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IMPACTS OF BEACH NOURISHMENT AND BEACH SCRAPING ON CRITICAL HABITAT AND PRODUCTIVITY OF SURF FISHES

FINAL REPORT

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ABSTRACT

This project was initiated to determine the impacts on biological resources of the beach and surf zone habitats as a result of beach nourishment and beach bulldozing, which are currently the only permitted responses to shoreline erosion in North Carolina. The disturbance of beach bulldozing (scraping) to the structure and composition of the beach community, specifically the infaunal macro-invertebrates, surf fish and shorebirds, has been largely overlooked, yet scraping is a frequently used method of responding to beach and dune erosion. Ten sites along Bogue Banks, NC were established in 1998 to monitor recovery of macroinvertebrates following bulldozing. Sampling of study sites before and after bulldozing events failed to show significant impacts on the dominant beach infauna, but high natural variability in organism distributions produced consequent low power of the analyses. Declines in surf fish and shorebird use of scraped beaches were also not observed. However, significant declines in abundance of the ghost crab, *Ocypode quadrata,* occurred on bulldozed beaches (especially on the dune face) for 6-8 months following beach scraping. Recolonization of bulldozed sites by ghost crabs occurred through recruitment of juvenile crabs only two months before bulldozing activities resumed. Hence, complete recovery of ghost crabs on beaches that undergo repeated scraping each year is unlikely. Also established in 1998 were three study areas on N. Topsail Island where recovery of macroinvertebrates in response to beach disposal activities was monitored. Sampling of control and disposal beaches before and after each of two separate disposal events (April-June, 1999 and April -May, 2000) indicated that several taxa were negatively impacted by the disposal activities. Significant impacts on coquina clams (*Donax variabilis* and *Donax parvula*), mole crabs (*Emerita talpoida*), ghost crabs and several species of amphipod (*Parahaustorius longimerus* and *Haustorius* spp.) were observed following either one or both of the disposal events. Effects of the elevated turbidity that is created in nearshore waters during beach nourishment and beach disposal projects were examined by conducting experiments in laboratory wave tanks. Elevated turbidity (within the range measured in the field during a disposal event) resulted in a 40.5% decrease in predation on coquina clams by Florida pompano, a visually foraging surf fish. A separate experiment indicated a 30% decrease in pompano predation on mole crabs under elevated turbidity conditions. Significant effects on growth of the filter-feeding coquina clams was also observed in a wave tank experiment in which elevated turbidity was generated with clay. Thus, turbidity plumes, which can travel some distance downstream from the disposal point, have the potential to affect growth of filter-feeding invertebrates and affect predator-prey interactions. Benthic data from N. Topsail also indicated that populations of mole crabs and coquina clams at the disposal site had significantly different size distributions than the populations at nearby control sites. Large individuals were not as abundant at the disposal beach as at the control beaches. The repeated disturbance of beach disposal appears to prevent the full recovery of these populations and consequently results in their decreased productivity and decreased energy flow to vertebrate consumers.

INTRODUCTION

As a result of a decision by the NC Coastal Resources Commission (CRC) in 1985, municipalities and private property owners became limited to only two types of general responses to beach erosion: beach scraping and beach nourishment. Engineered solutions that were previously available, such as sea walls, revetments, jetties and groins, were removed from the list of options and thus no longer permitted on the ocean shoreline. Since this "no hardening" rule was established, the increased frequency of Atlantic coastal hurricanes and rising sea level have greatly intensified the demand for the "soft solutions" of beach nourishment and bulldozing to combat shoreline erosion on North Carolina's barrier beaches. In addition, the public's demand for these two types of erosion control strategies is not likely to lessen, since human populations in coastal areas have been growing at twice the rate as those in other areas of the state for the past 20+ years (NCCF, 1999). Meanwhile, no study has adequately addressed the impacts of beach nourishment and bulldozing projects on beach and surf zone habitats and their economically and recreationally valuable biological resources. Our study takes an important step towards understanding the consequences of our current erosion control practices by investigating the ecological impacts of both beach nourishment and bulldozing.

About 70% of the world's sandy beaches are eroding, and over 80% of all U.S. East coast sandy beaches have been eroding during the past 150 years (Galgano et al., 1998; Bird, 1985). Although the cause of shoreline erosion is often a complex interaction of several factors, the effect of sea level rise on shoreline erosion is becoming increasingly well understood and documented (Leatherman et al., 2000). According to best estimates of the Intergovernmental Panel on Climate Change (IPCC), global sea level will rise approximately 20 cm by the year 2050 (IPCC, 1996), which translates into shoreline erosion rates of about 1m/ year (Leatherman et al., 2000). Although this erosion rate is small, ocean-front structures on beaches that are already narrow (e.g. 10-30 m at high tide) may become considerably jeopardized within a single generation. On much shorter time scales (hours - days), hurricanes and storms can cause severe erosion and remove large volumes of sediment from sandy shores. Following severe storm events, the recovery of the beach occurs over a longer time scale (years- decades) and may not be complete. The return to historical hurricane frequencies along the Atlantic coast combined with predicted eustatic sea level rise have magnified the concern over shoreline erosion in the Southeast U.S. and have intensified the demand for the management interventions of nourishment and beach bulldozing.

Beach nourishment is currently the nation's most frequently employed response to shoreline erosion, and recent decades have seen a significant increase in the number of nourishment projects along East coast barrier island beaches (Valverde et al., 1999). Beach nourishment can be defined as the placement of sand from an outside source onto an eroding beach. The objectives of nourishment are to provide a wide beach that will reduce storm damage to development from flooding waves and to increase the recreational area of the beach. Many projects involving placement of sand onto the beach result from federal navigation projects that require subsequent beach disposal of dredge spoil, but the majority of beach nourishment occurs through federally funded storm and erosion control projects. Although cost varies with the size of the project, beach nourishments are often extremely expensive, and the burden for funding such projects is increasingly becoming the responsibility of state and local governments as the availability of federal funds decreases (Valverde et al., 1999). In contrast, the routine disposal of material from maintenance dredging of inlets, channels and harbors onto beaches represents a "free" nourishment to those beaches that receive the added sediment. For both beach nourishment and disposal projects, the size criterion used by the Army Corps to determine whether sediments are suitable for addition to the beach is the same: no more than 10% fines (0.074 mm) by weight may be present in the fill material.

In contrast to the rise in reliance on beach nourishment to counteract erosion of our beaches, our level of understanding of nourishment's impacts on the ecosystem has advanced very little. The majority of research on nourishment impacts has been limited to short-term monitoring of recovery of beach invertebrates (Reilly & Bellis, 1983), monitoring of damage occurring at the borrow site (e.g. Gustafson, 1972; Courtenay et al., 1980) and evaluations of impacts on sea turtle nesting (e.g. Fletemeyer, 1980). Very little research has been conducted to address longer-term effects on resident beach organisms or to identify impacts on surf fish or shorebirds. In their review of data for the South Atlantic Bight, Hackney et al. (1996) indicated that there has been 'almost no assessment' of effects on surf fishes for this region (see also Van Dolah et al., 1994). Among the specific side-effects of beach nourishment that may potentially affect surf fishes and their benthic prey are elevated turbidity in the near-shore zone and altered sediment characteristics of the beach (Nelson, 1989; Hackney et al. 1996). An important food source for surf fishes, benthic invertebrates can suffer significant mortality when poorly matched sand is used in a nourishment project (Nelson, 1989; Hackney et al., 1996; Peterson et al., 2000b). High concentrations of suspended sediments in the near-shore area may interfere with respiration, the ability to visually forage for prey, or recruitment of invertebrate larvae (Reilly & Bellis, 1983; Hackney et al., 1996; Peterson et al., 2000b). Hackney et al. (1996) mention anecdotal reports from South Carolina of declines in hook and line catches in areas of nourishment projects. Data to evaluate the actual effects of turbidity and sediment alterations on surf zone fish and their benthic invertebrate prey remain scarce.

Beach bulldozing, which is comparatively less expensive than nourishment, has become a very widely used method of erosion mitigation on the North Carolina coast and has been employed by coastal municipalities for at least four decades as a 'soft' approach to combating beach erosion (Wells & McNinch, 1991). Beach bulldozing (or scraping) is the process of mechanically redistributing beach sand within a limited area of the littoral zone in order to enhance the size of the primary dune or to create a sediment reservoir in the backshore where no dune existed. Although the exact method of scraping can vary, sand is usually taken from the foreshore (or intertidal beach) and pushed landward to the base of the primary dune or to an area just seaward of beachfront structures. Unlike beach nourishment, beach bulldozing does not add new sediment to the beach, nor does it provide a wider recreational beach. The goal of beach bulldozing is solely to protect existing beachfront structures during storms. Only a few studies have been conducted on the U.S. East coast that included independent monitoring to test the effectiveness of beach bulldozing during storms, and almost no monitoring has been conducted to investigate the effects of scraping on the biological resources of the beach and nearshore zone (Peterson et al., 2000a).

Surf-exposed, sandy beaches represent an environment that is primarily organized by physical forces and abiotic factors (McLachlan, 1983; McArdle & McLachlan, 1992; Jaramillo & McLachlan, 1993). Modification of critical physical factors, such as nearshore wave patterns, turbidity, beach morphology and granulometric properties, can easily occur when beaches are bulldozed. As a result, the infauna (organisms living within the sediments) of the intertidal zone, dominated in biomass by coquina clams, *Donax* spp. and mole crabs, *Emerita talpoida*, can suffer losses through direct transport up into uninhabitable higher portions of the beach, by burial lower on shore, by longshore transport into inlets, or by enhanced exposure to predation. Results of a short-term study conducted in 1993 by Peterson et al. (2000a) on Bogue Banks, NC showed a 35-55% reduction in densities of *Emerita talpoida* on bulldozed beach segments of 0.5 and 3 km three months after bulldozing occurred. *Ocypode quadrata*, which forms burrows in the supralittoral zone of the beach may be significantly impacted by the alteration of sediment composition in the backshore. The coarse, shelly material that is pushed up the beach during scraping may not be consolidated enough to retain the ghost crabs' burrows, and consequently, the habitat may become unsuitable for them. Peterson et al. (2000a) found a 55-60% decline in counts of active ghost crab burrows on bulldozed beaches in July, three months after completion of bulldozing.

Increased understanding of human impacts in the ocean and coastal zone has recently been categorized (by the Intercommission Review Committee) as a high priority of the Coastal Habitat Protection Plan (mandated by the NC Fisheries Reform Act of 1997) to be developed by 2003. The management interventions of beach nourishment and bulldozing are intended to protect oceanfront beaches and structures; however, these projects also have the potential to significantly impact the ecology of the beach and surf zone system. The surf zone off ocean beaches harbors a diverse assemblage of commercially and recreationally valuable fishes. The near-shore area has also been identified as an important sheltering and/or feeding area for juveniles of many fish species, especially Florida pompano and Gulf kingfish (sea mullet), which use the surf zone almost exclusively as a juvenile nursery habitat (Modde, 1980; Lenanton et al., 1982; Lasiak, 1986; Hackney et al., 1996). Our current understanding of the surf fish community and how it is directly or indirectly impacted by nourishment and bulldozing projects is inadequate and does not allow for a rigorous evaluation of the ecological costs of these management strategies or improvement of their practice.

Our project had several objectives concerning the ecological impacts of both beach bulldozing and nourishment on the biological resources of the beach environment. First, we examined the effects of beach scraping and nourishment on the abundance of beach invertebrates, which serve as prey for many species of surf fish. Prior to bulldozing and nourishment activities and then repeatedly afterwards during monthly revisits to treatment and control beaches, we measured the abundance of beach macroinvertebrates to determine whether the treatment (i.e. scraping or nourishment) caused significant reductions in beach organisms and to determine the time period for their recovery. We assessed the abundance and diet of fish that use the surf zone as a foraging area to examine whether losses suffered by the invertebrate community translated into impacts to the next trophic level. By conducting laboratory experiments, we investigated the effects of elevated turbidity on growth and survivorship of the (numerically) dominant filter-feeding beach invertebrate, *Donax variabilis*. Experiments were also conducted to test the effect of elevated turbidity on the ability of a visually foraging surf fish (Florida pompano: *Trachinotus carolinus*) to capture prey (*Donax variabilis* and *Emerita talpoida*). Finally, we tested experimentally the effect of altered sediment characteristics on the burrowing ability of *Donax variabilis*.

METHODS

Study Sites

Bogue Banks, NC is a developed barrier island located in the northern section of Onslow Bay (Figure 1). The island's position west of Cape Lookout and its east-west orientation provide protection from typical storm waves and winter waves approaching from the northeast, but the island is vulnerable to tropical storms and hurricanes approaching from the south or southeast. The longest (45 km) and widest (average 600 m) island in Onslow Bay, Bogue Banks has been classified as a regressive barrier island and exhibits multiple forested beach ridges (Cleary & Pilkey, 1996). Although Bogue Banks has a regressive history and contains 15-20 times more sand than the transgressive barrier islands in southern Onslow Bay (Cleary, 1996), the island is no longer prograding seaward, and has suffered extensive erosion as a result of recent hurricanes. Sections of the island contain high, wide dunes but other sections, especially Atlantic Beach and eastern Emerald Isle, contain low, very narrow dunes. The island experiences a mean tidal range of 1 m and an average wave height of 1.2 m (Brooks & Brandon, 1995). For years Bogue Banks has undergone beach scraping in the winter months (November 15th – April 30th) on beaches from Pine Knoll Shores to Emerald Isle. The island has also received repeated beach nourishments (1973, 1978, 1986, 1990, 1994) in the areas of Fort Macon and Atlantic Beach as a result of pump-outs of Brandt Island, a dredge spoil disposal site (Valverde et al., 1999). All field studies on the impacts of beach bulldozing were conducted on Bogue Banks.

Topsail Island, located farther south, is the second longest barrier island (36.2 km) in the Onslow Bay region (Figure 2). Topsail is a very low and narrow (average width is 280 m) barrier island that has been ravaged by storms and hurricanes, particularly during the period 1944-1962 and during the late 1980's (Cleary & Pilkey, 1996). The island's northeast-southwest orientation exposes the island to winter storms. Classified as a transgressive barrier, Topsail Island has experienced erosion along its northern half since 1856 (Cleary & Pilkey, 1996). The shoulder of the island adjacent to the New River Inlet, however, has been prograding seaward since 1959 as a result of dredging activities and modification of the inlet (Cleary & Pilkey, 1996). Beach scraping and the addition of sediment (by truck) from outside sources have been used all along N. Topsail to re-establish a dune line. Routine beach disposal of dredge spoil also occurs on the northernmost section of N.Topsail beach on an almost annual basis. This island experiences a mean tidal range of about 1 m. All field studies on the impacts of beach nourishment were conducted on N. Topsail.

Study Design

Benthic Sampling

During February - April 1998, a set of five pairs of scraped and unscraped beaches was located along Bogue Banks. Pairs of beach sites (scraped and unscraped control respectively) were located in Pine Knoll Shores (109 Dogwood Circle, 223 Salter Path Road), Indian Beach (Ocean Glen Condominiums, Trinity Center), Salter Path (Salter Path Family Campground, undeveloped beach just west of campground), and two pairs in Emerald Isle (Emerald Isle Pier Point, undeveloped lot to the west; 1911 Ocean Drive, 1713 Ocean Drive) (Figure 1). All scraped sections were of similar size, ranging from 113 m to 270 m and averaging 207 m in length. Larger scraped sections were not evaluated, because nearby control (unscraped) beach sections of comparable size could not be located due to the intensity of beach scraping in the 1998-1999 season. Thus, our results are specific to a certain spatial scale of scraping.

Beginning in February 1998, site pairs were sampled to monitor abundances of beach macroinvertebrates. Prior to bulldozing and then repeatedly afterwards during monthly revisits, sampling of beach macroinvertebrates was conducted to assess their response to and recovery from bulldozing. Sampling began at each site one to four weeks before the site was bulldozed and then within several days following bulldozing. Sampling continued through September during monthly revisits. Post-bulldozing sampling of sites occurred on the following dates (with bulldozed location indicated for each pair): Salter Path (Salter Path Family Campground), 2/24/98; Pine Knoll Shores

(107 Dogwood Circle), 3/17/98; Emerald Isle (Pier Point), 3/25/98; Indian Beach (Ocean Glen), 4/22/98; and Emerald Isle (1911 Ocean Drive), 4/28/98.

Core samples of the macro-infauna (e.g. *Donax* spp., *Emerita talpoida*, amphipods, and polychaete worms) were taken along three replicate, vertical transects extending from the high tide mark to one meter water depth at low tide and spaced 40 m apart. Samples were collected using an aluminum "clam gun", a hand operated corer 82 cm^2 in surface area taken to a depth of 20 cm and sieved on 1.0 mm mesh. Three cores were taken and combined to form a single sample at each of five tidal elevations (i.e. high tide line, high intertidal, mid-intertidal, low intertidal, and shallow subtidal) along each replicate transect. Tidal elevations were defined based on physical factors. The high tide line was defined by the position of the drift line, and samples were collected in the dry sand just seaward (0.5 m) of this drift line. The high intertidal was the zone where sand became dry during low tide. The mid-intertidal zone was the zone where sand remained wet during low tide even after gravitational water was lost. The low intertidal, or swash zone, was defined as the area of final run-up of waves at low tide. Finally, the shallow subtidal was defined as being 1 m deep into the surf zone. All samples were taken to the lab, fixed in 10% buffered formalin, and organisms were subsequently sorted, counted and identified. Ghost crab (*Ocypode quadrata*) abundance was assessed at each transect by counting recently active burrow openings along a swath four meters wide from the mid-intertidal to where ghost crab burrows disappear over the dune. (Burrows were considered to be recently active when tracks from the crab were present.) Locations of ghost crab burrows were also classified as one of 2 positions: on the face of the primary dune or on the beach. Results were analyzed using analysis of variance procedures after testing the assumption of homogeneity of variances by Cochran's test (Underwood, 1997).

Sediment cores were also collected with a plastic tube (internal diameter 4.8 cm) to a depth of 10 cm along each transect at each of five elevations: the dune toe, the high intertidal, the mid-intertidal, the low intertidal zone and the shallow sub-tidal zone. Sediments were brought back to the lab, rinsed repeatedly with deionized water to remove all salt and then dried over-night (15 hrs.) in ovens at 90° C. Samples were first sieved by hand on a $-1\ \phi$ (2 mm) screen to remove gravel fraction and the remaining fraction was split down to a weight of 30-70 g (Folk, 1980). Split fractions were then dry-sieved using -0.5 to $3.5\ \phi$ screens at $\frac{1}{2}\ \phi$ intervals. Samples collected from the dune face contained a small percentage of fine sediments ($< 4.0\ \phi$, comprised mainly of coarse silt), which was isolated during the initial deionized water rinses by decanting into filter paper with 30 µm pores. Filter papers were then dried and subtractive weighing was used to obtain the weight of fines.

Beginning in October 1998, preliminary sampling to monitor abundances of beach macroinvertebrates at control and disposal sites on N. Topsail Beach was initiated. Two control sites (Topsail Dunes and Roger's Bay) and two disposal sites (Topsail Reef I and Topsail Reef II) were established (Figure 2). At each site, core samples of invertebrates, sediment samples and ghost crab counts were obtained following the same design used on Bogue Banks. However, in June 1999, the number of invertebrate core samples collected in each of the five tidal elevations was increased from three to eight. Sampling effort was increased as a result of finding low animal abundances on all Topsail study beaches. In addition to sorting, counting and identifying all organisms collected, size of clams and mole crabs was measured (with calipers). Clam size was measured along the greatest anterior-posterior length of the whole clam, and mole crab size was measured along the anterior-posterior length of the carapace. Lengths were recorded to the nearest 0.01 cm.

