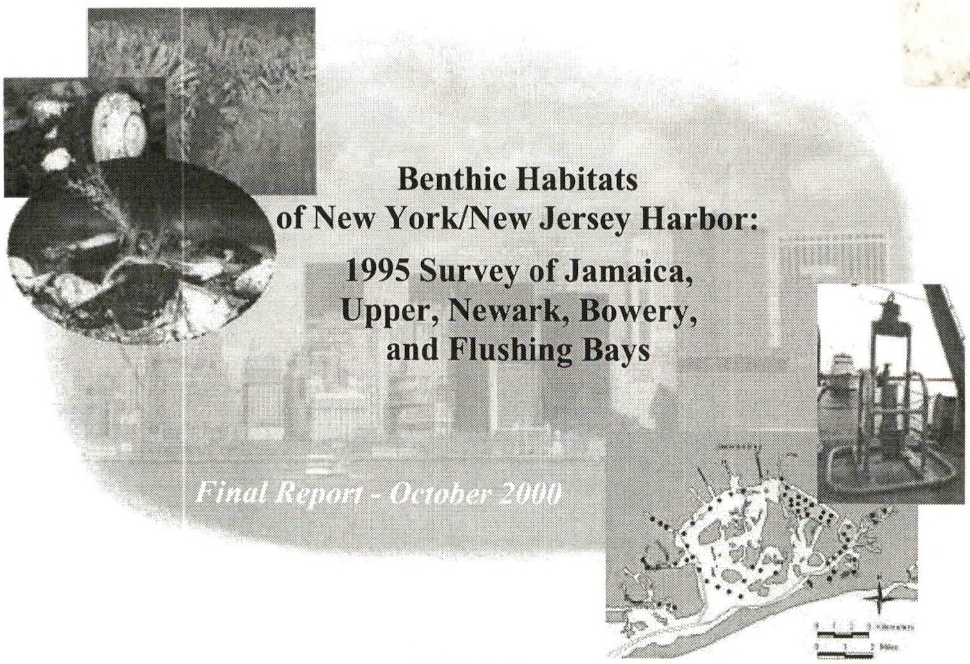

Benthic Habitats of New York/New Jersey Harbor:

1995 Survey of Jamaica, Upper, Newark, Bowery, and Flushing Bays

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Abstract

Sediment profile imagery (SPI) and grab sampling were used to examine benthic communities in selected bays of New York/New Jersey Harbor in June and October 1995. This effort was stimulated by the need for benthic habitat maps to develop environmentally sound and economically feasible disposal alternatives for dredged material management. The habitat classification system developed for New York/New Jersey Harbor was based on sediment type and observed faunal assemblages, and twenty-one habitat classes were identified and mapped in a geographic information system (GIS) for each survey. Upper and Jamaica Bays contained the widest range of habitat types, including areas of shellfish beds, amphipod mats, and sandy-bottom and silty-bottom communities. Shellfish beds were relatively stable across both surveys, as were sandy-bottom communities. Benthic habitats in Newark, Bowery, and Flushing Bays consisted predominantly of silty-bottom communities; the presence of subsurface methane pockets indicated organic contamination in areas of Bowery and Flushing Bays and some of the peripheral basins of Jamaica Bay. Notable temporal shifts, seen in all the bays from June to October, included increases in infaunal polychaete density, general deepening of the apparent Redox Potential Discontinuity (RPD), and changes in species dominance within communities. Inferences to habitat quality were drawn from these trends and abundance data. Communities in each bay were dominated by opportunistic or pollution-tolerant species, and few noticeable differences in overall habitat quality were observed.

Introduction

The New York District of the U.S. Army Corps of Engineers (District) and the states of New York and New Jersey are developing a long-term dredged material management plan for New York/New Jersey (NY/NJ) Harbor. Maps of the harbor's benthic habitats will allow the District, the Port Authority of New York/New Jersey, and resource agencies to examine the benthic environment and evaluate the overall condition of its communities and sediments. This will assist planners in comparing the general condition of the harbor to previous assessments and in examining the relative ecological value of habitats within the harbor and how these values might be affected by alternative management options.

Benthic communities have been studied in the bays of NY/NJ Harbor, primarily Lower Bay and New York Bight Apex. Steimle (1985) measured productivity and biomass in benthic communities in New York Bight Apex and found those parameters were similar to or higher than those of other (presumably uncontaminated) North Atlantic areas. He also suggested that sediment toxins and nutrient enrichment near the sewage dump site could have inhibited or eliminated some species, potentially explaining observed differences in community composition. Within the harbor, more species generally have been found in Lower Bay than in the other bays (USACE 1998), and density and diversity are negatively correlated with pollution and silt-clay content throughout the harbor (Stainken 1984, Cerrato 1986). Sediment contamination, including synthetic compounds used in herbicide and pesticide production (Bopp et al. 1991), metals, and petroleum hydrocarbons (Conner et al. 1979), has resulted from combined sewer discharges, urban runoff, stormwater runoff, industrial discharges, and maritime and industrial accidents (Long et al. 1995, HEP 1996). The spatial distribution patterns of these contaminants varies, but the presence and concentrations of these sediment pollutants within the bays could influence benthic community composition, species distributions, and species abundance (Stainken 1984, Cristini 1991, Long et al. 1995).

Data taken within and adjacent to dredged sediment borrow pits in Lower Bay indicated that benthic assemblages were less stable and diverse than sites farther from borrow pits, and that pit assemblages were numerically dominated by opportunist species (Cerrato and Scheier 1984). Most recently, data collected by the U.S. Environmental Protection Agency suggested that greater than 40% of the benthic communities in each of the harbor sub-basins are impacted by chemical contamination and sediment toxin levels (Adams et al. 1998).

In 1994, the District commissioned a study of benthic habitats in Lower Bay (reported separately), and in 1995 it extended the study area to include the smaller inland bays to examine how those habitats would be affected by different dredged material management alternatives. The primary objective of this study was to map benthic habitats in the bays of the upper region of NY/NJ Harbor in a geographic information system (GIS) using data collected from sediment profile imagery (SPI), sediment surface imagery (plan-view), and benthic grabs. These methods were selected because they provided complementary views of benthic systems, they can be easily incorporated into a GIS, and they are cost-effective tools for mapping benthic habitat at fine spatial scales over large areas. Specific project goals included identifying benthic habitat types, mapping their occurrence and distribution, and documenting their variability. These maps will provide District managers with preliminary information necessary to evaluate potential environmental impacts of disposal options. In addition, these habitat maps will allow the District, Port Authority, and resource managers to develop effective disposal alternatives and to evaluate sites for future restoration through the use of dredged material.

Methods

General Field Methods

Sediment profile imagery (SPI), plan-view imagery, and benthic grab samples were collected from Newark Bay, Upper Bay, Flushing Bay, Bowery Bay, Jamaica Bay, and Dead Horse Bay. Sample stations were distributed evenly throughout the bays, generally located at 100- to 500-meter intervals (Figure 1) provided water depth was at least 2 meters (the depth requirements of the survey vessel). Surveys were conducted in June 1995 and October 1995; most stations overlapped between the two surveys, but additional stations were sampled in Jamaica and Upper Bay during October, and there was little overlap between the two surveys in Newark Bay.

The bays were surveyed from the *Hudson*, a survey vessel operated by the District. A differential Global Positioning System (GPS) referenced to the North Atlantic Datum 1983 was used for navigation. Station coordinates, date, and time of day were recorded in a field log upon arrival at each station. Coordinates and time were also recorded at about 25% of the stations after all sampling was completed to check how far the boat drifted while at a station. Drift distances were generally less than 0.002 minutes, a distance that was not discernable at the spatial scale used for mapping the results.

Collection of Sediment Profile Images

SPI images were collected with a Hulcher Model sediment profile camera (Figure 2). The camera apparatus had two basic parts: (1) a camera encased in a pressure housing and (2) a 45° prism with a 15 x 23 cm clear Plexiglas faceplate and mirror to reflect the image of the sediment into the camera lens. The bottom edge of the prism was sharpened to cut through the sediment neatly. The prism was filled with clear freshwater to prevent hydrostatic pressure from distorting the faceplate as the prism was lowered below the sea surface. The lens and light source (strobe light) used to illuminate the sediment were contained inside the water-filled prism. The camera was focused on the prism faceplate and recorded sediment features. Fujichrome slide film was used to record the images. This configuration allowed the camera to work in complete darkness with image clarity independent of turbidity. Lead weights fastened to the camera frame pushed the prism into the sediment, and a hydraulic piston slowed the rate of penetration to minimize disturbance of the sediment. A switch, triggered by the prism penetrating the sediment, controlled a timer keyed to the camera. A watch with digital time and date displays was attached to the prism and recorded in each image, which enabled photographs to be matched to station locations. Rhoads and Cande (1971) provide additional details on camera design and operation.

The SPI camera was typically deployed twice per station during each survey, and a timer triggered the camera 2 and 12 seconds after the prism contacted the sediment. The second picture was timed to catch the sediment-water interface after the camera had stopped penetrating the sediment and was the primary picture from that camera deployment. In particularly soft sediments, the camera's field of view would completely pass the sediment-water interface by 12 seconds. In these cases, the first picture became the primary picture. Taking two pictures per camera deployment and deploying the camera twice per station balanced time efficiency with the need for obtaining at least one good quality image from each station. The camera operator kept a log of stations, times, and other information (e.g., test pictures, approximate penetration depth) so the pictures could be matched to the stations after the slides were mounted and so stations could be revisited if the camera malfunctioned.

Analysis of SPI Images

One picture, usually the second, was analyzed from each camera deployment (i.e., two pictures per station per survey). Pictures were analyzed visually by projecting the images and recording key features into a standardized spreadsheet file (Table 1). One picture from each station was then selected and digitized with a Scan Maker slide scanner through Adobe PhotoShop, and the computer image was analyzed using a Power Macintosh microcomputer and image analysis software. Computer analyses were standardized across images by automating the analyses with macro commands. Data from each image were saved to an ASCII file for further analysis. Only one picture from each station per survey was chosen for computer analysis because of the lesser importance of this portion of the analysis to the objectives of this particular study. The following sections briefly describe the data collected from the SPI images. Details of how these data were actually obtained can be found in Kiley (1989) and Viles and Diaz (1991).

Prism penetration provides a geotechnical estimate of sediment compaction with the camera prism acting as a dead-weight penetrometer. The further the prism enters into the sediment, the softer the sediments and likely the higher the water content. Penetration depth is measured as the distance the sediment moved up the length of the faceplate (25 cm). If the weight of the camera frame is not changed in the field, prism penetration provides a means for assessing the relative compaction between stations or different habitat types. Deep prism penetration usually indicates recent, rapid accumulation of sediments that have not had time to de-water (Don Rhoads, personal communication).

Surface relief, the difference between the maximum and minimum distances the prism penetrates across the faceplate (15 cm) on a single deployment, estimates small-scale bed roughness. The causes of roughness are often apparent from the images. In physically dominated sandy habitat, surface relief typically shows small sand waves or bedforms. In muddy habitat, surface relief is typically smooth or irregular (from biological activity of benthic organisms, such as mounds or pits formed during feeding and burrowing). Biological surface roughness ranges from small fecal mounds and tubes to large colonies of hydroids. Surface relief provides qualitative and quantitative data on habitat characteristics that can be used to evaluate present and past habitat quality.

Depth of the apparent Redox Potential Discontinuity (RPD), the depth to which sediments are oxidized, is an important estimator of benthic habitat quality. The term "apparent" is used because no actual measurement is made of the redox potential. An assumption is made that, given the complexities of iron and sulfate reduction-oxidation chemistry, reddish-brown sediment color tones indicate oxidizing sediments, or at least not intensely reducing sediments (Diaz and Schaffner 1988). This is in accordance with the classical concept of RPD depth, which associates RPD depth with sediment color (Fenchel 1969). RPD depth was defined as the area of all pixels in the image discerned as being oxidized divided by the width of the digitized image. The area of the image with oxic sediment was obtained by digitally manipulating the image to enhance characteristics associated with oxic sediment (reddish-brown color tones). The enhanced area was then determined from a density slice of the image or, when image quality was poor, the area was delineated with the cursor.

RPD depth is useful in assessing habitat quality for epifauna and infauna from both physical and biological points of view. Rhoads and Germano (1986), Revelas et al. (1987), SAIC (1987), Day et al. (1988), and Diaz and Schaffner (1988) all found the depth of the RPD from profile images to be directly correlated to the quality of the benthic habitat in polyhaline and mesohaline estuarine zones. Shallow RPD depths (<1 cm) tend to be associated with environmental stress, whereas deeper RPD depths (≥3 cm) usually indicate flourishing epibenthic and infaunal communities.

Sediment grain size, a geotechnical feature used to determine sediment texture, is used to infer the nature of the physical forces acting on the benthic habitat. The sediment texture descriptions followed the Wentworth classification as described in Folk (1974) and represented the major modal classes for each layer identified in an image. Grain size was determined by comparison of collected images with a set of standard images for which mean grain size had been determined in the laboratory.

Surface features, both physical and biological in origin, can be seen at or on the sediment surface and included worm tubes, fecal pellets, epibenthic organisms, bacterial mats, algal mats, shells, mud clasts, bedforms, feeding pits, and mounds. Each of these features provides information on habitat type and quality. The presence of certain surface features indicates the overall nature of a habitat. For example, bedforms are associated with physically dominated habitats, whereas worm tubes and feeding pits indicate a more biologically accommodated habitat (Rhoads and Germano 1986, Diaz and Schaffner 1988). Surface features were visually evaluated from each slide and compiled by type and frequency of occurrence.

Subsurface features include burrows, water-filled voids, infaunal organisms, gas voids, shell debris, detrital layers and sediment lenses of different grain size. Subsurface features reveal information about the balance of physical and biological controls within the habitat. For example, the presence of gas voids with a mixture of nitrogen and methane from bacterial metabolism (Reineck and Singh 1975) indicates anaerobic metabolism (Rhoads and Germano 1986) and is associated with high rates of bacterial activity. Muddy habitats with large amounts of methane gas often indicate areas of oxygen stress or high organic loading (SAIC 1987, Day et al. 1988). Conversely, habitats with burrows, infaunal feeding voids and/or visible infauna are generally more biologically accommodated and considered "healthy."

Community succession stage, in the sense of Rhoads and Germano (1986), was not consistently estimated from the SPI images in this study. SPI images often clearly show characteristics of pioneering or colonizing assemblages (in the sense of Odum 1969), such as dense aggregations of small, surface polychaete tubes and shallow apparent RPD layers. Characteristics of advanced or equilibrium assemblages, such as deep RPD depths and subsurface feeding voids, also can often easily be seen in the pictures. Unfortunately, the succession stage sequence does not clearly apply to sandy habitats, and because of the large amount of sandy habitat in the survey areas, this parameter was of little value for this study.

