Ecological Monitoring
of a Constructed Intertidal Flat at
Jonesport, ME

Disposal Area Monitoring System DAMOS

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Intertidal flats are ecologically and commercially important habitats to the New England region of the U.S. They provide forage for commercially important fish species and both migratory and resident shorebirds. They also support shellfish and bait-worm industries. As a demonstration of the potential for beneficial use of dredged material in construction of these habitats, dredged materials from a harbor construction project were placed on a site on the western side of Sheep Island, Jonesport, Maine. After nine years the physical integrity of the site has not been compromised. The site quickly developed a substantial population of the commercially important soft-clam, Mya arenaria, as well as a diverse and abundant infaunal community. A population of the bait-worm Nereis virens was initially established but commercial-sized worms were absent during the last sample period. The absence seems most likely due to normal interannual fluctuations in abundance. A second, older constructed flat, resulting from intertidal disposal of dredged material, Beals Island, has an extensive bait worm population but few soft-clams. Differences in species' abundances appear most likely to be due to substrate differences. The infaunal community, the principal source of forage for fish and shorebirds, at both sites is comparable in diversity, abundance, biomass, and species composition to other New England intertidal flat assemblages.

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EXECUTIVE SUMMARY

Intertidal flats are ecologically and commercially important habitats to the New England region of the U.S. They provide forage for commercially important fish species and both migratory and resident shorebirds. They also support shellfish and bait-worm industries. As a demonstration of the potential for beneficial use of dredged material in construction of these habitats, dredged materials from a harbor construction project were placed on a site on the western side of Sheep Island, Jonesport, Maine. After nine years the physical integrity of the site has not been compromised. The site quickly developed a substantial population of the commercially important soft-clam, Mya arenaria, as well as a diverse and abundant infaunal community. A population of the bait-worm Nereis virens was initially established but commercial-sized worms were absent during the last sample period. The absence seems most likely due to normal interannual fluctuations in abundance. A second, older constructed flat, resulting from intertidal disposal of dredged material, Beals Island, has an extensive bait worm population but few soft-clams. Differences in species' abundances appear most likely to be due to substrate differences. The infaunal community, the principal source of forage for fish and shorebirds, at both sites is comparable in diversity, abundance, biomass, and species composition to other New England intertidal flat assemblages.

1.0 INTRODUCTION

A major portion of the sediment dredged annually from our nation's harbors and navigation channels has the potential for beneficial use. Habitat development, an important example of such a use, has been employed in the construction, restoration and enhancement of a variety of coastal habitats including salt marshes, oyster beds, and waterbird nesting sites (e.g., Yozzo, Titre, and Sexton, 1996; Parnell, DuMond, and McCrimmon, 1986). Since 1988, the US Army Engineer New England District (CENAE) has been examining construction of intertidal flats as a viable alternative to dredged material disposal (Fleming et al., 1991). Construction of intertidal flats as a beneficial use of dredged materials has previously been suggested by Kirby (1995) as a mechanism to replace lost habitat and protect fragile shorelines from erosion. Hosokawa (1997) has also supported the concept as a method of restoring lost sandy intertidal habitat in Japan. Monitoring of constructed sand flats in Japan has indicated rapid colonization of deposited sediments and establishment of benthic communities similar in biomass to natural flats (Hosokawa, 1997; Okada, Lee, and Nishijima, 1997).

Intertidal flats account for 15.6% of coastal wetlands along the North Atlantic coast of the United States (Field et al., 1991). Providing high levels of primary productivity and forage for commercial fisheries species, they are ecologically and commercially important (Peterson and Peterson, 1979; Whitlach, 1982). Intertidal flat primary producers, dominated by microalgae such as diatoms, provide a third of the total organic carbon budget for southern New England coastal areas (Marshall, 1970) and in the South Atlantic provide up to 50% of total estuarine primary productivity (Pinckney and Zingmark, 1993). Unlike vascular plants, whose high proportion of structural materials requires lengthy decomposition periods, microalgae represent a concentrated and immediately accessible food source to higher trophic levels (Olivier et al., 1996). The principal consumer groups are dense assemblages of benthic invertebrates comprised primarily of polychaetes, amphipods, and molluscs (Larsen and Doggett, 1991). These assemblages serve directly and indirectly as forage for demersal fish and migratory shorebirds. Winter Flounder (Pleuronectes americanus), a commercially important fish species, feed heavily on the intertidal flat infauna (Wells, Steele, and Tyler, 1973). Juvenile flounder and other fishes such as Atlantic herring (Clupea harengus), Atlantic Tomcod (Microgadus tomcod), Atlantic Cod (Gadus morhua), longhorn sculpin (Myoxocephalus octodecemspinosus), shorthorn sculpin, (M. scorpius), little skate (Raja erinacea), oceanpout (Macrozoarces americanus), and sea raven (Hemitripterus americanus) are commonly found on intertidal flats (Tyler, 1971). In addition, intertidal flats support large populations of sand shrimp (Crangon septemspinosus) which are forage for flounder, other bottom feeding fishes, and migratory shorebirds (Schneider and Harrington, 1981). Many shorebirds including dowitchers, sandpipers, sanderlings, and plovers use Bay of Fundy and Maine intertidal flats as stopover sites prior to their fall migrations to overwintering

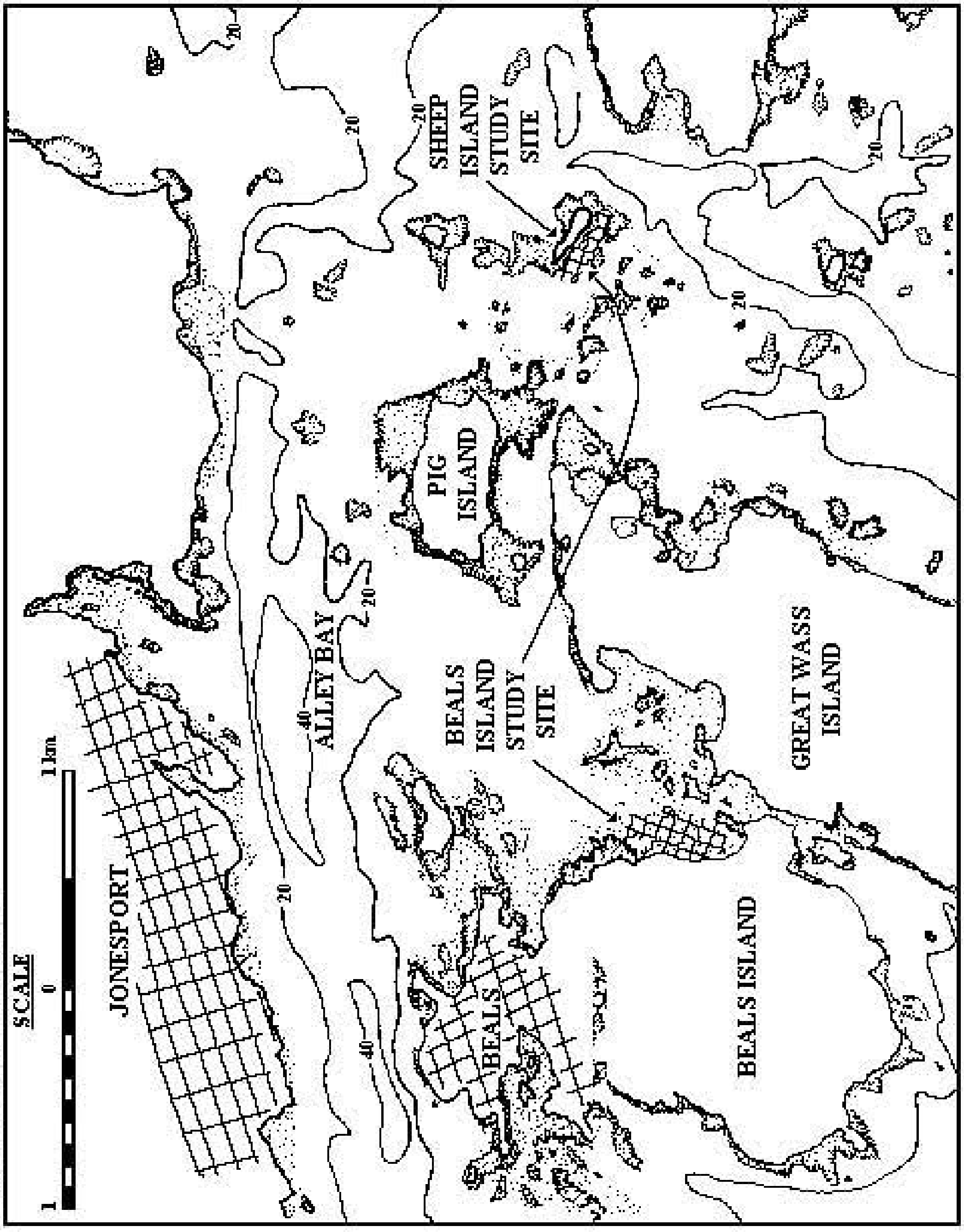


Figure 1-1. Map of Study Area.

grounds in South America (Hicklin, 1987). Benthic invertebrates provide a major portion of the food resources needed to make these nonstop flights (Schneider and Harrington, 1981; Matthews, Boates, and Walde, 1992). The amphipod Corophium volutator in particular, has been found to be an important food source (Peer, Linkletter, and Hicklin, 1986). Intertidal infauna such as Nereis virens also provide forage for resident shorebirds such as herring and black-backed gulls (Ambrose, 1986). Intertidal flats also provide habitat for commercial soft-clam (Mya arenaria) and bait-worm (Nereis virens and Glycera dibranchiata) fisheries. Commercial fisheries statistics available on-line through the Maine Department of Marine Resources website[*] indicate that between 1989 and 1997 an average of 2 million lbs. of soft-clams were landed annually with an estimated value of $7.6 million/year. Clam-worm, N. virens, landings averaged 381,000 lbs./year between 1989 and 1996 representing a value of just under one million dollars/year while blood-worm (G. dibranchiata) landings averaging 452,000 lbs./year were valued at $2.3 million/year. Together these resources represent nearly 12 million dollars in income each year.

To explore the potential for beneficial use of dredged material in constructing muddy intertidal flat habitat, approximately 74,500 cubic meters (100,000 cubic yards) of dredged material resulting from breakwater construction and channel dredging in Sawyers Cove, Jonesport, Maine (Washington County), were deposited on Sheep Island (Figure 1-1). Sediments were placed in a shallow, circular basin (365 m diameter) surrounded by rocky ledges on the leeward side of the island (Figure 1-2; Figure 1-3). In addition, bedrock ledge material resulting from breakwater construction was placed along the periphery of the site to help contain the dredged materials. Placement was initiated in January 1988, interrupted in March 1988 for an environmental dredging window, and finally completed in January 1989 (Fleming et al., 1991). The project resulted in creation of 1.2 hectares (3 acres) of intertidal flat habitat. During the course of the study a second site adjacent to Beals Island was identified as a mud flat resulting from intertidal disposal of dredged material disposal in the 1960's (Figure 1-4). Previously, Fleming et al. (1991) and Ray et al. (1994a and 1994b) have reported results from monitoring of sediments, soft-clam and bait-worm populations, and infaunal communities at Sheep and Beals Islands between 1990 and 1992. The present report incorporates these results with those from additional sampling efforts conducted in 1993, 1994, and 1998.

[*] www.state.me.us/dmr/Comfish.comsfish.htm

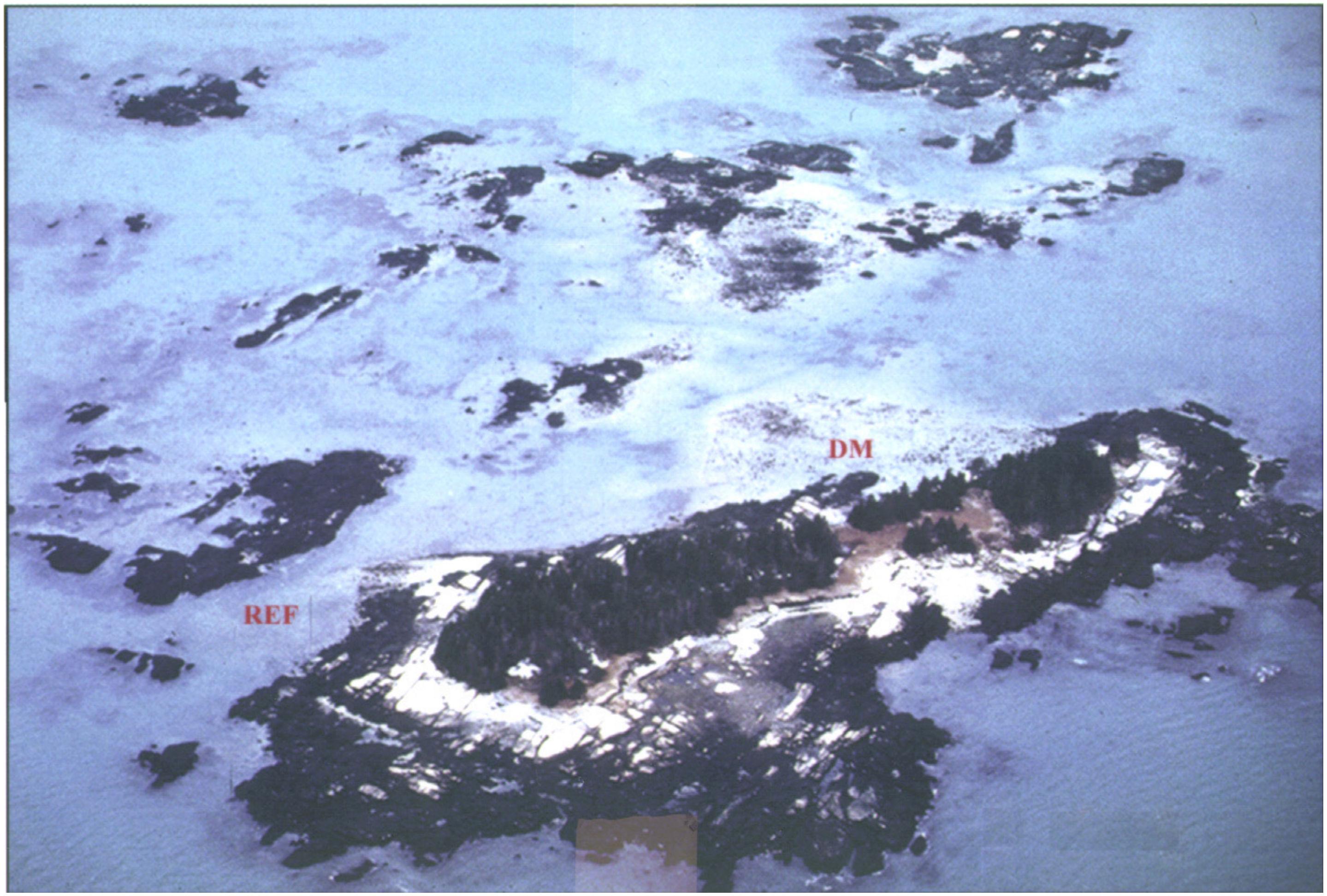


Figure 1-2. Aerial view of Sheep Island. DM=Constructed Intertidal Flat, REF=Reference Site

Figure 1-3. Panoramic view of the Sheep Island Constructed Intertidal flat

Figure 1-4. Aerial view of Beals Island. DM=Constructed Intertidal Flat, REF=Reference Site

2.0 METHODS

2.1 Description of Study Area

Jonesport, Maine is located 80 km (50 miles) southeast of the Canadian border. The coastline is typified by broad embayments and numerous granite islands (Kelley, 1987). Intertidal flats have formed on the leeward side of most islands (e.g., Beals, Great Wass, and Head Harbor) and other sites protected from oceanic swells (e.g., Machias Bay). The climate is northern temperate with a mean annual air temperature of 43oC and mean annual precipitation of 107 cm (Fefer and Schettig, 1980). Jonesport and the surrounding area lies midway between two estuarine drainage areas, Englishman and Narraguagus Bays, but not within the estuarine mixing zones (0.5 - 25 ppt) of either (NOAA, 1985). It is unlikely that waters surrounding the islands experience salinities lower than 25 ppt even during peak river flows. However, local salinity dilution undoubtedly occurs during periods of high runoff. The principal natural threat to intertidal flats is erosion by storms and ice scouring. Hurricanes and severe storms are infrequent but can result in substantial erosion (Yeo and Risk, 1979). Ice scouring, the chief source of erosion, occurs when ice blocks are pushed across flats by strong onshore winds, by the movement of tides, or during the spring breakup of shorefast ice (Dione, 1969; Gordon and Desplanque, 1983).

The primary study area, Sheep Island, is a 3.9 hectare granite island located 2.3 km southeast of Jonesport (Figure 1-1). Topped with a small copse of trees, it has extensive rocky intertidal habitat with a gravelly sand intertidal flat at its base (Figure 1-2; Figure 1-3). Sheep Island is unpopulated and accessible only by boat. The second study area, Beals Island, is a much larger island (approximately 300 hectares) located 2 km due south of Jonesport (Figure 1-1). It is connected to the mainland by a bridge and to Great Wass Island to the east by a small causeway. The eastern connecting point was obviously once a tidal channel but has since been filled. The area between Beals and Great Wass Islands, Alley Bay, is now a sand and mud flat (Figure 1-4). The perimeter of the bay is rimmed by riprap on the west and south and by a small pocket marsh, granite outcrops and sand flats on the east. A water treatment facility is present at the northeastern tip of the bay. Easily accessible by car, Alley Bay is a popular spot for digging soft-shell clams and bait-worms. Species of concern in the area include soft-clams, bait-worms, harbor seals, and shorebirds (USFWS, 1980).

2.2 Project History

The primary study site is an intertidal mud flat constructed with dredged materials on the west side of Sheep Island (Figure 1-2). The constructed flat and an adjacent area of gravelly intertidal sands (reference area) have been sampled to characterize changes in sediment and monitor development of soft-clam and bait-worm populations, and benthic macro-invertebrate (infauna) communities. During the initial sampling trip (1990), local residents informed project personnel of an earlier dredged material deposit placed during the 1960's at nearby Beals Island (Figure 1-4). The Beals Island disposal operation occurred prior to the National Environmental Protection Act (NEPA) and apparently no records were kept of the precise location of the disposal area. An area corresponding to residents' descriptions was examined and the presence of stiff clays similar to dredged sediments (clay balls) below the sediment surface seemed to confirm the area as a disposal site. In 1991, the Beals Island site was added to the study as an example of a much older (approximately 30 years) constructed intertidal flat.

In June 1990 the New England District (CENAE) and Normadeau Associates conducted a survey of soft-clam populations, infauna and sediments at Sheep Island. All sampling in subsequent years occurred in August or September during the lowest tides available. In 1991, CENAE personnel and members of the Waterways Experiment Station's Coastal Ecology Branch (CEB) repeated the sampling of Sheep Island, extended the survey to include bait-worms, and sampled the constructed flat and an appropriate reference area at Beals Island. This sampling scheme was repeated in 1992. Only the Beals Island site was accessible in 1993 due to inclement weather. Infaunal and sediment samples were taken but no bait-worm or soft-clam sampling occurred. Infauna and sediments were sampled at both sites in 1994. In 1998 sediments, infauna, and bait-worm and soft-clam populations were sampled at Sheep Island, while at Beals Island only infauna and sediment samples were taken.

2.3 Data Collection

Bait-worm and soft-clam samples were taken using several different methods (Tables 2-1 and 2-2). Sampling methods changed from year-to-year as progressively more experience was gained and limitations of individual methods were recognized. In 1990 and 1991 thirty 0.04 m^2 pits were dug using a shovel and sediments were rinsed over a 0.63 cm (0.25 in.) mesh screen. Soft-clams collected on the screen were identified, counted, and specimen widths measured to the nearest mm in the field. When sampling was expanded to include bait-worms in 1991, it was recognized that while this method provided quantitative samples it would not capture the full range of different sized worms due to the small sampling area. In particular, it would undersample large commercial-size animals. Clam-worms can reach 90 cm in length (Pettibone, 1963) and the maximum dimension of the pits was only 20 cm. Commercial worm rakes were employed in order to collect these larger specimens. Rakers collected all specimens encountered during a series of 5-minute sampling periods, counted the specimens and measured their total lengths to the nearest mm. Although this procedure resulted in collection of large animals it was relatively nonquantitative. To address this issue, in 1992, nine 1 m^2 areas were thoroughly hand-raked at each site. No pit (shovel) samples were taken at this time. This method produced reliable results but a considerable amount of time was required to adequately rake each sample plot and a question arose as to the efficacy of the method to quantify medium and small sized animals. Accordingly, in 1998, the area raked was reduced to 0.5 m^2 (a maximum of eight areas were raked) and pit samples were taken from the corner of each of raked plot and sieved over a 5 mm screen to insure collection of medium-sized animals. Sampling was limited to the Sheep Island sites.

