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Infaunal Assemblages on Constructed Intertidal Mudflats at Jonesport, Maine (USA)

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Dredged materials have been used to construct two mudflats near Jonesport, Maine (USA). A flat at Sheep Island was constructed in 1989 and along with an adjacent reference area (REF) has been monitored for infaunal assemblage development and sediment texture since 1990. The second site, Beals Island, an example of a much older constructed flat (CF), has been monitored since 1991. Infaunal taxa richness, total numerical abundance, species composition, and diversity values were similar between the Sheep Island natural and constructed sites within two years of construction. At Beals Island, taxa richness and other diversity measures were similar between sites, however, abundance and total biomass values were lower at the constructed site. Although total biomass was also lower at the Sheep Island CF than its REF, biomass values at both constructed sites (Sheep Island and Beals Island) were within the range of values previously reported for natural flats. Published by Elsevier Science Ltd.

Keywords: benthos; mudflat; dredged material; habitat construction; community structure; Maine.

Introduction

Dredged materials have been used to construct or restore a variety of coastal habitats, including salt marshes, sea grasses, oyster beds, coastal dunes, and waterbird nesting sites (e.g., Parnell *et al.*, 1986; Yozzo *et al.*, 1996; Clarke *et al.*, 1999). Coastal habitats have also resulted incidentally from engineering projects, such as the creation of intertidal sandflats during construction of aquaculture facilities in Japan (Hosokawa, 1997). Kirby (1995) has suggested that serious consideration should be given to employing dredged materials in the construction of intertidal mudflats to help protect shorelines and replace lost habitat.

Intertidal mudflats are critical components of coastal ecosystems throughout the world, providing forage for large populations of fish, invertebrates, and birds (e.g., Quammen, 1982; Baird *et al.*, 1985; Thrush *et al.*, 1994). Extensive mudflats are found along the Atlantic coast of North America (Peterson and Peterson, 1979; Whitlach, 1982). In the state of Maine (USA), intertidal flats account for 27% of all intertidal habitat (Maine State Planning Office, 1983). Infauna associated with these habitats support demersal-feeding fish such as commercially important winter flounder (*Pleuronectes americanus*) (Wells *et al.*, 1973) and ecologically important tomcod (*Microgadus tomcod)* and Atlantic silversides (*Menidia menidia*) (Gilmurray and Daborn, 1981; Salinas, 1980). Migratory shorebirds, including short-billed dowitcher (*Limnodromus griseus*), semipalmated sandpiper (*Calidris pusilla*), and black-bellied plover (*Pluvialis squatarola*), rely on intertidal infauna for a major portion of their diet in preparation for their annual migrations (Schneider and Harrington, 1981; Matthews *et al.*, 1992). The amphipod *Corophium volutator* is particularly important for several of these species (Gratto *et al.*, 1984; Peer *et al.*, 1986). Resident shorebird species such as herring, ring-billed, and black-backed gulls (*Larus argentatutus*, *L. delawarensis*, and *L. marinus*, respectively) feed heavily on the infaunal polychaete *Nereis virens* (Ambrose, 1986). In addition, the infaunal clam *Mya arenaria* (soft-clam) and the baitworms *N. virens* (clamworm) and *Glycera dibranchiata* (bloodworm) are fished commercially (e.g., Brown, 1993).

To explore the potential for beneficially using dredged material in the construction of intertidal mudflats, the US Army Corps of Engineers New England District (CENED) deposited 53 500 m^3 of muddy dredged materials, resulting from breakwater construction and channel dredging at Jonesport, Maine, along the leeward side of Sheep Island (Fig. 1). Sediments were placed in a shallow, circular basin surrounded by rocky

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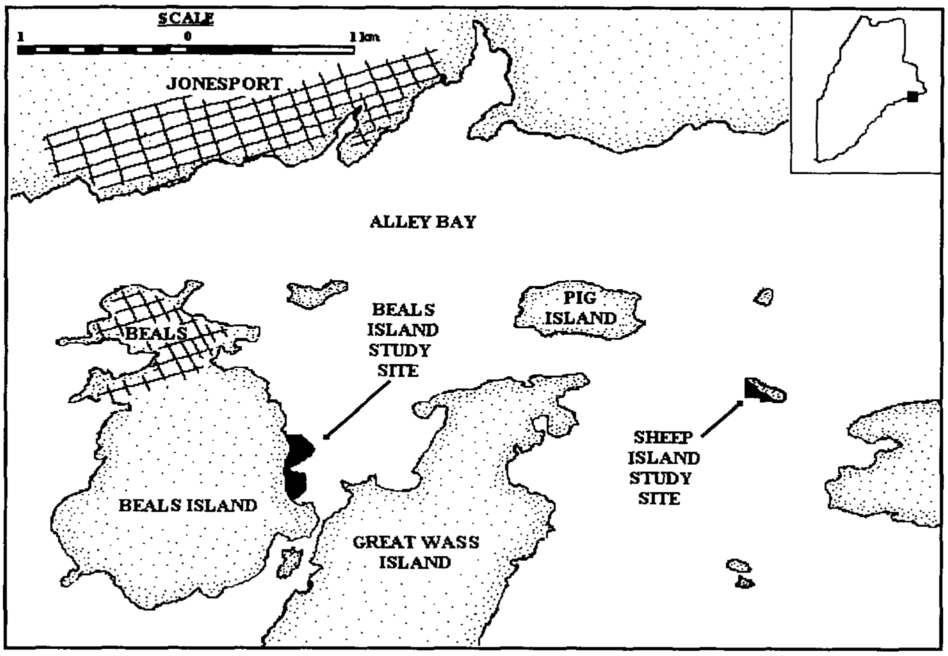

Fig. 1 Map of study area. Study sites indicated as darkened areas. Inset-location of study area in State of Maine (USA).

ledges and additional rocky material resulting from breakwater construction placed along the edges of the site to help protect and stabilize the dredged materials. Begun in January 1988 and completed in January 1989, the dredging and construction project resulted in 1.2 ha of muddy intertidal habitat (Fleming *et al.*, 1991). The constructed flat (CF) and a nearby reference area (REF) of intertidal muddy sand were monitored with respect to infaunal community structure and sediment texture in June 1990 (Flemming *et al.*, 1991). Monitoring over the next two years indicated that the constructed mudflat was rapidly colonized by benthos. While species composition became similar to that of the REF within three years, differences in relative abundances persisted (Flemming *et al.*, 1991; Ray *et al.*, 1994a,b). During these studies, an additional mudflat resulting incidentally from intertidal disposal of dredged material was identified by local residents at Beals Island (Fig. 1). The Beals Island disposal operation occurred prior to the National Environmental Protection Act of 1969 and US Army Corps of Engineers project files contained no information on the precise location of the disposal area. The area corresponding to resident descriptions was examined and the presence of stiff clays similar to dredged sediments (clay balls) below the sediment surface confirmed the area as a probable disposal site. Initial results of sampling in 1991 and 1992 (Ray *et al.*, 1994a,b) revealed subtle differences in species and biomass structure between the CF and an adjacent REF. The limited database for the two study areas (maximum of three sets of annual samples) and presence of differences in infaunal assemblage structure between sites suggested that additional sampling over a longer time period was advisable. In the present work, the original data are re-analysed and compared to results from three additional annual sampling efforts conducted over six years. The primary objective of this study is to determine if there are differences in benthic assemblage structure between constructed and natural mudflats.

Methods

Monitoring for the original project began at Sheep Island in June 1990 with a survey of infauna and sediments conducted by the CENED and Normadeau Associates at both the CF and a nearby REF of intertidal muddy, gravelly sand (Flemming *et al.*, 1991). There are no natural mudflats adjacent to Sheep Island and, although sediment texture of the REF selected for the study differed from that of the CF, it was deemed to be the most reasonable alternative. In all years after 1990, sampling occurred in August or September during low tides and was conducted by the CENED and the US Army Engineer Research and Development Center. Sheep Island was sampled in 1991, 1992, 1994, and 1998. No samples were taken in 1993 due to inclement weather. Beals Island was sampled annually between 1991 and 1994 and again in 1998. As at Sheep Island, there are no natural mudflats in the vicinity and a nearby area of intertidal muddy sand was established as the REF. Differences between the Beals Island sites include a slightly lower elevation (~10 cm) and moderate density of *Zostera marina* at the REF, while the CF had more cohesive sediments and only a sparse cover of *Z. marina*, as well as the aforementioned differences in sediments.

