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Resilience and Stability in an Offshore Benthic Community: Responses to Sediment Borrow Activities and Hurricane Disturbance

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ABSTRACT

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Placement of sand on coastal beaches (nourishment) has been used to reduce losses from storm erosion and barrier island movement, with sediment coming from a variety of potential sources including offshore borrow areas. We examined recovery of benthic fauna in an offshore borrow area as well as long-term patterns of community dominance and responses to storm disturbance. Benthic fauna were sampled in a borrow and a control site 2 years before and 2 years after sediment removal (1995–1999). Video surveys from an ROV were used to examine potential burial effects on hardbottom communities. Less than 30% of taxa exhibited differences between borrow and control sites at any time and only 2 of 29 numerically dominant species showed site differences after sediment removal. Strongest effects were related to temporal variations in abundance with some species exhibiting seasonal variations in abundance, some taxa exhibiting single periods of higher abundance, and other taxa exhibiting more variable patterns. Three hurricanes affected the sites during the study, but there was little evidence of acute changes associated with storm disturbance. Shifts in abundance corresponding to the time of sediment removal occurred for some taxa, but were present in both borrow and control areas. The data suggest relatively quick recovery from borrow activities with interannual variability explaining more of the observed differences than sediment removal effects. Limited effects of sediment removal may be related to timing of activities (in fall and winter before peak infaunal recruitment), small size of the area affected, and the opportunistic nature of many of the infaunal species.

ADDITIONAL INDEX WORDS: *Borrow, sediment dredging, infauna, hurricanes, North Carolina, temporal stability.*

INTRODUCTION

With increased development along coastal beaches, there has been increased demand for beach nourishment to restore eroded areas and protect structures behind degraded sand dunes (Finkl, 1996; Valverde *et al.,* 1999). However, nourishment projects often face problems in obtaining sand of sufficient quality from inlets or sounds. One solution has been to utilize offshore sand deposits (Finkl *et al.,* 1997). Considerable research has concentrated on the potential effects of sand deposition and movement on littoral organisms, especially *Emerita, Donax, Ocypode, Orchestia,* and related beach fauna (Cultor and Mahadevan, 1982; Hackney *et al.,* 1996; Peterson, 2000; Peterson *et al.,* 2000). However, less is known about the potential effects on benthic soft-sediment communities in an offshore sand borrow area. It is generally assumed that the initial act of removing sand results in mortality of organisms in the borrow site (Kaplan *et al.,* 1974; van Dolah *et al.,* 1984). After sediment removal, the community is expected to begin recovery. The opportunistic nature of many benthic infauna (Levinton, 1982) promotes relatively quick recovery of former dominant species and abundance patterns (van Dolah *et al.,* 1984, Johnson and Nelson 1985, Posey and Ambrose, 1994), especially if there are minimal long-term effects on substrate characteristics (Newell *et al.,* 1998). However, several studies have indicated the potential for longer-term changes in soft-substrate communities associated with sediment removal or bottom disturbance (Kaplan *et al.,* 1974; Groot, 1979; Newell *et al.,* 1998; Thrush *et al.,* 1998). More dramatic effects may occur on adjacent hardbottom habitats that are subject to burial from resuspended sediments (Lindeman and Snyder, 1999).

One factor that complicates assessments of offshore community responses to sediment removal is an understanding of the stability of these assemblages (persistence and resilience). Periodic natural disturbances may preselect for taxa capable of recovering quickly from sediment removal effects or may obscure responses to human impacts. Nearshore estuarine and lagoon infaunal communities are often characterized by high variability in abundance and dominance patterns between years (Peterson, 1975; Mahoney and Livingston, 1982; Flint and Kalke, 1985; Holland, 1985; Nichols, 1985; Posey, 1986), although there are examples of long-term stability in dominance for lower salinity areas (Holland *et al.,* 1987; Hines *et al.,* 1986; Mallin *et al.,* 1999). Long-term studies of offshore benthic community as-

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semblages are not as numerous as those in estuarine, lagoon or sound habitats. However, limited studies have indicated stability in guild structure (POSEY *et al.,* 1998; MAURER *et al.,* 1995), but variability in species composition and dominance patterns over time, though to a lessor extent than in estuarine habitats. Multiple long-term studies are needed to assemble a sufficient data set to determine the physical and biotic parameters that may affect community persistence in shelf environments. Understanding persistence and resilience patterns is critical to knowing the degree to which a community may be expected to return to a previous state after a disturbance.

Along the Atlantic and Gulf coasts of North America, periodic storms impact bottom communities to depths >35 m (POSEY *et al.,* 1996; RENAULD *et al.,* 1996, 1997). Shallower areas (<15–20 m depth), typical of most sediment removal operations, may be impacted more frequently by smaller storm events. These storms may have significant effects on the relative abundance and dominance of benthic fauna (POSEY *et al.,* 1996; MALLIN *et al.,* 1999), possibly favoring opportunistic taxa if disturbances occur at a sufficient frequency. If the natural community is dominated by opportunistic taxa, recovery to ambient conditions may occur more quickly than if longer-lived taxa with more limited dispersal potential dominate adjacent habitats.

We examined benthic macro-infaunal responses to sediment removal offshore in southeastern North Carolina, USA. If sediment removal affects the benthic macroinfaunal community, it should be apparent as distinct differences in abundance and/or species composition shifts in the borrow site from before to after sediment removal. Control sites are predicted to be similar to borrow sites before sediment removal but to differ from borrow areas after sediment removal if there are significant community effects of borrow activities. The study spanned 5 years (1995–1999, with actual sediment removal occurring from summer 1997 into early winter 1998), allowing observation of interannual variability in faunal composition as well as actual removal effects. During 1996, 1998 and 1999, hurricanes passed over the study site allowing a unique opportunity to also monitor responses to natural storm disturbance.

METHODS

Benthic infaunal samples were taken from two sites offshore from Kure Beach, North Carolina, an area impacted by sediment removal and an adjacent control site (Figure 1). The borrow site is a region of relatively deep sand deposits, part of an old channel formed from New Inlet, approximately 4 km by 0.8 km in extent. The average water depth at this site before sediment removal was 12–15 m and 1–2.5 m of sediment was subsequently removed by pipe dredge. The control area was chosen to be of similar overall size and configuration as the borrow area and is located approximately 3 km to the east of the borrow site. The control site has variable depth sand deposits overlying patchy hard ground, typical of offshore areas along the North Carolina coast (RENAULD *et al.,* 1996, 1997). The water depth and mean sand grain size at this site is similar to that of the borrow area (POSEY and ALPHIN, 2001). Sampling at both sites was conducted along 3 transects, with 5 sampling stations along each transect line per site.

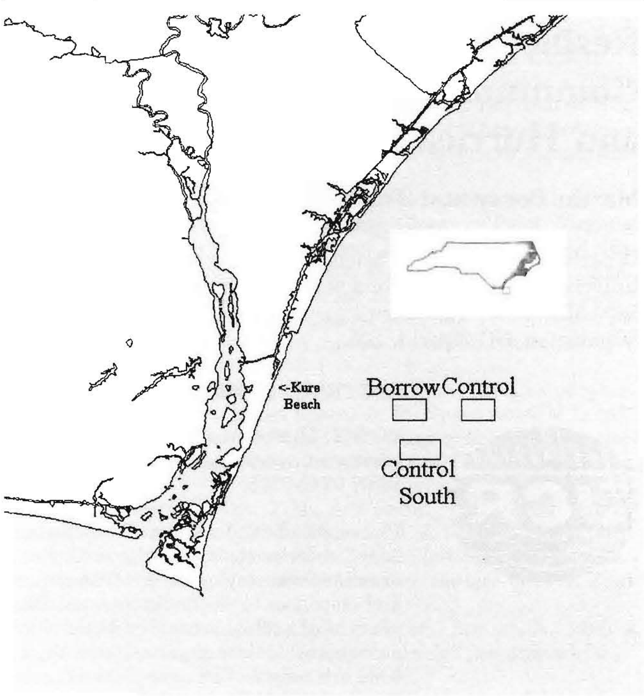

Figure 1. Relative location of Borrow and Control sites (sites for infaunal sampling and ROV video studies) and Control South site (used only for ROV video studies) off the southeastern coast of North Carolina. The mouth of the Cape Fear River and the lower river system, location of 2 hurricane landfalls, is shown running N-S just inland from Kure Beach.

