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A WETLAND ANALYSES IN A HIGHLY POLLUTED HARBOR NEW BEDFORD, MASSACHUSETTS USA

Russell Joe Bellmer
Marine Ecologist
New Bedford Superfund Office

New England Division
Corps of Engineers
424 Trepalo Road
Waltham, MA 02254-9149

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SUMMARY

Wetlands are important ecological areas for: habitat, nurseries, wildlife foraging, very high productivity, wilderness aesthetics, nature recreation, and nature education In April 1985, the U.S. EPA Environmental Photographic Interpretation Center (EPIC) completed an identification of the vegetated tidal wetlands in the Acushnet River estuary area. This study identified over 160 ha of wetlands using the Federal definition. The Corps of Engineers has regulatory authority over wetlands. The New England Division (NED) of the Corps was requested by the Environmental Protection Agency (EPA), Region I to evaluate these wetlands as part of EPA's superfund activities in the Acushnet River Estuary/New Bedford Harbor, Massachusetts. This study consisted of: field surveys, laboratory tests, and literature search over a 3 yr period from 1985 to 1988.

The area of PCB contamination extends from the northern end of the Acushnet River Estuary to sediments in the vicinity of Clark's Point, Buzzards Bay, a distance of over 10 km (MCZM 1982). Toxic metals such as copper (Cu), chromium (Cr), cadmium (Cd), zinc (Zn), and lead (Pb) were also discharged to these waters by metals manufacturing and textile dying operations. Due to the very high contamination levels; many regulatory biologists were of the opinion, that these wetlands were no longer a significant resource and destruction during clean-up would be acceptable. This paper contains a description and comparison of hydrological, physical, chemical, and biotic conditions within the Acushnet River estuary vegetated tidal wetlands. Since EPAs' proposed remedial action plans may eliminate some of the wetland system within the estuary, it was appropriate to examine the functional integrity of these ecosystems. The results of this study showed that there was no statistical differences: in avifauna habitat utilization; vegetative cover type, stem height, and stem density; in fish species, number of individuals, and weight/length measurements between the reference site and the contaminated site. The utilization by wildlife was high and diverse. The gut contents of the fish species examined showed the usual prey species within an estuary environment. *Pseudopleuronectes americanus* were visually surveyed for neoplasms on their livers none recorded The data indicated an increase of the PCB concentration, from vegetative matter to herbivore/filter feeder to the gull. The metals analyses indicate an elevated levels in most samples, but are not an indication of biomagnification. Concentrations of metals and PCBs in the grass shrimp (*Palaemonetes pugio*) showed a trend reflective of the sediment contamination. The infauna data showed a statistical difference between Site 1 (lower) and Site 2 (higher) in diversity.

There were many administratively important species in the esturay: fisheries: soft-shelled clam (*Mya arenaria*), hard shelled clam (*Mercenaria mercanaria*), American eel (*Anguilla rostrata*), winter flounder (*Pseudopleuronectes americanus*), summer flounder (*Paralichthys dentatus*), alewives (*Alosa pseudoharengus*), blue back herring (*Alosa aestivalis*); avifauna: American black duck, Mallard, Canvasback, Canada Goose, Peregrine Falcon Federal endangered species, Sharp-shinned Hawk State special concern, Least tern State special concern. Despite high levels of PCBs, Cr, Zn, Hg, Pb, Cd, and Cu these wetlands continue to function as effective systems; and from a regulatory and administrative view point have high resource values. Although these data showed no clear evidence for biomagnification, the data does suggest a trend of bioaccumulation. The potential for contaminant release through the food chain does exist and the ramification of PCB pollution are very significant. Therefore, the focus should be on the need for selective sediment removal and site specific wetland restoration.

INTRODUCTION

For decades, tidal wetlands have been known to be valuable as avifauna habitat, fish nursery areas, and mammal foraging areas. Tidal wetlands also have high productivity rates, as well as, aesthetics, recreation, and education values. Teal (1964) estimated 40% of marsh vegetation productivity was exported into the tidal creeks. Odum (1980) presented conclusions that wetland production is exported to coastal waters. Turner (1977) showed the dependence of shrimp fishery on salt marshes. Pomeroy and Wiegert (1981) showed the relationship between blue crab fisheries and salt marshes. Canadian geese feed on a significant amount of the *Spartina* production (Buchsbaum, et. al. 1982). Because of the important values and functions of marshes, several Federal and State wetland protection laws have been put into affect. A study completed in April 1985 by the Environmental Photographic Interpretation Center had identified 9 tidal wetlands (mostly high salt marsh) with a total area of 157.0 ha within a 6 km radius of this estuary. The mouth of the Acushnet river forms New Bedford Harbor (Figure 1) at the confluence with Buzzards Bay. This river (the only tributary) has a mean annual discharge estimated at 0.85 m^3/sec., which represents < 1% of the average tidal prism.

The Acushnet River estuary is part of the Buzzards Bay coastal drainage area and is one of a series of tidal estuaries and bays along the southern coast of Massachusetts. Previous investigations have documented that the upper estuary, north of the Coggeshall Street Bridge, is severely contaminated with polychlorinated biphenyls (PCB's) and heavy metals (NUS 1984). The area of PCB contamination extends from the northern end of the Acushnet River Estuary to sediments in the vicinity of Clark's Point, Buzzards Bay, a distance of over 10 km (MCZM 1982). Toxic metals such as copper (Cu), chromium (Cr), cadmium (Cd), zinc (Zn), and lead (Pb) were also discharged to these waters by metals manufacturing and textile dying operations. Due to the very high contamination levels; many regulatory biologists had the opinion that the wetlands were no longer a significant resource and destruction during clean-up would be acceptable. Preliminary studies focusing on vegetation, ornithology and social values were undertaken to evaluate the existing biological resources. These preliminary studies showed a potentially viable wetland system and the need a for the detailed indepth studies presented in this paper.

The effort presented here was in support of remedial clean up alternatives developed by the Environmental Protection Agency Region I (EPA) to address the sediment contamination issues of the Acushnet River estuary area. One proposed alternative considered sediment dredging and disposal within the wetlands. New England Division Corps of Engineers (NED) was requested to provide technical expertise and assistance in the form of a wetland study to EPA in order to evaluate existing biological functions and values relative to the Clean Water Act. NED's responsibilities consisted of a study focused on contaminant availability and the effects of contamination on the wetland ecosystems. In addition to studying the estuary, a similar tidal marsh and mudflat system on Buzzards Bay was evaluated as a reference site. These studies involved limited field efforts during winter, summer, fall, and spring from February 1985 to May 1988. Since EPA's proposed remedial action plans may eliminate some of the wetland system within the estuary, it was appropriate to examine the functional integrity of these ecosystems. The questions to address were:

- Despite contamination, do these wetlands support a viable and productive community of organisms?
- How do these wetlands compare with a similar, but less contaminated wetland?
- How would these wetlands be rated under Federal and State evaluation procedures?

- Which habitat characteristics should be preserved during the remedial clean-up action?

Study Site Description

Cover Types: Four (4) major cover types are dominant within the estuary: tidal flats, salt marsh, common reed marsh, and upland. These tidal marshes (Sites 1, 3, 4, 5, 9) are primarily located in the upper estuary, and are dominated by high salt marsh vegetation (Figure 2). A predominantly high salt marsh (34.2 ha) similar to the Acushnet River estuary wetlands and in the closest proximity (EPIC 1986) was used as a "reference" site (Site 2). Site 1 has one major tidal creek with extensive lateral and longitudinal ditching. The estuary edge is marked by a peat bank rising from 15 to 30 cm above the intertidal flat with dense aggregates of *Geukensia demissa* Site 3, located directly north of Site 1, fringes a small cove and with a drainage ditch on the landward side. Site 5 consists of *Spartina alterniflora* which forms a narrow fringe around a cove, with a few isolated clumps in the cove of unconsolidated mud. *G. dimessa* is present throughout the *Spartina alterniflora*. *Mya arenaria* is abundant in the sandy intertidal area. Site 4 is a narrow band of salt marsh which surrounds a cove of unconsolidated mud. *G. demissa* are abundant throughout the tall *Spartina alterniflora* zone. Site 9 is small *Spartina* marsh with a gravel beach, south of site 4. *G. demissa* were uniformly distributed throughout the tall *Spartina alterniflora* and the gravel areas between this vegetation. Two major creeks trisect Site 2 with mouths 6-7 m across and 1-2.5 m depths. The bank is scattered with dense aggregates of *G. dimessa*.

Estuary Characteristics: A large body of data has been collected on the hydrography, sediments and water quality of the Acushnet River estuary by Hoff (1973), Summerhayes, et. al. (1977), EPA (1983), and ACOE (1986). The estuary is shallow, characterized by a well defined channel and extensive shoals and tidal flats. Circulation ranges from weakly stratified (Pritchard, 1975) during periods of high fresh-water discharge to vertically well mixed at other times. The hydrology of the estuary is complex, with constrictions at 3 locations: Coggeshall Street bridge, Popes Island, and the hurricane barrier creating a complex series of eddies and greyers. The tide (mixed semi-diurnal, mean 1.2 m) is the force controlling circulation patterns. Tidal current velocities in the upper estuary are generally low, ranging from 0.0 to 0.3 m/sec. with average velocities of approximately 0.15 m/sec. (ACOE, 1986). Summerhayes, et al.(1977) found that flood current velocities are generally higher than ebb current velocities in this estuary. An asymmetric temporal flow pattern occurs in many marshes in which a briefer period of faster flow characterizes flood tide and longer periods of slower flow occur during ebb tide (Mitch & Gosselink, 1986). Tidal flushing of the upper

estuary is estimated at about 1.4 tidal cycles (18.2 hrs), based on tidal prism calculations; detailed estimates based on net flux through the Coggeshall Street Bridge range from 2 days (winter conditions) to 8 days (summer conditions) (R. Geier, pers. comm.). Suspended sediment concentrations in the Acushnet River estuary, which were found to be generally low (< 10 ppm) by Teeter (1987), increased upstream resulting in a turbidity maximum in the upper harbor. The net flux of total suspended materials was found to be in an upstream direction, although contaminant transport was found to be in the opposite direction. Summerhayes, et al. (1977), found that, under average conditions, near bottom concentrations of suspended sediments are generally highest, with peak concentrations occurring during flood tide. Due to the asymmetric current velocities, the silt and clay portions of the suspended load tend to fractionate, resulting in a net import of silt into the estuary and a net export of clay.

Salinities: A large salinity data base has been collected in the vicinity of the Coggeshall Street Bridge, with ranges from 10 to 32 0/00 (ave. 30 0/00). Salinities in the upper estuary ranged from 7 to 31 0/00 (ave. 30 0/00). Vertical salinity gradients varied with an average of 1 0/00. The average horizontal salinity gradient was 4 0/00 per 5000 m Salinity was higher in the low marsh than the high marsh, with salinity fluctuations greatest near mean high water. Interstitial salinities increased from that of the adjacent estuary to a maximum value at the low/high marsh transition and decrease again in a landward direction. Salinity values within low marsh soils are generally fairly constant with depth, whereas in high marsh soils, salinity values fluctuate with depth, depending on seasonal effects (Mitsch & Gosselink, 1986; Frey and Basan, 1978).

METHODS

Sediment Sampling

The sediment sampling methodology used for Site 1 is described in Condike (1986). The reference Site 2 was sampled at random using a grid for the placement of 7 samples. Soil cores were collected 0-15 cm deep (7 cm). The upper layer of sediment was collected using a soil auger; samples were placed in Teflon-lined glass containers, and stored at 4°C. These samples were obtained from high marsh and low marsh. Grain-size analysis was conducted on 1 sample (0.0081 m^2 core) from each station. Due to the large amount of peat in the substrate, the percent of organic material was also measured. Sediment samples taken from

Sites 1 and 2 were analyzed for copper, chromium, lead, zinc and PCB's. Samples taken from Sites 4, 5, and 9 were analyzed for these parameters, plus mercury, and cadmium.

Vegetation Survey

The community-types were defined and delineated reflecting the hydrologic regime and vegetative species composition which dominate within each wetland as defined by Cowardin et al. (1979). *S. patens* community-type has been associated with higher interstitial salinities and more reduced soil conditions than regularly flooded zones of *S. alterniflora* (Teal 1986; Neiring and Warren 1980; Nixon 1980). In order to assess productivity and characterize the composition of plant communities indirect indices of vegetation productivity were measured for Sites 1, 2, 3, 5, & 9 during late summer 1987. Vegetation was sampled along randomly placed transects, which were evenly spaced (100 m intervals) and perpendicular to the estuary. One hundred and fifty (150) sample plots were distributed proportionately according to the size of each site. Within each community, 1 m^2 random sample plots were established. Percent cover and height were measured for all species with a cover greater than 5%. In addition, mean stem density was measured for all species occurring in a sub-plot (0.2 m x 0.5 m). Above-ground vegetative primary productivity was measured at Sites 1, 2, 5 & 9 by collecting all above-ground vegetation within 0.1 m^2 plots. Three (3) samples were taken in each of the major communities (total of 36 samples): 12 samples (4 communities) at Sites 1, and 2; 9 samples (3 communities) at Site 9; and 3 samples (1 community) at Site 5. All vegetation was cut to within 2 cm of the substrate. Ten percent of each sample was dried at 105° C for 48 hrs to determine dry weight.

Mammal Utilization

Mammal utilization was documented by direct observation or signs (ie. tracks, scat, scrapes, nests, dens, burrows, signs of foraging activity). Efforts to attract mammals to scent posts were conducted (4 days) in September 1987. Scent posts (fox urine) were established at 500 m intervals along the wetland/upland boundary on Sites 1, 3, 4, 5, & 9 and were revisited at 3 days(Taber and Cowan 1969). In addition to scent posts, in April 1985, field personnel placed 206 snap-traps (a 206 trap night effort) randomly along the eastern edge of Site1 to collect small mammals. Traps (baited and unbaited) were placed along the salt marsh upland border in grass and shrubs.

Avifauna Survey

To document the abundance and diversity of resident avifauna species during the breeding season, surveys were conducted at Sites 1 & 2 ,during summer 1987. All surveys

were begun within 1 hour after sunrise. Three habitats (tidal open water, salt marsh and salt marsh/upland edge) were censused at each site. Only individuals observed using the habitat (foraging, resting, preening, & courtship display) were included in the analysis. Breeding status was confirmed by a nest or observing: copulation, parent with food in bill, or parent feeding newly fledged young. At Site 1, surveys of the open water habitat were conducted from 2 points on the marsh edge. Birds were enumerated in the open water habitat by scanning pre-established segments and recording individuals. All tidal open water, mudflat, and shore habitats were surveyed with the aid of a 20 x 60 spotting scope. The salt marsh and marsh/upland edge habitats were censused using the variable-strip method Emlen (1971). Transects were staked at 100 m intervals. At Site 1, a continuous transect of 800 m was established, and a 900 m transect, split in 2 sections, was established in the marsh/upland edge. At Site 2, an 800 m transect, in 3 sections, and a single transect 800 m on the marsh/upland edge were established.

Benthos Sampling

A stratified random sampling of Sites 1 & 2 benthos was conducted during June and September 1987. Mud bank and tidal creek habitats were sampled in 3 random locations on each Site. Three replicate 1 L. cores (surface area = 0.0081 m^2; depth = 0.12 m) were collected. Each sample was sieved through a 0.5-mm sieve, and all organisms retained were identified and counted. Blotted wet weight biomass was determined to 0.01 g for major taxon groups (Arthropoda, Annelida, Mollusca). Two-way analysis of variance (ANOVA) was used to determine sampling period and station differences in abundance (log (x + 1)) for: Annelida, Oligochaeta, *Polydora ligni* , *Mya arenaria*, taxa number, and biomass (square root). Shannon-Weaver diversity, H' and evenness, J' indices were used to compare Sites and sampling period differences in number of taxa and distribution of abundance among taxa. These indices were computed for each station and date using the mean abundance of each species. Skewedness was calculated for each station and date using the total abundance (sum of all individual species abundances) from each of 3 replicates. Shellfish were sampled by tossing a 0.25 m^2 frame randomly within the station boundaries to obtain 3 replicate samples. Material within the frame was excavated to a depth of 0.1 m, washed through a 1 mm sieve, all organisms retained were identified and counted. Bivalve shell length and gastropod shell height were measured to the nearest millimeter. ANOVA (log (x + 1)) was used to compare sampling periods and stations for: bivalve abundance, bivalve taxa number, gastropod abundance, and bivalve taxa number. One mm increments were used to calculate mean size. Length frequency histograms were developed by summing replicate data for each species. Bivalve species data were grouped into 5 mm size classes.