Situated on the leeward side of their respective islands, both study areas (Sheep Island and Beals Island) are protected from erosion by oceanic swells and storm-driven waves. Erosion due to breakup of shorefast ice may be of concern during the spring, however no sediment gouges were noted during the study. Both areas also lie outside the estuarine mixing zones of nearby estuaries (Englishman and Nassaguagus Bays) limiting their exposure to lowered salinity. Although Sheep Island is unpopulated and accessible only by boat, evidence of soft-clam digging in 1994 and 1998 indicates that it is subjected to some anthropogenic disturbance. Digging for soft-clams and bait-worms at Beals Island is sufficiently intense to result in some alteration of infaunal assemblages (e.g., Brown and Wilson, 1997). There are also a number of private residences along the shore of Alley Bay, which may contribute to disturbance of the area.

Infaunal samples were collected with a 7.5 cm diameter coring tube taken to a sediment depth of 10 cm. A maximum of 30 cores were collected at each site on each sampling date, 1990–1993; sample size was reduced to 15 cores in 1994 and 1998. Samples were spaced at least 2 m apart along three transects oriented perpendicular to the shoreline. Samples were rinsed over a 0.5-mm mesh screen, fixed in 4% formalin, and transported to the laboratory where they were transferred to 70% ethanol and stained with rose bengal solution to facilitate sorting of specimens. After staining, the samples were examined under 3x magnification and the specimens separated from the remaining sediment and detritus and stored in 70% ethanol. Specimens were then identified to the lowest practicable taxonomic level and counted. Taxonomic verification of oligochaetes was performed by Dr Robert Diaz, Virginia Institute of Marine Sciences. All other taxonomic verifications were the responsibility of the author. Wet-weight biomass was determined for major taxonomic groups (e.g., Polychaeta, Crustacea).

Differences in the level of identification for oligochaete worms were encountered between 1990 and post-1990 samples due to a change in taxonomists. The taxonomist identifying the 1990 specimens recorded all specimens as oligochaetes whereas, in subsequent samples, the presence of a number of oligochaete species was confirmed, including the two most numerically abundant taxa, *Tubificoides benedini* and *Tectadrilus gabriella*. Since attempts to locate the 1990 specimen collection were unsuccessful, it was impossible to compare directly species composition for all years. As a result, two separate analyses were performed: (1) 1990 and 1991 data were compared using the 1990 taxonomic classifications (i.e., all oligochaete taxa pooled) and (2) 1991 and later data were compared using the full range of oligochaete identifications. Differences between 1990 and post-1991 data are inferred from their relationship to the 1991 results.

Taxa richness (taxa/sample), total numerical abundance/m^2, and total wet-weight biomass/m^2 data were examined for normality and homogeneity of variance prior to Analysis of Variance (ANOVA) and were log-transformed ($\log_{10}(x+1)$) where necessary. All three parameters were tested using a repeated measures two-way ANOVA and the Bonferroni correction applied to correct for multiple comparisons (Underwood, 1997). Since a total of six comparisons was made, a p-value of $\leqslant 0.008$ was required for statistical significance. The Tukey–Kramer test was employed to test for differences between means when either main effect was significant. If the interaction factor was significant, the main effects could not be interpreted (Zar, 1996) and linear contrasts were performed to determine differences among sites and dates. Here again, the Bonferroni adjustment was used to correct for multiple comparisons. All parametric statistical tests were performed with SAS Institute's JMP (Version 3.2.2) software. Shannon–Weiner diversity (H'), Pielou's evenness (J'), and Simpson's dominance indices were calculated for pooled samples.

Assemblage structure was examined by Hierarchical Clustering, Nonmetric Multidimensional Scaling (MDS), Analysis of Similarity (ANOSIM), and Similarity Percentage (SIMPER) using the Plymouth Routines in Multivariate Ecological Research (PRIMER) statistical package. Both clustering and MDS were employed to identify groups of samples with similar species structure. ANOSIM was used to formally identify the presence of differences in assemblage structure, while SIMPER was employed to specify the importance of individual taxa to assemblage differences. Prior to analyses, the total species list was reduced by considering only those taxa that composed 1% or more of total abundance during any given sampling event or were present in 50% or more of the cores. To conform to the computational limits of the software, the number of samples was reduced by pooling samples by site and date for Clustering and MDS and by randomly selecting only 10 cores from each sample date and site for inclusion in ANOSIM and SIMPER. Abundance values were logarithmically transformed ($\log x + 1$) and Bray–Curtis similarity values calculated for all possible combinations of samples for Clustering, MDS and ANOSIM. Clustering was performed using a group averaging sorting strategy. Because of the large number of ANOSIM tests performed, $p \leqslant 0.001$ was assumed to be necessary for an individual test to be considered significant. For SIMPER analyses, abundance was fourth-root transformed as recommended by Clarke and Warwick (1994).

Nine sediment grain size samples were collected at each site with a 5-cm diameter coring tube to a sediment depth of 10 cm, in all years except 1991. Samples were taken at three randomly selected positions along each of the three sampling transects. Sediment grain size analysis was performed using a combination of wet-sieving and flotation methods (Folk, 1968; Galehouse, 1971). Sediment organic content was measured by loss on ignition. No organic content analyses were performed on the 1990 samples and none were possible in 1998 due to unavoidable delays in sample shipment.

Results

Sheep Island

Ninety taxa were collected at the Sheep Island sites (Table 1): 64 at the constructed intertidal flat, 81 at the REF. Species composition was similar between sites; 49 of the 90 taxa were present at both. Twenty taxa constituted 1% or more of numerical abundance during any single collection period or were present in 50% or more of the samples; none of the 20 taxa was found exclusively at either site (Table 1). The 11 most abundant taxa included (in order of dominance) the amphipod *C. volutator*, the oligochaetes *T. gabriella* and *T. benedini*, the polychaetes *Streblospio benedicti* and *Capitella* sp., the gastropod *Hydrobia* sp., the polychaetes *Polydora ligni* and *Exogene hebes*, the amphipod *Gammarus oceanicus*, and the polychaetes *Clymenella torquata* and *Fabricia sabella*. The relative dominance of individual taxa varied substantially among sites and collection dates. For instance, although both *C. volutator* and *S. benedicti* were among the most abundant species overall, neither occurred in abundance at either site until 1991 or 1992 (respectively). Likewise, the amphipods *C. bonelli* and *Phoxocephalus holbolli* and the polychaete *E. hebes* were found in very high abundances at both sites in 1992 but not thereafter. The polychaete *Pygospio elegans* was very abundant in 1990 at both sites, but declined in importance for the remainder of the study, while the gastropod *Hydrobia* sp. was absent through 1992, but abundant at both sites in 1994 and 1998.

Both taxa richness and total abundance (no. animals/m^2) differed significantly ($p < 0.008$) between the Sheep Island constructed flat and REFs over time (Table 2). In both cases, linear contrasts indicated values were higher at the constructed intertidal flat than the REF in 1990, but not afterwards (Fig. 2). Although ANOVA of the biomass data indicated no significant interaction between sites and sample dates ($p > 0.008$), the power of the estimate for the interaction factor was too low to reliably interpret the result (Table 2). Tukey test results for the main factors indicated that REF biomass was greater than that of the CF and that 1994 values were higher than 1990 values (Fig. 2).

The distribution of biomass among major taxonomic groups differed between sites over time (Table 3). Molluscs dominated biomass at both sites, but almost always constituted a greater proportion of biomass at the REF than the CF. The exception was 1991, when molluscs composed 57% of total biomass at the CF.

