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Comparison of benthic invertebrate assemblages at *Spartina alterniflora* marshes reestablished after an oil spill and existing marshes in the Arthur Kill (NY/NJ)

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Abstract

In January 1990, an oil spill damaged salt marshes along the banks of the Arthur Kill (New York and New Jersey, USA). In the years following the spill, *Spartina alterniflora* seedlings were planted at a number of the oil damaged sites and successfully reestablished at these sites. In 1996, the National Marine Fisheries Service began a study to compare the benthic invertebrate assemblages at the reestablished *S. alterniflora* marshes to those at nearby existing marshes in the Arthur Kill. Oligochaetes, nematodes, and the small tube-building polychaete, *Manayunkia aestuarina* were the dominant taxa in the study. Significant differences were found in the abundances of all invertebrate individuals, oligochaetes, and nematodes between the September and May sampling times but not between reestablished and existing marshes. Although benthic invertebrate community structure was similar at reestablished and existing marshes three to four years after planting, the functional similarity of these marshes was not assessed in this study.

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Keywords: Benthic invertebrates; Community structure; Salt marsh; Oil spill; Arthur Kill; *Spartina alterniflora*; Sediments.

1. Introduction

In January 1990, a spill of 576,000 gallons of No. 2 fuel oil from a ruptured underwater pipeline damaged salt marshes along the banks of the Arthur Kill, New York/New Jersey (USA) harbor estuary (Fig. 1a). The spill occurred near Morses Creek in the northern reaches of the Kill and oil quickly spread northward into Newark Bay and the Kill Van Kull and southward to the Isle of Meadows (Fig. 1b). In the areas closest to the spill, the dominant vegetation of the low marsh, salt marsh cordgrass (*Spartina alterniflora*), was totally eliminated and some ribbed mussel (*Geukensia demissa*) beds suffered 100% mortality. Total petroleum hydrocarbon concentrations in the sediments at these sites were as high as 120,000 ng/g (Burger, 1994a,b; Hauge and Tucker, 1994).

Beginning in 1992, the Salt Marsh Restoration Team (SMRT) of New York City Parks planted *S. alterniflora* seedlings at some of the marsh sites in the Arthur Kill affected by the oil spill. In the years following the planting, SMRT monitored stem height, stem density, flower density, and above ground biomass of *S. alterniflora* at sites affected by the spill and planted with *S. alterniflora* seedlings, at sites where *S. alterniflora* was damaged by the spill and was not planted, and at sites with existing unaltered stands of *S. alterniflora*. Based on the similarities of these measures at planted sites and sites with existing *S. alterniflora* in contrast to differences in these measures at sites damaged by the oil and not planted, Bergen et al. (2000) concluded that *S. alterniflora* had been successfully reestablished at a number of the oil damaged sites.

In 1996, the National Oceanic and Atmospheric Administration, National Marine Fisheries Service,

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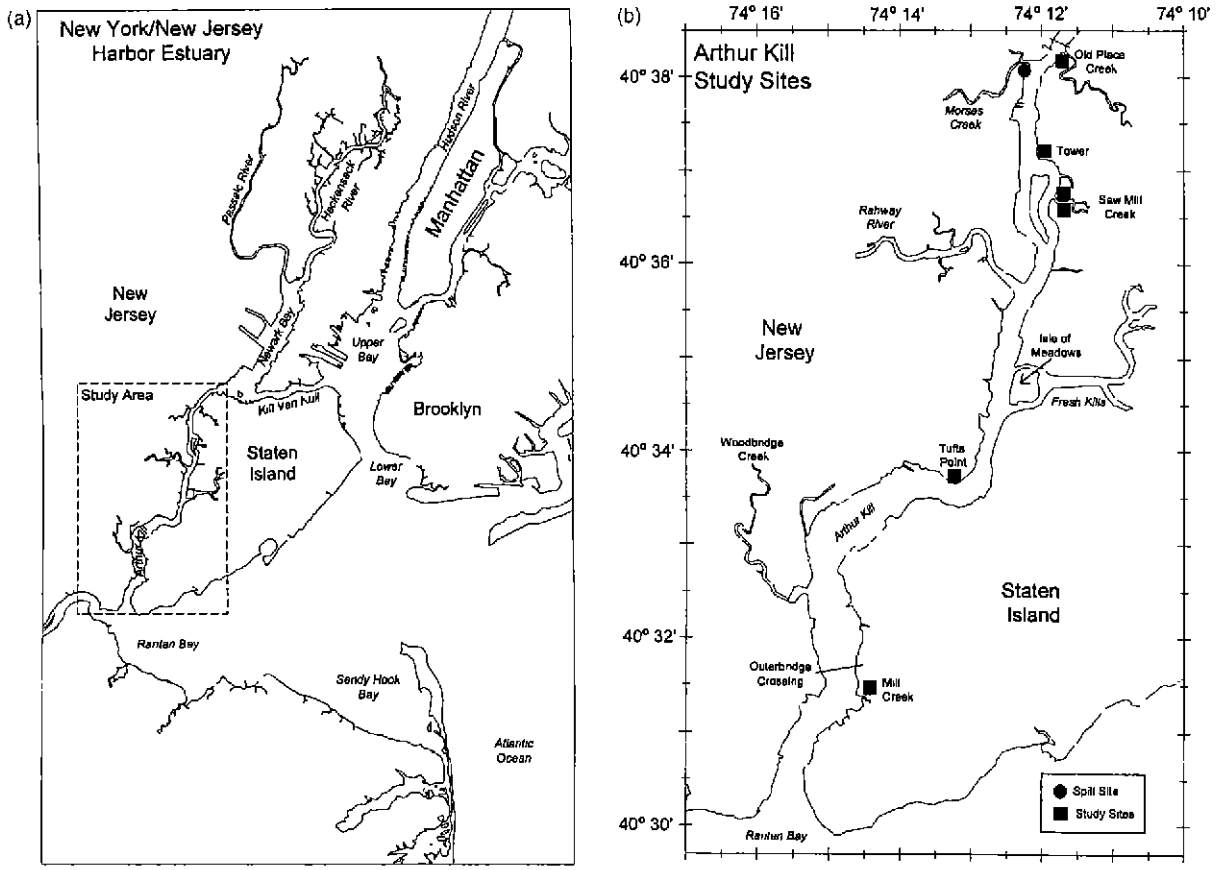