Table 2-1. Sheep Island Pit and Rake Samples*

Year	No. Pit Samples	Pit Area	No. Rake Samples	Rake Area	Total Area
1990	30	0.04 m^2	---	---	1.2 m^2
1991	30	0.04 m^2	?	?	+1.2 m^2
1992	---	---	9	1.0 m^2	9.0 m^2
1998	9	0.125 m^2	9	0.475 m^2	4.5 m^2

Table 2-2. Beals Island Pit and Rake Samples*

Year	No. Pit Samples	Pit Area	No. Rake Samples	Rake Area	Total Area
1991	30	0.04 m^2	?	?	+1.2 m^2
1992	---	---	9	1.0 m^2	9.0 m^2

* Represents type and number of samples taken at each sample site.
? Number of samples not recorded

Infauna were collected by forcing a 7.5 cm diameter coring tube into the sediment to a depth of 10 cm. During the early part of the study a total of 30 cores were taken at each site (Tables 2-3 and 2-4), however, the sample size was later reduced to 15. Equal numbers of cores were taken at each of three different distances from the shoreline and each core was taken at least 2 m away from any previous sample. Samples were washed over a 0.5 mm mesh screen in the field, fixed in 4% formalin, and transported to the laboratory. A total of 9 sediment grain size samples were collected at each site with a 5 cm diameter coring tube to a sediment depth of 10 cm. Samples were placed in a plastic bag and transported to the laboratory for analysis.

Table 2-3. Sheep Island Infaunal and Sediment Samples

	Constructed Flat		Reference	
Year	Infauna	Sediment	Infauna	Sediment
1990	30	5	30	5
1991	30	0	30	0
1992	30	9	30	9
1994	15	9	15	9
1998	15	9	10	6

Table 2-4. Beals Island Infaunal and Sediment Samples

	Constructed Flat		Reference	
Year	Infauna	Sediment	Infauna	Sediment
1991	29	0	19	0
1992	30	9	30	9
1993	30	9	30	9
1994	15	9	15	9
1998	15	9	15	9

2.4 Sample Processing

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 upon ignition (550° C). No organic content analysis was performed on the 1990 samples and none was possible in 1998 due to unavoidable delays in sample shipment. In the laboratory infaunal samples were rinsed over a 0.5 mm mesh sieve to remove formalin, transferred to 70% ethanol and stained with rose bengal solution to facilitate sorting of specimens. After staining, the samples were rinsed to remove excess stain, examined under 3X magnification, specimens separated from the remaining sediment and detritus and stored in 70% ethanol. Specimens were then identified to the lowest practical taxonomic level and enumerated. Wet-weight biomass was determined for major taxonomic groups (e.g., Polychaeta, Crustacea).

Because of a change in contractors processing the samples, differences arose in the level of taxonomic identifications between the 1990 and post-1990 sample sets particularly in the identification of oligochaete worms (Annelida). The initial contractor was apparently unfamiliar with the group so all specimens were recorded simply as Oligochaeta. Examination of later samples indicated the presence of a number of species, including Tubificoides benedini and Tectadrilus gabriellae, two of the most numerically abundant taxa. Attempts to locate the 1990 specimen collection were unsuccessful making it impossible to reexamine the specimens or measure biomass.

2.5 Statistical Analyses

Soft-clam and bait-worm abundances are reported on a per square-meter basis by sampling method: core or pit and rake. Pit and rake data could not be analyzed statistically due to differences in sample area and sampling method, however, abundances from core samples could be evaluated using Analysis of Variance (ANOVA). Abundance data for bait-worms and soft-clams were tested for normality and heterogeneity of variance prior to ANOVA and transformed where necessary to conform to assumptions of the test. Sheep Island Nereis virens and Mya arenaria data required fourth-root ($x^{1/4}$) transformations as did clam-worm densities from Beals Island. Too few specimens were collected to permit analysis of M. arenaria at Beals Island and Glycera dibranchiata at either site. Data were tested using a two-way ANOVA with sampling date and site (constructed flat or reference) as the main effects. When either site or year effects were significant ($p<0.05$) Tukey's test was empoyed to determine differences between means. Where the Site by Year interactions were significant, the main effects could not be interpreted (Zar, 1996). Linear contrasts were performed in order to determine where significant differences occurred between sites among the sampling dates using the Bonferroni adjustment (p = 0.05/no. comparisons) to correct for multiple comparisons (Underwood, 1997). Since there are five relevant site by date combinations (e.g., Sheep Island Constructed Flat 1991 vs. Reference 1991), a p value of 0.01 was required for a comparison to be considered statistically significant. Where only four comparisons were possible (e.g., biomass data) a p value of 0.0125 was required.

Soft-clam and bait-worm population structures were examined by construction of size frequency histograms. Measurements for individual species were pooled by site and date and the relative abundance of animals in each of at least 10 size classes were plotted. A minimum sample size of 30 animals was required in order to reduce the influence of a few very large or very small animals. In general, this restricted the size frequency analyses to the 1991-1992 sample collections and excluded consideration of Glycera populations.

Summary sediment grain size data (e.g., % silts, % gravel) are presented as stacked bar graphs. Infaunal assemblage parameters; taxa richness (taxa/sample), total numerical abundance/m^2 and total wet-weight biomass/m^2 were tested using ANOVA. Logarithmic transformations were required for abundance and biomass. Where significant differences were detected between main effects (Site or Year) or by linear contrasts, mean values ± one standard error have been plotted.

Infaunal taxonomic structure was examined using the nonparametric ordination technique, Nonmetric Dimensional Scaling (NMDS) and Similarity Percentage (SIMPER), a procedure that estimates the relative contribution of each taxon to overall similarity. The total species list was reduced by considering only those taxa that comprised 1% or more of total abundance or were present in 50% or more of the cores. In order to conform to computational limits of the statistical software, the number of samples was reduced by randomly selecting only 10 cores from each sample date and site for inclusion in the analyses. For NMDS, abundance values were logarithmically transformed (log x+1) and Bray-Curtis (BC) similarity values calculated for all possible combinations of samples. Stress, a goodness-of-fit measure, was calculated for all NMDS comparisons. Stress values less than 0.2 are considered to be adequate for interpretation of results (Clarke and Warwick, 1994). For SIMPER analyses, abundances were fourth-root transformed as recommended by Clarke and Warwick (1994). SIMPER calculates average sample dissimilarity using the Bray-Curtis (BC) dissimilarity index (dissimilarity = 1- BC value).

Because of the oligochaete identification problem with Sheep Island 1990 data, it was impossible to directly compare all years simultaneously. Instead, two separate analyses were performed. First, 1990 and 1991 data were compared using the 1990 taxonomic classifications (all oligochaete taxa pooled) and second, 1991 and all later samples 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.

3.0 RESULTS

3.1 Sediment Texture and Sediment Organic Content Results

3.1.1 Sheep Island

As might be expected, sediment texture was finer at the Sheep Island constructed intertidal flat than the reference area. The constructed flat was composed primarily of silts and clays with relatively little (<25%) sand while the reference area was mostly sand and gravel with less than 30% silts and clays (Figure 3-1). Sediment texture appeared to coarsen at both sites in 1994 most likely representing methodological error. Sediment texture at both sites in 1998 was similar to previous years. Sediment organic content was higher at the Sheep Island constructed flat than the reference area in both 1992 and 1994 (Figure 3-2), although it decreased by 1-2% at both sites between years. As previously noted no sediment organic content was measured in 1990 and logistical problems prevented analysis of the 1998 samples.

Figure 3-1. Sheep Island Sediment Texture

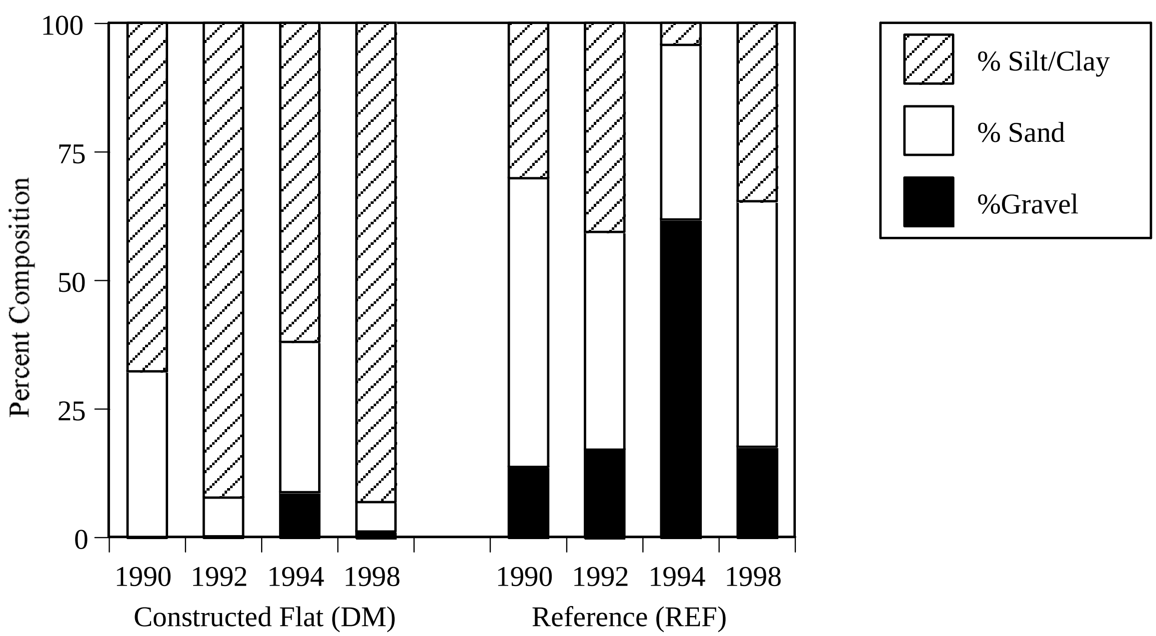
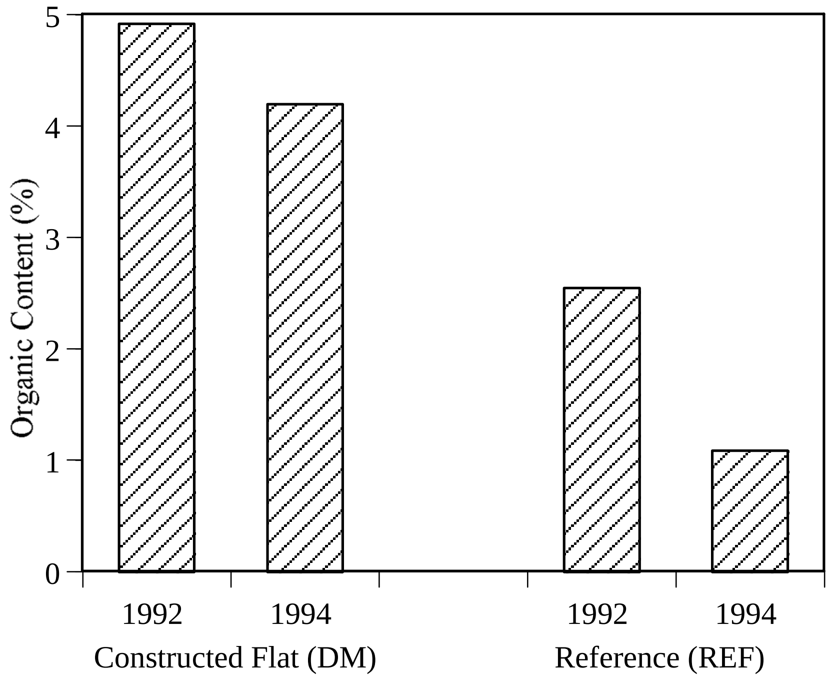


Figure 3-2. Sheep Island Sediment Organic Content



3.1.2 Beals Island

Beals Island constructed intertidal flat sediments were also finer grained than those of the respective reference site. In this case however, the difference was less pronounced than at Sheep Island. Beals Island constructed flat sediments contained approximately 75% silts and clays, while reference area sediments had 30-50% fines (Figure 3-3). The same apparent coarsening of sediments found in 1994 Sheep Island samples was present in the Beals Island sediments. Likewise, by 1998 sediment texture was similar to previous years. Sediment organic content was also higher at the constructed flat than the reference site and also declined between 1992 and 1994 (Figure 3-4).

Figure 3-3. Beals Island Sediment Texture

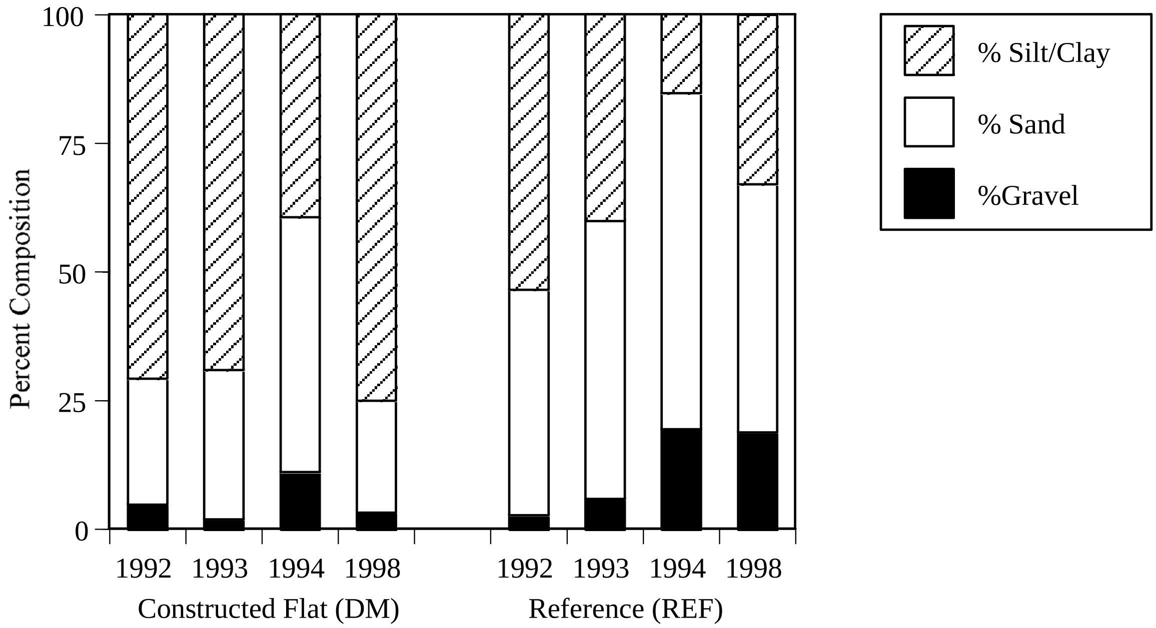
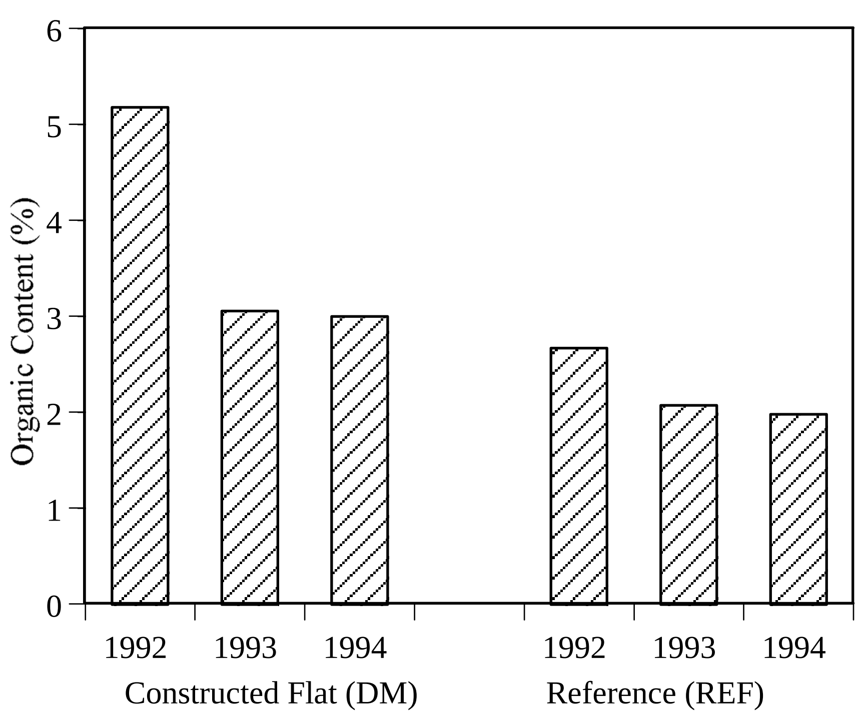


Figure 3-4. Beals Island Sediment Organic Con



3.2 Soft-clam and Bait-worm Survey Results

3.2.1 Sheep Island

3.2.2 Soft-Clams (Mya arenaria)

Initial rake and pit sample soft-clam abundances (animals/m^2) were approximately the same at both sampling sites, however, after 1991 densities were 2-3 times higher at the constructed flat than the reference site (Table 3-1). Abundances from core samples, a measure primarily of small-sized animals, indicated no differences between sites ($p>0.05$) for either species (Table 3-2). The only significant differences ($p<0.05$) detected were between sampling dates; Mya arenaria abundances were highest in 1994 (Figure 3-5).