Collection and Processing of Plan-View Images

Plan-view images were collected with a sediment surface camera from approximately one-third (June) to two-thirds (October) of the stations. A PhotoSea Model 1000A camera and a PhotoSea Model 1500S strobe light were attached to the frame of the SPI apparatus. A weight attached to a pressure sensitive switch triggered the camera and strobe light when the weight hit the sea bottom, yielding a plan-view image of the sediment surface just before the frame reached bottom. Good quality plan-view images were visually examined for sediment texture, surface shells, pebbles, epifauna, clams, mussels, and clam siphons.

Collection and Processing of Benthic and Sediment Samples

A Shipek grab (0.04 m^2) was used to collect benthic and sediment samples from one-third of the stations[1], and the grab was operated concurrently with deployment of the camera from the *Hudson*. Two grabs were taken at each of the grab-sampled stations. All sediments collected in the first grab were prepared for benthic analyses by gently washing the material through a 0.5-mm mesh sieve and washing the contents into a labeled cloth bag that was immersed and stored in 10% buffered formaldehyde and seawater. In the laboratory at Barry A. Vittor & Associates, Inc., Mobile, Alabama, organisms were separated from the remaining debris by flotation and handpicking, identified by experienced taxonomists, and enumerated. Quality assurance and control measures included randomly selecting 10% of the samples, reconstituting them with the original debris and repeating the entire separation, identification, and enumeration process. The quality assurance plan followed by Barry A. Vittor & Associates, Inc., called for all samples processed by a particular technician to be redone if more than 10% of that technician's work showed any samples to differ by more than 5% from the original results. For this project, all discrepancies were within 5%. The taxonomists previously worked on several projects for the NY/NJ area and verified each other's identifications. When differences of opinion occurred or when significant doubt remained, outside specialists examined the specimens. Identifications were to the lowest practical identification level (LPIL) when not to the species level.

The following situations commonly cause LPIL, rather than species, identifications. Sorting organisms from sediments damages some specimens, removing structures necessary for a positive taxonomic identification. This problem can be common when unpreserved samples are sieved in the field, as was true for this study. Damaged specimens were identified at the level supported by the actual specimen. Under most circumstances, this problem leads to extra taxa in the species list (e.g., undamaged specimens identified at the species level plus damaged specimens from the same species listed at one or more higher taxonomic levels). However, damage also can cause two or more taxa to be listed as a single LPIL taxon. LPIL identifications also are common for groups requiring specialized taxonomists or laboratory preparations for identification (e.g., juvenile specimens, oligochaetes, and rhynchocoels). LPIL designations for juveniles typically yield extra taxa in the species list because adult specimens are identified at the species level. Obviously, LPIL designations for groups such as

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[1] Several samples taken in June were lost prior to processing, so SPI and grab data are available for only twenty-two (22) stations.

oligochaetes and rhynchocoels typically reduce a species list. Finally, LPIL designations are used when taxonomists cannot agree on a specimen. All these factors should be considered when comparing numbers of taxa and biodiversity between and within studies.

Based on knowledge of the Hudson/Raritan system, eleven LPIL taxa were combined with taxa identified to the species level. Three involved taxa that comprised more than 1% of the individuals collected. Ampeliscidae (LPIL) and *Ampelisca* (LPIL) were combined with *A. abdita*. *Heteromastus* (LPIL) was combined with *H. filiformis*.

Two samples, one for sediment texture and one for total organic content (TOC), were collected in the field from the second grab using either a 5 cm PVC tube or 125 ml plastic beaker. The samples were then placed in numbered Whirl-Pak bags and stored in a freezer prior to analysis. Tierra Consulting, Inc., Mobile, Alabama, performed laboratory analyses of sediment texture. Each sample was washed with deionized water, dried, and weighed. The coarse fraction was separated from the fine fraction (sand/silt) by sieving through U.S. Standard Sieve Mesh No. 230 (62.5 μm). Sediment texture of the coarse fractions was determined at half-phi intervals by passing the sediment through nested sieves on a Ro-Tap apparatus. The weight of the material collected on each sieve was recorded. A Sedigraph 5000 ET Particle Size Analyzer was used to analyze the fine fraction (<62.5 μm). Sediment texture descriptions followed the Wentworth classification as described in Folk (1974).

Total organic carbon (TOC) analyses were done at the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station, Vicksburg, Mississippi, using a weight-loss-upon-ignition procedure (APHA 1989, method 5310A). After thoroughly mixing the thawed contents of the bag, two 10-gram samples of sediment were removed, dried, weighed, ignited at 500°C to drive off organic material and reweighed. TOC was assumed to be the weight lost upon ignition and expressed as a percentage. If the two subsamples differed by more than 10% (e.g., if sediment TOC was 1%, the replicate subsample must have a TOC between 0.9% and 1.1%), the analyses were repeated for that sample.

Habitat Classification

A habitat classification strategy that combined the SPI and grab data was developed to identify the principal benthic habitats in NY/NJ Harbor, while providing a means for addressing the management issues associated with dredged material disposal. This strategy focused on economically important bivalves, species that build substantial biogenic structures or control important physical processes, and sediment characteristics that likely correlate with the diversity and biomass of benthic infauna. For NY/NJ Harbor, this meant focusing on northern quahogs (*Mercenaria mercenaria*), surf clams (*Spisula solidissima),* softshell clams (*Mya arenaria),* blue mussels (*Mytilus edulis*), American oysters (*Crassostrea virginica*), amphipods and polychaetes that build extensive tube mats, and polluted sediments. While this strategy meets USACE's objectives, a different approach to habitat classification than developed here may be needed to address different management concerns. Unless otherwise indicated, the term "clam" will be used in this report to refer only to northern quahogs, surf clams, and softshell clams.

This study is the first to integrate extensive amounts of SPI, benthic, and sediment data to develop habitat maps, so a precise integration process needed to be developed. Although the sampling methodology used in this study provided a low probability of yielding "false positive" results (i.e., concluding a particular habitat is present when in fact it is not), probabilities of "false negative" results (i.e., concluding a particular habitat is absent when in fact it is present) were not insignificant. To address this concern, the results of the SPI, benthic, and sediment analyses were combined in an additive manner. For example, if SPI showed a clam bed was present but the benthic grab yielded no clams, the station was still considered a clam bed.

Five habitat classes and twenty-one habitat subclasses were recognized in the five survey areas (Table 2). The five classes were shell beds, mats of the tube-dwelling amphipod *Ampelisca abdita*, sandy bottom, silty bottom, and bottoms with no discernable infauna and/or bacterial mats ("oligozoic"). These classes were not designed to be mutually exclusive. Some stations fit into more than one class, so clear assignment rules were needed for consistency, and these rules tried to anticipate the management decisions of the District, resource agencies, and the public. Shell beds were considered a valuable habitat with functions difficult to replace without concerted mitigation efforts, so this habitat class was given the highest priority; i.e., stations with shell beds present were classified as shell bed habitat even when the station had characteristics of other habitat classes. Similarly, *Ampelisca* mats were given priority over the sandy bottom and silty bottom classes. Bacteria mats, *Beggiatoa* spp., indicated high concentrations of pollutants or organic material, so this subclass was given priority over the silty and sandy classes. At stations where it co-occurred with shell beds or *Ampelisca*, the habitat assignment reflected one of the latter classes and special distinction was given to these stations. As indicated below, several subclasses also were not mutually exclusive. In both subclass and class assignments, distinguishing features emphasized characteristics that showed high repeatability in SPI images and features not usually examined by traditional benthic sampling. Operational definitions for each habitat type were developed to combine the data streams, and these will be discussed as they arise under the appropriate habitat description.

Data Management and Mapping

A geographic information system (GIS), specifically ArcView® 3.2, was used to map all data and analyze habitat distributions. All survey data were brought into ArcView as points stored in DBF files and projected to Universal Transverse Mercator (UTM) Zone 18, using ArcView's projection function. Locations were stored as decimal degrees in the DBF files to five decimal places. Projected data were then stored as ArcView shape files. Because two SPI images were usually analyzed per station but only one SPI record was made per station for the GIS files, the two images were summed for the GIS record. For example, surface pebbles were listed as characteristic of a station even if only one SPI image from that station had surface pebbles. To test the validity of this approach, similarities between data extracted from different images of the same station were compared using a scale of -2 to +2, with -2 representing major differences, +2 representing complete agreement and 0 representing stations with only one SPI image. Only 8% and 1% of the stations from June and October, respectively, had dissimilar images (i.e., scores of -1 or -2). The extracted data were highly similar or identical (i.e., scores of +1 or +2) for 31% of June stations and 79% of October stations.

Results

Habitat Classes

Shell Beds: The shell bed class keyed on the presence of live bivalves and consisted of three subclasses (Figure 3): blue mussels (*Mytilus edulis*), clams (surf – *Spisula solidissima*, soft – *Mya arenaria*, and hard – *Mercenaria mercenaria*), and American oysters (*Crassostrea virginica*). Clam beds were difficult to identify. This stemmed in part from the lack of a widely accepted definition of the threshold density above which an assemblage of clams becomes a "bed." This distinction, derived more from a fisheries perspective than an ecological one, is subject to change based on economic, ecological, regulatory, and other factors, all of which can vary monthly or annually. Therefore, the operational definition of clam bed habitat used in this study required either a) that clams were present in the SPI imagery or b) that three or more individuals from one of the three target clam species were present in the benthic grab. Similarly, mussel beds were defined to be stations with a) mussels present in the imagery or b) ten or more adult mussels present in the benthic grab. Since only one oyster was found in a single benthic grab in June, oyster beds were defined to be stations where oysters were present in the imagery.

These shellfish subclasses were mutually exclusive in this study, and shell bed habitats made up 10% of June stations and 7% of October stations (Table 3). During both surveys, two clam bed stations were classified based on grab samples and all other clam bed stations were classified based on imagery data. No station was identified as clam bed by both characterization methods. Mussels and oysters were observed in very low numbers in grab samples, so all mussel and oyster bed habitats were identified by imagery data only (Table 4).

Clam and mussel beds, observed in relatively equal numbers, typically were associated with fine sediments (Figure 4). Camera penetration ranged 0-17 cm, and was usually deeper than 4 cm. RPD depths (when measurable) in June shell bed habitats were <1 cm at 62% of stations, 1-2.9 cm at 38% of stations. October RPD depths (when measurable) in shell bed habitats were 1-2.9 cm at 100% of stations. Feeding voids and gas voids were absent from all shell bed stations during both surveys, but anoxic voids were seen below two clam bed stations during June. *Ampelisca* mats were observed at 13% of June shell bed habitats (mussel and clam beds) and at 20% of October shell bed stations (clam beds only). Infaunal polychaetes were present at 27% of June shell beds and 22% of October shell beds. Surface bacteria mats were present at one clam bed station in the October survey, which was also populated by a mat of *Ampelisca*. Grab data, taken at three of the June shellbed stations (clams), showed highest average abundance of Cirratulidae (LPIL; 4,150 individuals/m^2), *Mediomastus* (LPIL; >1,605 individuals/m^2) and *A. abdita* (>1,000 individuals/m^2). October grab data, taken at three shell bed stations (2 clam, 1 mussel), showed highest average abundance of *A. abdita* (>9,350 individuals/m^2), *Sabellaria vulgaris* (>4,200 individuals/m^2), *Mediomastus* (LPIL; >3,800 individuals/m^2), *Streblospio benedicti* (>3,400 individuals/m^2) and Oligochaeta (LPIL; >1,770 individuals/m^2).

Ampelisca mats: The three subclasses of *Ampelisca* mat were distinguished by the type of sediment underlying the tubes (sand, sandy silt, and silt), and these subclasses were mutually exclusive (Figure 5). High densities of tubes characterize *Ampelisca* mats, and, similar to seagrass beds, they may occur as a patch quilt of open areas and areas with different tube densities. Given the ecological importance of this habitat class in terms of secondary production, all stations with a) *Ampelisca* present in the imagery or b) 200 or more *Ampelisca* in the benthic grab were classified as *Ampelisca* mat habitat.

Ampelisca mat habitats made up 19% of June stations and 21% of October stations (Table 3), with the majority of *Ampelisca* habitats associated with silty sediments (Figure 6). Twenty-six and 37 stations were classified as *Ampelisca* mat habitats in June and October, respectively, based on SPI data. Grab and plan-view data verified these classifications at three and 20 stations, respectively, in June. In October, grab data were consistent with SPI classifications at five stations, and plan-view data corresponded with SPI data at 27 stations. When all data were combined, five additional stations were reclassified as *Ampelisca* habitat and two *Ampelisca* stations were reclassified as shell beds in June, and four *Ampelisca* stations were reassigned in October (Table 4). Camera penetration depths ranged 5-23 cm in June and 2-29 cm in October, with increasing penetration as sediment grain size decreased. Measurable RPD depths in June were <1 cm at 25% of stations, 1-2.9 cm at 65% of stations and ≥3 cm at 10% of stations. In October, measurable RPD depths were <1 cm at 10% of stations, 1-2.9 cm at 87% of stations and ≥3 cm at 3% of stations. Oxic, anoxic, and gas voids were present at 24% of June *Ampelisca* stations, but only gas voids were observed at *Ampelisca* stations in October (12% of stations). Infaunal polychaetes were observed in both surveys across all subclasses, and they were more commonly seen in the later survey (17% of June *Ampelisca* stations and 76% of October *Ampelisca* stations). Epifauna commonly present in SPI imagery from all subclasses at *Ampelisca* stations included snails, hermit crabs, algae, hydroids, mysids and *Crangon* shrimp. Grab data from six *Ampelisca* stations in June showed highest average abundance of *Corophium tuberculatum* (>8,460 individuals/m^2), *A. abdita* (>8,450 individuals/m^2), *Microdeutopus gryllotalpa* (>1,660 individuals/m^2) and *S. benedicti* (1,240 individuals/m^2). October grab data, taken at eleven stations, showed highest average abundance of *A. abdita* (>12,800 individuals/m^2), *C. tuberculatum* (>4,500 individuals/m^2), *M. gryllotalpa* (>3,400 individuals/m^2) and *Gemma gemma* (>1,540 individuals/m^2).

Sandy Bottom: Sandy-bottom habitat was defined as the sandy areas that did not have shellfish beds or *Ampelisca* mats. These habitats made up 5% of all June stations and 8% of all October stations (Table 3). The characteristics of sandy habitat most amenable to SPI analyses had a physical, rather than biological, origin, and delineation of 10 subclasses within the sandy-bottom class reflected this strength. Unlike the other classes, subclasses within the sandy-bottom habitat class were hierarchical, and results had a greater dependency on the order in which the subclasses were assigned. The first division grouped the subclasses into two mutually exclusive families, sandy bottoms with bedforms and sandy bottoms without bedforms. Within each of these families, five subclasses were recognized (Figures 7 and 8): epifauna present (usually hydroids, algae, or tube-dwelling polychaetes), surface gravel, surface shell hash, infauna present, and no modifier. These subclasses were not mutually exclusive, so order-of-assignment rules were needed, and the above list indicated this order. The first three subclasses represented habitats with structural features that might provide refuge from disturbance, indicate disturbance intensity, and/or simply increase habitat diversity. The latter two subclasses represented habitats lacking a structural component. This hierarchical scheme placed greater emphasis on the SPI and plan-view data compared to the benthic grab data, so the grab data played a smaller role in the classification of sandy habitats than any other habitat class.