Fig. 1 (a) The Arthur Kill study area within the New York/New Jersey Harbor Estuary. (b) Locations of the oil spill and study sites within the Arthur Kill

James J. Howard Marine Sciences Laboratory at Sandy Hook, NJ began a study of other important components of the salt marsh ecosystem at some of the same sites studied by SMRT. Sediment grain size, sediment biogeochemistry, sediment contaminant levels, contaminant levels in ribbed mussels, and species composition and abundances of benthic invertebrates were determined. This paper will focus on the comparison of benthic invertebrate assemblages at marsh sites where *S. alterniflora* was reestablished following the oil spill and existing *S. alterniflora* marsh sites.

Benthic invertebrates are important members of the salt marsh ecosystem since they are part of detrital food webs linking marsh productivity to resource species (Minello and Zimmerman, 1992; Moy and Levin, 1991). The effects of oil or its components on invertebrates and their habitats are well documented (Burger, 1993; Jewett et al., 1999; Saunders et al., 1980; Suchanek, 1993). There is also considerable information available on the benthic invertebrate assemblages of created salt marshes compared to the invertebrate assemblages of nearby natural marsh sites (Levin et al., 1996; Minello and Zimmerman, 1992; Moy and Levin, 1991; Sacco et al., 1994). Little information is available, however, about the benthic invertebrate assemblages at reestablished *S. alterniflora* marsh sites that not only were denuded by an oil spill but have also been historically affected by petroleum products and trace metals in the Arthur Kill.

2. Materials and methods

2.1. Study area

The Arthur Kill, a 25 mile long tidal strait, runs northeast to southwest from Newark Bay to Raritan Bay and separates Staten Island, New York (NY) and northern New Jersey (NJ). The Kill is part of a complex estuarine system known as the NY/NJ harbor estuary (Fig. 1a). It is in a highly industrialized area surrounded by dense human population and oil refineries and storage facilities. The shoreline of the Arthur Kill is extensively bulkheaded or otherwise modified by docking facilities and the natural banks that remain are continually being eroded by waves generated by passing vessels in the channel. Since the Kill is influenced by the tides

from both its northern and southern ends, water as well as contammants are not rapidly flushed out to sea. Although water and sediment quality in the Arthur Kill improved in recent years due in part to treatment of sewage and industrial wastewater, levels of trace metals and PCBs in some sediments remain high. The accidental discharge of oil and its components into the Arthur Kill is a chronic concern because of the large number of oil transfer facilities along the Kill. Although major oil spills occur infrequently, hundreds of small oil spills occur in the NY/NJ harbor estuary each year. In 1990, however, there were several major oil spills in addition to the January 1990 pipelme spill from tankers and barges in the Arthur Kill and adjacent waters. Urban runoff is also a continual source of oil to the Arthur Kill (Burger, 1994a,b).