Pre-borrow sampling was conducted during late spring/summer and fall 1995–1997 (July 1995, October 1995, May 1996, October 1996, and May 1997). Spring/summer sampling represented the period after spring recruitment and fall sampling occurred immediately after the smaller fall recruitment pulse observed for some benthic taxa in this area (Posey et al. 1995). Hurricane Fran, with sustained winds in excess of 120 mph, passed over the study area in September 1996, the eye making landfall at the mouth of the Cape Fear River ~5 km SW. Sediment removal occurred from summer 1997 to January 1998 and the presence of dredge pipes in the borrow area at this time prevented fall 1997 sampling. Post-borrow samples were taken in February 1998, May 1998, early November 1998, May 1999 and October 1999. Hurricane Bonnie, with sustained winds of 118+ mph, passed over the site in September 1998. Hurricane Floyd, with sustained winds of 112 mph, made landfall in the mouth of the Cape Fear River, 5 km to the SW, in November 1999. During the spring/summer periods, grab samples were taken at all stations in both borrow and control sites (3 transects × 5 stations per transect). However, because of rough sea conditions and boat availability problems during several years (especially after hurricanes in 1996, 1998 and 1999), the fall/winter sampling was conducted only along the middle transect at each site (1 transect × 5 stations).

Two petite ponar grab samples, 15 cm × 15 cm opening and 15 cm depth, were taken at each station. To standardize samples, grabs were considered successful only if they were full. Faunal samples were sieved through a 0.5 mm screen after collection, preserved in 10% buffered formalin with rose bengal dye added, and transferred after 2–14 days to 50% isoproponal for storage until sample sorting and identification. Samples were sorted under a dissecting microscope and all fauna were identified to the lowest practical taxonomic level (genus or species in most cases). Some taxa, such as oligochaetes, certain juvenile clams and certain polychaetes, or incomplete specimens, could only be identified to higher taxonomic levels.

A two-way analysis of variance on log-transformed densities was used to determine differences between sampling dates, sites (borrow vs. control) and interactions between date and site effects for densities of common taxa (those taxa representing at least 3% of the individuals at a single site on at least one sampling date). Log transformation was needed to correct heterogeneity of variances for analyses (SOKAL and ROHLF, 1981). An SNK test for comparison of means was used to determine differences among dates when significant date effects were detected. This 2-way design allowed testing of the prediction of site*date interactions as might be expected with borrow effects. Possible changes in the relationship between borrow and control sites were also tested by comparing these sites separately for samples before and after sediment removal. Because *a priori* hypotheses predicted different patterns over time among control and borrow sites and because May sampling periods had greater sampling effort, the 5 May periods were also compared separately for each site using a one-way analysis of variance on log-transformed data. An SNK test was used to distinguish differences among individual May sample periods where a significant difference among dates occurred. Similarity in species composition among control and borrow sites was determined for each sampling date using Sorenson's Index (Cox 1996).

Univariate tests, such as ANOVA conducted on individual taxa, are useful for understanding detailed faunal responses but present problems with multiple testing and may be difficult to interpret because of varying patterns among taxa. We also conducted *principal components analysis* (PCA) utilizing abundance data for all taxa to determine general patterns of community composition and sample groupings related to site and time. A biplot of the first two principal components was used to distinguish major site/date groupings (De'ath 1999) and Wards Minimum Variance Cluster Analysis was used to determine major site/date clusters ($p < 0.05$).

To provide broad survey information on the location and prevalence of potential hard substrate habitats that may be affected by sediment resuspension from borrow activities, we conducted video surveys with a remotely operated submersible vehicle (ROV). ROV transect observations were conducted on 13 October and 16 October 1995 (before removal) and on 16 October and 27 October 1998 (after removal). Observations were made in the borrow area, in the control area described above (located to the east of the borrow area) and in a second reference site to the south of the borrow area (Figure 1). Five ROV video transects, running east-west, were made across each site. These videos were used to determine percent cover on each transect for sand, veneer hardbottom and high-relief hardbottom, determined as percent of total transect, n = 5 transects per area. For this study, high-relief hardbottom was defined biologically as areas where there were well-developed hardbottom assemblages, including gorgonians, sponges, macroalgae and/or hard corals, and the underlying rock was exposed. Veneer habitat was defined as areas where hardbottom organisms such as gorgonians and corals were present but the underlying rock was covered by a layer of sand. Sand bottom included areas where no rock was visible and no hardbottom organisms were seen (except attached to shell or hard debris).

RESULTS

The benthic community offshore from Kure Beach, North Carolina, is very diverse, with over 600 species taken during the 5 sampling periods (POSEY and ALPHIN, 2001). This diversity is much higher than previously reported for nearby Masonboro Sound (POSEY *et al.,* 1995) or for a sand plain associated with a hardbottom outcrop 25 km offshore from this area ("23 mile reef", POSEY and AMBROSE, 1995). This benthic community was dominated by polychaetes, with crustaceans and bivalves comprising most of the remaining taxa. However, most species were relatively uncommon, with only 29 taxa comprising at least 97% of the individuals sampled for any single date (Table 1).

There were significant interactions between sampling period and site for only 11 of the 30 comparisons (29 common taxa + total fauna; Table 2). Interactive effects were small relative to main effects for all but one taxa (*Amastigus*), allowing use of a 2-way ANOVA model for comparisons. Densities differed more among dates than among sampling sites. (Table 1, Figures 2–3) Only 10 of the 30 taxa (including total fauna) exhibited significant density differences among sites (Table 2, Figure 3), and most of these involved small magnitude differences relative to sampling date effects. Oligochaeta, *Crysinella* (bivalve), *Tellina* (bivalve) and *Branchiostoma* (cephalochordate) were more dense in the borrow site. *Amastigus* (polychaete), *Armandia* (polychaete), Haustoriidae (amphipod), *Lucifer* (decapod) and *Rhepoxynius* (amphipod) were more common in the control site. The similarity among sites is also reflected in concordant temporal patterns of density for dominant fauna when analyzed separately by site for the summer sampling periods. Twenty-two of the thirty taxa compared had similar patterns of density differences among years for both control and borrow sites for the 5 summer sampling periods (Table 3). This is also reflected in abundance patterns for higher taxonomic groupings (polychaetes, bivalves, crustaceans) when compared across sites and all dates (Figure 2). When sites were compared separately for before and after sediment removal, only 6 taxa exhibited changed among site patterns. These included 2 taxa that did not exhibit site differences before borrow activities but did exhibit differences after removal (*Armandia maculata* lower in the borrow area; and *Glycera* higher in the borrow area) and four

Table 1. *Mean density per 0.023 m^2 (Coefficient of Variation) of numerically dominant infauna (taxa representing at least 3% of the total fauna collected within a site on at least one sampling period) by sampling date in borrow and control sites. Po=Polychaete, Cr=Crustacean, Bi-Bivalve.*