Stations with epifauna were identified first because hydroids and algae, and to a lesser extent worm tubes, provided additional physical structure to the habitat. There were two stations assigned to the epifauna subclass in June (29% of sandy habitats in June), and both stations belonged to the bedform family. In October, five sandy stations had epifauna (42% of sandy stations): four with bedforms and one without bedforms. All epifauna stations also had shell hash at the sediment surface, and the single station in June without bedforms also contained rocks at the sediment-water interface. Twenty-nine percent of sandy stations in June were assigned to the shell hash subclass (all with bedforms), and 33% of October sand stations (two with bedforms, two without bedforms) were composed predominantly of shell hash. A gravel subclass was also created based on data from Lower Bay, but no stations in this study area were assigned to this subclass. Finally, the presence of infauna (critters) differentiated stations with obvious infauna from those without infauna (no modifier). Distinctions between these two subclasses were generally difficult to make using the imagery alone, so grab samples were particularly useful for identifying infauna within sandy bottoms. Infauna were observed at one sandy station in June (without bedforms) and three sandy stations in October: two with bedforms, one without bedforms. Two sandy-bottom stations with bedforms in June had no infauna.

Typical camera penetration depths were less than 10 cm, and RPD depths were measurable at seven (100%) and ten (83%) stations in June and October, respectively. For June sandy-bottom habitats, RPD depths were <1 cm at 14% of stations, 1-2.9 cm at 43% of stations and $\geq$3 cm at 43% of stations. Measurable RPD depths in October were 1-2.9 cm at 70% of stations and $\geq$3 cm at 30% of stations. Voids were never observed in sandy-bottom habitats, which may have been due to shallow camera penetration. Infaunal polychaetes were observed infrequently in June (one sandy-bottom station), but were more numerous in October (42% of sandy stations), and epifauna observed in sandy habitats included algae, hydroids, hermit crabs and snails. Based on grab data collected only in October, the benthos of sandy-bottom habitats were less abundant than most other habitats. Grab data collected from six sandy-bottom stations showed the highest average abundances of *Mulinia lateralis* (>775 individuals/m^2), *S. benedicti* (>760 individuals/m^2), and *Mediomastus* (LPIL; >640 individuals/m^2).

Silty Bottom: The silty-bottom subclasses (60% of all June stations and 44% of all October stations) first distinguished silts with high pollutant or organic loads (the gas void subclass), then those with evidence of high sedimentation (soft sediments), and finally those with the presence of algae or infauna (Table 3). These three subclasses (Figure 9) were not mutually exclusive, so order-of-assignment rules were needed. The gas void subclass was identified first because methane pockets were clear indicators of high concentrations of pollutants or organic material. This subclass made up 30% of all silty-bottom stations in June and 25% of all silty-bottom stations in October. Stations with deep camera penetration (>18 cm) without gas voids composed 44% of June silty stations and 3% of October silty stations. Silty bottom with epifauna/infauna (predominantly polychaetes, small bivalves, and algae) was the last subclass in the order-of-assignment rules. This subclass composed 26% of June silty stations and 72% of October silty stations.

Camera penetration in all silty habitats ranged 5-23 cm, with penetration depths increasing as sand content decreased. As a result of deep camera penetration, 13% of

June and 12% of October stations in the gas void subclass overlapped the soft sediment subclass. June RPD depths (measurable at 66% of stations) were <1 cm at 75% of stations and 1-2.9 cm at 25% of stations. October RPD depths (measurable at 94% of stations) were <1 cm at 10% of stations, 1-2.9 cm at 76% of stations and $\geq$3 cm at 14% of stations. Feeding and anoxic voids were rarely observed at stations in the gas void subclass (4% in June, 24% in October), but they were more common in the infauna subclass (70% in June, 27% in October) and variable in the soft sediment subclass (40% in June, 0% in October). Epifauna, observed infrequently in SPI images, included algae, hydroids, crabs, snails, and limpets from all silty habitats.

SPI imagery showed infauna present at 15% of June and 88% of October stations in the gas void subclass. Grab data from 26% and 41% of gas void stations (June and October, respectively) showed highest average abundances of *S. benedicti* (1,250 individuals/m^2) in June and *Mulinia lateralis* (>1,250 individuals/m^2) in October. Infauna were observed in 30% of June stations (0% in October) in the soft sediment subclass based on SPI imagery. Grab samples, taken at 8% and 50% of those stations (June and October, respectively), showed highest average abundances of Cirratulidae (LPIL; 1,250 individual/m^2) and *Leitoscoloplos* (LPIL; 750 individuals/m^2) in June and showed no significant presence of infauna in October. Finally, grab samples were taken at 13% of June stations and 40% of October stations belonging to the final subclass defined by the presence of benthic fauna. In June, *S. benedicti* predominated on average (>2,195 individuals/m^2) with Cirratulidae (LPIL) present in moderate abundance (average of 720 individuals/m^2). *M. lateralis* (>1,435 individuals/m^2) predominated in October with *S. benedicti* (>1,170 individuals/m^2) and *Mediomastus* (LPIL; >670 individuals/m^2) in moderate average abundance.

Oligozoic: Oligozoic stations (Figure 10) composed 6% of June stations and 20% of October stations (Table 3). Azoic stations, which had no obvious epifauna, infauna or trails of infauna, composed 33% of oligozoic stations in June and 3% of oligozoic stations in October. Stations assigned to the bacteria subclass, which had *Beggiatoa* spp. mats at the sediment surface, were observed at 67% of June oligozoic stations and 97% of

October oligozoic stations. In merging the data for habitat classification, stations classified as azoic based on SPI data but having more than 30 individual infauna in a grab sample were assigned to the silt with infauna subclass. This resulted in a change to one station in June from azoic to silt with infauna. Plan-view imagery were useful in distinguishing surface bacteria mats that were obscured in sediment profile images where deep camera penetration occurred. Combining the data from both sets of imagery resulted in reassignment of several stations to the bacteria subclass in June and October (6 and 12 stations, respectively; Table 4).

Oligozoic habitats were associated with silts and sandy silts, and measurable camera penetration depths ranged 2-22 cm. June RPD depths (measurable at 33% of stations) were consistently <1 cm, and October RPD depths (measurable at 74% of stations) were <1 cm at 91% of stations and 1-2.9 cm at 9% of stations. Gas voids were observed at 33% (June) and 77% (October) of bacteria stations, and they were never observed at azoic stations. Anoxic voids were seen at one station (azoic habitat) in June and two in October (bacteria habitat). No oxic voids were observed in oligozoic habitats. Infaunal polychaetes were observed in October SPI imagery from 33% of bacteria stations. Grab data, sampled from 35% of October oligozoic stations, showed a depauperate benthic community with a predominance of *A. abdita* (<62 individuals/m^2) and *C. tuberculatum* (<50 individuals/m^2) in bacteria habitats.

Habitat Maps

Bowery Bay: There were ten stations in Bowery Bay visited in June and resampled in October. All stations were composed of fine sediments during both surveys, and gas voids occurred at 30% of June stations and 70% of October stations. June RPD depths were <1 cm at all stations where it was measurable (50% of stations) and October RPD depths were <1 cm at 44% of stations, 1-2.9 cm at 44% of stations and ≥3 cm at 11% of stations where it was measurable (90% of stations). *Ampelisca* habitat was observed in the northwestern and southeastern portion of the survey area during June, but was not present in October. Bacteria mats were also observed in the western portion of the survey area in June. *Ampelisca* and gas void habitat in the southeastern portion of the bay shifted to bacteria habitat in October (Figure 11; Table 5). Infaunal polychaete presence was observed to increase in SPI imagery from June to October. Grab data (Table 6) were taken at four stations in October and showed highest average abundances of *Capitella capitata* (>1,250 individuals/m^2) and *S. benedicti* (>390 individuals/m^2).

Flushing Bay: Stations were sampled in three major areas of Flushing Bay: (1) the northwestern region, west of the main channel, (2) the northeastern region, east of the main channel, and (3) the lower basin (Figure 11). All stations in Flushing Bay were composed of silty sediments with one exception in October. This station was located near the shore in the lower basin and was composed of rock and shell hash. Soft sediment habitats were observed only in June and at 60% of stations distributed throughout the three regions of the bay. Oyster beds occupied the northwestern corner of the sampling area west of the channel and stations closest to the coast consisted of silty habitats with faunal communities in June. The presence of epifauna and infauna increased in this region of Flushing Bay in October, and RPD depths ranged <1 cm (93%) and 1-2.9 cm (7%) in June and <1 cm (8%), 1-2.9 cm (84%) and ≥3 cm (8%) in October. Stations on the eastern side of the channel mainly were composed of soft sediments and few gas voids in June, and these habitats shifted to shallow sediment communities with infaunal worms and some gas voids in October (Table 5). RPD depths were <1 cm in June and <1 cm (18%) and 1-2 cm (82%) in October. Gas voids were observed at 7% and 21% of stations in June and October, respectively, and were most concentrated in the lower basin. In June, the lower basin contained soft sediments and bacteria habitats with over-penetration of the camera preventing RPD measurements. These habitats predominantly shifted to gas void habitats with RPD depths ranging <1 cm (50%) and ≥3 cm (50%) in October. June grab data (Table 6), taken at one station on the eastern side of the main channel, showed highest abundances of *Oligochaeta* (LPIL; >1,500 individuals/m^2) and *M. lateralis* (>1,250 individuals/m^2). Grab data from October, taken from nine stations distributed in each region, showed highest average abundances of *S. benedicti* (>1,700 individuals/m^2), *Leitoscoloplos robustus* (>590 individuals/m^2), *M. lateralis* (>400 individuals/m^2) and *Asabellides oculata* (>360 individuals/m^2).

Upper Bay: Sampling in Upper Bay (Figure 12) occurred in four areas (Upper Bay, Bay Ridge Flats, Bush Terminals, Atlantic Basin) in June, and three of those areas (excluding Bay Ridge Flats) were revisited in October. Stations along the Atlantic Basin were almost entirely composed of dark, silty sediments with gas voids (75% in June, 50% in October). Sandy sediments were observed at one station in Atlantic Basin during June, but this station was composed of silty sediments with gas voids by October (Table 5). RPD depths were not measurable at three of four stations in June, but they ranged between 1-2.9 cm (75%) and ≥3 cm (25%) in October. A few infaunal polychaetes were seen in June at one station, and many more were present at all stations in October. Grab data were taken at three of the four stations sampled in Atlantic Basin in October, and they showed highest average abundances of *S. benedicti* (>1,100 individuals/m^2), *Mediomastus* (LPIL; >950 individuals/m^2) and *M. lateralis* (>430 individuals/m^2).

Dark silty sediments characterized habitats in Bush Terminals, located along the Brooklyn waterfront. RPD depths were <1 cm in June and <1 cm (10%), 1-2.9 cm (80%) and ≥3 cm (10%) in October at stations where over-penetration did not prevent measurement. Relative numbers of stations having gas voids and anoxic voids were equal between the two surveys. Infaunal polychaete abundance increased from June to October, and bacteria mats were present at one station in October that had been previously characterized as having soft sediments (Figure 12). Grab data were taken at four stations in October and showed highest average abundances of *M. lateralis* (>1760 individuals/m^2), *S. benedicti* (>1000 individuals/m^2) and *Mediomastus* (LPIL; >700 individuals/m^2).

Benthic habitats west of Anchorage Channel in Upper Bay primarily consisted of silty sediments interrupted by patches of shell bed, sandy sediments, and small *Ampelisca* mats (Figure 12). RPD depths ranged <1 cm (55%) and 1-2.9 cm (45%) in June and 1-2.9 cm (84%) and ≥3 cm (16%) in October. Mussels and clams overlaid sandy silts along the western side of Anchorage Channel during both surveys. Isolated stations of sandy habitat, with and without bedforms, were scattered along the New Jersey Flats and near Global Marine Terminal pier. *Ampelisca* habitat was transiently located near shell bed habitat in northwestern Upper Bay. Infaunal polychaetes and bivalves generally increased in abundance from June to October based on SPI imagery. Grab data, taken from five October stations in this region, showed highest average abundances of *M. lateralis* (>4,750 individuals/m^2), *Mediomastus* (LPIL; >3,800 individuals/m^2), *S. vulgaris* (>2,540 individuals/m^2), *S. benedicti* (>2,250 individuals/m^2) and Oligochaeta (LPIL; >1,050 individuals/m^2).

Bay Ridge Flats, located east of Anchorage Channel in Upper Bay, was characterized by shell bed habitat (Figure 12). Mussel and clam beds overlaid fine sand and silty sediments, and all stations contained shell hash. RPD depths ranged between <1 cm (50%) and 1-1.8 cm (50%), and subsurface voids were absent from all stations on Bay Ridge Flats. Infaunal polychaetes were observed at two stations in the SPI imagery, though grab data were taken from a single station with no obvious infauna. These data showed highest abundances of *Heteromastus filiformis* (>2,100 individuals/m^2), Oligochaeta (LPIL; >1,870 individuals/m^2), *Mediomastus* (LPIL; >1,400 individuals/m^2) and *S. benedicti* (700 individuals/m^2).

Newark Bay: Sampling in Newark Bay occurred entirely outside of the channels (Figure 12), and predominantly silty sediments and a few sandy patches characterized all stations. RPD depths were <1 cm (53%), 1-2.9 cm (42%) and >3 cm (5%) in June and <1 cm (13%), 1-2.9 cm (75%) and ≥3 cm (13%) in October. Gas voids were observed infrequently in both surveys (11% in June, 10% in October), while feeding and anoxic voids were abundant in June (63% of stations) and much less commonly observed in October (10% of stations). Sandy habitats primarily had bedforms, and all sandy stations contained shell hash, although no live shell beds were found in Newark Bay in these surveys. Infaunal polychaetes were observed at 42% of June stations and 60% of October stations, based on SPI imagery. Grab data, taken from both surveys (32% of June stations, 70% of October stations; Table 6), indicated a shift in species dominance.

S. benedicti (>2,875 individuals/m^2), Cirratulidae (LPIL; >1,375 individuals/m^2) and *Leitoscoloplos* (LPIL; >650 individuals/m^2) had the highest average abundances in June while *M. lateralis* (>1,240 individuals/m^2), *Mediomastus* (LPIL; >1,025 individuals/m^2) and *S. benedicti* (>1,000 individuals/m^2) had the highest average abundances in October.