2.2. Study sites

Six marsh sites in the Arthur Kill were chosen for study following consultation with SMRT (Fig. 1b; Table 1). Since the restoration project was ongoing and our presence and sampling methods would disturb the sites, SMRT could only make a limited number of sites available to us. The six sites were sampled in early September 1996 and again in early May 1997. Two sites, Saw Mill Creek North and Old Place Creek, were denuded by the 1990 pipeline oil spill and planted with *S. alterniflora* seedlings by SMRT in 1992 and 1993 respectively. These two sites were among the first sites planted by SMRT following the pipeline spill. Prior to our sampling in September 1996, SMRT concluded that *S. alterniflora* had been successfully reestablished at these two sites. See Bergen et al. (2000) for details about the planting procedures. Two existing *S. alterniflora* marsh sites, Tufts Point and Mill Creek, considered to be "typical" marshes within the Arthur Kill system, were also sampled. Tufts Point, on the NJ side south of Isle of Meadows, was moderately affected by the 1990 pipeline spill (74 per cent mussel mortality; Hauge and Tucker, 1994), however, little permanent damage to the *S. alterniflora* beds was observed at this site (Alderson, personal communication). The marsh at Mill Creek, just south of the Outerbridge Crossing on the NY side, was only minimally affected by oil from the January 1990 pipeline spill (see Hauge and Tucker, 1994). We also sampled Saw Mill Creek South and the Tower site. These two sites were denuded by the oil spill but were not planted with *S. alterniflora* seedlings. The Tower marsh site is directly on the Kill and has remained unvegetated since the oil spill. Saw Mill Creek South is located in a tidal creek on the opposite shore from the planted Saw Mill Creek North site. Although oil from the spill affected *S. alterniflora* at this site, the denuded area was not as wide as the planted site on the opposite shore. By the time we sampled the site in 1996 and 1997, erosion of the denuded banks and natural reestablishment of *S. alterniflora* along the fringe had occurred (Alderson, personal communication).

2.3. Sampling methods

At each site, four stations were selected along a transect 0.2 m above and parallel to the midtide level of the intertidal zone. The positions of the stations along the transect were chosen based on the need to minimize disturbance to the site. Also, access to the specific sites was influenced by unique logistical difficulties. For this reason, distances between stations along the transect at a site ranged from 2 to 20 m and the total length of the transects among sites ranged from 12 m at Saw Mill Creek South to 39.5 m at Old Place. At the reestablished and existing marsh sites, stations along the transect were located within the vegetated zone. At Tower (not planted), the transect was in a wide unvegetated area and stations were located in mud and peat that contained chunks of asphalt. At Saw Mill Creek South (not planted), the transect was along the edge of the grass and barren mud and peat banks (see Section 2.2).

Sampling methods for benthic invertebrates follow Sacco et al. (1994). A 3 cm diameter (7 cm^2) metal coring tube was used to collect 5 cm deep sediment samples from

Table 1
Characteristics of the six study sites in the Arthur Kill

Study sites	Old Place	Saw Mill Creek		Tower	Tufts Point	Mill Creek
		North	South			
Location	On the Kill	Marsh Creek	Marsh Creek	On the Kill	On the Kill	Marsh Creek
Latitude	40 63432N	40.61027N	40 60983N	40 61715N	40.55929N	40.52055N
Longitude	74.19620W	74.19700W	74 19736W	74.20057W	74.22065W	74.24016W
Site type	Reestablished	Reestablished	Not planted	Not planted	Existing	Existing
Vegetation	Vegetated	Vegetated	Vegetated	Unvegetated	Vegetated	Vegetated
Wave energy	High	Sheltered	Sheltered	High	High	Sheltered
Salinity (SU)	23.0	16 5	16 5	25.0	21.0	21.0
Temperature (°C)	25.1	25.7	25.7	26 9	25.9	24 1
DO (ppm)	4.30	3.27	3.27	4 20	5 69	4.59
Sediments	Sand–gravel–mud	Mud–peat	Mud–peat	Mud–peat–asphalt	Mud–peat	Mud–sand–peat

the marsh surface. During both sampling times and at low tide, two core samples were taken at each of the four stations along the transect at each site, for a total of eight core samples per site per sampling time. Sediments and biota were removed from the core and fixed in 10% buffered formalin in seawater with rose bengal added to aid in sorting and identification of the invertebrates. Prior to sorting, samples were sieved through a 0.3 mm stainless steel sieve. We used a 0.3 mm sieve to retain a portion of the smaller invertebrates such as oligochaetes that are numerically dominant in most salt marshes (Sacco et al., 1994; Levin et al., 1998). The retained sediments and invertebrates were transferred to 70% ethanol with 5% glycerin and were examined using dissecting microscopes. All organisms were removed, identified to the lowest taxonomic level practicable, and counted.

Sediment samples for the determination of mineral particle size and organic carbon content were collected synoptically with the benthic invertebrate samples using plastic cores. Care was taken to prevent disturbance of the sediment surface layer by maintaining the cores upright. The sediment cores were stored on ice in the field. Upon return to the laboratory the sediment cores were frozen and held at −20 °C until processed.