A limited survey was conducted to statistically compare the benthic fauna (as an indication of secondary production) between a site (Site 1) within the influence of the PCB contamination and one that was relatively unpolluted (Site 2). Sampling took place during two months (June and September) to bracket the summertime recruitment period. In addition, a comparison of Sites 1, 2, 3, 4, 5 & 9 was made in the fall of 1987 emphasizing the wetland-open water interface. Shellfish samples (using a 0.0625 m^2 frame) were stratified at the tidal flat-mud bank interface. Samples were sieved through a 1.0 mm sieve and bivalve shell length and gastropod shell height measured. Comparisons were made using abundance and length frequency data.

Fisheries Population Sampling

Fish populations were sampled with beach seines and minnow traps in summer at 6 Sites. Commercial minnow traps (1/4-inch mesh) were baited and set for two consecutive tidal cycles (24 hours). Seining was conducted with 3/8-inch mesh beach seine (50 by 6 feet or 25 by 4 feet). Seining stations (from 3 to 8 seine hauls) were a pseudo-random distribution. All individuals collected were identified and counted. Twenty individuals per species from each trap sample and 50 specimens per species from each seine sample were preserved and total length and wet weight recorded. The stomach contents (>10 full stomaches) of *Fundulus heteroclitus* and *Pseudopleuronectes americanus* were analyzed. The contents were identified to the lowest practical taxon and grouped into categories which were weighed to the nearest 0.01 g (blotted wet weight).

Bioaccumulation & Body Burden Analysis

To determine the bioaccumulation of PCB's, Cu, Cr, Hg, Pb, Zn, Cd, & aromatic hydrocarbons (PHC's), *G. demissa* were collected during April from Site 2 (5 stations) and 3, 4, 5, & 9 (2 stations each). All *G. demissa* were collected at random locations along a 15 m transect located within the *S. alterniflora* zone. Replicates from 1 station at each Site were analyzed, with the remaining samples archived. On the remaining mussels whole wet weight, shell weight, meat wet weight & length were measured. Within each station, sufficient tissue weight were pooled to form 3 replicate laboratory analyses samples. *Palaemonetes pugio* were collected from randomly generated stations on Sites (1, 2, 3, 4, 5, & 9) during the summer for body burden analysis. Sufficient biomass was obtained to conduct 3 replicate analyses for Cu, Cr, Pb, Zn, Cd, Fe, Hg, & PCB measurements. Standard EPA methods (level 1 QA/QC procedures) for CG and metals analysis were used to measure concentrations for all tissue analyzed.

Fundulus heteroclitus and *Pseudopleuronectes americanus* specimens were collected and analyzed for body burdens of PCB, Cu, Cr, Hg, Pb, Zn, & Cd. The individuals were collected by groups (3 groups: Sites 1, 3, & 5 (group 1); Sites 4 & 9 (group 2); and Site 2 (group 3); pooled analysis of 3 replicates per group and each species was analyzed separately to establish invertebrate-fish food chain, bioaccumulation links, for a total of 18 replicates. The livers of *P. americanus* were visually surveyed for neoplasms.

To determine the bioaccumulation of PCBs in the trophic system; Ring-billed gulls and *Peromyscus leucopus* food chains were sampled (April, 1985); 10 birds and 20 *G. demissa* were collected from 5 stations. In addition, 36 *Orchestia grillus* were collected at 5 stations. *P. leucopus* (15) were trapped at the upland-marsh border. It's food source were collected including: *Distichlis spicata, Spartina alterniflora, Juncus gerardii,* and Orthoptera, Hemiptera, Coleoptera.

In addition, to determine the bioaccumulation of PCBs in the *G. demissa* -- Ring-billed gull food chain, 20 *G. demissa* were collected. At each station *G. demissa* were collected at random points along a 15 meter transect located 1-2 meters below the estuary limit of *S. alterniflora.* Whole wet weight, shell length, shell weight, and meat wet weight were measured. *G. demissa* shells were scrubbed before weighing. Shell length was measured to 0.05 mm, and meats were placed on filter paper for 2 min. before weighing. Ten *G. demissa* from each of the 5 stations were measured (total of 50). Within each station, the meats of 5 *G. demissa* were pooled to form 2 replicate samples for analysis from each of the 5 stations and then frozen. *Melampus bidentatus* were collected, counted, weighed wet, and frozen. *Orchestia grillus* (abundant in the upper estuary) were collected at each station (average of 36) and frozen. Ring-billed gulls were chilled until breast muscle and subcutaneous fat samples could be separated, and the birds sexed, measured, weighed and frozen. *U. Lactuca* and *G. demissa* were collected, during winter, at random locations. Two samples were collected at each stations (total of 10 samples). The samples were washed with sea water, blotted dry, and weighed. One Black duck was killed (shotgun) and frozen until subcutaneous fat and muscle tissure was removed.

The collection of *P.leucopus* food was concentrated at the upland-wetland edge. In April 1985, bayberry fruits, acorns, horse-brier fruits, rose fruits, black grass shoots (*J. gerardi)*, insects (Orthoptera, Hemiptera, Coleoptera), isopods, and millipedes were collected and stored. *M. bidentatus* was also collected. The number of specimens in each sample

were counted (excepting bayberry fruits), wet weight determined, and the samples frozen. Collection consisted of 206 snap-traps randomly set. One hundred and fifty-two traps were baited with a mixture of oatmeal and peanut butter, and 50 with beef hotdogs. Traps were checked after 24 hrs, captured *P. leucopus* were sexed, weighted, homogenized, and frozen.

RESULTS

Sediment Findings

Sediment grain size characteristics were determined for the upper estuary (Table 1). The surface sediments were predominately silt and clay. Site 1 tidal creek substrates were 62 % clay/silt, with 7 % organic matter (peat). The creek sediments in Site 2 were coarser, with over 50% sand and 3% peat. These grain size differences are attributable to numerous factors (e. g. tidal current speed, wave exposure, and sediment origin). The proportion of peat was higher in the mud banks than the tidal creeks. At the mud banks in Site 2, peat composed 28% of the sediments, with 46% silty sand. On Site 1, the mud banks were characterized as 33% sand, with 16% peat.

The concentration of heavy metals (Cr, Cu, Pb, & Zn) and PCBs in the surface marsh sediments (15 cm) was highest at Sites 1 and 3. There was a trend for the lower elevations to have higher levels of contaminations and contaminant levels to decrease toward the harbor entrance. The reference Site 2 outside the harbor had the lowest levels. These data show a pattern of widespread elevated contaminant levels and may indicate a distribution related both to chronic disposal and to distribution from many localities throughout the region. Previous studies demonstrate a substantial PCB content in the estuary sediments (ACE,1986). Portions of this contaminant reservoir in the sediment may be potentially available for redistribution. The chemical and physical characteristic of the contaminants and the surrounding sediment may effect levels and state.

Vegetation Findings

Cover types: Site 1 (17.4 ha) is nearly 1.41 km. in length and 200 m wide at its widest point (Table 2). It is dominated by two near monotypic cover types, *S. patens* (> 48%) and *Iva frutescens* (> 32%) (Table 3). The tall form of *S. alterniflora* (>18% of the vegetation) grows in a narrow (< 50m) band along the entire marsh/river border. Site 3 (5.4 ha) has a variety of species, but the community size is limited by its narrow width and small size. Tall

S. alterniflora and *S. patens* high marsh communities and *Phragmites australis* stands are the dominant cover types, all occupying 30% of the vegetated wetland. Site 5 (1.4 ha) has steep banks supporting a narrow band of tall *S. alterniflora* (covering 68%), *S. patens* (covering 26%), and small patches of *Iva* sp. and *P. australis*. Site 4 (4.3 ha) has been altered considerably and as a result, *P.australis* covers over 80% of the area. A narrow band of tall *S. alterniflora* covering 9% lines the water edge. Site 9 (0.69 ha) is dominated (53%) by *S. patens* .

Site 2 (49.8 ha) has seasonally flooded freshwater habitats which are contiguous on the north and east sides, with the estuarine marsh comprising 28.7 ha of the area. The widespread distribution of tidal creeks and mosquito ditches has created zonation patterns that are complex, with cover types patchily distributed and high marsh communities co-dominated with a variety of species (Table 4). This site is dominated (55%) by *S. patens* cover type, with stands of tall *S. alterniflora* (coverage 3%) occurring along the water edge. Stands of *P. australis*, limited to the upland edge, dominate (over 23%) the area north of the floodgate structure.

Productivity: Sample-plot data for Site 1 (consisting of 63 plots distributed among 10 transects) correspond well with the data obtained from the cover type mapping (Figure 4). Analysis of these data reflects a wetland dominated by the high marsh grasses *S. patens*, which occurred in 50.8% of the plots, and *D. spicata* which occurred in 49.2% of the plots. For plots in which it occurred, the mean percent cover of *S. patens* was 77.6 and the mean stem density 259.1 stems/0.1m^2. The percent cover of *D. spicata*, with a mean of 54.4%, varied considerably; mean stem density for plots in which this species occurred was 72.8 stems/0.1m^2. High marsh communities were dominated by up to 5 species, a complex community composition that could not be delineated in the cover type mapping. *Juncus gerardi* occurred in 40% of the plots, with a mean cover of 66.7 % and a mean stem density of 22.7 stems/0.1m^2. *Solidago sempervirens* also occurred in 40% of the plots, but had an low percent cover (26%) with stem density (7 stems/0.1m^2). *Distichlis spicata* and *Iva frutescens* both occurred in 33.3% of the plots. *Spartina patens*, which occurred in 20% of the plots, had a high percent cover (75%) and stem density (274.5 stems/ 0.1m^2). Twelve (12) sample plots were distributed among 9 transects in Site 5. Tall *S. alterniflora* dominated this site occurring in 83.3% of the sample plots. The *S. alterniflora* at this site had the highest density (mean % cover = 96.5; mean stem density = 32.3 stems/0.1m^2) and tallest (mean height = 150cm) recorded in this study. Two (2) transects and 14 sample-plots established in Site 9 indicated a predominantly high marsh; the 3 most frequently encountered species were *D. spicata, S. patens, and J. gerardi*. *D. spicata* occurred in the greatest number of plots (50%), but had a

low mean percent cover (40.7%) and stem density (76.1 stems/0.1m^2) when compared to *S. patens*, which occurred in 42.8% of the sample plots and had a mean percent cover of 66.7% and mean stem density of 237.8 stems/0.1m^2, and *Juncus gerardi*, which occurred in 21.4% of the plots and had the highest percent cover (86.7) and stem density (330 stems/0.1m^2) of all species encountered at this site.

Fifty-one (51) sample plots were distributed among 6 transects in Site 2. The 17 species encountered was the highest number of species recorded in this study. *S. patens* had the highest (51%) frequency of occurrence, with a mean cover of 63.9 % and a mean stem density of 244.4 stems/0.1m^2. *D. spicata* (47% occurrence) was often co-dominant in the high marsh communities with a mean stem density of 59.5 stems/0.1m^2. Five (5) species occurred in more than 20% of the plots making this community composition fairly complex. The short form of *S. alterniflora*, occurring in 43.1% of the plots, had the highest mean percent cover (79.5%) and a high stem density of 91.4 stems/0.1m^2. *Limmonium nashii* occurred in 23.5% of the plots and had a low percent cover of 17%. *Juncus gerardi* occurred in 21.6% of the plots with a mean cover of 62.8%; stem densities for this species varied considerably, the mean stem density for plots in which this species occurred was 264 stems/ 0.1m^2. The tall form of *S. alterniflora* occurred in 7.8% of the plots, but had the highest mean cover (80%).

The estimates of above-ground primary productivity for this study compare well with values from other studies conducted in southern New England. Values for tall *S. alterniflora* correspond well with both data from Teal (1986) and with the indirect indices data collected here. In the Sites where samples of tall *S. alterniflora* were collected, above-ground primary productivity values ranged from 1023 g dry wt./m^2/yr (Site 1) to 1800 g dry wt/m^2/yr (Site 5). In comparison, Teal (1986) reports a value of 1320 g dry wt/m^2/yr for tall *S. alterniflora* communities. The high productivity value for tall *S. alterniflora* at Site 5 can be expected based on the height and density values obtained in the collection of indirect indices data. These values may be due to the high degree of tidal flushing this community receives (Teal 1986): tall *S. alterniflora* at Site 5 occurs in a very narrow (< 5m) band along steep banks which are completely flooded and exposed twice daily, thus facilitating constant nutrient exchange and oxidation of soils. Productivity values for *S. patens* communities on the high marsh ranged from 935 g dry wt/m^2/yr (Site 2) to 1040 g dry wt/m^2/yr (Site 9). In comparison, Nixon (1980) reports a value of 1100 g dry wt/m^2/yr for a Massachusetts salt marsh, and a value of 430 g dry wt/m^2/yr for a Rhode Island salt marsh. Using the ratios given by Teal (1986) for below-ground productivity of *S. alterniflora* communities, and that

given by Nixon (1980) for below-ground productivity of high marsh communities, estimates of total marsh productivity for those communities ranged from 2557 g dry wt/m^2/yr (Site 1) to 4500 g dry wt/m^2/yr (Site 5) for tall *S. alterniflora* communities, and from 2874 g dry wt/m^2/yr (Site 2) to 4220 g dry wt/m^2/yr (Site 9) for high marsh communities (includes *S. patens*, short *S. alterniflora*, & high marsh mix communities).

Mammals Findings

The 206 trap night effort yielded (Table 5): *Mus musculus* (3), *Rattus norvegicus* (1) and *Peomyscus leucopus* (15) with a trapping success of 9.2 percent. Based on this study, the characteristics of these wetlands, and existing literature (e.g., DeGraaf and Rudis, 1986), small mammals are the most abundant resident vertebrates. Mammal use was observed in all the habitat types. Scat, tracks, small mammal nests and clippings, burrows and dens of medium sized mammals were the most frequently observed signs. Results of scent post sampling yielded 3 additional species: *Sylvilagus floridanus* scat (Site 1) in *S. patens* habitat, *Procyon lotor* tracks (Site 4) adjacent to *Phragmites* habitat, and *Vulpes fulva* and *S. floridanus* scat (Site 3) in *S. patens* habitat.

S. floridanus was the only mammal observed directly at Site 1, with scat found throughout the high marsh. Two (2) active *Marmota monax* burrows were found in the *I. frutescens* community; a *Microtus pensylvanicus* nest and system of runways were found in the *S. patens* habitat; *Ondatra zibethica* scat was found on the high marsh; and *Procyon lotor* tracks were observed in the non-vegetated portion of the wetland. Other observations recorded *Mephitis mephitis* and *Peromyscus leucopus*. At Site 3 *Ondatra zibethica* was observed swimming. A *Vulpes fulva* compound with10 burrows was found on an adjacent upland knoll. *S. floridanus* scat was found in the high marsh. At Site 5 *S. floridanus* scat was littered throughout the upland edge. *S. floridanus* were observed foraging in *Ammophila breviligulata* habitat and a *Marmota monax* was observed at the upland edge of Site 4. *Procyon lotor* tracks were present at a scent post placed adjacent to a stand of *Phragmites*. At Site 9 a *Sciurus catolinensis* was observed foraging on the high marsh and *S. floridanus* scat was found on the high marsh. *Procyon lotor* tracks and *Ondatra zibethica* scat were found in the regularly flooded areas; and *S. floridanus* scat was found on the high marsh of Site 2. *Sciurus caatolinensis* , *Didelphis virginiana*, and *Tamias striatus* utilize the wooded swamp in the northeast section of Site 2.

Avifauna Findings

Open Water Habitat: The size and exposure of Sites 1 and 2 differ, with Site 1 abutting relatively shallow upper estuary waters, and Site 2 abuting deeper open water habitat (Table 7). Intertidal flats are minimal at Site 2, but extensive at Site 1. Comparisons of use at these two sites required a combination of quantitative measures and site utilization knowledge. Thus avian densities, the total number of a species observed, and the frequency in which a species occurred were analyzed. A total of 16 species were observed Site 1, for a total density of 13.0 birds/405 ha, and 24 species at Site 2, for a total density of 12.8 birds/405 ha. Five species were common (observed >50% of the time) to both sites: Herring Gull, Double-crested Cormorant, Mallard Duck, Great Black-backed Gull and Rock Dove. Four species were unique to wetland 1: Mute Swan, Black-crowned Night Heron, Great Egret, and Least Tern. The Least Tern (a species of special concern of the Massachusetts Natural Heritage Program, MNHP) nests primarily on mainland beaches in variable sized colonies and forages on *Menidia menidia* in the waters adjacent to Site 1 throughout August and early September. Twelve species were unique to Site 2: Horned Grebe, Great Blue Heron, Green-backed Heron, Lesser Yellowlegs, Spotted Sandpiper, peep sp. (one or more of the small calidrid sandpipers including the Least and Semi-palmated Sandpipers), Laughing Gull, Common Tern, Common Grackle, Osprey, and American Kestrel. Osprey and Common Tern are species of special concern of the MNHP. Of the observed species, the Herring Gull was the most abundant and most frequently seen. The greater number of Herring Gulls observed at Site 2 reflects the greater size of the study area. Although this group was frequently observed, greater abundance may be expected at both sites in the fall/winter when post-breeding gulls come inshore.

