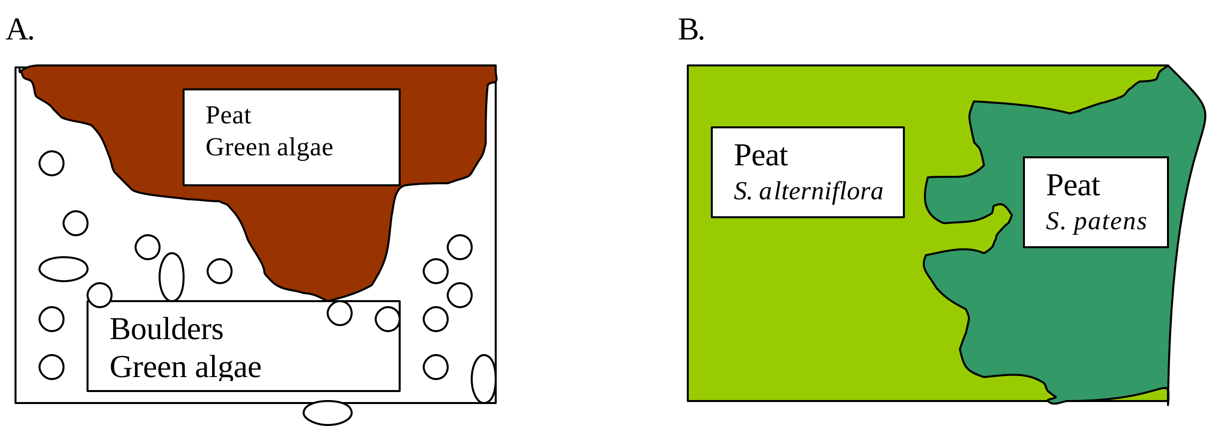
Table 4a. Substrate menu, one substrate was chosen from the menu to describe the entire polygon	Table 4b. Assemblage menu, one assemblage was chosen from the menu to describe the entire polygon

SUBSTRATE	ASSEMBLAGE
rock	No Macrobiota
Boulder	Black Zone
Hardpan	Green Crust
Cobble	Transition zone
mixed coarse	Semibalanus
gravel	Ascophyllum
sand	Fucus
shells	Brown algae
mixed coarse and fine	Mixed brown/Semibalanus
mud	Other brown algae
peat	Mixed brown/Semibalanus green algae
Cultural	High intertidal green algae
Reef	Green algae
Seep	Red encrusting algae
	Red foliose algae
	Kelp
	Mytilus edulis
	Mixed zonation assemblage
	Mixed assemblage
	Mytilus edulis reef
	Mixed brown/Mytilus reef
	Mixed brown/ Semibalanus reef
	Mudflat
	Spartina alterniflora

Spartina patens
Salicornia
Suaeda
Juncus gerardii
Iva frutescens
Phragmites australis
High marsh
Tide pool
Creek
Other

Areas where one type of assemblage was found on two different types of substrates (e.g., Fig. 8) were mapped as two different polygons. Conversely when two different assemblages were present on the same substrate type they were mapped as two different polygons.

Figure 8. (A)The assemblage "Green Algae" growing on two different substrates. Two distinct polygons were mapped. (B) Two different assemblages growing on Peat substrate. Two distinct polygons were mapped.



Percent Cover Menu

The percent cover menu provided greater resolution to the specific substrates and organisms present within each polygon. After identifying the polygon as a single substrate and a single assemblage the third section, the percent cover menu, recorded the visually estimated percent cover of all the substrates and major space occupying organisms present in the polygon (Table 5). The percentages were split into seven categories and were similar to those found in Bailey *et al* (1993). 0%, <1%, 1-5%, 6-25%, 26-50%, 51-75%, 76-100%. This method and scale allowed for rapid assessment in the field and had good agreement between different users. The estimated cover of each category in the substrate column was the percent cover over the entire polygon. The estimated cover of each category in the assemblage column was the percent of the total *biotic* cover in a polygon.

Table 5. Percent cover menu

SUBSTRATE	%	ASSEMBLAGE	%
rock		No Macrobiota	
Boulder		Black Zone	
Hardpan		Green Crust	
Cobble		*Semibalanus*	
gravel		*Ascophyllum*	
sand		*Fucus*	
shells		Brown algae	
mud		Other brown algae	
peat		Green algae	
Cultural		Red encrusting algae	
Reef		Red foliose algae	
Seep		Kelp	
		Mytilus edulis	
		Mytilus edulis reef	
		Spartina alterniflora	
		Spartina patens	
		Salicornia	
		Suaeda	
		Juncus gerardii	
		Limonium carolinianum	
		Iva frutescens	
		Phragmites australis	
		Other	

Not all categories were in the original data dictionary. A few were added in the editing process through good field notes and information entered in the notes field of the data dictionary.

This breakdown allowed for fine scale mapping of the intertidal. The components of assemblages that were combinations of other assemblages (i.e., Mixed Assemblage) could be interpreted from the percent cover menu and areas that were too small to be mapped were accounted for in the survey.

The polygon from Fig. 4 would be labeled as in Table 6:

Table 6. The designation of the “No Macrobiota” polygon in the data dictionary.

Substrate menu: *mixed coarse*
Assemblage menu: *No Macrobiota*-because the polygon had <30% biotic cover
Percent cover menu:

SUBSTRATE	%		ASSEMBLAGE	%
rock	0%		No Macrobiota	76-100%
Boulder	6-25%		Black Zone	0%
Hardpan	0%		Green Crust	0%
Cobble	26-50%		*Semibalanus*	0%
gravel	26-50%		*Ascophyllum*	0%
sand	0%		*Fucus*	0%
shells	1-5%		Brown algae	0%
mud	0%		Other brown algae	0%
peat	0%		Green algae	0%
Cultural	0%		Red encrusting algae	0%
Reef	0%		Red foliose algae	0%
Seep	0%		Kelp	0%
			Mytilus edulis	0%
			Mytilus edulis reef	0%
			Spartina alterniflora	0%
			Spartina patens	0%
			Salicornia	0%
			Suaeda	0%
			Juncus gerardii	0%
			Limonium carolinianum	0%
			Iva frutescens	0%
			Phragmites australis	0%
			Other	0%

The percent cover menu agrees with the substrate and assemblage menus and further explains the composition of the polygon. If the polygon in Fig. 4 had an area of *Spartina alterniflora* less than 25m^2 this could also be accounted for in the data dictionary. The substrate and assemblage menus would remain the same. The patch of *Spartina alterniflora* was too small to be mapped; thus the polygon remained as a No Macrobiota assemblage with < 30% biotic cover. The change would be registered in the percent cover menu. *Spartina alterniflora* would change from 0% to 76-100% because *Spartina alterniflora* constitutes all of the biotic cover. The No Macrobiota category from the percent cover menu would remain unchanged because this was the percent of the entire polygon that lacked biota.

In another example, a potential polygon could be found on rip-rap, labeled as a Mixed Brown/*Semibalanus* assemblage, and have a small pocket of marsh grass, *Spartina alterniflora*, less then 25 m^2 growing on peat. This polygon would be labeled as in Table 7.

Table 7. Hypothetical Mixed Brown/ Semibalanus assemblage with marsh grass on rip rap.

Substrate menu: *Boulders*

Assemblage menu: *Mixed brown/Semibalanus*

Percent cover menu:

SUBSTRATE	%		ASSEMBLAGE	%
rock	0%		No Macrobiota	1-5%
Boulder	76-100%		Black Zone	0%
Hardpan	0%		Green Crust	0%
Cobble	0%		*Semibalanus*	26-50%
gravel	1-5%		*Ascophyllum*	6-25%
sand	0%		*Fucus* sp.	6-25%
shells	0%		Brown algae	0%
mud	0%		Other brown algae	0%
peat	1-5%		Green algae	0%
Cultural	76-100%		Red encrusting algae	0%
Reef	0%		Red foliose algae	0%
Seep	0%		Kelp	0%
			Mytilus edulis	0%
			Mytilus edulis reef	0%
			Spartina alterniflora	1-5%
			Spartina patens	0%
			Salicornia	0%
			Suaeda	0%
			Juncus australis	0%
			Limonium carolinianum	0%
			Iva frutescens	0%
			Phragmites australis	0%
			Other	0%

In the Substrate percent cover menu, the rip-rap, a human constructed boulder wall, was marked as 76-100% boulder because the dominating substrate was boulders and 76-100% cultural because the boulders were a human made structure. 1-5% peat was also present, in this polygon. The peat was too small to be mapped as its own polygon and was therefore included. Gravel was also present in this polygon, but not enough to be mapped separately and was marked as 1-5%. In the Assemblage percent cover menu, No macrobiota was marked as 1-5%. This means that 1-5% of the total area of the polygon was devoid of life. The remaining area had biotic cover and 75% or more was the assemblage mixed brown/*Semibalanus*. Of that biotic cover 26-50% was *Semibalanus*, 6-25% was *Ascophyllum*, and 6-25% was *Fucus*. A small patch of *Spartina alterniflora* was also present and was too small to map on its own. It was included and marked as 1-5%.

For those assemblages, substrates or specific organisms that were not in the data dictionary there was a menu with the same list of seven percentages titled OTHER and a notes field. The assemblage, substrate, specific organism or noteworthy item was typed into the notes section and its percent cover was estimated in the OTHER field when applicable.

Other Features

In the fourth section of the data dictionary two more components of the intertidal were measured and a number of features were recorded by the GPS unit (i.e., time, date, area). Slope was estimated in degrees as noted in Table 8.

Table 8. Slope menu.

<2 degrees
2-5 degrees
6-15 degrees
15-45 degrees
45-70 degrees
70 degrees/ cliff

The densities of three commonly occurring invertebrates were measured as average density over the entire polygon: *Littorina littorea, Ilyanassa obsoleta, Geukensia demissa*. The density scale in table 9a was used for most of the 2001 season, but needed improvement as densities were often found >100/m^2. The density scale in table 9b was used for the entire 2002 season. An improved scale might be recommended for future monitoring efforts.

Table 9. Invertebrate density menu

Table 9a. 2001 season
0
<5 in polygon
always <1/ m^2
locally more <1/ m^2
1/ m^2
1< x <10/ m^2
>10/ m^2

Table 9b. 2002 season
0
<5 in polygon
always <1/ m^2
locally more <1/ m^2
1/ m^2
1< x <10/ m^2
10/ m^2<x<100/ m^2
>100/ m^2

Always <1/ m^2 was used in areas were the density of animals was evenly distributed over the whole polygon and was <1/ m^2. *Locally More <1 m^2* was used when the average density in a polygon was <1 m^2, but certain areas of the polygon had higher densities.