The frozen sediment cores for organic carbon analysis were thawed and the overlying water, if any, carefully removed. The upper surface layer of the sediment cores was subsampled to a depth of 1 cm using a clean stainless steel blade. These sections were freeze dried, shell fragments (carbonate) greater than 1 mm were removed with forceps, and the sediments were then homogenized. A 25 mg to 50 mg subsample was removed from each homogenized section for acidification using the technique of Yamamuro and Kayanne (1995). This method of removing the remaining carbonate was used because it minimizes the dissolution of acid-soluble organic material. The acidified samples were again freeze dried and homogenized. Aliquots of the acidified samples, ranging from 0.5 mg to 42 mg, were weighed into tin combustion cups and sealed in preparation for organic carbon analyses by flash combustion in oxygen at 1020 °C on a Carlo Erba 1108 Elemental Analyzer. Instrument calibration was maintained by performing a series of linear regressions using PACS-1 Standard Reference Material (SRM). This SRM was also analyzed at regular intervals during sample analyses for further verification of optimal instrument operation and maintenance of calibration.

Particle size distribution of the mineral fraction was determined in the top 5 cm of the sediment core using the standard wet and dry sieving procedures of Folk (1980), Galehouse (1971), and Ingram (1971).

2.4. Data analyses

A two way ANOVA was run on the log transformed abundance data of the most common benthic invertebrates to test for differences between site types (reestablished and existing) and sampling times (September and May). We realized that the power of the ANOVA to detect significant differences between site types would not be optimal due in part to the limited number of reestablished sites available for sampling (see Study sites). Also, the not planted site type was not compared to the reestablished or existing site types using ANOVA since vegetation was found at Saw Mill Creek South (not planted) at the tidal level where samples were taken.

The program CLUSTER in the PRIMER software package (Plymouth Marine Laboratory, UK) was used to produce a dendrogram of Bray–Curtis similarity coefficients by site and time (Clarke, 1993). The average abundance data of all taxa found at each site and time was transformed ($\ln[n+1]$) and used in this analysis.

3. Results

Forty one taxa were identified in the study collections (Table 2). The mean abundances of all benthic invertebrate individuals were greatest in the May samples at all sites (Table 3; Fig. 2). Overall, oligochaetes were the most abundant taxon, comprising 60% of all individuals counted and were the numerically dominant taxon at 9 of the 12 site-time combinations (Table 3; Fig. 3). Nematodes were the next most abundant taxon, comprising 20%, followed by the small tube-building fan worm, *Manayunkia aestuarina*, 14% (Table 3; Figs. 4 and 5). Together these three taxa made up approxmately 94% of all individuals in the samples. Although most of the individuals found are considered meiofauna, juveniles of larger invertebrates including the ribbed mussel, *G. demissa*, were also present. Larger amphipods, isopods, and aquatic insects were found at most sites.

The results of ANOVA (Table 4) indicate a significant ($p < 0.05$) effect of sampling time on the mean abundances of all invertebrates, oligochaetes, and nematodes. No significant differences were found in the mean abundances of all invertebrates, oligochaetes, nematodes, and *M. aestuarina* between reestablished and existing sites. There was no significant interaction between site types and sampling times. The power of the ANOVA test to detect differences was low for most comparisons and ranged from 0.606 for nematodes to 0.0503 for *M. aestuarina* for the comparisons between sampling times and from 0.129 for oligochaetes to 0.0503 for all invertebrates, nematodes, and *M. aestuarina* for the comparisons between site types. The power of the ANOVA is the probability that the test will detect the observed difference among the groups if there really is a difference. The closer the power is to 1.000 the more sensitive the test.

The dendrogram comparing Bray–Curtis coefficients between all site and time combinations indicated that the

Table 2
Invertebrate taxa collected at the six study sites in the Arthur Kill

Platyhelminthes	Unidentified
Nemertinea	Unidentified
Nematoda	Unidentified
Mollusca	Unidentified bivalve
	Anadara sp.
	Mytilus edulis
	G. demissa
	Siliqua costata
Annelida	*Eteone heteropoda*
	Eumida sanguinea
	Nereis grayi
	Drilonereis longa
	Polydora sp
	Polydora websteri
	Streblospio benedicti
	Polydora cornuta
	Pygospio elegans
	Spio filicornis
	Capitella spp
	M aestuarina
Arthopoda	*Halacarus* sp
	Scaptognathus sp.
	Unidentified Copepoda
	Leptocheila savignyi
	Cyathura polita
	Edotea triloba
	Gammarus palustris
	Gammarus mucronatus
	Elasmopus levis
	Ampithoe valida
	Jassa marmorata
	Sesarma reticulatum
	Anurida maritima
	Thysanoptera
	Ceratopogonidae
	Chironomidae larvae
	Dolichopodidae
	Tabanidae
	Muscidae