TABLE 1

Sheep Island summary biological data.[a]

Taxa	Total	Constructed flat					Reference area				
		1990[b]	1991	1992	1994	1998	1990[b]	1991	1992	1994	1998
Oligochaeta		5.74	–	–	–	–	66.90	–	–	–	–
Tubificoides benedini	14.6 (58)	–	0.81	0.11	33.06	19.73	–	1.26	43.81	26.90	17.34
Tectidrilus gabriella	21.2 (61)	–	11.99	1.96	19.04	17.04	–	26.02	21.57	20.30	17.31
Enchytraeidae	0.9 (13)	–	–	–	0.63	0.85	–	–	0.87	1.07	1.54
Capitella sp.	7.3 (69)	24.03	0.51	1.34	11.12	9.97	7.57	1.46	12.66	9.58	10.36
Clymenella torquata	1.5 (11)	–	1.92	–	1.15	0.59	0.63	3.60	0.96	0.91	0.44
Fabricia sabella	1.5 (16)	–	–	–	3.10	1.52	10.37	–	4.27	2.34	1.50
Polydora ligni	3.3 (75)	4.14	1.66	3.17	2.61	3.44	1.00	3.72	1.17	3.42	3.20
Polydora quadrilobata	0.5 (25)	22.56	–	0.16	0.49	0.78	1.65	0.24	0.21	0.67	0.81
Pygospio elegans	0.3 (11)	37.25	1.85	0.02	0.19	0.13	7.19	2.68	0.12	0.18	0.10
Streblospio benedicti	7.4 (60)	–	–	2.47	8.79	10.28	–	–	7.77	8.40	10.38
Exogene hebes	2.5 (31)	0.13	31.76	0.53	2.72	1.46	0.50	32.42	2.54	2.15	1.15
Nereis virens	1.3 (73)	0.80	1.41	1.11	1.67	1.50	0.03	1.10	1.25	1.72	1.46
Ampelisca vadorum	0.3 (15)	–	1.34	0.02	0.12	0.12	0.02	1.95	0.06	0.15	0.10
Corophium volutator	26.7 (64)	0.80	7.73	83.73	6.76	14.24	0.02	1.22	0.21	8.30	13.83
Corophium bonelli	1.4 (5)	–	16.29	–	–	0.03	–	7.43	–	0.02	0.03
Gammarus oceanicus	2.0 (50)	0.13	0.38	3.23	0.48	5.37	0.38	0.12	0.29	0.88	7.50
Phoxocephalus holbolli	0.9 (19)	0.27	7.03	0.07	0.33	0.21	0.08	6.64	0.21	0.31	0.16
Littorina littorea	0.8 (21)	–	–	–	0.98	1.93	0.20	–	0.04	2.12	1.46
Hydrobia sp.	3.5 (25)	–	–	–	3.79	5.66	–	–	–	5.65	5.33
Taxa (Total)[c]	90	22	33	27	25	29	28	29	31	23	33
Diversity (H')[d]		1.62	2.57	1.66	2.37	2.17	1.28	2.69	2.34	2.36	2.37
Evenness (J')[e]		0.54	0.73	0.50	0.74	0.64	0.34	0.80	0.68	0.75	0.69
Dominance (Simpson)[f]		0.26	0.13	0.44	0.16	0.17	0.48	0.11	0.17	0.17	0.19
Samples (n)	205	15	30	30	15	15	15	30	30	15	10

[a] Relative abundance (%) of the dominant taxa. Percent occurrence in parentheses.
[b] Data calculated from Flemming *et al.* (1991).
[c] Total taxa.
[d] Shannon–Weiner Diversity Index (H').
[e] Pielou's evenness Index (J').
[f] Simpson's Dominance Index (D).

TABLE 2

Sheep Island analysis of variance results.[a]

Source	DF	Sum Sq.	*F*-ratio	*p*-value
Sheep Island taxa richness				
Site	1	38.5333	0.4679	0.5309
Year	4	187.8952	0.5301	0.7231
Site × Year	4	354.4571	9.5713	< 0.0001
Error	200	1851.6667	6.5146	
Sheep Island total abundance				
Site	1	4.1234	2.7053	0.1743
Year	4	5.2992	0.8065	0.5800
Site × Year	4	6.5704	11.4846	< 0.0001
Error	200	28.6052	11.0781	
Sheep Island total biomass				
Site	1	2.4295	13.6463	0.0057
Year	3	6.5773	22.1020	0.0151
Site × Year	3	0.2976	0.1524	0.9281 (0.08)[b]
Error	162	105.4706	2.0963	
Beals Island taxa richness				
Site	1	6.9586	0.7006	0.4037
Year	4	1923.4351	48.4153	< 0.0001
Site × Year	4	143.2451	3.6057	0.0075
Error	179	1777.8202	9.9320	
Beals Island total abundance				
Site	1	6.2128	83.5578	< 0.0001
Year	4	11.7915	39.6469	< 0.0001
Site × Year	4	1.0169	3.4194	0.0101 (0.85)[a]
Error	179	13.3092	0.0744	
Beals Island total biomass				
Site	1	3.2452	20.2734	< 0.0001
Year	4	10.6248	16.5937	< 0.0001
Site × Year	4	8.8021	13.7471	< 0.0001
Error	178	28.4923	0.1601	

[a] DF = Degrees of freedom; Sum Sq. = Sums of squares.

[b] Values in parentheses are *a posteriori* estimates of statistical power.

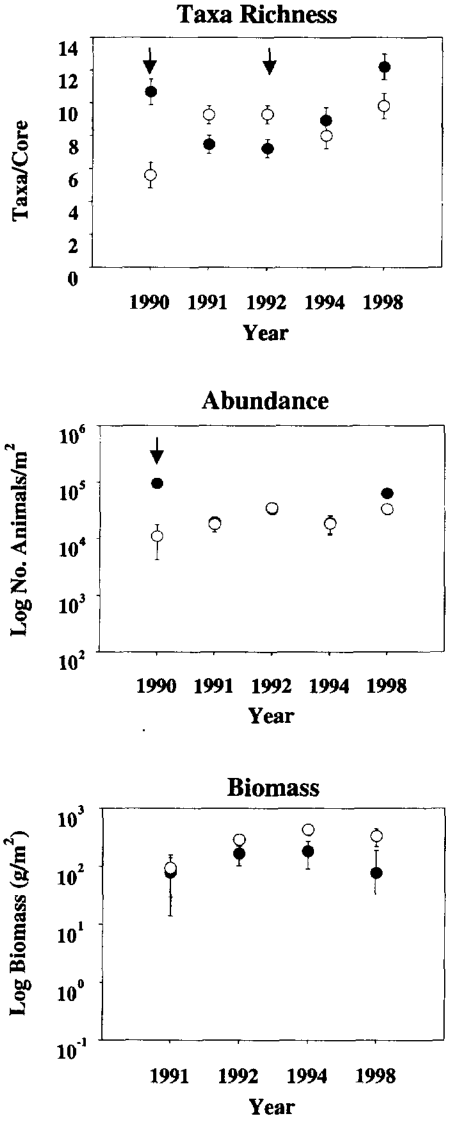

Fig. 2 Sheep Island taxa richness (Taxa/Core), Total Abundance (No. animals/m^2), and total biomass (g/m^2). Mean ± S.E. Filled symbols indicate the Constructed flat and open symbols indicate the Reference area. Arrows indicate where linear contrasts detected significant differences ($p < 0.008$) between means.

Polychaete biomass also composed more of REF biomass than CF biomass with the single exception of 1994, when values were similar at both sites. Crustaceans made up a higher proportion of biomass at the CF than the REF in all years except 1991, and oligochaetes always constituted a greater proportion of biomass at the CF than the REF.

Species diversity (H') and evenness (J') values at the REF were equal to or greater than CF values in all years except 1990 (Table 1). Low diversity at the REF in 1990 appears to be related to high relative dominance by (Table 1).

Clustering of the 1990–1991 species data produced three clusters at the 63% similarity level; the 1990 sites clustered as distinct groups, while in 1991 both sites formed a single cluster (Fig. 3). MDS of the same data produced similar patterns. Clustering of the 1991–1998 data also produced three clusters at approximately the 60% similarity level based on either site or year of sampling (Fig. 3). The first cluster was composed of the 1991 samples, the second by the remaining CF samples, and the third by the remaining REF samples. MDS of the 1991–1998 data yielded similar patterns (Fig. 3).

ANOSIM detected significant differences ($p < 0.001$) for global tests for sites in both the 1990–1991 and 1991–1998 data, but only among years for the 1991–1998 comparisons (Table 4). Pair-wise comparisons of the 1990–1991 data revealed significant differences ($p \leqslant 0.001$) only between sites in 1990 ($r = 0.480$). A similar result was found among the 1991–1998 pair-wise comparisons, where significant differences ($p < 0.001$) were found between all sites except in 1991. r-values for these comparisons ranged from 0.634 to 0.957 (Table 4).