Taxa	Site	July 1995	Oct 1995	May 1996	Oct 1996	May 1997	Feb 1998	May 1998	Nov 1998	May 1999	Oct 1999
Oligochaeta	Borrow	3.43(115.4)	0.44(228.1)	3.00(182.6)	4.83(137.5)	1.89(144.7)	0.22(259.8)	1.39(161.5)	1.00(278.6)	2.94(168.8)	0
	Control	2.64(138.3)	0.22(198.4)	1.43(152.9)	0.33(212.1)	0.05(430.0)	0.03(547.7)	0.56(157.6)	0.68(257.0)	0.5(178.9)	0
Amastigus sp. (Po)	Borrow	0	0	0	0	0	0	0	0	0	0
	Control	0	0.67(212.1)	0	0.56(203.5)	0	0	0	0	0	0
Armandia agilis (Po)	Borrow	0.78(305.7)	0	0	0	0	0.04(519.6)	0	0	0	0
	Control	1.55(166.7)	0	0	0	0	0	0	0.21(232.7)	0	0
Armandia maculata (Po)	Borrow	0.52(172.1)	0	0	0.33(244.9)	3.11(114.4)	0.19(213.8)	0	1.12(263.9)	0.13(273.3)	0
	Control	1.27(171.8)	0.44(163.5)	0.1(305.1)	0.11(300.0)	3.53(113.8)	0.27(239.9)	0.03(538.5)	3.25(169.7)	0.5(146.1)	0
Glycera sp. (Po)	Borrow	0.17(282.3)	0.22(198.4)	0.71(237.5)	0	1.61(116.1)	0.33(186.1)	0.96(142.5)	1.23(149.5)	3.13(89.7)	0.20(223.6)
	Control	0.32(149.8)	0.11(300.0)	1.53(178.6)	0	0.53(157.7)	0.33(198.3)	0.52(216.9)	1.11(139.8)	1.44(184.9)	0.29(170.8)
Goniadides carolinae (Po)	Borrow	0.17(373.9)	0	0.21(294.0)	1.00(89.4)	0.14(600.0)	0	0	0	0	0
	Control	0.14(342.9)	0.44(300.0)	0.03(547.7)	0.44(300.0)	0	0	0	0	0	0
Mediomastus spp. (Po)	Borrow	0.13(350.9)	0	0.21(529.2)	0.33(244.9)	0.06(418.2)	0.11(519.6)	0.79(144.3)	0.35(346.1)	4.56(153.3)	0
	Control	0.55(275.6)	0	0.27(367.6)	0.22(300.0)	0.08(454.5)	0	0.28(191.2)	0.07(367.2)	2.06(154.8)	1.57(264.6)
Prionospio cristata (Po)	Borrow	2.04(119.4)	0	0.61(324.3)	1.67(105.1)	19.75(178.0)	0.11(288.2)	0.07(367.2)	1.27(216.7)	3.88(116.9)	0
	Control	5.91(140.2)	0.33(212.1)	1.03(226.6)	3.00(97.2)	13.56(150.8)	0.37(167.7)	0.10(395.6)	2.04(228.3)	1.13(161.8)	0.29(170.8)
Prionospio steenstrupi (Po)	Borrow	3.57(104.5)	0	0	0	2.33(256.5)	0	0	0.08(353.3)	0	0
	Control	6.59(93.5)	0	0	0	2.11(385.1)	0	0.03(538.5)	0.32(328.5)	0.06(400.0)	0
Spiophanes bombyx (Po)	Borrow	0	0.11(300.0)	4.21(99.3)	0	2.06(98.6)	0	3.71(86.3)	0.08(353.3)	4.19(86.0)	0
	Control	0.23(232.5)	0.22(300.0)	4.67(65.5)	0.33(150.0)	2.84(102.0)	0.03(547.7)	3.72(83.0)	0.07(367.2)	4.13(84.8)	0
Syllidae spp. (Po)	Borrow	7.83(151.5)	0.56(240.0)	0.68(216.2)	0	0.17(304.3)	0	0	0.08(509.9)	0.94(400.0)	0
	Control	5.64(115.8)	0.67(129.9)	0.10(305.1)	0	0.11(483.4)	0.03(547.7)	0.10(538.5)	0.21(367.2)	0	0
Mediomastus ambiseta (Po)	Borrow	0.26(237.4)	0	0	0	0.03(600.0)	0	0.29(529.2)	3.23(377.5)	0.06(400.0)	0
	Control	0.64(171.8)	0	0.27(428.5)	0.11(300.0)	0	0	0	0.14(413.7)	0.19(290.1)	0
Axiothella sp. (Po)	Borrow	0.04(479.6)	0	1.61(517.1)	0	0	0.04(519.6)	0	0	0.56(171.4)	0
	Control	0	0	3.0(329.9)	0	0.11(616.4)	0.27(547.7)	0	0	0.56(171.4)	0
Prionospio dayi (Po)	Borrow	0	0	0	0	0	0.07(360.3)	0.11(529.2)	1.35(234.9)	0	2.60(223.6)
	Control	0	0	0	0.78(300.0)	0.03(616.4)	0	0	2.07(148.0)	0.19(290.1)	0.29(170.8)
Prionospio fallax (Po)	Borrow	0	0	0.04(529.2)	0	1.67(274.0)	0	0	0	0	0
	Control	0	1.33(201.9)	0.60(380.6)	0	1.39(327.7)	0	0.14(538.5)	0.14(413.7)	0.25(400.0)	0
Crysinella lunata (Bi)	Borrow	10.26(159.4)	2.33(71.1)	1.86(255.8)	2.67(139.6)	2.81(203.7)	0	0	0	0.31(279.4)	0
	Control	2.36(157.5)	1.67(108.2)	0.60(402.6)	1.44(193.1)	0.16(313.3)	0	0.07(538.5)	0	0.31(324.6)	0

Table 1. *Continued.*

Taxa	Site	July 1995	Oct 1995	May 1996	Oct 1996	May 1997	Feb 1998	May 1998	Nov 1998	May 1999	Oct 1999
Ervillea concentrica (Bi)	Borrow	2.57(421.0)	0.33(212.1)	0	0	0.11(470.3)	0	0	0	0	0
	Control	0.27(201.8)	0	0.13(547.7)	0.22(198.4)	0	0	0	0	0	0
Tellina sp. (Bi)	Borrow	0.91(127.5)	0.67(150.0)	0.93(298.8)	0.83(192.2)	0.31(232.3)	0.89(140.7)	1.89(143.3)	0.12(282.4)	0.81(191.8)	0
	Control	0.68(188.7)	0.67(198.4)	0.10(305.1)	0.11(300.0)	0.03(616.4)	0.53(277.4)	0.21(299.6)	0.29(187.1)	0.13(273.3)	0.71(155.8)
Astarte sp. (Bi)	Borrow	0	0	2.75(220.1)	0	0	0.30(395.1)	2.00(224.8)	0.35(282.4)	0.06(400.0)	0
	Control	0	0	1.43(184.8)	0	0	0.1(547.7)	0.83(164.9)	0.43(350.3)	0.25(230.9)	0
Haustoridae sp. (Cr)	Borrow	0.04(479.6)	0.56(300.0)	0.04(529.2)	0	0.03(600.0)	0.04(519.6)	0.11(529.2)	0	0	0
	Control	0.05(469.0)	0.89(142.8)	0.40(363.2)	0.56(158.7)	0.34(228.2)	0	0.14(319.8)	0	0.06(400.0)	0
Rhepoxynius Epistomus (Cr)	Borrow	0	0	0.04(529.2)	0	0	0.26(172.3)	0.46(271.7)	0.31(239.2)	0.38(165.1)	0.4(136.9)
	Control	0	0.33(212.1)	0.50(244.9)	0.89(104.4)	0.16(346.1)	0.7(184.4)	0.69(160.3)	0.18(342.6)	0.63(247.0)	0
Bathyporeia sp. (Cr)	Borrow	0	0.76(255.4)	0.04(529.2)	0	0	0	0	0	0	0
	Control	0	0.33(212.1)	0.10(305.1)	0	0	0	0	0	0	0
Lucifer faxoni (Cr)	Borrow	0	0	0	0.17(244.9)	0	0	0.07(367.2)	0	0	1.40(223.6)
	Control	0.14(257.6)	0	0	0	0	0	0	0	0.06(400.0)	0
Ophiuroidea	Borrow	0.52(162.1)	1.67(140.7)	1.89(187.9)	0.33(154.9)	0.03(600.0)	0.41(207.2)	0.29(299.1)	0.62(159.7)	0.56(233.8)	0
	Control	0.68(145.9)	0.44(163.5)	6.03(187.9)	0.78(255.4)	0	0.43(240.0)	0.45(235.4)	0.57(161.0)	0.62(192.7)	0.29(170.8)
Cumacea	Borrow	0	0.11(300.0)	1.71(183.7)	0	0.03(600.0)	0	0	0	0	0
	Control	0	0.44(118.6)	3.53(191.2)	0	0	0	0	0	0	0
Oxyurostylis smithi (Cr)	Borrow	0	0	1.75(151.3)	0	1.11(293.2)	2.26(176.9)	3.46(77.6)	0.54(168.0)	6.69(93.7)	0
	Control	0.05(469.0)	0	3.43(128.8)	0	0.55(225.4)	2.4(122.1)	3.07(65.1)	0.50(158.7)	9.31(89.9)	0
Branchiostoma caribaeum	Borrow	3.57(93.7)	3.67(157.3)	0.93(255.4)	0.83(140.3)	0.03(600.0)	0.07(360.3)	0.14(413.7)	1.46(205.9)	0	0.20(223.6)
	Control	3.14(196.1)	0.33(212.1)	0.13(325.6)	0.11(300.0)	0.18(330.5)	0.07(547.7)	0	0.43(184.4)	0	0.29(264.6)
Nemertea	Borrow	0	0	0	0	0	14.30(68.0)	4.64(160.9)	17.65(148.4)	19.50(92.7)	3.40(155.1)
	Control	0.05(469.0)	0	0.03(547.7)	0	0	9.0(109.0)	2.48(158.4)	8.64(140.1)	5.12(89.8)	2.14(95.0)
Brania sp. (Po)	Borrow	0	1.22(270.7)	0	0	0.11(358.6)	0	0	0	0.06(400.0)	0
	Control	0	0	0.03(547.7)	0	0.08(616.4)	0	0.07(373.9)	0	0	0
Total Fauna	Borrow	56.43(75.8)	22.67(74.0)	39.93(96.9)	19.83(115.5)	60.28(74.3)	40.22(44.3)	45.21(47.4)	51.73(118.2)	85.38(51.1)	17.0(69.0)
	Control	54.0(65.2)	20.78(32.6)	46.3(70.4)	14.33(53.7)	51.05(75.5)	46.47(51.1)	41.07(59.9)	40.5(79.0)	63.12(49.4)	18.71(52.9)
Species Richness	Borrow	116	46	130	37	139	112	138	117	142	25
	Control	164	68	154	36	139	124	163	138	149	45
Diversity (H')	Borrow	1.56	1.44	1.63	1.30	1.55	1.17	1.71	1.50	1.58	1.09
	Control	1.73	1.68	1.62	1.31	1.59	1.26	1.76	1.62	1.76	1.43