Jamaica Bay: Stations were predominantly composed of silty sediments and located in North Channel, Hendrix Creek, Paerdegat Basin, Mill Basin, Dead Horse Bay, Runway Channel, Big Fishkill Channel, Broad Channel, Beach Channel, Grass Hassock Channel, Sommerville Basin, Little Bay, Norton Basin, Head of Bay, and Grassy Bay (Figure 13). Isolated stations of rippled sand were observed in North Channel, at the mouth of Paerdegat Basin (October only), in Big Fishkill Channel, and in Beach Channel. *Ampelisca* mats, observed at 45% of June stations (24 of 53) and 48% of October stations (31 of 64), were located in all waterways except Paerdegat Basin, Mill Basin, Big Fishkill Channel, Dead Horse Bay, Little Bay, and Sommerville Basin. Live clam and mussel beds were found among *Ampelisca* mats in the Head of Bay (clam) and North Channel (mussel). One June station in Grassy Bay was assigned to the shell bed habitat because of the presence of clams, but this station also contained dense *Ampelisca* mats and bacteria mats. Silty habitats with gas voids, soft sediments, and bacteria mats predominated in Grassy Bay, Paerdegat Basin, Mill Basin, and Dead Horse Bay in June. By October, many of these habitats had shifted to bacteria habitats (41%; Grassy Bay, Paerdegat Basin, Mill Basin) and others had shifted to *Ampelisca* habitats (27%; Grassy Bay, Mill Basin, Dead Horse Bay). In addition, bacteria mats were observed in Hendrix Creek and Sommerville Basin at stations surveyed only in October.

RPD depths ranged <1 cm (32%), 1-2.9 cm (64%) and >3 cm (5%) in June and <1 cm (40%), 1-2.9 cm (57%) and ≥3 cm (2%) in October for stations where over-penetration did not prevent measurement (44% of stations in June, 74% of stations in October). Stations where over-penetration occurred were predominantly in silt and bacteria habitats (Grassy Bay, Bergen Basin, Paerdegat Basin, Mill Basin, and Grass Hassock Channel in June; Grassy Bay, Little Bay, Mill Basin, and Vernam Basin in October). Anoxic and feeding voids were rarely observed in SPI imagery from either survey (8% and 2% of stations in June and October, respectively), but infaunal polychaete presence appeared to increase from June (8% of stations) to October (46% of stations). Grab data (Table 6) taken at 26% of June stations showed highest average abundances of *A. abdita* (>3,975 individuals/m^2), *C. tuberculatum* (>3,625 individuals/m^2), *S. benedicti* (>1,150 individuals/m^2) and Cirratulidae (LPIL; >1,150 individuals/m^2). October grab data, taken at 39% of stations, showed highest average abundances of *A. abdita* (>6,475 individuals/m^2), *C. tuberculatum* (>1,975 indivuduals/m^2) and *Microdeutopus gryllotalpa* (>1,475 individuals/m^2).

Discussion

Various approaches have been taken to assess habitat quality using benthic community parameters (reviewed in Diaz 1992). Abundance, biomass, species richness, and diversity are commonly used in conjunction with physical and geochemical features of the sediment (e.g., grain size, RPD depth) as indicators of benthic community "health." Sediment profile imagery is a useful tool for identifying dominant functional groups of benthos (e.g., deep-burrowing polychaetes) and for developing indices based on these physical and biological features of the sediment-water interface (Rhoads and Germano 1982, Grizzle and Penniman 1991, Nilsson and Rosenberg 1997). Although many of these parameters were measured in this study, the patchy distribution of sampling stations within each bay and the uneven allocation of grab sampling among the bays limited assessment of habitat quality. Therefore, interpretation of these results will be restricted to descriptive statistical comparisons of each bay, and inferences on habitat quality will rely on supporting results from other studies.

The habitat classes were patchily distributed in the small bays of NY/NJ Harbor. Many of the habitat classes occurred consistently in each survey, but varied seasonally in location so representation in a single map was difficult. Shell beds were relatively stable in location while *Ampelisca* mats were more variable, except in Jamaica Bay. Sandy habitat subclasses distinguished habitats dominated by physical processes, such as currents or waves (bedforms), from habitats dominated by biological processes (no bedforms). Bedforms were nearly ubiquitous in the sandy habitats of Upper and Newark

Bays, which receive river inputs from the Passaic and Hackensack rivers (Newark Bay) and the Hudson and East rivers (Upper Bay), and lead into the lower harbor, facilitating tidal mixing. Thus, it was not surprising that bedforms predominated in these sandy habitats. Silty-sediment habitats were relatively stable across the surveys, though there was a considerable amount of spatial overlap among the subclasses. The azoic subclass within oligozoic habitat was not consistently observed across surveys. This subclass was only observed at two stations in Flushing Bay during the June survey, and was likely due to poor penetration of the SPI camera, resulting in "false negative" classifications. In addition, benthic communities are typically patchy in distribution, both spatially and temporally, so the azoic subclass was not an informative category for assessing habitat quality or bottom-type distributions. Conversely, bacteria habitats, commonly seen in association with gas voids, were observed during both surveys. Many of these bacteria habitats persisted both spatially and temporally within the study areas. Their correlation with the presence of gas voids was not unexpected, however, so bacteria habitats were considered indicative of organic contamination and a stressed benthic community.

Seasonal Changes

Seasonal changes consistent throughout the harbor sub-basins included deepening of the apparent RPD and increased infaunal densities in SPI images. These changes were most apparent in Bowery, Flushing, and Upper Bays where stations were resampled. Since the majority of stations in Newark Bay did not overlap between surveys, inferences on seasonal effects were limited to a few isolated areas. In general, Newark Bay habitats followed trends similar to the other bays. Sampling in Jamaica Bay increased in the October survey, and several of the small basins and creeks were sampled only in the fall. RPD depths increased slightly from June to October, but overall this shift was minimal in Jamaica Bay; infaunal densities generally increased here as seen in the other bays. Development of bacteria mats in particular areas of Bowery, Upper, and Jamaica Bays increased in the fall, and often occurred in close proximity to other stations characterized as bacteria habitat during June. The distribution of these habitats corresponded with isolated areas where the apparent RPD depth decreased, and very often developed from habitats with an abundance of gas voids.

Benthic Habitat Quality

Many of the studies conducted in NY/NJ Harbor have focused on the Lower Bay/Raritan Bay area (e.g., Cerrato and Scheier 1984, Stainken 1984, Cerrato et al. 1989, Steimle and Caracciolo-Ward 1989, MacKenzie 1990); therefore, data from the bays in the upper region of the harbor are limited. In addition to this study, the U.S. Environmental Protection Agency (EPA; Adams et al. 1998) surveyed both the upper and lower regions of the harbor between July and October 1993 and 1994. Its results included characterization of benthic communities and quantification of chemical, toxicological, and physical parameters within harbor sediments. Older studies conducted in Newark and Jamaica Bays focused on benthic community characterization (Cerrato 1986, USACE 1998).

Newark Bay: Historically, Newark Bay benthic assemblages have been characterized by low diversity (Cerrato 1986). The results of this study supported these observations. The majority of stations sampled were composed of mud with few infauna, predominantly consisting of worms. Adams et al. (1998) estimated that 85% of the area of Newark Bay consisted of mud, and they determined that abundance, biomass and species richness were lower in Newark Bay than in Upper, Lower, and Jamaica Bays.

Bivalves were absent from Newark Bay stations in these surveys, but preliminary SPI sampling in 1994 (USACE, unpublished data) and previous studies indicated the presence and high abundance of clams, particularly *M. arenaria* (Cerrato 1986, USFWS 1998, USACE 1998). Additionally, infauna were seen more often in silty sediments rather than sandy sediments, although this did not support previous observations (Cerrato 1986). These discrepancies were most likely related to differences in sampling methods. Sediment profile imaging is limited by camera penetration depth, which is often shallow in sandy sediments and shell beds. Therefore, infauna present in sandy sediments may not have been observed where camera penetration was shallow.

Seasonal changes in species abundance for Newark Bay were reported to be substantially lower in fall 1984 than in summer and spring 1985, presumably indicating high larval recruitment following the winter season (Cerrato et al. 1989). Opposing trends were observed in this study, resulting in an overall increase in infaunal polychaete abundance and deepening of the RPD with time. This apparent disagreement between studies should be evaluated cautiously, however, since the species from 1984/1985 were not identified, and the assemblages from the two studies may have differed in successional stage. Grab data from this study showed a seasonal shift in species dominance, but this may have been an artifact of sampling design.

Upper Bay: The common occurrence of shellfish beds in Upper Bay was unique among the harbor sub-basins. Historically, shellfish beds extended along the Jersey City piers, and though they have reduced in number, shell beds contributed substantially to the Upper Bay benthic habitat in this study. Adams et al. (1998) determined that biomass was highest in Upper Bay compared to the other harbor sub-basins surveyed, and bivalves (particularly mussels, *M. edulis*) were especially abundant.

Areas of potentially high pollutant and/or organic enrichment, as indicated by the gas void subclass, were concentrated around the Brooklyn waterfront and the northwestern region of the bay. Shallow RPD depths were loosely correlated with these habitats, though temporal changes in RPD depths were noted, as discussed previously. The results of the EPA study supported these findings and identified sediment contaminants present at notable levels (Adams et al. 1998). The study reported a predominance of silty sediments in Upper Bay and measured high levels of mercury, polyaromatic hydrocarbons (PAHs), and endrin (chlorinated pesticide). Abundant species in Upper Bay from this study included those identified by Adams et al. (1998) as pollution-tolerant species.

Jamaica Bay: All habitat classes were represented in the benthic assemblages of Jamaica Bay, though amphipod mats predominated. Stations found by Adams et al. (1998) containing sediment toxic to *A. abdita* were located in Grassy Bay and near the entrance to Jamaica Bay. This loosely correlated with the distribution of *Ampelisca* mats observed in this study, but stations sampled near the entrance to Jamaica Bay did not overlap with those surveyed by Adams et al. (1998) in the previous two years. Grassy Bay sediments, characterized by bacteria mats, gas voids, soft sediments, and few infauna, were also found by Adams et al. (1998) to contain high levels of total organic carbon and highly impacted benthos.

Benthic habitats observed in borrow pits (i.e., Grassy Bay, Mill Basin, Dead Horse Bay, Little Bay, Norton Basin, and Head of Bay) predominantly consisted of silty sediments both with and without amphipod mats. *A. abdita* frequently occurs in intermediate assemblages (Rhoads and Germano 1982), and its density typically varies through time (Steimle and Caracciolo-Ward 1989), as observed in this study. This suggested early and intermediate stages of colonization (Rhoads and Germano 1982) in these periodically disturbed areas. Shipping channels, maintained by recurrent dredging activities, exhibited similar habitat characteristics.

Bowery and Flushing Bays: Changes in these bays primarily consisted of habitat shifts among silty sediment subclasses, and only two areas within Bowery Bay and one in Flushing Bay experienced a shift in habitat class. The shift from silt to sand habitat in Flushing Bay may have been an artifact attributed to poor penetration of the SPI camera. Most notably, bacteria mats developed over soft, silty sediments and *Ampelisca* mats in the lower region of Bowery Bay, while recruitment to *Ampelisca* habitat failed in the upper region of the survey area. Additionally, grab data from both bays showed highest abundances of pollution-tolerant species. These data suggested that habitat quality was poor in these bays.

Comparisons with Lower Bay

Comparisons between the upper harbor bays and Lower Bay (including Raritan Bay and Sandy Hook Bay) indicated that habitat types seen commonly in Lower Bay were well represented in Upper Bay and Jamaica Bay (this study). Nearshore waterways located further inland (i.e., Newark, Bowery, and Flushing Bays) had much lower habitat diversity, with the majority of stations characterized by sandy or silty sediments. This may reflect differences in physical parameters (such as dissolved oxygen concentrations and salinity) and limited recruitment from open-water sources. Jamaica and Upper Bays open directly into Lower Bay, so tidal flow mediates larval transport to these areas. Newark, Bowery, and Flushing Bays receive tidal inputs through the Kill Van Kull (Newark Bay) or the East River (Bowery and Flushing Bays), so river currents may reduce larval input. The disparity in habitat types between Lower Bay and the more inland bays might also reflect different disturbance levels among the sites, including sedimentation rates or pollutant loading. These potential factors, however, could not be quantified from these data.

Oligozoic stations characterized by bacteria mats, which were scattered among Brooklyn Piers (Upper Bay), Bowery Bay, and Jamaica Bay, were not observed in Lower Bay. *Beggiatoa* mats occur in environments where a supply of free sulfide reaches the sediment surface, and their presence can indicate environmental degradation (Bernard and Fenchel 1995). Distributions of bacteria mat habitats may be explained by localized physical conditions (i.e., stagnant basins and anoxic sediments) and pollutants or organic contaminants that provide a nutrient source.

Conclusions

Upper and Jamaica Bays contained the greatest benthic habitat diversity. Shell bed habitat was relatively temporally stable, occurring predominantly in Upper Bay near channels. Similarly, *Ampelisca* habitat was temporally stable in Jamaica Bay, but this was not the case in the other bays. Silty sediments were ubiquitous in all the waterways surveyed, and the habitat types characterized as such dominated Newark, Bowery, Flushing, and Upper Bays. Bacteria mats seemed to indicate degraded habitat and were often located over silty sediments containing gas voids. Sandy sediments were mostly observed in Newark Bay and Upper Bay near channels where current energy was presumably higher.

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Table 1. Example spreadsheet of data collected from projected sediment profile images.

Station	Drop	Sediment	Texture	Interface	Ampelisca	Other	Epifauna	Burrows	Critters	Voids	VType	RPD	Pen
1	1	fs	Sand	sh;b;d	z	z	z	0	0	0	z	3.3	3.3
2	1	si	Silt	e;m	z	z	z	0	11	2	an	1	15.1
3	1	si	Silt	e;m	z	worms-few	z	3	5	3	an;ox	0.6	17.4
4	1	si	Silt	b;e	z	worms-some	z	0	7	5	an;ox	0.8	16.7
5	1	si	Silt	sh;b;e	z	worms-some	z	0	2	1	an	1.6	19.8
6	1	sifs	Sandy Silt	b;e	z	worms-few;bivalve	z	1	2	1	an	1.4	13.1
7	1	sifs	Sandy Silt	sh;b	z	worms-some	z	0	0	0	z	1.3	8.9
8	1	si	Silt	sh;d;e;p	z	z	z	0	0	1	ga	0.5	16.5
9	1	si	Silt	p	z	worms-few	z	0	4	0	z	0.9	20.1
10	1	sifscl	Sandy Mud	sh;c;e	z	worms-many	z	0	0	0	z	0.4	6.8
11	1	si	Silt	e;p	z	worms-few	z	0	7	0	z	0.4	19.6
12	1	sifscl	Sandy Mud	bed	z	z	z	0	1	0	z	1	7.5
13	1	sifs	Sandy Silt	bed	z	z	z	0	0	0	z	0.9	7.6
14	1	si	Silt	e	z	bivalve	z	0	22	0	z	1.2	21.2
16	1	sifscl	Sandy Mud	sh;bed;p	z	z	z	0	0	1	an	0.6	11.4
17	1	si	Silt	sh;e;p	z	worms-some	z	0	1	3	ga	1.6	20.1
18	1	si	Silt	z	z	z	z	0	0	1	ga	99	99
19	1	sicl	Clayey Silt	e	z	worms-some	z	0	3	1	ox	0.7	14.1
20	1	si	Silt	z	z	z	z	0	0	0	z	99	99
21	1	sifscl	Sandy Mud	sh;bed;m	z	z	z	0	0	0	z	0.4	9.7
22	1	sifs	Sandy Silt	m	z	worms-some	z	0	0	0	z	1.3	13.8
23	1	sifs	Sandy Silt	b	z	z	z	0	0	0	z	0.7	2.6
24	1	si	Silt	sh	few	worms-few	z	1	0	3	an;ga	1.3	19.3
25	1	si	Silt	sh	z	worms-some	z	0	0	0	z	1.8	17
26	1	fs	Sand	sh;bed;b	z	z	z	0	0	0	z	4.8	4.8
28	1	si	Silt	sh	z	worms-some	z	0	0	0	z	0.8	11.3
29	1	fs	Sand	sh;b	z	z	z	0	0	0	z	0	4.5
30	1	fs	Sand	sh	z	z	z	0	0	0	z	1.2	7.1

Table 2. Classification scheme for benthic habitats in NY/NJ Harbor.