SIMPER results were consistent with the taxonomic composition, clustering, MDS, and ANOSIM comparisons. In 1990, the constructed intertidal flat and REFs were distinguished primarily by higher densities of oligochaetes, the polychaetes *F. sabella*, *P. elegans*, and the amphipod *G. oceanicus* at the REF, and *P. quadrilobata* and *P. elegans* at the CF (Table 5). After 1990, oligochaetes, specifically *T. gabriella*, contributed greatly to

TABLE 3

Taxonomic distribution of biomass with comparisons to other New England Mudflats.[a]

Area	Site/Year	Annelid[b]	Polychaete	Oligochaete	Crustacea	Mollusc	Misc.
Sheep Island	CF 1991	29.5	28.6	0.9	13.2	57.3	0
Sheep Island	CF 1992	30.1	30.1	0.0	17.0	52.9	0
Sheep Island	CF 1994	4.6	4.6	0.0	4.6	90.8	0
Sheep Island	CF 1998	30.6	19.7	10.9	40.6	28.8	0
Sheep Island	REF 1991	70.3	68.2	2.1	20.3	9.4	0
Sheep Island	REF 1992	27.8	23.6	4.2	0.1	72.1	0
Sheep Island	REF 1994	6.5	1.9	4.6	0.2	93.2	0
Sheep Island	REF 1998	39.7	11.0	28.7	2.6	53.5	4.2
Beals Island	CF 1991	91.6	86.7	4.9	8.4	0	0
Beals Island	CF 1992	84.3	65.9	18.4	15.5	0.1	0
Beals Island	CF 1993	83.6	76.9	6.7	12.1	4.2	0
Beals Island	CF 1994	81.4	60.9	20.5	16.2	2.6	0
Beals Island	CF 1998	57.2	47.7	9.5	6.3	1.8	34.7
Beals Island	REF 1991	90.9	79.4	11.5	9.1	0	0
Beals Island	REF 1992	94.2	66.3	24.9	5.2	0.6	0
Beals Island	REF 1993	96.0	70.6	25.4	3.5	0.5	0
Beals Island	REF 1994	96.4	75.6	20.8	3.5	0.2	0
Beals Island	REF 1998	79.5	55.7	23.8	4.1	8.8	7.8
Maine[c]							
Maine[c]		21.5	–	–	1.0	78.0	0
New Hamshire[c]		87.0	–	–	4.3	8.7	0
Massachusetts[c]		91.9	–	–	0.0	8.1	0
Massachusetts[c]		83.3	–	–	0.0	16.7	0
Massachusetts[c]		31.9	–	–	67.0	1.1	0
Connecticut[c]		96.1	–	–	1.7	1.7	0

[a] Values represent percent composition. CF = Constructed mudflat; REF = Reference area.

[b] Sum of polychaete and oligochaete values.

[c] Data from Bowen *et al.* (1989).

overall site dissimilarity and were always more abundant at the REF. *T. benedini* contributed the most to dissimilarity in 1992 and was generally more abundant at the REF. *C. volutator* was always most abundant at the CF, while *P. quadrilobata* was most abundant there in 1990, again in 1998. The remaining dominant taxa were inconsistent in their temporal distributions, i.e., they would be most abundant at the CF one year and at the REF in another. For instance, the polychaete *E. hebes* was most abundant at the CF in 1991, but in previous and subsequent years it was most abundant at the REF. *Capitella* sp. was most abundant at the constructed mudflat in 1990 and 1994, but was most abundant at the REF in 1992. Likewise, *S. benedicti* was more numerous at the REF than the CF in 1992, but the opposite was true in 1994 and 1998.

Sediments at the Sheep Island constructed mudflat were composed primarily of silts and clays with relatively little (<25%) sand, while the REF had mostly sands and gravel with less than 30% silts and clays (Fig. 4). Sediment texture appeared to coarsen at both sites in 1994, but was similar to previous years again in 1998. Sediment organic content at the Sheep Island CF ranged from 4.2% to 4.9%, while that of the REF ranged from 1.1% to 2.5%.

Beals Island

Seventy-eight taxa were collected at the Beals Island sites between 1991 and 1998 (Table 6): 69 taxa were collected at the CF, 65 at the REF. Twenty-six taxa were classified as dominants, none of which were found exclusively at either site. The ten most abundant taxa included (in declining order of abundance) *T. benedini*, *E. hebes*, *S. benedicti*, *T. gabriella*, *Capitella* sp., *Ampelisca vadorum*, *E. verugera*, *G. oceanicus*, *P. holbolli*, and *P. quadrilobata*. *T. benedini*, *S. benedicti and G. oceanicus* were always most abundant at the REF, while *T. gabriella* and *A. vadorum* were always most abundant at the CF. *E. hebes*, *Capitella* sp. and *P. quadrilobata* were most abundant at the CF in 1991, but were more abundant at the REF in ensuing samples. The opposite was true for *P. holbolli*. *E. verugera* was found in exceptionally high densities in 1992.

ANOVA of Beals Island infaunal taxa richness data indicated that sites differed significantly ($p < 0.008$) among years (Table 2). Linear contrasts of the interaction means showed that CF values differed significantly ($p < 0.001$) from reference values only in 1992, when taxa richness was highest at the CF (Fig. 5). Total numerical abundance differed among sites and over time, but the site by date interaction was not significant ($p > 0.008$) (Table 2). Tukey test results for site and year comparisons indicated that abundance was higher at the REF than the CF and that abundance differed annually only between the highest (1998) and lowest values (1991) (Fig. 5). Total biomass differed significantly ($p < 0.008$) between sites among years (Table 2) and linear contrasts

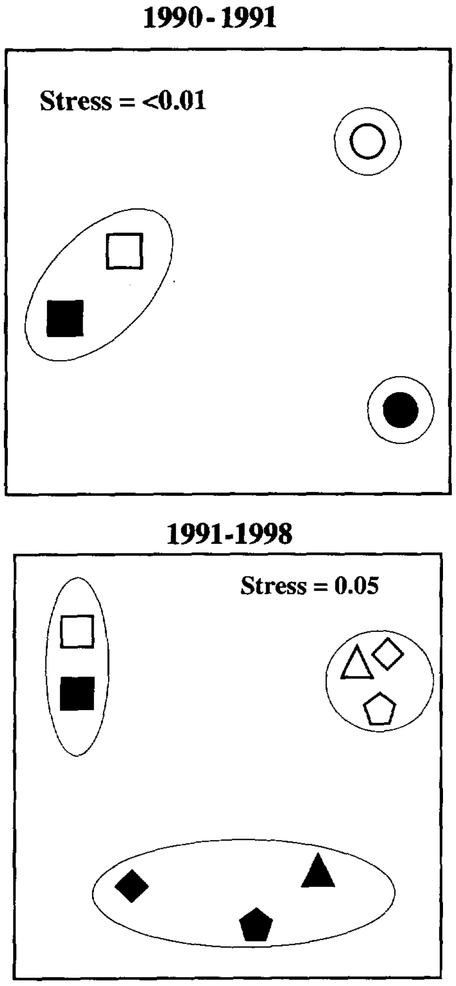

Fig. 3 Clustering and MDS results for comparison of Sheep Island 1990–1991 and 1991–1998 data. Filled symbols represent Constructed flat samples and open symbols represent Reference area samples. Symbol shapes indicate year: Circle = 1990, Square = 1991, Diamond = 1992, Polygon = 1994, and Triangle = 1998. Circled groups of symbols indicate clustering results.