Shorebird numbers were low and reflect trends observed throughout the region (Lloyd Center 1986) during this part of the year when the vast majority of shorebirds are on their breeding ground to the north. Except for the Killdeer and Spotted Sandpiper breeders at Site 2, the few shorebirds observed were recorded at Site 2 near the end of the census period and probably represented the first migrants of the fall. These early migrants included the Lesser Yellowlegs, Greater Yellowlegs, and peep sp. The Killdeer was the only shorebird observed at Site 1 during the study period. However, sightings throughout August and September of Yellowlegs, Spotted Sandpipers, and peep sp., suggest that the tidal open water habitat of the estuary receive increased use by shorebirds as fall migration progresses. Shorebirds observed at Site 2 (Killdeer and Spotted Sandpiper) were resident and suspected breeders. The Mallard Duck was common at Sites 1 and 2; and was a breeder at Site 2. The American Black Duck was less common at both sites, but was a breeder at Site 3. Sightings of up to 25 Black Ducks were recorded throughout August and September at Site 3. Although not abundant, herons

and egrets were observed throughout the study period. The Snowy Egret was the most frequently observed wader at both Sites. The sightings at Site 1 throughout August and September show a much greater abundance of this group, especially immature birds, which foraged in the shallow water adjacent to Site 3 in the post-breeding season. The doves and passerines observed at both wetlands used the intertidal habitat for foraging. Least Bittern (listed as a threatened species by Massachusetts Natural Heritage Program) was observed foraging at the edge of a *P. australis* community adjacent to Site 3.

This study also censused the open water/mud flat habitats from Tarklin Hill Road to the estuary mouth during late winter/early spring of 1985 and late summer of 1986. Based on trends reported by the Lloyd Center (1986), the abundance of the various bird groups reported here were within the expected range for this region during the spring/summer. The Lloyd Center data showed a decrease in the numbers of bird species and densities as summer approaches. Heron, egret, and tern numbers at both sites were lower than those reported by the Lloyd Center (1986). However, this may be due to the proximity of this study area to the breeding grounds. Both the Common and Least Tern are known to breed in the Plymouth County region of Buzzards Bay (Lloyd Center 1986). Furthermore, the broad, shallow lagoon, along with the undeveloped and undisturbed shoreline characteristic of the Lloyd Center (1986) study site, offers favorable foraging and resting areas for long-legged waders and terns, and nesting habitat for the latter group. This accounts for the overall greater abundance of these groups reported by the Lloyd Center. Although species diversity was greater at Site 2, densities between Sites 1 and 2 were nearly equal. Differences between wetlands in the abundance of certain species may be expected based on their location. Site 2 is more centrally located with respect to nesting grounds of colonial nesters such as terns and long-legged waders. Greater use of Site 2 by these groups can be expected, as birds commuting to and from coastal foraging areas are more likely to encounter Site 2 than Site 1. Trends observed at Site 1 in August and September suggest that the tidal open water habitat at this site become more important during fledgling dispersion and migration, when terns and long-legged waders are not restricted in their foraging range, and when shorebirds pass through the region on their journey south.

Salt Marsh Habitat: Twelve (12) species for a total density of 276 birds/405 ha were recorded in the salt marsh habitat at Site 1. Eighteen species for a total density of 305.4 birds/405 ha were recorded in Site 2. These densities are within typically reported values for southern New England salt marshes (Reinert and Kilpatrick 1986; Reinert et al 1981). Of the seven species unique to Site 2, only the Clapper Rail and Spotted Sandpiper, had densities greater than 1.9

birds/405 ha. The Clapper Rail was a nesting species at Site 2 which was placed in a stand of short (< 40cm) *S. alterniflora* . The Spotted Sandpiper may be nesting at Site 2. Sites 1 and 2 received the greatest use by passerines species. Passerine densities were very similar (231 birds/40 ha, Site 1; 236.3 birds/40 ha, Site 2), but use of the salt marsh habitat between Sites differed. Use at Site 1 was dominated by birds nesting in the upland edge that use the marsh to forage. One salt marsh obligative (Sharp-tailed Sparrow) was recorded at this Site. The Sharp-tailed (nesting species) had a density of 22.6 birds/405 ha which was low compared to Site 2 of 143.0 birds/405 ha. The greater diversity and more highly interspersed nature of the cover types at Site 2 contributed to the higher densities. Site 2 use was dominated by the Sharp-tailed Sparrow, which was abundant and distributed throughout the marsh. Both Sites received irregular use by American Kestrels, and regular, similar use by Mourning Doves and aerial insectivores (e.g. Chimney Swifts, Barn Swallows, and Tree Swallows). The narrow width of Site 1 allows upland edge nesting species easy access to foraging areas in the *S. alterniflora* habitat and also provides suitable foraging areas for the Sharp-tailed Sparrow. The vegetation communities at Site 2 are much more heterogeneous and provide different habitats for foraging, nesting, and mating activities of marsh nesting birds.

Upland Edge Habitat: Shrub communities < 75 m wide form a broad transition zone between the salt marsh and forested upland habitat; this transition zone supported the highest density of birds (531.0 birds/405 ha). Twenty-seven (27) species were recorded at Site 1. Five (5) species were confirmed breeding with17 additional species suspected breeding. The 5 dominant species at this site (Red-winged Blackbird, European Starling, Northern Mockingbird, Song Sparrow, and American Robin) account for 66% of the total density of birds recorded in this habitat. At Site 2, the upland edge habitat is dominated by *P. australis* which occurs in narrow (< 50 m) strips. Shrub communities are sparsely distributed and the transition from salt marsh to oak-hickory forest is abrupt. The influence of forest associated species (e.g. Black-capped Chickadee, Tufted Titmouse, House Wren, and White-eyed Vireo) at this site contributed to the highest species diversity observed (32 species). These species were observed singing and foraging along the edge and made up 6% of the total density found in this habitat. The 5 dominant species (Red-winged Blackbird, Common Yellowthroat, Song Sparrow, and European Starling) made up 50% of the total species density; all, except the European Starling, are commonly found nesting in wetland or wetland edge habitat. Dominance by this group of primarily wetland associated species indicates a greater homogeneity of habitat at Site 2. Other wetland species including the Mallard Duck (confirmed nesting species) the Killdeer, a suspected nesting species, the American Black Duck and the Clapper Rail were recorded in this habitat.

A least bittern (listed as threatened by the MNHP) was observed foraging adjacent to Site 3. Least terns (listed as a species of special concern by MNHP) were observed throughout August and early September foraging in the waters adjacent to Sites 1 and 3. Both the osprey and common tern (listed as species of special concern MNHP) were observed at Site 2 in July and during July and August for the latter species. A peregrine falcon was observed in the vicinity of Site 1 in February 1985.

Benthic Infaunal Community Findings

Tidal Creeks: Tidal creek stations at Site 1 were dominated by oligochaetes and *Capitella* sp. during both sampling periods (Table 8). Abundances of the spionid *Streblospio benedicti* were also high during September. Three taxa were important numerically in the tidal creek stations of Site 2 as well. During both sampling periods, numerous additional taxa were apparent in moderate (< 102/m^2) to high densities (> 103/m^2) at Site 2, while the number of abundant taxa at Site 1 was limited. The most abundant taxa are typical estuarine species; primarily surface and subsurface deposit feeders. The bivalves collected from tidal creeks at Site 2 are filter feeders, with *Mya arenaria* being very abundant. The pattern of community structure was evidenced in the diversity and evenness indices for the tidal creeks. Diversity values varied between Sites, with Site 2 values higher than Site 1 values. Only one station x sampling period combination result had values over 1.0 (ranged from 0.883-3.098). From Site 1, only one station exceeded a value of 1.0 (September), and was close to 1.0 in June. The other stations on Site 1 had low diversity values ranging from 0.120 to 0.330. Site 2 supported 3 times as many taxa as Site 1. The greatest disparity between the 2 sites was the number of polychaete species. Evenness values were low, indicating that each station had only a few species with high abundances, while the remaining species had low abundances. Only at 2 stations was evenness moderately high (> 0.6). There was no strong difference between sampling periods, suggesting a similar distribution of species abundances in the 2 months. In June, skewness values for Site 2 were greater than for Site 1, indicating greater within-station (i.e. among replicates) variability in abundance in Site 2 than Site 1. A reverse trend was noted in September.

The tidal creek stations at Site 2 tend to support a greater variety of infaunal particularly polychaetes and bivalve species than those on Site 1, regardless of the month sampled. There were 3 to 4 times as many taxa with abundances greater than 100/m^2 at Site 2 than Site 1 during June and September. Site 2 stations were more likely to have several abundant co-dominant species than were Site 1 stations. Sample period was less of a contributing factor

than location. The influence of sediment grain size is apparent at Site 2 in June, where sediments at station 2T1 (gravel) are much coarser than those at stations 2T2 and 2T3 (medium sand). Taxa such as *M. arenaria, Scoloplos* sp., *Scolecolepides* sp. and syllidae were much more abundant at station 2T1, while *S. benedicti* was more abundant at stations 2T2 and 2T3. The presence of herbivores (e.g. *L. littorea* and *G. inucronatus*) at station 2T1 was the result of the presence of algae rather than substrate differences. Wet-weight biomass measurements for major taxa showed that the stations containing mollusks had the highest biomass values, partially attributable to shell weight.

Mud Banks: The mud bank stations at Site 1 was dominated by Oligochaeta, *Fabricia sabella, Capitella* sp. and *S. benedicti* during both sampling periods. In June, amphipods, bivalves and gastropods were moderately abundant (102-103/m^2). Of these taxa, all but gastropods were moderately abundant in September. These species encompass several feeding: types; filter feeding, surface grazing/scraping, burrowing deposit feeding, and surface deposit feeding. Of the 30 taxa collected from Site 1, 10 were polychaetes and 7 were amphipods. Oligochaetes and *F. sabella* also predominated on Site 2 during June and September. The surface deposit feeder *P. ligni* was numerous also. Abundances of *M. arenaria, Nereis succinea* (June), *Capitella* sp., *Edotea triloba* and *Syllis typosyllis* sp. (September) exceeded 103/m^2. Moderately abundant (102-103/m^2) taxa represented several major taxonomic (polychaetes, bivalves, amphipods) and feeding (surface deposit feeders, burrowing deposit feeders, carnivores, filter feeders) groups. Sixty-one taxa were recorded from Site 2, predominantly polychaetes, amphipod, and bivalve species.

The diversity index varied more between the 2 sampling periods than Sites. For both Sites, all stations exhibited diversity indices above 1.0 (ranging from 1.025 to 1.357) in September. In June, with the exception of one station (H'= 1.285) values fell below 1.0 (ranging from 0.262 to 1.285). Evenness values were highest in September at most stations, although no value exceeded 0.5. There were no apparent differences between the Sites. This implies that all stations had only a few species with high abundances, while the remaining species had low abundances. Skewness was affected more by Site and station location than by sampling period. Highest values were in Site 2 indicating greatest within station variability. Species distributions appeared to be affected by the presence of mussel clusters (both Mytilidue & *G. demissa*) which were patchy in their distribution throughout the mud bank surface. These clumps provide habitat and refuge for other organisms, as seen in September at Site 2. The station with mussel clumps had more taxa (37) than stations without

(26 taxa) and (12 taxa), including infaunal (*Neresis succinea, Petricola pholadiformis*) as well as epifaunal taxa (*Edotea triloba, Hiatella* sp.).

Habitat Comparisons: The most abundant taxa (> 104) were similar in all wetland-habitat groups. These species are adapted to the stressful intertidal habitat by their burrowing or tube dwelling existence. Abundant (> 103) and moderately abundant (> 102) species were variable between habitats and between Sites. This may be due to the physical differences in the habitats. Mud bank stations provide a somewhat more complex substrate than tidal creeks due to the presence of *S. alterniflora* and large pieces of detritus. This provides a niche for grazers (e.g. *L. littorea, Llyanassa obsoleta*) and detritivores (e.g. *Hydrobia totteni, Corophium insidiosum* and *Gammarus* sp.). Tidal creek bed may be a less stressful habitat because the exposure duration during the tidal cycle is shorter. In addition, longer and earlier exposure to flooding may provide a slight advantage in terms of recruitment. Within a particular habitat, sediment grain size characteristics were sufficiently different to account for some of the among-station variability. In all cases, significant differences were observed among stations and among station x sampling period groups. Of the parameters tested statistically, differences between sampling periods were observed only for *P. ligni, M. arenaria* and biomass. Four (4) of the 6 stations at Site 2 exhibited a significantly greater number of taxa than all stations at Site 1.' Tidal creek stations at Site 1 contained significantly fewer taxa than the mud bank stations. The significance test on station x season interaction exhibited no strong pattern as evidenced by large numbers of overlapping groups. Each Site tended to exhibit differences between the months. At Site 2, number of taxa was higher in June than in September. The opposite was true on Site 1. In addition, the Site 1, habitat seemed to affect the number of taxas, with mud banks higher than tidal creeks.

Total abundance and annelida abundance (including *F. sabella*) paralleled each other, indicating the dominance of this phylum in the marsh environment. Patterns among stations are not clear. There is much overlap among station groups and among station x sampling period groups. Generally, mud bank stations at Site 2 achieved higher abundances than the same habitat at Site 1. Tidal creek stations at Site 2 exhibited lowest abundances. Stations 2M4 and 2M5 attained highest abundances during both sampling periods, in part due to the abundance of *F. sabella* . Site stations sampled in September were next in abundance. Four (4) stations were consistently lower in abundance. Annelida abundance (excluding *F. sabella*) and oligochaeta abundance, exhibited very similar patterns. Site 1 tended to rank higher than Site 2. Neither habitat nor sampling period seemed to be a major factor influencing the results. Abundance of *P. ligni* was higher at Site 2 than Site 1. Within Site 2, abundances tended to be

higher in June than September at each station. Abundances at Site 1 were low, therefore patterns between months or habitat were not apparent. Abundance of *M. arenaria* was greater in the June than the September. This species was present in cores from 6 of the 12 stations. Only at one station did *M. arenaria* occur during both sampling periods. The stations exhibiting the highest abundances were at Site 2 (during both months).

Biomass was higher in September than June, but station and station x sampling period patterns were indistinct (Figure 5). Significant differences were due to the presence of large organisms (particularly mollusks) in a few of the samples. An examination of mean annelid biomass suggests that the biomass of this group was higher at Site 2 stations. The greater abundances of such large species as *N. succinea*, as well as the extremely high abundances of *F. sabella*, may account for biomass differences. The relatively high annelid biomass observed at 1 Site 1 station during June was due to high abundances of *S. benedicti*, Oligochaeta and *Capitella* sp. Among the tidal creek stations annelid biomass showed no patterns. Although the mean values at 2 site 1 stations were relatively high in September, the high standard deviations indicated that the mean was strongly influenced by 1 or 2 replicates. Of the annelids at these stations, oligochaetes were the most abundant and exhibited variability among the replicates.