Table 2. *Summary of date, site and date*site interaction effects for common taxa. Shown are the significance levels for effects (NS = not significant, *p < 0.05, ** p < 0.01, *** p < 0.0001) and individuals treatment differences as indicated by SNK tests. For SNK data comparisons, dates are ordered from highest to lowest abundance. Dates with different letter superscripts differ significantly. B = Borrow site, C = Control site, 795 = July 1995 samples, 1095 = October 1995 samples, 596 = May 1996 samples, 1096 = October 1996 samples, 597 = May 1997, 298 = February 1998, 598 = May 1998, 1198 = November 1998, 599 = May 1999, 1099 = October 1999. Po = Polychaete, Cr = Crustacean, Bi = Bivalve*

Taxa	Site	Date	Date*Site
Oligochaeta	B > C ***	*** $795^{a}\ 596^{ab}\ 1096^{abc}\ 599^{bcd}\ 598^{bcde}\ 597^{bcde}\ 1198^{bcde}\ 1095^{cde}\ 298^{de}\ 1099^{e}$	NS
Amastigus sp. (Po)	C > B ***	*** $1096^{a}\ 1095^{a}\ 795^{b}\ 597^{b}\ 596^{b}\ 298^{b}\ 598^{b}\ 1198^{b}\ 599^{b}\ 1099^{b}$	***
Armandia agilis (Po)	NS	*** $795^{a}\ 1198^{b}\ 596^{b}\ 1096^{b}\ 597^{b}\ 598^{b}\ 1095^{b}\ 599^{b}\ 1099^{b}$	NS
Armandia maculata (Po)	C > B *	*** $597^{a}\ 1198^{b}\ 795^{c}\ 599^{c}\ 298^{c}\ 1095^{c}\ 1096^{c}\ 596^{c}\ 598^{c}\ 1099^{c}$	**
Glycera sp. (Po)	NS	*** $599^{a}\ 1198^{b}\ 597^{bc}\ 596^{bc}\ 598^{bcd}\ 298^{bcd}\ 1099^{bcd}\ 795^{bcd}\ 1095^{cd}\ 1096^{d}$	**
Goniadides carolinae (Po)	NS	** $1096^{a}\ 1095^{b}\ 795^{b}\ 596^{b}\ 597^{b}\ 298^{b}\ 598^{b}\ 1198^{b}\ 599^{b}\ 1099^{b}$	*
Mediomastus spp. (Po)	NS	*** $599^{a}\ 598^{b}\ 1099^{b}\ 795^{b}\ 1096^{b}\ 1198^{b}\ 596^{b}\ 597^{b}\ 298^{b}\ 1095^{b}$	NS
Prionospio cristata (Po)	NS	*** $597^{a}\ 795^{b}\ 1096^{b}\ 599^{bc}\ 1198^{bcd}\ 596^{cd}\ 298^{d}\ 1099^{d}\ 1095^{d}\ 598^{d}$	NS
Prionospio steenstrupi (Po)	NS	*** $795^{a}\ 597^{b}\ 1198^{b}\ 599^{b}\ 598^{b}\ 298^{b}\ 1096^{b}\ 1095^{b}\ 596^{b}\ 1099^{b}$	NS
Spiophanes bombyx (Po)	NS	*** $596^{a}\ 599^{a}\ 598^{a}\ 597^{b}\ 1096^{c}\ 1095^{c}\ 795^{c}\ 1198^{c}\ 298^{c}\ 1099^{c}$	NS
Syllidae sp. (Po)	NS	*** $795^{a}\ 1095^{b}\ 596^{b}\ 599^{b}\ 597^{b}\ 1198^{b}\ 598^{b}\ 298^{b}\ 1096^{c}\ 298^{c}\ 1096^{b}\ 1099^{b}$	NS
Mediomastus ambiseta (P0	NS	** $795^{a}\ 1198^{b}\ 599^{c}\ 596^{c}\ 1096^{c}\ 598^{c}\ 597^{c}\ 298^{c}\ 1095^{c}\ 1099^{c}$	NS
Axiothella sp. (Po)	NS	*** $599^{a}\ 596^{a}\ 298^{b}\ 597^{b}\ 795^{b}\ 1095^{b}\ 598^{b}\ 1198^{b}\ 1096^{b}\ 1099^{b}$	NS
Prionospio dayi (Po)	NS	*** $1198^{a}\ 1099^{b}\ 1096^{c}\ 599^{c}\ 598^{c}\ 298^{c}\ 597^{c}\ 795^{c}\ 596^{c}\ 1095^{c}$	NS
Prionospio fallax (Po)	NS	*** $597^{a}\ 1095^{ab}\ 596^{ab}\ 599^{b}\ 1198^{b}\ 598^{b}\ 795^{b}\ 298^{b}\ 1096^{b}\ 1099^{b}$	NS
Crysinella lunata (Bi)	B > C **	*** $795^{a}\ 1095^{a}\ 1096^{ab}\ 597^{bc}\ 596^{c}\ 599^{c}\ 598^{c}\ 298^{c}\ 1198^{c}\ 1099^{c}$	*
Ervillea concentrica (Bi)	NS	** $795^{a}\ 1095^{b}\ 1096^{b}\ 597^{b}\ 596^{b}\ 298^{b}\ 598^{b}\ 1198^{b}\ 599^{b}\ 1099^{b}$	NS
Tellina sp. (Bi)	B > C *	** $795^{a}\ 598^{ab}\ 1095^{ab}\ 298^{ab}\ 1099^{ab}\ 599^{ab}\ 1096^{ab}\ 596^{ab}\ 1198^{ab}\ 597^{b}$	*
Astarte sp. (Bi)	NS	*** $596^{a}\ 598^{a}\ 1198^{b}\ 598^{b}\ 298^{b}\ 597^{b}\ 795^{b}\ 1095^{b}\ 1096^{b}\ 1099^{b}$	NS
Haustoridae sp. (Cr)	C > B **	*** $1095^{a}\ 1096^{b}\ 597^{b}\ 596^{b}\ 598^{b}\ 795^{b}\ 599^{b}\ 298^{b}\ 1198^{b}\ 1099^{b}$	NS
Rhepoxynius epistomus (Cr)	C > B *	*** $1096^{a}\ 598^{ab}\ 298^{ab}\ 599^{ab}\ 596^{ab}\ 1198^{ab}\ 1099^{ab}\ 1095^{ab}\ 597^{ab}\ 795^{b}$	*
Bathyporeia sp. (Cr)	NS	*** $1095^{a}\ 596^{a}\ 795^{b}\ 597^{b}\ 1096^{b}\ 298^{b}\ 598^{b}\ 1198^{b}\ 599^{b}\ 1099^{b}$	NS
Lucifer faxoni (Cr)	C > B **	*** $1099^{a}\ 1096^{b}\ 795^{b}\ 598^{b}\ 599^{b}\ 1095^{b}\ 298^{b}\ 1198^{b}\ 596^{b}\ 597^{b}$	**
Ophiuroidea	NS	*** $596^{a}\ 1095^{ab}\ 795^{ab}\ 1198^{ab}\ 599^{ab}\ 1096^{ab}\ 298^{ab}\ 598^{ab}\ 1099^{ab}\ 597^{b}$	NS
Cumacea (Cr)	NS	*** $596^{a}\ 1095^{b}\ 597^{b}\ 795^{b}\ 1096^{b}\ 298^{b}\ 598^{b}\ 1198^{b}\ 599^{b}\ 1099^{b}$	NS
Oxyurostylis smithi (Cr)	NS	*** $599^{a}\ 598^{b}\ 298^{c}\ 596^{c}\ 597^{d}\ 1198^{d}\ 795^{d}\ 1095^{d}\ 1096^{d}\ 1099^{d}$	NS
Branchiostoma caribaeum	B > C **	*** $795^{a}\ 1095^{b}\ 1198^{bc}\ 1096^{bc}\ 596^{bc}\ 1099^{c}\ 597^{c}\ 298^{c}\ 598^{c}\ 599^{c}$	*
Nemertea	*	*** $298^{a}\ 599^{a}\ 1198^{a}\ 598^{b}\ 1099^{b}\ 795^{c}\ 596^{c}\ 1095^{c}\ 1096^{c}\ 597^{c}$	*
Brania sp. (Po)	NS	* $1095^{a}\ 597^{b}\ 598^{b}\ 599^{b}\ 596^{b}\ 298^{b}\ 795^{b}\ 1198^{b}\ 1096^{b}\ 1099^{b}$	*
Total Fauna Density	NS	*** $599^{a}\ 597^{ab}\ 795^{ab}\ 298^{ab}\ 598^{ab}\ 596^{b}\ 1198^{b}\ 1095^{c}\ 1099^{c}\ 1096^{c}$	NS