Areas of Potential Problems

Where two communities meet there is a transition from one to the other. In some areas such as a fringe marsh in the high intertidal the boundary between the *Spartina alterniflora* and the No Macrobiota area around it is rather abrupt. In other cases, such as the border of a *Mytilus* reef with another assemblage the boundary can be quite difficult to distinguish. Keep in mind that these are imperfect human constructs used as a tool to understand and manage the intertidal zone. All the borders in this survey have some error (+ or – 1m) due to the capabilities of the technology, observer bias, and the difficulties of defining natural transitions. We used our best professional judgment in the field to delineate polygons that adhered to the definitions in the BHICS.

The following shows how particular problems, which were common, were dealt with in the data dictionary:

Mytilus reefs were divided into two categories. Full *Mytilus* reefs were composed primarily of live and dead *Mytilus edulis* shells as well as other biogenic structures and were labeled as Reef substrate and Mytilus reef assemblage. Areas in which *Mytilus edulis* was in and around boulders, cobble and gravel, holding the substrate together, but not covering it, were labeled as Mixed Coarse substrate and *Mytilus* reef assemblage. The substrate Reef was applied to biogenic structures which consisted of both live and dead *Mytilus* as long as they were held together in a bar, bed or reef form. The shell substrate was used for areas composed of dead empty shell, ground up shell (as on a beach) and all other areas where shells did not form a bar or reef like structure.

Mixed Assemblage was used whenever an area did not fit into the BHICS definitions or the border between assemblages was unable to be determined. Most often these occurred where two assemblages met or in areas where there were a number of small patches of different assemblages. The different components of the polygon were recorded in the percent cover menu.

The Cultural substrate was used only to delineate large human-made structures that did not fit the definitions of any other substrate. This usually applied to washed up docks and boats. Rip-rap, jetties and walls were labeled as Boulders with the correct percentage marked off in the percent cover menu under Cultural Hard (as in Table 7).

Rock walls, jetties, cliffs and rip-rap were often part of the intertidal. Whenever one of these was a border of a polygon, it was simply walked on or climbed over.

Post Processing

The settings for the GeoExplorer III can be found in Appendix 3. The rover files from the GeoExplorer III were uploaded to a computer via Pathfinder Office 2.51. Rover files were corrected with base files from base stations in Woburn, MA, Yarmouth, ME and the University of Rhode Island (Kingston, RI) and the corrected files were edited in Pathfinder Office 2.51 to remove loops. The corrected edited files were exported to ArcView 3.2 where all abutting polygons were snapped together. Work was done in Mass State Plane and the final product was projected to adhere to National Park Service guidelines:

UTM
Zone: 19N
NAD 83
Meters

ANALYSIS OF INTERTIDAL HABITATS

Substrata and Assemblages – All Islands pooled.

Mixed coarse was the most common type of substratum in the Boston Harbor Islands (Fig. 9). It contained over twice as much area as the next most common type, mixed coarse & fine. Reefs, mostly composed of mussels, were another frequently encountered substrate type. *Mytilus edulis*, the blue mussel, was the most common species assemblage (Fig. 10).

Figure 9. Hectares of substrate types of all twenty islands.

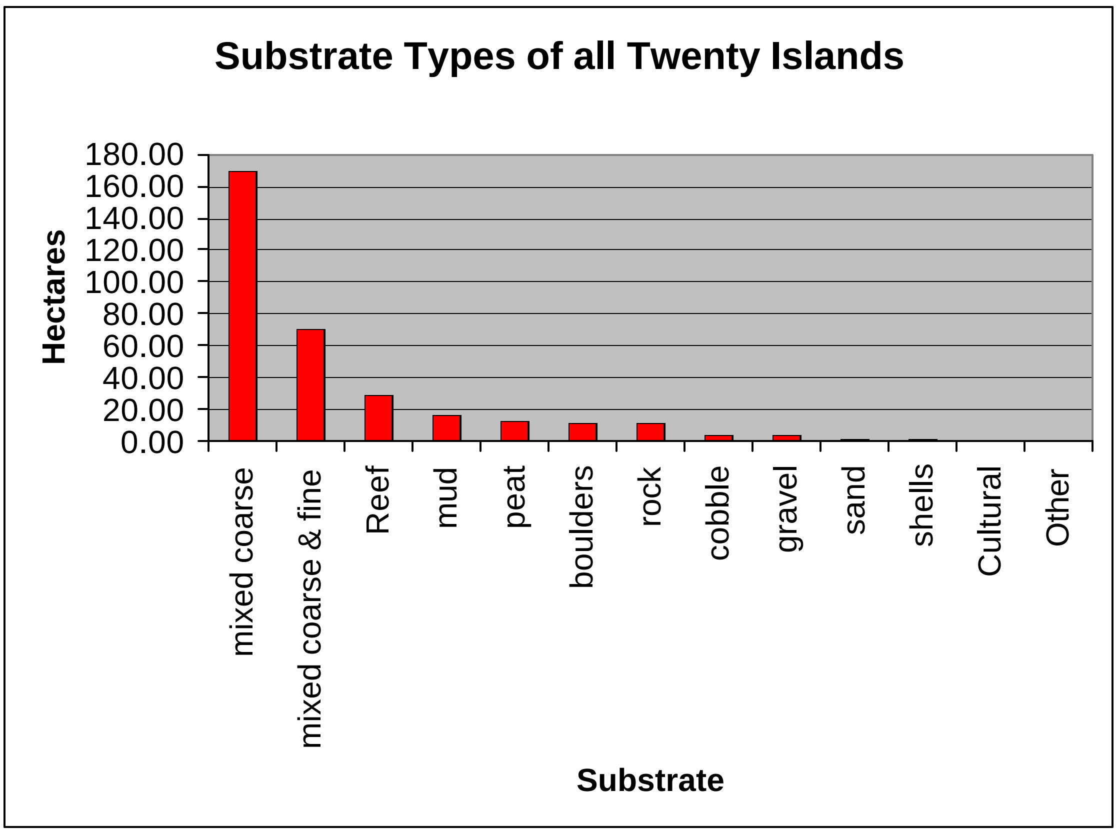
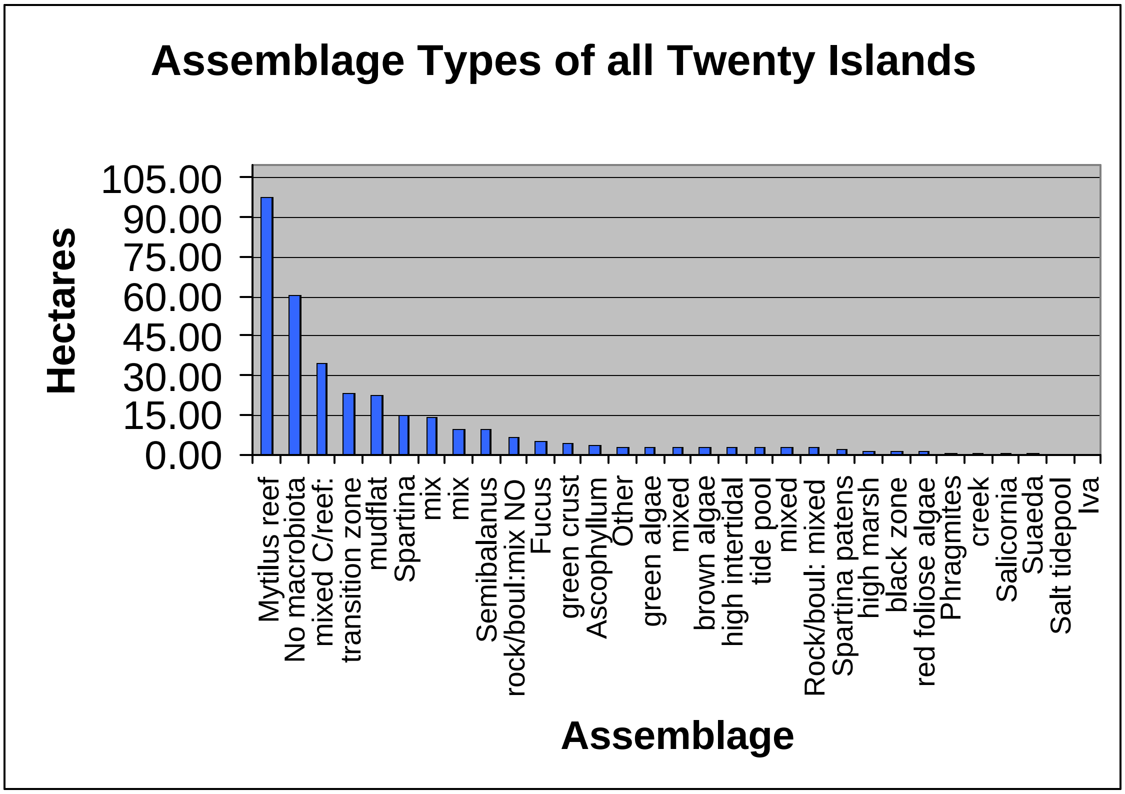


Figure 10. Hectares of assemblage types of all twenty islands.



Substrata and Assemblages – Individual Islands

Mixed substrata (coarse, coarse and fine) were the most common substrata on most islands, however the islands differed substantially in the preponderance of other types (Table 10). Two of the outer islands (Outer and Little Brewster) were the only ones of the Boston Harbor Islands to be dominated by rocky substrata (greater then 50 percent rocks, cobbles, boulders etc.). Two islands closest to the mainland, Thompson Island and Worlds End, had the highest percentage of peat and fine sediments. Georges, Gallops and Lovell islands were notable for large mussel reefs. Langlee and Raccoon Island had a much higher percentage of rocky substrata than other islands in protected parts of the harbor.

Not surprisingly, the outer islands tended to have higher percentages of the types of biotic assemblages one would expect on exposed rocky habitats (Table 11). Many of the middle and inner islands and those of Hingham Bay contained over 20 % of their intertidal area as *Mytilus* reefs. Salt marshes were best developed on Thompson's Island

and World's End. In keeping with its anomalous substrata, Langlee Island was atypical of the inner islands in having a high percentage of *Ascophyllum* assemblage.

Maps and graphs of the substrata and assemblages for each of the islands are presented in Appendix 1.