TABLE 5

Similarity Percentage (SIMPER) results for Sheep Island.[a]

Year	1990	1991	1992	1994	1998
Average dissimilarity	60.42	62.08	72.41	62.51	53.34
Oligochaeta	(*27.76*^{c})	(*12.42*^{c})	–	–	–
Tectidrilus gabriella	–	*13.38*^{c}	*5.65*^{c}	*14.18*^{c}	*11.99*^{c}
Corophium volutator	1.90	*12.77*^{b}	*18.58*^{b}	*12.96*^{b}	*7.75*^{b}
Exogene hebes	*5.28*^{c}	*12.13*^{b}	3.82	1.11	2.87
Phoxocephalus holbolli	3.78	*7.99*^{b}	2.28	–	–
Polydora ligni	*7.06*^{c}	*7.50*^{c}	4.34	*7.16*^{c}	4.94
Fabricia sabella	*15.80*^{c}	–	*6.36*^{c}	0.87	*5.00*^{c}
Pygospio elegans	*9.27*^{b}	5.86	0.51	–	–
Clymenella torquata	3.27	*6.68*^{c}	–	–	–
Corophium bonelli	–	*5.42*^{b}	–	–	–
Ampelisca vadorum	–	*5.28*^{b}	1.23	1.27	–
Nereis virens	0.66	*5.27*^{b}	3.74	4.08	3.99
Gammarus oceanicus	*7.95*^{c}	4.58	*7.61*^{b}	*5.35*^{c}	4.94
Capitella sp.	*6.75*^{c}	4.57	*8.43*^{c}	*6.59*^{b}	3.99
Tubificoides benedini	–	4.19	*16.04*^{c}	*10.04*^{c}	4.52
Polydora quadrilobata	*9.50*^{b}	2.83	2.01	1.34	*5.38*^{b}
Hydrobia sp.	–	–	–	*11.53*^{b}	–
Streblospio benedicti	–	–	*6.54*^{c}	*6.38*^{b}	*11.18*^{b}
Littorina littorea	–	–	–	4.63	–
Enchytraeidae	–	–	1.16	1.60	4.48

[a] Values in italic are the taxa contributing 5% to dissimilarity for a comparison. Superscripts indicate where abundances were highest (^{b} Constructed flat; ^{c} Reference); ( ) indicates where oligochaetes were treated as single taxon.

of interaction means indicated that REF biomass was significantly higher ($p < 0.001$) than that of the CF in all years except 1991 (Fig. 5).

Biomass structure differed consistently between sites over time (Table 3). Polychaetes constituted the majority of biomass at both sites, however, total polychaete biomass was always several times greater at the REF than the CF. Oligochaetes, the second most important taxon, consistently made up a higher proportion of biomass at the constructed site than at the REF. Crustacean biomass distribution varied among years with CF biomass being higher than REF values in 1991 and 1992, but there was little or no difference in values afterward. Molluscs and miscellaneous taxa contributed little to biomass except in 1998 when both were relatively high at the REF.

Species diversity (H') was greater at the REF than the CF on all sampling dates except 1991; there was virtually no difference between sites at this time (Table 6). Evenness (J') was similar between sites throughout the study as was relative dominance (Table 6).

Clustering of the Beals Island data produced results similar to that found for Sheep Island. There were four

TABLE 4

Two-way crossed Analysis of Similarity (ANOSIM) results for Sheep Island and Beals Island data.[a]

	Sheep Island (1990–1991) Site $r = 0.653^{*}$ Year $r = 0.330$ Pairwise r	Sheep Island (1991–1998) Site $r = 0.634^{*}$ Year $r = 0.560^{*}$ Pairwise r	Beals Island (1991–1998) Site $r = 0.679^{*}$ Year $r = 0.591^{*}$ Pairwise r
CF90-REF90	0.480^{*}	No test	No test
CF91-REF91	0.180	0.205	0.479
CF92-REF92	No test	0.957^{*}	0.909^{*}
CF93-REF93	No test	0.742^{*}	0.757^{*}
CF94-REF94	No test	No test	0.629^{*}
CF98-REF98	No test	0.634^{*}	0.619^{*}

[a] r-value is Global r for ANOSIM test calculated for all sites and years. Pairwise r is the r-value for selected site by year combinations. CF = Constructed mudflat, REF = Reference area. Numbers = years (1990–1998).

$^{*}p \leqslant 0.001$.

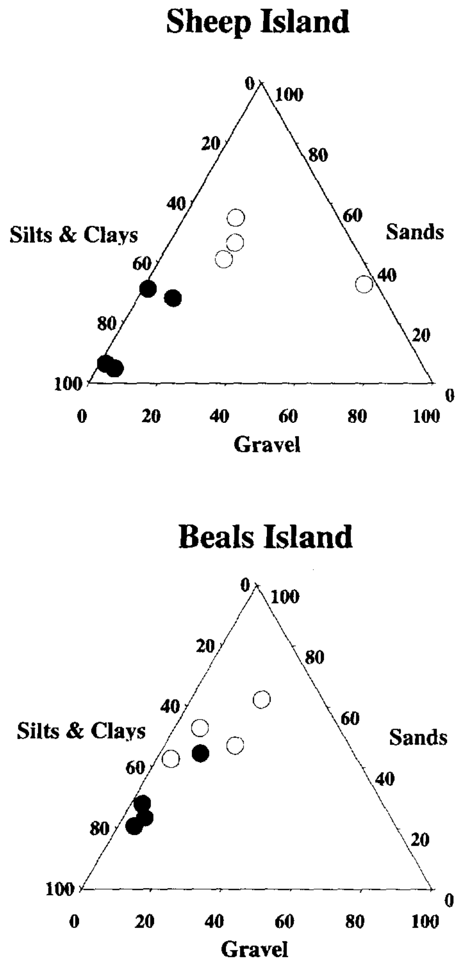

Fig. 4 Sediment texture results. Filled symbols = Constructed flat; Open symbols = Reference area.

clusters at the 63% level of similarity; the first cluster was made up of the 1991 samples and the second was composed of the remaining CF samples (Fig. 6). The third cluster contained only the 1992 REF sample, while the fourth cluster was composed of the remaining REF samples. MDS of the Beals Island data produced similar patterns (Fig. 6).

ANOSIM detected significant differences ($p < 0.001$) between both sites ($r = 0.679$), years ($r = 0.591$), and all pair-wise comparisons except 1991 (Table 4). As might be expected, SIMPER results corresponded closely with the patterns detected in comparisons of relative abundance (Table 6). *T. benedini* and *Capitella* sp. contributed greatly to dissimilarity and were found in highest abundance at the REF. Taxa with high abundances at the CF included *T. gabriella* and *A. vadorum*. *E. verugera* and *F. sabella* both contributed to dissimilarity, but only during single sampling periods (1992 and 1994, respectively). As at Sheep Island, the distribution of many taxa varied among years. For instance, *E. hebes* contributed greatly to dissimilarity and was generally most abundant at the REF, but was absent in 1992 and most abundant at the CF in 1990. Both *P. elegans* and *S. benedicti* were most abundant at the REF in 1990, but were more abundant at the CF in subsequent years. Taxa such as *E. verugera*, *F. sabella*, *Spio setosa*, and *Hydrobia* sp. contributed more than 5% to dissimilarity, but only during individual years.

Beals Island constructed intertidal flat sediments were finer-grained than those of the corresponding REF, however, differences between sites were less pronounced than at Sheep Island (Fig. 4). Beals Island CF sediments contained 75% silts and clays, while REF sediments had 30–50% fines. The same coarsening of sediments found in 1994 at Sheep Island was also observed at Beals Island. In 1998, sediment texture was again similar to previous years. Sediment organic contents ranged from 3.0% to 5.2% at the CF, 1.9–2.7% at the REF (see Table 7).

Discussion

Dredged materials are a valuable resource in the restoration, enhancement, and *de novo* construction of coastal habitats in the United States (Parnell *et al.*, 1986; Yozzo *et al.*, 1996; Clarke *et al.*, 1999). An average of 242 million cubic meters of sediment are dredged annually from US waterways (USACE, 1999), of which approximately 30% is used for beneficial uses such as habitat development or commercial fill (Landin, 1997). The three most common habitat applications are salt marsh creation, sandy beach nourishment, and bird island construction (USACE, 1987). Use of dredged materials in the construction of other coastal habitats, such as oyster reefs and seagrass beds, has occurred primarily on an experimental basis (e.g., Clarke *et al.*, 1999).

The relative success of habitat construction efforts has depended largely on the original purpose of the project (Streever, in press). Where the purpose has been to replace ecological functions, the rate and extent to which functions develop have varied widely, with some being realized quickly, others very slowly (e.g., Craft *et al.*, 1999). Success in the development of infaunal assemblages has varied among habitats and individual projects. A number of authors have indicated that infaunal assemblages quickly develop on constructed marsh sediments (e.g., Cammen, 1976; LaSalle *et al.*,1991; Sacco *et al.*, 1994), however, it may take decades before they are similar to those of natural marshes (Levin *et al.*, 1996; Posey *et al.*,1997; Craft *et al.*, 1999). Conversely, it has been argued that inherent differences between natural and constructed marshes may prevent assemblages from ever becoming identical (e.g., Moy and Levin, 1991). Streever (in press) reported that a meta-analysis of constructed salt marsh studies indicated persistent differences in infaunal assemblage structure and no indication of a predictable trajectory to assemblage development.