Table 3-1. Sheep Island Soft-Clam (Mya arenaria) Survey Results*

Year	DM	n	REF	n
1990	15.0	13	14.2	19
1991	26.7	75	9.2	38
1992	26.6	228	10.2	92
1998	3.3	13	0	0

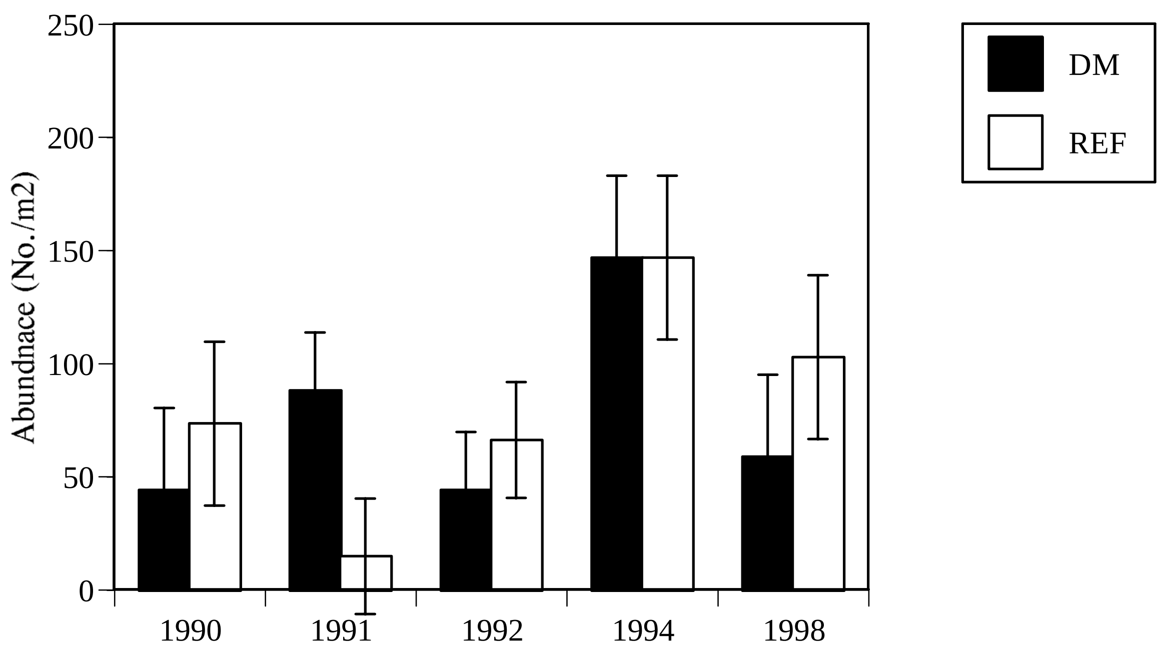
Table 3-2. ANOVA Results for Sheep Island Mya arenaria Abundance (Cores)

Effect Test

Source	DF	Sum Sq.	F Ratio	p
Site	1	0.0106	0.0525	0.8190
Year	1	2.2516	2.7976	0.0272
Site*Year	4	1.1691	1.4526	0.2181
Error	200	40.2413	0.2012	

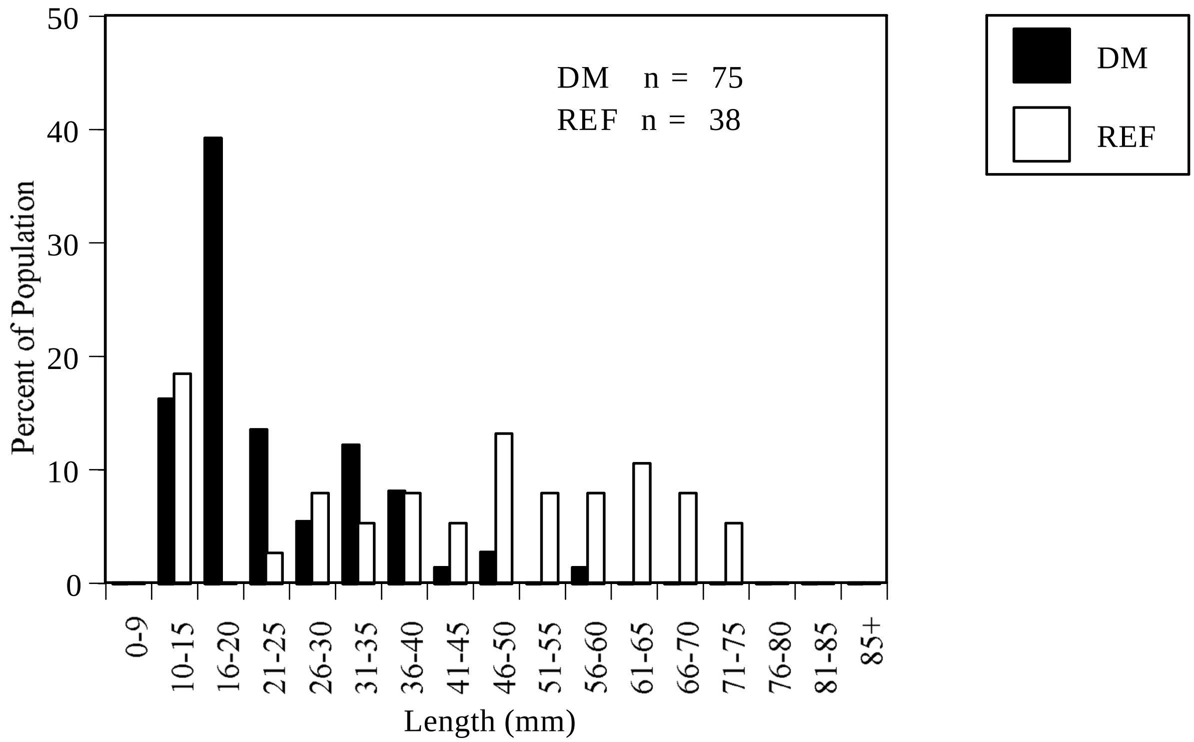
*Abundances in No. animals/m^2; n = total numbers collected

Figure 3-5. Abundance of Mya arenaria from Sheep Island Infaunal Cores*



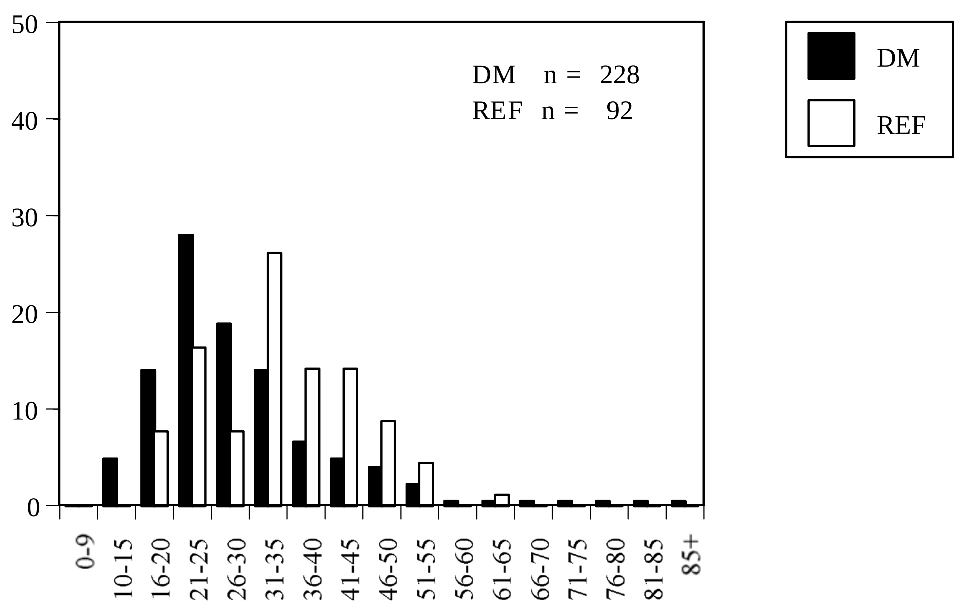
Size frequency analysis of soft-clam populations was possible for both Sheep Island sites, but only in 1991 and 1992. In 1991 the Mya population at the constructed intertidal flat was smaller in size than that of the reference area; specimens in the 16-20 mm size range constituted the bulk of the population (Figure 3-6). The reference area population was bimodal with peaks at the 10-15 mm and 46-50 mm size ranges. In 1992 the modal size of individuals from the constructed flat population had increased with the highest proportion of individuals being 21-25 mm in length (Figure 3-7). Specimens from the reference area population were smaller than previous samples with most specimens being in the 31-35 mm size range. Although too few animals were collected in 1998 to perform size frequency analysis, over half of those found were greater than 50 mm in length (Appendix 1).

Figure 3-6. Size Frequency Histograms for Mya arenaria: Sheep Island 1991*



*DM = Constructed Intertidal Flat REF = Reference Site

Figure 3-7. Size Frequency Histograms for Mya arenaria: Sheep Island 1992*



From these data and the abundance results it appears that a substantial set (recruitment) of soft-clams occurred soon after construction of the flat. Analysis of the core abundances, a measure of small-sized animals, suggests that recruitment was and continues to be equally successful at both sites. The abundance of larger-size animals, collected by rake and pit sampling, indicates that large animals were evenly distributed among the sites at first, but became substantially more abundant on the constructed flat than the reference area (Table 3-1). The trend for increasing length of animals from the constructed flat (Figures 3-7 and 3-8; Appendix Table 1) indicates that individuals rapidly grew to commercial length (~50 mm). The numerous raking pits evident on the flat during the 1998 field sampling (personal observation) is perhaps the clearest, if anecdotal, evidence for establishment of a commercially viable population.

3.2.2.1 Clam-worms (Nereis virens)

Survey results for Sheep Island clam-worm populations are similar to those for soft-clams (Table 3-3; Table 3-4). Abundances from rake and pit samples reflected considerable annual variation with twice as many animals present at the reference area than the constructed flat in 1991, the opposite result in 1992, and no animals found at either site in 1998 (Table 3-3). Clam-worms are large-bodied, mobile animals which periodically leave their burrows to swim and breed in the water column (Pettibone, 1963). It is unclear how much of the variation in rake/pit abundances was due to reproductive behaviors, natural interannual variations in abundance, site-specific differences, or other factors. Data for small-sized animals, i.e. the core data, indicate no difference ($p>0.05$) in abundance between sites or between sites over time (Table 3-4). Differences among years were restricted to the highest and lowest values with 1990 abundances being the least and 1998 being the highest (Figure 3-8). Size frequency analysis, limited to the 1991 and 1992 data, indicates that while the 1991 constructed flat and reference area populations had similar structures (Figure 3-9), in 1992 constructed flat populations were dominated by much smaller animals than those found at the reference area (Figure 3-10).

Table 3-3. Sheep Island Clam-worm (Nereis virens) Survey Results*

Year	DM	n	REF	n
1990	0	0	0	0
1991	16.7	19	33.3	40
1992	27.8	213	4.1	37
1998	0	0	0	0

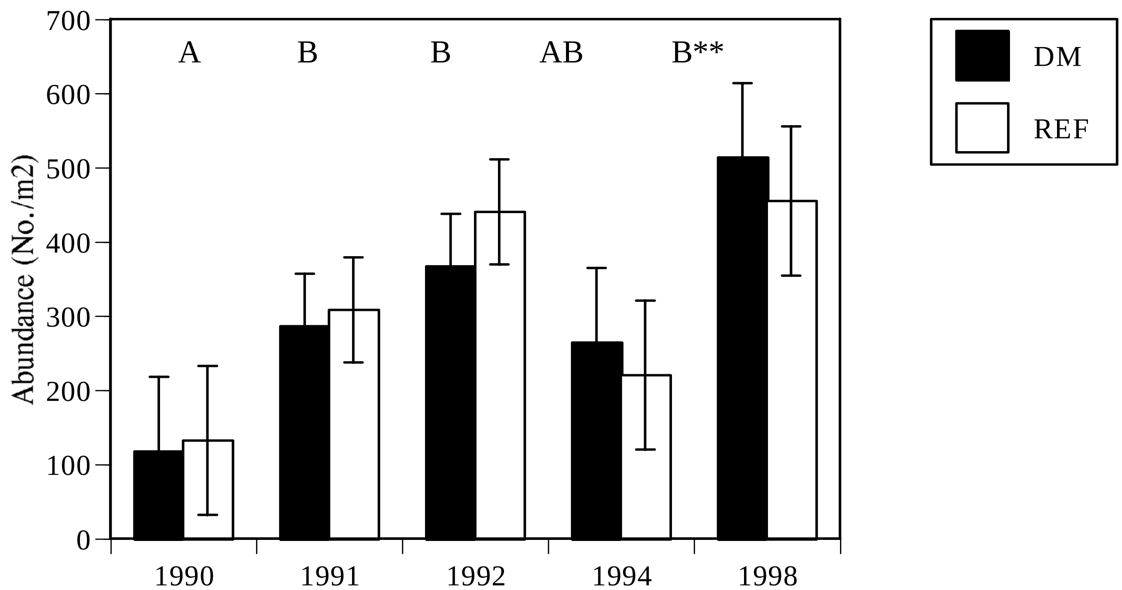
Table 3-4. ANOVA Results for Sheep Island Nereis virens Abundance (Cores)

Effect Test

Source	DF	Sum Sq.	F Ratio	p
Site	1	0.0589	0.1919	0.6618
Year	1	7.5649	6.1594	0.0001
Site*Year	4	2.3019	1.8742	0.1164
Error	200	61.4103	0.3071	

*Abundances in No. animals/m^2; n = total numbers collected

Figure 3-8. Abundance of Nereis virens from Sheep Island Infaunal Cores*



*DM = Constructed Intertidal Flat REF = Reference Site
**Years with the same letter are not significantly different (p>0.05) by Tukey test

Figure 3-9. Size Frequency Histograms for <u>Nereis</u> <u>virens</u>: Sheep Island 1991*

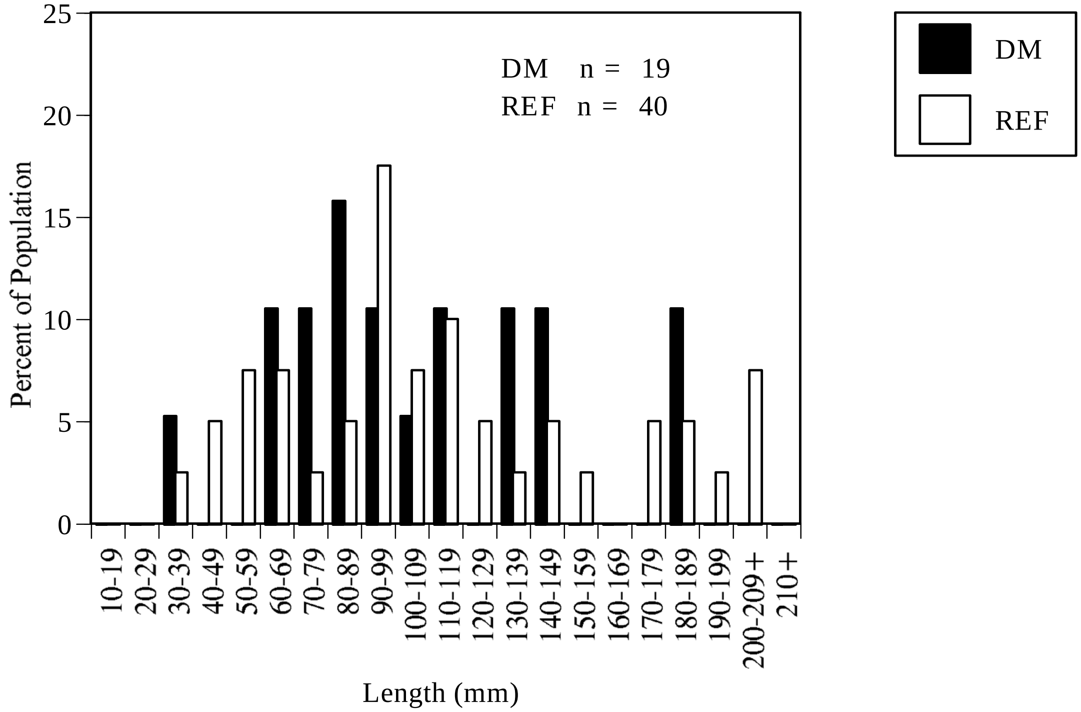
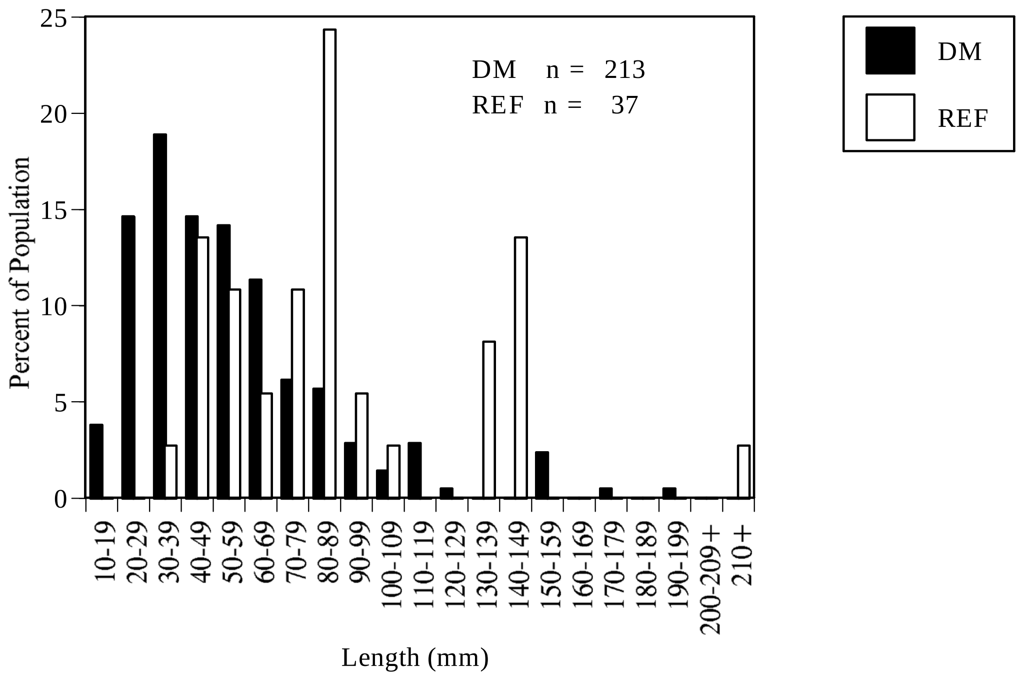


Figure 3-10. Size Frequency Histograms for <u>Nereis</u> <u>virens</u>: Sheep Island 1992*



*DM = Constructed Intertidal Flat REF = Reference Site

In contrast to the soft-clam data, clam-worm abundance and size frequency data suggest that a large recruitment of clam-worms did not occur until 1992. As with the soft-clam, recruitment was not site-specific and varied primarily among years. The high abundances encountered in 1998 core samples suggest that a second “good” year for recruitment may have occurred at this time.

3.2.3 Beals Island

3.2.3.1 Soft-Clams (Mya arenaria)

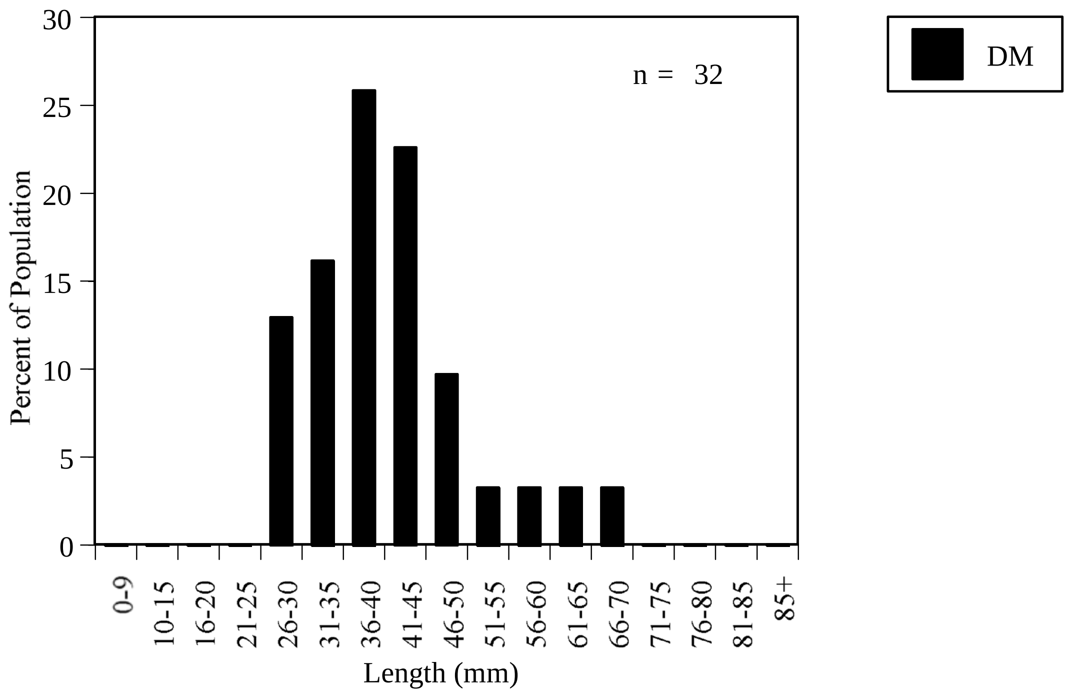
Soft-clams were much less abundant at Beals Island than Sheep Island throughout the study. Practically no large-sized animals were collected in rake and pit samples in either 1991 or 1992 (Table 3-5) and too few were collected in the core samples to analyze densities. It was only in 1992 that sufficient specimens were collected to construct a size frequency histogram and then only for the constructed intertidal flat (Figure 3-11). The resulting figure indicates that the population was dominated by animals 36-45 mm in length, a distribution similar to that of Sheep Island reference area populations for the same time period (Figure 3-8).

Table 3-5. Beals Island Soft-Clam (Mya arenaria) Survey Results*

Year	DM	n	REF	n
1991	0	2	0	2
1992	3.6	32	0.7	6

*Abundances in No. animals/m^2; n = total numbers collected

Figure 3-11. Size Frequency Histograms for Mya arenaria: Beals Island 1992*



3.2.3.2 Clam-worms (Nereis virens)

Clam-worms were far more abundant in rake and pit samples at the Beals Island constructed flat than the reference area in both 1991 and 1992 (Table 3-6). The same is true for three of the four years where linear contrasts detected significant differences ($p<0.01$) between the constructed flat and reference area (Table 3-7; Figure 3-12). Differences were detected between sites for all years except 1990 and reference values were higher than constructed flat abundances only in 1993. Size frequency analysis was possible only for the 1992 constructed flat samples; the population was bimodal with peaks in the 110-199 and 200-209 mm categories (Figure 3-13).