Several additional physical variables were quantified during monthly sampling visits to N. Topsail: organic content of the sediments, penetrability of the sediments, and turbidity of the nearshore water. At each study beach on N. Topsail, sediment samples for the estimation of organic content were collected. During monthly visits between October 1998 and August 1999, three 5 cm-deep sediment samples were collected using a plastic core tube (internal diameter 4.8 cm) along each transect. Sediments were collected from the seaward edge of the dune toe, in the mid-intertidal beach (at low tide) and in the swash zone. These samples were taken back to the lab and allowed to dry for 5 days at room temperature. Once dry, the samples were weighed, placed in a combustion oven (375° C) for 24 hours and then re-weighed. Weight of organic material present in the original sample was then found by subtracting the weight of the combusted sample from the original sample weight. A relative measure of beach hardness or the penetrability of the sediment (which varies with sediment composition) was obtained for control and disposal sites using a home-made penetrometer. To operate the penetrometer, a 20 oz. weight is dropped a fixed distance through a pvc pipe and drives a solid metal rod into the sand. The distance the rod penetrated into the sand was recorded (to the nearest 0.5 cm) and used as a measure of beach compaction. Three measurements were made in each of three tidal elevations: just seaward of the dune toe, mid-intertidal and swash zone (same locations as where organic sediments were collected). A single weight drop was used to measure hardness of the beach at the dune toe location, and two weight drops were used at the two lower beach elevations. Turbidity of the nearshore water was measured by collecting six 23 ml water samples from just below the surface in water 1-2 m deep. Turbidities were recorded in the field (to the nearest 0.1 nephelometric turbidity units) using an Orbeco-Hellige turbidity meter.

Statistical Analyses

Benthic sampling data from N. Topsail were analyzed using Stewart-Oaten et al.'s (1986, 2001) BACI (Before, After, Control, Impact) model, in which differences between control and disposal sites are compared between times prior to the disposal and times after the disposal by (unpaired, two-tailed) t-test. First, mean abundances for each organism were calculated for each sampling time using control site transect totals (Roger's Bay and Topsail Dunes) and disposal site transect totals (Topsail Reef I and II). Transects, which were spaced at forty meter intervals at each location, were considered independent, and thus means were calculated from the six replicate transects. Tests for serial independence of transects (using total abundances of individual taxa) were conducted to test the assumption that transects were spatially independent (Sokal & Rohlf, 1995). For each sampling date, the difference between mean control abundance and mean disposal-area abundance of each organism was then calculated, thereby reducing the data to a single value for each sampling date and each organism. Next, the data were checked graphically for nonadditivity, and a Durbin-Watson test (Stewart-Oaten, 1986) was used to verify the independence of temporal replicates (i.e. the differences). Additivity and independence are critical assumptions of this BACI model. For all species examined, the means were log transformed ($\log_{10}(x+1)$) in order to meet the assumptions of this model, and differences were recalculated using the transformed data. 'Before' disposal versus 'After' disposal differences were then compared using an unpaired, two-tailed t-test. For all of the analyses the data were divided into two years such that each disposal event (Spring 1999 and Spring 2000) was examined separately. The two disposal events were treated separately since, although they occurred at the same location, they involved the disposal of different volumes of sand obtained from different sources. In addition, the timing and duration of the disposal operation differed for each event. December of 1999 was included in year 2 as the first 'Before' sampling data for the second year. Winter represents a phase in the seasonal cycle when organism abundance is very low and precedes annual recruitment to the intertidal beach.

Clam and mole crab size data were analyzed using one sample t-tests. First, mean size for each month of sampling was calculated for disposal and control beaches using all individuals collected and measured. Differences between control and disposal means were then calculated for each month. A one sample t-test (two-tailed with hypothesized mean= 0) was then performed on these differences. Separate analyses were performed for clam and crab data.

Surf Fish Sampling

Surf fish abundance at each of the five site pairs on Bogue Banks was assessed throughout the summer of 1998 (June – August). A 40' x 6', ¼" stretch mesh, beach seine with a 5' x 5' x 6' bag was operated by two to four individuals to make three hauls during low tides under calm surf conditions. Sampling was conducted during daytime and nighttime low tides, as species composition and feeding behaviors can vary depending on time of day. Fish caught by the three hauls were pooled to form a single sample. Seine hauls were made parallel to shore for a distance of 20 m before pulling the seine onto shore. All fish were identified, counted and measured in the field. Fifteen Florida pompano (when possible) per site per sampling period were immediately placed in formalin to arrest digestion and taken back to the lab for gut content analysis. Florida pompano were chosen for gut analysis, because they are common surf zone residents and were the most common species captured in the seine samples. In addition, previous diet analysis for Florida pompano caught in NC has shown that mole crabs and coquina clams comprise the majority of this fish's diet (Hackney et al., 1996).

Pompano stomachs were dissected out and placed in 70% ethanol with rose bengal stain. Gut contents were then identified to the lowest taxonomic level possible. For each stomach, the number and volume of each type of food item was recorded. Volume of each food type was estimated by counting the number (or fraction) of 1mm x 1mm squares covered by a thinly spread layer of the particular food item. For each major food item, an Index of Relative Importance (IRI) was calculated using the following equation:

$$\text{IRI} = (\%N + \%V) \times \%F$$ (Pinkas et al., 1971; Hayse, 1990).

Percent frequency of occurrence (%F), percent of the total number (%N) and percent of total volume (%V) of stomach contents were calculated for each prey at each site by month of sampling (June, July and August). Because stomachs were often found to contain high numbers of very small food items (e.g. mysids) an additional index was calculated. Several researchers have argued that a biased importance ranking can result when a high number of very small food items is present in the stomach contents (Lagler, 1956; Crow, 1982). Therefore, a Modified Index of Relative Importance (MI) was also calculated:

$$\text{MI} = \%F \times \%V$$ (Hayse, 1990).

This modified index does not include %N in the calculation. When possible, a sample size of 15 fish was used to calculate these two indices. A mean index was then calculated for each treatment (bulldozed or control) and month combination (June, July, August).

Statistical Analyses

Surf fish abundance was analyzed in a 2-way, model-I multivariate analysis of variance (MANOVA) testing the effects of beach treatment (bulldozed vs. control) and date (June, July, August). Heterogeneity of variances was checked with Cochran's test when sample sizes were equal and with Bartlett's test when samples were unequal. Three dependent variables were used in the MANOVA: abundance of Florida pompano, Gulf kingfish and silversides (rough and Atlantic species pooled). These three surf fishes were the most common fish caught during sampling. Subsequent univariate analyses of variance were performed when the MANOVA indicated significant effects. Although our design originally incorporated a comparison of day vs. night surf fish abundance, too few nighttime seining attempts were successful, making statistical tests difficult. (Surf conditions were often too rough and/or longshore current was too strong during nighttime seines.) All statistical analyses were thus performed on daytime seine data only.

Many of the food items found during gut analysis were fragmented (e.g. shell, tissue, polychaetes), resulting in potential overestimates of the number (%N) of these food items in the stomach. Thus, all statistical analyses on gut contents were done using MI values. An MI value was calculated for each site and date combination. MI values of numerically dominant food items were analyzed in a 2-way, model-I MANOVA to examine the effects of beach treatment (bulldozed, control) and date (June, July, August). A significant MANOVA result was followed by separate univariate analyses for each dependent variable. Heterogeneity of variances was checked with Bartlett's test and was reduced by performing square-root transformations.

Growth and Condition Experiments

To test the hypothesis that high levels of turbidity, such as those experienced during a nourishment event, can affect the growth and condition of filter-feeding organisms of the beach, we conducted short-term experiments in laboratory wave tanks. The oscillatory wave tanks located at the

Institute of Marine Sciences are a unique tool for conducting experiments with beach organisms in that they can be modified to mimic the physics of an intertidal beach. Tanks were partially filled with beach sand, which when sloped simulates a natural beach. The tanks are 7 feet long, 4 feet wide and 2 feet deep, and waves are generated by a periodically dumping bucket at one end of the tank. Turbidity was generated and maintained in a 350 gallon head-tank receiving a mixture of unfiltered seawater and sediment and was delivered to six tanks by gravity flow. Twelve wave tanks were used to conduct experiments, each receiving unfiltered sea water pumped directly from Bogue Sound. Six (non-turbidity) tanks served as controls. Two separate experiments were conducted with *Donax variabilis*, each using a different sediment source. In the first experiment, organic mud collected from settling ponds at the Institute of Maine Sciences was used to generate turbidity. In the second experiment, pulverized inorganic clay (Albion Kaolin Company, Georgia) was used to generate turbidity. Kaolin clay is a very fine sediment that is readily suspended and inexpensive, and similar clay has been used successfully by researchers to generate turbidity (Benfield & Minello, 1996). The inorganic clay treatment was used to compare to the organic mud treatment, since filter-feeding organisms may be able to utilize suspended organic material for nutrition. During the experiments, sediment was periodically added by hand to the head-tank and was maintained in suspension by a bubbling air-system at the bottom of the tank that created gentle mixing. Since sediment had to be added hourly, turbidity was not maintained throughout the night (for a period of 12 hours). During beach disposal operations, dredging and pumping is often interrupted by periods of no pumping in order to lay additional pipe, redistribute the fill sediment or change the dredge or because water conditions have become too rough. Thus, interruptions in the turbidity treatment during the experiments were not unrealistic. Both experiments were run for a period of two-weeks.

Individual clams were marked with colored finger-nail polish for later identification, measured (anterior to posterior length) with calipers to the nearest 0.01 cm, towel dried, weighed (to the nearest 0.1 mg) and placed in wave tanks (six turbidity and six control tanks) for two weeks. Initial length of clams averaged 1.00 (± 0.22) in the first experiment and averaged 0.83 (± 0.13) in the second experiment. To test the interaction of clam density and elevated turbidity, 20 clams were placed in each of three control and turbidity tanks and 40 clams were placed in each of the remaining three control and turbidity tanks (i.e. a 2 x 2 factorial design). To ensure complete recovery of all clams at the conclusion of experiments, clams were initially placed in vexar baskets measuring 30 cm x 30 cm and 15 cm deep with 0.5 cm mesh. (Thus, density of clams was equivalent to 222 clams/m^2 in the low-density treatment and 444 clams/ m^2 in the high-density treatment.) Baskets were buried into the sediment so that the lip was almost flush with the sediment surface and were then filled with sand. Clams were then placed inside the baskets and allowed to burrow into the sand. Clams were recovered by carefully excavating the baskets and sieving out all sediment. At the conclusion of two weeks, clams were removed from the tanks and were again weighed and measured. Clams were frozen at – 20° C until condition analysis was performed.

During the course of the experiments, the wave buckets at each tank were timed three times a day (morning, mid-day and afternoon) with a stopwatch and adjusted, if necessary, to tip every 30 seconds. The temperature of the water in each tank was also measured twice each day (morning and afternoon). Turbidity in each tank was measured twice daily and adjusted to about 80 NTUs in turbidity tanks. Three water samples (500 mls each) were collected from the surface water of each wave tank at the end of each two-week experiment and also at the mid-point (one week) of the second experiment. Samples were immediately placed inside a cooler to protect the samples from the light and then taken into the laboratory for immediate filtering. Using low vacuum, 100 mls of each sample were filtered on GF/F Whatman filters and stored at –20° C. Pigments were extracted in 10 mls of 90% acetone with the aid of a sonication bath (15 min. bath). Samples were allowed to steep for 22 hours in a -20° C freezer to ensure thorough extraction of chlorophyll a. Samples were then filtered through GF/F filters (to ensure clarity of the solution) into glass tubes, and fluorescence was measured with a TD-700 Turner Designs fluorometer (range set at 250 μg/L).

A condition index (CI) reflecting nutritive stress was calculated for each clam according to the following equation: CI = [dry soft tissue weight (g) x 100]/ dry shell weight (g) (Lucas & Beninger, 1985; Rainer & Mann, 1992). Soft tissue was removed from clam valves, dried for 48 hours at 75° C and weighed to the nearest 0.1 mg. Shells were air-dried for several hours after soft tissue was removed and weighed to the nearest 0.1 mg. A mean index was then calculated for each tank.

Statistical Analyses

Data were first examined to determine the appropriate statistical analysis. Initially, a multivariate analysis of covariance (MANCOVA), using initial length as the covariate and proportional length change, proportional weight change and condition index as dependent variables, was considered. Mean values of the covariate, however, did not differ significantly among treatments (t-tests), indicating that an ANCOVA was inappropriate (Underwood, 1997). Histograms of the size-frequency distributions of clams used in each treatment are shown in Figures 3 & 4. Kolmogorov-

Smirnov tests performed to compare the distribution of sizes among treatments also indicated no significant differences. Results for both growth experiments were consequently analyzed using 2-way multivariate analysis of variance (MANOVA) followed by univariate 2-way analyses of variance when MANOVAs were significant. Cochran's test was used to assess homogeneity of variances except when sample sizes were unequal, in which case Bartlett's test was used.

Evaluation of Relative Catch Success Among Piers

The potential effects of beach bulldozing and nourishment on recreational catches of surf fish were to be evaluated by surveying pier fishermen and recording catch data before, during and after the disturbance of bulldozing or nourishment. The distribution of beach bulldozing along Bogue Banks did not, however, allow for interspersion of piers near bulldozed areas and piers near unscraped, control areas. The two (of five) piers near bulldozed areas (Bogue Inlet and Iron Steamer piers) were located towards the western end of the island, and the three (of five) piers near non-bulldozed areas (Sportsman, Oceanana and Triple S) were closely grouped at the eastern end of the island. In addition, one of the two fishing piers within the bulldozed area (Iron Steamer) was destroyed by Hurricane Bonnie on August 27, 1998, so only a few months of data were obtained from this pier. Thus, a rigorous evaluation of the effects of bulldozing on recreational catches was not possible. Since the participation from some piers was extremely poor during the early part of our surveys (May and June 1998), we altered our original design (in which fishermen voluntarily completed survey forms) and used a single observer to conduct surveys of fishermen at each of five piers on Bogue Banks in July, August, September and October of 1989. From East to West, the piers surveyed were Bogue Inlet, Iron Steamer, Sportsman, Oceanana and Triple S. Total catch by species for the duration of the survey is shown for each pier in Appendix I. No piers were located within the beach disposal area on N. Topsail.

Effects of Turbidity on Predation by Surf Fish

Although the proposed field evaluation of turbidity on catch success of surf fish was not possible, we were able to use laboratory wave tanks to conduct experiments to evaluate the effects of turbidity on predation by surf fish. These experiments were designed to help provide a realistic picture of the impacts of nourishment/ disposal on predator-prey interactions in the nearshore waters and provide information on whether turbidity should be controlled during these projects. We hypothesized that the elevated turbidity generated during a nourishment event would reduce the ability of visually foraging surf fish to detect and capture prey. Reactive distance, the maximum distance at which predators are able to detect their prey (Vinyard & O'Brien, 1976), is a function of several factors including turbidity. Experiments conducted by Benfield and Menillo (1996) for Gulf killifish and grass shrimp showed that significantly fewer prey were consumed in turbid waters. Turbidities measured at the nourishment site in N. Topsail ranged from 340.3 NTUs near the mouth of the discharge pipe down to 59.0 NTUs 70 meters downstream from the pipe (see Table 1). (Natural turbidity generally ranged from 6 to 30 NTUs and varied with surf conditions.) To test our hypothesis we used the common surf zone resident, *Trachinotus carolinus* (Florida pompano) as the predator, and *Donax variabilis* (coquina clams) and *Emerita talpoida* (mole crabs) as prey in two separate experiments.

In the first experiment, 25 mole crabs were placed in each of 12 wave tanks to which 3 fish had been randomly assigned. All mole crabs were measured (carapace length) with calipers and crabs measuring 1.1-1.5 cm long were used. Fish lengths (total length) were also measured and averaged between 9.90 cm and 12.95 cm for each tank. The wave tank set-up was identical to the set-up used during growth and condition experiments. Turbidity was generated using inorganic clay (Albion Kaolin Company, Georgia) in the same manner as described for the clam condition experiments. Elevated turbidity was maintained in six wave tanks for four days (except for 12 hours each night), and turbidity was measured in each tank immediately following the start of the experiment and again on the third day. Pompano typically forage during daylight hours (Modde & Ross, 1983; Armitage & Alevizon, 1980), so the lack of elevated turbidity during nighttime was unlikely to compensate exactly for any treatment effect (i.e. reduced predation) during the day. (Three water samples were collected per tank, measured with an Orbeco-Hellige turbidity meter and averaged for each tank.) Over the course of the experiment, average turbidity was 74.1(± 19.5) NTUs versus 7.6 (± 1.2) NTUs in control tanks. After four days, uneaten mole crabs were recovered from the 12 tanks by sieving through the sand in each wave tank, spending equal time (effort) sieving each tank. The proportion of prey consumed was analyzed in a 1-way ANOVA. Homogeneity of variances was tested with Bartlett's test, which indicated that no transformation was necessary (at α=0.05). Data from one of the six turbidity tanks were removed from the analysis, because a blue crab had invaded the tank.

In a second experiment, sets of 28 coquina clams were placed in each of 12 wave tanks, each containing 3- 4 fish. Prey individuals of equivalent size (0.7 – 1.1 cm anterior-posterior length) were used in all replicates. Elevated turbidity was again generated in six wave tanks using kaolin clay, and was measured (in the same manner described for mole crab experiment) just prior to beginning the experiment. To ensure complete recovery of uneaten prey, clams were tethered by supergluing the posterior end of clams to 30 cm long, 4 lb. test lines, which were tied to a metal staple. Seven clams were tethered to a single metal staple, and four staples were deployed per wave tank during the experiment (28 clams total). When deployed, staples were pushed into the sediment until flush with the surface. Four wave tanks, which contained no predators, were used to test the reliability of the tethers in ensuring complete recovery of clams. The experiment was run for one hour and was repeated on the following day after re-randomizing fish to individual tanks. Average turbidity was 114.8 (± 51.0) NTUs (day 1) and 87.7 (±18.5) NTUs (day 2) in turbidity tanks and 9.7 (± 0.3) NTUs (day 1) and 9.5 (± 0.4) NTUs (day 2) in control tanks. The response variable was the proportion of prey consumed during one hour. A two-way analysis of variance was used to analyze the effects of turbidity and date (i.e. dates of the two experimental runs) after checking the homogeneity of variances with Cochran's test. Data from one turbidity tank and one control tank from the first experimental run were not included in the analysis, because staples were not removed at the correct time.

In a two-way, model III ANOVA on untransformed data (with date as a random factor), the interaction of date x turbidity was not significant (p=0.3285) and the effect of date was not-significant (p=0.3822). Thus date was removed from the analysis, and a one-way ANOVA was subsequently performed to test the effect of turbidity on proportion of prey consumed.

Burrowing Experiment

Field experiments were conducted to test the hypothesis that sediment characteristics affect burrowing efficiencies of the coquina clam, *Donax variabilis*, an important prey item for several species of shorebirds and surf fish. For the coquina clam, the ability to burrow efficiently is critical for maintaining a favorable position on shore to feed and avoid erosion and unintended transport. Three aluminum, circular 'arenas', 30 cm in diameter and 25 cm deep, were implanted 15 cm into the beach surface near the low tide line and filled with one of three sediment types: fine (mean grain size 180 µm, moderately well sorted), coarse (mean grain size 500 µm, moderately sorted) or shelly (mean grain size 1 mm, poorly sorted). Constant additions of sea water were made in order to keep the sediments within the arenas saturated. Twenty, freshly collected (10-20 min. prior to experiment) clams of similar size (1.5 - 2.0 cm) were dropped individually into each arena and burrowing speed was timed with a stopwatch. Timing began when the clam began digging action with its foot and ended when the clam was no longer visible. The same experiment was then repeated with a natural density (as determined by replicated quadrat samples) of *Donax* included in the sediment treatment (e.g. fine sand +123 clams, coarse sand + 123 clams, shelly sand + 123 clams). Finally, the experiment was repeated using double the observed field density of clams. Thus, we conducted a 3 x 3 factorial experiment with three sediment types (fine, coarse, shelly) and three densities of clams (0, 123, 246). Each of these nine treatments was replicated three times and took several days to complete. Burrowing speed was analyzed in a 2-way, model-II ANOVA after checking the assumption of homogeneity of variance with Bartlett's test.