Shellfish: Twenty-three (23) species were collected in total, only 10 of which were mollusks. Non-molluscan species were not treated quantitatively. However, the presence of these other species is at least indicative of their distribution on the study marshes. The omnivorous burrowing polychaete *N. succinea* was collected from the banks of both marshes. Xanthid crabs, *Rhithropanopeus harrisii* and *Neopanope sayi* were collected from Site 2. The marsh crab *Sesarma reticulatum*, whose burrows generally occur in the *S. alterniflora* zone, (Daiber 1982) was collected at Site 1 as was the fiddler crab *Uca pugnax*. Absence of any of these species from the collections in a particular area may be an artifact of sampling. Sampling the tidal creek habitat at Site 1 revealed low abundances of bivalves represented by only 1 species, *G. demissa* . Only the mud snail *L. obsoleta*, a typical inhabitant of salt marsh creeks, (Daiber 1982) ever reached moderate densities. As this species feeds on benthic unicellular algae, its presence in September suggests that the sediment surface of Site 1 tidal creeks supports microfloral production. The tidal creeks on Site 2 supported populations of filter feeding bivalves (*M. arenaria* and *M. mercenaria*) as well as the deposit feeding *Macoma balthica*. *M. arenaria* and *M. balthica* are often associated with salt marsh creeks (MacDonald 1969 a,b). Sediment-grazing gastropods were in evidence during June. Three (3) bivalve and 2 gastropod species were collected from Site 2 tidal creeks. Sediment textural differences

between the two Sites is one factor affecting their diversity. The 2 stations that contained the highest proportion of coarse sediments, also exhibited the highest number of bivalve species. *G. demissa* was the only bivalve collected at any of the other stations. The presence of *L. littorea* at station 2T1 may have been related to its exposed location and secondarily, to its coarse substrate since this species is generally associated with rocky intertidal areas. *L. obsoleta*, present in all sampling of Site 1 tidal creeks, occurred only occasionally at Site 2. In this case, the finer sediments occurring at Site 1 probably influenced the distribution. *G. demissa* was the predominant member of the molluscan assemblage in the mud bank habitat at both Sites. This species has been reported to have a mutual relationship with *S. alterniflora* (Bertness 1984). In addition, aggregations of the mussel help to stabilize the seaward edge of the marsh, reducing erosion from wave action. *M. arenaria* occurred in low numbers at both Sites. Other than *G. demissa* and *M. arenaria* no other bivalves were collected from Site 1. In addition to the 2 species occurring at Site 1, *M. balthica, M. edulis* , *M. mercenaria* and *Petricola pholadiformis* were found at Site 2. Differences in sediment grain size distribution between the two Sites contribute to the observed differences in species composition. Gastropods were present on mud bank stations at both Sites. *L. obsoleta* was abundant at Site 1 in June. *L. littorea* was abundant during both collection periods at Site 2. Its presence at Site 2 is influenced by higher energy there than at Site 1. *Bittium alternatum* occurred at Site 2 in September.

Habitat Comparisons: Analysis of variance was conducted to assess differences among stations, between sampling periods and among station sampling period groups on 4 parameters: number of bivalve taxa, total bivalve abundance, number of gastropod taxa, and total gastropod abundance. The number of bivalve taxa was significantly different among stations, but the groups of similar stations were not distinct from one another. Site 2 stations had the largest number of taxa, followed by the mud bank stations from Site 1. Tidal creek stations from Site 1 had the lowest number of taxa 1 (*G. demissa*) or 0. The 6 stations with the smaller numbers of taxa were also those with the lowest abundances. Site 1 mud bank stations had the highest bivalve abundances, since random sampling fell within patches of *G. demissa* . Only 4 gastropod species were collected in the shellfish quadrats. Tidal creek stations never contained more than 1 species in any collection. Three mud bank stations (2M4, 2M5, 1M5), however, were inhabited by 2 or more gastropod species in at least 1 sampling period. Gastropod abundance station groupings fell in roughly the same order as a number of taxa. Significant differences in station x sampling period groups were detected. Highest abundances occurred in September for Site 1 tidal creek stations and in June for mud bank samples (stations from both sites).

Population Size Structure: Shell length data were obtained for all bivalve individuals collected as part of the current study. Mean length and size class distribution for the dominant bivalve, *G. demissa* and the commercially valuable *M. arenaria* were determined. The mean size of *G. demissa* were not different among stations or Sites, since the means generally fall within one standard deviation of each other. Apparent differences might be attributable to a number of factors: the number of individuals varied widely among the samples; location within a patch of mussels can affect the size of the individuals; the random sampling did not evenly sample different locations in the patches; and there may be environmental differences affecting growth. Hampson and Moul (1978) observed that *G. demissa* was virtually the only species to recover within a few years from the effects of a spill of Bunker C oil. If *G. demissa* populations experienced mortalities from exposure to PCBs, a comparison of length data between Sites 1 and 2 suggests that the effects are no longer manifested in population structure, despite continued uptake of PCBs. Rough age groups can be ascribed only to small mussels: 1 year old (< 10 mm) ; 2 year old (< 40 mm) ; 3 - 4 year old (< 60 mm). Older mussels may grow more slowly, depending on environmental conditions, and may survive 10-20 years. Thus, stability of an aggregate or population is not dependent on frequent input of juveniles. Relatively low numbers of small *G. demissa* is attributable to several factors such as preferential predation on small individuals, low recruitment rates, or intraspecific competition. Few *M. arenaria* were collected, with most occurring at Site 2. Shell lengths ranged from 10-80 mm. Based on growth rates observed in this species (Brousseau 1978), recruitment has occurred over a number of years. The smallest clams (10-15 mm) are probably young-of-the-year clams. Few *M. arenaria* were collected from Site 1, none in the tidal creeks. Most were collected from Station 1M5, because of the relatively large proportion of sandy sediment. *M. arenaria* was found to be tolerant of moderate levels of PCB's (0.05-0.16 ppm) and metals in the ranges observed (Tsai, et al. 1979). However, the concentrations of PCBs observed in this study are much higher than Tsai, et al. tested and may reduce the success of recruitment of *M. arenaria* to Site 1. Collection of other bivalve species was sparse and was restricted to Site 2.

The gastropods *L. littorea* and *L. obsoleta* both distribute their larvae planktonically (Yamada 1987; Gooch et al. 1972). Thus, within an ecosystem such as the estuary, it is expected that population size class structures are similar throughout. This appeared not to be the case for *L. obsoleta* collected at Site 1 versus 2, although data from Site 2 may be less representative of the overall population due to the relatively low numbers of specimens collected. Sediment textural characteristics varied between the two Sites, potentially

contributing to the disparity in occurrence. Other environmental factors affecting growth could include sediment-borne contaminants either directly ingested by the gastropods or which inhibit production of benthic microalgae or salinity. *L. littorea* occasionally occurred in moderate numbers, particularly at mud bank stations. Size class structure exhibited no differences between these stations or between sampling periods. The collection of *M. bidentatus* was incidental, since this species generally resides in the *S. patens* zone. Absence of larger specimens may indicate that the marsh environment provides unsuitable habitat for this species.

Fin Fisheries Findings

A total of 16 species of fin fish were collected. *P. americanus* were collected only at Site 2. A total of 13 *P. americanus* were examined for neoplasms and tumors. No neoplasms or tumors were observed on the livers of the examined fish. Neoplasms have been found in soft shell clams from the Harbor (Reinisch et al. 1984). Cell extracts from the tumors showed detectable levels of PCB congeners which suggest an association between the high prevalence of diseased tissue (10-90%) and the presence of contaminated sediment. In another study (Brown et al. 1977) soft shell clam neoplasms were common (12.5%) in New England sites with varying degrees of hydrocarbon contamination. Hydrocarbon levels in clam tissue were related to sediment hydrocarbon concentrations.

The beach seine efforts were characterized by large numbers of *Menidia menidia* (76.8% of the total catch). *M. menidia* were the most numerous fish caught in the estuary and marsh making up 97.7% and 88.6% of the catch in Sites 9 and 2, respectively. In the upper estuary (Sites 1, 3, & 5), *M. menidia* accounted for 74.7% of the fish caught. The second most numerous species, *F. heteroclitus*, was present in greater numbers in the upper estuary. In the upper estuary *F. heteroclitus* accounted for 24.4% of the fish caught, compared to 0.7% and 3.0% in lower estuary and Buzzards Bay, respectively. The *F. majalis* exhibited the reverse situation accounting for only 0.2% of the fish caught in the upper estuary compared to 1.4% and 7.5% in the lower estuary and Buzzards Bay, respectively. Of the other 8 species caught, each contributed < 1% of the total. There were 4 species caught in the minnow traps. *F. heteroclitus*, the most numerous, accounted for 95.5% of the total catch from all Sites. This species made up 98.9% of the catch in the upper estuary, 95.8% in the middle estuary and 87.0% in Buzzards Bay. *F. majalis*, the second most abundant species, accounted for 12.9% of the catch in Buzzards Bay and only 4.1% of the total number. The 2 remaining species combined contributed less than 1% of the total number and catch at any Site.

Length and Weights: Length and weight measurements were obtained from 1,781 specimens of 11 species from 5 Sites (beach seines). Lengths for *M. menidia* (the most numerous species caught) ranged from 22 - 132 mm, with 95.3% of them measuring < 80 mm. The larger specimens (89-132 mm) were only caught at Sites 2 & 9. Weights ranged from 0.1 - 13.6 gms, most of them measuring from 0.1 - 3.0 gms. *M. menidia* were caught at 5 Sites. *F. heteroclitus* lengths ranged from 22 - 100 mm, with 66.7% of the specimens measuring from 30 - 50 mm. Weights for *F. heteroclitus* ranged from 0.1 - 17.5 gms, with 68.5% < 1.5 gms. *F. heteroclitus* was caught at all Sites. *F. majalis* lengths ranged from 26 - 131 mm, with 98.1% < 60 mm. Weights ranged from 0.1 - 33.3 gms, with almost all < 3.0 gms. *F. majalis* was caught at all Sites. Length for *A. sapidissima* caught at all Sites, ranged from 33 - 57 mm, with all weights <= 2.5 gms. *Apeltes quadracus*, caught at Sites 1 & 2, had narrow lengths (27 - 39 mm) and weights (0.1 - 0.3 gms). The length range for *M. cephalus* was from 54 - 113 mm, with weight measurements from 1.1 - 17.7 gms. This species was caught at 3 Sites (1, 5, & 9). The last species present in any number, *Pomatomus saltatrix*, was caught at Sites 1 & 2, with lengths 107 - 139 mm and weights 12.0 - 21.3 gms. During this study only one specimen of *Tautoga onitis, Caranx hippos, Pseudopleur-onectes americanus*, and *Alosa pseudoharengus* were caught. A total of 1318 fish from 4 species were collected in minnow traps from 6 Sites. *F. heteroclitus* (91.7% individuals) had ranges of lengths 33 - 112 mm and weights 0.5 - 26.7 gms. This was the only species to be caught at all Sites. *F. majalis* (7.2% individuals) had lengths from 37 to 56 mm and weights from 0.5 to 2.3 gms. *M. menidia* (1% individuals) had lengths of 52 - 70 mm and weights of 0.9 - 2.3 gms. There was 1 specimen of *A. pseudoharengus* caught at Site 4. The length frequency distribution of *M. menidia* at Site 2 exhibited a bimodal pattern indicating two age classes. Site 9 had fish of the larger size group. In the upper estuary (Sites 1, 3, 5) the larger size group was not present, due to the physical make-up of this area. Percent composition of *F. heteroclitus* was the highest at Site 1 and exhibited a decrease further down the estuary. The length frequencies of *F. heteroclitus* exhibited a bimodal distribution indicating the presence of two size groups. However, unlike *M. menidia*, both size groups were present at all Sites. *F. majalis* had the highest percent composition at Site 1. Although only a few specimens of larger fish were caught, there are also indications of a bimodal distribution in the length frequencies of *F. majalis*.

Gut Contents: Seventeen specimens of *F. heteroclitus* were examined for gut contents, 10 of which contained food. All fish ranged from 70-75 mm in length. Gut contents included 7 major groups of organisms. Bivalve mollusks accounted for 53% of the total number of organisms found. Fish and fish eggs, decapod crustaceans, and polychaets accounted for

17.8%, 13.3%, and 11.1% respectively. Chordates and gastropods each accounted for 2.2%. Plant material, which was found in 3 of the 10 stomaches, was less than 1%. Biomass (blotted wet weight in gms) was measured for each prey category. Bivalves comprised 44% of the total biomass found in the guts. Fish and fish eggs and decapods accounted for 29% and 14%, respectively. Plant material accounted for 13% of the biomass. The remaining 3 groups (polycheats, chordates, & gastropods) each accounted for less than 1% of the biomass. Analysis of the gut contents were performed on 10 *P. americanus* individuals (from Site 2), with lengths between 50 - 60 mm. Two taxa (isopods & polychaetes) were found: isopods (63.8% of number of organisms) accounted for 21% of the biomass; polychaetes (31.9% of number of organisms) made up 73% of the biomass. The only other group present was amphipods, accounting for 4.3% of the total number of organisms and 6% of the biomass.

Bioaccumulation Findings

Biota within two food chains were sampled to help assess the potential for bio-concentration/ bioaccumulation of PCBs and selected heavy metals (Cu, Cr, Pb and Zn) in site organisms (Table 9). Ring-billed gulls were collected along with some of their food items (e.g. ribbed mussels, amphipods, and gastropods). Other major foods of the ring-billed gull include: fish, amphibians, insects, polychaets, grubs, and sometimes bird eggs and mice; they also scavenge (DeGraaf and Rudis 1986, Martin et al. 1951). Ring-billed gulls breed near open beaches, mud flats and harbors, and winter near salt water. *P. leucopus* along with some foods items were collected at Sites 1 and 2. *P. leucopus* diet is versatile, reflecting availability of food (eg. insects, snails, centipedes & small amounts of carrion). Plant foods include seeds, fruits, acorns, tender green plants, and roots or tubers (DeGraaf and Rudis 1986, Martin et al. 1951). *P. leucopus* are most abundant within the upland border of the salt marsh and areas of salt marsh shrub. In February and March the collection of Black ducks, *G. demissa* and *U. lactusa* occurred. Black ducks are a game bird. If contaminated, they may pose a potential risk to humans. Black ducks are known to breed in brackish marshes and winter exclusively in open marshes of the coast and interior. Their major foods include: mollusks, submerged aquatic plants, algae, acorns, seeds of marsh plants, salt marsh grasses, crustaceans, polychaets, amphibians and fishes (DeGraaf and Rudis 1986, Martin et al. 1951).

PCBs and selected metals (Cr, Cu, Pb, & Zn) were detected in tissue samples (Tables 10 & 11). These data indicate that PCBs are incorporated in the tissue of the sampled organisms. PCBs were detected in all of the *G demissa* (Figure 6), *O. grillus* and *M. bidentatus* tissues which comprise the lower trophic level of the Ring billed gull food chain;

and in selected fruit and composite animal food samples which comprise the lower trophic level of the *P. leucopus* food chain (Martin, Zim, & Nelson, 1951). Average PCB concentration in *G demissa* was 10.6 ug/g. The PCB concentration in *G demissa* was highest at locations closest to the area with the highest contaminated sediment. The PCBs concentration in *M. bidentatus* sample was 3.2 ppm and 29.0 ppm in the *O. grillus* sample. The average PCB concentration in Ring-billed gull muscles and fat samples were 13.99 ug/g and 153.67 ug/g, respectively. These data indicate that biomagnification may be taking place within this food chain. The average PCB concentration in all mouse foods was 4.31 ug/g. PCBs levels in *J. gerardi* and acorns were below detection levels. *P. leucopus* PCB concentrations averaged 22.33 ug/g. These data suggest that biomagnification of PCBs may be taking place within this food chain as well. Concentrations of metals appear to be comparable throughout the samples with some exceptions. Relatively high concentrations of copper and zinc were detected in the *O. grillus* (Cu = 36.0 ug/g; Zn = 140 ug/g) and *M. bidentatus* (Cu = 25.0 ug/g; Zn = 630 ug/g) samples. The *M. bidentatus* sample also contained relatively high concentrations of lead (9.0 ug/g). The levels of zinc detected in the muscle and fat portions of Ring-billed gull suggest that zinc may be concentrated in fat tissue. Although these data do indicate that certain metals may be selectively concentrated, they do not suggest transfer within the two food chains or a potential trend for biomagnification as do the PCB data.