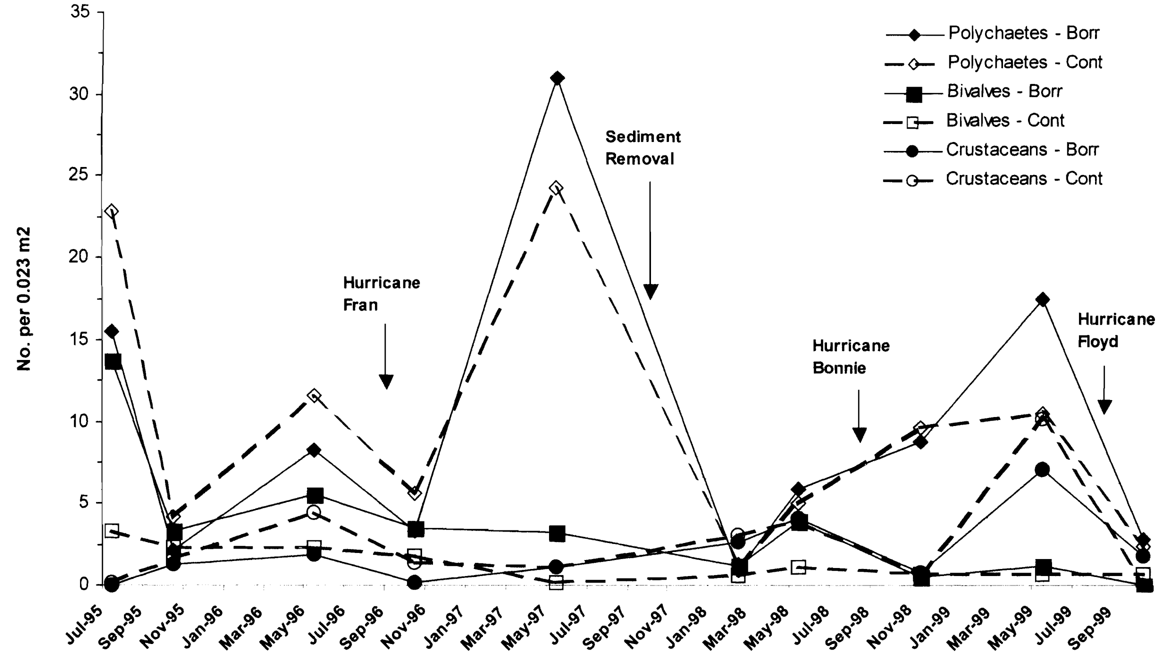

Figure 2. Mean of abundance of major taxonomic groups (polychaetes, bivalves, crustaceans) in borrow (borr) and control (cont) sites by sampling dates. Abundances for individual taxa within each group are given in Table 1. Time of sediment removal and hurricane effects are indicated by arrows.

taxa that showed site differences before sediment removal but not afterwards (*Crysinella*, Haustoriidae, *Rhepoxynius* and *Branchiostoma*). Coefficient of variations did not indicate consistent differences in variability (small scale patchiness within a site) among sites or with sediment removal (Table 1).

While there were few statistically significant differences in density between borrow and control sites, these sites did differ somewhat in qualitative patterns of dominance from before-borrow to after-borrow communities. Before sediment removal, there was strong similarity in dominant species, with over 56% average similarity of dominant taxa between the 2

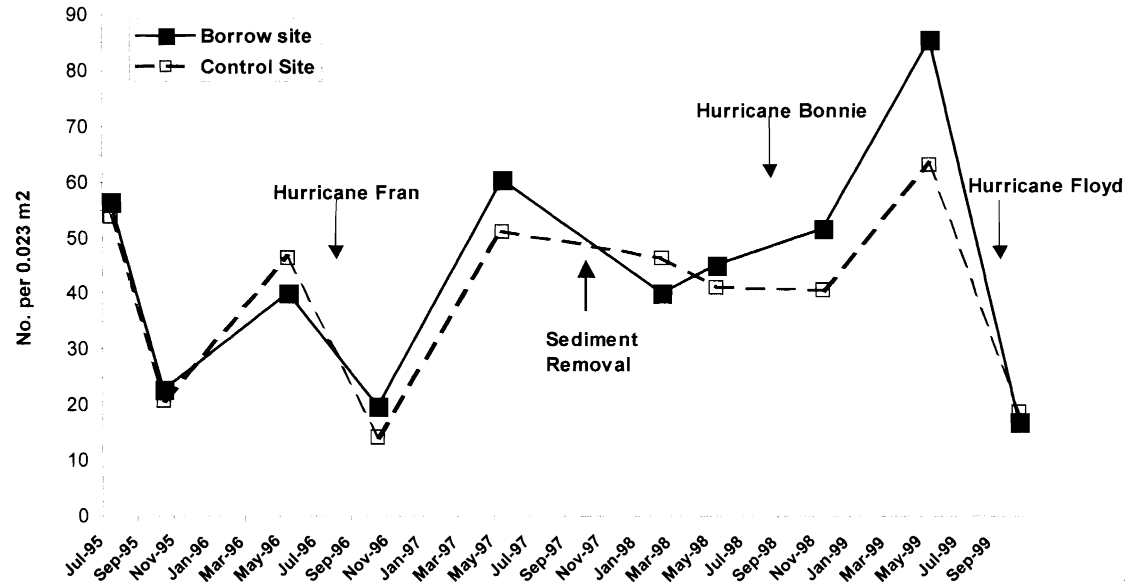

Figure 3. Mean total faunal abundance in borrow and control sites by sampling dates. Abundances for individual taxa are given in Table 1. Time of sediment removal and hurricane effects are indicated by arrows.