RESULTS

Effects of Beach Scraping

Benthic sampling data from the set of five paired beaches revealed no significant differences in changes between bulldozed and control beaches in average abundances of the dominant beach macroinvertebrates after scraping was completed. Fourteen different species representing four phyla were identified from beach sites; however, just three species comprised over 90% of the individuals (*Donax variabilis, Scolelepis squamata, Amphiporeia virginiana*). A complete species list for 1998 is provided in Table 2. Separate one-way ANOVAs were performed on the most common species of beach macroinvertebrates to test the main effect of time (before bulldozing, after bulldozing and one month after bulldozing) on differences in mean animal abundances between paired control and bulldozed beaches. (Before = 1-4 weeks prior to scraping, After = days- 1 week after scraping, 1 Month After= 1 month after the second sampling date.) Differences between paired beaches were calculated using mean organism counts per transect and then subtracting the means at bulldozed sites from the means at their paired control sites (i.e. mean count per transect at control – mean count per transect at bulldozed). By comparing these differences between pairs of beaches over time, one-way ANOVAs provided a test of the interaction between treatments and time. Differences were tested with Cochran's test, which revealed heterogeneity of variances. However, no transformation of the data enabled us to homogenize the variances, and analyses were performed on untransformed data.

Results of ANOVAs performed on heterogeneous data are valid when no significant differences are detected, because heterogeneity leads to increased probability of a Type I error (false positive) (Underwood, 1997). A finding of no significant difference in the analyses means that a Type I error did not occur.

ANOVA results for the numerically dominant *Donax variabilis* indicated no significant change in differences between control and bulldozed beaches (Figure 5). Figure 5 illustrates that following scraping the difference in *D. variabilis* abundance between control and bulldozed site pairs did not change (p= 0.8368). If scraping had caused a reduction in coquina clam abundance at bulldozed beaches, the difference between paired control and bulldozed beaches after scraping would be large and positive with respect to the before scraping difference. In addition, sampling conducted approximately one month after bulldozing occurred showed that on average *D. variabilis* abundance was higher on bulldozed beaches than on their paired control beaches (Figure 5). Figure 6 illustrates differences between pairs of beaches over the same three time periods. At three of the five site pairs (EI, SP and IB), *D. variabilis* abundances were greater at the bulldozed beach than the paired control beach right after scraping occurred. The data, therefore, do not indicate that scraping resulted in decreased abundances of *D. variabilis* on bulldozed beaches. These data also show a 45% increase in clams on bulldozed beaches relative to controls in samples taken 1 month after bulldozing, suggesting that clams were not impacted by scraping; however, this result was not significant. Power analysis (Sokal & Rohlf, 1995) indicated that given the observed standard deviation and sample size and setting alpha at 0.05 and power at 80%, a very large change in the differences would have had to occur in order to detect a significant effect of bulldozing. Results (not shown) for the much rarer coquina clam, *Donax parvula*, were similar, and again no bulldozing impact was detected. (*Donax parvula* comprised 1.2% of the organisms sampled.)

A common amphipod species was also examined separately in a one-way ANOVA, and again, no significant change in organism abundance was detected when control and bulldozed beaches were compared (p= 0.7835). Results for the numerically dominant amphipod species, *Amphiporeia virginiana*, are shown in Figure 7. After scraping, abundances of *A. virginiana* were, on average, 11.7% higher on bulldozed beaches. The change in differences between paired beaches from before to after-scraping (days – 1 week after) time periods shows an increase by 24.7% in mean abundances of *A. virginiana* on bulldozed beaches. However, Figure 8 indicates that this pattern occurred as a result of much larger counts of *A. virginiana* at only two of the five bulldozed beaches (EIP and IB). In addition, one month after scraping, *A. virginiana* abundances were greater at three of the five control beaches (EI, SP and IB) when compared to the paired bulldozed beaches (Figure 8). The change in differences between site pairs were not large enough nor were they consistent in direction among the site pairs to result in the detection of a significant effect, and the power of this analysis was very low (8%) (Sokal & Rohlf, 1995). Thus, the data do not provide consistent support for the hypothesis that bulldozing causes a reduction in amphipod abundance.

A separate one-way ANOVA was also performed on the second most abundant organism, the spionid polychaete, *Scolelepis squamata*. Results of this analysis are shown in Figure 9 and indicate that changes in *S. squamata* abundances were not significant when bulldozed and control beaches were compared (p= 0.5615). Following bulldozing, a decrease in the difference of *S. squamata* abundance between paired control and bulldozed beaches was observed (47.9% difference vs. 6.2% difference); however, this change was not significant. The lack of significance in this large decrease in *S. squamata* abundance (42%) at bulldozed locations relative to control locations reflects the low power of the analysis to detect an impact of bulldozing. (The power of the analysis was only 12.6% (Sokal &Rohlf, 1995).) One month after bulldozing occurred, however, *S. squamata* mean abundance was greater at bulldozed beaches relative to paired controls (Figure 9). Figure 10 illustrates the differences between bulldozed and control beaches for all site pairs over the three time periods and indicates that *S. squamata* abundances were greater at SP, IB and PKS control beaches following scraping. However, one month after scraping three of the five bulldozed beaches had higher abundances of *S. squamata* when compared to control beaches (EIP, EI, PKS).

The often numerous mole crab, *Emerita talpoida*, was not found in high abundance on any of the study beaches in 1998 and comprised only about 2.0% of the invertebrates collected. Results of the one-way ANOVA for *Emerita talpoida* are shown in Figure 11. This figure indicates that mole crab abundances were 12.2% greater at control beaches than at paired bulldozed beaches prior to scraping, and that this difference increased to 68% following scraping (i.e. even greater mole crab abundances on control beaches relative to bulldozed beaches). The change in these differences between control and bulldozed beaches, however, was not significant in the analysis (p= 0.7463) as a result of uncontrolled variability, low mole crab counts and thus low power of the test (8.6 %). This 56% increase in mole crab abundance on control beaches relative to bulldozed beaches following scraping suggests that scraping may have a negative impact on mole crab abundances. In addition, one month following scraping, mole crab abundances on control beaches remained elevated in comparison to paired bulldozed beaches (Figure 11). Figure 12 indicates that this increase in mole crabs at control beaches relative to paired bulldozed beaches following scraping occurred mainly at two site pairs (EIP and SP). At the three remaining site pairs (EI, IB and PKS), mole crab abundances at control beaches declined or did not change with respect to paired bulldozed beaches.

Ghost crabs

Surveys of active *Ocypode quadrata* (ghost crab) burrows indicated a substantial reduction in ghost crab abundance at bulldozed beaches for 6-8 months following scraping. During April, the month when *Ocypode* first became active, bulldozed beaches had 40% lower abundances of ghost crabs. (Although beaches had been bulldozed during February- April, ghost crabs could not be censused until April, when they became active and began to form burrows.) Two-way ANOVAs were performed on log-transformed mean ghost crab abundances (after testing variances with Cochran's test) to test treatment (bulldozed, control) and site and indicated that ghost crab abundances at bulldozed sites remained significantly depressed until September (Figures 13-18). Beachgoer interference with censusing of ghost crab burrows (i.e. obscuring burrow openings) occurred at two sites (Salter Path and Emerald Isle) during two months of sampling (August and September) so a three-way ANOVA testing the additional effect of date was not possible. Separate two-way ANOVAs were instead performed for each month of censusing. Significant site x treatment interactions occurred in April and May only (Figures 13 & 14). In April fewer crabs were counted at the SPV control beach (Trinity Center in Pine Knoll Shores) than at the paired bulldozed beach; however, this relationship was reversed in May when more ghost crabs became active at all sites. The site x treatment interaction plot for May (Figure 14) indicates that all bulldozed sites had fewer ghost crabs than paired control beaches, and a significant interaction occurred because this relationship differed in magnitude among the site pairs. ANOVA results show that significantly lower abundances of *Ocypode* at bulldozed sites occurred in each month except September. During September we observed that the majority of ghost crab holes were much smaller in diameter than usual (approximately dime-sized), indicating a period of recruitment.

Position of ghost crab burrows was examined by comparing counts of burrows on the beach and dune face at bulldozed and control beaches in April when *Ocypode* initially became active and in July when *Ocypode* approached a maximum seasonal abundance. Separate two-way ANOVAs were performed on log-transformed burrow counts located on the dune face and the beach to test the main effects of treatment and site. Figure 19 illustrates the results of analyses performed on April ghost crab data, and indicates a significant treatment x site interaction for burrows located on the beach. Examination of the interaction plot shows that this interaction is driven by one site, PKS, which had a much greater difference between bulldozed and control beaches in comparison to the other site pairs. Significantly fewer ghost crabs were found on the beaches of bulldozed sites, but no significant differences in ghost crab abundances on the dune face occurred in April (Figure 19). Mean counts on dune faces in April were very low at all sites (mean counts ranged from 0 – 2.3 per site). In July, when active burrows were more numerous, significant differences in beach counts of crab burrows at bulldozed and control beaches did not occur (Figure 20). ANOVA results for dune face burrows show a significant site x treatment interaction and a significant treatment effect for July data (Figure 20). The site x treatment interaction plot (Figure 20) shows a common pattern among sites (i.e. lower mean counts at bulldozed than at control sites); however, this relationship differed sufficiently in magnitude among sites to generate an interaction. ANOVA results also show that, in July, significantly fewer burrows were located on dune faces of bulldozed sites. Thus, in July, the depression in ghost crab abundances at bulldozed areas occurs primarily because of a reduction in the number of dune face burrows.

Grain size analysis was performed on sediments collected from the face of primary dunes to compare mean grain sizes and sorting (i.e. variance of grain sizes in the sample). Ten-centimeter deep sediment cores were collected on dune faces both before and after (days –1 week after) bulldozing occurred, and results of grain size analysis are shown in Table 3. Paired, two-tailed t-tests were performed on mean grain size and sorting data (in phi units) for samples collected both before and after bulldozing. Comparison of samples from bulldozed and control sites collected prior to bulldozing indicated marginally significant differences in mean grain size (p= 0.0481) and in sorting (p= 0.0602). Table 3 shows that the mean grain size at control dunes were finer (1.987 phi) than bulldozed dunes (1.600 phi) prior to scraping. Several bulldozed sites in this study had been bulldozed in previous years, which may account for this pre-existing difference in mean grain size. However, immediately following scraping, mean phi sizes at bulldozed and control dunes were very similar (1.702 and 1.796 phi, respectively). Paired t-test results for dune sediments collected following completion of scraping indicate that while mean grain sizes at bulldozed and control dunes were not significantly different (p= 0.3605), average sorting values were significantly different (p = 0.0424). Following Folk's (1980) classifications, bulldozed dunes were only "moderately well sorted" (0.634 phi), while control dunes were "well sorted" (0.389 phi).

Surf Fish Sampling

Beach seine sampling captured a total of 15 fish species from the surf zone off our beach sites (Table 4), but one species, Florida pompano (*Trachinotus carolinus*), comprised the majority (75.8%) of the total fish caught during the sampling period (June 9 – August 21, 1998). The Gulf kingfish (*Menticirrhus littoralis*) was the second most abundant species, comprising 15.1% of the total catch. Six percent of the total catch consisted of two species (pooled) of silversides, *Menidia menidia* and *Membras martinica*, and all other species caught represented less than one percent of the total catch. Total abundances of surf fish for each month of sampling are shown in Figure 21, which indicates a general decline in total catch from June to August and indicates some variation among sites within each month.

MANOVA results indicated a significant date effect only (Wilks' Lambda, $p<0.001$). Subsequent 2-way ANOVAs indicated a significant effect of date on (log-transformed) pompano and Gulf kingfish abundance but not on (log-transformed) silverside abundance (Table 5). The main effect of treatment was not significant in any of the analyses, nor were any of the (treatment x date) interactions significant. A 2-way ANOVA testing the effects of beach treatment (bulldozed, control) and date (June, July, August) was also performed on total surf fish abundance, and results are given in Table 5. Total abundances were log-transformed to achieve homogeneity of variances after examination of the variances with Cochran's test. The main effect of date was significant as a result of higher catches in June (see Figure 21). Again, the interaction term and the main effect of treatment were not significant.

Importance values (IRI and MI) for the ten catagories of food items identified from pompano stomachs are given in Table 6. From the table and from Figure 22, which presents mean MI values by treatment and date, it is clear that gut contents varied among sampling times. A 2-way MANOVA was performed on three consistently high-ranking food items, polychaetes, *Donax* and *Emerita*. These food items were chosen for the analysis, because in addition to having high importance values, these food items were identified to a specific taxonomic group. MANOVA results indicated a significant date effect (Wilks' Lambda, $p= 0.0254$) and a marginally significant treatment effect (Wilks' Lambda, $p=0.0909$). Results of 2-way ANOVAs performed for each of the three food items are given in Table 7. Neither of the main effects, treatment and month (date), was significant for *Donax* MI values, nor was the treatment x month interaction significant. The effect of month was significant for polychaete MI values ($p= 0.0024$), and Figure 23 indicates that polychaetes were much more prevalent in pompano diets during the month of June. ANOVA results for *Emerita* importance did not indicate a significant month effect or a significant treatment x month interaction. The effect of treatment was, however, significant for *Emerita* MI values ($p= 0.0099$). Figure 23 shows that importance values of *Emerita* were significantly higher for pompano caught at control sites versus bulldozed sites.

Burrowing Experiment

Coquina clam burrowing speed was significantly affected by sediment type ($p<0.0001$) but not by background clam density ($p= 0.1796$). Table 8 provides the complete ANOVA results and shows that the sediment type x clam density interaction was not significant ($p=0.4955$). Post-hoc comparisons (Scheffé's F) showed significantly greater burrowing speeds in coarse vs. shelly sediment and fine vs. shelly sediments, but burrowing ability did not differ in coarse vs. fine sediments. Figure 24 illustrates that burrowing speed was greatly decreased in shelly sediments. Although background densities of clams did not significantly affect burrowing speed, a trend of slower burrowing rates at high clams densities was suggested (Figure 24).

Tables 9 & 10 provide results of grain size analysis performed on sediments collected at four tidal elevations (high intertidal, mid-intertidal, low intertidal and shallow subtidal) at each of the five pairs of study beaches on Bogue Banks. Paired, two-tailed t-tests were performed on the differences in mean phi size between paired bulldozed and control sites to compare before vs. after bulldozing samples. Samples from all four zones were averaged to analyze changes between controls and paired bulldozed sites before vs. after scraping (after= days-1 week after). The analysis indicated a marginally significant change in sediment sizes before vs. after scraping took place ($p=0.0524$). Table 9 shows that following bulldozing sediments became more fine in the surf zone (zone 5) and became more coarse in the high intertidal zone (zone 2). Sorting values were compared in a similar analysis, but no significant changes in sorting were indicated.

Effects of Beach Disposal

Twenty-two species representing four phyla were identified from the benthic samples collected at N. Topsail field sites; however, just two species (*Donax variabilis* and *Scolelepis squamata*) comprised 89% of the total organisms collected. A complete species list is provided in Table 11, and mean abundances for all but the most rare organisms are presented in Table 12 for each location and time period of sampling.

A significant effect of beach disposal on the abundance of several numerically dominant beach invertebrates was indicated for the second beach disposal (Spring 2000) that took place during the study period. Figure 25 illustrates the changes in average abundance over time at control and disposal areas for the six most numerically abundant organisms. The typical seasonal trends are revealed in Figure 25 (e.g. summer maxima, winter minima); however, trends between control and disposal beaches are also indicated. For example, higher mean abundances for both of the bivalve species, *Donax variabilis* and *Donax parvula,* (Figure 25 A & B) occur at control beaches (versus disposal beaches) during the summer months following the beach disposal operations. BACI analysis (Stewart-Oaten et al., 1986) was performed for each disposal event (Spring 1999 and Spring 2000) to determine whether the differences between clam abundance at control and disposal sites changed following the disposal event. Due to the very low abundance of *Donax parvula* in our samples (see Table 12), clam abundance was analyzed for the pooled abundances of the two bivalve species and also for *Donax variabilis* alone. Before vs. After differences (calculated using log transformed means) were significantly different in the second year (p= 0.028) for pooled clam abundances and also for *D. variabilis* alone (p= 0.026), indicating a significant impact on clam abundance at the disposal site as a result of the Spring 2000 disposal event. Before vs. After differences were only marginally significant following the 1999 disposal for pooled clam abundances (p=0.075) and for *D. variabilis* alone (p=0.069).

Figure 25 C exhibits a trend opposite to that of the bivalves: the polychaete, *Scolelepis squamata*, occurs in greater abundance at the disposal area during the summer months following the disposal operations than at the control area. *Scolelepis* flourished on the disposal beaches. BACI analysis, however, did not indicate that the differences between (log-transformed) control and disposal mean abundances were significantly altered following the disposal. This result prompted further scrutiny of the data. Examination of mean *Scolelepis* abundance at the two control beaches (Roger's Bay and Topsail Dunes) revealed a dramatic difference between the two sites (Figure 25 C). In 11 of 16 months of sampling, the Roger's Bay control beach had comparatively low polychaete abundances. Figure 26 also provides comparison plots for each of the five other organisms evaluated and shows that, in general, their abundances are similar at the two control sites.) Due to the dramatic differences in *Scolelepis* abundance at the two control areas, separate BACI analyses were performed on *Scolelepis* abundance using each control area separately. A significant Before vs. After effect was found (p= 0.038) in year two when differences were calculated using Roger's Bay control data. No significant impact was detected in either year when Topsail Dunes data were used in calculations.

Figure 25 (D – F) provides average abundance through time for the three most common amphipod genera. Higher abundances of *Parahaustorius longimerus* and *Amphiporeia virginiana* occur on control beaches following both the 1999 and 2000 disposal events. A slight trend of higher abundance at control beaches occurs for *Haustorius* spp. in the second year only. BACI analysis (Stewart-Oaten, 1986) revealed a significant impact of the Spring 2000 disposal on *P. longimerus* abundance (p=0.003). *Haustorius* spp. and *P. longimerus* abundances were pooled (due to low abundance of *Haustorius*) for BACI analysis, which again indicated a significant impact on amphipod abundance at the disposal area in 2000 (p= 0.023). *A. virginiana*, however, showed no significant effects in either year when analyzed separately or when pooled together with the other amphipods.

Figure 27 displays the mean abundances for the mole crab, *Emerita talpoida*. Mole crabs were not abundant in samples collected at any beach location (see Table 12), and large, summer aggregations of crabs typically found on NC beaches (e.g. Bogue Banks) were not observed on Topsail Island beaches during the course of this study. Figure 27, however, shows a large disparity between control and disposal means following the 1999 disposal. BACI analysis did not indicate a significant change in the difference between (log-transformed) control and disposal means in either year (p= 0.172 in 1999, p= 0.148 in 2000). May 1999 was the only month in which average mole crab abundance was greater on disposal beaches (2.67 vs. 1.83; see Figure 27). Since beach disposal continued until June 8, 1999, May samples were actually collected *prior to* completion of the beach disposal project. When May 1999 was removed from the BACI analysis, the test indicated a significant impact effect (p= 0.026). (May samples were removed since they were collected *during* the disposal and could not be defined as either "before" or "after" samples.) Separate one-way comparisons for each month of sampling (Mann-Whitney U test) were also conducted on the mean abundances and showed that control means were significantly higher than disposal means in June 1999 – October 1999 and February 1999. (U test results do not necessarily reflect an impact effect since they compare means within each month of sampling and not through time.)

Results of ghost crab censuses are shown in Figure 28. Higher ghost crab abundance (measured by counting active burrows) occurred at control sites versus disposal sites following the second disposal event. These higher abundances were due largely to differences in the number of burrows located on the beach and not to burrows located on the primary dune (Figure 28 B &C). BACI analysis was performed on total counts (beach and dune) and on beach and dune counts separately. A significant impact was detected for the second year on total counts (p= 0.027) and on beach counts (p= 0.015). No impacts were detected for the first disposal event, and no impacts were detected for the dune counts. Throughout the study period, ghost crab burrow counts on primary dunes were low in comparison to beach counts for both control and disposal beaches, indicating that crabs preferred the beach location and did not alter this preference following a beach disposal event. Most of the primary dunes on the N. Topsail study beaches had been altered at various times by either beach bulldozing, the addition of trucked-in sediment or by severe erosion (e.g. Hurricane Floyd). Thus, these dunes may represent low quality habitat for ghost crabs.