A Classification of the Islands by Ordination

We conducted an ordination, by Detrended Correspondence Analysis (DCA), on the substrate and biotic assemblage data presented in Tables 10 and 11. Our goal was to use an objective technique to organize the islands based on their similarity, or dissimilarity, in substrate and biotic assemblages. Fig. 11 is a DCA plot of the island substrate data. Distance between the points on the plot is a measure of their similarity or difference. Points close together represent islands with very similar substrate composition, while points further apart have different substrate composition. There is a clear gradient along Axis 1, with Worlds End and Outer Brewster Island at extreme ends, demonstrating that the substrate composition of these islands is very different. A grouping of islands toward the center of the plot (Long, Great Brewster, Rainsford, Gallops, Peddocks, Spectacle) all has quite similar substrate composition. The distribution of substrate types on the DCA plot clearly indicates that Outer Brewster, and Little Brewster are dominated by the rock substrate, whereas mud, mixed coarse and shell substrates best define the Worlds' End site. Lovell, Grape and Georges have similar substrates, best characterized by the mussel reef type. In general, the islands to the right of the plot are the most exposed as reflected by rock or boulder substrates, while islands toward the left are within more protected areas or are composed of mixed coarse substrates characteristic of drumlins.

Fig. 12 is a DCA ordination plot based on the biotic assemblage mapping. As with the substrate plot, there is a clear gradient from the exposed outer islands (Outer Brewster, Little Brewster, Calf) to the most protected sites. The plot is quite busy, but in general, biotic assemblages that define the rock substrate islands (Outer Brewster, Little Brewster, Calf) are rock/mixed zonation and no zonation habitats, along with *Ascophyllum*. At the other extreme, mudflats, *Fucus*, and salt marsh species (e.g., *S. alterniflora, Iva, Salicornia*) dominate the protected sites as expected. Long, Spectacle, Lovell and Peddocks have very similar biotic assemblages as reflected by their tight grouping on the DCA plot.

Table 10. Percentages of different substrata of the 20 Boston Harbor Islands analyzed for this study. Islands grouped geographically. Both those labeled as Inner Islands and as within Hingham Bay are located in more protected parts of Boston Harbor. The outer islands are most exposed to waves and wind.

	Outer Islands				Middle Islands								Inner	Hingham Bay						
Substrate	Outer Brewster	Calf	Great Brewster	Little Brewster	Lovell	Georges	Gallops	Peddocks	Hangman	Rainsford	Long	Spectacle	Thompson	Grape	Slate	Langlee	Worlds End	Sheep	Raccoon	Bumpkin
Cultural	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.68	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Reef	0.00	0.00	4.61	0.00	50.27	44.30	20.96	4.99	3.55	0.00	0.23	0.27	7.31	14.19	0.00	16.07	0.09	0.00	0.00	0.00
boulders	1.67	20.00	1.51	20.79	7.09	30.85	9.57	0.00	19.57	7.70	6.27	9.32	0.49	0.35	0.07	0.00	0.16	0.00	0.00	0.78
cobble	0.00	0.00	4.21	0.00	0.00	0.86	0.00	0.87	0.00	0.17	0.00	0.00	0.00	14.09	0.20	0.00	0.00	0.00	0.00	0.00
gravel	0.00	0.00	0.33	0.00	4.23	2.19	0.00	5.19	0.45	1.18	0.19	0.00	0.01	0.00	0.00	0.00	0.37	0.00	0.00	7.31
mixed coarse	7.88	51.26	88.68	4.90	36.80	21.61	69.07	71.88	46.01	78.75	88.21	79.75	32.14	38.44	33.51	37.57	18.76	43.36	34.99	62.18
mixed coarse & fine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.29	2.24	0.00	5.08	0.00	30.13	20.76	62.54	0.29	56.23	53.56	10.20	29.64
mud	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.42	7.54	0.00	0.00	13.41	0.00	1.86	0.00
peat	0.00	5.30	0.00	0.00	0.00	0.00	0.00	3.47	1.08	0.00	0.00	0.00	12.27	3.51	0.74	6.50	7.21	1.99	17.82	0.00
rock	90.45	22.03	0.66	74.31	0.00	0.18	0.00	0.00	27.11	12.19	0.00	3.10	0.00	1.13	2.25	39.57	0.92	0.00	33.75	0.00
sand	0.00	0.00	0.00	0.00	1.60	0.00	0.40	0.13	0.00	0.00	0.02	7.55	0.07	0.00	0.00	0.00	0.46	0.00	0.56	0.00
shells	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.00	2.39	1.09	0.15	0.00
Total Hectares	4.49	6.55	19.65	1.84	28.80	5.57	11.19	41.28	2.23	9.32	34.84	11.41	52.94	18.83	15.16	1.40	43.78	8.41	3.23	12.68

Table 11. Percentages of different biotic assemblages in the Boston Harbor Islands intertidal zone.

	Outer Islands				Middle Islands								Inner	Hingham Bay						
ASSEMBLAGE	Outer Brewster	Calf	Great Brewster	Little Brewster	Lovell	Georges	Gallops	Peddocks	Hangman	Rainsford	Long	Spectacle	Thompson	Grape	Slate	Langlee	Worlds End	Sheep	Raccoon	Bumpkin
Ascophyllum	7.93	18.35	0.00	2.89	0.00	0.74	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.66	34.79	0.16	0.00	5.14	0.00
Fucus	0.00	0.00	0.00	0.00	0.88	0.00	0.00	0.00	0.00	3.64	0.00	4.13	1.48	1.07	10.53	0.00	2.51	0.00	0.00	0.00
Iva	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Mytilus reef	0.00	1.19	7.13	6.86	52.23	42.80	21.94	31.15	3.55	24.77	49.69	43.93	30.09	18.58	28.48	17.29	29.04	6.70	0.00	13.25
No macrobiota	11.09	11.15	6.24	13.06	23.92	18.90	20.58	32.21	7.59	15.46	25.03	21.56	20.24	28.16	12.52	36.00	5.95	0.49	1.39	3.32
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	5.33	0.00	0.00	0.00	0.24	0.04	0.56	0.00
Phragmites	0.00	1.16	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.18
Rock/boul: mixed zon	17.02	0.00	0.16	36.20	0.00	0.00	4.27	0.00	0.00	0.00	0.00	3.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salicornia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.11	0.00	0.00	0.00
Salt tidepool	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Semibalanus	0.85	0.32	5.02	8.22	3.06	4.49	5.24	3.37	0.45	0.69	4.04	3.20	2.03	0.82	0.00	0.00	1.51	0.00	0.00	9.24
Spartina alterniflora	0.00	1.47	0.00	0.00	0.11	0.00	0.00	1.13	1.66	0.65	0.00	0.03	11.45	3.67	7.22	6.79	11.63	3.78	16.45	1.85
Spartina patens	0.00	2.73	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.32	0.00	0.18	0.00	2.78	0.00	1.36	0.04
Suaeda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
black zone	0.00	1.39	0.00	0.00	0.00	6.27	0.00	0.00	4.49	0.00	1.41	0.51	0.00	0.00	0.00	0.00	0.00	0.37	6.72	0.00
brown algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.02	6.51	0.00	3.27	0.00	0.00	0.00
creek	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
green algae	0.67	0.00	0.67	0.00	0.11	0.00	0.37	0.09	0.58	0.00	0.00	3.91	3.47	1.65	0.57	0.00	0.00	0.00	0.00	0.00
green crust	0.33	0.00	13.18	0.00	0.00	0.00	2.71	0.00	5.70	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	8.48	6.38	0.00
high intertidal green	0.82	0.27	6.40	0.00	0.62	4.13	0.87	0.03	0.00	3.19	0.76	2.06	0.00	0.00	0.12	0.00	0.00	0.51	0.00	0.00
high marsh	0.00	0.56	0.00	0.00	0.00	0.00	0.00	2.14	0.00	0.00	0.00	0.00	0.03	0.00	2.15	0.07	0.14	0.07	1.86	0.00
mix brown/*Semi*/reef	0.00	0.00	6.58	3.21	0.27	0.00	10.60	0.17	13.24	0.65	0.83	0.08	0.00	0.06	0.00	0.00	0.00	23.85	6.10	31.97
mix brown/*Semibalanus*	0.67	22.22	9.18	1.20	2.06	14.57	1.75	0.41	20.06	8.55	0.30	0.33	0.00	1.84	1.00	4.29	10.72	15.84	27.80	0.04

mixed C/reef: mixed	0.71	0.58	34.18	0.00	9.11	6.41	23.33	13.02	41.16	15.89	2.86	4.18	0.13	29.66	7.89	0.29	4.46	32.98	20.73	9.13
mixed br/*Semi*/green	0.00	3.65	3.71	0.00	1.56	0.18	0.20	0.00	0.00	0.00	2.03	0.60	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mixed brown/*Mytilus*	0.00	0.00	4.38	0.00	0.39	1.31	0.00	0.00	0.00	2.63	0.00	0.00	2.91	0.44	0.00	0.00	0.00	0.00	0.00	0.00
mudflat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.78	0.00	0.00	0.00	0.00	15.11	0.00	18.01	0.00	24.23	0.00	0.00	0.00
red foliose algae	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.17	0.00	0.00	2.04	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
rock/boul:mix NO zon	59.38	32.51	0.46	28.36	0.00	0.00	1.25	0.00	1.53	6.87	0.00	0.00	0.00	0.00	0.17	0.50	0.27	0.00	0.00	0.00
tide pool	0.53	1.53	1.65	0.00	3.01	0.20	1.69	0.65	0.00	0.90	0.31	3.57	0.15	0.00	0.00	0.00	0.00	0.00	2.48	0.00
transition zone	0.00	0.00	1.06	0.00	2.40	0.00	4.83	11.83	0.00	16.05	9.20	6.58	5.59	14.03	0.00	0.00	2.56	6.89	3.01	30.99
ASSEMBLAGE	Outer Brewster	Calf	Great Brewster	Little Brewster	Lovell	Georges	Gallops	Peddocks	Hangman	Rainsford	Long	Spectacle	Thompson	Grape	Slate	Langlee	Worlds End	Sheep	Raccoon	Bumpkin
Total Hectares	4.49	6.55	19.65	1.84	28.80	5.57	11.19	41.28	2.23	9.32	34.84	11.41	52.94	18.83	15.16	1.40	43.78	8.41	3.23	12.68

Figure 11. DCA Plot of Boston Harbor Islands based on substrate type.