Table 3. *Summary of spring/summer year differences by site for all common taxa. Shown are the significance levels for effects (NS = not significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.0001$) and individuals treatment differences as indicated by SNK tests. For SNK data comparisons, dates are ordered from highest to lowest abundance. Dates with different letter superscripts differ significantly. 795 = July 1995 samples, 596 = May 1996 samples, 597 = May 1997, 598 = May 1998, 599 = May 1999. Po = Polychaete, Cr = Crustacean, Bi = Bivalve*

Taxa	Site	Date	Effect
Oligochaeta	Borrow	NS	795^{a} 596^{ab} 598^{bc} 599^{bc} 597^{c}
	Control	***	
Amastigus sp. (Po)	Borrow	NS	
	Control	NS	
Armandia agilis (Po)	Borrow	**	795^{a} 597^{b} 596^{b} 598^{b} 599^{b}
	Control	***	795^{a} 597^{b} 596^{b} 598^{b} 599^{b}
Armandia maculata (Po)	Borrow	***	597^{a} 795^{b} 599^{b} 598^{b} 596^{b}
	Control	***	597^{a} 795^{b} 599^{bc} 596^{c} 598^{c}
Glycera sp. (Po)	Borrow	***	599^{a} 597^{b} 598^{bc} 596^{bc} 795^{c}
	Control	NS	
Goniadides carolinae (Po)	Borrow	NS	
	Control	NS	
Mediomastus sp.. (Po)	Borrow	***	599^{a} 598^{b} 795^{b} 596^{b} 597^{b}
	Control	***	599^{a} 795^{b} 598^{b} 596^{b} 597^{b}
Prionospio cristata (Po)	Borrow	***	597^{a} 599^{b} 795^{bc} 596^{cd} 598^{d}
	Control	***	597^{a} 795^{a} 599^{b} 596^{b} 598^{b}
Prionospio steenstrupi (Po)	Borrow	***	795^{a} 597^{b} 596^{c} 598^{c} 599^{c}
	Control	***	795^{a} 597^{b} 599^{b} 598^{b} 596^{b}
Spiophanes bombyx (Po)	Borrow	***	599^{a} 596^{a} 598^{a} 597^{a} 795^{b}
	Control	***	596^{a} 599^{ab} 598^{ab} 597^{b} 795^{c}
Sylliade sp. (Po)	Borrow	***	795^{a} 596^{b} 599^{b} 597^{b} 598^{b}
	Control	***	795^{a} 596^{b} 597^{b} 598^{b} 599^{b}
Mediomastus ambiseta (Po)	Borrow	NS	
	Control	**	795^{a} 599^{b} 596^{b} 597^{b} 598^{b}
Axiothella sp. (Po)	Borrow	*	599^{a} 596^{ab} 795^{b} 597^{b} 598^{b}
	Control	**	596^{a} 599^{ab} 597^{b} 598^{b} 795^{b}
Prionospio dayi (Po)	Borrow	NS	
	Control	*	599^{a} 597^{b} 795^{b} 598^{b} 596^{b}
Prionospio fallax (Po)	Borrow	**	597^{a} 596^{ab} 795^{b} 598^{b} 599^{b}
	Control	NS	
Crysinella lunata (Bi)	Borrow	***	795^{a} 597^{b} 596^{bc} 599^{bc} 598^{c}
	Control	***	795^{a} 596^{b} 599^{b} 597^{b} 598^{b}
Ervillea concentrica (Bi)	Borrow	**	795^{a} 597^{b} 596^{b} 598^{b} 599^{b}
	Control	**	795^{a} 596^{b} 597^{b} 598^{b} 599^{b}
Tellina sp. (Bi)	Borrow	*	598^{a} 795^{ab} 599^{ab} 596^{ab} 597^{b}
	Control	**	795^{a} 598^{b} 599^{b} 596^{b} 597^{b}
Astarte sp. (Bi)	Borrow	***	598^{a} 596^{a} 599^{b} 597^{b} 795^{b}
	Control	***	596^{a} 598^{a} 599^{b} 597^{b} 795^{b}
Haustoriidae sp. (Cr)	Borrow	NS	
	Control	NS	
Rhepoxynius epistomus (Cr)	Borrow	**	599^{a} 598^{a} 596^{b} 597^{b} 795^{b}
	Control	*	598^{b} 599^{ab} 596^{ab} 597^{ab} 795^{b}
Bathyporeia sp. (Cr)	Borrow	NS	
	Control	*	596^{a} 597^{b} 795^{b} 598^{b} 599^{b}
Lucifer faxoni (Cr)	Borrow	NS	
	Control	*	795^{a} 598^{ab} 597^{b} 598^{b} 596^{b}
Ophiuroidea	Borrow	***	596^{a} 795^{b} 599^{b} 598^{b} 597^{b}
	Control	***	596^{a} 795^{b} 599^{b} 598^{b} 597^{b}
Cumacea (Cr)	Borrow	***	596^{a} 597^{b} 795^{b} 598^{b} 599^{b}
	Control	***	596^{a} 597^{b} 795^{b} 598^{b} 599^{b}
Oxyurostylis smithi (Cr)	Borrow	***	599^{a} 598^{b} 596^{c} 597^{cd} 795^{d}
	Control	***	599^{a} 598^{b} 596^{b} 597^{c} 795^{c}
Branchiostoma caribaeum	Borrow	***	795^{a} 596^{b} 598^{c} 597^{c} 599^{c}
	Control	***	795^{a} 597^{b} 596^{b} 598^{b} 599^{b}
Nemertea	Borrow	***	599^{a} 598^{b} 795^{c} 597^{c} 596^{c}
	Control	***	599^{a} 598^{b} 795^{c} 596^{c} 597^{c}
Brania sp. (Po)	Borrow	NS	
	Control	NS	
Total Faunal Density	Borrow	**	599^{a} 597^{b} 598^{b} 795^{b} 596^{b}
	Control	NS	

sites (Table 4). However, after sediment removal there was only an average 26% similarity in dominant taxa. This difference in pre-borrow and post-borrow similarity is almost entirely the result of November 1998 and October 1999 samples. Both of these dates were after the passage of major hurricanes (Bonnie in 1998 and Floyd in 1999). It is possible that the reduced similarity during these two time periods represents differing immediate responses to storm disturbance.

There were strong variations in density of most taxa between sampling periods. All 30 taxa (including total fauna) exhibited significant temporal differences in density (Table 2). The temporal patterns appeared to occur as one of four types: 1) summer (May–July) vs. fall (Oct–Nov) differences, 2) single events of exceptionally high density, 3) changes correlated with timing of sediment removal, and 4) variations over time with no clear seasonal component or a single peak period of occurrence.

Apparent seasonal variations in density were observed for 4 taxa. Oligochaetes, *Spiophanes*, *Axiothella*, and *Oxyurostylis* all trended towards higher density during late spring and summer sampling periods. Total faunal density was also higher during this time (Figure 3). Fourteen taxa showed peaks in density, being significantly more dense during one or two sampling periods compared with all others. These included *Armandia agilis*, *Armandia maculata*, *Glycera* sp., *Goniadides*, *Mediomastus*, *Prionospio steenstrupi*, Syllidae, *Astarte*, Haustoriidae, *Rhepoxynius*, *Bathyporeia*, *Lucifer*, Cumacea, and *Brania*. Eight of these peaks in abundance occurred in July 1995 samples, while the remaining occurred over various dates for different taxa. Five taxa showed temporal patterns of density apparently correlated with the time of sediment removal. *Amastigus* was common in fall samples before sediment removal but not afterwards. *Prionospio dayi* was common in fall samples after sediment removal but not before. Both *Crysinella* and *Ervillea* were less dense in post-borrow samples compared to pre-borrow samples, while nemertea showed the opposite pattern. However, while these patterns corresponded in time with borrow activities, borrow and control sites varied together (Tables 2–3). Diversity remained relatively constant across spring/summer and fall/winter periods with little consistent difference among sites (Figure 4). However, there was relatively high richness in November 1998 compared to other fall periods (Table 1). Lower richness in fall samples compared to spring/summer is expected as a result of differing sampling effort.