Mean size for both *Donax variabilis* and *Emerita talpoida* from control and disposal beaches was analyzed and is presented in Figure 29. Larger mean coquina clam size occurred in all months, and a one-sample t-test (two-tailed with hypothesized mean= 0) on differences between control and disposal means was significant (p= 0.003). The trend of larger individuals on control beaches was not as strong for *Emerita* (Figure 29 B), and a one sample t-test (two-tailed with hypothesized mean= 0) on differences between control and disposal means was marginally significant (p=0.053). Figures 30 & 31 provide frequency distributions of sizes at disposal and control beaches by season. Frequency curves are provided on each histogram to help illustrate the skewness of the distributions.

Mean sediment grain sizes were finer at the disposal beach at all tidal elevations following the 1999 disposal event (Figure 32). From May 1999 until December 1999, sediment samples collected at the disposal beach in zones 1-3 (i.e. the supratidal beach, the mid-intertidal and low-intertidal beach) were much finer (i.e. larger mean phi size) than at the control beaches. Prior to disposal in 1999, sediments were not finer at the disposal site in these zones, indicating that the difference among sites was a result of the addition of dredge spoil material. Sediments collected from zones 4 and 5 (swash and surf zones) were also finer at the disposal site versus control sites following the addition of dredge spoil, but this effect was not as persistent as it was in the other beach zones. Sediments were also finer in zones 1-4 of the disposal site in June, 2000, just after disposal activities were completed for the second time. The second disposal event did not result in as great a difference between disposal and control mean grain sizes, especially because mean grain sizes at the control beaches were finer than in the previous year. In addition, the second disposal event added a much smaller volume of sediment to the beach (139,000 yds^3 in 1999 vs. 39,978 yds^3 in 2000). Sorting values (Figure 33) provide additional evidence that the sediments at the disposal site were altered with respect to the undisturbed control beaches. Sorting values were lower at the disposal beach versus the control beaches in almost all months and zones following the 1999 disposal event. Sorting values at the disposal site averaged 0.437 phi, indicating that sediments were well sorted (Folk, 1980). Control beaches had average sorting values of 0.904 and 0.951, indicating that these beaches were moderately well sorted (Folk, 1980). Thus, the addition of dredge spoil material to the disposal beach resulted in a beach that consisted of sands that were both finer and more well-sorted.

Results of turbidity measurements taken before and after the Spring 1999 disposal event are shown in Figure 34. Control and disposal turbidities were similar on all but a few dates (e.g. 5/3/99 and 5/28/99). Disposal had begun at the northern end of the island prior to measurements made at beach sites on 4/20/99. Prior to the 4/26/99 and 5/3/99 measurements no further pumping appeared to have been done; however, on 5/3/99 side-cast dredging was taking place outside the New River Inlet. The surf zone at both the Topsail Dunes and Roger's Bay beaches appeared brown and turbid on 5/3/99. On 5/17/99, no pumping occurred, but additional pipe was being laid along the beach. Water samples collected on 5/28/99 were taken during active pumping at Topsail Reef, which showed a spike in turbidity. Pumping was completed on 6/8/99, prior to the collection of 6/17/99 samples. The 6/17/99 samples indicated that Topsail Reef turbidity had remained slightly elevated above control turbidities. In subsequent sampling, control and disposal area turbidities were again similar. During active pumping on the Topsail Reef disposal area in Spring 2000, turbidity measurements were made within the turbidity plume generated in the nearshore water (Table 1). These measurements indicate the magnitude of the increase in turbidity during active pumping of dredge spoil.

Measurements of organic content in sediments collected from control and disposal areas are presented in Figure 35. On all sample dates the percent of organic material in sediments was very low, and on 3/19/99, prior to any disposal activities, percent organic content of control and disposal sediments was very similar. Sediments collected between 4/20/99 and 5/28/99 were taken while disposal activities were ongoing; however, only sediments collected on 5/28/99 were actually collected during active pumping of dredge spoil at the disposal site. Comparison of percent organic content values between control and disposal sediments for samples collected on 5/28/99 show no difference in percent organic material at any tidal elevation sampled. A slight trend of higher organic content at control beaches in the high and mid-intertidal elevations was observed during disposal operations and an opposite trend (i.e. higher organic content in disposal sediments) was observed for sediments collected from the swash zone. Following disposal, no difference in mean percent organic content at any tidal elevation was observed. Overall, these results indicate that dredge spoil disposal did not add significant quantities of organic material to beach sediments.

Relative beach hardness measurements are reported in Figure 36 for control and disposal beaches. No trend in beach hardness was observed for the low and mid tidal elevations, but control beaches tended to be relatively softer in the supratidal zone. A one sample t-test (two-tailed with hypothesized mean= 0) on differences between control and disposal means from the supratidal zone indicated a marginally significant trend (p= 0.064).

Growth and Condition Experiments

MANOVA results for the first clam growth experiment indicated a significant density effect (Wilks' Lambda, p= 0.0027) on clam growth (length and weight change) and condition index. Two-way ANOVAs testing the effects of clam density and turbidity (organic mud) were subsequently performed (on untransformed data) and indicated that proportional length change and condition of clams were significantly affected by clam density (p= 0. 0124 and 0.0001, respectively). The main effect of density was also marginally significant for proportional weight change (p= 0.0624). Table 13 provides results for each univariate analysis. Plots of the main effects for each of the dependent variables (i.e. proportional length change, proportional weight change and condition index) are provided in Figure 37 and illustrate that the high density clam treatment had higher mean values of each dependent variable than the low density clam treatment. The main effect of turbidity (organic mud) was not significant in any of the analyses; however, for both length and weight change, control tanks had lower means versus turbidity tanks (Figure 37). No mortality occurred during this experiment, and all clams were recovered.

MANOVA results for the second experiment, in which inorganic clay was used to generate turbidity, indicated marginal significance for the main effects of density and turbidity (Wilks' Lambda p=0.0592 and 0.0533, respectively) and a significant interaction (Wilks' Lambda p=0.0371). Results of separate univariate analyses (on untransformed data) are provided in Table 14 and indicate significant interactions for two response variables, proportional length change and proportional weight change (p= 0.0032 and 0.0060, respectively). The 2-way ANOVA on clam condition shows a marginally significant density x turbidity interaction (p=0.0746). Interaction bar plots for each of the three measured response variables are provided in Figure 38. Scheffé's F (1953) test was used to conduct post-hoc comparison of means within each main effect. Results of post-hoc comparisons had the same pattern for each of the three dependent variables and are shown in Figure 38. High density clams in the turbidity treatment grew significantly more than the low density, turbidity treatment clams, and low density, control (i.e. no turbidity) clams grew significantly more than low density, turbidity treatment clams.

Regular temperature measurements taken showed that control and turbidity tanks were the same temperature throughout both experiments. Wave tank water temperature ranged from 27° C to 33° C during the first experiment and from 24° C to 27° C in the second experiment, but did not vary among treatments. Turbidity of the unfiltered sea water in the control tanks varied with conditions of the sound and ranged between 5.6 and 16.8 NTUs during the first experiment (mud) and 10.2 and 35.6 NTUs during the second experiment (clay). Turbidity levels in tanks with organic mud or clay additions averaged 61.02 NTUs during the first experiment and 96.52 NTUs during the second. The 2-way ANOVA performed (on square-root transformed data) to test the effects of clam density and turbidity on Chl a concentrations showed that the interaction, density x turbidity, and clam density were not significant. However, chlorophyll a (Chl a) concentrations measured at the end of the first experiment showed that wave tanks receiving organic mud additions had significantly higher amounts of Chl a than in control tanks (p=0.0021). Two-way ANOVAs performed on chlorophyll a measurements made during the second experiment showed no significant differences among treatments (e.g. turbidity vs. control and high vs. low clam density).

Effects of Turbidity on Predation by Surf Fish

Elevated turbidity reduced the ability of Florida pompano to forage on the mole crab, *Emerita talpoida*, by 30% (Figure 39); however, 1-way ANOVA results for this experiment were only marginally significant (p= 0.0781, Table 15). Turbidity conditions significantly reduced pompano predation on the coquina clam, *Donax variabilis*, and resulted in a 40.5% decline in clam consumption (p= 0.0219, Figure 39 B & Table 15 B). Control tanks in which the reliability of tethers was tested had 100% clam recovery rates.

DISCUSSION

Impacts of Beach Bulldozing

Significant impacts on the numerically dominant macroinvertebrates of the intertidal beach were not detected from the sampling conducted in 1998 primarily as a result of low power of the analyses. These data did, however, suggest two patterns that agree with results found by Peterson et al. (2000a). Sampling conducted by Peterson et al. (2000a) three months after bulldozing was completed indicated a 35-37% decline in abundances of *Emerita talpoida* (mole crab) and a greater than 100% increase in *Donax variabilis* (coquina clam) on bulldozed beaches. Although our results were not significant, we also saw a decline (of 56% on average) in mole crab abundances at bulldozed beaches relative to control beaches and no obvious decline in coquina clams on bulldozed beaches. It is thus possible that bulldozing may be negatively affecting some taxa while not affecting others.

Surf fish and gut analysis data did not provide strong evidence of a bulldozing impact on surf fishes during Summer 1998. Surf fish abundance varied significantly among dates but not between bulldozed and control beaches (Table 5). Gut contents of pompano also varied with date (Figure 22), but one food item, the mole crab, *Emerita talpoida*, had significantly higher importance values (MI) at control sites versus bulldozed sites (Figure 23). Mole crabs have previously been described as important food items in the diet of Florida pompano caught along Masonboro Island, NC and comprised between 36%- 62% (by frequency) of their diet (Hackney et al., 1996). A significant reduction in mole crab abundance at bulldozed sites could potentially result in their displacement to non-bulldozed beaches. The benthic data, however, did not indicate a significant impact on *Emerita* abundance following bulldozing, so evidence to support a displacement hypothesis is lacking in this particular case. However, Peterson et al. (2000a) did find significant impacts on *Emerita* abundances at bulldozed locations. Considering that undisturbed beaches typically become increasingly smaller percentages of the island as more and more surrounding beaches become bulldozed, significant displacement of pompano and other surf fishes is possible when significant reductions of mole crab abundance occur (such as in Peterson et al., 2000a).

Results of field experiments testing the effect of sediment characteristics on the burrowing ability of coquina clams combined with results of sediment analyses suggest a potential mechanism for altering abundances of clams. *Donax* burrowing ability is significantly inhibited in sands that are very coarse (Figure 24), and our sediment analyses indicated that bulldozing can cause significant changes in the distribution of sediments, making some beach zones more coarse and others more fine (Table 9). This study did not find a significant impact on clams; however, this study has identified a potentially important mechanism by which these organisms may be affected by beach bulldozing. Potential consequences of a reduced burrowing ability are increased transport of clams away from favored habitat, increased (or decreased) susceptibility of clams to predation or increased energetic costs to tidally migrating clams.

Based on the results of this study, the greatest impact of beach bulldozing on the sand beach community is the reduction in the number of ghost crabs occupying bulldozed dunes. The depression in ghost crab abundance was shown to persist for up to 8 months after scraping ended, indicating that ghost crabs were slow to recolonize these disturbed beaches and, in particular, the dune face. By following transmitter–tagged ghost crabs, Wolcott (1978) showed that following a night of foraging, ghost crabs do not return to the same burrow and instead establish a new burrow that can be up to 300 m away from their previous one. During the course of feeding in the swash each night, ghost crabs therefore migrate along the beach. Thus the persistence of lower ghost crab abundances at bulldozed areas may result from deliberate avoidance of these areas. Recovery of ghost crabs to bulldozed sites, however, was observed in September, when juvenile crabs were recruiting to the beach. These data suggest that juvenile crabs are able to maintain burrows on beaches that have been bulldozed (approximately 8 months before).

Following bulldozing (days – 1 week after), bulldozed dunes had significantly lower sorting values than control dunes (Table 3), indicating greater variance in grain sizes on bulldozed dunes. This difference in sorting reflects the fact that bulldozed dunes are comprised of a mixture of grain sizes not usually found in a dune formed by natural processes. Dune sediments are typically well sorted and consist of sands that are readily transported by wind, the major force that controls formation of dunes. Bulldozed dunes contain a larger percentage of coarse sands and gravel sized particles along with other beach sands and are thus a more poorly sorted mixture of sediments than natural dunes. The poorly sorted sands on the face of a bulldozed dune may be unattractive to ghost crabs, which must be able to form stable burrow structures in the sediment. In July, when ghost crabs approached a maximum seasonal abundance, the depression in ghost crab abundance at bulldozed sites occurred primarily because of a reduction in the number of dune face burrows (Figure 20). Peterson et al. (2000a) also concluded that significant reductions in ghost crab abundance on bulldozed beaches occurred primarily as a result of a decline in burrow counts on the artificial dune face.

Both Leber (1982) and Wolcott (1978) described seasonal patterns for *Ocypode quadrata* and indicated that the crabs first become active on the beach in April – May and return to burrows full-time by mid-November to over-winter. Thus the timing of *Ocypode*'s full-time residence in burrows corresponds exactly with the timing of beach scraping (i.e. November 15th- April 30th). Since ghost crabs are below ground in burrows that are at least one meter deep (Leber, 1982) during the scraping season, it is possible that they become sufficiently buried that they cannot survive. Then, through the possible combination of direct mortality by burial and subsequent avoidance of bulldozed beaches by migrating crabs, recovery of scraped beaches becomes a very slow process. In addition, recovery was observed only a few months before beach scraping activities resumed, suggesting that on beaches that are re-scraped each year, ghost crab abundances can never truly recover.

Impacts of Beach Disposal

Beach disposal on N. Topsail had significant impacts on the abundance of *Donax* spp., amphipods (*P. longimerus* and *haustorius* spp.), *Emerita talpoida* and the ghost crab, *Ocypode quadrata*, in either one or both of the disposal events (Figure 25). Clams, amphipods and mole crabs serve as prey for fish and bird species that use the beach-surf zone system as habitat (Nelson, 1986). Impacts on these prey thus have the potential to translate into impacts at higher trophic levels. Larger projects, such as a typical beach nourishment project, which can cover miles of beach, would obviously increase the spatial extent of any such prey loss and predator-displacement. A critical question remains, however, over whether or not habitat (food and space) for these predators is limited and whether displacement of predators out of nourished/ disposal beaches will translate into population level effects. With the increased rise in sea level, hurricane frequency and public demand for beach nourishment, a greater number of nourishment projects will likely occur along the coast. Undisturbed beaches would then become an increasingly smaller percentage of the coastline, thereby increasing the potential for population-level impacts on fish and birds that require this habitat. On a more immediate time scale and on a more local spatial scale, displacement of predators could affect recreational fishermen and could decrease the value of a specific beach as a recreational and natural area.

In addition to finding significant effects on the numbers of *Emerita talpoida* and *Donax* spp. following disposal, the size distributions of these invertebrates were significantly different when compared to size distributions on control beaches (Figures 30 & 31). The lack of large individuals in the populations of mole crabs and clams at the disposal site suggests that, while mole crabs and clams are recruiting to the disposal site, they either do not survive long, experience reduced growth rates or larger individuals suffer differential mortality following disposal events. *Donax variabilis* reaches a maximum size of approximately 2 mm in length and is thought to have a 1-3 year life span (Ansell, 1983; Morrison, 1971). Male *Emerita talpoida* reach their maximum size of ~14 mm long in approximately 9-10 months and females reach ~24 mm maximum carapace length in 16 – 20 months, depending on when they settle (Diaz, 1980; Williams, 1984). The frequency of beach disposal at N. Topsail varies depending on the condition of the nearby waterways but typically occurs on an annual basis. The disturbance of beach disposal thus occurs at a high enough frequency to eliminate established clams and mole crabs and prevent the populations from containing many large adults. The repeated disturbance of disposal therefore has a long-term impact on the population of *Donax* and *Emerita* and reduces the productivity of the impacted beach.

Following disposal it was observed that the polychaete, *Scolelepis squamata*, was present in much greater abundance at the disposal site than at control beaches, especially the Roger's Bay area (Figures 25 & 26). The increase in polychaetes at the disposal areas was accompanied by the addition of sand much finer than the sediments at the control beaches (Figure 32). Following disposal it was also observed that the surface sediments of the disposal beach were gray and sediments taken in core samples were often dark gray to black, indicating that they had been dredged from an anoxic environment. *Scolelepis squamata* appeared to flourish under these sediment conditions, and the addition of finer sediments to the disposal site had the effect of altering the relative abundance of species in the benthic community from coquina-dominated to polychaete-dominated. In contrast to the findings of this study, several studies on the impacts of beach restoration projects indicated significant declines in *Scolelepis squamata* abundance (Saloman & Naughton, 1984; Reilly & Bellis, 1983). In a review of beach nourishment impacts, Nelson (1989) found that significant mortality of beach invertebrates was only demonstrated in cases where sediments were poorly matched to the native sands or when the added sands contained high levels of organic matter and fine grained sediment. This study showed a significant increase in a polychaete species following the addition of poorly matched, fine sands and a significant decrease in abundance and biomass of *Donax variabilis* and *Emerita talpoida*. Thus, the addition of poorly matched sands may have different effects for different taxa.

Elevated turbidity, such as that generated and maintained in the nearshore waters downstream from a beach disposal or nourishment project, can affect the growth of filter-feeding organisms (e.g. *Donax variabilis*) and affect the ability of visually foraging surf fish (e.g. pompano) to capture prey. Turbidity experiments using kaolin clay resulted in significantly reduced growth of clams (in low density treatments only) and in 40.5% and 30% reductions in predation on *Donax* and *Emerita* (respectively) by Florida pompano (Figures 38& 39). Experiments demonstrating these effects were done under controlled conditions in laboratory wave tanks and were conducted over short time periods. Sediment quality and timing of pumping are two variables that vary with each given nourishment project but that can be readily managed to reduce the potential impacts of turbidity on growth and predation. Using sediments with low percentages of clays and silts would reduce the intensity and duration of turbidity, and completing pumping activities prior to months when surf fish and benthic invertebrates are present in high abundance would greatly reduce their exposure to elevated turbidity.

Wave tank experiments testing the effects of elevated turbidity on growth of *Donax variabilis* showed that the effects of turbidity can vary depending on the density of clams. Clams in high density treatments under mud-generated or clay-generated turbidity conditions grew faster than clams at low density under the same turbidity conditions (e.g. Figure 38). In the clay experiment, high and low density treatments were not significantly different for clams grown in the absence of turbidity, indicating that food was not limiting for clams in the high-density treatments. This result also suggests a possible mechanism for faster clam growth in high versus low density treatments under turbidity conditions: high density clams were able to filter water more rapidly and draw down the level of suspended sediment in the wave tanks. Low density clams may not have been able to filter water as quickly and may have been subjected to more consistently high levels of turbidity, and consequently, greater interference with filter-feeding. These results suggest that in the field, clams in high-density patches may suffer less of an impact from elevated turbidity than clams at low density, depending on the rate of input of suspended sediments. Results from the experiment in which mud was used to generate turbidity showed, however, that clams grown under non-turbidity conditions had higher condition index values in high density treatments (Scheffé's post hoc comparison, p= 0.0242). This unexpected result suggests that the high-density clams may have been able to feed more efficiently than low-density clams. The mechanism for this response is unclear and it is possible that this effect was an artifact of the experimental set-up. Benthic data from this study showed significant impacts on clam abundance and biomass, and did not indicate that beach disposal provided any benefit to coquina clam growth.