Evaluation of the concentrations of metals and PCBs taken from samples of *Palaemonetes pugio* show a similar trend as demonstrated in the sediment samples. Metal concentrations from *P. pugio* taken in upper estuary Sites are more elevated than Site 9 or 2. *P. pugio* from Site 1 exhibited the highest levels for chromium, copper, and iron. The highest PCB values were found in *P. pugio* taken at Site 3 (25.3 mg/kg). The *P. pugio* PCB values were 7.63 mg/kg from Site 1. *P. pugio* taken near Site 2 has the lowest average concentrations for chromium, copper, PCB and iron. The most evident change was the two order of magnitude drop in PCBs between the *P. pugio* collected at Site 3 (25.3 mg/kg) and that from Site 2 (0.33 mg/kg). *G. demissa* were taken at Sites 2, 3, 4, 5, and 9. Metal and PCB concentrations from *G. demissa* tissue taken at Site 5 were generally higher than other stations, followed by decreasing concentrations from Sites 4 , 9 to 2. The total PCB and zinc concentrations were highest in tissue from Site 5. Copper and mercury concentrations were high from tissue from Site 2. The cadmium level was highest at Site 2. *F. heteroclitus* were taken from Sites 1, 2, and 4 and *P. americanus* from Site 2. With the exception of chromium and lead concentrations found in fish tissue from Site 1, there was little differences between contaminant values from the various wetland stations. Fish samples taken from Site 5 exhibited PCB values an order of magnitude higher (44 mg/kg) than all other stations. PCB

concentrations at Sites 9 and 2 were 8.1 mg/kg and 3.0 mg/kg respectively. Concentrations of PCBs in the tissues of *F. heteroclitus* were 4 times higher in the middle estuary (Site 4) than in the fish caught at Site 2. The upper estuary (Site 1) had concentrations 5 times higher than the middle estuary. There was 20 times as much PCB contamination in the fish from the upper estuary than fish from Site 2. Concentrations of copper and lead were higher in upper estuary fish than in fish from Buzzards Bay. *F. heteroclitus* would be susceptible to PCB and heavy metal contamination from prey species. Analysis of tissue from *P. americanus* from Site 2 showed much lower concentrations of copper, lead, and zinc than the concentrations found in *F. heteroclitus* from Sites 1 & 4. Concentrations from *P. americanus* and *F. heteroclitus* caught at Site 2 were almost identical. The PCB concentrations for *F. heteroclitus* at Site 2 were 5% of the concentrations found in fish from Site 1. Analysis of tissue from *P. americanus* caught at Site 2 showed half the concentration of PCBs in *F. heteroclitus* caught at the same Site. If the high levels of PCBs and metals in *F. heteroclitus* in the upper estuary are a result of its diet, then *P. americanus* would also be expected to contain higher contaminant levels than in the fish sampled from Buzzards Bay.

DISCUSSION

Biological trends

Sediment: Salt marshes are known to be sinks for nutrients, organic material and toxins, although they also export large quantities of nutrients and detritus on a seasonal basis. These marshes have trapped large quantities of metals and PCBs. Most of this is associated with the sediment deposition within the accretion portions of the wetlands, as the metals and PCBs are adsorbed onto the particulates. Although there is debate in the scientific literature regarding the specifics of salt marsh import-export behavior (Nixon 1980), largely because of the difficulties in measuring these processes, a general understanding is possible. Import-export roles are affected by the structure, age, and hydrology of the marsh, and are parameter-specific. Odum et al. (1979) classification of salt marshes by flow and tidal exchange characteristics show that marshes with low currents have limited export. Age is also a factor. As the marsh fills its basin to the high tide level it only acts as a sediment sink primarily in relation to sea level rise. The lower metal and PCB concentrations in the high marsh portions of the study wetlands support the notion that sediment accretion rates within these older parts of the marsh is minimal at present. Younger marshes typically have greater accretion rates, and may actually show a net import of particulate organic carbon, while older marshes tend to export carbon through their creek systems.

The Sites in this study appear to be primarily older marshes and occur in a setting which is moderately constricted. This indicates that they likely have a net export of organic carbon within, or slightly below, the normal range determined for east coast marshes of 100-200 g $C/m^2/yr$ (Nixon 1980). The significance of this export in secondary production of adjacent waters is difficult to assess; Nixon (1980) notes that "the path from the emergent marsh to the open coastal water is not through a pipe, but through a complex chain of sub-systems, each of which is characterized by its own internal cycling as well as its own inputs, outputs, transformations and storages". Tidal flats adjacent to the wetlands may be important sites for trapping nutrients which leave the marsh on ebb tides, ultimately converting plant production into animal biomass (Whitlatch 1982).

Benthos: Sediment characteristics and other physical differences determines species distribution. A comparison of the benthic communities between Sites 1 and 2 is complicated by the physical differences. Based on the relationship of particle size and current speed (Hjulstrom 1939), sediment particles at Site 2 measuring less than 4.5 mm, over 90% of the surface sediments could be resuspended by the estimated 0.6 kt current speed. Current speeds at Site 1, estimated at 0.2 kt could potentially transport particles measuring less than 1.4 mm, or an average 90% of all surface sediments. Another difference is the contaminant levels. Site 1 is located adjacent to the highest polluted sediment, while Site 2 is located in much less polluted area. Site 1 exhibited a higher proportion of fine grained sediments, suggesting a greater potential for contaminant concentration, because fine grained sediments tend to have a higher affinity for contaminants. There were marked differences in infauna between tidal creeks on Sites 1 and 2. Dominant species on Site 1 were surface deposit feeders and shallow burrowing deposit feeders. The dominant taxa (Oligochaeta, *Capitella* sp., *Streblospio benedicti*) are generally considered to be opportunistic (Grassle and Grassle 1974). Diversity was low, indicative of a stressed environment, as estuaries generally are (Rhoads et al. 1978). The shellfish fauna (2 species) was depauperate in Site 1 tidal creeks. There were 3 times as many infaunal species in the creeks on Site 2 than at Site 1 (particular in polychaetes & bivalves).

A greater variety of mollusks species (most filter feeders) occurred at Site 2 than at Site 1. The same taxa dominating tidal creek fauna at Site 1 were also numerical dominants in the mud banks. Several amphipod species were also moderately abundant in the mud banks. These species generally have a strong association with the marsh grasses, either as detritivores or grazers of microorganisms associated with the plants (Daiber 1982). Species composition

in Site 2 mud banks exhibited higher diversity, particularly among polychaetes, bivalves and amphipods than at Site 1. The higher proportion of organic material and fine grained sediments at Site 2 may offer an enhanced habitat value for deposit feeders and detritivores over Site 1. Mud banks on neither Site support a wide array of mollusks. The dominant bivalve, *G. demissa*, is especially adapted to existence in and near the *S. alterniflora* zone by its ability to "air gape" (Daiber 1982). There was no size difference in the *G. demissa* populations at the two Sites. The higher diversity at Site 2 suggests that this site provides a more conducive environment for benthic fauna.

Sites 1 and 2, both include a variety of intertidal habitats which contribute to the potential primary and secondary (invertebrate) production. Some of the biological differences found are due to physical differences (e.g. location in or out of the estuary, exposure to high energy environment, and/or sediment characteristics). The abundance and diversity of fauna at Site 2 indicates a high level of secondary production. Although diversity is greatly reduced at Site 1, the size (especially linear distance of marsh-open water interface) and elevated abundances of a few taxa suggest that this invertebrate production makes a substantial contribution to the system. Although Site 3 is large, it exhibited low invertebrate production and diversity, a combination which does not provide good feeding habitat. Sites 4 and 5 are both small fringing marshes associated with very soft mud flats. *G. demissa* are prominent features of both Sites. Site 5 has a greater variety of microhabitats (determine by grain size) than Site 4, and consequently supported a greater variety of shellfish. At Site 9 *G. demissa* and *L. littorea* are abundant, but the gravel substrate is not conducive for benthic infauna. This Site provides minimal feeding habitat for demersal fish and limited export of primary and secondary production.

Flora: Tidal marshes are among the most productive ecosystems in the world. Net primary productivity values reported for northeastern U.S. low marsh vegetation range from 507 - 840 g dry wt/m^2/yr; high marsh values are about 430 g dry wt/m^2/yr (Mitsch and Gosselink 1986). The mature salt marsh in this study was about 68% high and 17% low marsh vegetation. The average plant height for high marsh grasses was about 53 cm and for low marsh grass 143 cm. In general, plant heights were greater in the estuary Sites than the reference Site (Figure. The greater grass growth is probably due to the elevated nitrogen and phosphorous levels in the waters. Based on plant heights these Sites appear very productive for their age. Estimates of net marsh productivity (Figure 4) derived solely from above-ground plant harvesting are known to underestimate the total energy within a marsh system (Nixon 1980; Teal 1986). However, net above-ground productivity values for *S. alterniflora*

have been correlated with below-ground production (Nixon 1980; Teal 1986). Teal (1986) reports ratios of above/below - ground productivity in Massachusetts of 2.5 for stands of tall *S. alterniflora* and 8.3 for stands of short *S. alterniflora.* Nixon (1980) reports a ratio of 4.0 for high marsh communities in a Massachusetts marsh. The values presented here are well above those expected for this region. The detritus, dead leaves and stems of the salt marsh grasses, are broken down by bacteria, fungi, protozoa, and nematodes which are in turn eaten by large deposit feeders (Weibe and Pomeroy 1972). Estuaries with a constricted opening such as this tend to trap and recirculate materials instead of exporting them.

The plant species composition of these marshes is representative of that found in this region for regularly flooded marshes (Teal 1986) and high salt marshes (Nixon 1980). One unusual feature is the relative abundance of *I. frutescens* at Site 1; this is related to the hydrologic regime which has developed. There were no indications of stress related to contamination in this study. There are no signs of abnormal rates of plant mortality or stress as might be reflected in chlorosis or other color or morphological aberrations. The above-ground standing crop data indicate vascular plant productivity is within the range of reported values for southern New England. The highest biomass of herbaceous vegetation was recorded for tall *S. alterniflora* at Site 5. This site is close to contamination sources, yet no indication of reductions in plant productivity were observed. There is little available data on what levels of contaminants such as heavy metals or PCBs are damaging to salt marshes (Teal 1986). Existing studies are limited (see Giblin, 1982, Hampson & Moul, 1978). Since PCBs are not known to accumulate in *S. alterniflora* tissues, no manifestion is visible relative to species composition or productivity

Fauna: *S. floridanus* were the most frequently observed mammals (Table 5). Medium-sized mammals (e. g. *M. monax*, *O. zibethica*, and *P. lotor*) were found at the larger Sites and *V. fulva* have inhabited these Sites for some time. Mammals were abundant on all of the Sites. Small mammal diversity and abundance was the lowest on the marsh proper where *M. pensylvanicus* and *P. leucopus* are known to nest. In the upland edge, a greater abundance and diversity of species, (including *S. cinereus*, *S. aquaticus*, *M. musculus*, & *Z. hudsonius*) were found. Differences in the size and compositional characteristics of these sites affects the mammal diversity and abundance among them because the majority of use is foraging by animals which live in marsh edge or upland habitats. Therefore Sites containing larger transition zones had the greatest diversity and abundance of small and medium sized mammals. Sites 1 and 3 provide suitable habitat for *M. pensylvanicus* , which builds its nest in *S. patens* (sometimes in *S. alterniflora)*, and feeds exclusively on salt marsh plants. Foraging areas are

also found for larger mammals (e.g. *S. floridanus, O. zibethica* , *P. lotor, D. verginiana* , *M. mephitis* , *M. frenata*, and *V. fulva*, which live in upland areas, but feed in marshes. In addition, the extensive transition zones provide suitable habitat for burrowing mammals (e.g. *S. cinereus, M. monax*), and for seed eaters (eg. *P. leucopus* , *Z. hudsonius*) which build nests in old logs or tufts of grass.

There is little inhabitable area at Site 5, since it is dominated by the intertidal form of *S. alterniflora.* The mammal density and diversity is low. Site 4 is not inhabitated by mammals, rather it is used by mammals living in the adjacent stand of *P. australis* and upland areas (e.g. *P. leucopus, S. floridanus, P. lotor, D. virginiana, & M. mephitis).* The small size of Site 9 precludes extensive use of by mammals other than *M. pensylvanicus* and *P. leucopus.* Although Site 2 has less transitional marsh/upland edge habitat than Site 1, adjacent shrub and forested areas provide suitable habitat for small mammals (e.g. *S. cinereus* and *P. leucopus* , and larger mammals (e.g. *M. erminea, M. vison, M. mephitis* , *D. verginiana* , & *P. lotor*). The extensive area of salt marsh at this site and its high interspersion of cover types provides rich foraging areas for the species living in adjacent upland areas, as well as for wetland nesting species such as the *O. zibethica* and *M. pensylvanicus* .

Fish: Fish species composition (Table 6)in the study area was found to be comparable to that of other estuaries (Curley et. al. 1971, 1974; Nixon & Oviatt 1973). The dominant species (*M. menidia, F. heteroclitus*, & *F. majalis*) were also dominant in the other estuary studies of Massachusetts. *M. menidia,* which accounted for 76.8% of the total catch was also reported by Curley et al. (1974) for the Taunton River and Mount Hope Bay estuary where *M. menidia* made up 66.6% of the total catch. The dominant species caught at all 5 Sites, were consistent with McHugh's (1967) classification,which considers them to be general estuarine residents. *M. menidia* enter the shallows and tidal creeks of the upper estuary to feed and breed. *A. sapidissima* and *M. cephalus*, both migratory species, appeared to be more abundant in the upper estuary (Sites 1, 3, 5). These 2 species utilize the estuary as a nursery area. The specimens caught were all young-of-the-year. *A. quadracus* , categorized as an estuarine resident, was restricted almost entirely to Site 1. *P. saltatrix* was found at Sites 1 and 2, occurring in comparable numbers in those two areas. This species, a top predator, usually enters estuaries in pursuit of migratory planktivores such as *A. sapidissima* and *M. cephalus*. *C. hippos* and *P. americanus*, primarily marine species, were caught at Site 2. There were only 4 species of fish caught with minnow traps. Of these species *F. heteroclitus* and *F. majalis* were caught in large numbers. The *M. menidia* and *A. sapidissima* swim and feed in the middle to upper areas of the water column. In the beach seines, *F. heteroclitus* was

present at all Sites and was more abundant in the estuary than at Site 2. Length frequencies from fish caught in minnow traps showed a bimodal distribution, though less distinctly than in the beach seine data. *F. majalis* was caught at 3 Sites (1, 2, and 9). The number of specimens increased further down the estuary; similar to observations in the beach seine collections. The average number of *F. heteroclitus* caught by minnow traps did not differ substantially among the 6 Sites, showing that comparable concentrations of this species are present in suitable habitat throughout the estuary. The higher the contamination in a Site, the greater the total amount of contamination is likely to be in the fish biomass in that area. *F. heteroclitus* would come into contact with contaminants associated with particulate matter in the water column as well as the sediments since they tend to burrow in the soft mud to over-winter (Chidester 1920). *F. heteroclitus* also tend to stay in the same general area throughout the year, moving very little within an estuary (Lotrich 1975). *F. majalis* would exhibit the same general behavior as *F. heteroclitus* , but *F. majalis* is a smaller component of the fish fauna in the areas of high contamination. The plankton feeding species *M. menidia* and *A. sapidissima* would come into contact with the contaminants bound to the particulate matter in the water column either through ingestion or physical contact. The diet of *F. heteroclitus* consists of: benthic organisms, decapods and other crustaceans, and plant material. Comparison of the diets of examined specimens with fish caught in other estuaries shows no variation in diet composition; however there is a difference in the percent occurrence of various groups in their diets. *F. heteroclitus* usually consume prey items in proportion to prey occurrence in the environment (Fraser,1973).

Functional attributes and values

Despite very heavy levels of contaminants, the project area Sites continue to function as effective systems and to have high values. The Wetland Evaluation Technique (WET) developed by the Corps of Engineers (1987) has been employed for the assessment of the relative wetland significance for 15 functions. The WET method assumes that wetland characteristics in combination contribute certain functions, and therefore rating those characteristics can provide a relative assessment of how well a particular wetland functions for certain purposes. This method was unable to distinguish differences in functional values between these sites. Larger size wetlands,with more diversity of vegetative types would be expected to have a greater potential to provide a wider array of functions to a degree which has more local significance than smaller, less diverse marshes. In considering the range of factors which, in combination, determine overall wetland value, the following ranking of these Sites (from highest to lowest) is suggested: 2, 1, 3, 5, 4, 9. The first three areas would be logically

grouped together in a "higher value" assessment, versus the latter three in a "lower value" category.

Estuary resources are presumed to have functional values in the Massachusetts Wetlands Protection Act (M.G.L. Chapter 131, Section 40) and selected literature (Adamus 1983). These regulations contained in the Act (310 CMR 10.00), identify 7 resource categories that are present in this estuary:

- land under the ocean, banks of, or land under, the ocean, river, or creek that underline anadromous fish runs (ie. *A. pseudoharengus* & *A. aestivalis*);
- coastal beach (ie. tidal mud flats);
- salt marsh (all sites);
- land containing shellfish (ie. *M. arenaria* & *M. mercenaria*);
- coastal bank (ie. vegetative wetland edge);
- bordering vegetated wetland (ie. all sites);
- land subject to coastal storm flowage (ie. all sites within 100yr flood plain).