Table 3-6. Beals Island Clam-worm (Nereis virens) Survey Results*

Year	DM	n	REF	n
1991	26.7	20	0.4	4
1992	8.9	90	0.4	3

*Abundances in No. animals/m^2; n = total numbers collected

Table 3-7. ANOVA Results for Beals Island Nereis virens Abundance (Cores)**
Effect Test

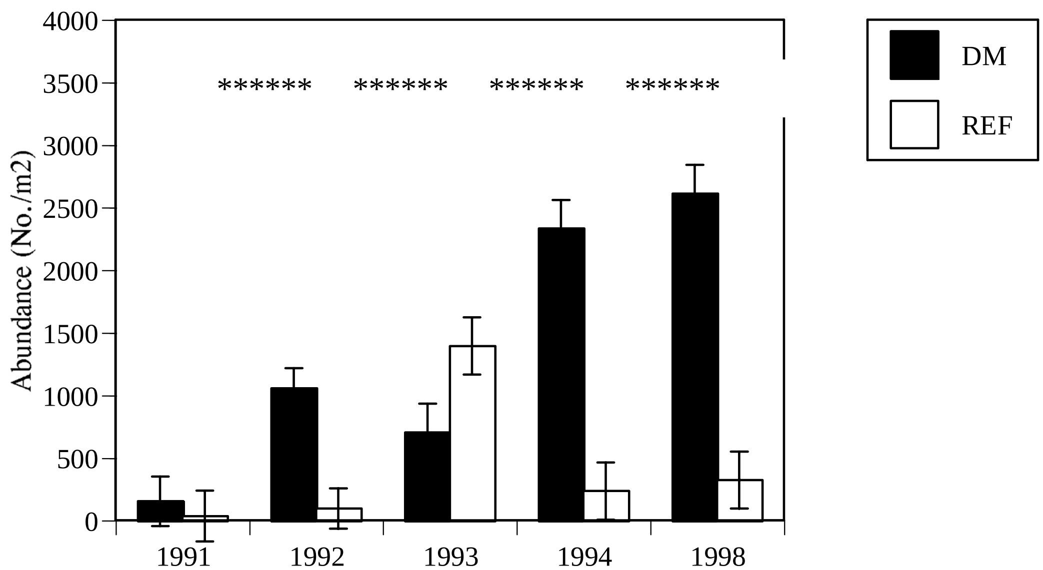
Source	DF	Sum Sq.	F Ratio	p
Site	1	15.5506	54.2444	<0.0001
Year	1	23.6299	20.6329	<0.0001
SiteXYear	4	17.1409	14.9479	<0.0001
Error	179	51.3153	0.2866	

Linear Contrasts**

	1991	1992	1993	1994	1998
Estimate	0.3353	1.0286	-0.5670	1.0505	1.1280
t Ratio	1.9548	7.4407	-2.9000	5.3732	5.7695
Prob>|t|	0.0522	**<0.0001**	**0.0042**	**<0.0001**	**<0.0001**

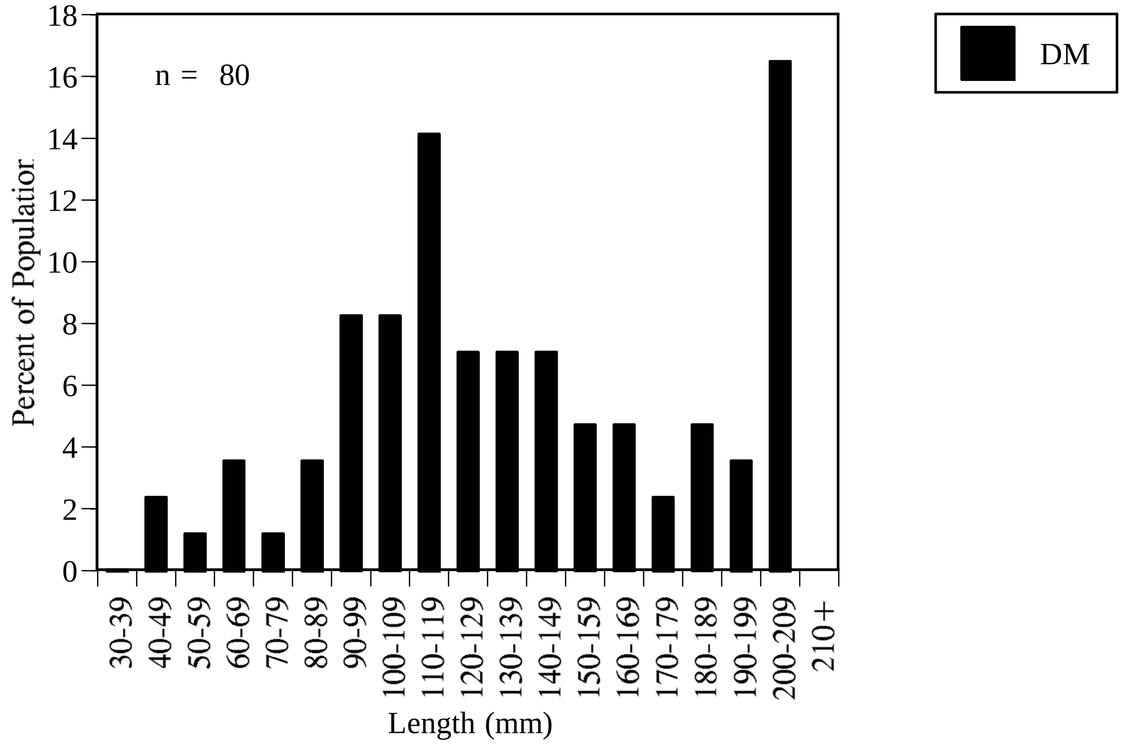
Negative estimates indicate Dredged Material site abundances less than Reference site values; positive estimates indicate abundances are higher than reference. Figures in **bold are significantly different at p≤0.01.

Figure 3-12. Abundance of Nereis virens from Beals Island Cores*



* DM = Constructed Intertidal Flat   REF = Reference Site
Values with ****** indicate linear contrasts are significantly different at p <0.01

Figure 3-13. Size Frequency Histograms for Nereis virens: Beals Island 1992*



*DM = Constructed Intertidal Flat REF = Reference Site

3.3 Infauna

3.3.1 Sheep Island

3.3.1.1 Assemblage Structure

The structure of Sheep Island infaunal assemblages was compared by examining taxa richness (a measure of diversity), total numerical abundance, total wet-weight biomass, and biomass structure (proportional composition by major taxonomic groups). Taxa richness differed significantly ($p<0.05$) among sites over time (site by year interaction factor) thus requiring linear contrasts to determine which sites were different and when (Table 3-8). Significant linear contrasts ($p<0.01$) were detected in 1990 and again in 1992. In 1990 taxa richness was higher at the constructed intertidal flat than the reference area by more than 3 taxa/core, whereas in 1992 reference area taxa richness was higher than constructed flat values by 1 taxon/core (Figure 3-14). A significant interaction factor was also encountered in the ANOVA for total numerical abundance (Table 3-9). Linear contrasts of site means over time resulted in only one significant comparison (p<0.01), the constructed flat versus reference area comparison for 1990. At this time abundance was far greater at the constructed flat than the reference area (Figure 3-15). Analysis of the total biomass data resulted in only the time factor (year) being significant (p<0.05) (Table 3-10). Tukey tests of the annual means indicated that only the lowest (1991) and highest (1998) biomass values were significantly different (p<0.05) (Figure 3-16).

Table 3-8. Sheep Island Infaunal Taxa Richness ANOVA Results

Source	DF	Sum Sq.	F Ratio	p
Site	1	38.5333	4.1620	0.0427
Year	4	187.8952	5.0737	0.0006
Site*Year	4	354.4571	9.5713	<0.0001
Error	200	1851.6667	9.258	

Linear Contrasts Results

	1990	1991	1992	1994	1998
Estimate	5.0667	-1.8	-2.067	0.9333	2.4
t Ratio	4.5602	-2.291	-2.631	0.84	2.1601
Prob>|t|	**<0.0001**	0.023	**0.0092**	0.4019	0.032

Table 3-9. Sheep Island Infaunal Total Abundance ANOVA Results

Source	DF	Sum Sq.	F Ratio	p
Site	1	4.1234	28.8302	<0.0001
Year	4	5.2992	9.2627	<0.0001
Site*Year	4	6.5704	11.4846	<0.0001
Error	200	28.6052	0.1430	

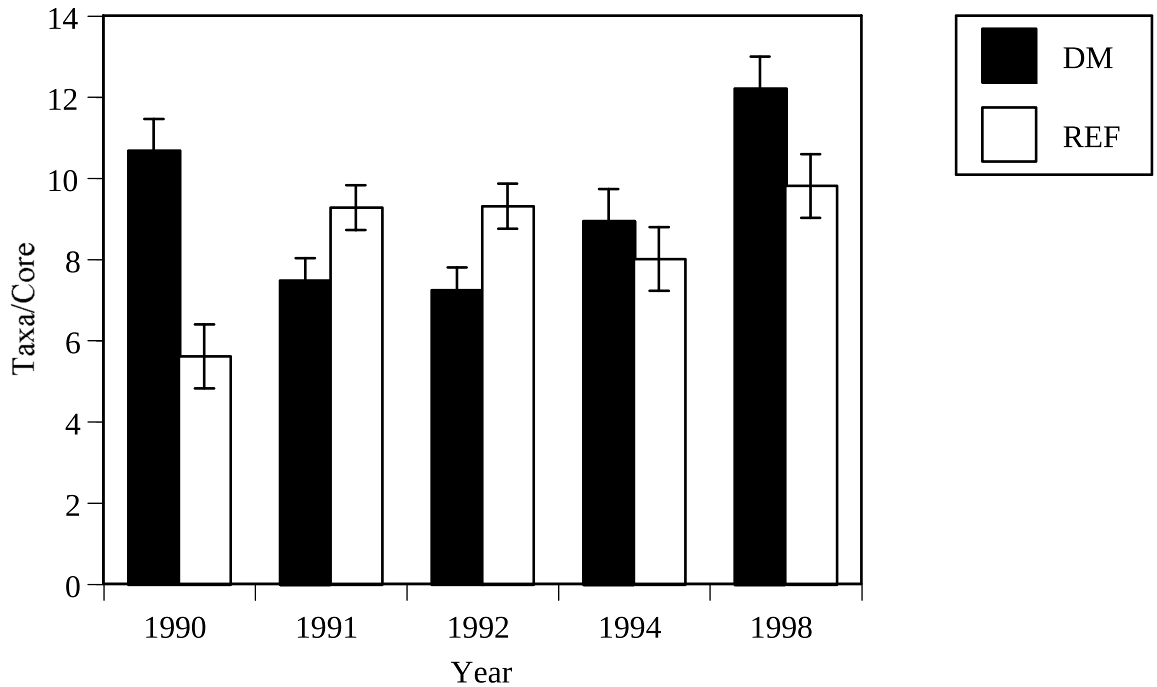
Linear Contrasts

	1990	1991	1992	1994	1998
Estimate	1.0382	-3e-4	0.0111	0.1109	0.3231
Std Error	0.1381	0.0976	0.0976	0.1381	0.1381
Prob>|t|	**<0.0001**	0.9972	0.9097	0.4229	0.0203

Table 3-10. Sheep Island Infaunal Total Biomass ANOVA Results

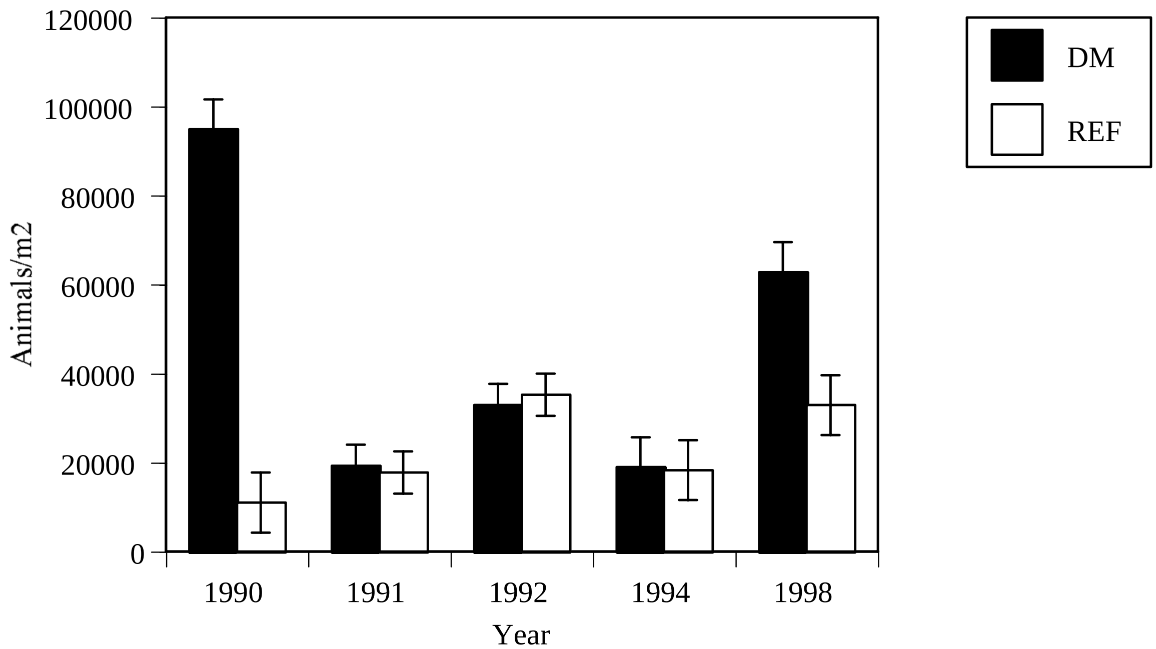
Source	DF	Sum Sq.	F Ratio	p
Site	1	2.4295	3.7316	0.0551
Year	3	6.5773	3.3675	0.0201
Site*Year	3	0.2976	0.1524	0.9281
Error	162	105.4706	0.6511	

Figure 3-14. Infaunal Taxa Richness (Taxa/Core) at Sheep Island*



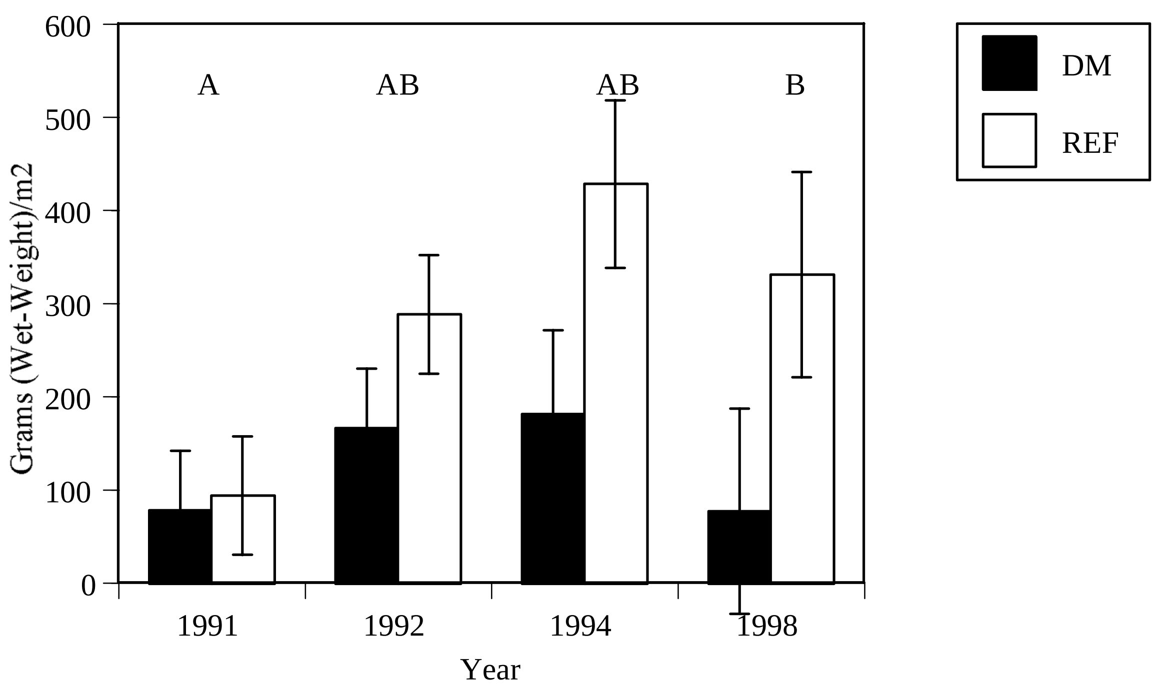
*DM = Constructed Intertidal Flat REF = Reference Site
Values with ****** indicate linear contrasts are significantly different at p <0.01

Figure 3-15. Infaunal Abundance (Animals/m^2) at Sheep Island*



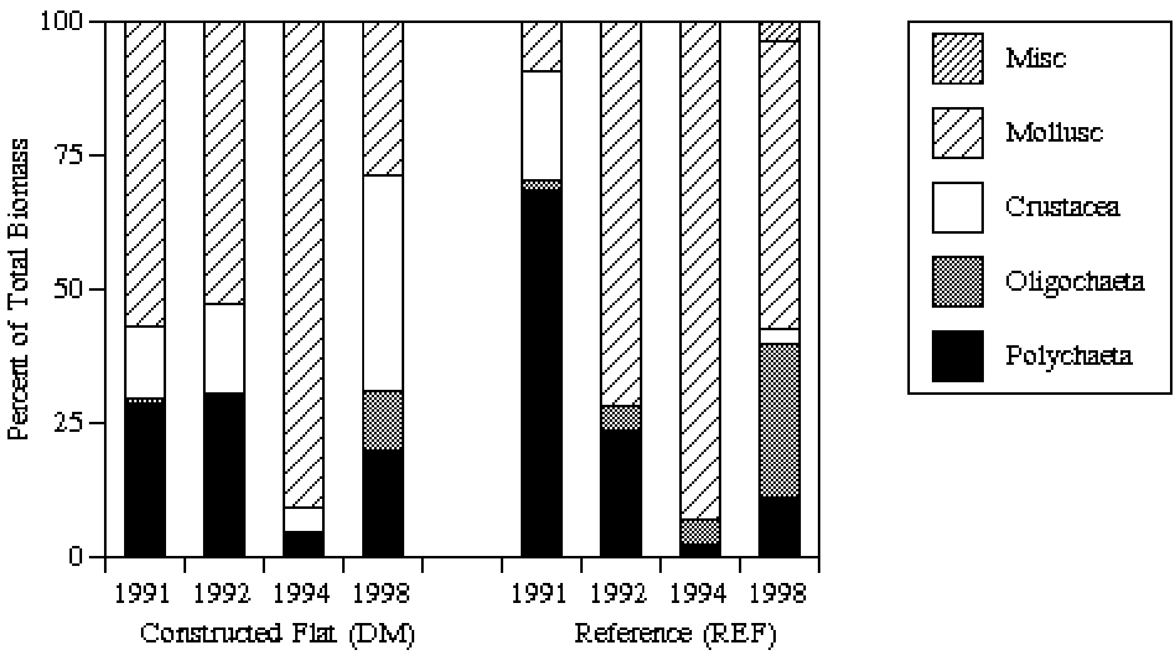
*DM = Constructed Intertidal Flat   REF = Reference Site
Values with ****** indicate linear contrasts are significantly different at p <0.01

Figure 3-16. Infaunal Biomass (Grams Wet-Weight/m^2) at Sheep Island*



The proportion of biomass contributed by major taxonomic groups (e.g., oligochaetes, polychaetes, etc.) differed both among sites and over time (Figure 3-17). In 1991 and 1992, molluscs provided approximately 50% of total biomass at the constructed intertidal flat while polychaetes and crustaceans, respectively, made lesser contributions. By 1994 molluscs accounted for 90% of all biomass at the constructed flat, however, this value fell to 29% in 1998 when crustacean biomass increased from 15% to 40% of total biomass. At the reference area polychaetes were the overwhelming dominant in 1991 (68%), but were replaced by molluscs (53-93%) in subsequent samples. As at the constructed flat, the highest proportion of mollusc biomass was found in 1994.

Figure 3-17. Sheep Island Infaunal Biomass Structure.



Together, the assemblage structure parameters indicate that a diverse and abundant infaunal assemblage was quickly established at the constructed intertidal flat. The absence of site or site by year differences in biomass values also suggests that the assemblage developed rapidly, achieving and maintaining levels comparable to the reference area. The overall dominance of biomass by molluscs and the tendency for periods of particularly high dominance to be identical at both sites (e.g., 1994) also indicates a high degree of similarity between sites.