Class and subclass	Description
Shell beds	
mussels	blue mussels (*Mytilus edulis*) in SPI, plan-view, or benthic grab (10+ individuals per grab)
oysters	American oysters (*Crassostrea virginica*)
clams	surf clams (*Spisula solidissima*), northern quahogs (*Mercenaria mercenaria*), or softshell clams (*Mya arenaria*) in SPI, plan-view, or benthic grab (3+ individuals per grab)
***Ampelisca* mats**	
sand	*Ampelisca* mat on sandy bottom in SPI, plan-view, or >200 individual per grab
silty sand	*Ampelisca* mat on silty sand bottom in SPI, plan-view, or >200 individual per grab
silt	*Ampelisca* mat on silty bottom in SPI, plan-view, or >200 individual per grab
Sandy bottom (Bedforms)	
epifauna	Sandy bottom with bedforms and either worms, algae or hydroids at interface
gravel	Sandy bottom with bedforms and gravel at interface
shell hash	Sandy bottom with bedforms and shell hash at interface
infauna	Sandy bottom with bedforms and obvious infauna/burrows (polychaete or bivalve)
no modifier	Sandy bottom with bedforms and none of the above modifiers applicable
Sandy bottom (No Bedforms)	
epifauna	Sandy bottom without bedforms and either worms, algae or hydroids at interface
gravel	Sandy bottom without bedforms and gravel at interface
shell hash	Sandy bottom without bedforms and shell hash at interface
infauna	Sandy bottom without bedforms and obvious infauna/burrows (polychaete or bivalve)
no modifier	Sandy bottom without bedforms and none of the above modifiers applicable
Silty bottom	
gas	Silty bottom and at least 50% of subsurface voids are methane pockets
deep penetration	Silty bottom and SPI camera prism penetrates >18 cm into the sediment
infauna	Silty bottom with obvious infauna/burrows (polychaetes, nemerteans or bivalves) in SPI, plan-view, or >30 individuals per benthic grab
Oligozoic	
azoic	Silty bottom without any of the above modifiers or bacteria mat at surface
bacteria mats	Silty bottom with bacteria mats (*Beggiatoa* spp.) at interface

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Table 3. Sums and averages of biogenic and physical features in each habitat class. Average calculations excluded stations for which no data were available.

June 1995 Survey

Habitat Class (subclass)	Avg Pen (cm)	Avg RPD (cm)	Total Amp	Total Infauna	Burrows	Voids	Bedforms	Algae/Hyd	Shell Hash	Avg Infauna	Stations	Percent
Amp(fine)	19.2	1.0	1164	2647	1	38	0	1	1	529	22	14.7
Amp(sand)	5.1	5.1	866	3334	0	0	1	0	1	3334	1	0.7
Amp(sifs, sims)	12.4	2.5	No data	No data	0	1	1	0	1	No data	6	4.0
SandBed(epifauna)	4.3	0.9	No data	No data	0	0	2	2	2	No data	2	1.3
SandBed(hash)	3.8	4.4	No data	No data	0	0	2	0	2	No data	2	1.3
SandBed(no modifier)	4.1	2.4	No data	No data	0	0	2	0	2	No data	2	1.3
SandNoBed(critters)	13.4	1.0	No data	No data	0	0	0	0	0	No data	1	0.7
SB(clams)	7.4	1.3	121	1244	0	2	2	0	6	415	9	6.0
SB(mussel)	9.8	1.0	No data	No data	0	0	2	1	4	No data	5	3.3
SB(oyster)	11.5	0.0	No data	No data	0	0	0	0	1	No data	1	0.7
Silt(critters)	13.8	0.8	4	1140	8	29	3	0	4	380	23	15.3
Silt(gas)	17.5	0.9	93	539	3	423	0	0	2	77	27	18.0
Silt(pendeep)	20.8	0.7	1	546	3	26	1	0	2	182	40	26.7
Bacteria	No data	No data	No data	No data	0	7	0	0	0	No data	6	4.0
Azoic	9.6	0.5	No data	No data	0	1	1	0	0	No data	3	2.0
Totals			**2249**	**9450**	**15**	**527**	**17**	**4**	**28**		**150**	**100.0**

October 1995 Survey

Habitat Class (subclass)	Avg Pen (cm)	Avg RPD (cm)	Total Amp	Total Infauna	Burrows	Voids	Bedforms	Algae/Hyd	Shell Hash	Avg Infauna	Stations	Percent
Amp(fine)	13.4	1.3	3071	5587	0	20	0	1	0	698	24	15.6
Amp(sand)	2.0	1.0	No data	No data	0	0	1	1	1	No data	1	0.6
Amp(sifs, sims)	7.4	1.6	2570	6164	4	0	1	1	1	2055	8	5.2
SandBed(critters)	7.0	2.0	No data	No data	0	0	2	0	0	No data	2	1.3
SandBed(epifauna)	2.3	2.0	1	119	0	0	4	2	4	60	4	2.6
SandBed(hash)	5.7	2.7	0	519	1	0	3	0	3	173	3	1.9
SandNoBed(critters)	9.0	2.0	4	92	0	0	0	0	0	92	1	0.6
SandNoBed(epifauna)	0.0	No data	No data	No data	No data	No data	0	1	1	No data	1	0.6
SandNoBed(hash)	9.0	2.0	1	114	2	0	0	0	1	114	1	0.6
SB(clams)	5.8	1.0	1082	1452	0	0	0	0	4	726	5	3.2
SB(mussel)	5.2	1.0	41	1892	0	0	1	0	5	1892	5	3.2
SB(oyster)	12.0	1.0	No data	No data	0	0	0	1	1	No data	1	0.6
Silt(critters)	12.3	1.4	85	3777	83	24	5	6	3	199	48	31.2
Silt(gas)	14.6	2.0	15	1551	27	85	0	1	0	222	17	11.0
Silt(pendeep)	No data	No data	0	0	0	0	0	0	0	0	2	1.3
Bacteria	16.5	0.1	27	82	17	102	1	0	0	8	30	19.5
Azoic	5.0	0.0	0	20	0	0	0	0	1	20	1	0.6
Totals			**6897**	**21369**	**134**	**231**	**18**	**14**	**25**		**154**	**100.0**

Table 4. Frequency of habitat subclasses for June and October 1995 surveys based on sediment profiling imagery and all methods combined. Habitat reassignments and the data source used to reclassify stations are indicated in the final two columns.

June 1995 survey Habitat Class (subclass)	Stations assigned based on: SPI	All methods	No. stations reassigned due to Grab data: new habitat	No. stations reassigned due to Plan-view data: new habitat
Amp(fine)	19	22	0	1 stn: SB(clams)
Amp(sand)	0	1	0	0
Amp(sifs, sims)	7	6	0	1 stn: SB(mussel)
SandBed(epifauna)	2	2	0	0
SandBed(hash)	3	2	0	1 stn: SB(clams)
SandBed(no modifier)	3	2	1 stn: Amp(sand)	0
SandNoBed(critters)	1	1	0	0
SandNoBed(hash)	1	0	0	1 stn: SB(clams)
SB(clams)	3	9	0	0
SB(mussel)	5	5	0	1 stn: SB(clams)
SB(oyster)	1	1	0	0
Silt(critters)	23	23	0	1 stn: Amp(fine)
Silt(gas)	29	27	0	2 stn: Bacteria
Silt(pendeep)	49	40	2 stn: SB(clams)	4 stn: Bacteria; 3 stn: Amp (fine)
Bacteria	0	6	0	0
Azoic	4	3	1 stn: Silt(critters)	0

October 1995 survey Habitat Class (subclass)	Stations assigned based on: SPI	All methods	No. stations reassigned due to Grab data: new habitat	No. stations reassigned due to Plan-view data: new habitat
Amp(fine)	27	24	1 stn: SB(clams)	2 stn: Bacteria
Amp(sand)	1	1	0	0
Amp(sifs, sims)	9	8	1 stn: SB(clams)	0
SandBed(critters)	2	2	0	0
SandBed(epifauna)	4	4	0	0
SandBed(hash)	3	3	0	0
SandNoBed(critters)	1	1	0	0
SandNoBed(epifauna)	1	1	0	0
SandNoBed(hash)	1	1	0	0
SB(clams)	3	5	0	0
SB(mussel)	3	5	0	0
SB(oyster)	1	1	0	0
Silt(critters)	48	48	0	1 stn: SB(mussel)
Silt(gas)	26	17	0	9 stn: Bacteria
Silt(pendeep)	3	2	0	1 stn: Bacteria
Bacteria	18	30	0	0
Azoic	3	1	0	1 stn: Silt(critters); 1 stn: SB(mussel)

Table 5. Seasonal changes in habitat types of revisited stations from June to October 1995 in the smaller bays of NY/NJ Harbor. Numbers indicate station totals for each habitat type. Numbers in bold italics indicate change in habitat type.

BAY	JUNE	OCTOBER: Silt(critters)	Silt(gas)	Bacteria
Bowery	Amp(fine)	***1***	***1***	***2***
	Silt(critters)	1	-	-
	Silt(gas)	-	1	***1***
	Silt(pendeep)	-	***2***	-
	Bacteria	-	-	1
	Number of June stations not revisited (excluded):			0

BAY	JUNE	Azoic	SandNoBed (epifauna)	SB(oyster)	Silt(critters)	Silt(gas)	Bacteria
Flushing	Azoic	-	-	-	***1***	-	-
	SandNoBed(epifauna)	-	-	-	-	-	-
	SB(oyster)	-	-	-	-	-	-
	Silt(critters)	-	***1***	***1***	3	-	-
	Silt(gas)	-	-	-	-	2	-
	Silt(pendeep)	***1***	-	-	***14***	***3***	-
	Bacteria	-	-	-	***1***	-	1
	Number of June stations not revisited (excluded):			2			

BAY	JUNE	Amp(sifs,sims)	SandBed (critters)	SandNoBed (critters)	SB(clams)	SB(mussel)	Silt(critters)	Silt(gas)	Bacteria
Upper	Amp(fine)	-	-	-	-	-	***1***	-	-
	Azoic	-	-	-	-	***1***	-	-	-
	SandBed(hash)	-	***1***	-	-	-	-	-	-
	SandNoBed(critters)	-	-	-	-	-	-	***1***	-
	SB(clams)	-	-	-	2	-	-	-	-
	SB(mussel)	-	-	-	-	3	-	-	-
	Silt(critters)	***1***	***1***	***1***	-	***1***	4	-	-
	Silt(gas)	-	-	-	-	-	***5***	3	-
	Silt(pendeep)	-	-	-	-	-	***5***	***2***	***1***
	Bacteria	-	-	-	-	-	-	-	-
	Number of June stations not revisited (excluded):			5					

BAY	JUNE	SandNoBed (hash)	SandBed (hash)	Silt(critters)
Newark	SandBed(hash)	-	1	-
	Silt(critters)	***1***	***1***	-
	Silt(gas)	-	-	-
	Silt(pendeep)	-	-	***1***
	Number of June stations not revisited (excluded):			15

BAY	JUNE	Amp(fine)	Amp(sifs,sims)	Bacteria	SandBed (epifauna)	SB(clams)
Jamaica	Amp(fine)	14	-	-	***1***	***2***
	Amp(sand)	-	***1***	-	-	-
	Amp(sifs,sims)	***4***	2	-	-	-
	SandBed(epifauna)	-	-	-	1	-
	SandBed(no modifier)	-	-	-	***1***	-
	SB(clams)	***1***	***1***	-	-	1
	SB(mussel)	-	-	-	-	-
	Silt(gas)	***2***	-	***12***	-	-
	Silt(pendeep)	-	-	***2***	-	-
	Bacteria	-	-	3	-	-
	Number of June stations not revisited (excluded):			3		

Table 6. Ten most abundant species (average number per m^2) in NY/NJ Harbor Bays surveyed in June and October 1995 using a Shipek grab. Percentages in parentheses indicate percent of total infauna represented by top ten species.

Bay	Survey date (# stations)	Total	Survey date (# stations)	Total
Bowery Bay				
	June (0 stations)		October (4 stations)	
			Capitella capitata	1263
			Streblospio benedicti	394
			Oligochaeta (LPIL)	225
			Mulinia lateralis	194
			Rictaxis punctostriatus	175
			Asabellides oculata	88
			Ampharetidae (LPIL)	75
			Bivalvia (LPIL)	56
			Mediomastus (LPIL)	56
			Leitoscoloplos robustus	50
			Total (92.6%)	2575
Flushing Bay				
	June (1 station)		October (9 stations)	
	Oligochaeta (LPIL)	1550	*Streblospio bendicti*	1708
	Mulinia lateralis	1350	*Leitoscoloplos robustus*	597
	Leitoscoloplos fragilis	1075	*Mulinia lateralis*	408
	Leitoscoloplos (LPIL)	825	*Asabellides oculata*	361
	Streblospio bendicti	450	Bivalvia (LPIL)	200
	Cirratulidae (LPIL)	175	*Capitella capitata*	178
	Mediomastus (LPIL)	100	*Polydora cornuta*	169
	Eteone (LPIL)	50	Oligochaeta (LPIL)	136
	Tellina agilis	50	*Rictaxis punctostriatus*	117
	Nephtys incisa	25	Gastropoda (LPIL)	108
	Total (99.6%)	5650	Total (96.4%)	3983
Jamaica Bay (including Dead Horse Bay)				
	June (14 stations)		October (26 stations)	
	Ampelisca abdita	3993	*Ampelisca abdita*	6546
	Corophium tuberculatum	3648	*Corophium tuberculatum*	1983
	Cirratulidae (LPIL)	1173	*Microdeutopus gryllotalpa*	1480
	Streblospio benedicti	1168	*Gemma gemma*	725
	Microdeutopus gryllotalpa	713	*Mulinia lateralis*	374
	Mediomastus (LPIL)	657	*Mediomastus* (LPIL)	272
	Oligochaeta (LPIL)	348	*Streblospio benedicti*	264
	Caulleriella sp. J	223	*Podarke obscura*	159
	Nucula proxima	141	*Exogone dispar*	126
	Podarke obscura	123	*Elasmopus levis*	113
	Total (92.2%)	12188	Total (92.9%)	12041

Table 6 (continued). Ten most abundant species (average number per m^2) in NY/NJ Harbor Bays surveyed in June and October 1995 using a Shipek grab. Percentages in parentheses indicate percent of total infauna represented by top ten species.