The Massachusetts Wetlands Protection Act identifies and protects 7 statutory interests. Coastal wetlands also have additional functioonal values that include: shoreline anchoring, dissipation of erosive forces, sediment trapping, wildlife habitat and socio-economic attributes (Adamus 1983). The wetlands also afford storm damage protection (wave erosion, etc.) to adjacent uplands. The marsh vegetation secures the substrate beneath the sediment-water interface and thus promotes the accumulation of clayey, cohesive sediments. Salt marsh cordgrass may reduce wave heights by as much as 71% and wave energy by 92% (Wayne 1976). Stems and leaves of salt marsh vegetation help trap suspended sediment and nutrients by impeding current flow. Salts extruded from the leaves of salt marsh grasses may increase salinity within the vicinity of the plants. This increased salinity may in turn promote clay flocculation (Pestrong, 1972). Wetlands are also presumed by the Act to aid in the removal of contaminants through uptake of nitrogen and phosphorous, removal of suspended particulates, immobilization of heavy metals, etc.

The Sites in this study contain abundant *G. demissa* beds along their banks. These gregarious bivalves increase substrate coherence by their network of byssal threads and their rigid framework structures (Davis, 1985). Suspension feeders, like *G. demissa* , extract organic and inorganic material from the water column and pellitize it. Average rates of biodeposition in the form of pseudofeces for *G. demissa* is 549 g feces/year (Davis 1985). Because much of the PCBs and metals in the water column is attached to fine organic particles,

the deposition of pseudofeces by bivalves increases the levels of contaminants within the surface sediments of the marsh. Adjacent tidal flats in the upper estuary contain shellfish which are a food source for higher trophic level organisms. A number of fish species feed in the upper estuary and migrate through to spawn in the Acushnet River. In addition to the many fish and shellfish that feed along the marshes edges and on the marsh surface are crabs, snails, insects, birds and some small mammals that inhabit these marshes. The salt marshes of the Acushnet River estuary provide wildlife with open water, mud flat, herbaceous vegetation, low shrub habitat and a transition zone at the upland edge of the salt marsh which contains herbaceous, shrub and tree strata. The availability of food and protection are abundant in these wetlands. The estuary, because of its location amidst extensive development, is a habitat which provides valuable food, shelter and nesting sites for migratory waterfowl, herons and egrets, and year round residents such as, marsh sparrows. The wetland socio-economic attributes consist of observational, educational and scientific endeavors, and the amenities of open space located in the midst of heavy urban development. Sites 1 and 2 are located in the Sycamore Street wetland (Fairhaven conservation area) ,which make these wetlands important administratively.

Pollution trends: There is a trend of decreasing concentrations of metals and PCBs from the upper estuary wetlands south;' and a weak trend of stations close to mudflats or tidal waters having higher concentrations of metals and PCBs. This study has shown that metals and PCB contamination is tied to particulate matter. This estuary has been subjected to long term exposure to contaminated effluent from various activities. Although a previous study (Eisenriech, 1980) has indicated a net flow of contaminants south from the upper estuary to the lower portions, depending upon the mass of metals and PCBs released over time, a substantial residual mass of metals and PCBs exist in the sediments of the upper estuary. This large source of material makes potentially available a large mass of contaminants for redistribution within the estuary by both natural events (Eisenriech, 1980) (estuarine circulation, nutrient cycling) and anthropogenic events (dredging, filling, etc.). These events are similar to those described by Turk (1980) as being responsible for the redistribution of PCBs in the Hudson River. The distribution of PCB's within the entire estuary is influenced by estuarine circulation patterns. The highest concentrations of PCBs are found in low marsh which are subjected to daily tidal and circulation patterns and depositional processes. Periodic inundation of the high marsh areas, especially those close to open water, replenish these areas with contaminants during high water events. Sites 1 and 5 demonstrate similar levels of PCB. These are probably a reflection of their distance from contamination sources and the circulation effects. The low marsh station at Site 4 had elevated levels of PCBs, comparable to those in

Site 1 and 5. These levels are likely due to the Site 4 location relative to the harbor bridges and its intrusion into the central portion of the traditional channel. The physical structure of the bridge pilings and associated appurtances may also affect circulation patterns immediately downstream, which, when combined with the intrusion of the site, could result in depositional patterns leading to increased PCB concentrations. Low marsh PCB concentrations in Site 9, which is more physically remote from the center line of the traditional channel, are an order of magnitude less than those at Site 4. Though less than those at Site 4, the Site 9 PCB concentrations are yet an order of magnitude higher than at Site 2.

There is a weak upper to lower estuary trend in metals distribution; however there does not appear to be a quantitative difference between low and high marsh metal concentrations. The distribution patterns may result from both physical and biologically mediated processes which act both dependently or independently of each other. Metal contaminants may have been released from industrial activities into the estuary over a longer period of time, and in higher concentrations than PCBs. The sediment-metal reaction kinetics may be such that movement of metals from soluble aqueous forms in association with particulates differs from those for PCBs. Biologically mediated processes leading to the uptake of metals by the entire spectrum of biological systems may affect nutrient cycling rates in the water-mud-wetland system and the residence time within the various biological and physical resource sinks (Eisenreich, et. al. 1980). The pattern of chemical distribution is likely mediated by: the frequency, duration and concentrations of previous contaminant releases; depositional patterns created by the geographic, hydrologic, and circulatory processes specific to the confines of the estuary; and anthropogenic activities such as wetlands alteration, dredging and filling, construction within the estuary, and upland activities which can influence downstream physical, chemical and biological processes.

Bioaccumulation

PCBs enter the terrestrial environment primarily by attaching to fine particulate matter in the atmosphere. These fine particulates then deposit on vegetation and are available to the food chain through ingestion by herbivores. PCBs in the water are directly absorbed by organisms through gill membranes and other exposed tissue, or from the food chain via ingestion. The means of exposure to PCBs from an estuary would occur through ingestion, or contact with contaminated soil. Studies on the uptake and accumulation of heavy metals by marsh vegetation indicate that vegetation plays a major role in retention of various metals including cadmium, copper, lead, manganese, nickel, iron and zinc (Windom 1977, Gambrell et al. 1977, Chan and Hantzsche 1982, Simpson et al. 1983, Taylor and Crowder 1981).

Maximum uptake of metals in above ground tissues of marsh plants apparently occurs during the growing season, prior to the production of peak above ground biomass. During the dormant season, heavy metals are not translocated back to the roots and rhizomes, but remain in the stem and leaf parts. Studies have demonstrated correlations between metal contamination in the soil-sediment material and the uptake of various metals by marsh vegetation. Taylor and Crowder (1981) showed that the patterns of uptake of metals (Cu, Ni, Zn, Mn, and Mg) were similar. Roots showed higher concentrations than the rhizomes and above ground parts and young leaf tissue showed lower concentrations than the older tissue. Gambrell et al. (1977) determined that physiochemical parameters (e.g., Eh, pH, & salinity) play a major role in the availability of metals to salt marsh plants.

Fish and other aquatic organisms accumulate PCBs and metals by direct water intake, by absorption through gills, and by the ingestion of other aquatic organisms lower in their food chain. Because PCBs and some other chemicals are persistent in the body tissues of both the food source and the organisms, magnification occurs in organisms which are higher in the food chain. This phenomenon can result in contaminant concentrations one or several orders of magnitude higher than concentrations in the water or sediment. Larger fish, bottom feeders, and carnivores tend to accumulate (biomagnify) higher levels of contaminants (NUS, 1984). Many studies have documented the presence of contaminated materials in the estuary (NUS, 1984; Battelle, 1985; Reinisch et. al, 1984; Genest and Hatch, 1981). Many of the fish and shellfish living in the estuary exceed the FDA limit (2 ppm PCBs in the edible portion) while several others have concentrations near that limit (NUS, 1984). Species feeding in those areas of elevated contaminants can be expected to accumulate metals and PCBs. As massive volumes of sediment contaminated with PCB occur in the upper estuary, normal biological and abiotic forces (Eisenreich, 1980) will continue to make a portion of the PCBs and metals in the sediment sink available for bioaccumulation.

These data indicate that PCBs are incorporated into the tissue of the selected organisms from the estuary trophic levels. Concentrations of Aroclor 1254 exceeded FDA levels in the tissues of: *G. demissa*, Ring billed gull muscle tissue, *M. bidentatus*, and *P. leucopus* indicating that biomagnification may be taking place within this food chain. These data for *P. leucopus* system suggest that biomagnification of PCBs may be taking place within this food chain as well. Biomagnification of metals in the food chain(s) is less well defined. The inability to document metal biomagnification in this study may be due to a number of factors: the ubiquitous and chronic nature of metals contamination in the region leading to constant elevated levels of metals in water and sediment; differential metal uptake rates in the various

biological systems sampled; lack of statistical power (number of replicate samples) to mathematically describe uptake trends between the various trophic levels. Bioaccumulation data indicate a trend of a gradual decrease in concentrations of PCBs from the upper to the lower harbor.

Other literature has discussed food chain implications resulting from contamination that relate to in this estuary (Genest and Hatch, 1981; NUS, 1984). Substantial literature exists about food chain impacts on other systems (Swartz and Lee, 1980; Goerke et al., 1979; Marinucci, 1981), including modeling efforts in the Hudson River (Turk, 1980) for PCB cycling and bioaccumulation (Battelle, 1988). At the study area elevated levels of PCBs were found in nearly all samples, indicating an uptake of this contaminant at all the trophic levels in the wetland system. In general, the data shows a gradual increase in the order of magnitude of the PCB concentration, from vegetative matter to herbivore/filter feeder to gulls. The data do not support a comparison between different wetland sites for different PCB uptake rates. Data from the metals analyses are less indicative of biomagnification, although elevated levels of metals were found in most samples. These data indicate a potential for bioaccumulation/biomagnification trend in the estuary. PCBs have been shown to bioaccumulate from sediment to *S. alterniflora* tissue (Marinucci, 1981). PCB concentrations were 3 to 4 times higher in decomposing cordgrass detritus than in the sediment. This has obvious implications for detritivore based food chains. Lobsters have been shown to accumulate PCBs from the ingestion of contaminated mussels, and hard shelled clams have been shown to accumulate amounts of PCBs from contaminated sediment (Battelle, 1984). Bioaccumulation of PCBs by sandworms, grass shrimp and hard clams was demonstrated in 4 sites in New York Harbor (Rubinstein, et al., 1983). Uptake was highest for the sediments and was affected by the organic content of the substrate. Other studies (Black et al 1987) have been conducted to determine if the accumulation of PCBs has an effect on the growth and survival of the *P. americanus*. Eggs of the *P. americanus* taken from the harbor contained significantly higher levels of PCBs than reference populations, and larvae hatched from these eggs were significantly smaller than reference larvae. Biologically mediated processes leading to the uptake of metals by the entire spectrum of biological systems may affect nutrient cycling rates in the water-mud-wetland system and the residence time within the variolus biological and physical resource sinks (Eisenreich et al. 1980). The patterns seen here may result from both physical and biologically mediated processes which act independently. The sediment-metal reaction kinetics may be such that movement of metals from soluble aqueous forms in association with particulates differs from those for PCBs.

The issue of whether there is net import or export of inorganic nutrients by salt marshes remains unresolved. Valiela, Teal and Sass (1974) found that salt marshes can act as nutrient sinks when high-nutrient waters pass through them. The waters of the Acushnet River estuary are enriched with nitrogen and phosphorous. Since salt marsh sediments are usually high in organic matter and sulfides they are presumed to retain heavy metals. However, factors which tend to reduce metal retention such as increased redox and low sediment pH's are often overlooked. Fifty to one hundred percent of the Zn, Cu, Cd, and Hg entering wetlands may subsequently be lost from the system. Fe, Mn, and Pb are retained to a higher degree. Their losses range from 0-50% (Kelly, Harwell and Giblin 1982). The retention of metals may decrease under higher loading rates as the sorptive abilities of the sediments become saturated. In addition, there is an interaction between nutrient levels and heavy metal retention. Under eutrophic conditions wetland sediments are more oxidized due to increased vegetative growth. The increased oxidation decreases sulfides in the sediment and increases the solubility of metals in the pore water (Kelly, Harwell and Giblin 1982). This estuary is somewhat eutrophied and has been exposed to high concentrations of metals for a number of years, therefore, it is likely that metal retention by these salt marshes is poor. Although PCBs are relatively stable with long half lives in the natural environment, there is some evidence to indicate that transformation of PCBs is promoted under anaerobic conditions (EPA 1983). However, transformation of PCBs may lead first to more toxic compounds (polychlorinated dibenzofurans) prior to degradation to innocuous chemicals.

Administrative Biological considerations

There are no visual signs of heavy metal or PCB toxicity in the floral community. PCBs in the marsh sediments were not readily taken up by wetland vegetation. The metals (Cr, Cu, Pb, & Zn) did accumulate in the salt marsh vegetation. Kelly, Harwell and Giblin (1982) found several times higher concentrations of Hg, Pb, Zn, Cu, Cd, and Cr in salt marsh vegetation growing in contaminated marshes compared to vegetation from nearby control areas. These contaminated salt marshes had no reduction in yield. Metals released from marsh sediments can enrich metal levels in salt marsh grass litter, an integral part of the detrital food web within salt marshes. *U. lactuca* and other algae found within the Acushnet River estuary also accumulate metals (U.S. EPA 1981). The most northern marsh (Site 3) had no sign of *G. demissa*, few *I. obsoleta* on adjacent tidal flats and no *U. pugnax*. *U. pugnax* populations are known to decline when exposed to polychlorinated hydrocarbons (Krebs et al. 1974). The macrobenthic population in the estuarine bottom sediment at the northern most end of the estuary was dominated by the opportunistic "pollution indicator," *Streblospio benedicti* . It is not known what factor(s) are regulating the distribution of these organisms within the estuary.

It may be a combination of stresses including possible exposure to low salinity water, nutrient enrichment, and sublethal, toxic or terratogenic effects of heavy metals or PCBs that has excluded/ eliminated certain organisms from the northern most reaches of wetland. Some organisms, such as birds do not show any decreased diversity or numbers at the estuary when compared to a "reference" site (for PCBs only) on Buzzards Bay. However, these birds are feeding on contaminated organisms within the estuary and accumulating PCBs. PCBs degrade Vitamin D and estrogen in birds which results in eggshell-thinning and reproductive failure (Weaver 1982). To ascertain whether animal populations are in decline due to the presence of contaminants or other biotic or abiotic factors within the estuary, transplant experiments and experiments which expose organisms to known quantities of existing contaminants need to be performed. The administratively important species are presented in Table 12.

Using the definitions of the Council on Environmental Quality (40 CFR 1508.20), wetland mitigation includes: avoiding adverse impacts by not taking a certain action; minimizing impacts by limiting the magnitude of action; rectifying the impact by repairing, rehabilitating, or restoring the affected wetland; reducing or eliminating the impact by preservation and maintenance operations; and compensating for losses by replacing or providing substitute resources or wetlands. The heavy metal and PCB contamination has done some harm to the wetlands in the study area; the actions to clean up these pollutants should not do more harm. The most contaminated portions of the wetlands are generally those where accretion continues to occur. The elevated levels in these sediments appears to be reflected in detritivores, which ingest the sediments and detrital matter. Similar trends are indicated for consumers of the detritivores. Biomagnification of PCBs may be occurring in the food chains invesitigated. These same studies suggest a trend of decreased levels away from the source of contaminants.

Despite very high levels of contaminants as well as evidence of bioaccumulation, these wetlands are functioning as effective systems and they have high resource values. These wetlands continue to support and produce biota representative of New England estuaries. Plant biomass and vegetative structure, benthic and fish community compostion and structure, and avian and mammal do not demonstrate PCB and heavy metal contamination effects. Most data for PCBs found in the literature are from tissue level studies. Without correlation with source of exposure concentrations, various physiological parameter studies and low solubility acutelly toxic static tests may result in erroneous interpurations. Natural environment impact evaluation is very complicated, because of several mixtures of PCBs were manufacatured and over 200 different chlorobiphenyls may have been produced. Each of these PCB components

is different in its physical, chemical , and biological properties. The environment subjected to each component may be modified by, but may in turn also modify it. Therefore, more field ecological assessment studies are needed to accurately document changes in wetlands due to contamination.