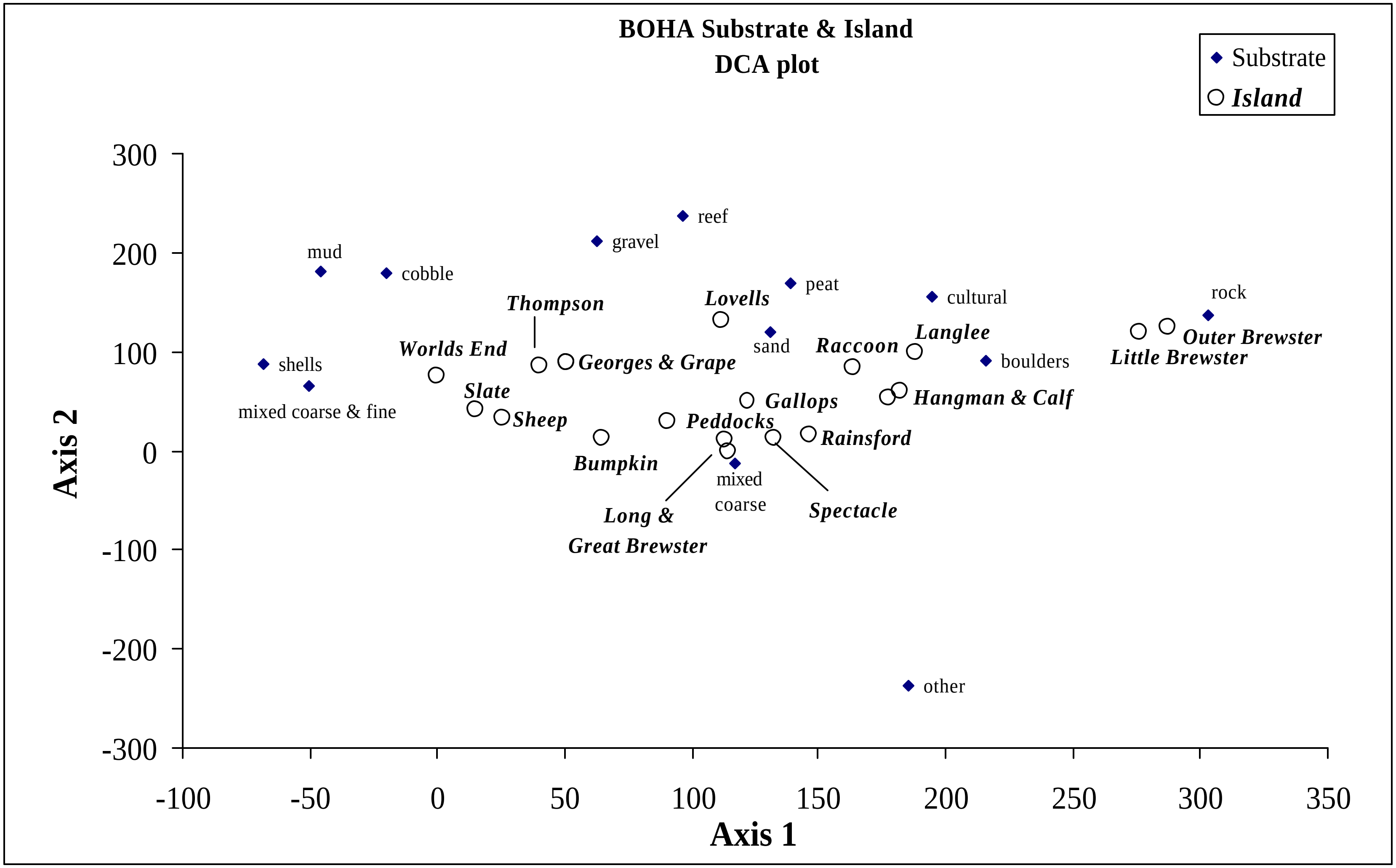
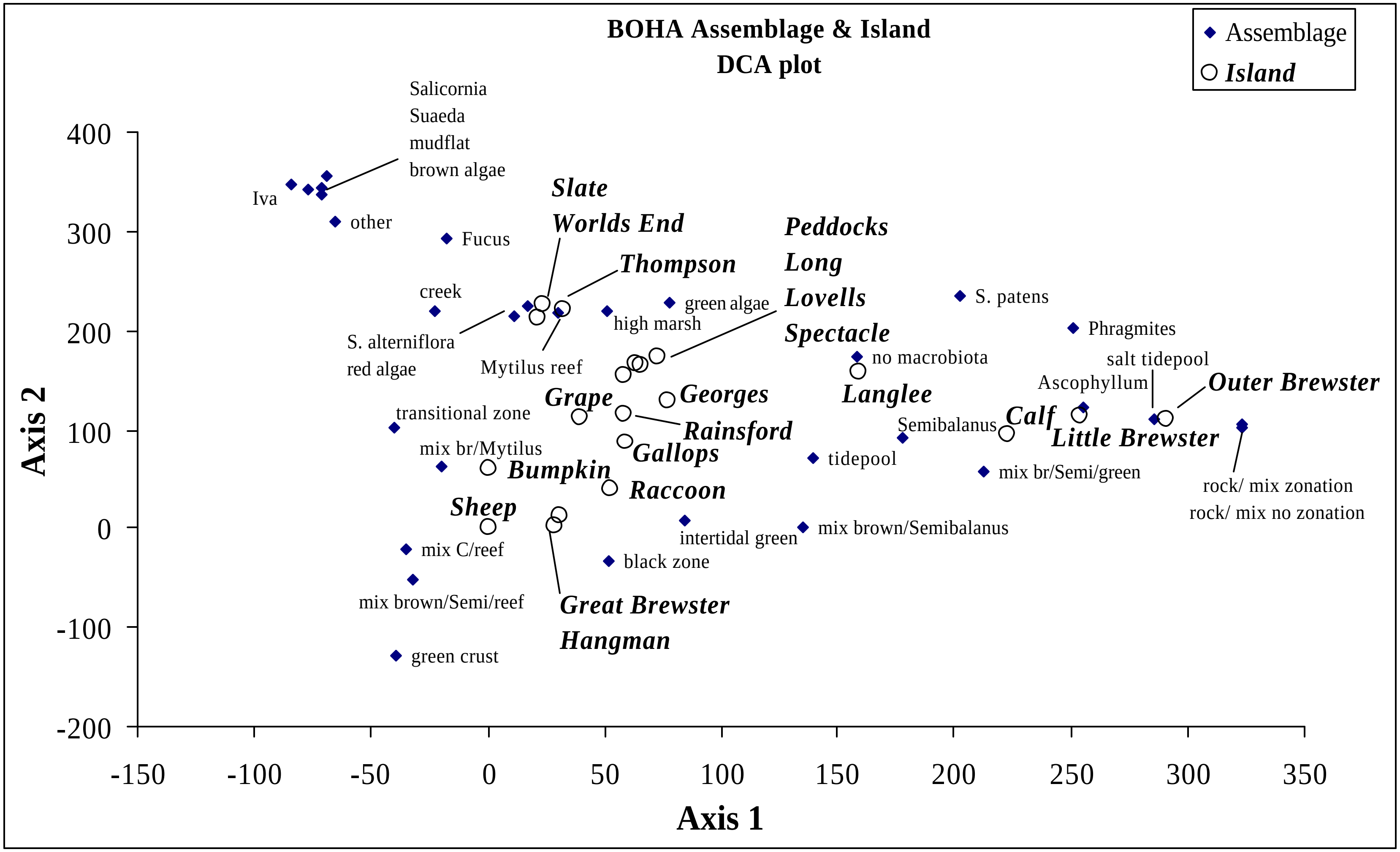


Figure 12. DCA Plot of Boston Harbor Islands based on types of biotic assemblage.



SPECIES LISTS OF INTERTIDAL ORGANISMS FROM THE BOSTON HARBOR ISLANDS

One of the tasks of the Boston Harbor Intertidal Survey was to create a species list of intertidal organisms. Because of the cryptic nature of many intertidal creatures, this list should be considered a working document. Undoubtedly future field visits will result in additional species.

Methods

As a guide to what organisms we expected to find within the intertidal areas of the Boston Harbor Islands, we requested and kindly received species lists from Northeastern University's Marine Science Center at Nahant, MA and from the Isle of Shoals Marine Laboratory (New Hampshire). These lists have been compiled over at least 20 years so they are naturally more extensive than the one we anticipated collecting for the Boston Harbor Islands. In addition, these lists include subtidal as well as intertidal whereas we restricted ourselves to intertidal organisms for the Boston Harbor Islands.

Species lists for the Boston Harbor Islands were based on two different sets of observations. We kept records of species observed in the course of our work delineating different biotic assemblages and substrata. We also were joined at various times in the field by three experts on the taxonomy of different groups of marine organisms. These were Dr. Larry Harris of the University of New Hampshire (hard bottom invertebrates), Dr. Arthur Mathieson of the University of New Hampshire (macroalgae), and Dr. Harlan Dean of the Museum of Comparative Zoology at Harvard University (soft bottom benthic invertebrates). Harris made four visits to four different islands, Mathieson three, and Dean two. Mathieson also provided us with lists of seaweeds recorded during the New England Offshore Mining Environmental Study (NOMES) survey of 1972-3 (Harris 1974).

We did not attempt a quantitative survey, but directed our experts toward representative habitats and those that we felt would yield the greatest diversity. Records were kept for different islands. Vertebrates were not heavily sampled during this project. An avian survey was conducted for the NPS by a research team from URI led by Peter Patons and fish and mammals received a low level of effort. Data were incorporated into the National Park Service's NPSpecies data base and each species was given a number from the International Taxonomic Identification System's data base. Species that were not on the ITIS data base were assigned a negative number.

All surveys were conducted within several hours of low tide, on numerous dates from April through October, 2001. Additional description of the methods used by Arthur Mathieson for identifying seaweeds is given in Appendix 2.