This study used beach disposal activities as a proxy for studying the effects of beach nourishment. Unlike beach nourishment projects, however, beach disposal operations usually involve the placement of sediments that may not be of a size that will allow a long residence time on the beach (NRC, 1995). Generally, beach disposal projects involve the addition of small volumes (50,000 to 150,000 cubic yards) of fine sands to the beach with the result that the material does not remain on the beach for a long period of time (< 1 year). This study showed that even when small volumes of fine sands are placed on relatively short segments of a barrier island, significant declines in several dominant benthic invertebrates can occur. It is generally recommended that in order to minimize biological impacts, sands added to a beach during a nourishment project be matched to the native sands as closely as possible (Nelson, 1989). However, the only criterion for beach disposal of dredge spoil is that sediments disposed of must contain no more than 10% fines (< 0.074 mm grain diameter) by weight. It is thus possible that negative impacts observed in this study (e.g. decreased mole crab abundance 7 months after disposal) were a result of adding poorly matched sediments to the disposal beach.

Summary

This study has shown that the repeated disturbance of beach bulldozing and beach disposal can have persistent impacts on benthic invertebrates. Beach bulldozing alters the sediment composition of the foredune, which results in a decline in ghost crab abundance. Repeat bulldozing in subsequent years prevents the recovery of the dune to a more stabilized and vegetated state and hinders the recovery of ghost crabs. Beach disposal causes significant declines in several invertebrate taxa that comprise the prey base for species of birds and fish that use the beach-surf zone system as habitat. Maintenance dredging of inlet crossings with subsequent beach disposal is a routine procedure in North Carolina and generally occurs for a given area on an annual basis. Repeat disposal on an annual cycle can reduce the productivity of the impacted beach by preventing individuals in the populations of mole crabs and coquina clams from attaining larger sizes. These disturbances can also change sediment distributions and create elevated turbidity, which can interfere with behaviors and growth of infaunal invertebrates and affect predator-prey interactions. Beach bulldozing and disposal are examples of how human activities can alter ecosystems and of how small, short-term disturbances can have much greater, persistent effects when repeated again and again.

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Table 1. Mean (+/- 1 SE) turbidities measured at N. Topsail beach disposal site during active pumping of dredge spoil in 2000. Turbidity was measured with an Orbeco-Helige turbidity meter and is reported in nephelometric turbidity units (NTUs). Location of samples are relative to the location of the outfall pipe. Means were calculated from three replicated water samples taken from surface waters at each position. Water depth refers to position of the individual while collecting water samples.

Water Depth	**Location**			
	70 m, Upstream	Pipe	20 m, Downstream	70 m, Downstream
swash	27.8 (1.6)	289.3 (4.4)	101.3 (2.0)	87.6 (2.4)
1 m deep	27.3 (4.0)	340.3 (3.5)	91.2 (1.8)	59.0 (2.0)

Table 2. Benthic infauna sampled from Bogue Banks, NC during February 1998 - September 1998. Organisms were identified to species when possible.

Phylum Annelida
Class Polychaeta
Order Spionida
Family Spionidae: *Scolelepis squamata*

Order Cirratulida
Family Paronidae: *Paraonis fulgens*

Order Eunicida
Family Lumbrineridae: *Lumbrineris impatiens*

Phylum Nemertea (Nemertean worms)

Phylum Mollusca
Class Bivalvia
Order Veneroida
Family Donacidae: *Donax variabilis*
Donax parvula

Phylum Arthropoda
Class Crustacea
Order Decapoda
Family Hippidae: *Emerita talpoidea*
Family Albuneidae: *Lepidopa websteri*

Order Amphipoda
Family Haustoriidae: *Haustorius spp.*
Parahaustorius longimerus
Amphiporeia virginiana
Family Gammaridae: *Gammarus mucronatus*
Family Ampithoidae: *Cymadusa compta*

Order Isopoda
Family Idoteidae: *Chiridotea coeca*

Class Malacostraca
Order Mysidacea
Family Mysidae

Table 3. Results of grain size analysis of sediments collected from the face of bulldozed and control dunes before and after bulldozing occurred (Folk, 1980). Mean grain size is reported in phi units (a logarithmic transformation of the Wentworth Scale); thus, smaller values indicate larger grain sizes. Sorting values (shown in B) reflect the variance of grain sizes in the sample. A smaller sorting value (in units of phi) indicates more well sorted sediments.

A) Mean Grain Size

	Control		Bulldozed	
	Before	After	Before	After
MEAN PHI	1.987	1.796	1.6	1.702
Std. Error	0.043	0.079	0.149	0.064

B) Mean Sorting Values

	Control		Bulldozed	
	Before	After	Before	After
MEAN PHI	0.444	0.389	0.965	0.634
Std. Error	0.153	0.05	0.348	0.095

Table 4. Fish species caught during beach seine sampling at bulldozed and control locations on Bogue Banks from June - August 1998.

FAMILY Carangidae

Trachinotus carolinus (Florida pompano)
Trachinotus falcatus (permit)

FAMILY Sciaenidae

Menticirrhus littoralis (Gulf kingfish)
Menticirrhus americanus (Southern kingfish)
Menticirrhus saxatilis (Northern kingfish)
Leiostomus xanthurus (spot)

FAMILY Antherinidae

Membras martinica (rough silverside)
Menidia menidia (Atlantic silverside)

FAMILY Engraulidae

Anchoa mitchillii (bay anchovy)

FAMILY Sparidae

Lagodon rhomboides (pinfish)

FAMILY Pomatomidae

Pomatomus saltatrix (bluefish)

FAMILY Mugilidae

Mugil cephalus (striped mullet)
Mugil curema (white mullet)

FAMILY Bothidae

Paralichthys dentatus (summer flounder)

FAMILY Balistidae

Monacanthus hispidus (planehead filefish)

Table 5. Results of 2-way model-I ANOVAs testing the effect of sampling date (June, July, August) and treatment (bulldozed, control) on log-transformed abundances of (A) *Trachinotus carolinus* (Florida pompano) and (B) *Menticirrhus littoralis* (Gulf kingfish) and for log- transformed (C) total fish abundance. Figure 21 provides total surf fish abundance for each month of sampling at all beach sites.

A. *Trachinotus carolinus*

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	2.91E-05	2.91E-05	2.22E-04	0.9883
date	2	5.067	2.533	19.323	<.0001
treatment * date	2	0.202	0.101	0.771	0.4747
Residual	22	2.884	0.131		

B. *Menticirrhus littoralis*

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	0.095	0.095	0.747	0.3969
date	2	2.335	1.168	9.22	0.0012
treatment * date	2	0.187	0.093	0.737	0.4902
Residual	22	2.786	0.127		

C. Total Fish

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	0.04	0.04	0.352	0.5589
date	2	1.568	0.784	6.964	0.0045
treatment * date	2	0.391	0.195	1.736	0.1995
Residual	22	2.477	0.113		

Table 6. Index of Relative Importance and Modified Index values (Hyslop, 1980) for items found in pompano stomachs collected during beach seine sampling at all Bogue Banks sites. When possible 15 fish were used (per site and date) to conduct gut analysis. IB = Indian Beach, EI= Emerald Isle, EIP= Emerald Isle Point, PKS= Pine Knoll Shores and SP= Salter Path. Mean Modified Index values by month and treatment (bulldozed, control) are illustrated in Figure 22.

Index of Relative Importance

Month	Site	Treatment	Time	Donax	Polychaete	Emerita	Amphipod	Shell	Tissue	Sand	Bug	Megalops	Mysid
June	IB	control	day	0	4840	860	680	0	0	30	150	0	24
June	IB	bulldozed	day	0	630	100	260	60	0	0	7510	0	0
June	EI	control	day	0	60	360	20	260	150	0	0	0	1810
June	EI	bulldozed	day	0	2100	40	0	8	4	50	0	0	5170
June	EI	control	night	0	0	0	1340	0	0	0	0	0	0
June	EI	bulldozed	night	1340	0	0	0	0	0	0	0	0	0
June	EIP	control	day	0	310	290	310	20	4240	170	410	130	0
June	EIP	bulldozed	day	410	30	0	90	50	2500	0	280	220	30
June	EIP	control	night	50	2900	0	90	540	2100	720	50	20	0
June	EIP	bulldozed	night	4500	89	0	0	0	0	0	0	0	80
July	EIP	control	day	1330	0	1380	0	0	780	0	0	0	0
July	EIP	bulldozed	day	3230	100	650	0	0	100	0	0	0	0
July	EIP	control	night	120	4440	860	70	30	30	20	0	0	0
July	EIP	bulldozed	night	4630	0	70	220	0	0	0	0	50	0
July	PKS	control	day	2190	200	680	80	70	1450	0	0	0	0
July	PKS	bulldozed	day	220	90	520	40	0	6280	40	0	0	0
July	IB	control	day	5000	0	0	0	0	0	0	0	0	0
July	IB	bulldozed	day	2220	0	0	0	0	0	0	0	0	0
July	SP	control	day	1550	0	570	120	0	0	0	0	0	120
July	SP	bulldozed	day	0	0	0	0	0	6600	0	0	0	0
Aug	PKS	control	day	0	0	0	0	0	0	0	0	20000	0
Aug	PKS	bulldozed	day	30	0	10	0	0	0	0	0	16500	0
Aug	IB	control	day	0	0	0	0	0	0	0	0	20000	0
Aug	IB	bulldozed	day	0	20	30	7	0	0	0	0	19300	0
Aug	IB	control	night	3010	0	0	0	0	560	0	0	1170	260
Aug	IB	bulldozed	night	0	0	0	0	0	0	0	0	8580	0
Aug	SP	control	day	180	0	1030	0	0	0	0	0	430	970
Aug	SP	bulldozed	day	0	0	0	190	0	0	0	100	120	0
Aug	EIP	control	day	4060	330	1940	0	0	0	0	0	0	0
Aug	EIP	bulldozed	day	0	0	0	0	0	0	0	0	0	0
Aug	EI	control	day	360	0	1780	480	0	0	0	0	0	0
Aug	EI	bulldozed	day	20000	0	0	0	0	0	0	0	0	0

Modified Index

Month	Site	Treatment	Time	Donax	Polychaete	Emerita	Amphipod	Shell	Tissue	Sand	Bug	Megalopa	Mysid
June	IB	control	day	0	2170	630	40	0	0	17	56	0	63
June	IB	bulldozed	day	0	270	65	74	13	256	0	4070	0	0
June	EI	control	day	0	30	320	10	140	97	0	0	0	710
June	EI	bulldozed	day	0	1054	33	0	2.5	0.25	33	0	0	2080
June	EI	control	night	0	0	0	670	0	0	0	0	0	0
June	EI	bulldozed	night	670	0	0	0	0	0	0	0	0	0
June	EIP	control	day	0	150	250	100	13	1900	125	1330	63	0
June	EIP	bulldozed	day	286	17	0	21	17	1130	0	110	69	17
June	EIP	control	night	45	1450	0	30	140	1140	450	27	2.7	0
June	EIP	bulldozed	night	2740	32	0	0	0	0	0	0	0	10
July	EIP	control	day	1000	0	1000	0	0	167	0	0	0	0
July	EIP	bulldozed	day	1620	15	450	0	0	15	0	0	0	0
July	EIP	control	night	110	1890	560	25	20	5.6	5.6	0	0	0
July	EIP	bulldozed	night	2740	0	17	7	0	0	0	0	8	0
July	PKS	control	day	1650	50	300	14	13	550	0	0	0	0
July	PKS	bulldozed	day	220	36	360	22	0	2480	22	0	0	0
July	IB	control	day	2500	0	0	0	0	0	0	0	0	0
July	IB	bulldozed	day	1110	0	0	0	0	0	0	0	0	0
July	SP	control	day	560	0	480	12	0	0	0	0	0	12
July	SP	bulldozed	day	0	0	0	0	0	3300	0	0	0	0
Aug	PKS	control	day	0	0	0	0	0	0	0	0	10000	0
Aug	PKS	bulldozed	day	25	0	5	0	0	0	0	0	7860	0
Aug	IB	control	day	0	0	0	0	0	0	0	0	10000	0
Aug	IB	bulldozed	day	0	18	25	5	0	0	0	0	9430	0
Aug	IB	control	night	2330	0	0	0	0	50	0	0	180	10
Aug	IB	bulldozed	night	0	0	0	0	0	0	0	0	4290	0
Aug	SP	control	day	100	0	680	0	0	0	0	0	85	300
Aug	SP	bulldozed	day	0	0	0	35	0	0	0	30	50	0
Aug	EIP	control	day	2150	70	980	0	0	0	0	0	0	0
Aug	EIP	bulldozed	day	0	0	0	0	0	0	0	0	0	0
Aug	EI	control	day	280	0	930	100	0	0	0	0	0	0
Aug	EI	bulldozed	day	10000	0	0	0	0	0	0	0	0	0

Table 7. Results of 2-way model-I ANOVAs testing the effects of sampling month (June, July, August) and treatment (bulldozed, control) on modified importance values (MI) of three consistently occurring food items, (A) *Donax*, (B) polychaetes and (C) *Emerita*. ANOVAs were performed on square-root transformed MI values.

A) *Donax*

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	3.556	3.556	0.006	0.9396
month	2	2402.299	1201.15	1.992	0.1654
treatment * month	2	559.677	279.839	0.464	0.6361
Residual	18	10856.109	603.117		

B) polychaetes

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	9.643	9.643	0.115	0.7385
month	2	1447.178	723.589	8.626	0.0024
treatment * month	2	17.292	8.646	0.103	0.9026
Residual	18	1509.982	83.888		

C) *Emerita*

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	960.537	960.537	8.319	0.0099
month	2	86.708	43.354	0.375	0.6922
treatment * month	2	87.344	43.672	0.378	0.6904
Residual	18	2078.265	115.459		

Table 8. Two-way model-I ANOVA testing the effects of sediment type (fine, coarse, shelly) and clam density (0, 123, 246 per experimental arena) on (log-transformed) burrowing speed of the coquina clam, *Donax variabilis* (n=3). See Figure 24 for main effect plots.

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
sediment type	2	0.82	0.41	31.9	<.0001
clam density	2	0.049	0.025	1.915	0.1796
sediment type * clam density	4	0.045	0.011	0.884	0.4955
Residual	16	0.206	0.013		

Table 9. Results of grain size analysis on samples collected from study beaches before (1 -4 weeks) and after (days- 1 week) bulldozing was conducted (*n*=5). Table A lists mean phi sizes for control sites according to time and tidal elevation (2, 3, 4 or 5). Tidal elevation 2 refers to samples collected near the high intertidal, tidal elevation 3 refers to the mid-intertidal zone, tidal elevation 4 refers to the low intertidal and tidal elevation 5 refers to samples collected at 1 *m* deep in the surf zone. Table B list mean phi sizes for sediments collected at bulldozed beaches.

A) Control

	BEFORE				AFTER			
Elevation	2	3	4	5	2	3	4	5
Mean phi size	1.86	1.754	1.611	1.377	1.534	1.717	1.321	1.186
Std. Dev.	0.205	0.094	0.247	0.26	0.402	0.127	0.144	0.331

B) Bulldozed

	BEFORE				AFTER			
Elevation	2	3	4	5	2	3	4	5
Mean phi size	1.794	1.234	1.374	0.909	1.455	1.49	1.367	1.215
Std. Dev.	0.224	0.806	0.605	0.861	0.266	0.132	0.087	0.136

Table 10. Results of grain size analysis on samples collected from study beaches before (1-4 weeks) and after (day- 1 week) bulldozing was conducted (n=5). Table A lists mean sorting values for control sites according to time and tidal elevation (2, 3, 4 or 5). Tidal elevation 2 refers to samples collected near the high intertidal, tidal elevation 3 refers to the mid-intertidal zone, tidal elevation 4 refers to the low intertidal and tidal elevation 5 refers to samples collected at 1 m deep in the surf zone. Table B lists mean sorting values for sediments collected at bulldozed beaches.

A) CONTROL

	BEFORE				AFTER			
Elevation	2	3	4	5	2	3	4	5
Mean	0.378	0.466	0.555	0.786	0.51	0.436	0.762	0.958
Std. Dev.	0.19	0.109	0.363	0.313	0.261	0.068	0.36	0.313

B) BULLDOZED

	BEFORE				AFTER			
Elevation	2	3	4	5	2	3	4	5
Mean	0.408	0.755	0.569	0.895	0.758	0.742	0.675	0.976
Std. Dev.	0.196	0.562	0.355	0.266	0.309	0.33	0.345	0.213

Table11. Benthic infauna sampled at northern Topsail Island, NC from March 1999 to September 2000 . Organisms were identified to species when possible.

- **Phylum Annelida**
  - **Class Polychaeta**
    - **Spionidae**
      - *Scolelepis squamata*
      - *Dispio uncinata*
    - **Nephtyidae**
      - *Nephtys bucera*
    - **Lumbrineridea**
      - *Lumbrineris brevipes*
      - *Lumbrineris verrilli*
    - **Paraonidae**
      - *Aricidea cerrutii*
    - **Glyceridea**
      - *Glycera spp.*
    - **Magelonidae**
      - *Magelona papillicornis*
      - *Magelona spp.*
    - **Arabellidae**
      - *Arabella sp.*

- **Phylum Nemertea** (Nemertean worms)

- **Phylum Mollusca**
  - **Class Bivalvia**
    - **Donacidea**
      - *Donax variabilis*
      - *Donax parvula*

- **Phylum Arthropoda**
  - **Class Crustacea**
    - **Hippidae**
      - *Emerita talpoidea*
    - **Albuneidae**
      - *Lepidopa websteri*
    - **Haustoriidae**
      - *Haustorius spp.*
      - *Parahaustorius longimerus*
      - *Amphiporeia virginiana*
    - **Gammaridae**
      - *Gammarus mucronatus*
    - **Caprellidae**
      - *Caprella penandis*
    - **Corophiidae**
      - *Cerapus tubularis*
    - **Idoteidae**
      - *Chiridotea coeca*
    - **Sphaeromatidae**
      - *Sphaeroma quadridentata*

  - **Class Malacostraca**
    - **Mysidae**

Table 12. Mean abundances of beach invertebrates collected at North Topsail from March 1999 to September 2000. Means (and 1 standard error) are reported for each site and sampling period and were calculated using transect totals (n=3). Organisms that did not have a mean (for a given sampling location and time) greater than or equal to one are not included in the table. Topsail Dunes control = TD; Roger's Bay control = RB; Topsail Reef disposal area = TR. See Figure 25 for mean abundance by treatment (disposal, control) for the most common species occurring in benthic samples.

	March '99				April '99						May '99						June '99			
	TD		TR		TD		RB		TR		TD		RB		TR		TD		TR	
Organisms	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.
Mollusca																				
Donax variabilis	4.33	2.03	14.67	2.19	13.67	5.46	1.67	0.88	5.50	2.00	3.67	0.33	2.67	0.88	1.33	0.88	16.17	5.22	6.33	1.76
Donax parvula	0.33	0.33	0.67	0.67	0.00	0.00	0.00	0.00	0.17	0.17	0.67	0.67	0.00	0.00	0.67	0.33	0.00	0.00	0.50	0.34
Arthropoda																				
Emerita talpoida	0.67	0.33	0.00	0.00	1.33	0.88	0.33	0.33	1.00	0.45	1.67	1.20	2.00	0.58	2.67	2.67	2.83	0.87	0.00	0.00
Lepidopa websteri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haustorius spp.	0.33	0.33	2.33	1.20	3.67	2.33	0.00	0.00	0.67	0.49	2.33	0.88	0.00	0.00	1.33	1.33	5.33	1.43	2.83	1.40
Parahaustorius longimerus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.68	0.00	0.00
Amphiporeia virginiana	18.00	7.00	3.33	0.33	13.00	2.08	1.67	0.67	3.00	0.86	0.00	0.00	11.67	3.76	0.00	0.00	14.00	8.02	0.00	0.00
Annelida																				
Scolelepis squamata	10.33	0.67	18.00	1.00	297.33	57.45	54.00	14.30	98.17	21.28	287.67	38.67	13.33	4.49	128.67	35.41	313.17	86.33	215.00	33.52
Lumbrineris brevipes	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.17	0.17	0.67	0.33	0.00	0.00	1.33	0.88	0.67	0.42	0.50	0.34
Nemertea																				
Nemerteans	0.33	0.33	0.00	0.00	0.33	0.33	0.00	0.00	1.00	0.45	0.00	0.00	0.67	0.33	0.00	0.00	0.00	0.00	1.67	0.33

Table 12. Continued.