3.3.1.2 Taxonomic Composition

A total of 90 taxa was collected at the Sheep Island sites between 1990 and 1998: 64 at the constructed intertidal flat and 81 at the reference site (Appendix Table 2). Species composition was similar with 49 of the 90 taxa being present at both sites. A total of twenty five taxa were classified as dominants, i.e., they constituted 1% or more of total numerical abundance or were present in 50% or more of the samples (Tables 3-11; 3-12). None of the dominants were found exclusively at either site.

The most abundant organism was the amphipod Corophium volutator. Reaching a maximum density of 28,000 animals/m^2 in 1992, it was generally most abundant and comprised the greatest proportion of the constructed flat assemblage (Appendix Table 2; Table 3-11; Table 3-12). Next in importance were the oligochaetes Tectidrilus gabriella and Tubificoides benedini. Tectidrilus was the more abundant of the two but its relative importance varied among years: in 1991 and 1992 it was more than twice as numerous as Tubificoides benedini at the constructed flat, but precisely the opposite was true in 1998. Tectidrilus populations at the reference site were at least twice as dense as Tubificoides populations in 1991, 1994, and 1998. The polychaete Capitella sp., the fourth most abundant taxon, was generally more numerous at the reference area than at the constructed flat and was one of the most commonly occurring taxa at both sites. Densities of the fifth most abundant taxon, the amphipod Gammarus oceanicus, varied widely between sites and over time. Highest densities of this species occurred at the constructed flat in 1998 when abundances were over 19,000/m^2 (Appendix Table 2). Of the ten most abundant taxa the remaining five were polychaetes: Exogene hebes, Streblospio benedicti, Fabricia sabella, Pygospio elegans, and Polydora ligni.

Taxonomic composition of the sites was also compared using Nonmetric Multidimensional Scaling (NMDS). As previously noted, differences in the level of taxonomic detail between data from 1990 and the remaining sample collections required two separate sets of comparisons: one between 1990 and 1991 data and a second comparing 1991-1998 collections. NMDS of the 1990-1991 data separated both sites by year but not by great degrees indicating small but persistent differences in species composition (Figure 3-18). Similar results were obtained from NMDS of the 1991-1998 data indicating small but persistent differences among sites (Figure 3-19).

Table 3-11. Relative Abundance and Occurrence of Dominant Taxa at Sheep Island Constructed Intertidal Flat*

	DM 1990		DM 1991		DM 1992		DM 1994		DM 1998	
Taxa	% Abund.	%Occur.	% Abund.	%Occur.	% Abund.	%Occur.	% Abund.	%Occur.	% Abund.	%Occur.
Oligochaeta	5.74	33.33	**20.64**	**53.33**	**2.10**	**40.00**	**52.75**	**33.30**	**37.77**	**100.00**
Tubificoides benedini			0.81	16.67	0.11	10.00	33.06	33.33	19.73	100.00
Tectidrilus gabriella			11.99	53.33	1.96	40.00	19.04	20.00	17.04	60.00
Enchytraeidae			0.00	0.00	0.00	0.00	0.63	0.00	0.85	20.00
Capitella sp.	24.03	93.33	0.51	40.00	1.34	53.33	11.12	93.33	9.97	100.00
Fabricia sabella	0.00	0.00	0.00	0.00	0.00	0.00	3.10	6.67	1.52	13.33
Polydora ligni	4.14	53.33	1.66	73.33	3.17	100.00	2.61	86.67	3.44	93.33
Polydora quadrilobata	22.56	73.33	0.00	10.00	0.16	13.33	0.49	20.00	0.78	73.33
Pygospio elegans	37.25	86.67	1.85	33.33	0.02	3.33	0.19	0.00	0.13	0.00
Streblospio benedicti	0.00	0.00	0.00	0.00	2.47	70.00	8.79	93.33	10.28	100.00
Eteone longa	0.53	20.00	0.00	0.00	0.02	3.33	0.04	20.00	0.26	53.33
Exogene hebes	0.13	6.67	31.76	40.00	0.53	33.33	2.72	20.00	1.46	33.33
Nereis virens	0.80	33.33	1.41	63.33	1.11	70.00	1.67	60.00	1.50	86.67
Ampelisca vadorum	0.00	0.00	1.34	40.00	0.02	3.33	0.12	6.67	0.12	0.00
Corophium volutator	0.80	26.67	7.73	66.67	83.73	100.00	6.76	86.67	14.24	100.00
Corophium bonelli	0.00	0.00	16.29	26.67	0.00	0.00	0.00	0.00	0.03	0.00
Gammarus oceanicus	0.13	6.67	0.38	46.67	3.23	76.67	0.48	66.67	5.37	53.33
Phoxocephalus holbolli	0.27	13.33	7.03	40.00	0.07	10.00	0.33	0.00	0.21	0.00
Edotea montosa	0.00	0.00	0.51	16.67	0.00	0.00	0.66	6.67	0.36	0.00
Jaera marina	0.00	0.00	0.00	0.00	0.20	23.33	0.07	6.67	0.10	6.67
Scottolana canadensis	0.00	0.00	0.26	6.67	0.13	10.00	0.36	6.67	0.28	6.67
Thalassomya sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.31	13.33	0.22	20.00
Mya arenaria	0.40	20.00	0.13	26.67	0.13	16.67	0.38	40.00	0.50	26.67
Mytilus edulis	0.00	0.00	0.00	0.00	0.00	0.00	0.41	6.67	0.51	20.00
Littorina littorea	0.00	0.00	0.00	0.00	0.00	0.00	0.98	80.00	1.93	0.00
Hydrobia sp.	0.00	0.00	0.00	0.00	0.00	0.00	3.79	86.67	5.66	100.00

*Values in bold represent total for group.

Table 3-12. Relative Abundance and Occurrence of Dominant Taxa at Sheep Island Reference Site*

	REF 1990		Ref 1991		REF 1992		REF 1994		REF 1998	
Taxa	% Abund.	%Occur.	% Abund.	%Occur.	% Abund.	%Occur.	% Abund.	%Occur.	% Abund.	%Occur.
Oligochaeta	66.90	100.00	**34.19**	**86.67**	**66.27**	**100.00**	**48.34**	**93.33**	**36.61**	**66.67**
Tubificoides benedini			1.26	33.33	43.81	100.00	26.90	93.33	17.34	66.67
Tectidrilus gabriella			26.02	83.33	21.57	56.67	20.30	93.33	17.31	66.67
Enchytraeidae			0.00	0.00	0.87	13.33	1.07	26.67	1.54	66.67
Capitella sp.	7.57	100.00	1.46	50.00	12.66	83.33	9.58	53.33	10.36	60.00
Fabricia sabella	10.37	86.67	0.00	0.00	4.27	50.00	2.34	6.67	1.50	33.33
Polydora ligni	1.00	60.00	3.72	80.00	1.17	70.00	3.42	46.67	3.20	46.67
Polydora quadrilobata	1.65	53.33	0.24	13.33	0.21	13.33	0.67	13.33	0.81	20.00
Pygospio elegans	7.19	80.00	2.68	63.33	0.12	16.67	0.18	0.00	0.10	0.00
Streblospio benedicti	0.00	0.00	0.00	0.00	7.77	80.00	8.40	66.67	10.38	33.33
Eteone longa	0.00	0.00	0.00	0.00	0.00	0.00	0.14	20.00	0.35	33.33
Exogene hebes	0.50	46.67	32.42	76.67	2.54	53.33	2.15	20.00	1.15	20.00
Nereis virens	0.03	6.67	1.10	76.67	1.25	86.67	1.72	60.00	1.46	46.67
Ampelisca vadorum	0.02	6.67	1.95	43.33	0.06	10.00	0.15	6.67	0.10	0.00
Corophium volutator	0.02	6.67	1.22	56.67	0.21	20.00	8.30	13.33	13.83	33.33
Corophium bonelli	0.00	0.00	7.43	46.67	0.00	0.00	0.02	0.00	0.03	0.00
Gammarus oceanicus	0.38	26.67	0.12	20.00	0.29	13.33	0.88	46.67	7.50	46.67
Phoxocephalus holbolli	0.08	26.67	6.64	63.33	0.21	30.00	0.31	0.00	0.16	0.00
Edotea montosa	0.08	20.00	0.37	26.67	0.54	43.33	0.55	0.00	0.34	20.00
Jaera marina	0.33	26.67	0.00	0.00	0.04	6.67	0.10	6.67	0.13	26.67
Scottolana canadensis	0.00	0.00	0.18	3.33	0.21	26.67	0.35	0.00	0.26	13.33
Thalassomya sp.	0.00	0.00	0.00	0.00	0.25	30.00	0.28	0.00	0.26	20.00
Mya arenaria	0.08	33.33	0.00	3.33	0.19	20.00	0.56	46.67	0.47	33.33
Mytilus edulis	0.05	20.00	0.00	0.00	0.31	13.33	0.52	40.00	0.45	13.33
Littorina littorea	0.20	33.33	0.00	0.00	0.04	6.67	2.12	93.33	1.46	0.00
Hydrobia sp.	0.00	0.00	0.00	0.00	0.00	0.00	5.65	13.33	5.33	0.00

*Values in bold represent total for group.

Figure 3-18. Nonmetric Multidimensional Scaling for Sheep Island 1990-1991

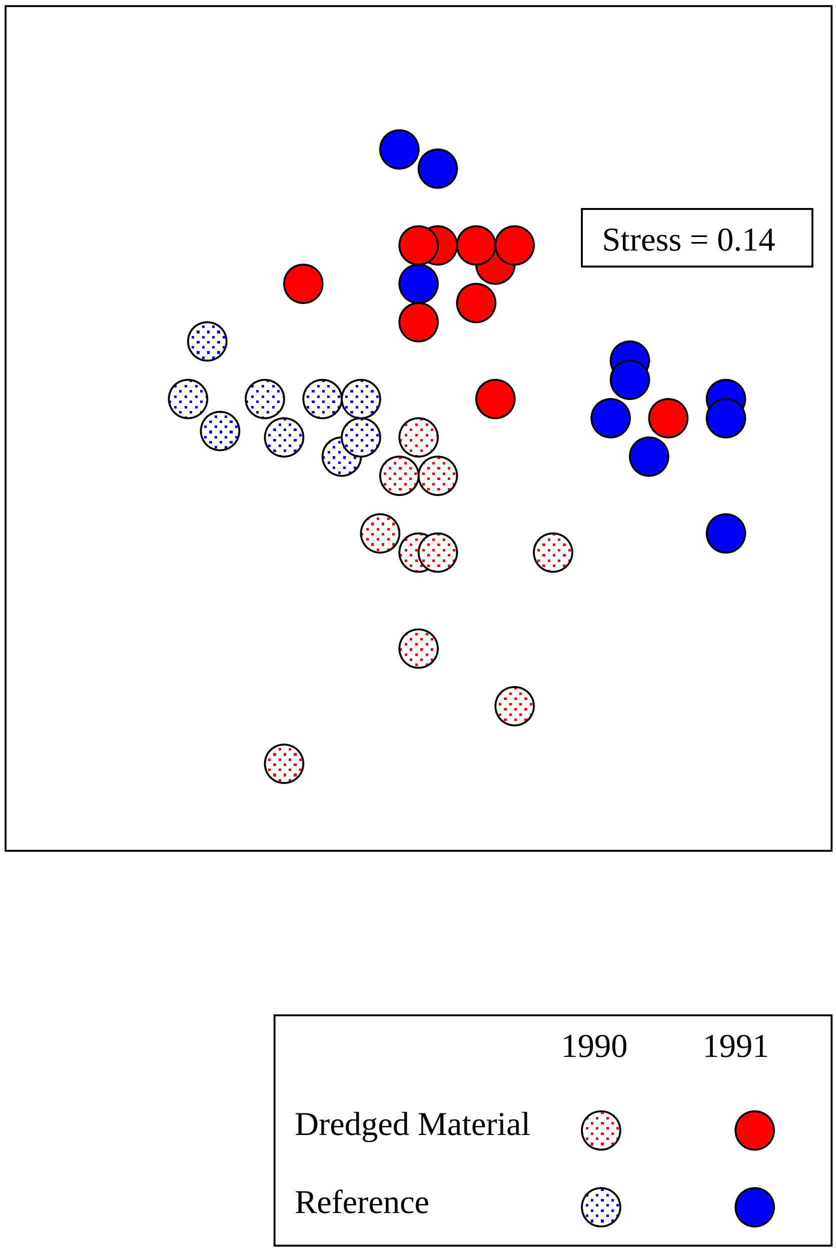
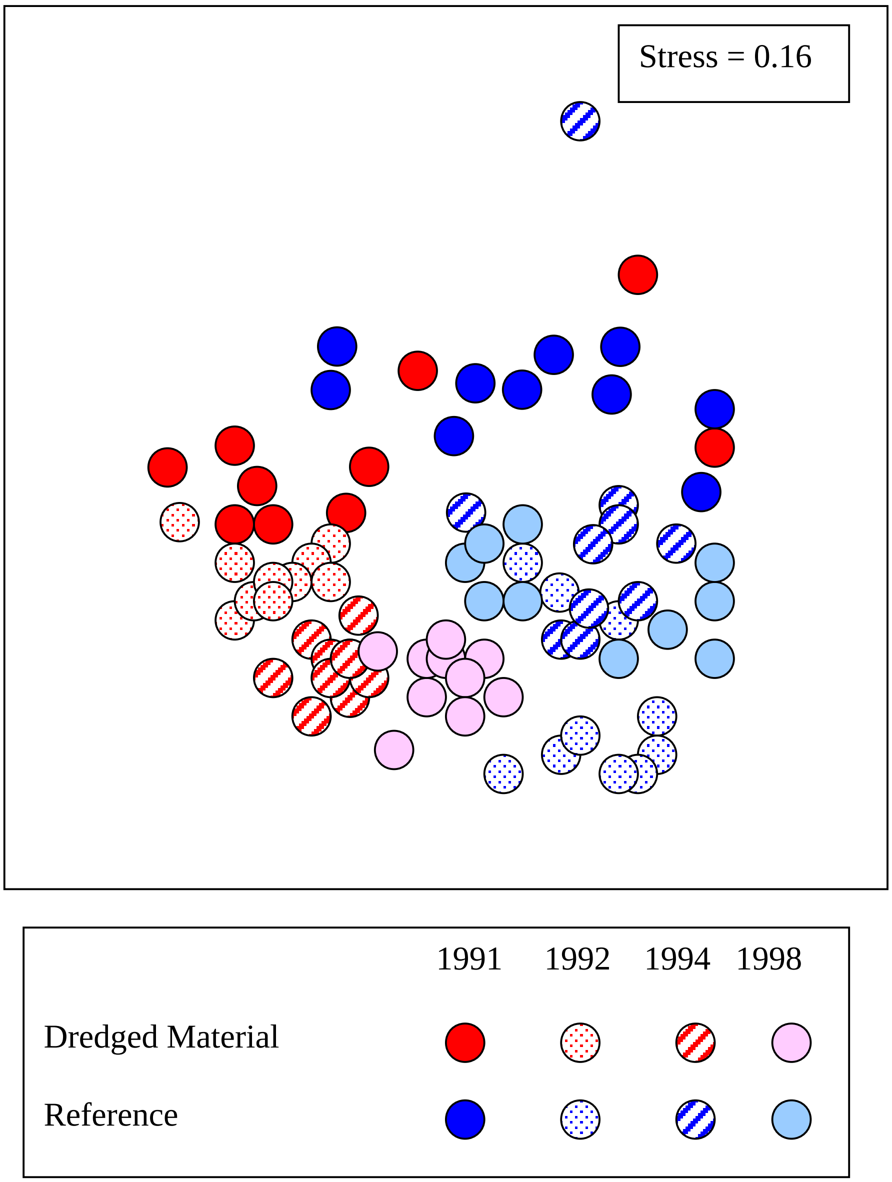


Figure 3-19. Nonmetric Multidimensional Scaling for Sheep Island 1991-1998



SIMPER results compliment the comparisons of taxonomic composition and NMDS results. In 1990 the constructed intertidal flat and reference sites were distinguished primarily by higher densities of oligochaetes, the polychaetes Fabricia sabella, Pygospio elegans, and the amphipod Gammarus oceanicus at the reference site, and Polydora quadrilobata at the constructed flat (Table 3-13). After 1990, oligochaetes, specifically Tectadrilus gabriella, contributed greatly to overall site dissimilarity and was always more abundant at the reference site. Tubificoides benedini, another oligochaete, was also generally more abundant at the reference site and was one of the five taxa contributing strongly to dissimilarity in 1992 and 1994. The amphipod Corophium volutator, another taxon making a large contribution to dissimilarity, was always most abundant at the dredged material site. The polychaete Polydora quadrilobata was most abundant at the constructed flat in 1990 and again in 1998. The remaining taxa among the top five taxa contributing to dissimilarity in any given year were inconsistent in their distributions, i.e., they would be most abundant at the constructed flat one year and at the reference area in another. For instance, the polychaete Exogene hebes was most abundant at the constructed flat in 1991, but in preceding and subsequent years it was most abundant at the reference site.

In summary, taxonomic composition, NMDS, and SIMPER results indicate that taxonomic structure of the Sheep Island constructed flat assemblage was slightly but persistently different from that of the reference area. Differences arose from the relative abundance of a few dominant taxa, the most important of which were the oligochaetes Tectadrilus gabriella and Tubificoides benedini at the reference site and the amphipod Corophium volutator at the constructed flat. Relative abundances of the remaining dominant taxa were inconsistent or contributed little to taxonomic similarity.

Table 3-13. Similarity Percentage (SIMPER) Results for Sheep Island Constructed Flat vs Reference Comparisons by Year*

Year	1990	1991	1992	1994	1998
Average Dissimilarity	60.42	62.08	72.41	62.51	53.34
Taxa					
Oligochaeta	**27.76**^{R}	**12.42**$^{R+}$	------	------	------
Tectidrilus gabriella	------	**13.38**^{R}	5.65	**14.18**^{R}	**11.99**^{R}
Corophium volutator	1.90	**12.77**^{D}	**18.58**^{D}	**12.96**^{D}	**7.75**^{D}
Exogene hebes	5.28	**12.13**^{D}	3.82	1.11	2.87
Phoxocephalus holbolli	3.78	**7.99**^{D}	2.28	------	------
Polydora ligni	7.06	**7.50**^{R}	4.34	**7.16**	4.94
Fabricia sabella	**15.80**^{R}	------	6.36	0.87	4.98
Pygospio elegans	**9.27**^{D}	5.86	0.51	------	------
Clymenella torquata	3.27	6.68	------	------	------
Corophium bonelli	-----	5.42	------	------	------
Ampelisca vadorum	-----	5.28	1.23	1.27	------
Nereis virens	0.66	5.27	3.74	4.08	3.99
Gammarus oceanicus	**7.95**^{R}	4.58	**7.61**^{D}	**5.35**^{R}	4.94
Capitella sp.	6.75	4.57	**8.43**^{R}	**6.59**^{D}	3.99
Tubificoides benedini	-----	4.19	**16.04**^{R}	**10.04**^{R}	4.52
Edotea montosa	-----	2.89	3.95	------	2.12
Mya arenaria	-----	2.86	2.09	3.67	2.98
Polydora quadrilobata	**9.50**^{D}	2.83	2.01	1.34	**5.38**^{D}
Gammarus annulatus	1.03	-----	-----	-----	-----
Scottolana canadensis	-----	2.47	0.62	0.69	1.92
Hydrobia sp.	-----	------	------	**11.53**^{D}	**------**
Streblospio benedicti	-----	------	**6.54**^{R}	6.38	**11.18**^{D}
Thalassomya sp.	-----	------	2.27	1.39	2.68
Mytilus edulis	-----	------	0.78	2.27	2.21
Littorina littorea	-----	------	------	4.63	------
Jaera marina	-----	------	2.00	0.74	2.69
Enchytraeidae	-----	------	1.16	1.60	4.48
Eteone longa	-----	------	------	2.17	3.16

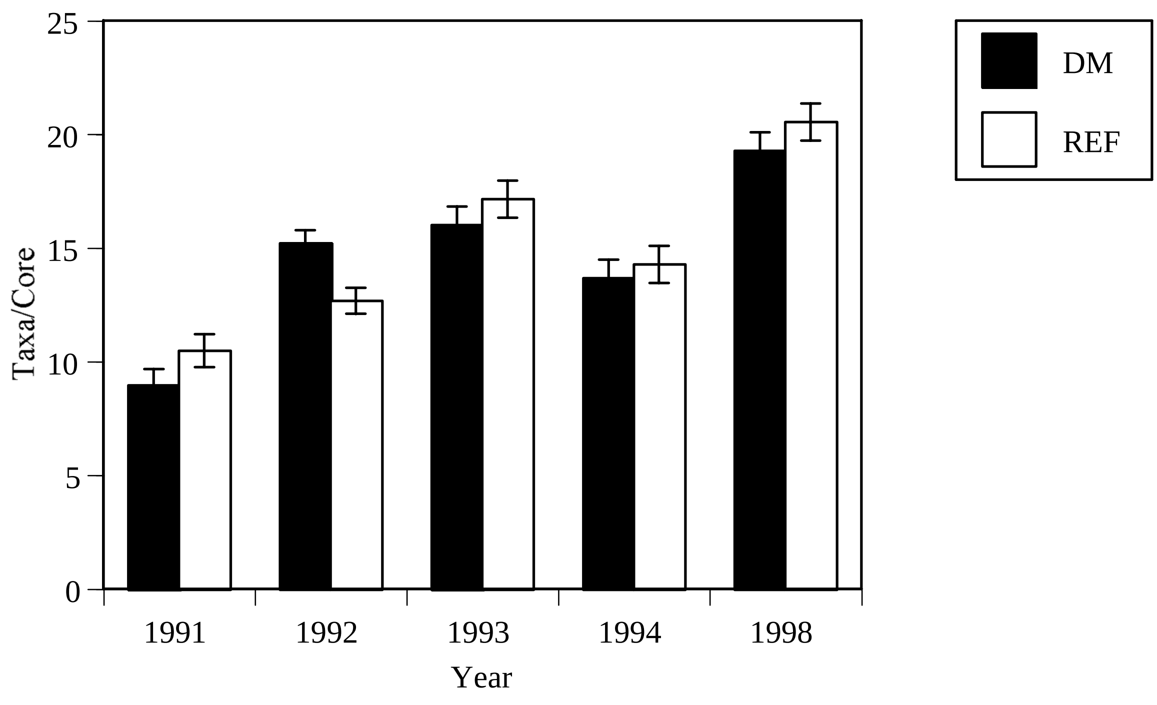
*Values in bold are the five taxa contributing the most to dissimilarity for a comparison. Superscripts indicate where abundances were highest (D= Constructed Flat; R = Reference); $^{+}$ indicates oligochaetes treated as single taxon for test.