The following sources were used as general taxonomic references:
Seaweeds – Villalard-Bohnsack (1995)
Vascular Plants - Gleason and Cronquist (1991)
Marine Invertebrates – Gosner (1979), Pollock (1998)

Arthur Mathieson provided a more detailed description of his protocols for collecting and identifying the seaweeds:

> The procedures for collection and identification of seaweeds were similar to those outlined by Mathieson et al. (1998), namely sampling of all conspicuous seaweeds were made from diverse intertidal (on foot) and shallow subtidal habitats. The samples were returned to the Jackson Estuarine Laboratory within ~0.5 day and were either processed immediately or kept under refrigeration for ~ 1-2. Macroscopic or microscopic evaluations were made and voucher specimens of each taxon were prepared and deposited in the Albion R. Hodgdon Herbarium at the University of New Hampshire (NHA). Several taxonomic references were utilized: Adey and Adey 1973; Bird and McLachlan 1992; Blair 1983; Bliding 1963, 1968; Blomster et al. 1999; Burrows 1991; Dixon and Irvine 1977; Düwel and Wegeberg 1996; Farlow 1881; Fletcher 1987; Harper and Saunders, 2000; Hoek 1963, 1982; Irvine 1983; Irvine and Chamberlain 1994; Kingsbury 1969; Maggs and Hommersand 1993; Schneider and Searles 1991; Sears 1998; Silva et al. 1996; Taylor 1957; Villalard-Bohnsack 1995; Webber and Wilce 1971; Woelkerling 1973; Wynne and Heine 1992). The nomenclature employed primarily follows South and Tittley (1986), except for recent changes noted by Sears (1998) and Silva et al. (1996).

Results and Discussion

Ninety five species of animals, 70 marine algae, 15 vascular plants and three fungi were identified to the species level in the Boston Harbor Islands intertidal surveys of 2001 (Tables 12-15). Annelida, Arthropoda, Mollusca, and Ectoprocta (Bryozoa) were the best represented animal phyla in terms of species (Table 16). Crustacea, Polychaeta, and Gastropoda had the highest number of species among the animal classes (Table 17).

The Rhodophyceae were the most frequently represented among the algal divisions (Table 18). Arthur Mathieson's comparison of the macroalgae he recorded during our surveys and the NOMES surveys is included in Appendix 2. The vascular plants were all common salt and brackish marsh species (Table 14).

Of the 95 animals, 85 are considered native species, eight as non-native, and two of unknown (cryptogenic) origin. The invasive animals included the recent invasive crab, *Hemigrapsus sanguineus*. All the animal species we recorded during our survey have also been recorded at Nahant and Isle of Shoals. Of the seaweeds, 67 are considered native and three non-native. The non-native seaweed, *Codium fragile*, which was recorded at both Nahant and the Isle of Shoals was not recorded at the Boston Harbor Islands, either in our survey or the 1971-1972 NOMES study (Harris 1974). This invasive seaweed is common at the Isle of Shoals.

We recorded the most seaweed taxa on the rocky islands of Calf, and Little Brewster and the rocky areas of Rainsford (Table 19). Lovell and Calf islands had the highest number of invertebrate taxa. Thompson Island contained the most intertidal vascular plant species, due to the presence of the most extensive salt marsh in the islands. The survey was designed to record the total diversity of species in the harbor and as such certain islands were sampled more intensely and at different times of year; some caution should be used when interpreting the results of between island comparisons.

It is clear by comparing the lists from our survey to those of others that there is a potential for finding many more intertidal species in the Boston Harbor Islands with continued observations (Tables 20-21). The three other surveys cited in these two tables included subtidal species, and the Shoals and Nahant surveys were collected over many years, so it is not surprising that their species lists are more extensive.

Table 12. Invertebrates recorded in the Boston Harbor Islands intertidal zone during out field surveys in 2001. TSN is to the taxonomic species number set by ITIS (International Taxonomic Identification System), the species database used by the National Park Service. A negative number indicates that this is a new species for the ITIS database.

Phylum	Class	Order	Family	Genus and Species	TSN	Abundance	Nativity
Porifera	Calcarea	Leucosoleniida	Leucosoleniidae	*Leucosolenia botryoides*	46950	Uncommon	Native
	Desmospongiae	Halichondrida	Halichondriidae	*Halichondria panicea*	48396	Uncommon	Native
				Halichondria bowerbanki	48398	Uncommon	Native
		Haplosclerida	Haliclonidae	*Haliclona loosanoffi*	47774	Unknown	Native
Cnidaria	Anthozoa	Actinaria	Haliplanellidae	*Haliplanella luciae*	52766	Unknown	Non-Native
			Metridiidae	*Metridium senile*	52737	Uncommon	Native
	Hydrozoa	Hydroida	Campanulariidae	*Obelia sp.*	49514	Unknown	Native
			Clavidae	*Clava multicornis*	48891	Unknown	Native
			Eudendriidae	*Eudendrium dispar*	49113	Unknown	Native
			Sertulariidae	*Sertularia pumila*	49916	Unknown	Unknown
			Tubulariidae	*Tubularia larynx*	48923	Unknown	Native
				Tubularia crocea	48921	Common	Native
		Scleractinia	Hydractiniidae	*Hydractinia echinata*	49363	Unknown	Native
Nemertea	Anopla	Heteronemertea	Lineidae	*Lineus ruber*	57463	Unknown	Native
	Enopla	Hoplonemertea	Amphiporidae	*Amphiporus angulatus*	57524	Unknown	Native
Entoprocta			Barentsiidae	*Barentsia laxa*	-3	Unknown	Native
Ectoprocta	Gymnolaemata	Cheilostomata	Bugulidae	*Bugula simplex*	206725	Common	Native
				Bugula turrita	156050	Common	Native
			Calloporidae	*Callopora aurita*	155914	Unknown	Native
			Cryptosulidae	*Cryptosula pallasiana*	156536	Unknown	Native

Phylum	Class	Order	Family	Genus and Species	TSN	Abundance	Nativity
Ectoprocta	Gymnolaemata	Cheilostomata	Electridae	*Electra pilosa*	155868	Common	Native
			Hippothoidae	*Hippothoa hyalina*	156197	Unknown	Native
			Membraniporidae	*Membranipora membranacea*	155824	Common	Non-Native
			Schizoporellidae	*Schizoporella unicornis*	156294	Unknown	Native
		Ctenostomata	Alcyonidiidae	*Alcyonidium polyoum*	155476	Common	Native
			Vesiculariidae	*Bowerbankia gracilis*	155559	Unknown	Native
		Cyclostomata	Crisiidae	*Crisia eburnea*	155608	Unknown	Native
Sipuncula			Sipunculidae	*Phascolopsis gouldi*	154595	Unknown	Native
Mollusca	Bivalva	Myoida	Myidae	*Mya arenaria*	81692	Abundant	Native
		Mytiloida	Mytilidae	*Mytilus edulis*	79454	Abundant	Native
				Geukensia demissus	79504	Uncommon	Native
		Ostreoida	Anomiidae	*Anomia aculeata*	79797	Unknown	Native
			Ostreidae	*Ostrea edulis*	79885	Uncommon	Native
		Veneroida	Pharidae	*Ensis directus*	81022	Unknown	Native
	Cephalopoda	Teuthida	Loliginidae	*Loligo sp.*	82370	Unknown	Native
	Gastropoda	Neogastropod	Muricidae	*Nucella lapillus*	73297	Abundant	Native
		Neotaenioglos	Calyptraeidae	*Crepidula fornicata*	72623	Abundant	Native
				Crepidula plana	72627	Common	Native
			Littorinidae	*Littorina obtusata*	70420	Common	Native
				Lacuna vincta	70381	Common	Native
				Littorina saxatilis	70405	Common	Native
				Littorina littorea	70419	Abundant	Non-Native
		Nudibranchia	Onchidorididae	*Onchidoris fusca*	78393	Unknown	Native
				Onchidoris muricata	78381	Unknown	Native
				Acanthodoris pilosa	78359	Uncommon	Native
			Polyceratidae	*Polycera lessonii*	182748	Unknown	Native
		Patellogastrop	Lottiidae	*Notoacmaea testudinalis*	69668	Common	Native

Phylum	Class	Order	Family	Genus and Species	TSN	Abundance	Nativity
Annelida	Oligochaeta	Haplotaxida	Enchytraeidae	*Marionina southerni*	68521	Unknown	Native
			Tubificidae	*Phallodrilus monospermathecus*	68711	Unknown	Native
				Peloscolex benedeni	68591	Unknown	Native
				Clitellio arenarius	68718	Unknown	Native
	Polychaeta	Aciculata	Nereididae	*Hediste diversicolor*	65991	Unknown	Native
			Phyllodocidae	*Eteone longa*	65263	Unknown	Native
			Polynoidae	*Lepidonotus squamatus*	64604	Common	Native
				Harmothoe imbricata	64513	Common	Native
		Ariciida	Orbiniidae	*Leitoscoloplos fragilis*	66656	Unknown	Native
				Leitoscoloplos robustus	182728	Unknown	Native
		Canalipalpata	Amphictenidae	*Pectinaria granulata*	67711	Unknown	Native
				Pectinaria gouldi	67709	Unknown	Native
			Cirratulidae	*Chaetozone setosa*	67157	Unknown	Native
			Serpulidae	*Spirorbis borealis*	68257	Common	Native
			Spionidae	*Polydora cornuta*	204501	Unknown	Native
				Streblospio benedicti	66939	Unknown	Native
				Spio setosa	66868	Unknown	Native
			Terebellidae	*Polycirrus eximius*	67963	Unknown	Native
		Capitellida	Capitellidae	*Capitella capitata*	67415	Unknown	Native
			Maldanidae	*Clymenella torquata*	67528	Unknown	Native
Arthropoda	Crustacea	Isopoda	Idoteidae	*Idotea balthica*	92595	Abundant	Native
			Janiridae	*Jaera marina*	92814	Unknown	Native
		Amphipoda	Aoridae	*Microdeutopus gryllotalpa*	93477	Unknown	Native
			Corophiidae	*Corophium volutator*	93601	Unknown	Native
			Gammaridae	*Gammarus mucronatus*	93783	Unknown	Native
				Gammarus oceanicus	93786	Abundant	Native
				Melita nitida	93812	Unknown	Native
		Decapoda	Cancridae	*Cancer borealis*	98678	Common	Native
				Cancer irroratus	98679	Common	Native
			Grapsidae	*Hemigrapsus sanguineus*	-1	Common	Non-Native

Phylum	Class	Order	Family	Genus and Species	TSN	Abundance	Nativity
Arthropoda	Crustacea	Decapoda	Nephropidae	*Homarus americanus*	97314	Uncommon	Native
			Paguridae	*Pagurus acadianus*	97803	Uncommon	Native
				Pagurus longicarpus	97807	Abundant	Native
			Portunidae	*Carcinus maenas*	98734	Abundant	Non-Native
		Thoracica	Archaeobalanidae	*Semibalanus balanoides*	89687	Abundant	Native
			Balanidae	*Balanus crenatus*	89606	Unknown	Native
	Insecta	Collembola	Hypogastruridae	*Anurida maritima*	100182	Common	Native
Echinodermata	Asteroidea	Forcipulatida	Asteriidae	*Asterias vulgaris*	157219	Common	Native
				Asterias forbesi	157217	Common	Native
		Spinulosida	Echinasteridae	*Henricia sanguinolenta*	157165	Uncommon	Native
	Echinoidea	Echinoida	Strongylocentroti	*Strongylocentrotus*	157969	Common	Native
	Ophiuroidea	Ophiurida	Amphiuridae	*Axiognathus squamatus*	157678	Unknown	Native
			Ophiactidae	*Ophiopholis aculeata*	157617	Unknown	Native
Chordata	Ascidiacea	Phlebobranchi	Cionidae	*Ciona intestinalis*	159113	Uncommon	Unknown
		Stolidobranchi	Styelidae	*Styela partita*	159332	Unknown	Native
				Styela clava	159337	Common	Non-Native
				Botryllus schlosseri	159373	Common	Non-Native
				Botrylloides violaceous	-4	Abundant	Non-Native

Table 13. Seaweeds and other algae recorded in the Boston Harbor Islands intertidal zone during out field surveys in 2001. Taxa in quotes are no longer considered distinct taxa but are growth forms of other species.