Organisms	July '99						August '99						September '99						October '99					
	TD		RB		TR		TD		RB		TR		TD		RB		TR		TD		RB		TR	
	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.
Mollusca																								
Donax variabilis	33.00	6.69	42.33	7.74	27.83	3.41	115.00	18.56	66.00	38.16	67.50	11.14	14.00	3.61	32.33	7.62	15.00	2.48	16.33	6.45	33.00	13.23	4.00	0.97
Donax parvula	0.83	0.83	0.50	0.50	0.42	0.19	1.67	0.88	0.67	0.33	0.17	0.17	0.00	0.00	0.00	0.00	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00
Arthropoda																								
Emerita talpoida	12.83	3.18	7.50	2.58	3.00	1.01	13.67	2.67	8.00	0.58	2.17	1.14	21.67	8.74	38.33	9.87	1.67	0.56	17.00	2.65	29.00	9.82	3.50	0.69
Lepidopa websteri	0.00	0.00	0.00	0.00	0.17	0.11	1.33	0.88	0.00	0.00	0.67	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haustorius spp.	9.83	2.87	9.00	2.03	5.17	1.07	2.33	1.86	27.00	5.69	43.50	9.22	24.33	12.86	1.67	0.88	12.17	1.56	3.67	0.88	6.67	2.91	12.17	1.22
Parahaustorius longimerus	31.83	8.89	24.83	18.55	3.17	1.16	48.00	15.63	1.67	1.20	2.17	1.40	3.67	0.88	22.33	14.35	8.17	3.75	0.00	0.00	0.00	0.00	0.00	0.00
Amphiporeia virginiana	10.00	6.80	13.17	10.99	0.83	0.83	1.00	0.58	1.67	0.67	0.00	0.00	2.67	1.45	65.33	36.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annelida																								
Scolelepis squamata	312.00	99.27	76.33	32.75	521.25	130.95	464.00	17.50	41.33	14.15	496.50	48.81	393.67	64.13	66.67	17.53	177.33	76.18	256.67	80.77	13.00	2.08	63.50	14.04
Lumbrineris brevipes	0.17	0.17	0.67	0.33	0.58	0.26	1.33	1.33	1.00	1.00	0.67	0.33	1.67	1.20	0.67	0.67	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00
Nemertea																								
Nemerteans	0.00	0.00	1.00	0.26	1.33	0.33	0.00	0.00	1.33	0.88	1.17	0.31	0.00	0.00	0.00	0.00	0.33	0.21	0.00	0.00	0.00	0.00	0.00	0.00

Table 12. Continued

Organisms	December '99						February '00						April '00						May '00					
	TD		RB		TR		TD		RB		TR		TD		RB		TR		TD		RB		TR	
	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.
Mollusca																								
Donax variabilis	2.33	1.86	2.67	0.33	4.00	2.05	8.33	0.88	2.67	0.67	6.67	2.74	40.00	4.04	28.00	8.51	37.00	8.72	132.67	73.96	208.33	57.85	56.00	16.60
Donax parvula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.00	24.00	11.50	0.17	0.17
Arthropoda																								
Emerita talpoida	3.33	1.20	13.33	1.20	2.33	0.72	3.33	0.88	4.00	1.53	0.50	0.50	1.67	0.33	2.00	0.58	1.67	0.88	0.00	0.00	3.00	1.15	0.17	0.17
Lepidopa websteri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.17
Haustorius spp.	11.00	4.36	8.67	1.20	7.00	1.95	2.33	1.20	4.00	1.16	4.50	1.38	9.67	2.40	22.67	16.19	7.33	1.45	16.67	6.29	15.00	3.06	2.00	0.52
Parahaustorius longimerus	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.00	1.00	0.58	0.33	0.33	4.67	2.33	32.33	13.86	0.67	0.67	1.83	0.87
Amphiporeia virginiana	0.00	0.00	0.00	0.00	0.00	0.00	16.00	5.51	17.67	4.18	6.17	1.45	24.33	6.98	66.00	31.39	2.00	1.53	48.00	15.89	67.00	8.72	1.67	0.56
Annelida																								
Scolelepis squamata	332.67	46.85	10.67	2.03	147.33	36.35	4.00	1.53	1.33	0.33	51.83	25.23	42.00	7.02	29.00	10.15	145.67	34.85	228.00	47.29	149.33	25.36	840.00	153.52
Lumbrineris brevipes	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.67	0.67	0.67	0.33	0.67	0.67	1.00	0.58	0.00	0.00	0.67	0.33	0.33	0.33	1.00	0.26
Nemertea																								
Nemerteans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.33	0.33	1.00	0.58	0.50	0.22

Table 12. Continued.

	June '00						July '00						August '00						September '00					
	TD		RB		TR		TD		RB		TR		TD		RB		TR		TD		RB		TR	
Organisms	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.	mean	st. err.
Mollusca																								
Donax variabilis	137.00	25.54	125.33	40.86	54.50	9.03	82.00	11.83	38.00	13.50	41.67	5.60	54.67	8.09	26.00	3.22	42.17	7.75	44.67	8.99	59.67	9.40	20.33	3.24
Donax parvula	8.33	3.64	21.00	6.02	8.83	2.70	2.33	2.33	1.33	1.33	2.33	0.49	2.00	2.00	0.67	0.67	0.50	0.22	0.67	0.67	2.00	0.58	0.33	0.21
Arthropoda																								
Emerita talpoida	1.00	1.00	2.00	1.00	2.00	1.24	2.33	0.67	8.00	1.53	6.00	1.37	10.33	2.96	45.33	10.73	22.83	6.64	6.00	2.08	17.33	1.67	8.67	2.93
Lepidopa websteri	0.67	0.67	0.00	0.00	0.33	0.21	0.33	0.33	0.67	0.67	0.17	0.17	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Haustorius spp.	61.33	19.27	8.00	3.22	30.33	10.65	38.33	5.21	7.67	3.18	13.67	5.02	14.00	7.51	1.00	0.00	15.67	6.49	7.33	1.67	10.00	1.53	11.83	1.72
Parahaustorius longimerus	117.00	40.93	1.00	0.58	0.83	0.31	21.00	19.52	11.67	7.86	2.17	1.25	31.67	19.10	37.33	10.88	4.67	3.90	60.33	55.89	3.67	2.03	2.33	0.99
Amphiporeia virginiana	3.67	2.19	167.33	152.40	3.83	2.16	1.67	0.88	17.67	9.53	1.17	0.31	34.67	32.67	3.67	2.19	0.33	0.33	0.33	0.33	0.33	0.33	0	0
Annelida																								
Scolelepis squamata	609.00	8.15	293.67	32.23	1319.00	172.09	532.33	73.83	210.00	16.01	962.50	105.63	440.33	14.44	127.67	21.89	348.83	38.97	293.33	64.28	94.00	13.05	220.83	40.68
Lumbrineris brevipes	2.33	0.33	0.67	0.33	0.67	0.21	1.00	0.00	0.33	0.33	0.33	0.21	2.00	0.58	1.67	0.88	0.00	0.00	0.67	0.33	1.00	0.58	0.67	0.33
Nemertea																								
Nemerteans	1.00	0.58	0.00	0.00	0.33	0.21	0.33	0.33	0.00	0.00	0.17	0.17	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0

Table 13. Two-way model-I ANOVAs testing the effects of clam density (40 vs. 20 clams per basket) and turbidity conditions (average 10.16 NTUs, control vs. average 61.02 NTUs, turbidity treatment) on A) proportional length change and B) proportional weight change and C) condition index of Donax variabilis. Turbidity was generated with organic mud and experiment was conducted over a two week period. See Figure 37 for main effect plots.

A) Length

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	4.08E-04	4.08E-04	0.187	0.6769
density	1	0.023	0.023	10.316	0.0124
treatment X density	1	2.13E-05	2.13E-05	0.01	0.9237
Residual	8	0.017	0.002		

B) Weight

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	0.041	0.041	0.702	0.4265
density	1	0.272	0.272	4.682	0.0624
treatment X density	1	0.005	0.005	0.087	0.7759
Residual	8	0.465	0.058		

C) Condition Index

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	0.094	0.094	0.573	0.4709
density	1	7.867	7.867	47.743	0.0001
treatment X density	1	0.248	0.248	1.503	0.255
Residual	8	1.318	0.165		

Table 14. Results of 2-way model-I ANOVAs testing the effects of clam density (40 vs. 20 clams per basket) and turbidity conditions (average 17.69 NTUs, control vs. average 96.52 NTUS, turbidity treatment) on A) proportional length change, B) proportional weight change and C) condition index for *Donax variabilis*. Turbidity was generated with inorganic clay, and the experiment was run for a period of two weeks. See Figure 38 for interaction plots.

A) Length

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treament	1	0.013	0.013	19.091	0.0033
density	1	0.012	0.012	17.463	0.0041
treatment X density	1	0.013	0.013	19.277	0.0032
Residual	7	0.005	0.001		

B) Weight

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treament	1	0.237	0.237	18.162	0.0037
density	1	0.122	0.122	9.358	0.0183
treatment X density	1	0.197	0.197	15.078	0.006
Residual	7	0.091	0.013		

C) Condition Index

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	0.491	0.491	0.614	0.4589
density	1	0.733	0.733	0.918	0.37
treatment X density	1	3.502	3.502	4.383	0.0746
Residual	7	5.593	0.799		

Table 15. ANOVA tables for proportion of prey consumed by pompano in turbidity vs. non-turbidity conditions. (A) One-way table for experiment using *Emerita talpoida* as prey and (B) one-way table for experiment using *Donax variabilis* as prey. See Figure 39 for main effect plots.

A. *Emerita talpoida*

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	0.127	0.127	3.95	0.0781
Residual	9	0.29	0.032		

B. *Donax variabilis*

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment	1	0.322	0.322	6.182	0.0219
Residual	20	1.041	0.052		

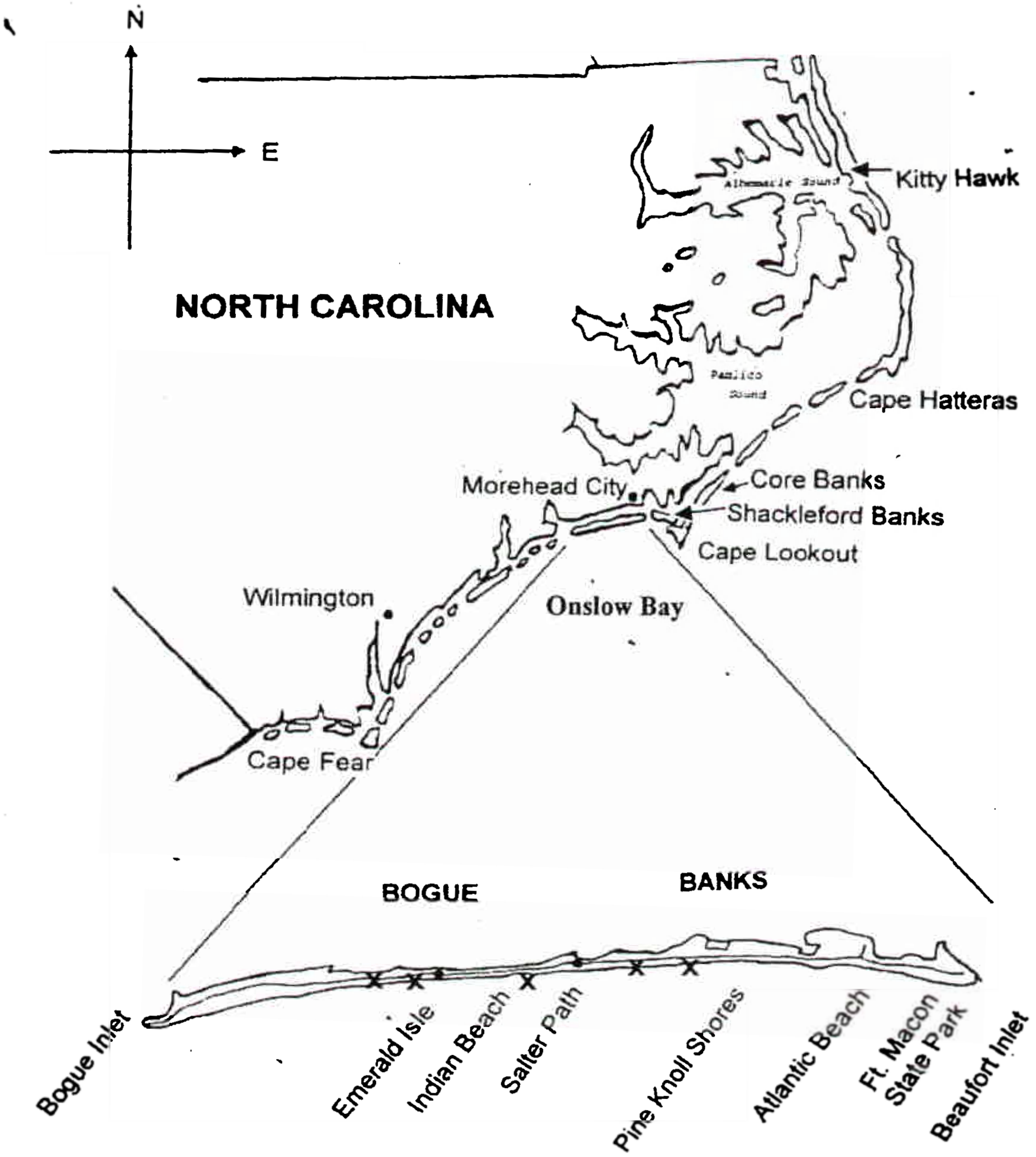


Figure 1. Location of Bogue Banks along North Carolina's coast and positions of the five paired bulldozed and control study beaches along Bogue Banks (indicated by a single '**X**'). Benthic sampling was conducted at each of these five pairs of beaches in 1998.

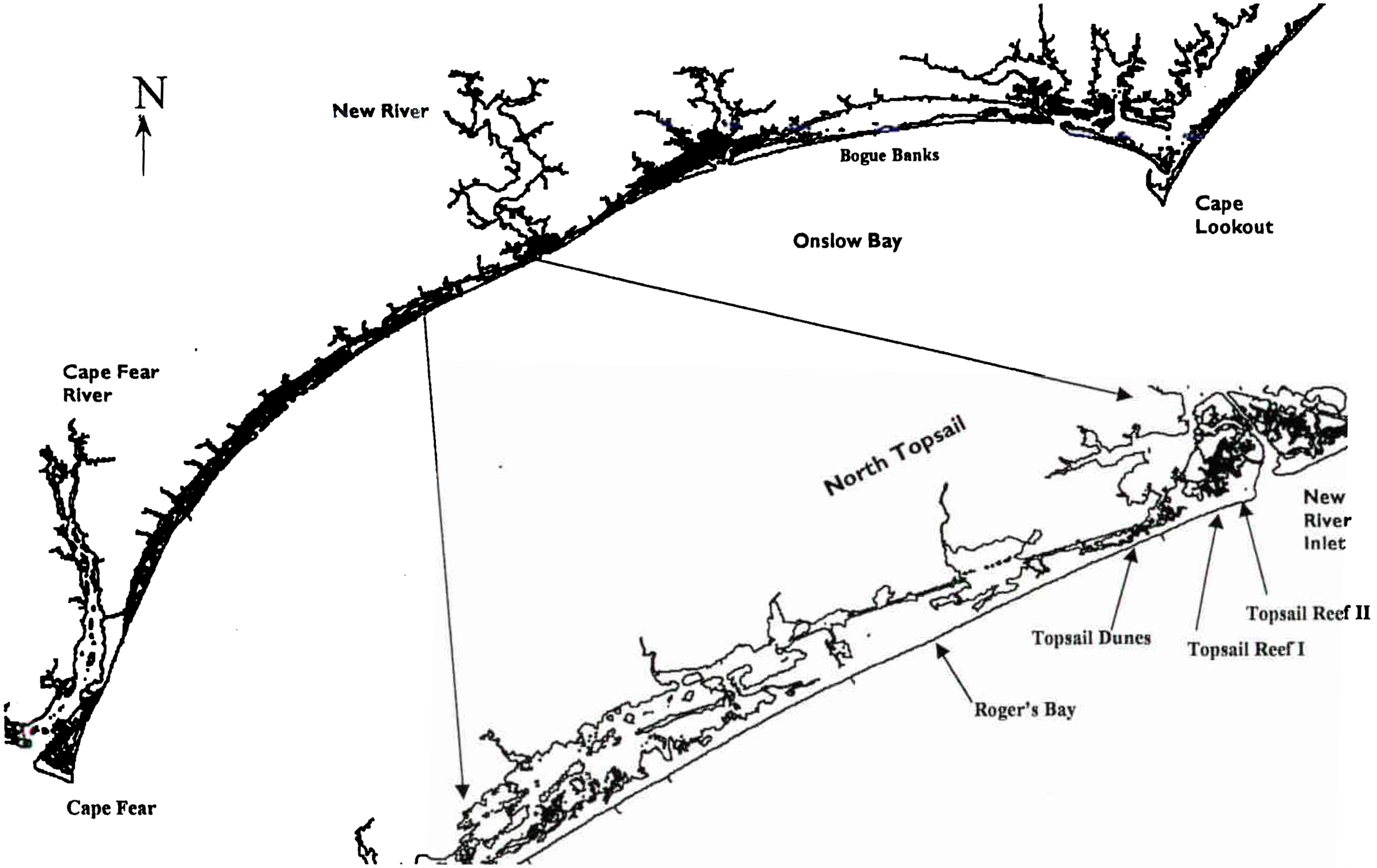
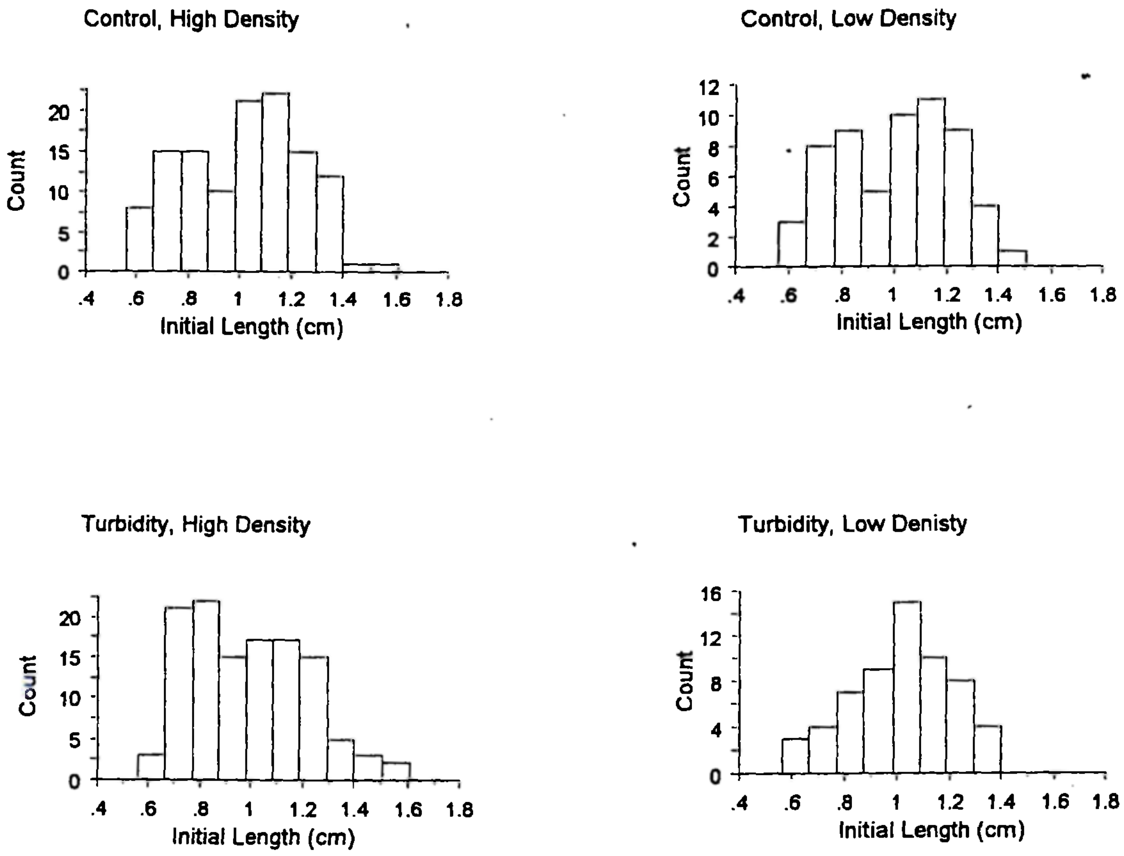


Figure 2. Position of Topsail Island along the NC coast and locations of study sites (indicated by arrows). Both Topsail Reef sites are within the dredge spoil disposal area.