Bay	Survey date (# stations)	Total	Survey date (# stations)	Total
Newark Bay				
	June (6 stations)		October (7 stations)	
	Streblospio benedicti	2900	*Mulinia lateralis*	1243
	Cirratulidae (LPIL)	1400	*Mediomastus* (LPIL)	1036
	Leitoscoloplos (LPIL)	667	*Streblospio benedicti*	1011
	Mediomastus (LPIL)	388	Bivalvia (LPIL)	507
	Marenzellaria viridis	271	*Pectinaria gouldii*	146
	Heteromastus filiformis	125	*Sabellaria vulgaris*	132
	Oligochaeta (LPIL)	117	*Leitoscoloplos robustus*	64
	Leitoscoloplos fragilis	75	Oligochaeta (LPIL)	61
	Tharyx acutus	63	*Glycera americana*	39
	Phyllodocidae (LPIL)	50	*Polydora cornuta*	32
	Total (95.2%)	6054	Total (96.1%)	4271
Upper Bay				
	June (1 station)		October (12 stations)	
	Heteromastus filiformis	2150	*Mulinia lateralis*	2694
	Oligochaeta (LPIL)	1875	*Mediomastus* (LPIL)	2077
	Mediomastus (LPIL)	1425	*Streblospio benedicti*	1590
	Streblospio benedicti	700	*Sabellaria vulgaris*	1060
	Tellina agilis	200	Oligochaeta (LPIL)	588
	Pelecypoda (LPIL)	175	Bivalvia (LPIL)	246
	Glycera americana	175	*Elasmopus levis*	85
	Eusarsiella zostericola	150	*Eumida sanguinea*	71
	Ampelisca abdita	100	*Crepidula fornicata*	65
	Ensis directus	75	*Leitoscoloplos robustus*	65
	Total (96.9%)	7025	Total (90.0%)	8540

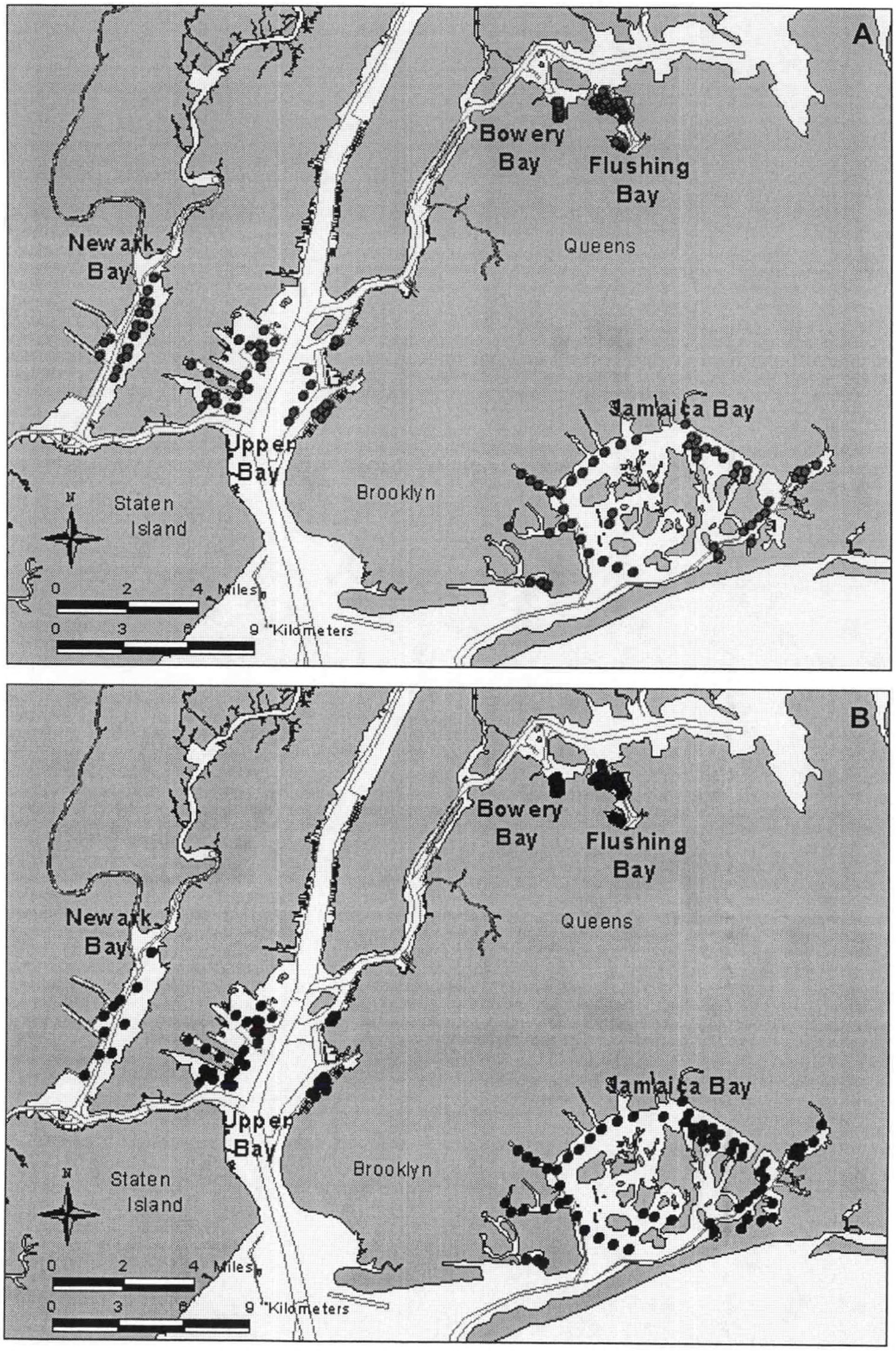

Figure 1. Sampling effort in June 1995 (A) and October 1995 (B).

Figure 2. Sediment Profile Camera.

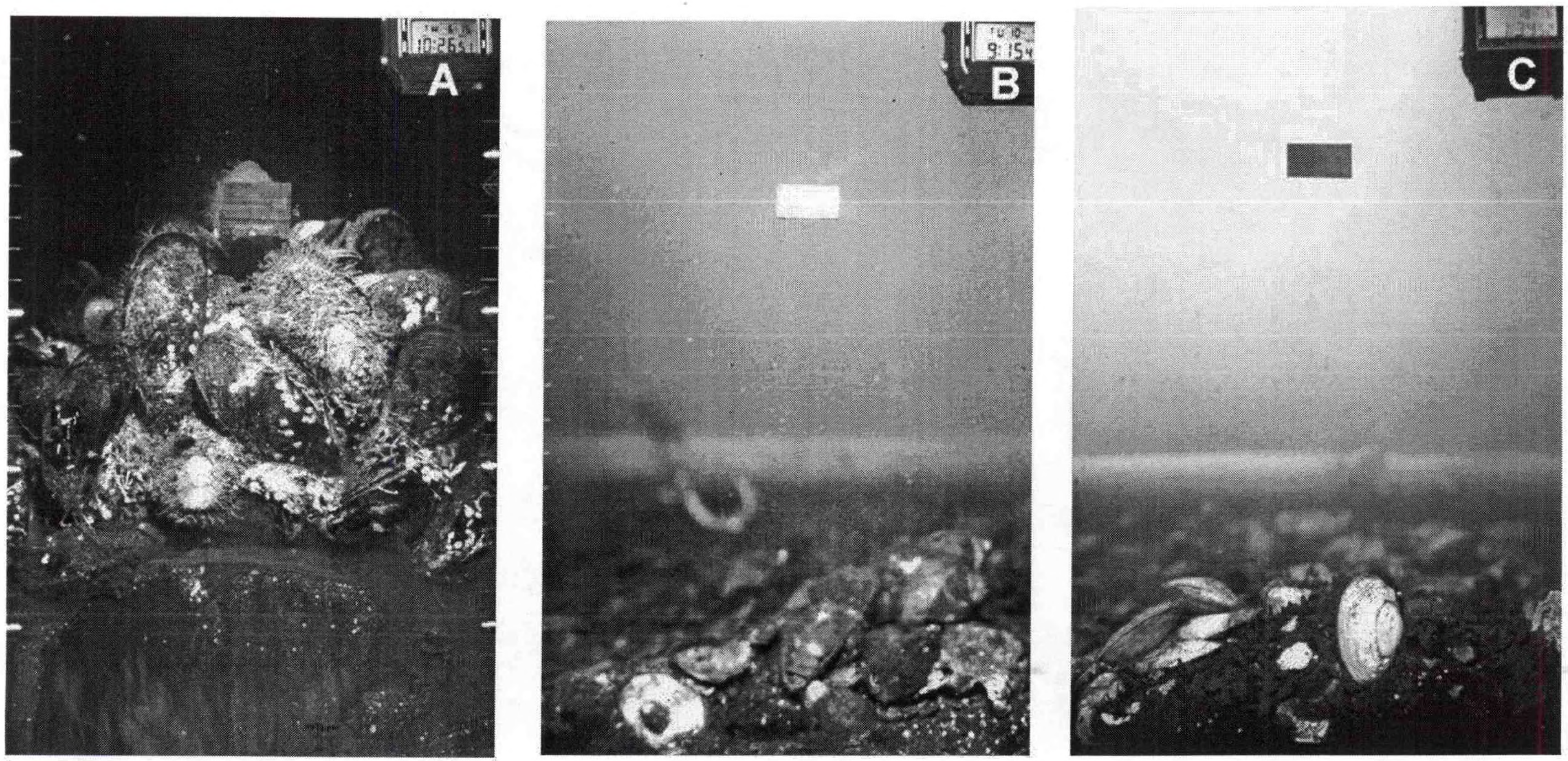

Figure 3. Shell bed habitat subclasses: mussels (A), oysters (B), clams (C).

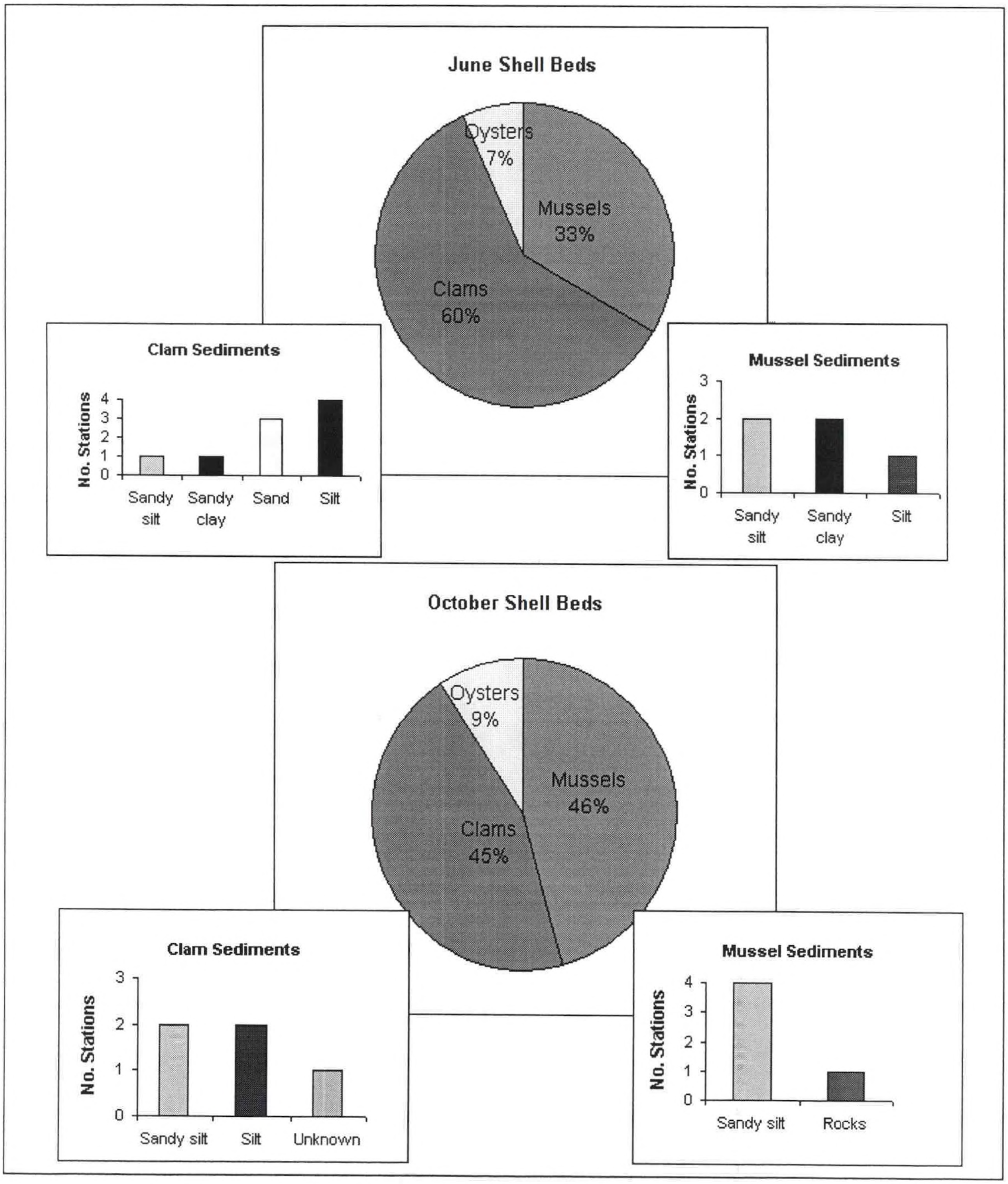

Figure 4. Frequency of shell bed subclasses and sediment types.