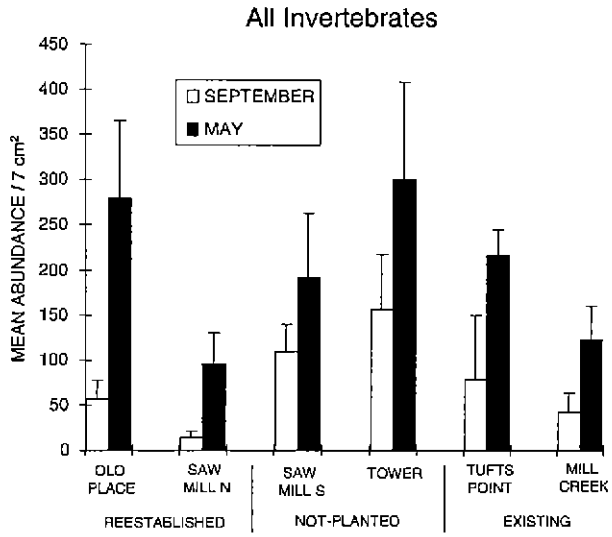


Fig. 2 Graph showing means/7 cm² (± one standard error) of the abundances of all benthic invertebrates from eight cores taken at each of six sites and two sampling times in the Arthur Kill.

greatest dissimilarity in species composition and abundances was between Saw Mill Creek North (reestablished) during September and all of the other 11 site and time combinations (Fig. 6). The similarity coefficients for the remaining 11 site and time combinations were all relatively high (between 61 and 83). Within this narrow range, Old Place (reestablished) and Tufts Point (existing) clustered together in September and again in May.

Mineral particle size analyses for the sediment samples taken during the September survey reveal muddy sediments at Saw Mill Creek South (98.3% silt and clay), Saw Mill Creek North (96.8% silt and clay), and Tufts Point (94.1% silt and clay), muddy sediments at Mill Creek with some sand (71.3% silt and clay; 28.7% sand) and sandy sediments with some mud (88.0% sand; 12.0% silt and clay) at Old Place (Table 5). Mineral grain size

Table 3
Means/7 cm² (± one standard error) of the abundances of all benthic invertebrates, Oligochaeta, Nematoda, and *M aestuarina* from eight cores taken at each of the six study sites and two sampling times in the Arthur Kill

Study sites	Old Place	Saw Mill Creek		Tower	Tufts Point	Mill Creek
		North	South			
September 1996						
All invertebrates	55.8 (21.1)	14.9 (7.7)	107.8 (30.2)	155.3 (63.0)	79.0 (69.9)	43.3 (20.7)
Oligochaeta	21.3 (12.7)	3.6 (1.7)	83.9 (22.3)	86.5 (35.1)	48 3 (45 0)	24.3 (13.6)
Nematoda	2.4 (1.5)	0	11.4 (5.7)	19.9 (8.7)	0.4 (0.4)	5 4 (4.3)
M. aestuarina	22 3 (11 8)	1 9 (1 0)	5 8 (3 5)	46.1 (22 5)	22 6 (22 6)	6 6 (3.7)
May 1997						
All invertebrates	276.1(85.7)	95.0 (34 2)	189 4 (70.5)	300 9 (106 6)	215.6 (29.3)	123.0 (36.8)
Oligochaeta	185.8 (58.3)	36.4 (12 0)	161.4 (61.3)	67.4 (24 7)	168.5 (23.7)	106.5 (31.9)
Nematoda	32.3 (15.2)	15.6 (7.6)	21.9 (10.2)	211.0 (91.6)	4.3 (1.4)	6 0 (2.9)
M. aestuarina	35 3 (11 2)	39.6 (15 2)	4 9 (1 4)	15.3 (7 8)	29 4 (12 2)	2.0 (0.7)

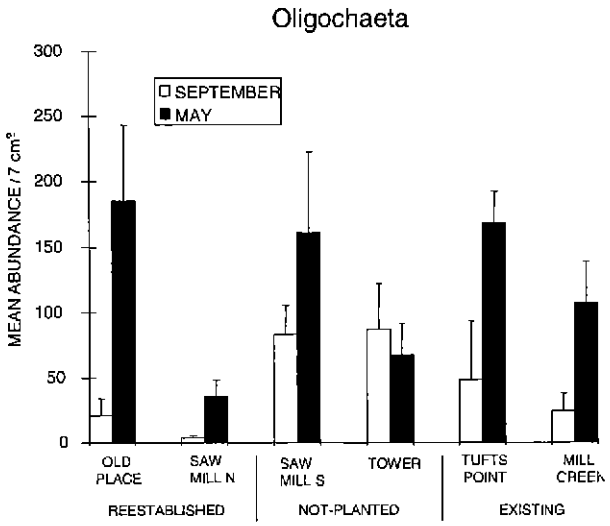


Fig 3 Graph showing means/7 cm² (± one standard error) of the abundances of Oligochaeta from eight cores taken at each of six sites and two sampling times in the Arthur Kill.