Principal components analysis emphasizes the similarity between paired borrow and control samples taken during the same time period (Figure 5). Six clusters were identified among the date/site sample groupings. In all cases, borrow and control sites sampled on the same date clustered together, with sampling period representing the major basis for division. Three clusters were dominated entirely by post-borrow samples, reflecting the cumulative effects of the individual species' responses described above. One included February samples, a second included all post-borrow May samples and the third included all post-borrow fall samples. This set of clusters suggests the importance of seasonality in this offshore community. The remaining 3 clusters included a grouping for summer 1995 (a period of high abundance for many

Table 4. *Dominant taxa (>5% total individuals collected) and Sorenson's Similarity Index for borrow and control sites on each sampling date.*

Date	Borrow	Control	Similarity
July 1995	Oligochaeta	Oligochaeta	0.86
	Prionospio cristata	*Prionospio cristata*	
	Prionospio steenstrupi	*Prionospio steenstrupi*	
	Syllidae sp.	Syllidae sp.	
	Crysinella lunata	*Crysinella lunata*	
	Ervillea concentrica	*Branchiostoma caribeaum*	
	Branchiostoma caribeaum		
	Nemertea		
October 1995	*Armandia agilis*	*Amastigus* sp.	0.29
	Chione cancellata	Syllidae sp.	
	Crysinella lunata	*Prionospio fallax*	
	Bathyporeia sp.	*Chione cancellata*	
	Ophiuroidea	*Crysinella lunata*	
	Branchiostoma caribeaum	*Tellina* sp.	
	Brania sp.	Haustoriidae sp.	
May 1996	Oligochaeta	Oligochaeta	0.75
	Spiophanes bombyx	*Glycera* sp.	
	Axiothella sp.	*Spiophanes bombyx*	
	Crysinella lunata	*Axiothella* sp.	
	Astarte sp.	Ophiuroidea	
	Batea cathariensis	Cumacea	
	Ophiuroidea	*Oxyurostylis smithi*	
	Cumacea		
	Oxyurostylis smithi		
October 1996	Oligochaeta	*Amastigus* sp.	0.38
	Goniadides carolinae	*Goniadides carolinae*	
	Prionospio cristata	*Mediomastus* sp.	
	Crysinella lunata	*Prionospio cristata*	
	Tellina sp.	*Prionospio dayi*	
	Branchiostoma caribeaum	*Crysinella lunata*	
		Haustoriidae sp.	
		Rheopoxynius epistomus	
		Ophiuroidea	
		Nemertea	
May 1997	Oligochaeta	*Armandia maculata*	0.53
	Armandia maculata	*Paraprionospio pinnata*	
	Phyllodocidae	*Prionospio cristata*	
	Prionospio cristata	*Prionospio steenstrupi*	
	Prionospio steenstrupi	*Spio pettiboneae*	
	Spiophanes bombyx	*Spiophanes bombyx*	
	Crysinella lunata	*Glycymeris pectinata*	
		Liljeborgia pallida	
February 1998	*Oxyurostylis smithi*	*Oxyurostylis smithi*	0.53
		Erycina sp.	
May 1998	*Spiophanes bombyx*	*Spiophanes bombyx*	0.31
	Leitoscoloplos robustus	*Onuphis eramita oculata*	
	Oligochaeta	*Erichthonius brasiliensis*	
	Tellina sp.	*Tiron* sp.	
	Oxyurostylis smithi	*Oxyurostylis smithi*	
	Astarte sp.		
November 1998	*Mediomastus ambiseta*	*Armandia maculata*	0
	Miliolidae	*Prionospio cristata*	
		Prionospio dayi	
May 1999	*Spiophanes bombyx*	*Spiophanes bombyx*	0.50
	Oxyurostylis smithi	*Oxyurostylis smithi*	
	Oligochaeta		
	Glycera sp.		
	Prionospio cristata		
	Belamus improvisus		
October 1999	*Glycera dibranchiata*	*Mediomastus californiensis*	0
	Prionospio dayi	*Tellina* sp.	
	Lucifer faxoni	*Scolelpsis squamata*	
	Toredo sp.	*Cresus* sp.	

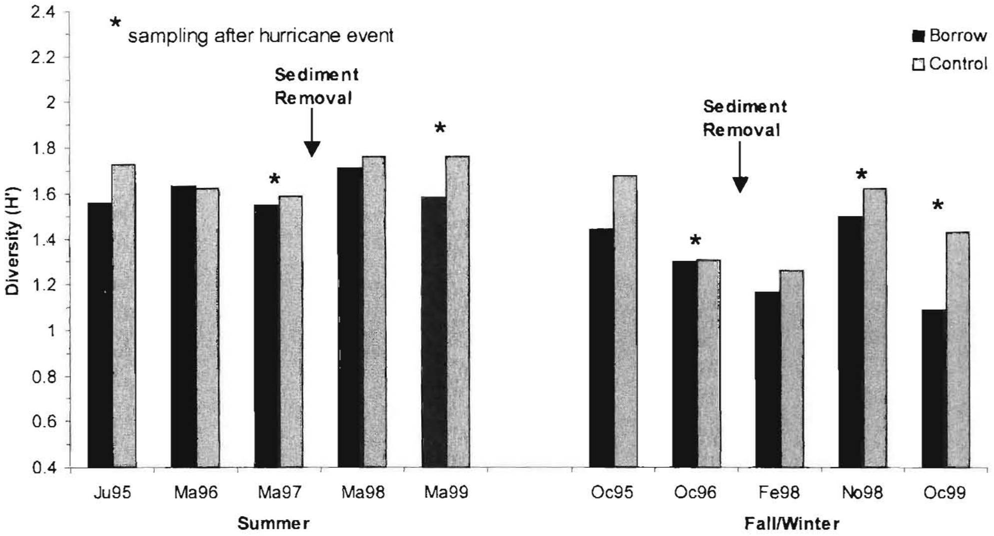

Figure 4. Diversity (Shannon-Weiner Diversity Index) by site and sampling date. N = 30 per site for July and May sampling periods and 10 per site for October, November and February periods.

taxa, Table 2), one cluster for May 1996, and a single group for the remaining samples.

ROV transects indicated little change in high relief hardbottom for the 3 areas sampled (Table 5). The largest decline was at the east control site where 5.8% of high relief habitat was observed in 1995 but only 2.5% was observed in 1998. However, this change represents only a few minutes difference in actual video observation time and may reflect sampling error. The largest change from pre-borrow to post-borrow conditions was in the relative occurrence of sand vs. ve-