Studies of development patterns for infaunal assemblages in other constructed habitats have been far less equivocal. Homziak *et al.* (1982) reported that infauna of transplanted eelgrass (*Z. marina*) beds are similar to

TABLE 6
Beals Island summary biological data.[a]

	Total	Constructed flat					Reference area				
		1991	1992	1993	1994	1998	1991	1992	1993	1994	1998
Tubificoides benedini	17.8 (82)	13.05	4.66	0.88	5.12	11.78	22.28	25.07	15.85	17.96	18.94
Tectidrilus gabriella	12.5 (83)	19.10	30.28	30.02	24.35	17.46	9.64	0.68	3.72	8.54	4.19
Tubificoides netheroides	1.2 (44)	1.27	1.25	1.75	0.40	3.16	1.61	0.31	1.54	0.62	1.64
Tubificoides sp.	0.2 (21)	0.91	1.12	2.50	0.80	–	11.25	–	0.17	0.23	–
Capitella sp.	9.2 (68)	5.09	1.80	0.77	1.25	12.83	1.95	11.31	9.11	5.41	10.42
Heteromastus filiformis	0.4 (51)	1.11	0.83	0.44	0.51	0.44	0.84	0.61	0.58	0.90	0.44
Clymenella torquata	0.8 (48)	3.71	1.65	0.44	1.20	0.88	4.62	1.39	0.64	1.06	1.24
Fabricia sabella	1.8 (25)	–	0.63	0.44	0.00	0.33	–	1.10	0.48	0.18	5.21
Polydora ligni	1.4 (77)	2.68	2.15	3.65	4.59	1.32	1.68	0.49	0.86	1.82	0.36
Polydora quadrilobata	2.4 (61)	5.98	3.83	0.82	0.50	6.10	5.96	0.92	1.06	2.52	3.28
Pygospio elegans	1.0 (30)	3.77	5.41	7.13	–	–	5.89	–	1.21	–	–
Spio setosa	0.3 (10)	–	–	–	5.06	0.22	–	–	0.17	–	–
Streblospio benedicti	16.8 (92)	3.13	12.29	7.60	8.26	3.57	5.74	14.09	15.46	24.99	10.36
Phylloduce arenae	0.2 (21)	–	–	–	0.40	1.89	–	–	–	0.18	0.35
Exogene hebes	11.8 (56)	7.64	–	2.25	4.69	4.14	5.32	–	35.76	20.09	19.07
Exogene verugera	5.3 (16)	–	3.06	–	–	–	–	27.45	–	–	–
Nereis virens	1.1 (68)	1.11	2.30	2.77	4.53	2.60	0.80	0.41	0.79	0.37	0.25
Ampelisca vadorum	4.3 (75)	12.52	8.90	10.95	15.73	8.34	5.73	0.34	1.36	1.38	2.57
Corophium volutator	0.3 (21)	0.95	1.36	2.82	–	1.12	–	0.19	0.17	–	0.36
Gammarus oceanicus	4.0 (64)	0.64	0.99	0.99	4.86	3.46	0.98	9.26	2.44	6.52	2.60
Phoxocephalus holbolli	2.6 (72)	6.49	6.33	8.09	6.25	5.17	8.16	0.66	1.56	0.69	1.14
Edotea montosa	1.1 (58)	1.06	0.71	1.27	1.52	1.96	1.25	1.30	1.70	1.87	1.27
Scottolana canadensis	0.3 (29)	0.64	3.47	0.80	1.40	0.80	0.54	0.25	0.17	–	–
Thalassomya sp.	0.5 (39)	–	0.40	0.44	0.40	0.34	1.07	1.06	0.39	0.49	1.10
Mya arenaria	0.1 (4)	1.06	0.40	–	–	0.22	–	–	–	–	0.16
Hydrobia sp.	1.1 (36)	–	–	2.15	2.20	0.40	–	–	0.19	0.41	3.87
Nemertea	0.1 (13)	–	0.40	–	0.40	0.33	0.54	0.26	–	0.25	0.21
Taxa (Total)[b]	78	26	33	37	34	43	26	32	43	29	43
Diversity (*H*′)[c]		2.75	2.66	2.71	2.68	2.91	2.68	2.10	2.226	2.27	2.66
Evenness (*J*′)[d]		0.83	0.74	0.75	0.76	0.78	0.81	0.60	0.60	0.68	0.71
Dominance (Simpson)[e]		0.09	0.13	0.13	0.11	0.08	0.10	0.18	0.19	0.15	0.11
Samples (*n*)	189	20	30	15	15	15	19	30	15	15	15

[a] Relative abundance (%) of the dominant taxa. Percent occurrence in parentheses.
[b] Total taxa.
[c] Shannon–Weiner Diversity Index (*H*′).
[d] Pielou's Evenness Index (*J*′).
[e] Simpson's Dominance Index (*D*).

those of natural beds less than a year after transplantation. Infaunal assemblages of nourished high-energy sandy beaches are generally similar to natural beaches within several months (see reviews by Nelson, 1985, 1993; Hackney *et al.*, 1996). For instance, Van Dolah *et al.* (1994) and Jutte *et al.* (1999a,b) reported re-establishment of beach infauna at South Carolina nourished beaches in 3–6 months. Slower recovery rates reported by Reilly and Bellis (1983) and Rakocinski *et al.* (1996) were most likely due to the presence of substantial amounts of silts and clays in the nourishment materials.

The importance of infauna to the ecology of intertidal mudflats makes establishment of natural assemblages on CFs of the utmost importance. As previously noted, mudflat infauna provide forage for commercially and ecologically important fish species and migratory and resident shorebirds, and support soft-clam and baitworm fisheries of direct importance to local economies (Peterson and Peterson, 1979; Whitlach, 1982; Brown, 1993).

Previous studies of benthic colonization of constructed, restored, or other 'new' intertidal flats have yielded inconsistent results. Turk *et al.* (1980) monitored infauna and sediments at three mudflats resulting from siltation after causeway construction in the Bay of Fundy. Examined over a four-year period and varying in age from 6 to 10 years old, none of the three sites had infaunal abundances equivalent to natural mudflats. These results were attributed primarily to the continuing high rates of siltation occurring at the new flats as well as sediment differences. Evans *et al.* (1998) examined the benthic communities of a restored mudflat in Tees Estuary (England) and found that three years after the restoration, abundances of taxa important to shorebirds (e.g., *N. diversicolor* and *C. volutator*) were still below those of undisturbed flats. Wilcox (1986) has also noted that shorebird usage of newly restored mudflats in Upper Newport Bay (California) was less than natural mudflats, presumably due to lower densities of their benthic invertebrate prey. In contrast, Lee *et al.* (1997, 1998) measured sediment properties, microbial respiration, and biomass of bacteria and macrobenthos at a number of natural and constructed intertidal sand flats in Hiroshima Bay, Japan. CF sediments generally had

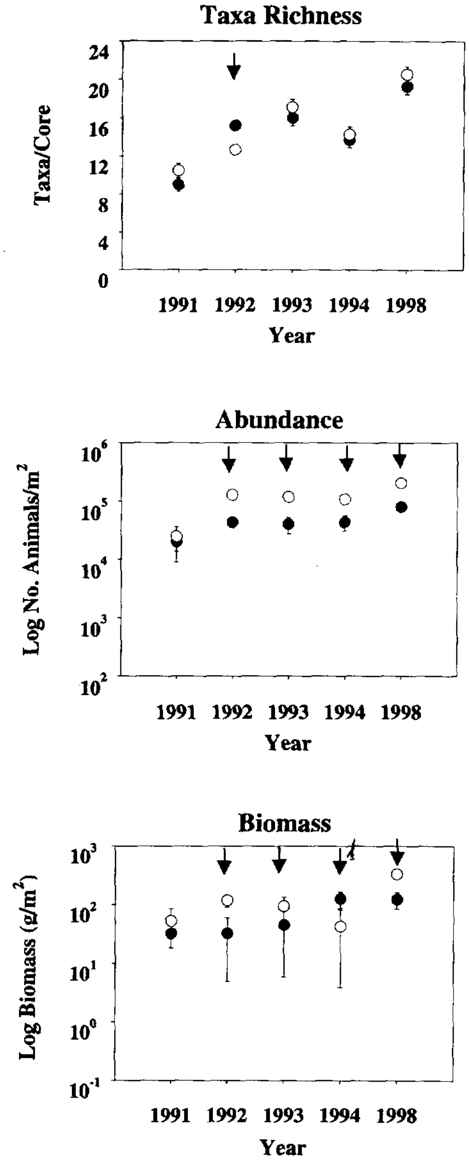

Fig. 5 Beals Island Taxa Richness (Taxa/Core), Abundance (No. animals/m^2), and Biomass (g/m^2). Mean ± S.E. Filled symbols indicate the Constructed flat and open symbols indicate the Reference area. Arrows indicate where linear contrasts detected significant differences ($p < 0.008$) between means.

less silt, organic content and bacteria than natural flats, but microbial respiration and infaunal biomass were similar to natural flats. Hosokawa (1997) has reported rapid benthic colonization of constructed sand flats and establishment of communities similar in biomass to natural flats in Tokyo Bay, Japan.