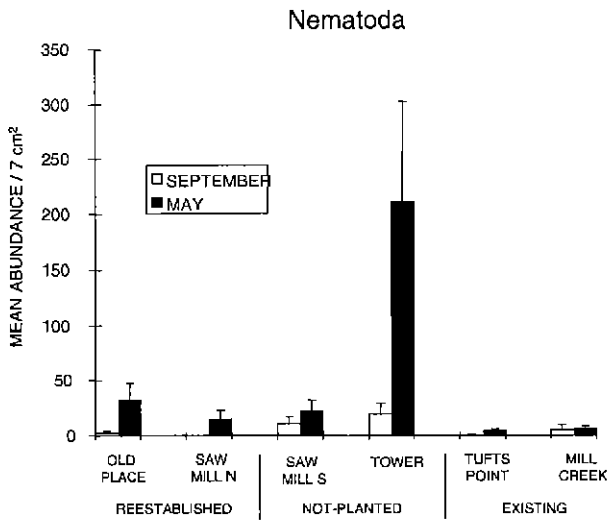


Fig 4 Graph showing means/7 cm² (± one standard error) of the abundances of Nematoda from eight cores taken at each of six sites and two sampling times in the Arthur Kill

determination could not be performed on the sediments from Tower. The sediments at this site contained tiny chunks of asphalt and visible oily residues which fouled the sieves in the mineral grain size procedure. Organic carbon content in the sediments was highest at Tower (not planted) and lowest at Old Place (reestablished) in both the September and May surveys (Table 5).

4. Discussion

Sampling time was detected as a variable influencing the abundances of the most common benthic inverte-

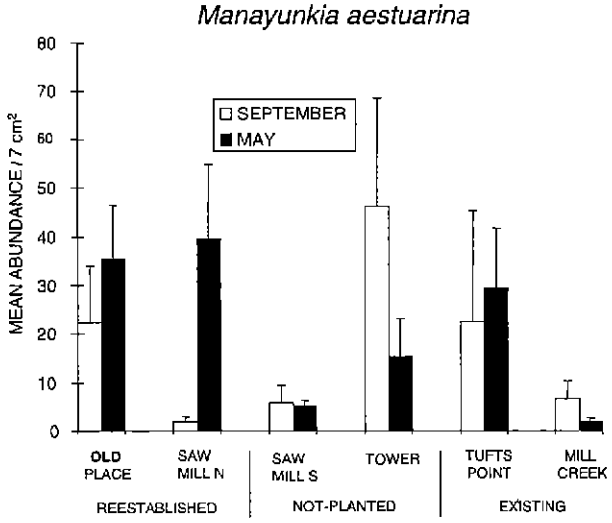


Fig. 5. Graph showing means/7 cm² (± one standard error) of the abundances of *M. aestuarina* from eight cores taken at each of six sites and two sampling times in the Arthur Kill.

Table 4
Results of a two way ANOVA ($p < 0.05$) testing the differences in mean abundances of all invertebrates, Oligochaeta, Nematoda, and *M. aestuarina* between site types (reestablished and existing) and sampling times (September and May) in the Arthur Kill

Taxa	Site type reestablished vs existing	Time. September vs May
All invertebrates	NS	May>Sept
Oligochaeta	NS	May>Sept
Nematoda	NS	May>Sept
M. aestuarina	NS	NS

NS = no significant difference.

brates at *S. alterniflora* marshes in the Arthur Kill (Tables 3 and 4, Figs. 2–5). Since the abundances of the most common benthic invertebrates were similar at reestablished and existing marsh sites (Tables 3 and 4, Figs. 2–5) and benthic invertebrate community structure was also similar between these sites (Fig. 6), recovery time is estimated at three to four years (or less) following planting of the *Spartina* seedlings. This is a preliminary estimate since benthic invertebrate sampling was conducted only at two times during the year and no sampling was conducted in the years immediately following planting. Also, the power of the ANOVA to detect differences between site types was low due in part to the low number of reestablished sites made available to us for sampling (see Study sites).