Control, High Density

Control, Low Density

Turbidity, High Density

Turbidity, Low Denisty

Figure 3. Size frequency histograms of clams used in each treatment combination for the growth experiment testing the effects of elevated turbidity (organic mud) and clam density on growth. Plotted are the initial anterior-posterior lengths of clams. Size distributions were not significantly different in Kolmogorov-Smimov tests (p= >0.9999 and p= 0.0621 for control, high vs. low density and turbidity, high vs low density contrasts, respectively; p= 0.3067 and p= 0.6883 for high density, control vs. turbidity and low density, control vs. turbidity contrasts, respectively).

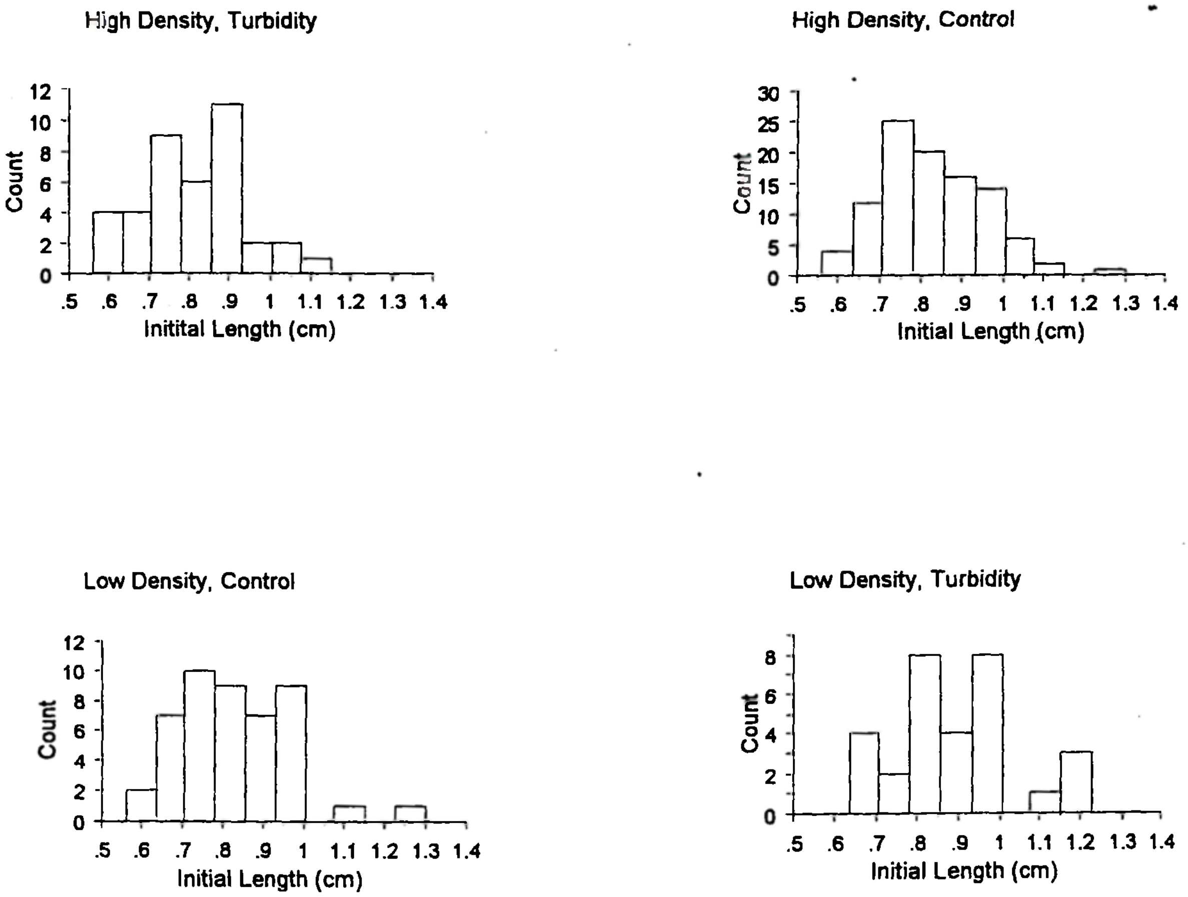


Figure 4. Size frequency histograms of clams used in each treatment combination for the growth experiment testing the effects of elevated turbidity (kaolin clay) and clam density on growth. Plotted are the initial anterior-posterior lengths of clams. Size distributions were not significantly different in Kolmogorov-Smimov tests (p=>0.9999 and p=0.1202 for high density, control vs. turbidity and low density, control vs. turbidity contrasts, respectively; p=0.0996 and p=>0.9999 for turbidity, high vs. low density and control, high vs. low density contrasts, respectively).

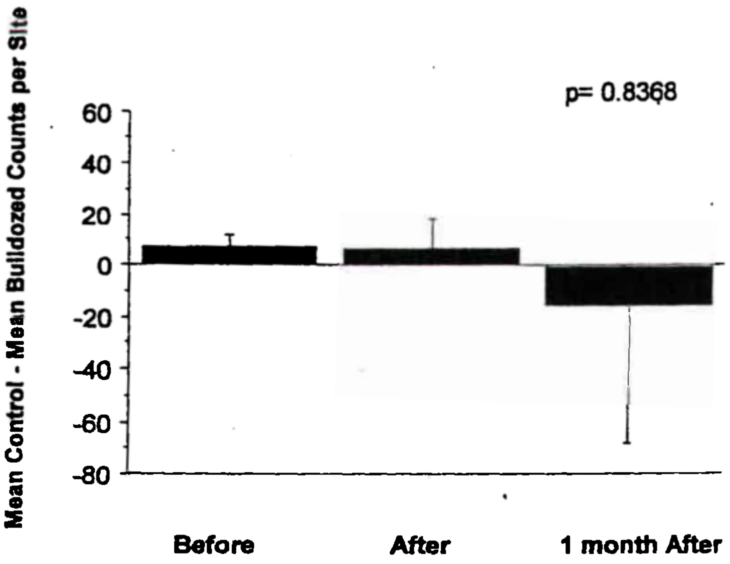


Figure 5. Results of one-way ANOVA testing the change in differences in mean *Donax variabilis* abundance between paired control and bulldozed beaches over three time periods. Mean differences in clam abundance were calculated for each of the five site pairs (see Figure 1) by subtracting mean clam abundance at a bulldozed beach from mean abundance at its paired control beach (control - bulldozed = difference). Differences between site pairs were then compared among the following times: Before scraping (1-4 weeks before), After scraping (days-1week after) and 1 month After scraping. Results of this ANOVA indicate that differences between paired control and bulldozed beaches did not change right after scraping. One month after scraping *Donax variabilis* abundances at bulldozed beaches were greater than at control beaches. The percent difference between control and bulldozed beaches Before, After and 1 month After bulldozing was 23.0%, 26.0% and -19.0% respectively. Error bars indicate one standard error (N= 5).

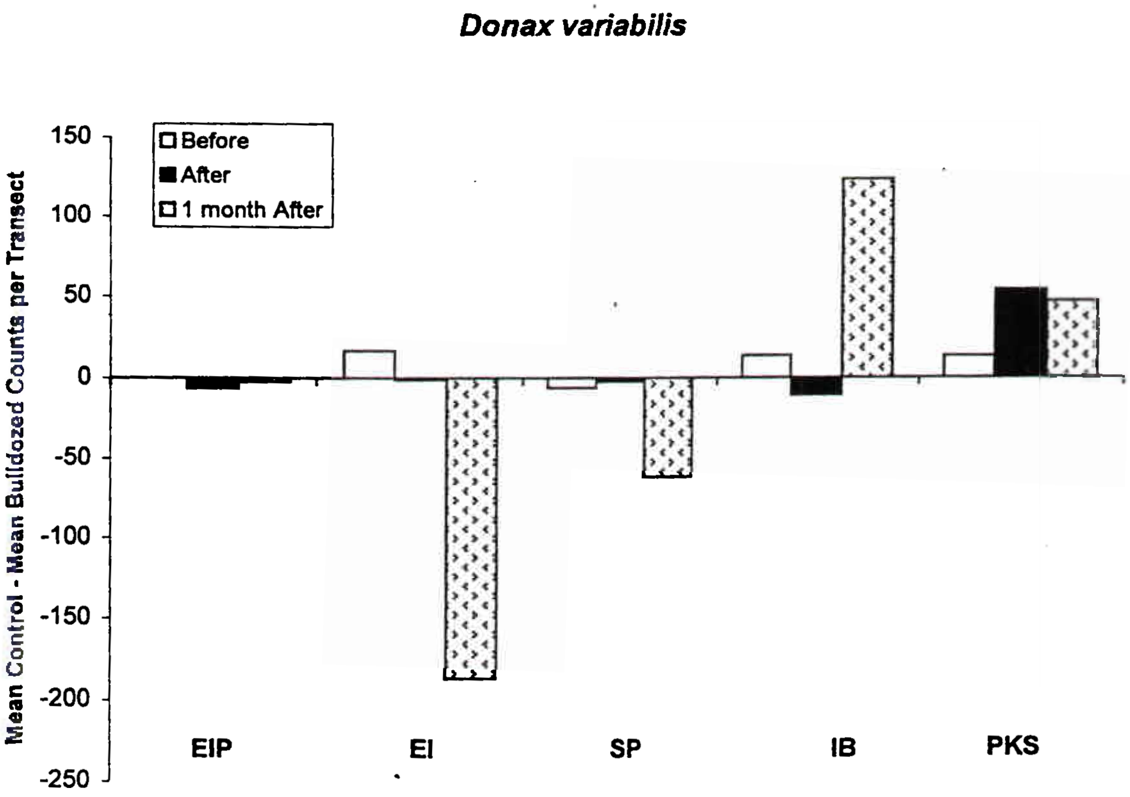


Figure 6. Change in differences between paired control and bulldozed beaches (control-bulldozed) over time. Differences between control and bulldozed beaches were calculated using mean counts of *Donax variabilis* per transect and subtracting mean counts at bulldozed beaches from mean counts at their paired control beach (control - bulldozed). A positive value indicates a higher mean count per transect at the control, while a negative value indicates a higher mean count per transect at the bulldozed beach. The change in this difference over time (e.g. before bulldozing vs. after bulldozing) illustrates the effect of bulldozing. For example, a large positive increase between Before (white bars) and After (black bars) differences indicates a decline in the mean count per transect at the bulldozed beach and no equivalent decline at the control beach. Before = 1-4 weeks before scraping took place. After = days to 1 week after scraping was completed. 1 month After = resampling of sites 1 month later. All sites are abbreviated as follows and represent the original set of five paired sites: EIP = Emerald Isle Pier Point, EI = Emerald Isle, SP= Salter Path, IB- Indian Beach, PKS = Pine Knoll Shores.

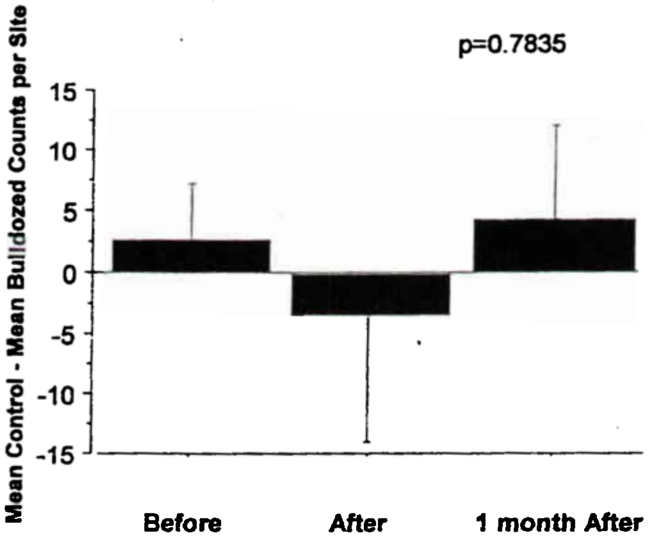


Figure 7. Results of one-way ANOVA testing the change in differences in mean *Amphiporeia virginiana* abundance between paired control and bulldozed beaches over three time periods. Mean differences in amphipod abundance were calculated for each of the five site pairs (Figure 1) by subtracting mean amphipod abundance at a bulldozed beach from mean abundance at its paired control beach (control - bulldozed = difference). Differences between site pairs were then compared among the following times: Before scraping (1-4 weeks before), After scraping (days-1week after) and 1 month After scraping. Results of this ANOVA illustrate that differences between paired control and bulldozed beaches became negative right after scraping (i.e greater amphipod abundance on bulldozed beaches versus control beaches). One month after scraping *Amphiporeia virginiana* abundances at control beaches were greater than at bulldozed beaches. The percent difference between control and bulldozed beaches Before, After and 1 month After was 13.0%, -11.7% and 6.5% respectively. Error bars indicate one standard error (N= 5).

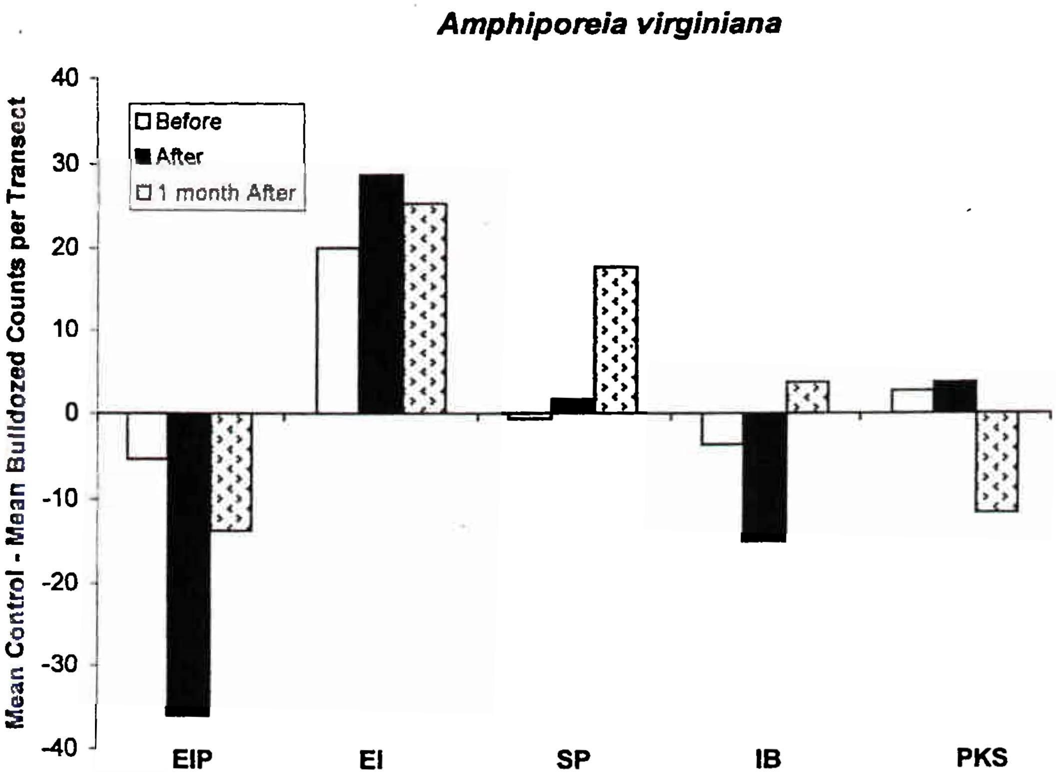


Figure 8. Change in differences between paired control and bulldozed beaches (control-bulldozed) over time. Differences between control and bulldozed beaches were calculated using mean counts of *Amphiporeia virginiana* per transect and subtracting mean counts at bulldozed beaches from mean counts at their paired control beach (control - bulldozed). A positive value indicates a higher mean count per transect at the control, while a negative value indicates a higher mean count per transect at the bulldozed beach. The change in this difference over time (e.g. before bulldozing vs. after bulldozing) illustrates the effect of bulldozing. For example, a large positive increase between Before (white bars) and After (black bars) differences indicates a decline in the mean count per transect at the bulldozed beach and no equivalent decline at the control beach. Before = 1-4 weeks before scraping took place. After = days to 1 week after scraping was completed. 1 month After = resampling of sites 1 month later. All sites are abbreviated as follows and represent the original set of five paired sites: EIP = Emerald Isle Pier Point, EI = Emerald Isle, SP= Salter Path, IB- Indian Beach, PKS = Pine Knoll Shores.

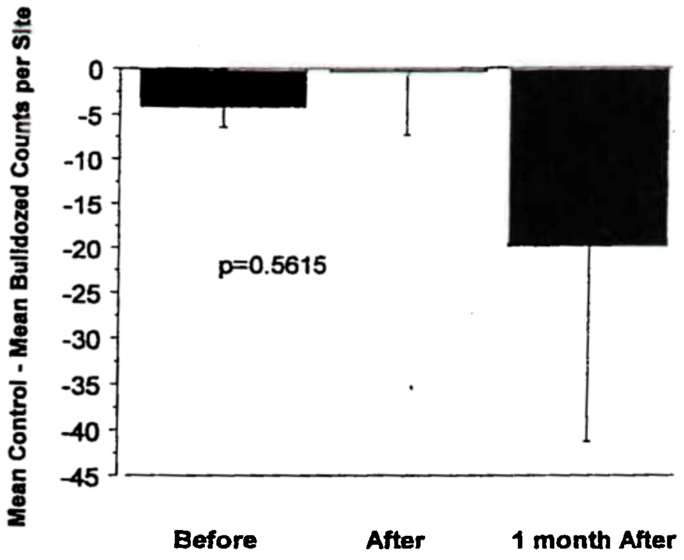


Figure 9. Results of one-way ANOVA testing the change in differences in mean *Scolelepis squamata* abundance between paired control and bulldozed beaches over three time periods. Mean differences in *Scolelepis* abundance were calculated for each of the five site pairs (Figure 1) by subtracting mean *Scolelepis* abundance at a bulldozed beach from mean abundance at its paired control beach (control - bulldozed = difference). Differences between site pairs were then compared among the following times: Before scraping (1-4 weeks before), After scraping (days-1week after) and 1 month After scraping. Results of this ANOVA illustrate that differences between paired control and bulldozed beaches became less negative right after scraping (i.e decreased difference in abundances between bulldozed and control beaches). One month after scraping, *Scolelepis squamata* abundances at bulldozed beaches were still greater than at control beaches. The percent difference between control and bulldozed beaches Before, After and 1 month After was -47.9%, -6.2% and -61.0% respectively. Error bars indicate one standard error (N= 5).