3.3.2 Beals Island

3.3.2.1 Assemblage Structure

ANOVA of Beals Island infaunal taxa richness data indicated that sites differed significantly ($p<0.05$) among years (Table 3-14). Linear contrasts of site by year means showed that constructed flat values differed from reference values ($p<0.01$) only in 1992 (Table 3-14) when taxa/core were highest at the constructed flat (Figure 3-20). Total numerical abundance also differed among sites over time, however, abundances were far greater at the reference area than the constructed flat (Figure 3-21) in all years except 1991 (Table 3-15). Total biomass was higher at the reference area than the constructed flat in all years except 1994 (Table 3-16; Figure 3-22).

Figure 3-20. Infaunal Taxa Richness (Taxa/Core) at Beals Island**



*DM = Constructed Intertidal Flat   REF = Reference Site
Values with **** indicate linear contrasts are significantly different at p <0.01

Figure 3-21. Infanual Abundance (Animals/m^2) at Beals Island*

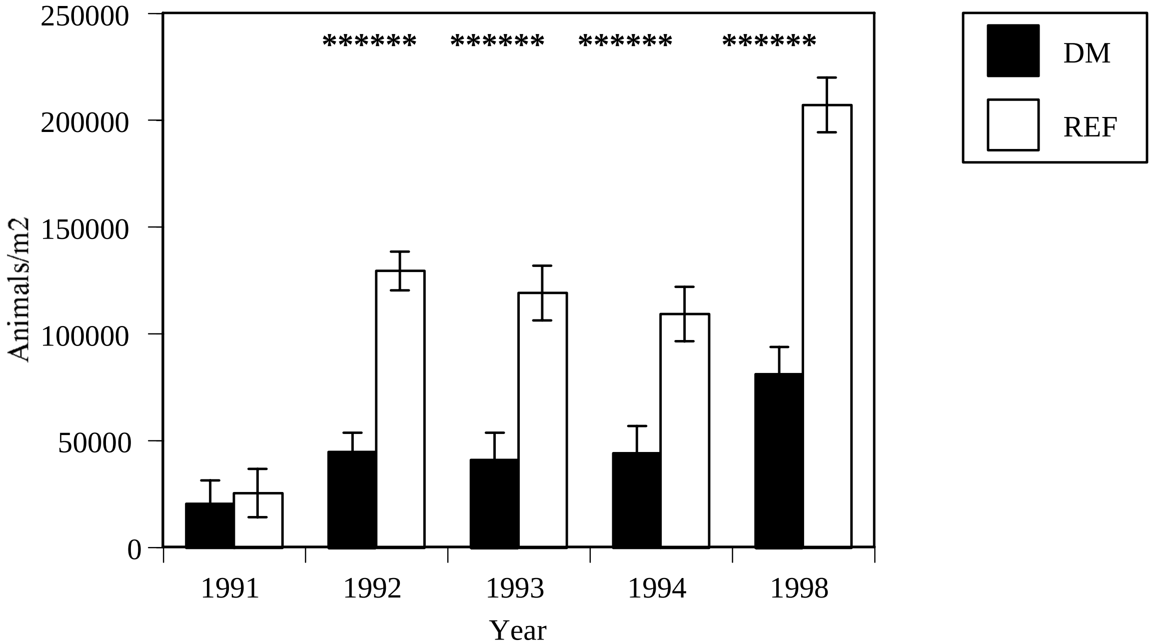


Table 3-14. Beals Island Infaunal Taxa Richness ANOVA Results

Source	DF	Sum Sq.	F Ratio	p
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	

Linear Contrasts Results

	1991	1992	1993	1994	1998
Estimate	-1.524	2.533	-1.133	-0.600	-1.267
t Ratio	-1.509	3.113	-0.985	-0.521	-1.101
Prob>|t|	0.133	**0.002**	0.326	0.6027	0.275

Table 3-15. Beals Island Infaunal Total Abundance ANOVA Results

Source	DF	Sum Sq.	F Ratio	p
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
Error	179	13.3092	0.0744	

Linear Contrasts

	1991	1992	1993	1994	1998
Estimate	-0.092	-0.436	-0.508	-0.395	-0.450
Std Error	0.087	0.070	0.099	0.099	0.099
Prob>|t|	0.2960	**<0.0001**	**<0.0001**	**0.0001**	**<0.0001**

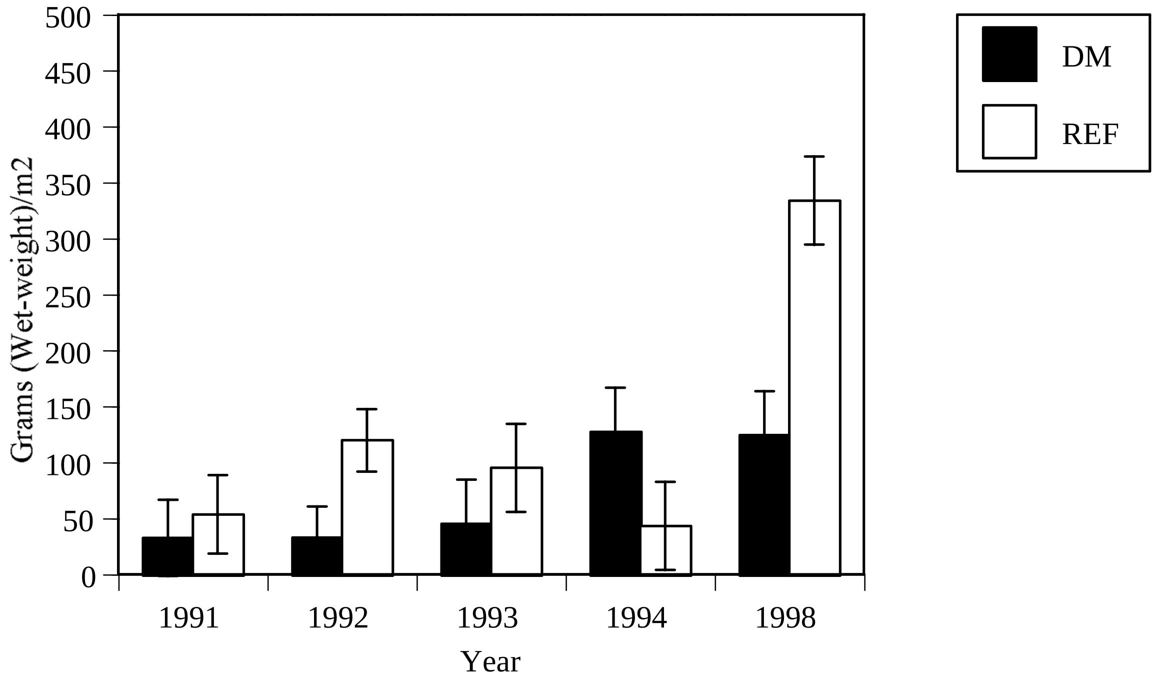
Table 3-16. Beals Island Infaunal Total Biomass ANOVA Results

Source	DF	Sum Sq.	F Ratio	p
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	

Linear Contrasts

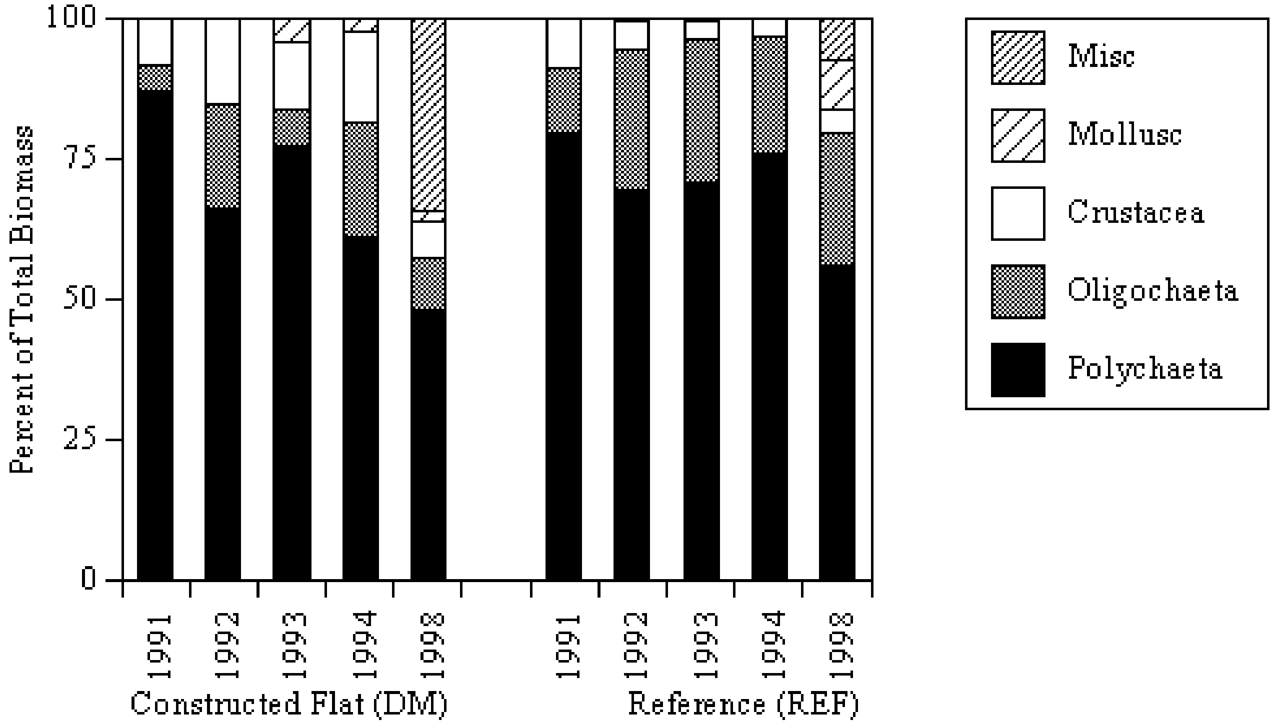
		1991	1992	1993	1994	1998
Estimate	-0.333	-0.702	-0.497	0.598	-0.431	
Std Error	0.128	0.103	0.149	0.146	0.146	
Prob>|t|	0.0102	**<0.0001**		**0.001**	**0.0001**	**0.0036**

Figure 3-22. Infaunal Biomass (Grams Wet-weight/m^2) at Beals Island*



Biomass structure was slightly different between sites, but was relatively consistent over time (Figure 3-23). Polychaetes constituted the majority of biomass at both sites with oligochaetes being second most important at the reference site and oligochaetes or crustaceans being second most important at the constructed flat. Molluscs contributed relatively little while miscellaneous groups formed a substantial amount of biomass only in 1998 when a number of large nemerteans were present (personal observation).

Figure 3-23. Beals Island Infaunal Biomass Structure



3.3.2.2 Taxonomic Composition

A total of 78 taxa was collected at the Beals Island sites between 1991 and 1998: Sixty-nine taxa were collected at the constructed flat and 65 at the reference area. A total of thirty-three taxa were classified as dominants (Tables 3-17; 3-18). None of the dominants were found exclusively at either site.

Table 3-17. Relative Abundance and Occurrence of Dominant Taxa at Beals Island Constructed Intertidal Flat

	DM 1991		DM 1992		DM 1993		DM 1994		DM 1998	
Taxa	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.
Tubificoides benedini	13.05	45.00	4.66	60.00	0.88	60.00	5.12	73.33	11.78	100.00
Tectidrilus gabriella	19.10	75.00	30.28	100.00	30.02	100.00	24.35	100.00	17.46	100.00
Tubificoides netheroides	1.27	15.00	1.25	56.67	1.75	26.67	0.40	6.67	3.16	66.67
Tubificoides sp.	0.91	40.00	1.12	16.67	2.50	66.67	0.80	26.67	0.00	0.00
Enchytraeidae	0.00	0.00	0.53	10.00	0.00	0.00	0.00	0.00	0.44	13.33
Capitella sp.	5.09	5.00	1.80	26.67	0.77	53.33	1.25	46.67	12.83	86.67
Heteromastus filiformis	1.11	40.00	0.83	46.67	0.44	26.67	0.51	46.67	0.44	26.67
Clymenella torquata	3.71	30.00	1.65	26.67	0.44	6.67	1.20	33.33	0.88	26.67
Fabricia sabella	0.00	0.00	0.63	40.00	0.44	13.33	0.00	0.00	0.33	13.33
Polydora ligni	2.68	75.00	2.15	76.67	3.65	80.00	4.59	93.33	1.32	86.67
Polydora quadrilobata	5.98	50.00	3.83	70.00	0.82	53.33	0.50	26.67	6.10	86.67
Pygospio elegans	3.77	70.00	5.41	93.33	7.13	100.00	0.00	0.00	0.00	0.00
Spio setosa	0.00	0.00	0.00	0.00	0.00	0.00	5.06	80.00	0.22	6.67
Streblospio benedicti	3.13	70.00	12.29	96.67	7.60	93.33	8.26	86.67	3.57	100.00
Eteone longa	0.64	5.00	0.00	0.00	0.66	40.00	0.48	33.33	0.66	66.67
Phylloduce arenae	0.00	0.00	0.00	0.00	0.00	0.00	0.40	33.33	1.89	100.00
Exogene hebes	7.64	45.00	0.00	0.00	2.25	46.67	4.69	53.33	4.14	60.00
Exogene verugera	0.00	0.00	3.06	50.00	0.00	0.00	0.00	0.00	0.00	0.00
Nereis virens	1.11	40.00	2.30	83.33	2.77	100.00	4.53	93.33	2.60	100.00
Glycera dibranchiata	0.85	15.00	0.40	16.67	0.44	13.33	0.80	6.67	0.00	0.00
Ampelisca vadorum	12.52	95.00	8.90	96.67	10.95	100.00	15.73	100.00	8.34	100.00
Corophium volutator	0.95	10.00	1.36	73.33	2.82	60.00	0.00	0.00	1.12	53.33
Gammarus oceanicus	0.64	5.00	0.99	63.33	0.99	53.33	4.86	73.33	3.46	93.33
Edotea montosa	1.06	15.00	0.71	46.67	1.27	60.00	1.52	33.33	1.96	93.33
Idotea balthica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	13.33
Oxyurostlis smithi	0.64	10.00	0.75	53.33	0.66	40.00	0.40	13.33	0.22	6.67
Scottolana canadensis	0.64	5.00	3.47	93.33	0.80	40.00	1.40	13.33	0.80	40.00

Table 3-17 (Cont.). Relative Abundance and Occurrence of Dominant Taxa at Beals Island Constructed Intertidal Flat

	DM 1991		DM 1992		DM 1993		DM 1994		DM 1998	
Taxa	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.
Crangon septemspinosus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	46.67
Thalassomya sp.	0.00	0.00	0.40	26.67	0.44	6.67	0.40	6.67	0.34	46.67
Mya arenaria	1.06	15.00	0.40	3.33	0.00	0.00	0.00	0.00	0.22	26.67
Gemma gemma	0.00	0.00	0.00	0.00	0.44	6.67	0.40	20.00	0.37	20.00
Hydrobia sp.	0.00	0.00	0.00	0.00	2.15	80.00	2.20	66.67	0.40	40.00
Nemertea	0.00	0.00	0.40	6.67	0.00	0.00	0.40	13.33	0.33	26.67

Table 3-18. Relative Abundance and Occurrence of Dominant Taxa at Beals Island Reference Site

	REF1991		REF1992		REF1993		REF1994		REF1998	
Taxa	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.
Tubificoides benedini	22.28	100.00	25.07	100.00	15.85	100.00	17.96	100.00	18.94	100.00
Tectidrilus gabriella	9.64	36.84	0.68	20.00	3.72	93.33	8.54	100.00	4.19	100.00
Tubificoides netheroides	1.61	5.26	0.31	3.33	1.54	86.67	0.62	33.33	1.64	86.67
Tubificoides sp.	11.25	10.53	0.00	0.00	0.17	6.67	0.23	26.67	0.00	0.00
Enchytraeidae	0.00	0.00	0.00	0.00	0.44	40.00	0.37	13.33	0.68	33.33
Capitella sp.	1.95	57.89	11.31	100.00	9.11	100.00	5.41	100.00	10.42	100.00
Heteromastus filiformis	0.84	36.84	0.61	66.67	0.58	80.00	0.90	80.00	0.44	53.33
Clymenella torquata	4.62	68.42	1.39	73.33	0.64	93.33	1.06	80.00	1.24	60.00
Fabricia sabella	0.00	0.00	1.10	63.33	0.48	60.00	0.18	13.33	5.21	93.33
Polydora ligni	1.68	78.95	0.49	40.00	0.86	60.00	1.82	73.33	0.36	93.33
Polydora quadrilobata	5.96	84.21	0.92	33.33	1.06	46.67	2.52	86.67	3.28	80.00
Pygospio elegans	5.89	5.26	0.00	0.00	1.21	20.00	0.00	0.00	0.00	0.00
Spio setosa	0.00	0.00	0.00	0.00	0.17	6.67	0.00	0.00	0.00	0.00
Streblospio benedicti	5.74	89.47	14.09	100.00	15.46	100.00	24.99	100.00	10.36	100.00
Eteone longa	0.54	10.53	0.00	0.00	0.17	33.33	0.26	33.33	0.31	46.67
Phylloduce arenae	0.00	0.00	0.00	0.00	0.00	0.00	0.18	13.33	0.35	60.00
Exogene hebes	5.32	78.95	0.00	0.00	35.76	100.00	20.09	100.00	19.07	93.33
Exogene verugera	0.00	0.00	27.45	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Nereis virens	0.80	10.53	0.41	16.67	0.79	66.67	0.37	53.33	0.25	53.33
Glycera dibranchiata	0.54	21.05	0.16	20.00	0.17	26.67	0.18	13.33	0.00	0.00
Ampelisca vadorum	5.73	68.42	0.34	60.00	1.36	53.33	1.38	26.67	2.57	46.67
Corophium volutator	0.00	0.00	0.19	13.33	0.17	13.33	0.00	0.00	0.36	20.00
Gammarus oceanicus	0.98	31.58	9.26	86.67	2.44	33.33	6.52	80.00	2.60	73.33
Edotea montosa	1.25	47.37	1.30	56.67	1.70	86.67	1.87	73.33	1.27	66.67
Idotea balthica	0.00	0.00	0.16	10.00	0.00	0.00	0.18	13.33	0.14	46.67
Oxyurostlis smithi	0.75	26.32	0.25	43.33	0.40	60.00	0.00	0.00	0.09	33.33
Scottolana canadensis	0.54	10.53	0.25	26.67	0.17	13.33	0.00	0.00	0.00	0.00

Table 3-18 (Cont.). Relative Abundance and Occurrence of Dominant Taxa at Beals Island Reference Site

	REF1991		REF1992		REF1993		REF1994		REF1998	
Taxa	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.	%Abund.	%Occur.
Crangon septemspinosus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	46.67
Thalassomya sp.	1.07	5.26	1.06	86.67	0.39	60.00	0.49	60.00	1.10	86.67
Mya arenaria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	26.67
Gemma gemma	0.00	0.00	0.19	13.33	0.00	0.00	0.18	20.00	0.34	60.00
Hydrobia sp.	0.00	0.00	0.00	0.00	0.19	40.00	0.41	26.67	3.87	93.33
Nemertea	0.54	5.26	0.26	33.33	0.00	0.00	0.25	20.00	0.21	53.33

The ten most abundant taxa included (in order of abundance) Tubificoides benedini, Exogene hebes and Streblospio benedicti, Tectadrilus gabriella, Capitella sp., the amphipod Ampelisca vadorum, E. verugera, the amphipods Gammarus oceanicus and Phoxocephalus holbolli, and Polydora quadrilobata (Appendix Table 3). Tubificoides benedini, S. benedicti and G. oceanicus were always most abundant at the reference area while T. gabriella and A. vadorum were always most abundant at the constructed flat. Exogene hebes, Capitella sp. and P. quadrilobata were most abundant at the constructed flat in 1991, but were more abundant in ensuing samples at the reference area. The opposite was true for P. holbolli. Exogene verugera was found in exceptionally high densities in 1992.