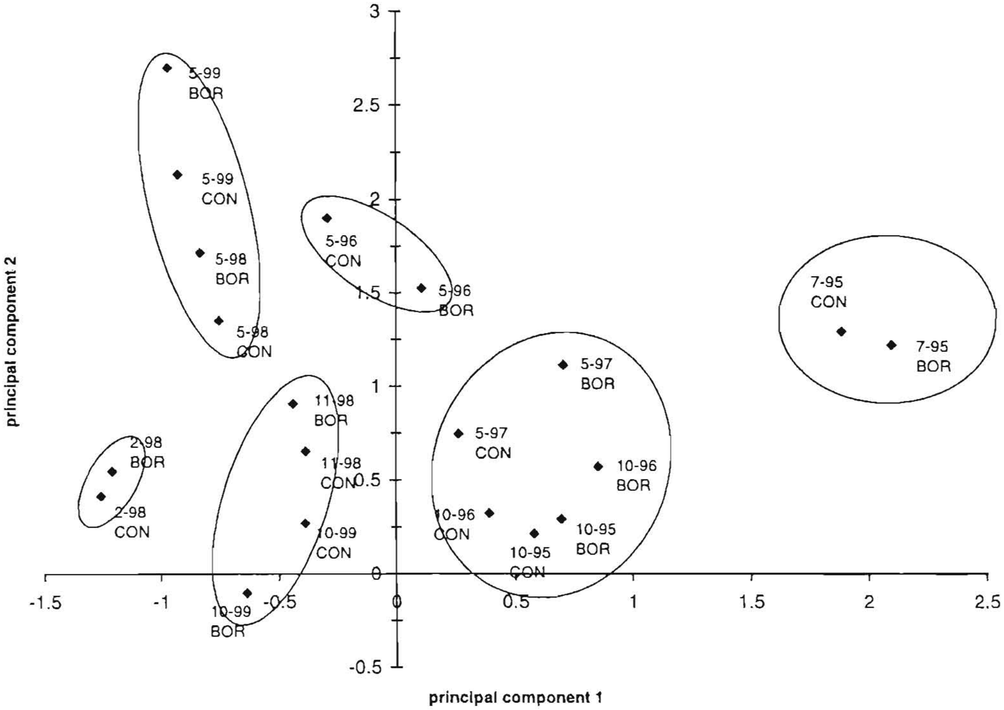

Figure 5. Biplot of first two principal components for dominant species found for all site-date sampling events. Circles indicate major clusters of samples as indicated by Ward's Minimum Variance method. Samples are designated by month-year and site (BOR = Borrow site and CON = Control site).

Table 5. *Percent of sand, veneer hardbottom, and high relief hardbottom habitat from ROV video transects. The East control site is also the location of infaunal sampling.*

Site	Sampling Period	% of Each Habitat Type Sand	Veneer	High Relief
East Control	Before sediment removal	78.0	16.2	5.8
	After sediment removal	93.0	4.5	2.5
South Control	Before sediment removal	92.6	4.6	2.8
	After sediment removal	80.0	17.8	2.5
Borrow	Before sediment removal	99.6	0.4	0
	After sediment removal	90.5	9.5	0

neer hardbottom habitat. Veneer habitat declined at the east control site while it increased in the borrow area and south control area after sediment removal. Five sites with high relief (greater than 25 cm) and well-developed hardbottom communities were identified 1995. These included 4 areas in the eastern control site and one area in the southern control site. Three of these outcrops were relocated (1 in the southern area and 2 in the eastern area) and had well-developed hardbottom communities present.

DISCUSSION

Because of the opportunistic nature of many infaunal species, benthic soft sediment communities may exhibit relatively quick recovery from disturbances if there are not strong changes to the underlying substrate (LEVINTON, 1982; VAN DOLAH *et al.*, 1984, POSEY *et al.*, 1996; MALLIN *et al.*, 1999). In this study, there were few significant differences between control and borrow sites, even for samples taken only 9 months after sediment removal. We believe this suggests quick recovery of the community from this disturbance that may reflect the dominance of opportunistic fauna that are adapted to recovery from natural disturbances (see discussion below) (POSEY and AMBROSE, 1994; POSEY *et al.*, 1995; MALLIN *et al.*, 1999) and the completion of sediment removal before the spring recruitment period. Several of the dominant polychaete taxa, including *Armandia*, *Mediomastus*, *Prionopsio*, and *Spiophanes* are known to quickly colonize after disturbances as are amphipods such as *Rhepoxynius* and many Haustoriidae (LEVINTON, 1982). However, it should be noted that the medium/small size grab used in this study may have undersampled larger or deeper burrowing taxa and these taxa may not have exhibited the same response patterns.

However, despite similarity in borrow and control site fauna, several dominant fauna at both sites exhibited differences in density in post-borrow compared to pre-borrow samples. If borrow activities have a greater spatial scale of effect than the distance between borrow and control sites in this study, it is possible that this could reflect large spatial scale for removal effects. This is not consistent with other studies of borrow sites (GROOT, 1979; JOHNSON and NELSON, 1985) and the method of removal, using a pipeline dredge, would not be expected to affect locations several km distant and not downcurrent in location. Thus, while this possibility cannot be completely dismissed, we consider it unlikely. One possible factor causing general difference in pre- and post-borrow communities was cumulative effects of hurricanes and the specific occurrence of hurricanes in 1998 and 1999 (see below). The movement of sand among control sites (with less veneer hardbottom visible at the control site sampled for infauna subsequent to multiple hurricanes) suggests sand movement occurred even though acute hurricane effects were not strongly apparent.

Although this study concentrated on the benthic infaunal communities, we also obtained data on potential effects for hardbottom habitats. The observed increase of veneer habitat in the borrow area is an expected result of sediment removal. Explanations for increases in veneer habitat at one control site and decreases at the other site are less certain. One possible explanation is movement of sediment related to storm (including hurricane) activity. Interestingly, the change for each site was of similar though opposite magnitude. Another possibility for loss of veneer habitat at the East Control area might be resuspension and sedimentation related to borrow activities. However, this is considered unlikely as it is difficult to postulate a mechanism, considering wave and current patterns, to explain the volume and spatial distance that sediment would have to be moved to cover the veneer habitat in the east control area that would not have affected the other control site as well.

The temporal patterns observed in this study emphasize the importance of seasonal and among year variability. Among the 29 numerically dominant taxa, densities and dominance patterns varied significantly among years, even when considering only the spring sampling periods (not immediately affected by hurricanes). This is similar to other long-term studies of offshore benthic communities (POSEY *et al.*, 1998) and those of many estuarine and lagoon systems. Greater densities in spring and early summer are also observed for estuarine locations (POSEY *et al.*, 1995; MALLIN *et al.*, 1999) and deeper offshore locations (POSEY and AMBROSE, 1994) adjacent to the areas studied here. Seasonal patterns may have been affected by responses to hurricanes, but the pre-hurricane sample (October 1995) clustered with other fall samples in the principal components analysis leading us to believe this is unlikely. Unlike individual species patterns, species richness and diversity were more constant across sampling dates, suggesting replacement of species among sampling dates and stability in qualitative dominance patterns within the community.

During the course of this study, 3 major hurricanes and one weaker storm passed over or near the study area. During July 1996, the eye of Hurricane Bertha (minimal Category I hurricane) passed within 5 km of the study site. This was followed in September 1996 by Hurricane Fran (Category III), whose eye passed directly over the study area, and Hurricanes Bonnie (Category II/III, September 1998) and Floyd (Category II, September 1999), which passed over the nearby Cape Fear River (making landfall 5 km to the SW of the study area). Major storm events have been shown to be associated with significant changes in faunal abundances in some offshore systems (POSEY *et al.*, 1998). Strong hurricane effects should be apparent in this study as differences between spring sampling following hurricanes (May 1997 and 1999) compared to non hurricane periods and/or fall periods when hurricanes occurred (1996, 1998, 1999) compared to the non-hurricane fall (1995). There were no samples taken during Fall 1997 because this was the time of sediment removal at the borrow site. Fall 1995 clustered with fall 1996 samples but were different from fall 1998 and fall 1999. Only fall 1998 was distinguished by exceptional abundance or diversity, with higher species richness than other fall periods. None of the May sampling periods were obvious in having consistently higher or lower faunal abundances across a majority of taxa. Both May 1998 and 1999 samples, including a post-hurricane period and a spring not following a hurricane, clustered together. Studies in the nearby Cape Fear River indicate benthic community recovery occurred by April–May of the year following a hurricane, even with strong initial declines due to hypoxia and low salinity (Mallin *et al.*, 1999). Although differences in density of several taxa between 1995–1997 and 1998–1999 samples may reflect cumulative hurricane effects, this is not discernable in the time-scale of this study. We suggest that either initial storm effects were minimal on these offshore communities or recovery occurred quickly within several months of the disturbance.

The benthic community along the southeast coast of North Carolina exhibited strong resilience to sediment removal, with little detectable difference between control and borrow sites after 1 year. There was also no distinctive change after the passage of several hurricanes, though the possibility exists for undetected long-term effects. However, the community did exhibit strong temporal variability, both among years and seasons.

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