The invertebrate taxa found at the six marsh sites sampled in the Arthur Kill (Table 2) appear to be typical of invertebrates found in tidal *Spartina* marshes elsewhere. Most of these invertebrates increase in abundance in late spring and early summer with a decrease in abundance in late summer to early fall. There are several important interacting factors controlling fluctuations in

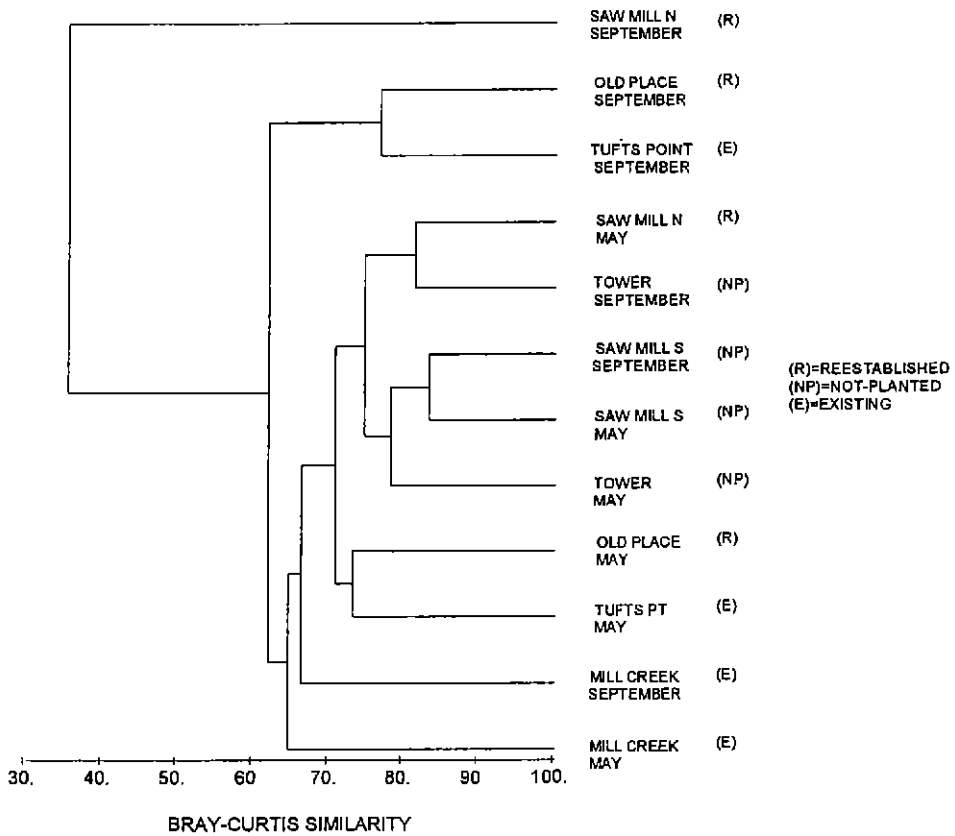


Fig. 6. Dendrogram showing the similarities in species composition and abundances calculated using the Bray–Curtis coefficient between all site and time combinations.

Table 5
Means of 4 cores (± one standard error) for percent sand (<4 phi) and percent silt and clay (>4 phi) in the top 5 cm sediment layer and percent by weight organic carbon in the top 1 cm sediment layer at each of the six study sites and two sampling times in the Arthur Kill

Study sites	Old Place	Saw Mill Creek		Tower	Tufts Point	Mill Creek
		North	South			
September 1996						
Percent sand (<4 phi)	88 00 (3.72)	3.28 (0.47)	1.68 (0.27)	ND	5 88 (2 69)	28.68 (12.30)
Percent silt and clay(>4 phi)	12 00 (3.88)	96 75 (0.46)	98.32 (0 27)	ND	94.13 (2.69)	71.32 (12 30)
September 1996						
Percent organic carbon	0.66 (0.24)	7.60 (0.79)	5 81 (0.20)	35.00 (8.71)	11.06 (1.08)	8.54 (0.44)
May 1997						
Percent organic carbon	2.98 (1.76)	7 54 (0 48)	7.38 (0 27)	20.07 (7 70)	9 71 (1.70)	13 35 (2.04)

benthic invertebrate densities. These include predation, species-specific reproductive strategies, and the availability of food (Levin et al., 1996, 1998; Minello and Zimmerman, 1992; Moy and Levin, 1991; Posey et al., 1997; Rader, 1984; Sacco et al., 1994; Sarda et al., 1994, 1995, 1998).

In a comparison of several artificially established and natural marshes in North Carolina, Levin et al. (1996) found recovery rates similar to those found in the Arthur Kill, e.g., created and natural marshes had comparable infaunal abundances and species diversity within two to three years. However, oligochaetes, a dominant taxon of natural marshes throughout the US, were present in low abundances at their created marsh sites. The spionid polychaete, *Streblospio benedicti*, was the dominant invertebrate found at the artificially established marshes. Differences in the modes of dispersal, e.g., *S. benedicti* has planktonic larvae whereas

oligochaetes brood their young, were thought to be responsible for the differences between natural and artificially established marshes (Levin et al., 1996).