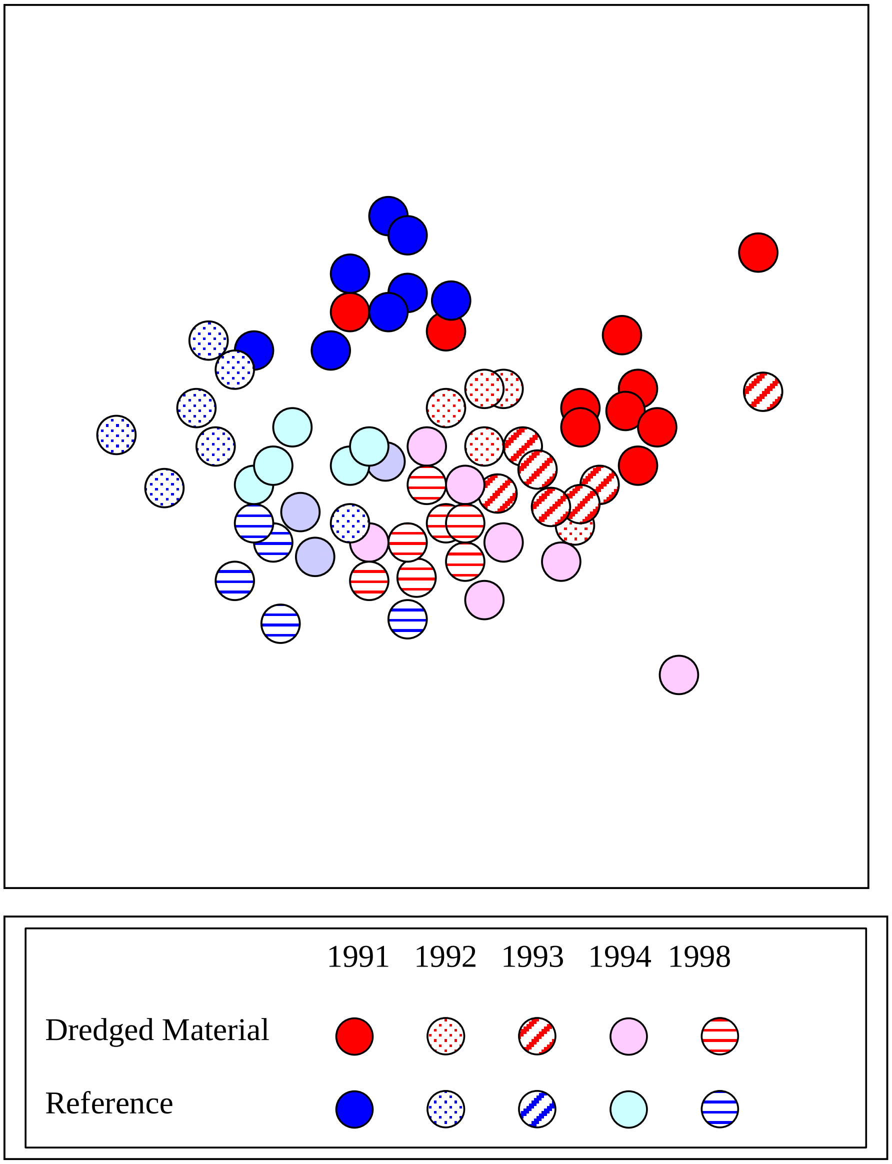
NMDS of the Beals Island data produced a result similar to that found at Sheep Island. There was a small but persistent difference in taxonomic composition of the assemblages (Figure 3-24). As might be expected, SIMPER results corresponded closely with patterns detected in comparisons of the relative abundances (Table 3-19). Tubificoides benedini, the overall dominant, contributed greatly to dissimilarity and was found in highest abundance at the reference site. Capitella sp. and Exogene hebes also contributed substantially to structural differences between assemblages and were most abundant at the reference site. Other taxa with high abundances at the constructed site included Tectadrilus gabriella and A. vadorum. Exogene verugera and Fabricia sabella both contributed to dissimilarity, but only during a single sample period (1992 and 1994 respectively). As at Sheep Island, the results of the Beals Island taxonomic composition analyses indicated the assemblages were composed of basically the same suite of taxa but in relatively different proportions. These differences persisted over time for the most abundant taxa, but varied between years for the less abundant forms.

Table 3-19. Similarity Percentage (SIMPER) Results for Beals Island Constructed Flat vs Reference Comparisons by Year*

Year	1991	1992	1993	1994	1998
Average Dissimilarity	56.86	60.15	56.33	49.33	45.47
Tubificoides benedini	**12.68^{R}**	**8.42^{R}**	**8.56^{R}**	**8.97^{R}**	**5.24^{R}**
Tectidrilus gabriella	**9.04^{D}**	**8.93^{D}**	4.52	2.21	2.73
Polydora quadrilobata	**6.93**	4.46	2.65	**5.72^{R}**	4.19
Ampelisca vadorum	**6.73^{D}**	4.67	**5.44^{D}**	**6.74^{D}**	4.87
Clymenella torquata	6.30	3.29	4.34	3.75	3.21
Streblospio benedicti	6.27	3.87	4.52	**8.39^{D}**	**5.77^{D}**
Pygospio elegans	6.13	**5.82^{D}**	**5.63^{D}**	------	------
Exogene hebes	5.87	------	**10.52^{R}**	**8.99^{R}**	**8.14^{R}**
Capitella sp.	4.78	**9.19^{R}**	**7.07^{R}**	5.17	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	2.6	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	------
Gammarus oceanicus	2.40	3.81	2.51	3.82	3.04
Tubificoides netheroides	2.07	3.44	4.78	2.23	4.06
Mya arenaria	1.36	0.40	------	------	1.71
Oxyurostylis smithi	1.31	2.21	2.24	0.38	1.33
Eteone longa	1.24	------	1.77	2.29	2.61
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^{R}**
Exogene verugera	------	**8.31^{R}**	------	------	------
Idotea balthica	------	0.31	------	0.83	1.97
Spio setosa	------	------	0.43	5.44	0.32
Hydrobia sp.	------	------	3.34	3.34	5.43
Phyllodoce arenae	------	------	------	1.55	2.62
Gemma gemma	------	------	------	1.40	2.43
Crangon septemspinosus	------	------	------	------	2.11

*Values in bold are the five taxa contributing the most to dissimilarity for a comparison. Superscripts indicate where abundances were highest (D= Constructed Flat; R = Reference).

Figure 3-24. Nonmetric Multidimensional Scaling Plot for Beals Island 1991-1998



4.0 DISCUSSION

Intertidal flats are important to the ecology and commercial fisheries of the New England region. They produce substantial amounts of primary production in a form that is immediately utilizable by consumer groups which in turn, provides forage for both commercial fisheries species and migratory shorebirds (Peterson and Peterson, 1979; Whitlach, 1982). In addition, intertidal flats support soft-clam and bait-worm fisheries which are of direct importance to local economies (Brown, 1993). As with other coastal resources, habitat loss or degradation of habitat function is a continuing concern. While restoration or replacement of coastal habitats such as salt marshes has received considerable attention over the years, the potential for construction of unvegetated intertidal habitats has largely been ignored and the potential for beneficial use of dredged material in construction of such habitats has remained relatively unexplored.

Overall, the project has been a success. Initial concerns that erosion would degrade the site appear to have been groundless. Although no topographic survey has been conducted since construction of the flat to directly measure changes in size or shape, repeated visual observation over nine years, including aerial photography, indicates that the physical integrity of the site has not been compromised (Figure 1-2; Figure 1-3). The flat still extends from the midpoint of the western side of Sheep Island to a small rocky outcrop near the northern end of the island (Figure 1-2). It has retained a roughly triangular shape at low tide and there is no physical evidence of erosion, e.g., no apparent decline in height or maximum extent from the shoreline (personal observation). Sediment texture of the constructed flat and reference areas has remained constant over time with the exception of 1994 when both sites had increased proportions of coarse materials (Figure 3-1). Sediment organic content has always been highest at the constructed flat, a reflection of the finer sediments present at this site, and although organic contents declined over time the decline was similar at both sites.

The project was also successful in that populations of soft-clams (M. arenaria) and clam-worms (N. virens) were established at the constructed flat. Of the two species, clearly the soft-clams were the most successful, with commercial-size clams (~50 mm) being present as early as 1992 (Figure 3-7). The continuing presence of adult clams in 1998 (Appendix Table 1) and smaller clams throughout the study (Figure 3-5) indicate that the soft-clam population is firmly established. Anecdotal evidence in the form of personal observations of rakers on the flat in 1994 and the presence of numerous raking pits on the flat's surface in 1998 are also indicative of a viable clam population. A clam-worm population was also established at the constructed site. Small worms have been consistently present throughout the study (Figure 3-8) and large worms were abundant in both 1991 and 1992. The absence of large worms in 1998 might seem to belie the conclusion that a clam-worm population has been established, but evidence from long-term monitoring of worm populations and life-history information indicate that periodic population "crashes" may be characteristic of the species. Monitoring of populations of the congener N. diversicolor in the middle reaches of the Forth estuary (Scotland) over a 35 year period detected periodic declines in abundance (McLusky and Martins, 1998). Similar patterns are evident in abundances of intertidal populations of the same species from the German coast (Dorjes, Michaelis, and Rhode, 1986). The periods of decline appear to occur at 5-6 year intervals or multiples of this interval which coincides with the reproductive period of the species. During reproduction the adult worms emerge from the sediment and swarm at the surface. After reproduction the adults disperse or die resulting in periodic disappearance of adult worms from the sediment. Nereis virens has an expected life span of seven years and shares most of the life-history characteristics of N. diversicolor including its reproductive behaviors (Pettibone, 1963). While other factors cannot be excluded in accounting for the absence of large worms, the simultaneous absence of large worms from both sites and the coincidence of the time period with the clam-worm's life span suggest the 1998 data are the result of normal interannual variation. Alternative explanations are obviously possible and include over-harvesting or some non-site selective disturbance (e.g., pollutant release, ice-scouring, etc.). There is no objective way of distinguishing between the potential explanations from the present database.

Finally, a healthy infaunal community has been established at the constructed flat. The infaunal assemblage is similar to the reference area in respect to taxa richness (Figure 3-14) and abundance (Figure 3-15). Diversity of the Sheep Island sites is also comparable to other North Atlantic intertidal assemblages (Table 4-1). Diversity, as measured by Shannon-Wiener's H', ranged from 1.18 to 2.88 at the constructed flat and 1.84 to 3.05 at the reference area. These ranges closely correspond to H' values reported for other Maine intertidal flats (e.g., Larsen and Doggett, 1991), Bay of Fundy flats (Ambrose, 1984) and Massachusetts flats (Whitlach, 1977). Likewise, abundances at the Sheep Island sites (11,000 to 95,000 animals/m^2) are similar to those reported for other North Atlantic intertidal flats (Table 4-1). Total biomass was lower at the constructed flat than the reference area, particularly after 1992 (Figure 3-16), reflecting higher abundances of oligochaetes and molluscs (Figure 3-17). While the similarity between the Sheep Island and Beals Island biomass results, i.e., lower biomass at constructed flats, might seem to be of concern, data from other New England intertidal flats indicates that these values are well within normal bounds (Table 4-3). Bowen, Pembroke and Kinner (1989) measured biomass at a number of intertidal flats in southern New England and reported values ranging from 6 to 612 g/m^2 and averaging 164 g/m^2. Biomass at the Sheep Island constructed flat ranged from 76 to 181 g/m^2 and averaged 125 g/m^2, while the Beals Island constructed flat ranged from 32 g/m^2 to 127 g/m^2 and averaged 72 g/m^2. Average biomasses at the Sheep Island and Beals Island reference areas were 285 g/m^2 and 139 g/m^2 respectively. Biomass composition varied substantially among the southern New England flats (Table 4-3) and like the study area flats, was dominated either by annelids or molluscs (Bowen, Pembroke, and Kinner, 1989).

Table 4-1. Diversity and Abundance of North Atlantic Intertidal Flat Infauna

Reference	Diversity (H')	Abundance ($X10^3/m^2$)
Larsen and Doggett (1991)		
Kittery	2.66	1
Falmouth	2.46	5
Boothbay Harbor	2.44	5.5
East Friendship	2.26	22
Addison	1.89	2
Whitlach (1977)	1.8-2.1	1-196
Sanders et al. (1962)		7-355
Ambrose (1984)	-	3-38
Thiel & Watling (1998)	-	5-240
Commito (1982)	-	11-20
Commito & Shrader (1985)	-	20-117
Sheep Island DM	1.18-2.88	11-33
Sheep Island REF	1.84-3.05	18-95
Beals Island DM	2.87-2.93	20-44
Beals Island REF	2.58-2.79	25-129

DM = Constructed Flat
REF = Reference Area

Table 4-2. Species Composition of North Atlantic Intertidal Flat Infauna

	ME	ME	ME	ME	ME	ME	ME	ME	ME	ME	ME	Fundy	MA	MA
Reference	1	2	3	4	5	6	7	SIDM	SIREF	BIDM	BIREF	8 - 10	11	12
Taxa														
Oligochaeta	+	+			+	+	+	+	+	+	+			+
(Tubificoides benedini)					+			+	+	+	+			
(Tectadrilus gabriella)								+	+	+	+		+*	
Amphitrite johnsoni			+		+									
Capitella sp.				+		+	+	+	+	+	+			+
Clymenella torquata				+		+		+	+	+	+		+	+
Eteone longa			+	+	+	+	+*	+	+	+	+		+*	+
Exogene hebes			+	+		+	+	+	+	+	+			
Fabricia sabella				+[1]				+	+	+	+			
Glycera dibranchiata				+		+		+	+	+	+		+	+
Heteromastus filiformis	+					+	+	+	+	+	+	+	+	+
Hobsonia florida		+												
Nephtys incisa		+	+	+	+									
Nereis virens	+	+	+	+	+	+	+*	+	+	+	+		+	+
Polycirrus eximus			+											
Polydora spp.		+	+	+	+	+	+	+	+	+	+		+	+
Pygospio elegans							+	+	+	+	+	+	+	
Scoloplos sp.	+	+		+		+						+	+	+
Streblospio benedicti	+	+	+	+		+	+	+	+	+	+	+	+	+
Tharyx sp.				+		+	+					+	+	+
Ampelisca vadorum								+	+	+	+			+*
Corophium volutator	+		+	+	+	+	+	+	+	+	+	+		+*
Gammarus sp.			+	+	+			+	+	+	+		+*	+
Phoxocephalus holbolli								+	+	+	+			
Hydrobia sp.	+		+	+		+	+	+	+	+	+		+	+
Gemma gemma	+				+		+	+	+	+	+		+	+
Macoma balthica	+	+	+	+	+	+	+	+	+	+	+			
Mya arenaria	+		+	+	+	+	+	+	+	+	+		+	+

\+ = Present +* = Listed as sp. or congenor

+[1] = listed as Sabella fabricia

References:

1 - Larsen and Doggett (1991)
2 – Ambrose (1984)
3 – Commito (1982)
4 – Commito and Shrader (1985)
5 – Commito (1987)
6 – Brown and Wilson (1997)
7 – Thiel and Watling (1998)
8 – Wilson (1988)
9 – Wilson (1989)
10- Wilson (1991)
11- Sanders et al. (1962)
12- Whitlach (1977)

Table 4-3. Comparison of Biomass and Biomass Composition Results with other New England Intertidal Flats

Area	Site	Biomass g/m2	% Annelid	% Crustacean	% Mollusc	% Misc.
Maine*	ME1	209	21.5	<1	78.0	0.0
Maine*	ME2	23	87.0	4.3	8.7	0.0
New Hampshire*	NH	62	91.9	0.0	8.1	0.0
Massachusetts*	MA1	6	83.3	0.0	16.7	0.0
Massachusetts*	MA2	185	31.9	67.0	1.1	0.0
Massachusetts*	MA3	51	96.1	1.7	1.7	0.0
Connecticut*	CONN	612	12.3	<1	88.9	0.0
Sheep Island	DM 1991	78	29.5	13.2	57.3	0.0
Sheep Island	DM 1992	166	30.1	17.0	52.9	0.0
Sheep Island	DM 1994	181	4.6	4.6	90.8	0.0
Sheep Island	DM 1998	76	30.6	40.6	28.8	0.0
Sheep Island	REF 1991	93	70.3	20.3	9.4	0.0
Sheep Island	REF 1992	288	27.8	0.1	72.1	0.0
Sheep Island	REF 1994	428	6.6	0.2	93.2	0.0
Sheep Island	REF 1998	330	39.7	2.6	53.5	4.2
Beals Island	DM 1991	32	91.6	8.4	0.0	0.0
Beals Island	DM 1992	33	84.4	15.5	0.1	0.0
Beals Island	DM 1993	45	83.7	12.1	4.2	0.0
Beals Island	DM 1994	127	81.2	16.2	2.6	0.0
Beals Island	DM 1998	124	57.2	6.3	1.8	34.7
Beals Island	REF 1991	54	90.9	9.1	0.0	0.0
Beals Island	REF 1992	120	94.2	5.2	0.6	0.0
Beals Island	REF 1993	96	96.0	3.5	0.5	0.0
Beals Island	REF 1994	44	96.4	3.5	0.2	0.0
Beals Island	REF 1998	334	79.5	4.1	8.8	7.6

DM = Constructed Flat
REF = Reference Area

Infaunal species composition of the Jonesport study sites was similar to other Maine, Bay of Fundy and New England intertidal flats (Table 4-2). In a study of a number of Maine flats Larsen and Doggett (1991) reported oligochaetes as the most abundant and commonly occurring taxon. In fact, more than half the regional studies of intertidal infauna list oligochaetes as one of the dominant taxa. While most of these studies do not identify which species are present, Commito (1987) has reported T. benedini as the most abundant species in a study at Bob's Cove, Maine (also in Washington County). Other taxa commonly described as dominants in North Atlantic intertidal assemblages include the amphipod Corophium volutator, the polychaetes Heteromastus filiformis, Nereis virens, Polydora spp. and Streblospio benedicti, and the bivalves Macoma balthica and Mya arenaria. All are among the Sheep Island dominants (Table 4-2).