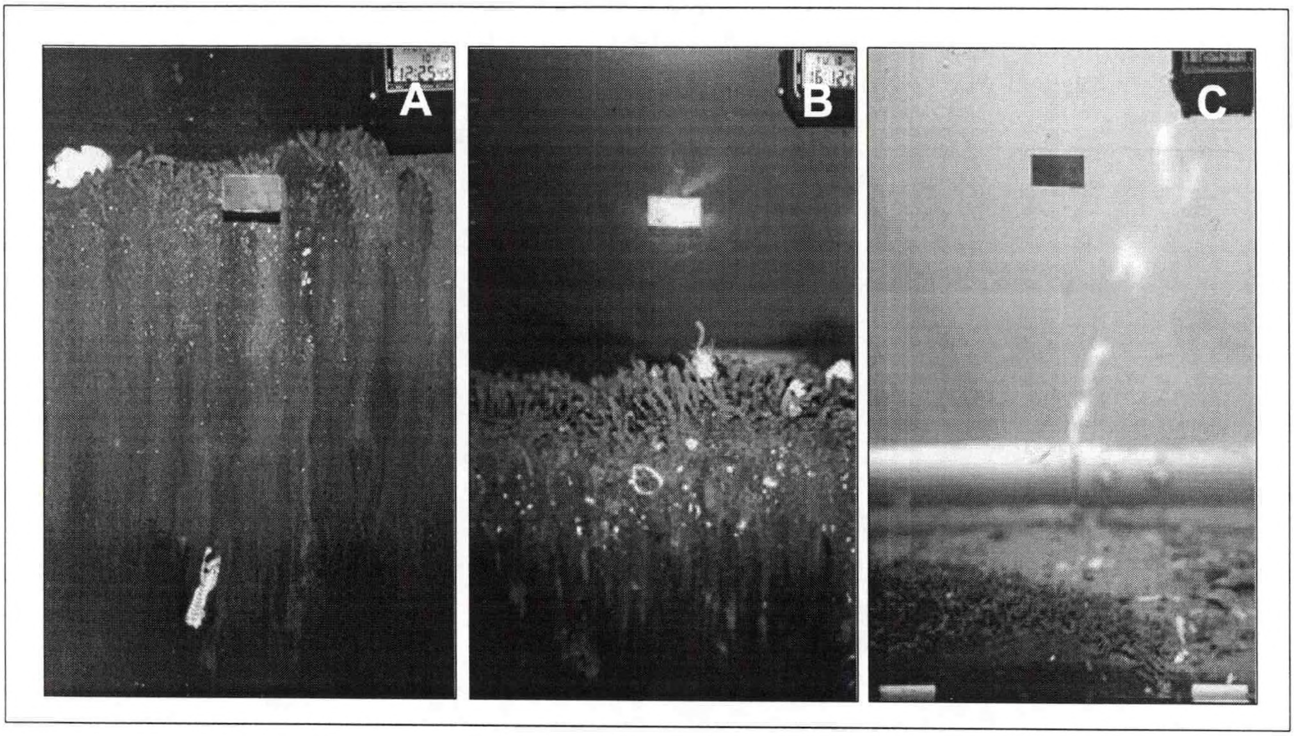

Figure 5. Ampelisca mat habitat subclasses: silt (A), sandy silt (B), sand (C).

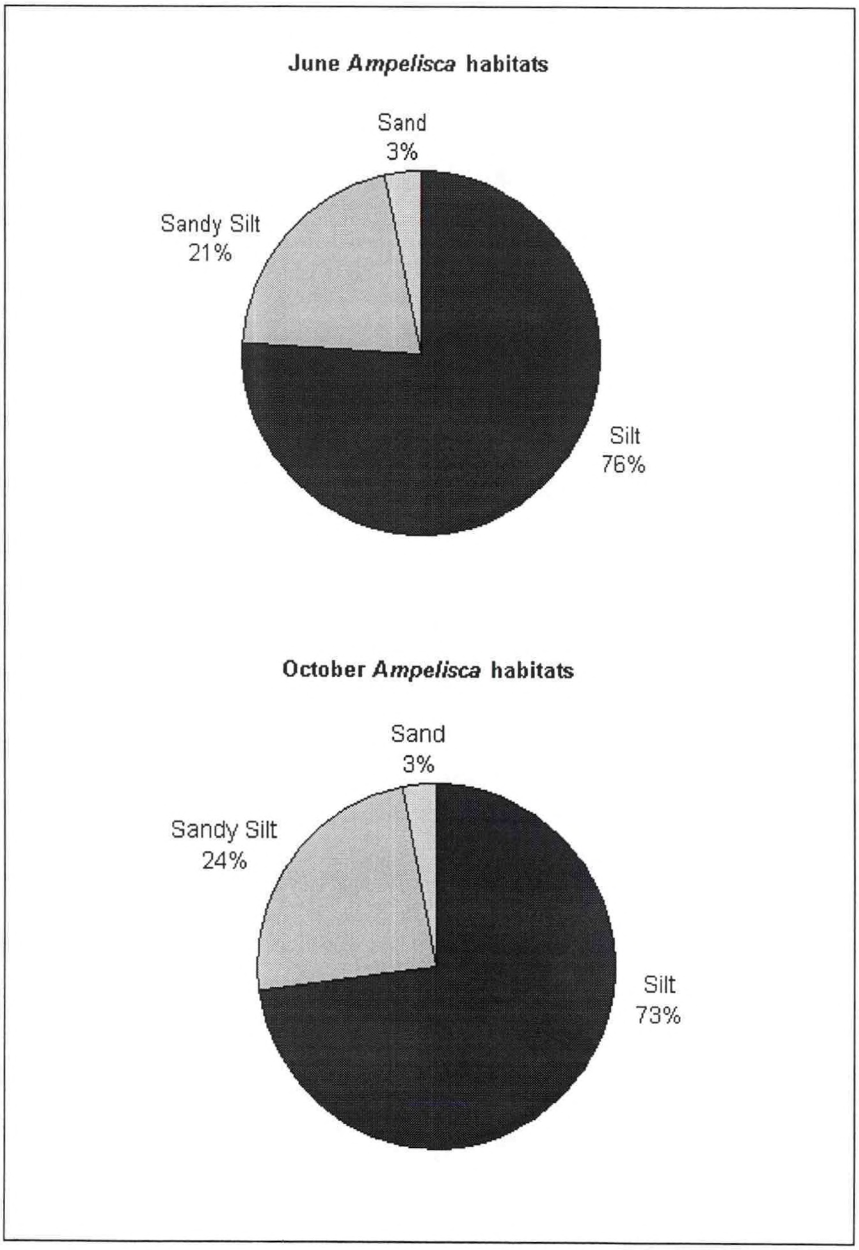

Figure 6. Frequency of *Ampelisca* habitat subclasses as defined by sediment types.

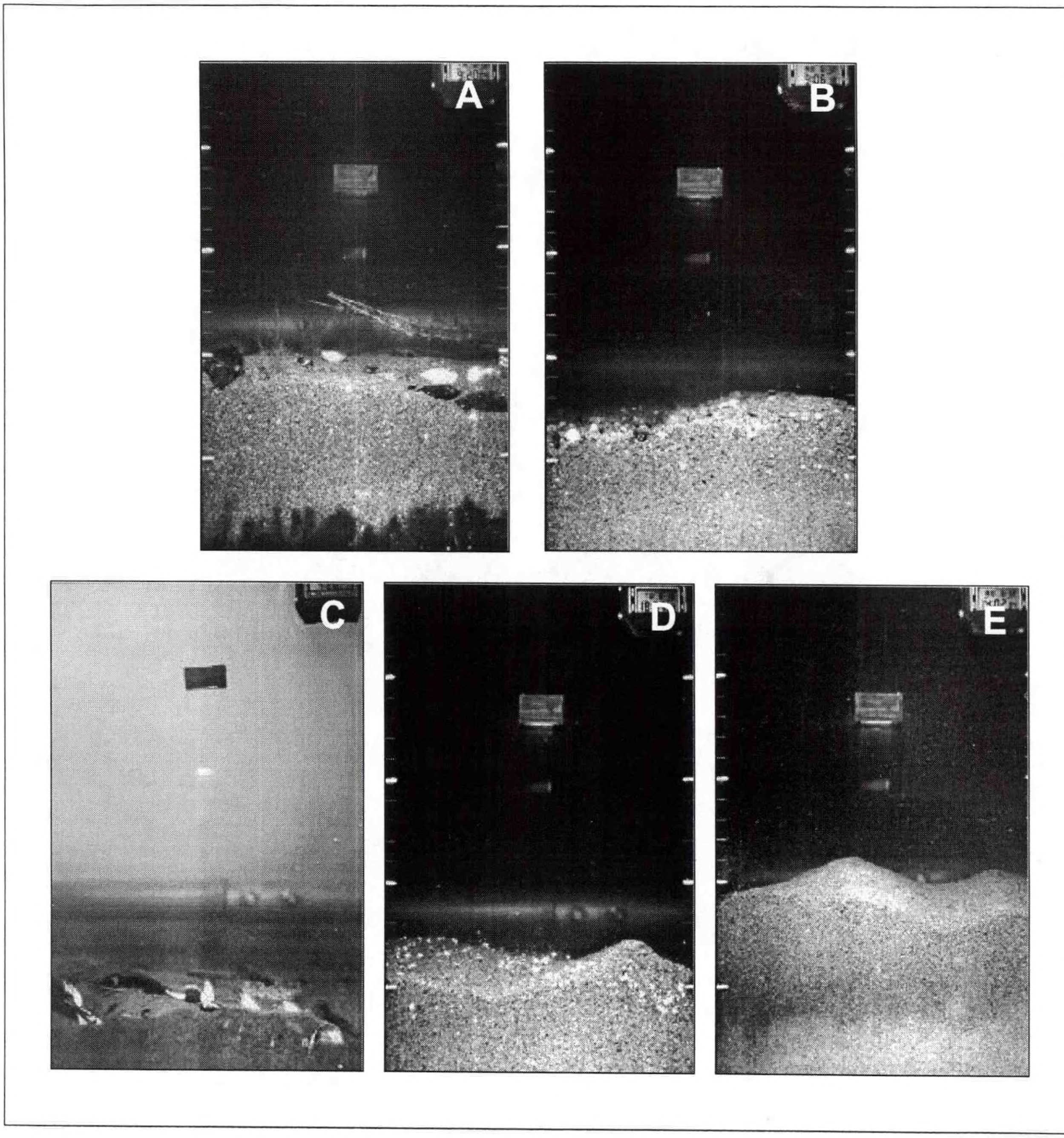

Figure 7. Sandy bottom with bedforms habitat subclasses: epifauna (A), gravel (B), shell hash (C), infauna (D), no modifier (E).

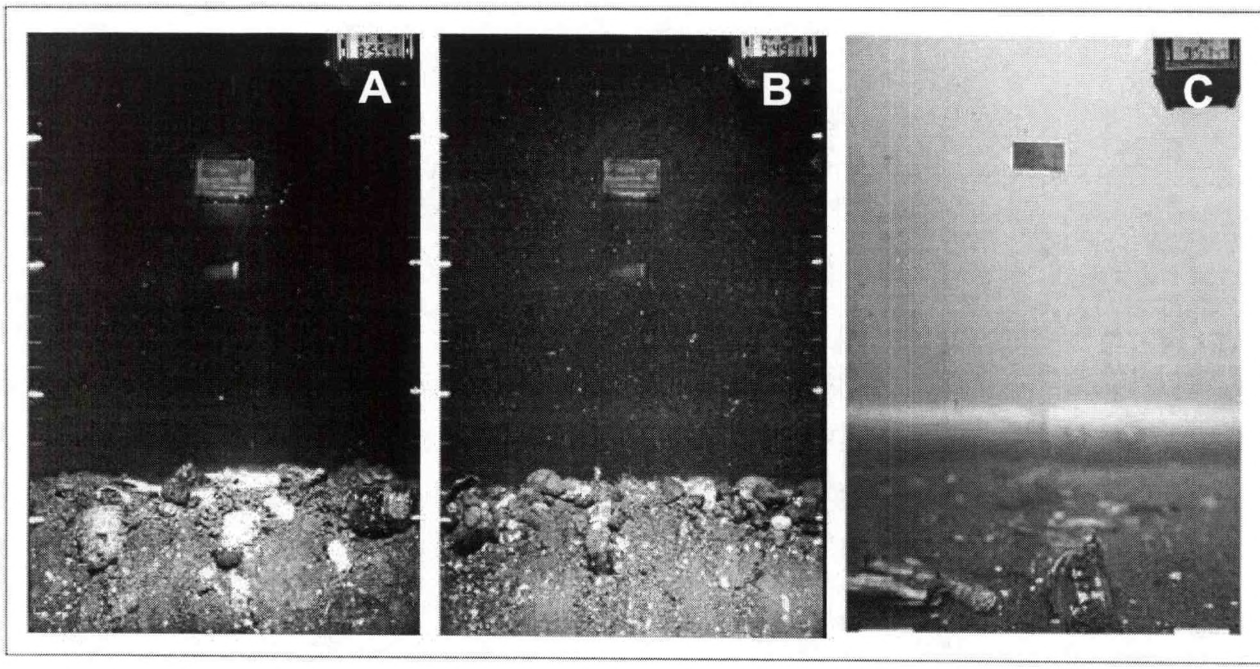

Figure 8. Sandy bottom without bedforms habitat subclasses: epifauna (A), gravel (B), shell hash (C).

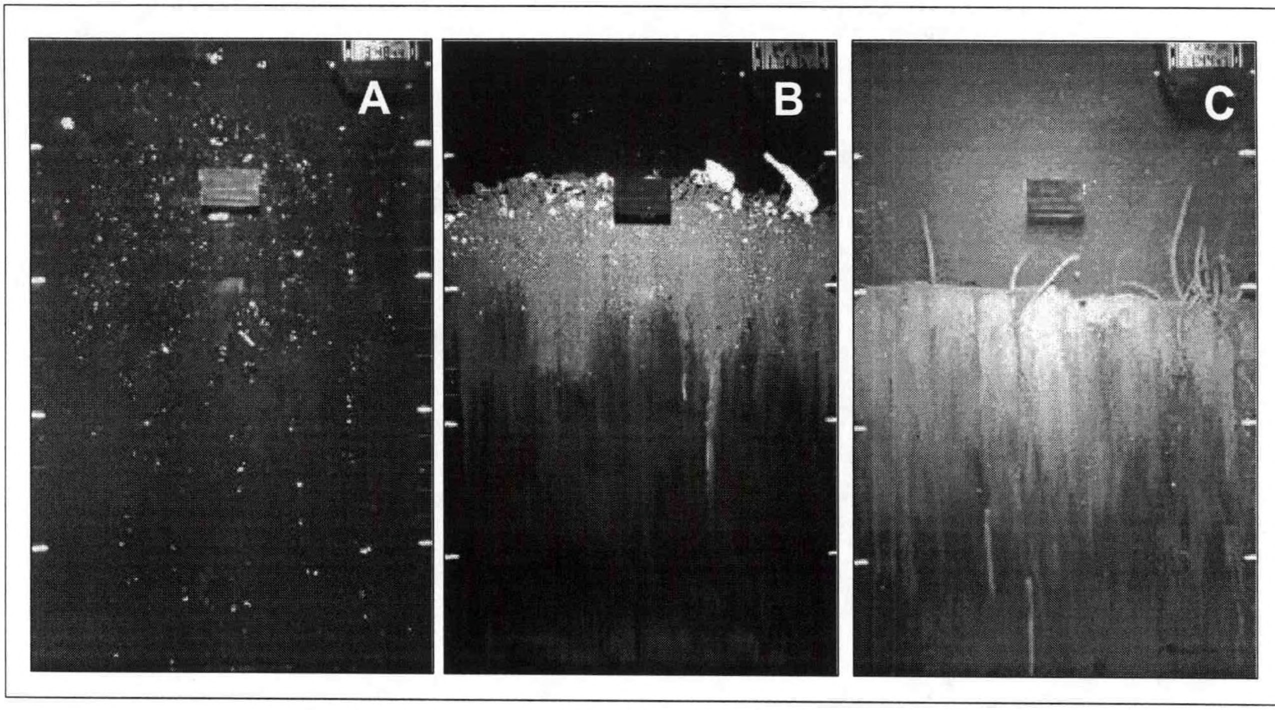

Figure 9. Silty bottom habitat subclasses: gas (A), soft sediments (B), infauna (C).