Kingdom	Division	Order	Family	Genus and Species	TSN	Abundance	Nativity
Monera	Cyanobacteria	Nostocales	Oscillatoriaceae	*Lyngbya majuscula*	877	Unknown	Native
				Oscillatoria sp.	917	Unknown	Native
			Rivulariaceae	*Calothrix crustacea*	1247	Common	Native
Protista	Bacillariophyceae	Blank	Blank	*Berkeleya rutilans*	-5	Common	Native
	Chlorophyceae	Ulvales	Monostromaceae	*Gomontia polyrhiza*	6028	Uncommon	Native
				Monostroma oxyspermum	6483	Uncommon	Native
		Ulvaceae		*Blidingia minima*	6503	Common	Native
				Enteromorpha intestinalis	6535	Common	Native
				Enteromorpha linza	6528	Common	Native
				Enteromorpha prolifera	6541	Unknown	Native
				Ulva lactuca	6562	Common	Native
		Prasiolales	Prasiolaceae	*Prasiola stipitata*	6398	Common	Native
		Acrosiphoniales	Acrosiphoniaceae	*Spongomorpha arcta*	6724	Uncommon	Native
				Spongomorpha spinescen	*s*6733	Unknown	Native
		Cladophorales	Cladophoraceae	*Chaetomorpha linum*	6751	Uncommon	Native
				Chaetomorpha melagonium	6757	Uncommon	Native
				Chaetomorpha picquotiana	-6	Unknown	Native
				Cladophora sericea	6768	Uncommon	Native
		Codiales		*Rhizoclonium riparium*	6855	Unknown	Native
				Rhizoclonium tortuosum	6857	Unknown	Native
	Phaeophyceae	Ectocarpales	Ectocarpaceae	*Ectocarpus siliculosus*	10703	Common	Native
				Pilayella littoralis	10824	Unknown	Native

Kingdom	Division	Order	Family	Genus and Species	TSN	Abundance	Nativity
Protista	Phaeophyceae	Ectocarpales	Elachistaceae	*Elachista fucicola*	10938	Common	Native
		Chordariales	Chordariaceae	*Chordaria flagelliformis*	10976	Common	Native
		Desmerestiales	Desmarestiaceae	*Desmarestia aculeate*	11315	Uncommon	Native
			Dictyosiphonales	*"Ralfsia bornetii"*		Unknown	
			Dictyosiphonaceae	*Dictyosiphon foeniculaceus*	11085	Uncommon	Native
			Scytosiphoaceae	*Petalonia fascia*	11432	Uncommon	Native
				Ralfsia verrucosa	10862	Common	Native
				Scytosiphon lomentaria	11435	Common	Native
		Laminariales	Laminariaceae	*Laminaria saccharina*	11222	Common	Native
			Alariaceae	*Alaria esculenta*	11300	Uncommon	Native
			Chordaceae	*Chorda tomentosa*	11215	Uncommon	Native
			Laminariaceae	*Agarum clathratum*	11247	Uncommon	Native
				Laminaria digitata	11228	Uncommon	Native
		Fucales	Fucaceae	*Ascophyllum nodosum*	11331	Abundant	Native
				Fucus distichus edentatus	11338	Common	Native
				Fucus distichus evanescens	11346	Common	Native
				Fucus spiralis	11340	Uncommon	Native
				Fucus vesiculosus	11335	Abundant	Native
				Fucus vesiculosus forma mytilii		Unknown	Native
	Rhodophyceae	Compsopogonales	Erythropeltidaceae	*Erythrotrichia carnea*	11502	Unknown	Native
		Bangiales	Bangiaceae	*Bangia atropurpurea*	11537	Unknown	Native
				Porphyra leucostricta	11541	Unknown	Native
				Porphyra purpurea	11575	Common	Native
				Porphyra umbilicalis	11543	Common	Native
		Bonnemaisoniales	Bonnemaisoniaceae	*Bonnemaisonia hamifera*	11779	Uncommon	Non-Native

Kingdom	Division	Order	Family	Genus and Species	TSN	Abundance	Nativity
Protista	Rhodophyceae	Palmariales	Order:	*Palmaria palmata*	12842	Uncommon	Native
		Hildenbrandiales	Hildenbrandiaceae	*Hildenbrandia prototypus*	12298	Common	Native
		Corallinales	Corallinaceae	*Clathromorphum*	12432	Common	Native
				Corallina officinalis	12328	Common	Native
				Lithothamnion glaciale	-8	Common	Native
				Phymatolithon lenormandii	12530	Unknown	Native
		Gigartinales	Cystocloniaceae	*Cystoclonium purpureum*	12183	Uncommon	Native
			Dumontiaceae	*Dumontia incrassata*	12242	Common	Non-Native
			Gigartinaceae	*Chondrus crispus*	12092	Abundant	Native
			Kallymeniaceae	*Callocolax neglectus*	12642	Uncommon	Native
				Euthora cristata	12664	Uncommon	Native
			Petrocelidaceae	*"Petrocelis cruenta"*	11886	Uncommon	
				Mastocarpus stellatus	12104	Common	Native
			Phyllophoraceae	*Gymnogongrus crenulatus*	12069	Unknown	Native
				Phyllophora pseudoceranoides	12051	Unknown	Native
		Ahnfeltiales	Ahnfeltiaceae	*Ahnfeltia plicata*	12043	Uncommon	Native
		Rhodymeniales	Champiaceae	*Lomentaria clavellosa*	12732	Unknown	Native
		Ceramiales	Ceramiaceae	*Ceramium rubrum*	12983	Common	Native
			Delesseriaceae	*Phycodrys rubens*	13292	Unknown	Native
			Rhodomelaceae	*Polysiphonia harveyi*	13461	Common	Non-Native
				Polysiphonia lanosa	13510	Common	Native
				Rhodomela confervoides	13580	Unknown	Native
	Xanthophyceae	Vaucheriales	Vaucheriaceae	*Vaucheria sp.*	2084	Unknown	Native

Table 14. Vascular plants recorded in the intertidal zone during the Boston Harbor Islands intertidal survey of 2001.

Order	Family	Genus and Species	TSN	Abundance	Nativity
Caryophyllales	Chenopodiaceae	*Atriplex patula*	20509	Uncommon	Non-Native
Caryophyllales	Chenopodiaceae	*Salicornia europaea*	20647	Uncommon	Native
Caryophyllales	Chenopodiaceae	*Suaeda maritima*	20662	Uncommon	Native
Myrtales	Lythraceae	*Lythrum salicaria*	27079	Uncommon	Native
Plumbaginales	Plumbaginaceae	*Limonium carolinianum*	21330	Uncommon	Native
Asterales	Asteraceae	*Solidago sempervirens*	36226	Common	Native
Najadales	Ruppiaceae	*Ruppia maritima*	39063	Uncommon	Native
Juncales	Juncaceae	*Juncus gerardi*	39235	Uncommon	Unknown
Cyperales	Poaceae	*Agropyron repens*	40382	Uncommon	Native
Cyperales	Poaceae	*Agrostis stolonifera*	40400	Uncommon	Native
Cyperales	Poaceae	*Distichlis spicata*	40662	Uncommon	Native
Cyperales	Poaceae	*Phragmites australis*	41072	Common	Non-native haplotype
Cyperales	Poaceae	*Puccinellia maritima*	41216	Uncommon	Native
Cyperales	Poaceae	*Spartina alterniflora*	41267	Common	Native
Cyperales	Poaceae	*Spartina patens*	41271	Common	Native

Table 15. Fungi recorded in the Intertidal Zone and immediately adjacent uplands in the Boston Harbor Islands, 2001. Identifications by Arthur Mathieson and Scott LeGreca.

Genus and Species	Abundance
Lichinia sp.	Uncommon
Pyrenocollema halodytes	Common
Verrucaria ditmarsica	Uncommon
Verrucaria erichsenii	Uncommon
Verrucaria mucosa	Unknown
Verrucaria maura	Common
Verrucaria striatula	Common
Xanthoria parietina	Unknown

Table 16. Number of species recorded from different animal phyla.

Phylum	Number of Species
Annelida	20
Mollusca	19
Arthropoda	17
Ectoprocta	11
Cnidaria	9
Echinodermata	6
Chordata	5
Porifera	4
Nemertea	2
Entoprocta	1
Sipuncula	1

Table 17. Number of species from different animal classes.

Phylum	Class	Number of Species
Porifera	Calcarea	1
Porifera	Desmospongiae	3
Cnidaria	Anthozoa	2
Cnidaria	Hydrozoa	7
Nemertea	Anopla	1
Nemertea	Enopla	1
Sipuncula		1
Ectoprocta	Gymnolaemata	11
Entoprocta		1
Mollusca	Bivalva	6
Mollusca	Cephalopoda	1
Mollusca	Gastropoda	12
Arthropoda	Crustacea	16
Arthropoda	Insecta	1
Annelida	Oligochaeta	4
Annelida	Polychaeta	16
Echinodermata	Asteroidea	3
Echinodermata	Echinoidea	1
Echinodermata	Ophiuroidea	2
Chordata	Ascidiacea	5

Table 18. Number of seaweeds and other algae from different divisions recorded during the Boston Harbor Islands (2001) intertidal survey.

Division	**Number of Species**
Cyanobacteria	3
Bacillariophyceae	1
Chlorophyceae	16
Phaeophyceae	21
Rhodophyceae	28
Xanthophyceae	1
Total	70

Table 19. Number of invertebrate, seaweed, and plant taxa recorded on different islands during different site visits.