The very high infaunal abundances encountered during the first sampling (June 1990) suggest that community development was not yet complete. Typically infaunal assemblages progress through a series of successional stages beginning with a community composed of a few pioneering species present in extremely high abundances (e.g., Pearson and Rosenberg, 1978; Rhoads and Boyer, 1982; Rhoads and Germano, 1982). This assemblage consists primarily of small tube-dwelling polychaetes or small bivalve molluscs colonizing the surficial sediments. Over time the pioneering fauna are replaced by slightly larger, longer-lived and deeper burrowing infauna. These later assemblages are more diverse but less abundant and often include tubiculous ampeliscid amphipods and shallow-dwelling bivalves (Santos and Simon, 1980). Finally, a highly diverse assemblage dominated by large, long-lived, and deep-burrowing animals such as maldanid polychaetes develops. Alternatively, there may be no predictable successional sequence, but simply a rapid colonization by whatever taxa are present in nearby sediments (e.g., Diaz, 1994; Zajac and Whitlach, 1982).

There may also be reported an annual successional sequence as described by Trueblood, Gallagher, and Gould (1994) in Boston Harbor. This sequence also has 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 P. ligni. Whitlach (1977) has reported a slightly different seasonal sequence with spring dominants being the amphipod C. insidiosum and the polychaetes Marenzellaria viridis and Scoloplos sp. Summer dominants included S. benedicti, H. filiformis, and Gemma gemma and fall-winter dominants included Mya arenaria and Capitella sp.

The high abundances encountered during the first sample period (June 1990) may correspond to the pioneering stage described by Pearson and Rosenberg (1978) and Rhoads and others (Rhoads and Boyer, 1982; Rhoads and Germano, 1982). Likewise, high constructed flat taxa richness at this time may reflect a change in community structure from the pioneering stage to a later more diverse assemblage, i.e., high diversity was due to the presence of both assemblages. Other lines of evidence include high variability in taxonomic composition of constructed flat samples (NMDS results), which is suggestive of infaunal response to disturbed conditions (Warwick and Clarke, 1993) and domination of constructed flat benthos by Capitella sp. and P. elegans, opportunistic species which are early colonizers of disturbed sediments (e.g., Shull, 1997; Thiel and Watling, 1998). Alternatively, both taxa were dominant at both sites and were equally or more abundant in later samples (Appendix Table 2). As previously noted these species have also been reported as summer dominants under undisturbed conditions (Trueblood, Gallagher, and Gould, 1994). It is unclear from the available information whether or not a pioneering assemblage was detected. What is clear, is that by 1991 the infaunal community of the constructed flat was similar in most regards both to the reference site and other intertidal flat assemblages in the North Atlantic.

Beals Island, an example of a thirty year old flat resulting from intertidal disposal of dredged material, appears to have been somewhat less successful. Unlike Sheep Island, a commercially viable soft-clam population has not been established, however, there is a substantial clam-worm population. Reasons for the relative failure of the soft-clam are uncertain but may be related to substrate. Sediments at the Beals Island constructed flat are far more cohesive than corresponding sediments at Sheep Island (personal observation). The cohesiveness of Beals Island sediments may be less conducive for the shallow burrowing behavior of the clam. The more intense disturbance of the Beals Island reference flat by worm-rakers may also result in increased clam mortality (Emerson, Grant, and Rowell, 1990). Differences in clam-worm abundances between Beals Island sites may also be related to substrate. The cohesive sediments of the flat are difficult to traverse and may be avoided by professional worm-rakers. The rakers have limited time between tides to gather their harvest and any delay means lost income. Although the constructed flat cannot be considered a success in the sense of direct harvest it still represents a "seed bank" of worms to replace animals harvested from the remainder of Alley Bay and elsewhere.

The infaunal community of the Beals Island constructed flat was also somewhat less developed than at the reference area. Although taxa richness and taxonomic composition were roughly equivalent between sites (Figure 3-20; Appendix Table 3), constructed flat abundance and biomass were much lower than reference area values (Figure 3-21; Figure 3-22). The differences in abundance and biomass were not restricted to a single group as evidenced by similar biomass composition (Figure 3-23), but are more general in nature.

Reasons for the difference between constructed flat and reference area values are most likely related to substrate, elevation and vegetation (intertidal Zostera marina beds). Despite these differences the constructed flat is still comparable in diversity, abundance and species composition to other intertidal flats. Diversity (H') at the constructed flat was well above most other North Atlantic flats (2.8-2.9), abundance was within normal ranges (~30,000 animals/m^2), and species composition was similar to other sites (Table 4-1; Table 4-2). As previously discussed biomass and biomass composition were also within the range of values measured at other New England intertidal flats (Table 4-3).

5.0 CONCLUSIONS

The principal conclusion from the monitoring effort at Sheep Island is that a physically stable and biologically functional intertidal flat has been produced. A commercially exploitable population of the soft-clam, Mya arenaria, has become established at the constructed flat as well as a population of the bait-worm Nereis virens. Within three years of construction, the infaunal community, an important source of forage for both fish and shorebirds, developed to within expected values for diversity, abundance, and species composition. At Beals Island, a much older constructed flat resulting from intertidal disposal of dredged material, a substantial population of N. virens and a well developed infaunal community were present. Neither constructed flat supported the same level of total infaunal biomass found at the respective reference areas, but the measured values were similar to those of other New England intertidal flats.

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Appendix Table 1. 1998 Worm-Rake Collection Data

Site	Species (No.)	Size (mm)
REF-1	None	
REF -3	None	
REF -5	Mya arenaria (1)	31
REF -7	None	
REF -9	None	
REF -11	None	
DM-1	Nepthys incisa (2)	53, 95
DM -3	Mya arenaria (2)	54, 33
DM -5	Glycera dibranchiata (1)	107
DM -7	Mya arenaria (1)	55
DM -9	Nepthys incisa (2) Mya arenaria (2)	58, 137 51,22
DM -11	Mya arenaria (3)	17, 22, 52
DM -13	Nepthys incisa (2) Mya aremaria (3)	57 20, 46, 53
DM –15	Nepthys incisa (1) Mya arenaria (2)	65 52, 64

Appendix Table 2. Sheep Island Taxa List and Abundances (No./m^2).

	Constructed Intertidal Flat					Reference Area				
Taxa	DM90	DM91	DM92	DM94	DM98	REF90	REF91	REF92	REF94	REF98
OLIGOCHAETA	608					61758				
Tubificoides benedini	0	924	367	220	2728	0	682	15429	4039	10736
Tectidrilus gabriella	0	4249	1613	440	1149	0	5650	13407	9837	22528
Tubificoides netheroides	0	0	220	0	0	0	0	0	0	1164
Tubificoides sp.	0	0	0	0	0	0	0	0	0	587
Enchytraeidae	0	0	0	0	513	0	0	2310	3245	2640
Paranis littoralis	0	0	0	0	605	0	0	220	0	0
POLYCHAETA										
Capitella sp.	2604	367	825	1996	8316	7132	455	5350	963	2517
Capitellides sp.	0	0	1027	0	0	0	0	0	0	0
Capitomastus jonesi	0	0	733	0	0	0	0	0	0	0
Heteromastus filiformis	29	220	880	220	220	0	220	0	220	0
Ophelina accuminata	0	293	440	0	0	0	264	220	0	0
Aricidea suecica	0	220	220	0	0	0	220	0	0	0
Naineris quadricuspida	0	0	0	0	0	101	0	0	220	0
Scoloplos acutus	0	220	0	0	0	0	0	0	0	0
Pherusa affinis	0	220	0	0	0	0	409	0	0	0
Clymenella torquata	0	943	0	0	0	579	2140	1265	0	0
Euclymene zonalis	0	0	0	0	0	14	0	0	0	0
Maldanidae	0	0	0	0	0	29	0	0	0	0
Tharyx sp.	0	0	0	0	220	0	264	0	0	1540
Fabricia sabella	0	0	0	220	220	9577	0	3007	440	3476
Polydora ligni	448	800	1041	1591	2011	926	1265	587	1729	944
Polydora quadrilobata	2445	293	385	953	800	1519	275	550	1100	367
Pygospio elegans	4036	682	220	0	0	6640	660	264	0	0
Scolocolepides viridis	0	0	0	0	0	14	0	0	0	0
Spio setosa	0	0	0	0	0	29	0	0	220	220
Streblospio benedicti	0	0	1163	2577	11000	0	0	3419	682	308
Eteone longa	58	0	220	220	468	0	0	0	293	264
Phyllodoce maculata	0	0	0	0	0	14	0	0	0	0
Anaitides mucosa	0	220	220	0	0	0	220	220	0	0
Phyllodoce arenae	0	0	0	0	220	0	0	0	0	0
Exogene hebes	14	9130	528	220	220	463	6734	1678	220	513
Exogene verugera	0	0	0	0	0	333	0	0	0	0
Nereis virens	72	452	524	440	592	29	402	508	367	1100
Nereis diversicolor	14	0	0	0	0	0	0	0	0	0
Nereis sp.	29	0	0	0	0	101	0	0	0	0
Nepthys incisa	0	220	0	0	0	14	220	275	0	0
Nephtys caeca	0	0	0	0	0	14	0	0	0	0
Nepthyidae	0	0	0	0	0	58	0	0	0	0

Appendix Table 2 (Cont.). Sheep Island Taxa List and Abundances (No./m^2).

	Constructed Intertidal Flat					Reference Area				
Taxa	DM90	DM91	DM92	DM94	DM98	REF90	REF91	REF92	REF94	REF98
POLYCHAETA										
Glycera capitata	0	0	0	0	0	14	0	0	0	0
Glycera dibranchiata	0	220	0	0	0	0	0	0	0	0
Hesionidae	0	0	0	220	0	0	0	0	0	0
Micropthamalus aberrans	0	0	0	0	0	72	0	0	0	0
Micropthamalus sp.	0	0	0	0	0	14	0	0	0	0
Protodorvillea kefertein	0	0	0	0	0	72	0	0	0	0
Protodorvillea gaspenses	0	0	0	0	0	217	0	0	0	0
Shistomeringos caeca	0	0	0	0	0	0	0	330	0	660
Harmothoe imbricata	0	0	0	0	0	0	0	0	0	220
Spirorbis spirillum	0	0	0	0	0	0	0	0	0	220
HIRUDINEA	0	0	0	0	0	0	0	0	0	220
CRUSTACEA-Amphipoda										
Ampelisca vadorum	0	422	220	220	0	14	745	220	220	0
Corophium volutator	87	11275	27544	8038	20607	14	2808	367	880	2112
Corophium bonelli	0	7013	0	0	0	0	2514	0	0	0
Dexominethea	0	0	0	0	0	58	0	0	0	0
Gammarus oceanicus	14	691	1387	374	19910	347	220	770	943	1665
Gammarus annulatus	101	0	0	0	0	101	0	0	0	0
Gammarus sp.	14	0	0	0	0	535	0	0	0	0
Leptocheirus pinguis	14	0	0	0	0	0	0	0	0	0
Pontogenia inermis	0	0	0	0	0	14	0	0	0	0
Aoridae	0	836	0	0	0	0	293	0	0	0
Caprellidae	0	0	220	0	0	0	0	0	0	0
Phoxocephalus holbolli	28	2035	220	0	0	72	1748	244	0	0
Melita sp.	0	1320	0	0	0	0	0	0	0	0
CRUSTACEA-Isopoda										
Edotea montosa	0	352	0	220	0	72	413	440	0	0
Jaera marina	0	0	283	220	0	304	0	220	220	1100
Ptilanthura tenuis	0	0	0	0	220	0	0	0	0	440
CRUSTCEA-Tanaidacea	0	0	0	0	0	14	0	0	0	0
Leptognatha cacea	0	0	0	0	0	29	0	0	0	0
Leptochelia savigni	0	2805	0	0	0	0	513	220	0	0
CRUSTACEA-Misc.										
Eudorella pusilla	29	0	0	0	0	14	0	0	0	0
Oxyurostylis smithi	0	257	220	220	0	0	264	0	0	0
Neomysis americana	0	513	0	0	220	0	220	0	0	0
Scottolana canadensis	0	440	440	220	220	0	660	275	0	0
Crangon septemspinosus	0	0	0	0	1320	0	0	0	0	330
Cephalocarida	0	0	0	0	220	0	0	0	0	440

Appendix Table 2 (Cont.). Sheep Island Taxa List and Abundances (No./m^2).

	Constructed Intertidal Flat					Reference Area				
Taxa	DM90	DM91	DM92	DM94	DM98	REF90	REF91	REF92	REF94	REF98
CRUSTACEA-Misc.										
Thalassomya sp.	0	0	0	220	0	0	0	293	0	0
Diptera	0	0	0	0	293	0	0	0	0	953
Collembolla	0	0	0	0	0	0	0	0	0	220
MOLLUSCA-Bivalves										
Macoma balthica	0	220	0	220	0	0	0	0	0	990
Mya arenaria	43	330	264	367	220	72	440	330	314	0
Mytilus edulis	0	0	0	220	220	43	0	825	623	308
Gemma gemma	0	0	0	0	220	0	0	220	0	330
Bivalve sp. 1	0	220	0	0	0	0	0	0	0	0
MOLLUSCA-Gastropoda	0	0	0	0	0	29	0	0	0	0
Littorina littorea	0	0	0	1228	220	188	0	220	1163	0
Polinices duplicatus	0	220	0	0	367	0	0	0	0	220
Hydrobia sp.	0	0	0	4688	0	0	0	0	330	0
Acetocina canaliculata	0	0	0	0	4620	0	0	0	0	0
Turtonia minuta	0	0	0	0	0	14	0	0	0	0
MISCELLANEOUS										
Nemertea	0	0	220	0	0	0	220	293	220	0
Platyhelminthes	0	0	0	0	0	0	0	0	0	220

Appendix Table 3. Beals Island Taxa List and Abundances (No./m^2).

	Constructed Intertidal Flat					Reference Area				
Taxa	DM91	DM92	DM93	DM94	DM98	REF91	REF92	REF93	REF94	REF98
OLIGOCHAETA										
Tubificoides benedini	4510	2567	440	2820	11821	9147	35413	21120	21501	46567
Tectidrilus gabriella	6600	16669	15077	13420	17527	3960	953	4950	10223	10296
Tubificoides netheroides	440	686	880	220	3168	660	440	2048	748	4028
Tubificoides sp.	314	616	1254	440	0	4620	0	220	275	0
Enchytraeidae	0	293	0	0	440	0	0	587	440	1672
Paranais littoralis	0	0	0	0	2420	0	0	660	0	13090
POLYCAHETA										
Capitella sp.	1760	990	385	691	12878	800	15979	12144	6483	25623
Heteromastus filiformis	385	456	220	283	440	346	858	770	1082	1074
Mediomastus ambiseta	0	0	220	0	0	0	0	0	0	0
Aricidea suecica	0	0	0	0	220	0	0	0	0	0
Scoloplos acutus	0	220	0	0	0	0	220	220	0	0
Pherusa affinis	0	0	0	0	0	0	0	220	0	0
Clymenella torquata	1283	908	220	660	880	1895	1960	849	1265	3056
Tharyx sp.	880	220	0	220	0	0	0	0	0	0
Fabricia sabella	0	348	220	0	330	0	1552	636	220	12806
Polydora ligni	927	1186	1833	2530	1320	689	697	1149	2180	895
Polydora quadrilobata	2068	2106	413	275	6126	2448	1298	1414	3012	8067
Prionospio sp.	0	0	0	220	0	0	0	0	0	0
Pygospio elegans	1303	2978	3579	0	0	2420	0	1613	0	0
Spio setosa	0	0	0	2787	220	0	0	220	0	0
Streblospio benedicti	1083	6767	3819	4552	3579	2355	19895	20592	29920	25461
Spiophanes bombyx	0	0	0	0	0	0	0	0	0	220
Eteone longa	220	0	330	264	660	220	0	220	308	755
Phyllodoce mucosa	293	264	0	0	0	220	308	0	0	0
Phyllodoce arenae	0	0	0	220	1892	0	0	0	220	856
Exogene hebes	2640	0	1131	2585	4156	2185	0	47637	24053	46875
Exogene verugera	0	1687	0	0	0	0	38764	0	0	0
Nereis virens	385	1267	1393	2499	2611	330	572	1056	440	605
Nepthys incisa	0	220	220	0	330	0	0	0	220	0
Glycera dibranchiata	293	220	220	440	0	220	220	220	220	0
Glycinde solitaria	220	0	0	0	0	0	0	0	0	0
Hesionidae	0	220	0	0	0	0	0	0	0	0
Micropthamalus sp.	0	0	0	0	440	0	0	220	0	0
Shistomeringos caeca	0	0	0	0	0	0	220	220	0	220
Harmothoe imbricata	0	220	220	220	257	220	0	0	0	0
Spirorbis spirillum	0	0	0	0	2347	0	0	0	0	0
HIRUDINEA	0	0	0	0	0	0	0	0	0	660

Appendix Table 3 (Cont.). Beals Island Taxa List and Abundances (No./m^2).

	Constructed Intertidal Flat					Reference Area				
Taxa	DM91	DM92	DM93	DM94	DM98	REF91	REF92	REF93	REF94	REF98
CRUSTACEA-Amphipoda										
Ampelisca vadorum	4327	4901	5500	8668	8375	2352	477	1815	1650	6316
Corophium volutator	330	750	1418	0	1128	0	275	220	0	880
Corophium bonelli	0	0	367	0	0	220	0	264	0	0
Gammarus oceanicus	220	544	495	2680	3473	403	13082	3256	7810	6380
Leptocheirus pinguis	0	0	0	330	825	0	0	0	0	0
Pontoporeia femorata	0	0	440	293	880	0	0	0	0	440
Aoridae	0	220	0	0	0	0	0	0	0	0
Phoxocephalus holbolli	2241	3486	4063	3447	5192	3349	931	2074	825	2805
Melita sp.	0	0	0	0	0	0	0	220	0	0
Stenothoidae	0	0	0	0	0	0	0	220	0	0
CRUSTACEA-Isopoda										
Edotea montosa	367	393	636	836	1964	513	1838	2268	2240	3124
Jaera marina	0	220	550	0	0	0	330	220	0	220
Ptilanthura tenuis	0	0	0	0	220	0	220	293	2347	623
Erichsonella filiformis	220	0	220	0	0	303	0	0	220	0
Idotea balthica	0	0	0	0	220	0	220	0	220	345
CRUSTACEA-Tanaidacea										
Leptochelia savigni	0	0	330	220	0	0	0	0	0	0
CRUSTACEA-Misc.										
Oxyurostylis smithi	220	413	330	220	220	308	355	538	0	220
Neomysis americana	440	220	0	220	0	0	0	330	0	0
Scottolana canadensis	220	1909	403	770	807	220	358	220	0	0
Crangon septemspinosus	0	0	0	0	346	0	0	0	0	409
Cephalocarida	0	0	220	0	0	0	0	0	0	0
Thalassomya sp.	0	220	220	220	346	440	1498	513	587	2708
Diptera	0	0	0	0	0	0	220	0	0	220
Halacaridae	0	0	0	0	0	0	0	220	0	220
MOLLUSCA-Bivalves										
Macoma balthica	0	0	0	220	220	0	0	0	0	0
Mya arenaria	367	220	0	0	220	0	0	0	0	385
Mytilus edulis	0	0	0	0	0	0	220	0	0	220
Gemma gemma	0	0	220	220	367	0	275	0	220	832
Nucula sp.	0	0	1430	0	0	0	0	0	0	0
Corbula sp.	0	220	0	0	0	0	0	0	0	0
MOLLUSCA-Gastropoda	0	0	0	0	0	0	990	0	0	220
Margarites costalis	0	0	0	0	0	0	0	0	0	5720
Littorina littorea	0	0	220	0	0	0	0	440	0	220
Littorina obsusata	0	0	0	0	550	0	0	0	0	220
Polinices duplicatus	0	0	0	0	0	0	220	0	0	0

Appendix Table 3 (Cont.). Beals Island Taxa List and Abundances (No./m^2).

	Constructed Intertidal Flat					Reference Area				
Taxa	DM91	DM92	DM93	DM94	DM98	REF91	REF92	REF93	REF94	REF98
Hydrobia sp.	0	0	1082	1210	403	0	0	257	495	9506
Acetocina canaliculata	0	0	0	0	220	0	0	220	0	220
MISCELANEOUS										
Nemertea	0	220	0	220	330	220	374	0	293	524
Platyhelminthes	0	0	0	0	0	0	0	660	0	0