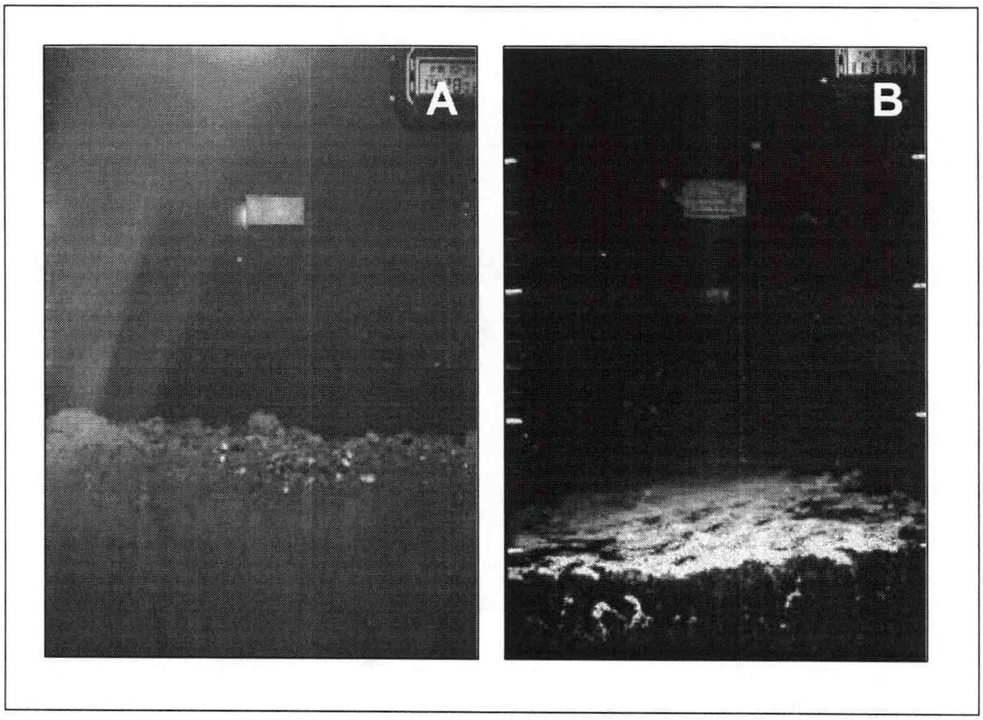

Figure 10. Oligozoic habitat subclasses: azoic (A), bacteria mat (B).

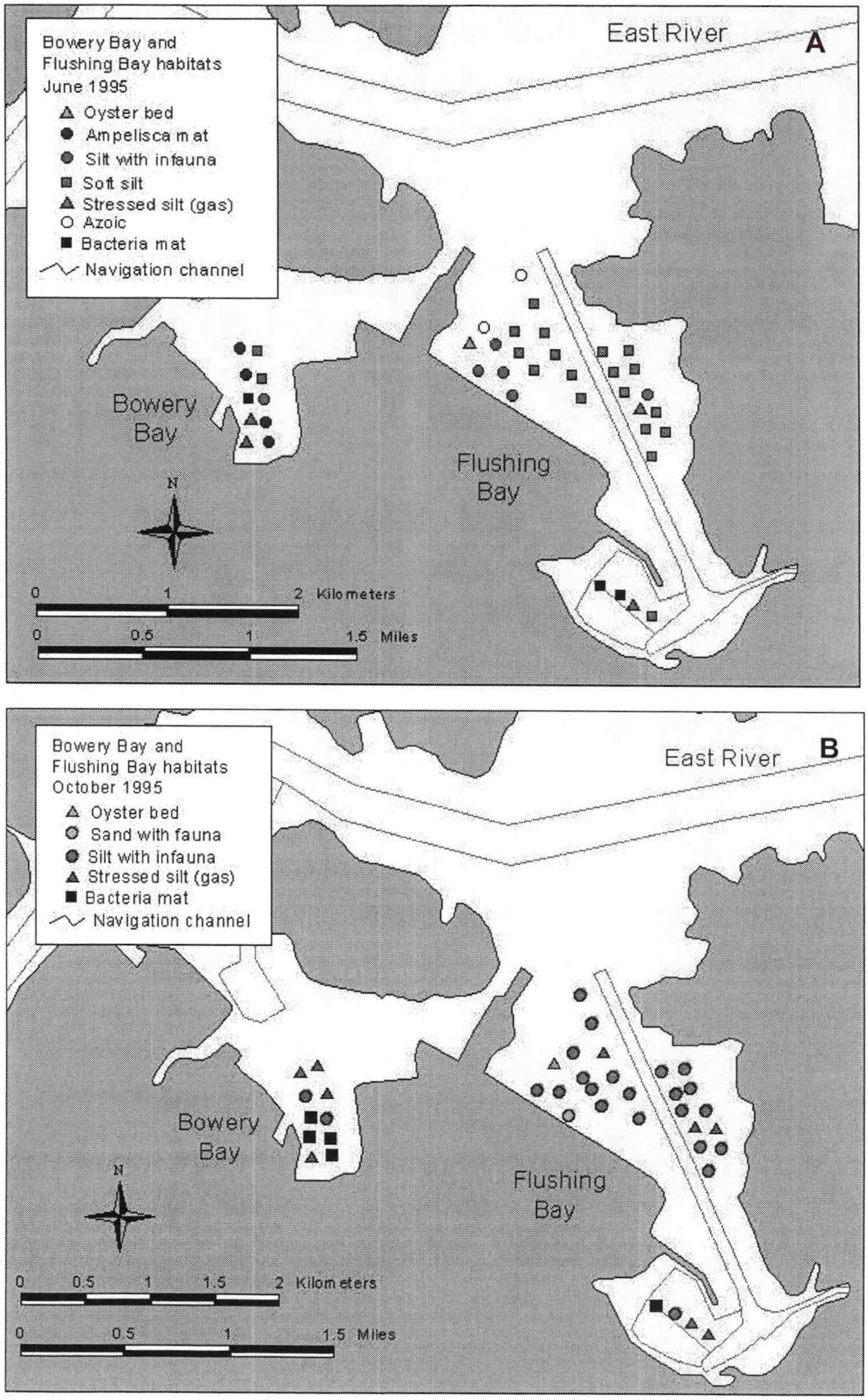

Figure 11. Benthic habitats of Bowery and Flushing Bays in June 1995 (A) and October 1995 (B).

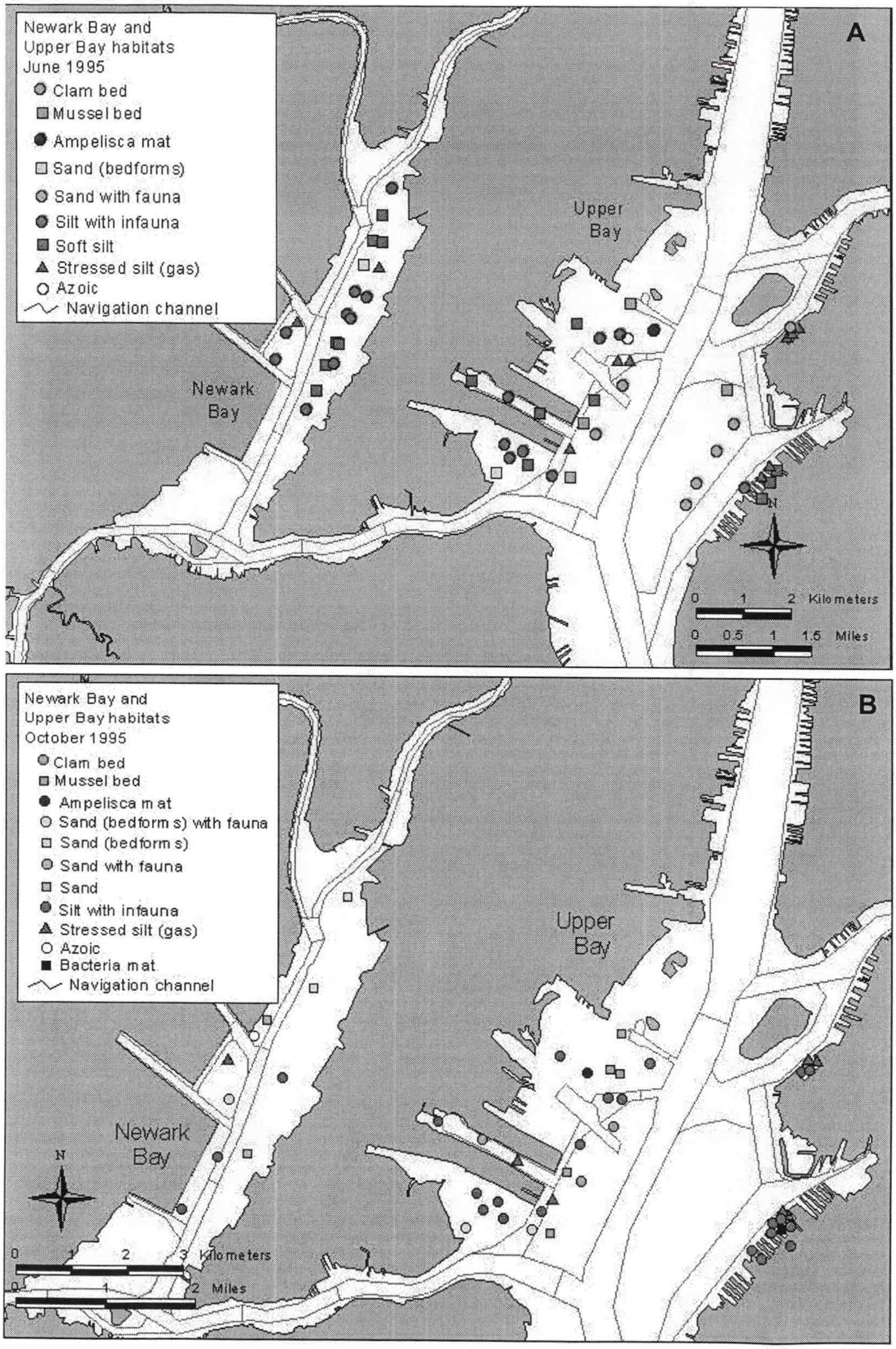

Figure 12. Benthic habitats of Newark and Upper Bays in June 1995 (A) and October 1995 (B).

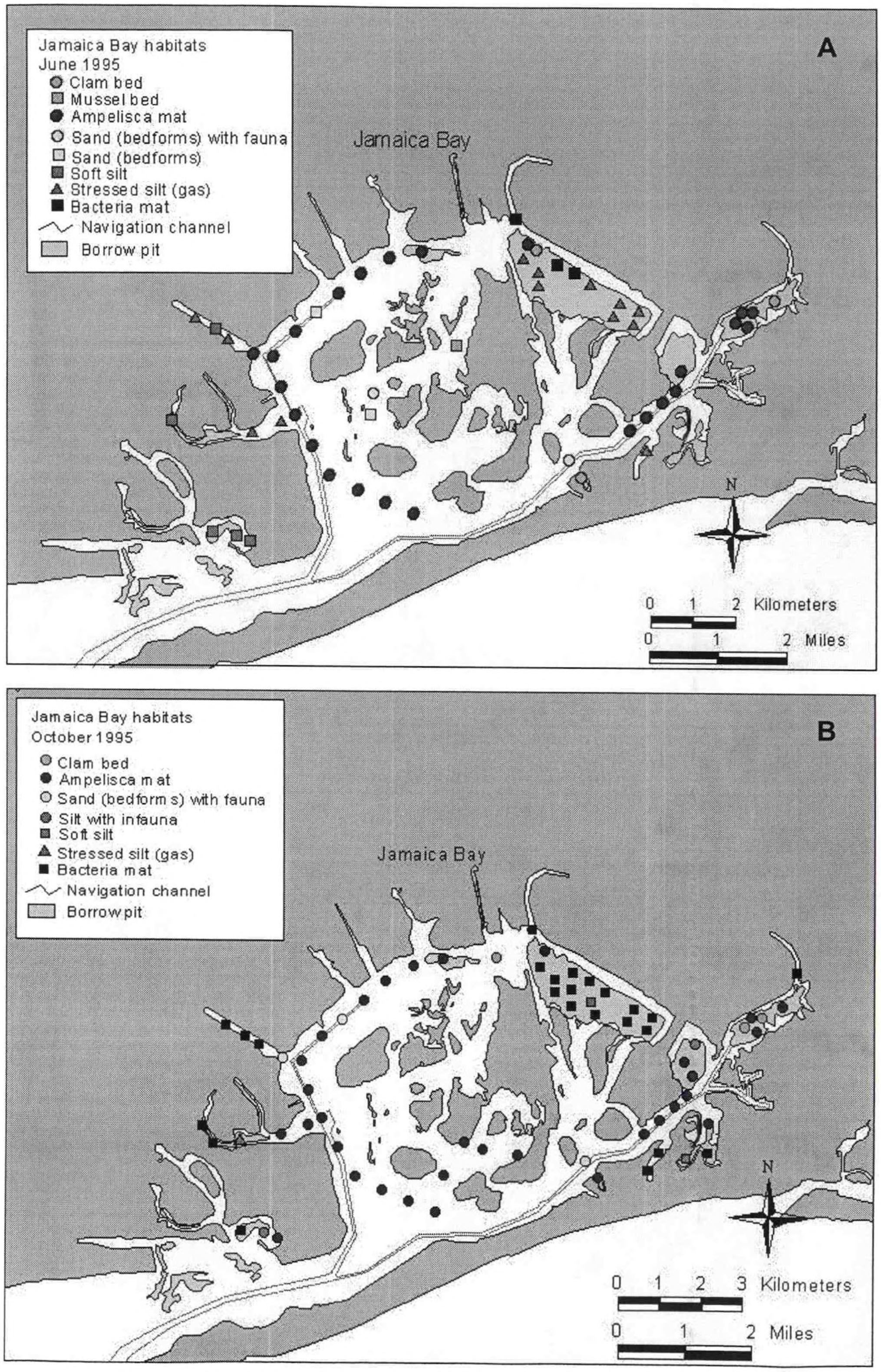

Figure 13. Benthic habitats of Jamaica Bay in June 1995 (A) and October 1995 (B).