Island	Date of survey	Invertebrates	Seaweeds	Plants
Thompson’s	4/13/2001	7	7	4
Lovell’s	5-1-2001	26	24	1
Little Brewster	5/3/2001	19	30	0
George's	5/15/2001	15	16	0
Thompson’s	7/19/2001	12	10	15
Little Brewster	8/1/2001	43	21	0
Lovell's	9/24/2001	44	15	4
Rainsford	9/27/2001	41	30	2
Calf	11/12/2001	46	29	5

Table 20. Comparison of invertebrate species recorded in the Boston Harbor Islands (2001), the Shoals Marine Lab, and Northeastern’s Marine Lab at Nahant. Numbers are the number of species recorded at each site within the particular phylum.

Phylum	BHI	Shoals	Nahant
ACANTHOCEPHALA	0	2	0
ANNELIDA	20	75	73
ARTHROPODA	17	132	83
BRACHIOPODA	0	1	0
BRYOZOA	11	37	2
CHAETOGNATHA	0	1	1
CHORDATA	5	16	12
CNIDARIA	9	49	32
CTENOPHORA	0	3	4
ECHINODERMATA	6	20	10
ENTOPROCTA	1	2	12
HEMICHORDATA	0	1	0
MOLLUSCA	19	126	61
NEMATODA	0	3	0
NEMATOMORPHA	0	1	0
NEMERTEA	2	10	15
PLATYHELMINTHES	1	23	32
PORIFERA	4	19	12
SIPUNCULA	1	2	0
TARDIGRADA	0	2	0
Total	96	525	349

Table 21. Number of macroalgae taxa. Comparison of Boston Harbor Islands (2001) study with others. NOMES = New England Offshore Mining Environmental Study carried out in 1972-3 (Harris 1974). Shoals = ongoing list of the Shoals Marine Lab. Nahant = ongoing list of the Northeastern University Marine Science Center at Nahant.

Division	BHI 2001	NOMES	Shoals	Nahant
Chlorophyceae	16	10	41	42
Phaeophyceae	21	15	48	41
Rhodophyceae	28	47	73	43
Total	65	72	162	126

Additional Notes on Boston Harbor Seaweed Populations by Arthur C. Mathieson

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A Comparison with the NOMES (1971-2) Survey

Several plants found on Calf & Rainsford Islands were not found during the New England Offshore Mining Environmental Study (NOMES) project around three decades ago. Even so, it should be emphasized that the latter studies were entirely subtidal, while collections on both Calf & Rainsford Islands included both intertidal and shallow subtidal collections, including some circumscribed salt marsh habitats. Overall, two blue-green algae (*Calothrix crustacea* & *Oscillatoria* sp.), one yellow-green (*Vaucheria* sp.), eight greens (i.e., *Blidingia minima, Enteromorpha intestinalis, Enteromorpha prolifera, Gomontia polyrhiza, Monostroma oxyspermum, Prasiola stipitata, Rhizoclonium riparium* and *Rhizoclonium tortuosum*), eleven browns (*Ascophyllum nodosum, Elachista fucicola, Fucus distichus L. ssp. edentatus, Fucus spiralis, Fucus vesiculosus, Fucus vesiculosus L. forma mytilii, Petalonia fascia, Pilayella littoralis, "Ralfsia bornetii", Scytosiphon lomentaria* & *Spongonema tomentosum*), six red algae (*Bonnemaisonia hamifera, Erythrotrichia carnea, Phymatolithon lenormandii, Polysiphonia harveyi, Porphyra ?leucosticta, Porphyra purpurea* and *Porphyra ?umbilicalis*), and yellow-green alga (*Vaucheria*) were found on the two islands but not during the NOMES studies. Most of these insular taxa are common coastal and estuarine intertidal taxa within the Gulf of Maine, including salt marsh habitats. The small microscopic red alga *Erythrotrichia carnea* could have been easily missed in the earlier NOMES studies. Both *Bonnemaisonia hamifera* & *Polysiphonia harveyi* may not have been present (?uncommon) three decades ago, as they are both introduced Japanese taxa (McIvor et al. 2000; Villalard-Bohnsack 1998). The former plant is a more recent introduction (Villalard-Bohnsack 1998) than the latter, which dates back to the mid 1800's in Connecticut (McIvor et al. 2000). Both of these red algae have rapidly expanded within the Gulf of Maine during the past ~20 years. The red alga *Lomentaria clavellosa* is also another introduced red alga (European), which was originally collected within Boston Harbor in 1963 (cf. Wilce and Lee 1964).

In comparing the diversity on Calf and Rainsford Islands (i.e., those that I evaluated, the outer exposed island (i.e., Calf I) is obviously richer than the inner one. Further Calf Island also has the greatest number of habitats, ranging from sheltered to exposed open coastal, tide pools, platforms, boulders, some sand, salt marshes, etc. Similar patterns of varying diversity are also known for sheltered versus exposed insular habitats throughout the Gulf of Maine (Mathieson & Penniman 1986; Mathieson et al. 1996,1998). A comparison of Robert Buchsbaum's sampling on Lovell Island showed 13 taxa that are also included in the attached tabulation (see Appendix 2). Probably other taxa would be here albeit if I had collected in a similar manner as on Calf and Rainsford. Lastly, a comparison of the NOMES data shows the highest overall diversity for several obvious reasons: (a) detailed seasonal collections were made at several sites; (b) diverse subtidal habitats were evaluated; (c) the shallow-mid subtidal habitats in open coastal habitats tend to have higher diversity than analogous intertidal habitats (Mathieson 1979).

Introduced seaweed taxa within Boston Harbor:

Bonnemaisonia hamifera: an introduced Asiatic taxon (i.e., gametophytic stage to *Trailliella intricata*).

Dumontia contorta: The potential introduction of this plant has not been appreciated; however, prior to the early 1900's it was unknown from New England, including sites from Maine-Massachusetts where F. S. Collins had collected extensively. It was first recorded in the early 1900's by Grace Dunn near Kittery Point and has subsequently been documented at many other New England and Canadian Maritime sites. W. A. Setchell's account of this plants disagrees with this evaluation, as he felt it had simply been confused with another plant (*Devaleraea ramentacea*). However, my evaluation of many historical herbarium specimens showed no records of this taxon or its confusion with *D. ramentacea*. Assuming *D. contorta* is an introduced taxon, it is probably of European origin, as it is abundant in northern Europe.

Lomentaria clavellosa: originally described as a European introduction from Boston Harbor (Wilce & Lee 1964); subsequently it has been found in NH and at selected sites in Maine. Typically it occurs in warm estuarine locations, as within the Great Bay Estuarine system. Hence, this may indicate a "warm temperate" source of the original European material.

Polysiphonia harveyi: the plant was initially described in the mid 1800's from Connecticut; recently (late 1990's) it was shown to be an introduced Japanese taxon that had previously been given another name in its native habitat; however, *P. harveyi* has priority over the newer Japanese name. The basis of its non-native status was documented by C. Maggs' and colleagues (UK) utilizing DNA technique and critical evaluations of Japanese and North Atlantic herbarium specimens.

Codium fragile ssp. *tomentosoides*: Found in some Boston Harbor sites during a rapid assessment studies of August 2000 (J. Pederson, MIT Sea Grant, unpublished results), but not recorded during this survey or the NOMES survey.

SUMMARY OF MANAGEMENT ISSUES AND RECOMMENDATIONS FOR INTERTIDAL HABITATS

Introduction

The Boston Harbor Islands are in the middle of an urban harbor with a long history of human use. As such, the intertidal zone, as well as other habitats are faced with numerous management issues that relate to habitat protection, water quality, and public access.

Protecting Habitats of Particular Concern

Salt Marshes

Significant acreages of salt marshes occur on Thompson's Island, World's End, and Peddocks Island. Calf Island contains a small marsh, the only one in the outer islands. Smaller fringing marshes are a common habitat type throughout the islands. In accordance with the Massachusetts Wetlands Protection Act (M.G.L. Ch 131, Sec. 40) these wetlands are protected, and further, a buffer protection zone of at least 100-ft into the upland border is recommended (310 CMR 10.00).

The salt marsh at the southwest side of Thompson's Island is the most extensive salt marsh in the islands outside World's End. It contains vegetated habitats, pannes, and creeks typical of Gulf of Maine salt marshes. Based on several site visits, the marsh serves as a feeding and loafing area for waterfowl (green-winged teal, black ducks, and mallards were noted) and herons (snowy egrets).

During our first survey year (2001), a substantial portion of the southwest corner of the Thompson's Island marsh was covered with a thick layer of wrack (mostly dead *Spartina alterniflora* plants) for several months. This is a natural phenomenon and will likely have an impact on the type of vegetation cover, at least in the short term.

The Thompson's Island marsh receives a fair amount of visitation due to the presence of the Outward Bound program on the island. There was some marsh erosion in the path on both sides of the bridge over the marsh creek. Education programs associated with the marsh are encouraged, but a boardwalk in this area would be helpful to restore the area. Another human disturbance we observed was evidence of driving along the upper edge of this salt marsh. Obvious tire tracks were left by vehicles and were still visible throughout the summer. The tracks were colonized to some extent by annual plants later in the growing season. We recommend that such driving not be permitted on the marsh.

A large float sits on the tidal flats near the salt marsh at the south end of Thompson's Island. Floats need to be stored in the off-season where they will have the least impact on marsh or beach vegetation.

A salt marsh restoration project is currently underway at World's End to address a tidal restriction. This is sponsored by the current owner (The Trustees of Reservations) and has been carried out in conjunction with the Massachusetts Wetlands Restoration Program.

See also the section on boat wakes.

Tide Pools

Tide pools and adjacent rocky areas are very attractive habitats to visitors. They occur on practically all the islands and may be within large boulder or bedrock-dominated shorelines or within gravel bars. Their educational value is tremendous; however overuse could cause their degradation. The interaction of visitors with tide pools should be managed to encourage visitation at certain pools, e.g., on George's Island and Thompson's Island, but not at others. Calf Island, which contains a particularly rich rocky shoreline, is a prime example of the latter. Visitation to certain pools could also be staggered over time to allow pools to recover if they are being impacted.