In the Arthur Kill, oligochaetes were numerically dominant at most sites in September and May (Table 3). Only 17 (average of two cores) *S. benedicti* individuals were found at one station along the transect at Old Place during the September survey (Vitaliano, unpublished data). It is possible that our sampling times, early September and early May, missed the peak abundance of spionids and other short-lived marsh invertebrates. The marsh at Tufts Point (existing) was sampled in late May 1997 in conjunction with another part of this study. We found over 100 *Polydora cornuta* and 100 *Pygospio elegans* per sediment core at this time (Vitaliano, unpublished data). Unfortunately, samples were not taken at our other sites in the Arthur Kill in late May, so comparisons of the abundances of these spionids between reestablished and existing sites could not be made.

In another study of salt marshes along a 200 mile stretch of the North Carolina coast, Sacco et al. (1994) found natural marshes to have nearly twice the sediment organic matter content as artificially established marshes and this was a possible cause for higher benthic invertebrate densities in natural marshes. In the Arthur Kill study, no clear relationship was observed between benthic invertebrate densities and sediment organic matter (Tables 3 and 5).

Artificially created marshes are usually established by the placement of fill (e.g., dredge spoils) in tidal areas followed by planting with marsh grasses. Planted (reestablished) Arthur Kill marshes, however, were situated on old marsh soils. Prior to the 1990 spill, these marsh soils had established *Spartina* stands along with their associated benthic invertebrates. Although some of the more sensitive invertebrate taxa were killed by the spill (100% mortality of the ribbed mussel at some oiled sites (Hauge and Tucker, 1994)), many of the more tolerant, sediment-dwelling taxa, including oligochaetes and nematodes, probably survived the oiling and loss of vegetation. It is likely that sediment characteristics (grain size and organic matter) in most artificially created marshes, as well as the availability of taxa with brooding reproductive strategies (Levin et al., 1996; Moy and Levin, 1991; Sacco et al., 1994) differ from those at the reestablished sites studied in the Arthur Kill. Thus comparisons between artificially created marshes studied elsewhere and the reestablished marshes in the Arthur Kill must be made with caution.

Most likely, there were changes in sediment characteristics at the reestablished sites in the Arthur Kill compared to the existing sites following the oil spill and during the course of planting *S. alterniflora* seedlings. The effect of wind, waves, and currents on unvegetated sediments, as well as the disturbances caused by humans during the planting process, probably changed sediment properties and disturbed the resident benthic invertebrates to some degree at the reestablished sites. It would have been desirable to have taken sediment cores for identification and enumeration of benthic invertebrates and for measurement of sediment quality indicators prior to, during, and immediately following the planting process. Such data may have enabled us to see initial differences between the recently planted and existing sites, follow the progression of change over time, and better evaluate the effect of reestablishing S. *alterniflora* on benthic invertebrates.

Site specific differences were found among our six study sites in the Arthur Kill. These included presence of vegetation, salinity, current and wave exposure, sediment texture (Table 1), sediment grain size and organic content (Table 5), and differences in predation pressure from the common killifish, *Fundulus heteroclitus*, (Steimle, personal communication). In particular, sediments at Old Place (reestablished) were mostly sand while at Tufts Point (existing) sediments were mostly silt and clay. Sediment organic content at Tufts Point compared to Old Place was approximately 17 times greater in September 1996 and approximately 3 times greater in May 1997 (Table 5). Despite these differences, benthic invertebrate assemblage structure at Old Place (reestablished) and Tufts Point (existing) were very similar in both September and May (e.g., both sites clustered together) and both sites had similar densities of the common invertebrate taxa (Table 3; Figs. 2–6).

The similarities in the benthic invertebrate measures among all six sites studied may be due to the characteristics of intertidal estuarine invertebrates in general and more specifically, those in the highly stressed habitats studied in the Arthur Kill. These invertebrates tend to be ubiquitous and highly tolerant of rapidly changing environmental conditions. In a study of salt marshes of upper Galveston Bay, Texas, an estuary also chronically influenced by oil spills, Rozas et al. (2000) found little evidence for a negative effect of low levels of weathered petroleum hydrocarbons on sediment invertebrates. It is also possible, as was suggested earlier, that our sampling times in early September and early May in the Arthur Kill missed the peaks in abundance for many typical and possibly more sensitive marsh invertebrates and that differences between marsh sites may have been found at those times of peak abundances.

Although the reestablished marshes studied in the Arthur Kill appear to be similar to nearby existing marshes in structure of vegetation and benthic assemblages, functional similarities (e.g. production, nutrient cycling, role in food webs) are more difficult to assess (Simenstad and Thom, 1996). Oligochaetes are the numerically dominant benthic invertebrate taxa found in most intertidal salt marsh ecosystems, but little is known about their functional role or that of specific taxonomic groups of oligochaetes in salt marshes ecosystems

(Healy and Walters, 1994; Levin et al., 1996, 1998; Minello and Zimmerman, 1992; Moy and Levin, 1991; Posey et al., 1997; Rader, 1984; Sacco et al., 1994; Sarda et al., 1995).

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