ACKNOWLEDGEMENTS

Numerous individuals put tremendous effort into this study. Their interest in wetland ecology and preservation have produced information very beneficial to the agencies that have to make decisions on the New Bedford Harbor clean up. Working in a hazardous environment over long hours with many hardships these individuals completed a very difficult task in a professional manner. The author and the public is indebted to each of them. The following firms were responsible for much of the work presented here: Sanford Ecological Services, I.E.P. Inc., Normandeau Associates Inc., Tetra Tech Inc., NUS Corporation Resource Analysts Inc., Enseco Inc., and Manomet Bird Observatory.

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APPENDIX

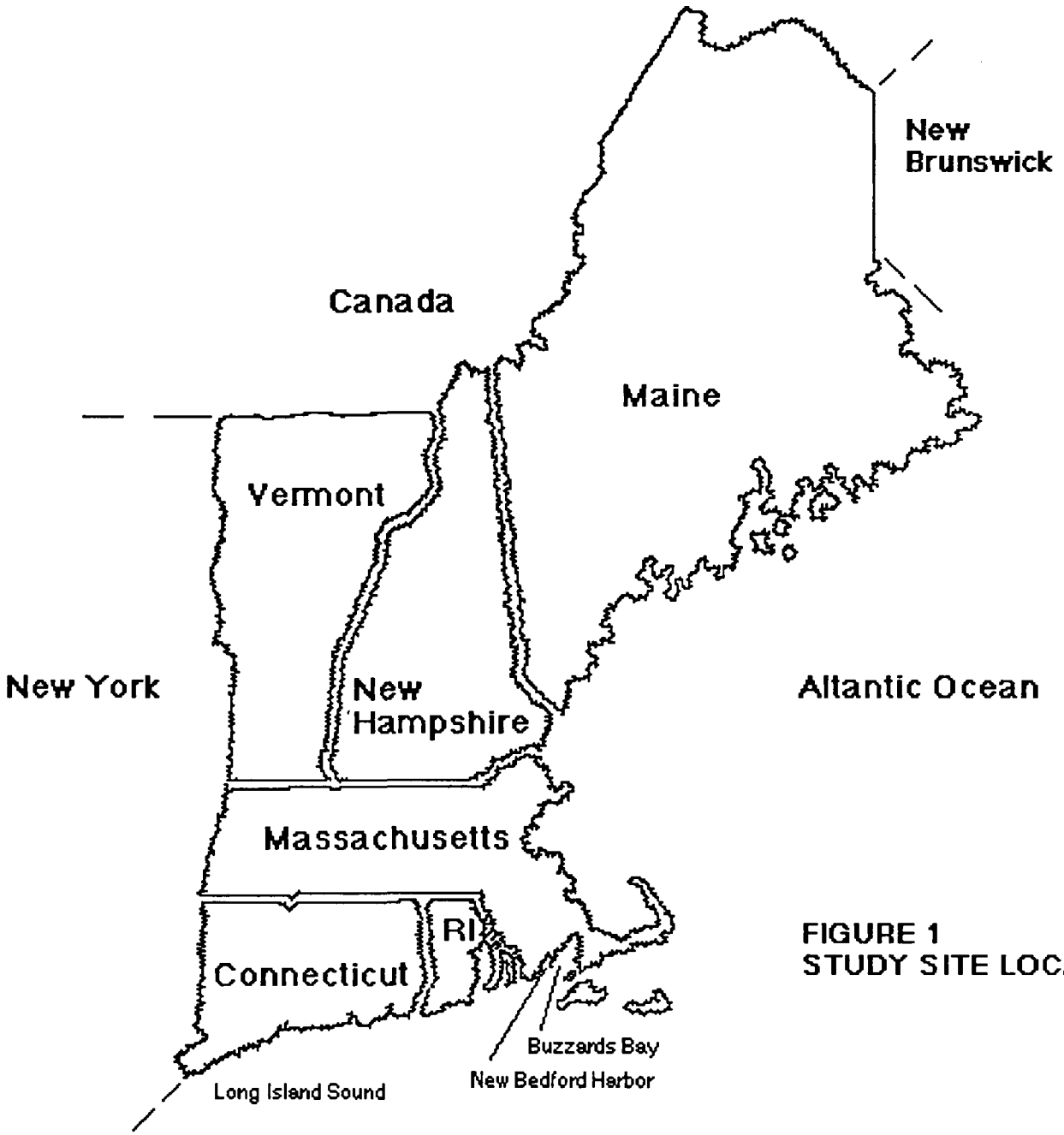

FIGURE 1
STUDY SITE LOCATION

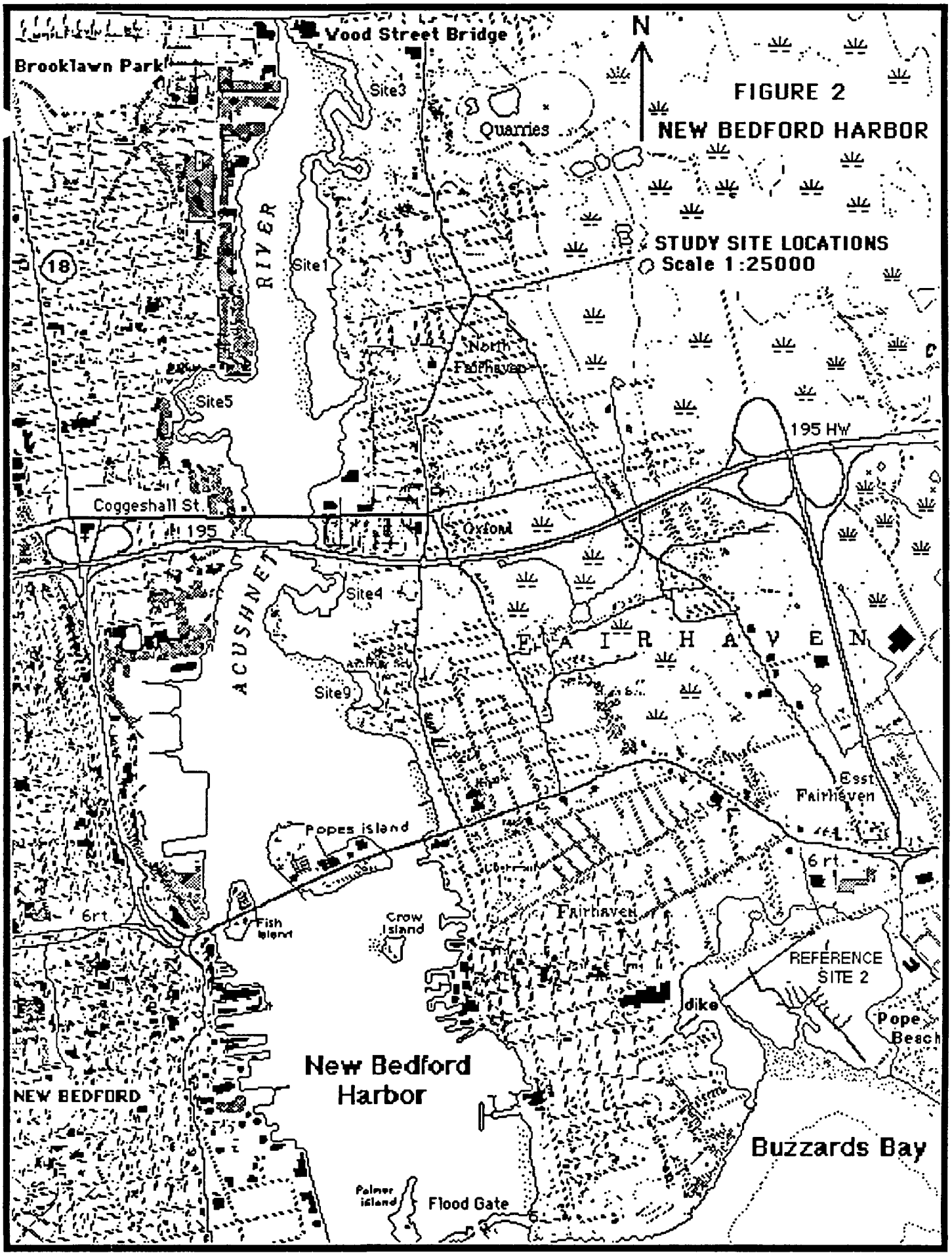
FIGURE 2
NEW BEDFORD HARBOR
STUDY SITE LOCATIONS
Scale 1:25000
N
Wood Street Bridge
Brooklawn Park
Site3
Quarries
Site1
RIVER
18
North Fairhaven
Site5
195 HW
Coggeshall St.
195
Oxford
ACUSHNET
Site4
FAIRHAVEN
Site9
East Fairhaven
Popes Island
6rt.
Fairhaven
Fish Island
Crow Island
REFERENCE SITE 2
dike
Pope Beach
New Bedford Harbor
NEW BEDFORD
Buzzards Bay
Palmer Island
Flood Gate