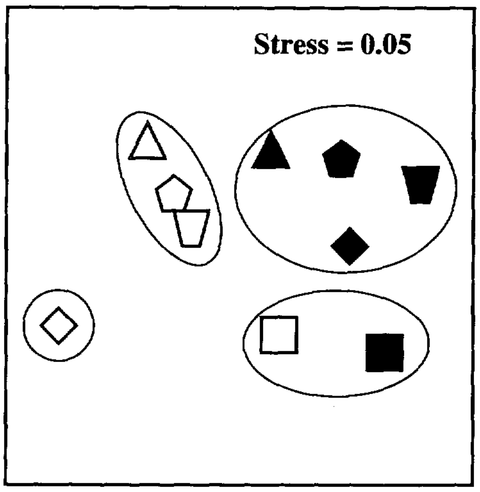

Fig. 6 Clustering and MDS results for comparison of Beals Island 1991–1998 data. Filled symbols represent Constructed flat samples and open symbols represent Reference area samples. Symbol shapes indicate year: Square = 1991, Diamond = 1992, Trapezoid = 1993, Polygon = 1994, and Triangle = 1998. Circled groups of symbols indicate clustering results.

TABLE 7

Similarity Percentage (SIMPER) results for Beals Island.[a]

Year	1991	1992	1993	1994	1998
Average dissimilarity	56.86	60.15	56.33	49.33	45.47
Tubificoides benedini	*12.68*[b]	*8.42*[b]	*8.56*[b]	*8.97*[b]	*5.24*[b]
Tectidrilus gabriella	*9.04*[b]	*8.93*[b]	4.52	2.21	2.73
Polydora quadrilobata	*6.93*[b]	4.46	2.65	*5.72*[b]	4.19
Ampelisca vadorum	*6.73*[b]	4.67	*5.44*[b]	*6.74*[b]	4.87
Clymenella torquata	*6.30*[b]	3.29	4.34	3.75	3.21
Streblospio benedicti	*6.27*[b]	3.87	4.52	*8.39*[b]	*5.77*[b]
Pygospio elegans	*6.13*[b]	*5.82*[b]	*5.63*[b]	–	–
Exogene hebes	*5.87*[b]	–	*10.52*[b]	*8.99*[b]	*8.14*[b]
Capitella sp.	4.78	*9.19*[b]	*7.07*[b]	*5.17*[b]	4.52
Phoxocephalus holbolli	4.26	4.14	4.40	4.05	3.55
Tubificoides sp.	4.15	0.38	3.13	1.96	–
Polydora ligni	3.50	2.81	3.40	3.27	1.56
Nereis virens	3.33	3.39	2.15	3.70	3.50
Heteromastus filiformis	3.21	2.60	2.93	3.78	2.05
Edotea montosa	3.09	2.38	3.23	4.40	3.08
Glycera dibranchiata	2.51	1.43	0.91	1.12	–
Tubificoides netheroides	2.07	3.44	4.78	2.23	4.06
Mya arenaria	1.36	0.40	–	–	1.71
Scottolana canadensis	1.04	4.48	2.23	1.30	2.18
Thalassomya sp.	0.62	4.53	2.22	3.00	3.73
Corophium volutator	0.61	2.68	2.83	–	2.53
Nemertea	0.56	0.42	–	0.72	2.57
Enchytraeidae	–	0.37	1.67	1.03	1.92
Fabricia sabella	–	3.27	2.56	0.43	*7.02*[b]
Exogene verugera	–	*8.31*[b]	–	–	–
Spio setosa	–	–	0.43	*5.44*[b]	0.32
Hydrobia sp.	–	–	3.34	3.34	*5.43*[b]
Phylloduce arenae	–	–	–	1.55	2.62

[a] Values in italic are for taxa contributing 5% to dissimilarity for a comparison. Superscripts indicate where abundances were highest ([b] Constructed flat; [c] Reference).

Analyses of the Jonesport study data suggest that benthic assemblages developed on both of the constructed mudflats and are similar to other natural North Atlantic mudflats (Table 8). Taxonomic composition is quite similar with the polychaetes *S. benedicti*, *Polydora* sp., and *N. virens* numerically dominant in almost all of the studies reviewed, and *Capitella* sp., *H. filiformis*, and *C. torquata* described as dominants in more than half the reports. Oligochaetes have been reported as numerical dominants in half of previous studies and the particular importance of *T. benedini* has been pointed out by Commito (1987). Other taxa common to nearly all the studies include the amphipod *C. volutator* and the clams *M. arenaria*, *G. gemma*, and *M. balthica*.

TABLE 8

Comparison of north Atlantic Intertidal Flat Infauna.[a]

Taxa	References cited													
	Larsen and Doggett (1991) [Maine]	Ambrose (1984) [Maine]	Commito (1982) [Maine]	Commito and Shrader (1985) [Maine]	Commito (1987) [Maine]	Brown and Wilson (1997) [Maine]	Thiel and Watling (1998) [Maine]	SIC	SIR	BIC	BIR	Wilson (1988) [Bay of Fundy] Wilson (1989) [Bay of Fundy] Wilson (1991) [Bay of Fundy]	Sanders *et al.* (1962) [Massachusetts]	Whitlach (1977) [Massachusett]
Oligochaeta	+	+			+	+	+	+	+	+	+			+
(*Tubificoides benedini*)					+			+	+	+	+			
(*Tectadrilus gabriella*)								+	+	+	+		+[b]	
Amphitrite johnsoni			+		+									
Capitella sp.				+		+	+	+	+	+	+			+
Clymenella torquata				+		+		+	+	+	+		+	+
Eteone longa			+	+	+	+	+[b]	+	+	+	+		+[b]	+
Exogene hebes			+	+		+	+	+	+	+	+			
Fabricia sabella				+[c]				+	+	+	+			
Glycera dibranchiata				+		+		+	+	+	+		+	+
Heteromastus filiformis	+					+	+	+	+	+	+	+	+	+
Hobsonia florida		+												
Nephtys incisa		+	+	+	+									
Nereis virens	+	+	+	+	+	+	+[b]	+	+	+	+		+	+
Polycirrus eximus			+											
Polydora spp.		+	+	+	+	+	+	+	+	+	+		+	+
Pygospio elegans							+	+	+	+	+	+	+	
Scoloplos sp.	+	+		+		+						+	+	+
Streblospio benedicti	+	+	+	+		+	+	+	+	+	+	+	+	+
Tharyx sp.				+		+	+					+	+	+
Ampelisca vadorum								+	+	+	+			+[b]
Corophium volutator	+		+	+	+	+	+	+	+	+	+	+		+[b]
Gammarus sp.			+	+	+			+	+	+	+		+[b]	+
Phoxocephalus holbolli								+	+	+	+			
Hydrobia sp.	+		+	+		+	+	+	+	+	+		+	+
Gemma gemma	+				+		+	+	+	+	+		+	+
Macoma balthica	+	+	+	+	+	+	+	+	+	+	+			
Mya arenaria	+		+	+	+	+	+	+	+	+	+		+	+
Diversity (H')	1.9–2.7							1.6–2.9	2.3–2.7	2.7–2.9	2.1–2.7			1.8–2.1
Abundance ($\times 10^3/m^2$)	1–22	3–38	11–20	20–117				11–33	18–95	20–44	25–129		7–355	1–196

[a] Species composition, diversity, and abundance (+ = Present, +[b] = Listed as sp. or congenor, +[c] = listed as *Sabella fabricia*, SI = Sheep Island, BI = Beals Island, C = Constructed flat, R = Reference area).