Bird Habitats of the Intertidal zone

Common and Least Terns nest adjacent to the intertidal zone on Rainsford Island. These are species of special concern. The presence of people in the intertidal zone would likely disturb the nesting of these birds. We recommend that any visitation to this small island by the public be limited to the non nesting season and that pets be leashed. Based on the results of ongoing visitor impact studies, tern wardens could be placed on the island to patrol the nesting area and educate the public if it looks like disturbance is a problem for the birds. Wardens currently patrol many beaches in Massachusetts where coastal birds nest. The period of concern is May through the end of July.

American oystercatchers, Haematopus palliatus, first began nesting on the Boston Harbor Islands in 1989 (Veit and Petersen 1989). Previous to that, the farthest north they had nested was on Cape Cod. Great Brewster Island holds the greatest number of nesting pairs in the region. The presence of people in the intertidal zone near their nests could disrupt the nesting of these birds, which are very sensitive to disturbance. We recommend that visitors be kept away from the area on this island (and other islands) where these birds breed during the breeding season.

Migratory shorebirds reach their peak numbers in this region in late July and August. Depending on the results of the bird surveys (data to be provided by URI), concentrations of these birds in feeding and resting areas should be clearly delineated by symbolic fencing and the public educated on the need to avoid stressing the birds.

Harbor Seal haul out beaches

Concentrations of harbor seals haul out at Green and Little Calf islands. Lovell's and Little Brewster islands are occasionally used as well. Most of this activity takes place in winter when boater activity and visitation is low. Nonetheless public education programs should stress the need to avoid disturbing these areas and if necessary access to certain areas should be limited and pets not allowed. Hauling out areas used by seals could change over time, therefore periodic updates are necessary.

Shellfish Reefs

See under boat wakes.

Invasive Species

Invasive marine species are receiving a great deal of attention in recent years, as evident from a number of articles (e.g., Carleton and Geller, 1993) and a series of national and international conferences (e.g., Pederson, 1999). Two invasive invertebrates, green crab (*Carcinus maenus*) and common periwinkle (*Littorina littorea*), have been in the New England region so long and are so common that they are no longer even recognized as being non native (Bertness 1999). Their ecological impacts are difficult to evaluate since we have no observations from before their invasions. The green crab is considered a major predator on small "seed" clams and also feeds on both native and nonnative periwinkles. It occurs in almost all intertidal habitats, from mud flats, to salt marsh, to tide pools. The common periwinkle is by far the most abundant herbivore in the intertidal zone, feeding on seaweeds and the microalgae that covers the surface of the rocks. Both the crab and periwinkle have tremendous impacts on the structure of the intertidal zone (Bertness 1999 and references therein).

Recent (within the past 30 years) invaders we commonly observed on most islands during our surveys include the Pacific colonial sea squirt (*Botrylloides violaceous*) and the Asian Shore Crab (*Hemigrapsus sanguineus*) (Carleton 1989, Ledema and O'Connor 2001). The Pacific colonial sea squirt is one of the most common encrusting marine organisms in the low intertidal zone. It is possibly out competing barnacles and seaweeds for space in these habitats. It also encrusts eelgrass blades in the subtidal zone and thus could be having a negative impact on eelgrass habitats.

The Asian Shore Crab has spread rapidly into New England from its first invasion point in New Jersey. In southern New England, it reaches densities of greater than 100 per m^2 in intertidal cobble habitats (Ledema and O'Connor 2001). Although we did not encounter it in such abundance, it has only been in the Boston Harbor region for a few years, and possibly could reach similar abundances in the near future. Its ecological effects in the United States are not yet known. In its native habitat, it feeds on a wide variety of animal and vegetation. Unlike the green crab, which occurs in a variety of habitats, the Asian shore crab is almost never encountered outside its preferred habitat of intertidal cobbles and small stones, under which it hides.

Other common invasives we found in our surveys were the Pacific Rough Sea Squirt (*Styela clava*) and Golden Star Tunicate (*Botryllus schlosserei*). The Pacific Rough Sea Squirt was very common throughout the harbor and was found attached to almost all hard substrate, including *Mytilus edulis* in the low intertidal. The Golden Star Tunicate was not as common, but was found frequently on hard substrate. More work is needed to determine the impact these species are having on native organisms.

We encountered a number of invasive seaweeds. *Dumontia contora*, a red alga unknown in New England before the 20th Century, was abundant in mid elevation intertidal pools for much of the spring and summer. *Polysiphonia harveyi*, another nonnative red alga, was also a common attached species in the intertidal pools, and *Bonnemaisonia hamifera* was frequently encountered in the tidal drift. On a positive note, we found no *Codium fragile* (green fleece), an invasive seaweed from the Pacific that is common on Cape Cod to the south and at the Isle of Shoals to the north.

Two invasive wetland plants, common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*), occur in the Boston Harbor Islands. They were both abundant around the salt pond on the southeastern shore of Thompson Island, not far from the Outward Bound Education Center campus. *P. australis* occurs at a number of other sites, including World's End, Long, Peddocks and Calf Island.

The Boston Harbor Island partners cannot address invasive species alone. Regional and national efforts to address marine invasives, such as initiatives to regulate the discharge of ballast water from ships and other procedures, should be supported. These would reduce the chances of new invasives, but would not assist in controlling those already present. We recommend including an invasive species watch in a long term, harbor-wide monitoring effort.

For the invasive intertidal plants, new invasions of *Phragmites* and purple loosestrife can be limited by pulling the plants out by hand where that is still feasible. The areas at biggest risk are those with some freshwater inputs. Selective use of herbicides is another control option. An ecological and hydrological analysis of the inlet on Thompson's Island to determine whether a program to reduce the abundance of these two plants is feasible may be warranted.

Boat Wakes

Wakes from boats have the potential for causing erosion of salt marshes, mussel beds, and other intertidal shorelines. Depending on the frequency of boat activity, wakes may be interfering with settling of benthic invertebrate larvae, such as clams and mussels. Wakes may also be limiting development of fringing marsh. Natural waves also affect these processes, thus a research project should address whether boat wakes have an impact above that caused by natural waves. Enforcement of no wake zones near the islands seems like a logical management solution, if it is determined that boat wakes are a serious issue.

Maintenance of Seawalls and Rip Rap

Most of the Boston Harbor Islands have some sections of coastal embankment that have been armored to control shoreline erosion. It is likely that islands formed of unconsolidated glacially deposited sand and gravel (e.g., George's Island) are more subject to change from erosion than those comprised mostly of bedrock (e.g., Little Brewster). Some of these seawalls protect important cultural and historical features, however seawalls may interfere with the natural movement of sand along the coast and create erosion based problems down current in the intertidal zone. The sand and gravel that erodes from headlands on the islands is what creates the sand spits that are good intertidal habitats for birds, mussels, and other organisms. A study should be commissioned to examine the impact of these structures on geomorphic processes.

Debris

A number of derelict docks and other structures exist in the BHI. Calf Island, for example, has two large broken down and non functional docks that span the intertidal zone. Although not an ecological issue, the presence of these derelict structures is an eyesore and a potential safety hazard.

Commercial shellfishing and bait fishing

Fishing for soft-shell clams and some collection of worms for bait occurs in tidal flats. These are under the authority of the Massachusetts Division of Marine Fisheries.

FUTURE INVENTORY, MONITORING AND RESEARCH NEEDS

Inventory

- Continue development of a comprehensive intertidal resources species list with the assistance of expert marine invertebrate zoologists and phycologists.
    - Greater focus on benthic infauna and mudflat habitats. We carried out only limited sampling in this habitat in our 2001 inventory.
    - Continue development of species list for rocky and cobble habitats. Our taxonomic experts visited fewer then half the islands we surveyed and their activities were focused in late summer and autumn. Additional monitoring of more islands and in more seasons will likely lead to many new additions to the species list.
    - Using the inventory data, compare species richness of the intertidal zone of Boston Harbor Islands to other nearby sites for which there are data, i.e., Nahant, Isle of Shoals. Can also compare richness between different Boston Harbor islands.

Monitoring

- Re-map the intertidal habitats of the 20 islands at 5-10 year intervals using field-based GPS techniques,

The spatial distribution and areal extent of intertidal habitats will change in response to major natural events (e.g., storms), contaminant spills, increased visitor use, increased commercial and recreational harbor activity, changing fishing pressure, changing status of harbor water quality, rising sea levels, and other natural and human-induced activities. Re-mapping the 20 islands at perhaps 5-10 yr intervals or after major events (e.g., contaminant spill) will assist managers in understanding links between habitat change and causes of change. Obviously, identification of such linkages will be greatly facilitated by simultaneous monitoring of harbor water quality (currently being done by the Massachusetts Water Resources Authority), boating activity, visitor use patterns, and other relevant factors.

- Consider baseline habitat mapping of Snake Island.

The twenty islands we selected for mapping in 2001 and 2002 represent a gradient of substrate, visitor use, habitats, wave exposure, etc. (Figs. 10-11). Snake Island has a nesting colony of common terns and is the only island with a large marsh that we were unable to delineate. We suggest mapping this island so that it can be used in conjunction with the other islands as a tool for assessing and managing the Park.

Habitat mapping is a fairly rapid method for assessing gross changes in an ecosystem. Monitoring aimed at evaluating the response of intertidal habitats to very specific potential impacts or at evaluating trends in specific species or habitats of concern may require more quantitative methods, such as monitoring of field quadrats or transects. The following are recommended:

- Quantitative species-level scale monitoring, with a focus on high visitor use vs. low visitor use intertidal zones
- Quantitative species-level monitoring focused on invasive/non-native species of concern (e.g., *Phragmites australis* - common reed; *Hemigrapsus sanguineus* – Asian Shore Crab)
- Quantitative species-level monitoring focused on overall patterns, trends and health of the environment

Research

- Spatial analysis of intertidal habitats

This inventory project has assembled an impressive spatial database of intertidal habitats for 20 Boston Harbor Islands. Each polygon mapped contains spatial information on substrate type (e.g., rock, cobble, mud, reef, tide pool, creek, peat, etc.) and biotic assemblage (e.g., no dominant macrobiota, *Semibalanus* assemblage, *Ascophyllum* assemblage, red encrusting algae assemblage, etc.). Also, for each biotic assemblage there is a listing of diagnostic species (those used to define the assemblage) and common species found within the assemblage.

From the ordination analysis, we began to address the question of the difference in intertidal resources between inner and outer islands. Additional questions to be pursued could be:

  - What is the relationship of habitat type to wave exposure?
  - What are the relationships between substrata and biotic assemblages?
  - Are there differences in assemblages between areas receiving high visitation vs. those that are not?

- Impacts of boat wakes on the habitat distribution and species composition of intertidal zones.
- Experimental control attempts for invasive organisms

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