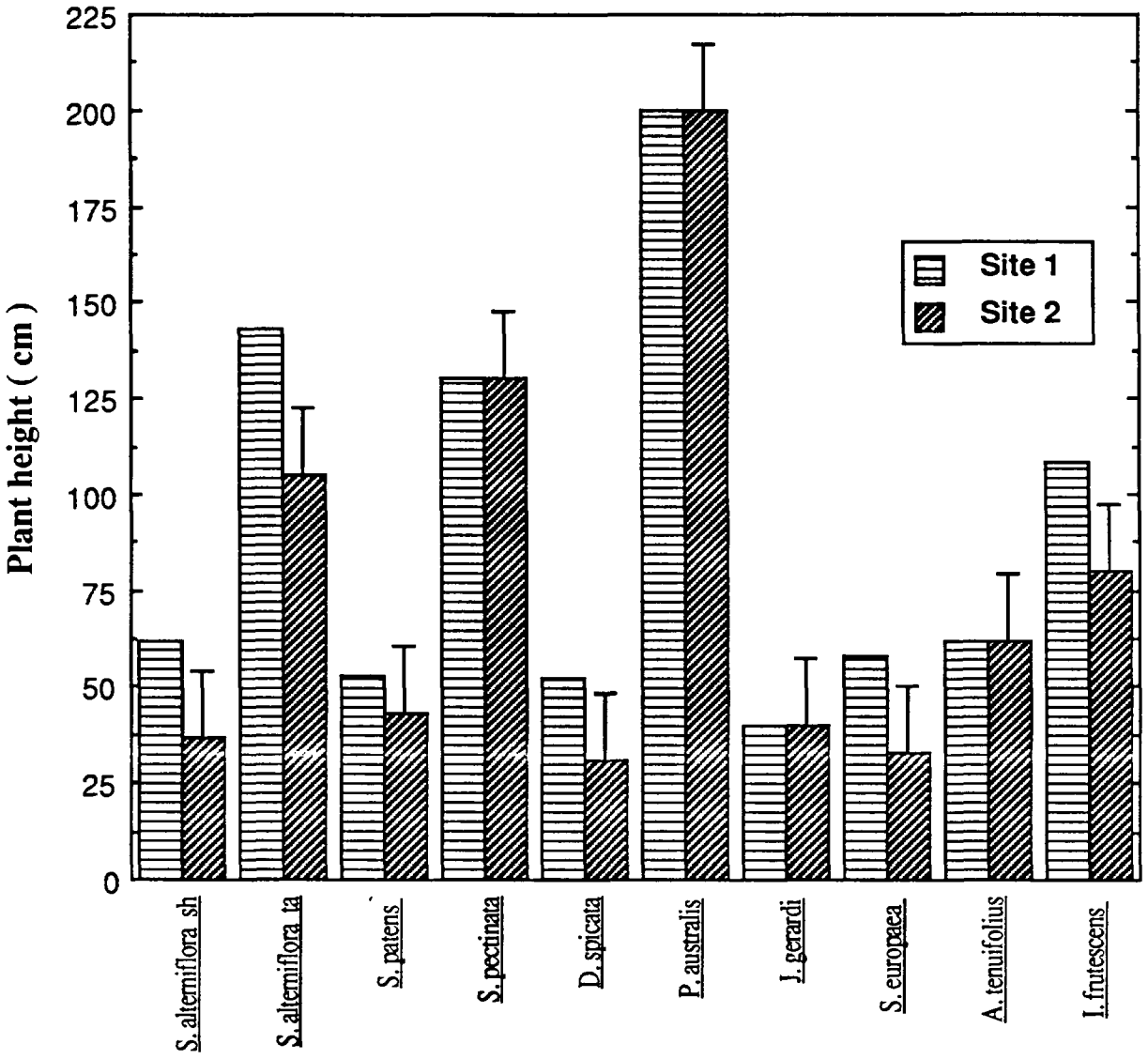

FIGURE 3 Selective Vegetation Heights for Sites 1 and 2

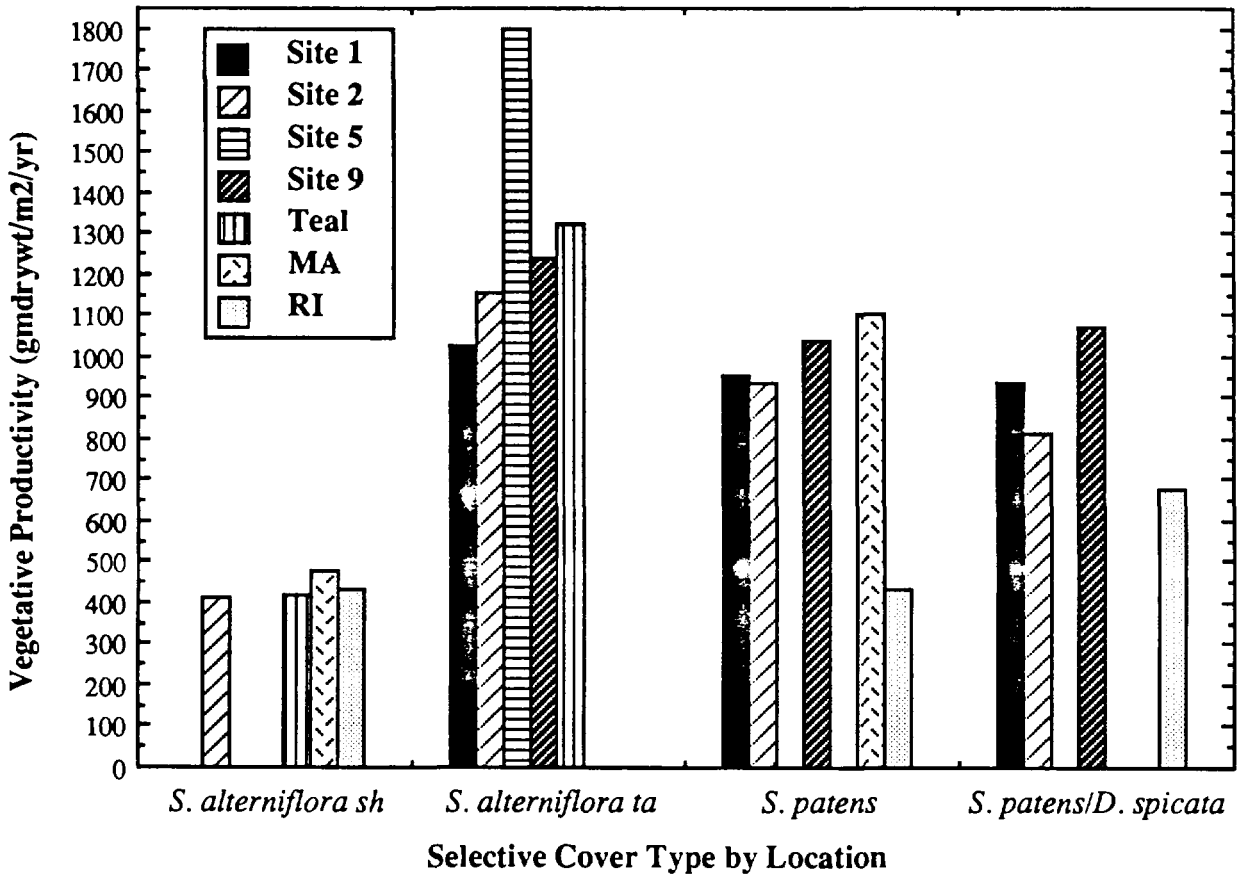

FIGURE 4 Productivity Comparisons Between Locations

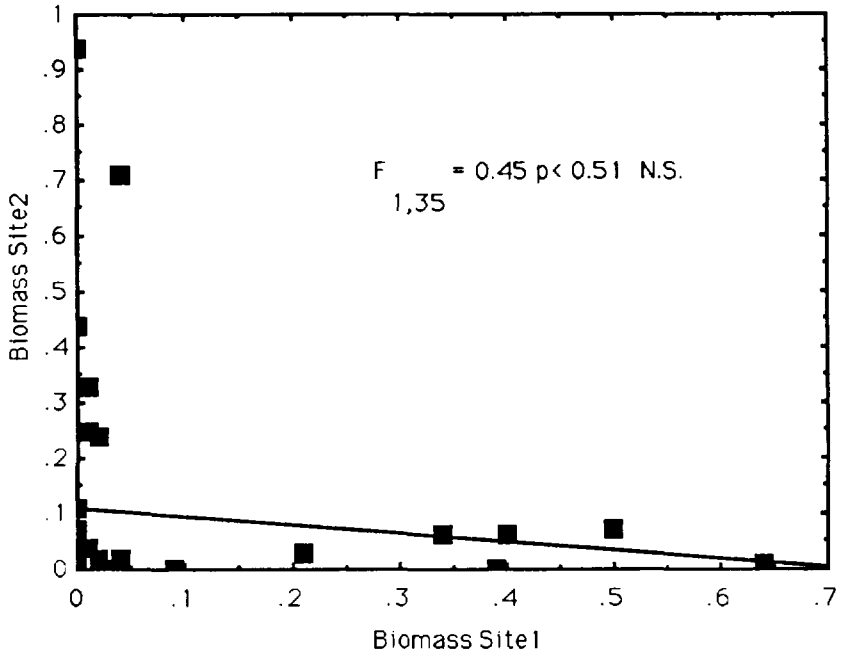

FIGURE 5 Biomass Analyses
Sites 1 and 2

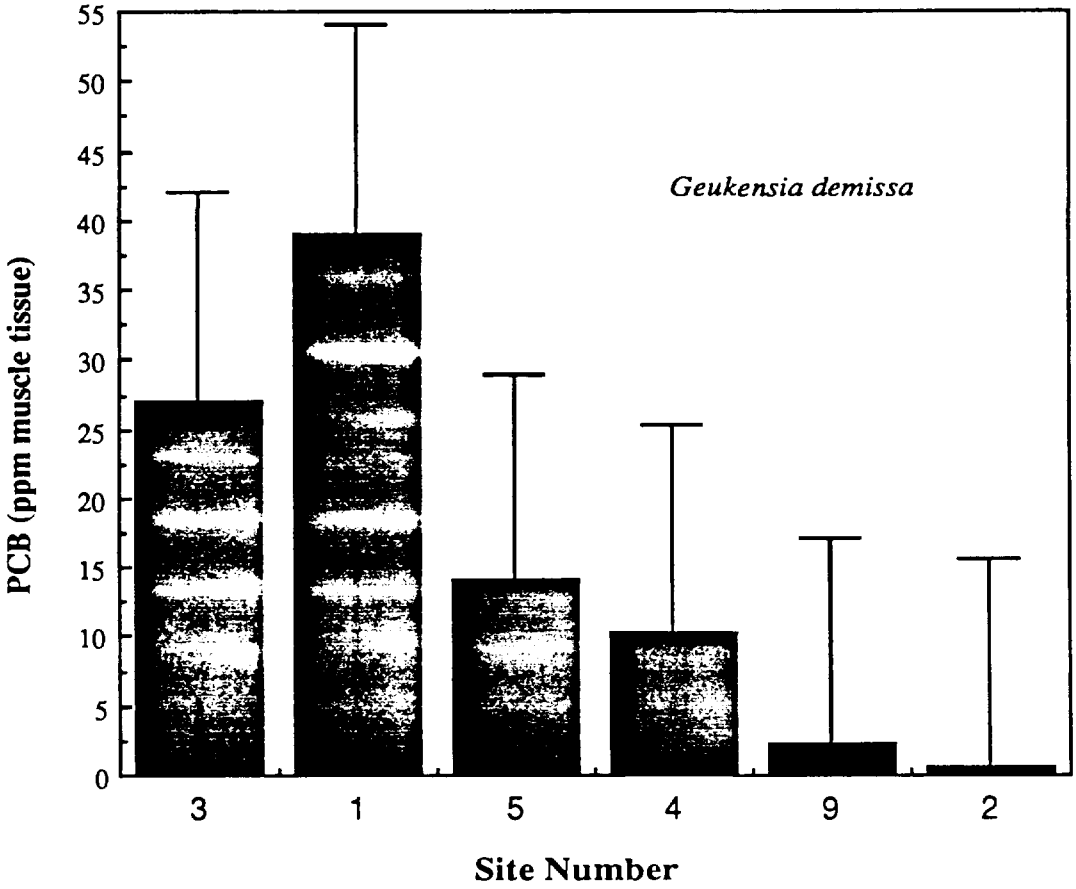

FIGURE 6 *Geukensia demissa* Tissue Levels of PCB for all Sites

TABLE 1 Sediment Characteristics

ollutant	3	sd	1	sd	2	sd	5	sd	4	sd	9	sd
Cadmium	0		0		0		7.3	12.7	0.3	0.69	0.3	0.81
Chromium	44.6	35.19	53.7	62.6	58.4	58.0	188.0	247.6	86.8	70.91	188.0	247.6
Copper	186.9	122.96	186.9	189.17	335.1	482.02	364.9	407.6	195.3	145.5	275.0	185.77
Lead	202.9	93.21	131.8	127.37	172.1	160.62	275.0	185.77	135.3	111.96	375.3	367.26
Mercury	0	0	0		0		0.3	0.39	0.1	0.24	0.22	0.28
Zinc	354.7	434.83	145.9	168.5	229.0	262.1	1637.8	3501.4	131.0	79.48	172.6	139.31
PCB	225.9	256.1	135.9	456.49	2.0	1.29	94.0	156.44	72.9	111.88	20.3	19.38
Grain size	0.03	0.01	0.03	0.01	0.25	0.12	0.07	0.04	0.08	0.04	0.024	0.008

TABLE 2 Cover-type Hectares by Site Number

Covertypes	Site Number					
	1	2	3	4	5	9
Spartina alterniflora Shrt	0.2	2.6	0.1	-	-	-
Spartina alterniflora tall	2.8	0.8	0.9	0.4	1.0	-
S. alterniflora short / tall	-	1.9	-	-	-	-
Spartina patens	7.3	15.5	0.9	0.1	0.3	0.4
S. patens / Iva frutescens	-	-	0.2	-	-	-
Iva frutescens	4.8	0.4	0.2	-	0.1	0.1
Phragmites australis	0.1	6.3	0.9	3.2	0.1	0.1
Phragmites / S. patens	-	-	-	0.1	-	-
Shrub swamp (FW)	-	3.0	-	-	-	-
Wooded swamp (FW)	-	16.5	-	-	-	-
Wet Meadow (FW)	-	0.5	-	-	-	-
Mudflat	2.1	2.3	2.5	0.5	-	0.2
Total Hectares	17.3	49.8	5.7	4.3	1.5	0.8
# Covertypes	6	10	7	5	4	4

Note: FW freshwater wetlands.

TABLE 3 Occurrence, Distribution, and Species Characteristics1 for Vegetation Site 1

	Percent Frequency of Occurrence	Relative Frequency Distribution	Mean Percent Cover	Mean Height (cm)	Mean Stem Density
Spartina patens	50.8	22.4	77.6 (6.2)	29.7 (3.1)	259.1 (39.3)
Distichlis spicata	49.2	21.7	54.4 (32.3)	31.5 (1.9)	72.8 (22.8)
Iva frutescens	28.6	12.6	64.4 (6.6)	87.8 (5.6)	28.6 (9.6)
Spartina alterniflora (shrt<1m)	19.0	8.4	74.5 (9.1)	73.4 (4.1)	33.4 (7.7)
Juncus gerardii	19.0	8.4	83.6 (8.0)	41.6 (4.0)	327.3 (72.5)
Spartina alterniflora (tall>1m)	14.3	6.3	89.4 (5.4)	133.1 (9.0)	27.5 (3.5)
Atriplex patula	12.7	5.6	5.0	47.0	5.0
Salicornia europaea	11.1	4.9	95.0	27.0	245.0
Suaeda linearis	4.8	2.1	5.0	17.0	1.0
Aster tenifolius	4.8	2.1	20.0	40.0	20.0
Spergularia marina	4.8	2.1	30.0	10.0	9.0
Elymus virginicus	1.6			0.7	
Solidago sempervirens	1.6	0.7	5.0	21.0	5.0

Note: Reported mean (standard error)
Total number of sample plots = 63
Percentage of plots in which species was found.
Measure of distribution, or chance of finding species in random selection.
Derived only from plots in which species occurred; measure of community characteristics.
Number of stems / 0.1m2.

TABLE 4 Occurrence, Distribution and Species Characteristics for Vegetation Site 2

	Percent Frequency of Occurrence	Relative Frequency Distribution	Mean Percent Cover	Mean Height (cm)	Mean Stem Density
Spartina patens	51.0	19.5	63.9 (7.1)	34.3 (1.5)	244.4 (33.2)
Distichlis spicata	49.0	18.8	53.1 (7.6)	34.8 (1.8)	59.5 (10.7)
Spartina alterniflora (shrt<1m)	43.1	16.5	79.5 (22.4)	43.2 (4.3)	91.4 (14.7)
Limonium nashii	23.5	9.0	17.1 (6.2)	30.4 (2.6)	40.0 (5.4)
Juncus gerardii	21.6	8.3	62.8 (10.8)	41.9 (3.4)	264.1 (80.0)
Salicornia europaea	5.7	6.0	5.0		9.0
Solidago sempervirens	9.8	3.8	7.5	40.0	
Spartina alterniflora (tall>1m)	7.8	3.0	80.0 (5.4)	105.5 (2.0)	30.0 (1.0)
Gerardia maritima	5.8	2.2	35.0	15.0	56.0
Iva frutescens	5.8	2.2	48.3 (13.6)	77.0 (4.4)	20.5 (7.7)
Ammophila breviligulata	3.9	1.5	52.5 (7.5)	50.0 (0.0)	45.5 (1.5)
Atriplex patula	3.9	1.5			
Elymus virginicus	3.9	1.5			
Triglochin maritima	3.9	1.5	10.0	57.0	
Suaeda maritima	2.0	0.8			
Convolvulus sp.	2.0	0.8	10.0		2.0
Plantago sp.	2.0	0.8	65.0	15.0	56.0

Note: Reported mean (standard error)
Total number of sample plots = 63
Percentage of plots in which species was found.
Measure of distribution, or chance of finding species in random selection.
Derived only from plots in which species occurred; measure of community characteristics.
Number of stems / 0.1m2.

TABLE 5 Mammals Utilizing Contaminated Sites (3,1,5,4,9)

Procyon lotor	Raccoon
Mephitis mephitis	Striped skunk
Vulpes fulva	Red Fox
Marmota monax	Woodchuck
Ondatra zibethica	Muskrat
Tamias striatus	Eastern Chipmunk
Sciurus carolinensis	Gray Squirrel
Peromyscus leucopus	White-footed Mouse
Microtus pennsylvanicus	Meadow Vole
Sylvilagus floridanus	Eastern Cottontail

TABLE 6 Dominant Fish Species Catch Comparisons

Species	Site 1	Site 3	Site 5	Site 9	Site 2
Menidia menidia	12800	389	1954	855	287
	378	208	52	316	654
	6078	2	65	718	318
	15				15
	1				0
	2				167
					55
					0
Fundus heterclitus	1070	137	4	6	0
	0	46	43	2	8
	33	47	160	6	0
	118				13
	189				1
	5329				0
					2
					34
F. majalis	48	1	0	17	1
	8	0	0	8	13
	1	0	6	3	0
	0				13
	1				1
	0				36
					5
					57
Alosa sapidissima	6	0	0	0	0
	0	29	3	1	0
	12	0	5	0	0
	1				1
	0				0
	1				1
					0
					0
Apeltes quadracus	5	0	0	0	0
	0	0	0	0	0
	69	0	0	0	0
	0				0
	0				0
	1				0
					0
					3

TABLE 7 Comparison of Avifauna Utilization of Sites 1 and 2

Survey	Site 1		Site 2	
	Species	Density	Species	Density
June / July 87 OW	16	13.0/40ha	24	12.8/40ha
June / July 87 SM	12	276.0/40ha	18	305.4/40ha
Spring 85 SM	13	12.2/40ha	15	12.9/40ha
June / July 87 M/UE	27	531.0/40ha	32	484.4/40ha
Spring 85 M/UE	28	281.4/40ha	26	211.6/40ha

Note: OW = open water
SM = salt marsh
M/UE = marsh upland edge

TABLE 8a Infaunal Species Numbers for Sites 1 and 2

	Site 1	Site2
Tidal Creeks (June)		
1	5.0	17.0
2	4.0	6.0
3	5.0	12.0
Mud Banks (June)		
1	8.0	16.0
2	7.0	11.0
3	11.0	16.0
Tidal Creeks (September)		
1	12.0	12.0
2	11.0	13.0
3	12.0	4.0
Mud Banks (September)		
1	16.0	32.0
2	16.0	17.0
3	11.0	7.0

TABLE 8b Infaunal Density for Sites 1 and 2 (numbers / m^2)

	Site 1	Site2
Tidal Creeks (June)		
1	19070.4	14796.0
2	40154.8	66617.1
3	15618.3	46606.9
Mud Banks (June)		
1	7809.0	8836.5
2	99914.0	8102.1
3	157207.7	49813.2
Tidal Creeks (September)		
1	42374.2	32551.5
2	43889.3	51621.3
3	153179.3	15289.6
Mud Banks (September)		
1	119313.1	251902.4
2	6521.9	76898.0
3	94570.3	14919.3

TABLE 9 PCB Tissue Levels from Different Food Chains

Biota	Muscle	sd	Fat	sd
Ring billed Gull	13.9	12.91	153.7	163.69
Geukensia demissa	39.1	24.06		
Amphipoda	46.0			
Gastropoda	5.6			
Peromyscus leucopus	22.3	22.95		
P. leucopus food	1.6	2.44		
Black duck	100.5	5042		
G. demissa	27.0	20.23		
Ulva lactuca	6.4	14.07		

Note: mean values; Amphipoda whole organism

TABLE 10 Metal Tissue Levels (mean and sd) (ppm)

Tissue	Cr	sd	Cu	sd	Pb	sd	Zn	sd
Ring billed gull muscle	2.23	0.72	5.48	0.651	1.59	1.396	41.2	26.046
Ring billed gull fat	2.9	1.1	2.933	0.603	1.767	0.987	100	36.056
Geukensia demissa meat	2.82	0.692	6.17	1.068	1.16	0.375	62.2	46.816
Amphipoda	2.8		36		1.3		140	
Gastropoda	2.5		25		9		630	
Peromyscus leucopus	2.975	0.525	7.275	1.367	2.55	1.136	57.25	24.473
P. leucopus food	2.7	0.7	6.233	2.597	2.667	1.71	39.667	25.17
Black Duck	0.2		5.7		0.9		10	
G. demissa meat	0.3	0.067	3.362	1.231	1.03	0.457	12.8	2.348
Ulva lactuca	3.418	1.007	17.909	7.727	12.791	5.061	52	28.125

TABLE 11 *Palemonetes pugio* Contaminant Tissue Levels (mean and sd)

Site	Cr		Cu		Pb		Zn		Fe		PCB	
3	0.35	0.30	40	1	0.82	0.08	20	0	41.3	2.08	25.33	6.80
1	0.97	0.13	44	2.64	0.89	0.02	20.33	0.57	72.33	1.15	7.63	1.35
5	0.81	0.01	36.33	0.88	1.16	0.05	20	0	76	2	3.6	0.17
4	0.16	0.28	35	1.15	0.22	0.38	15.33	0.57	50	1	2.4	0.44
9	0	0	38.66	1.20	0.62	0.01	17.33	0.57	43	2.64	1.66	0.41
2	0	0	33	1	0.85	0.35	20	1	41.33	4.16	0.35	0.11

TABLE 12 Species with Special Status

Administratively Important Species:

Fisheries:

- soft-shelled clam *Mya arenaria*
- hard shelled clam *Mercenaria mercanaria*
- American eel *Anguilla rostrata*
- winter flounder *Pseudopleuronectes americanus*
- summer flounder *Paralichthys dentatus*
- alewives *Alosa pseudoharengus*
- blue back herring *Alosa aestivalis*

Avifauna:

- American black duck, Mallard, Canvasback, Canada Goose
- Peregrine Falcon (Federal endangered species)
- Sharp-shinned Hawk (State species of special concern)
- Least tern (State species of special concern)