Differences in species composition between Sheep Island sites were limited to the relatively high abundance of *Capitella* sp., *P. elegans*, and *P. quadrilobata* at the CF in 1990, and the distribution of oligochaete species and *C. volutator* in later samples. *Capitella* sp. and *P. elegans* are opportunistic species and early colonizers of disturbed sediments, therefore their dominance in the 1990 samples may indicate the assemblage was still at an early stage of development (e.g., Shull, 1997; Thiel and Watling, 1998). By 1991, the CF and REF were very similar; however, in subsequent years there are persistent differences in the relative abundance of four of the dominant taxa. *T. gabriella* was always most dominant at the REF and *C. volutator*, *F. sabella*, and *T. benedini* were generally most abundant at the CF. Distributions of the remaining dominant taxa varied inconsistently among years. At Beals Island, there were persistent differences between sites throughout the study. *T. benedini* and *Capitella* sp. were generally most abundant at the REF, *T. gabriella* most abundant at the CF.

Species diversity values for the Jonesport sites were similar to those reported for other North Atlantic intertidal mudflats (Table 8). Previous studies of Massachusetts, Maine, and Bay of Fundy mudflats have found species diversities ranging from 1.80 to 2.66 (Whitlach, 1977; Ambrose, 1984; Larsen and Doggett, 1991). While diversity at both Sheep Island sites fell below this range in 1990, and at the CF in 1992 (Fig. 5), these results appear to have been due to high dominance (Table 1) rather than low taxa richness (Fig. 2). There were no distinctive trends over time in any of the diversity measures (taxa richness, *H*, *J'*, or dominance) that would indicate a persistent difference between the sites. At Beals Island, both sites had *H'* values in excess of 2.58 throughout the study and the only distinctive pattern among sites was the association of higher *H'* values with the CF (Table 6).

Abundances (animals/m^2) at the Jonesport sites were also within the range of previously reported values. Between 1000 and 355 000 animals/m^2 have been recorded for North Atlantic mudflats (Table 8). Abundances at the Sheep Island sites ranged from 11 000 to 95 000 animals/m^2, at Beals Island, from 20 000 to 120 000 animals/m^2. The principal difference in abundance between Sheep Island sites, that is, very high abundance at the CF, is also consistent with the interpretation that in 1990 the CF assemblage was still in the early stages of development. Infaunal assemblages typically progress through a series of stages beginning with a community composed of a few pioneering species present in extremely high abundances (Pearson and Rosenberg, 1978; Rhoads and Boyer, 1982; Rhoads and Germano, 1982). These early stage fauna consist primarily of small tube-dwelling polychaetes or small bivalve molluscs colonizing the surficial sediments. They are eventually replaced by larger, longer-lived and deeper burrowing species. Later stage assemblages tend to be more diverse but less abundant and are often dominated by ampeliscid amphipods and shallow-dwelling bivalves (Santos and Simon, 1980). In the final stage, a highly diverse assemblage dominated by large, long-lived, and deep-burrowing animals such as maldanid polychaetes develops. While this successional sequence has been noted by a number of authors, others have been unable to discern a predictable sequence. Rather, they report colonization by whatever taxa are present in nearby sediments or available for recruitment at the time of disturbance (Zajac and Whitlach, 1982; Diaz, 1994).

The 1990 results of the present study might also be influenced by time of sampling; the 1990 collections were made in June while all others occurred in August or September. Trueblood *et al.* (1994) have described an annual successional sequence for Boston Harbor mudflats in which there are three stages: a spring assemblage dominated by harpacticoid copepods, a spring-summer assemblage composed of oligochaetes and the polychaetes *Capitella* sp., *S. benedicti*, and *P. elegans*, and a fall-winter assemblage dominated by *Polydora ligni*. Whitlach (1977) has also reported a seasonal sequence for Massachusetts mudflat infauna with spring dominants being *C. insidiosum*, *Marenzellaria viridis*, and *Scoloplos* sp., summer dominants including *S. benedicti*, *H. filiformis*, and *G. gemma*, and fall-winter dominants being *M. arenaria* and *Capitella* sp. Because sampling was limited to a single collection period each year, the data cannot unequivocally be used to determine if colonization of the Sheep Island CF followed a particular successional sequence. It is clear, however, that by 1991 infauna of the CF were similar in abundance and species composition to the infauna of the REF, as well as other North Atlantic mudflat assemblages.

Beals Island abundance data present a considerably different picture. CF abundances were significantly lower than reference values for all but one of the five sampling dates (Fig. 5). Similarly, the biomass data also indicate a persistent difference between the sites. Differences in abundance and biomass were not restricted to a single taxonomic group, but were general in nature (Tables 3 and 6).

Differences in assemblage structure between sites at both study areas were undoubtedly influenced by differences in sediment texture. Both CFs have muddier sediments than their respective REFs. Unfortunately, the limited amount of information available from this study and the presence of confounding factors such as differences in elevation and vegetation density (intertidal *Z. marina* beds) preclude differentiation of the relative importance of individual factors. Additional studies will be required to make these determinations.

Two additional factors should be kept in mind in comparing CF and REF data from both the Sheep Island and Beals Island sites. First is the considerable variation between the two REFs, suggesting substantial background variability among natural mudflats. The Sheep Island REF had lower taxa richness and abundance than the Beals Island REF (Tables 1 and 6). Although the range of biomass values at the two REFs were similar (Figs. 2 and 5), molluscs made up a far larger proportion of REF biomass at Sheep Island (>9%) than at Beals Island (<9%). Likewise, the relative abundance of individual species varied greatly between the two REFs. Taxa such as *T. gabriella*, *F. sabella*, and *C. volutator* comprised a far greater proportion of the assemblage at Sheep Island than at Beals Island, while *C. torquata*, *S. benedicti*, *A. vadorum*, and *G. oceanicus* were most abundant at the Beals Island REF (Tables 1 and 6). Areas of great similarity between the REFs include overall species composition and values for the various computed diversity indices (Tables 1 and 6). The later is particularly true when comparisons are restricted to those years when sampling occurred at both sites (1991, 1992, 1994, and 1998). For instance, Shannon–Weiner (H') index values range from 1.28 to 2.69 at Sheep Island overall, but only from 2.34 to 2.69 when the restricted year set is employed. H' values at the Beals Island REF ranged from 2.10 to 2.68 in both cases.

The second consideration is that the REFs are actually muddy sandflats rather than pure mudflats. Their sediment characteristics make a precise correspondence of abundance and biomass values with true mudflats difficult. It should also be pointed out that although neither CF closely matched biomass values found at their respective REFs, values at both were nonetheless well within the range of values reported for natural flats. In one of the few studies reporting mudflat infaunal biomass, Bowen *et al.* (1989) found values ranging from 6 to 612 g/m^2 and averaging 164 g/m^2 for a series of New England mudflats. At Sheep Island, the CF averaged 125 g/m^2 and the REF averaged 285 g/m^2. At Beals Island, the CF and the REF averaged 72 and 139 g/m^2, respectively. Bowen *et al.* (1989) also described wide variation in biomass taxonomic structure among natural mudflats (Table 3). Annelids dominated biomass composition at most sites, while molluscs or crustaceans were dominant at a few. Virtually the same result was found at the Jonesport sites, where molluscs (primarily *M. arenaria*) made up most of the biomass at Sheep Island and annelids dominated biomass at the Beals Island sites (Table 3).

In summary, this research demonstrates that diverse, complex infaunal assemblages can be established on mudflats constructed of dredged materials. Within three years of construction of the Sheep Island mudflat, infaunal assemblages resembled those of natural flats with respect to species composition, assemblage structure, diversity, and abundance. The only variable that appeared to lag developmentally was total biomass, where CF values were generally less than values for the REF. This is of particular interest since similar results were found at the much older Beals Island site. While these persistent differences are, to a certain extent, less problematic when viewed in perspective with data from a range of natural flats, the ecological importance of infauna as forage for birds and fish species underscores a need for further investigation in future mudflat construction projects. Also, the results of this study encompass only two CFs. In a sense these represent only two 'replicates' and experience with a far larger number of CFs will be necessary before generalizations can be satisfactorily reached. In addition, a number of critical factors including microphytobenthic production, sediment nutrient concentrations, and indices of fish and shorebird utilization were not measured. Subsequent monitoring efforts should give serious consideration to examining these variables. Consideration should also be given to spatial scale. Both constructed habitats examined in this study were relatively small (<2 ha) and colonization and assemblage developmental rates of larger-scale constructed habitats will probably vary.

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