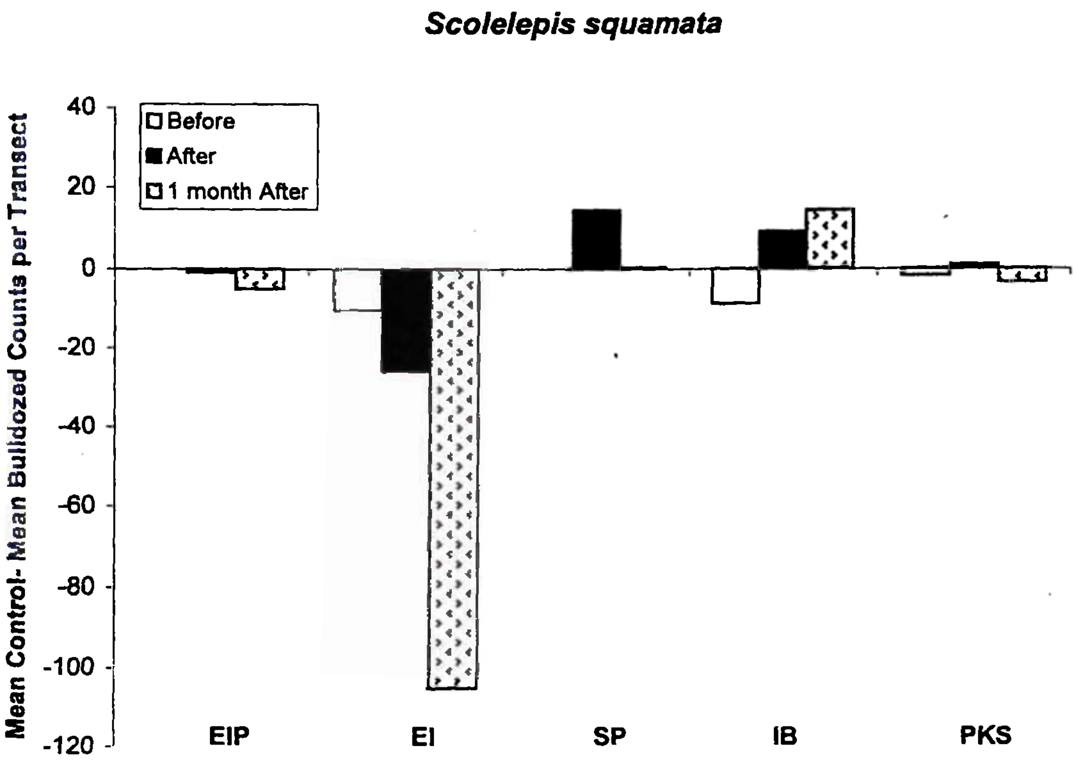


Figure 10. Change in differences between paired control and bulldozed beaches (control-bulldozed) over time. Differences between control and bulldozed beaches were calculated using mean counts of *Scolelepis squamata* per transect and subtracting mean counts at bulldozed beaches from mean counts at their paired control beach (control - bulldozed). A positive value indicates a higher mean count per transect at the control, while a negative value indicates a higher mean count per transect at the bulldozed beach. The change in this difference over time (e.g. before bulldozing vs. after bulldozing) illustrates the effect of bulldozing. For example, a large positive increase between Before (white bars) and After (black bars) differences indicates a decline in the mean count per transect at the bulldozed beach and no equivalent decline at the control beach. Before = 1-4 weeks before scraping took place. After = days to 1 week after scraping was completed. 1 month After = resampling of sites 1 month later. All sites are abbreviated as follows and represent the original set of five paired sites: EIP = Emerald Isle Pier Point, EI = Emerald Isle, SP= Salter Path, IB- Indian Beach, PKS = Pine Knoll Shores.

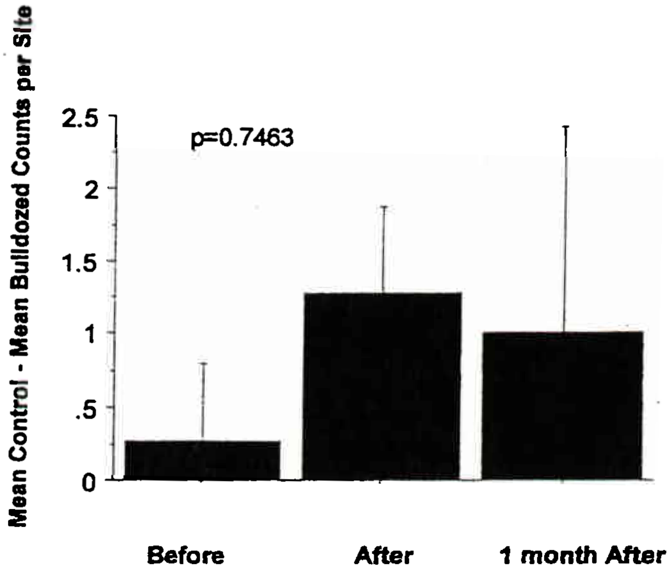


Figure 11. Results of one-way ANOVA testing the change in differences in mean *Emerita talpoida* abundance between paired control and bulldozed beaches over three time periods. Mean differences in mole crab abundance were calculated for each of the five site pairs (Figure 1) by subtracting mean crab abundance at a bulldozed beach from mean abundance at its paired control beach (control - bulldozed = difference). Differences between site pairs were then compared among the following times: Before scraping (1-4 weeks before), After scraping (days-1week after) and 1 month After scraping. Results of this ANOVA illustrate that differences between paired control and bulldozed beaches became more positive right after scraping (i.e greater crab abundance on control beaches versus bulldozed beaches). One month after scraping *Emerita talpoida* abundances at control beaches were still greater than at bulldozed beaches. The percent difference between control and bulldozed beaches Before, After and 1 month After was 12.2%, 68.0% and 40.5% respectively. Error bars indicate one standard error (N= 5).

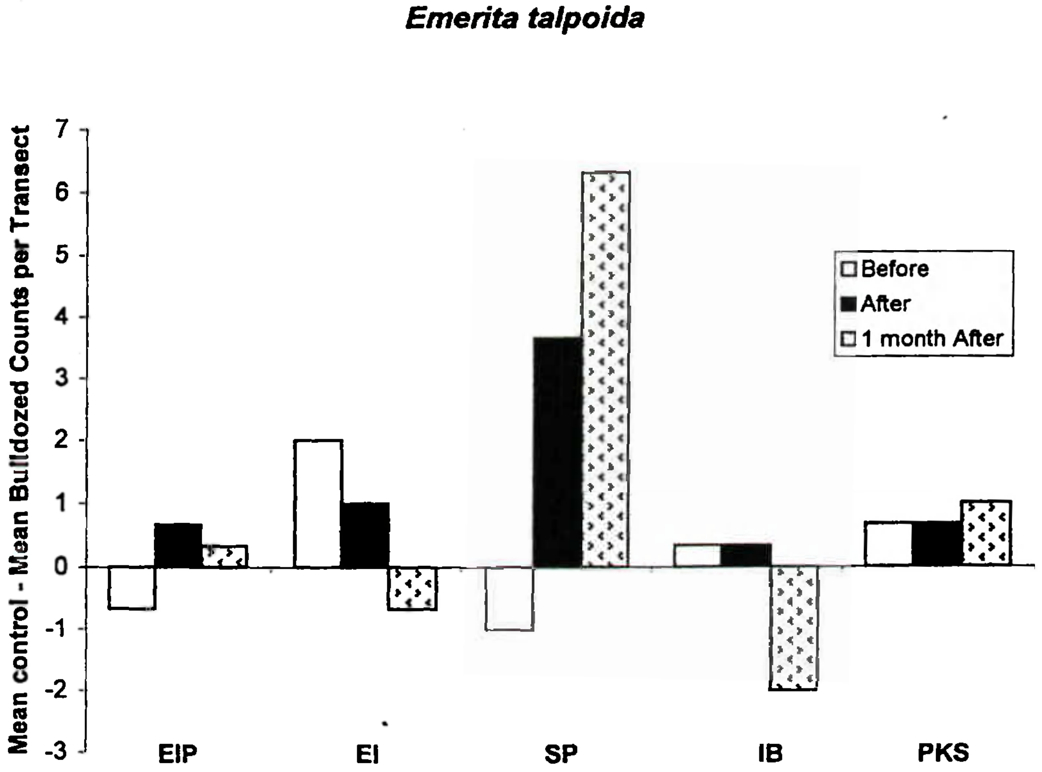


Figure 12. Change in differences between paired control and bulldozed beaches (control-bulldozed) over time. Differences between control and bulldozed beaches were calculated using mean counts of *Emerita talpoida* per transect and subtracting mean counts at bulldozed beaches from mean counts at their paired control beach (control- bulldozed). A positive value indicates a higher mean count per transect at the control, while a negative value indicates a higher mean count per transect at the bulldozed beach. The change in this difference over time (e.g. before bulldozing vs. after bulldozing) illustrates the effect of bulldozing. For example, a large positive increase between Before (white bars) and After (black bars) differences indicates a decline in the mean count per transect at the bulldozed beach and no equivalent decline at the control beach. Before = 1-4 weeks before scraping took place. After = days to 1 week after scraping was completed. 1 month After = resampling of sites 1 month later. All sites are abbreviated as follows and represent the original set of five paired sites: EIP = Emerald Isle Pier Point, EI = Emerald Isle, SP= Salter Path, IB- Indian Beach, PKS = Pine Knoll Shores.

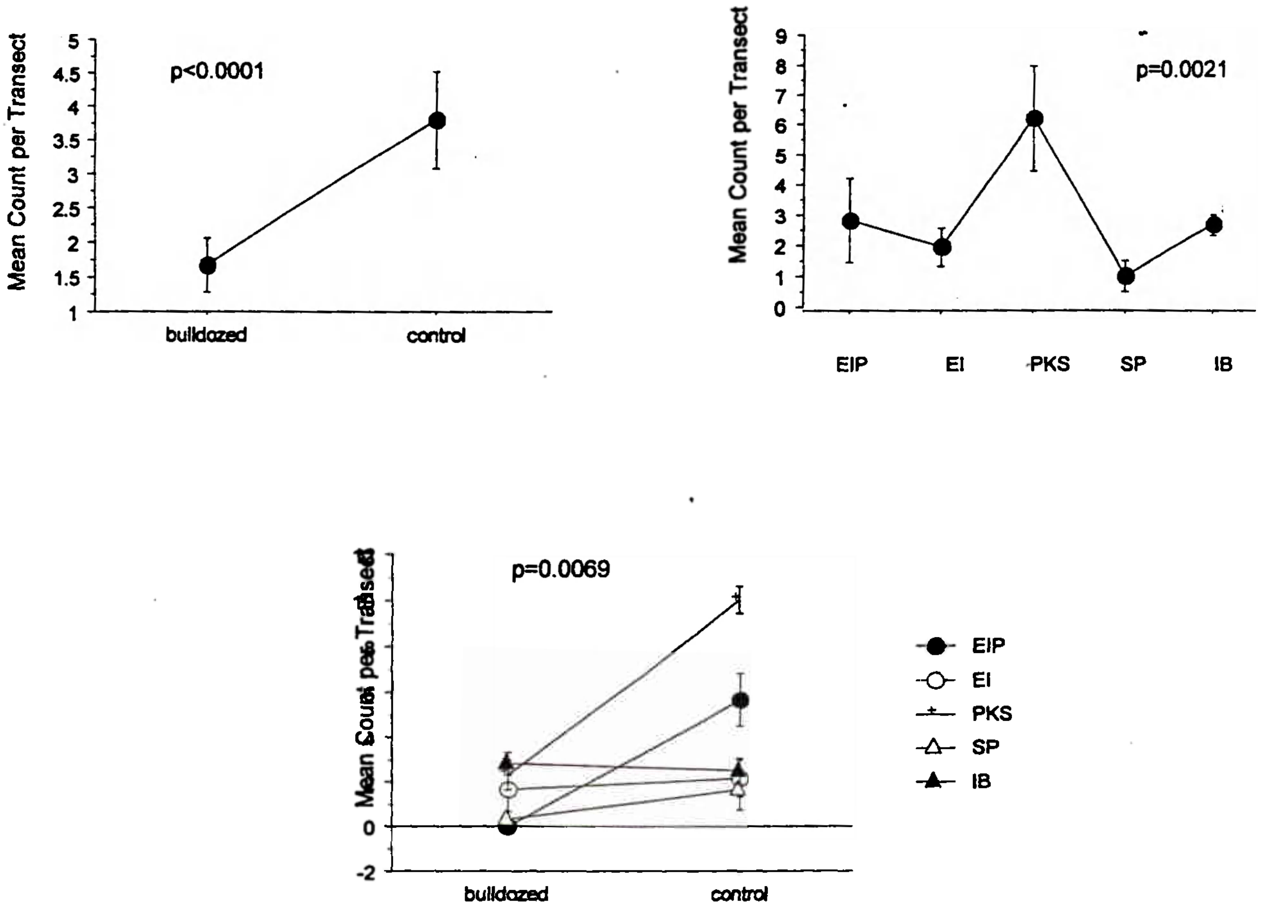


Figure 13. Results of two-way ANOVA testing the effects of treatment (bulldozed vs. control) and site on (log-transformed) total ghost crab abundances during April. All site abbreviations are as in previous figures and represent the the original set of five site pairs. Plots of all significant effects are shown, and error bars represent one standard error.

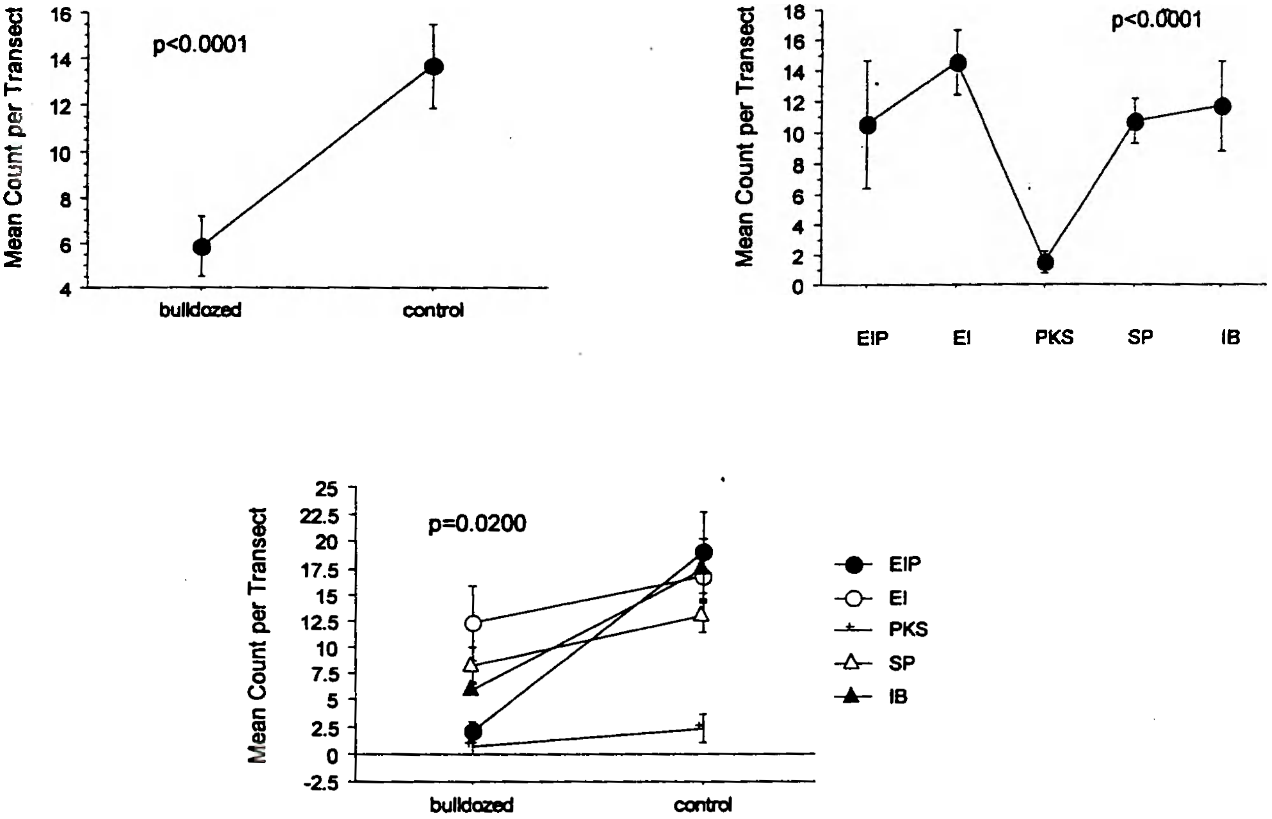


Figure 14. Results of two-way ANOVA testing the effects of treatment (bulldozed, control) and site on (log-transformed) total ghost crab abundance during May. All site abbreviations are as in previous figures and represent the original set of five site pairs. Plots of all significant effects are shown, and error bars represent one standard error.

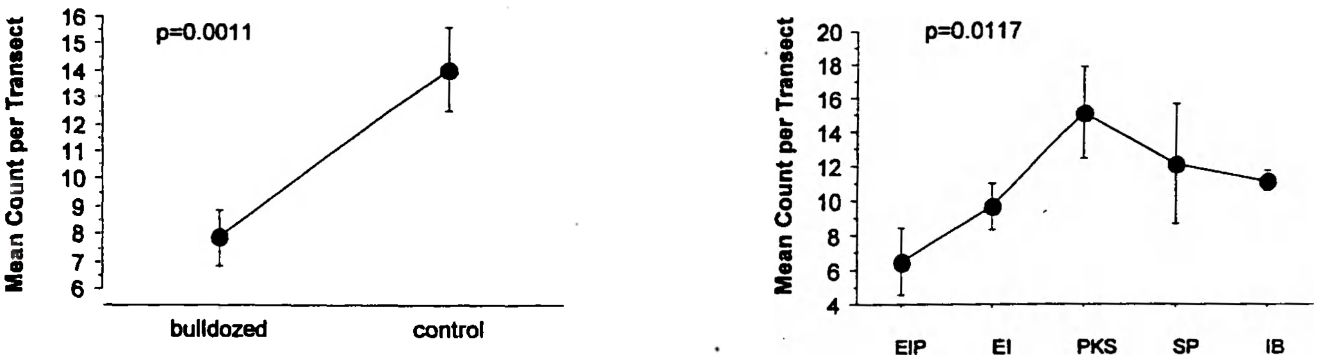


Figure 15. Results of two-way ANOVA testing the effects of treatment (bulldozed, control) and site on (log–transformed) total ghost crab abundance in June. All sites are abbreviated as in previous figures and represent the original set of five site pairs. Plot of all significant effects are shown, and error bars represent one standard error.

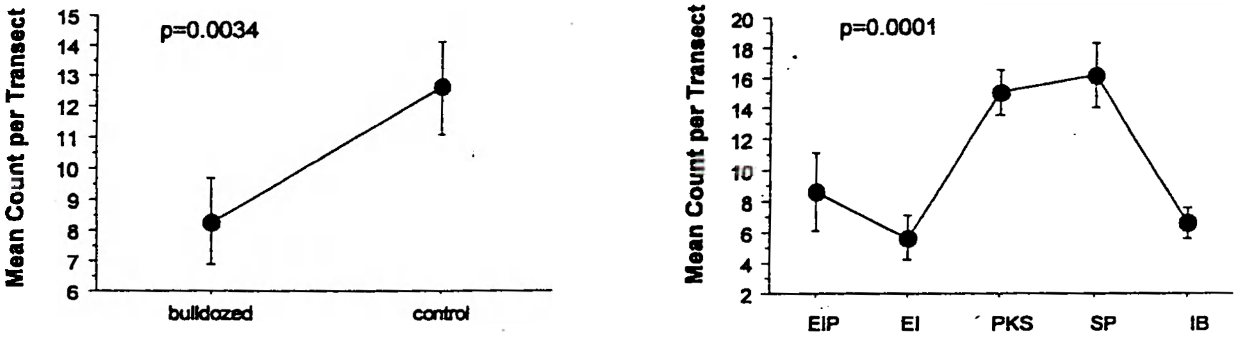


Figure 16. Results of two-way ANOVA testing the effects of treatment (bulldozed, control) and site on (log-transformed) total ghost crab abundances during July. All sites are abbreviated as in previous figures and represent the original set of five site pairs. Plots of all significant effects are shown, and error bars represent one standard error.

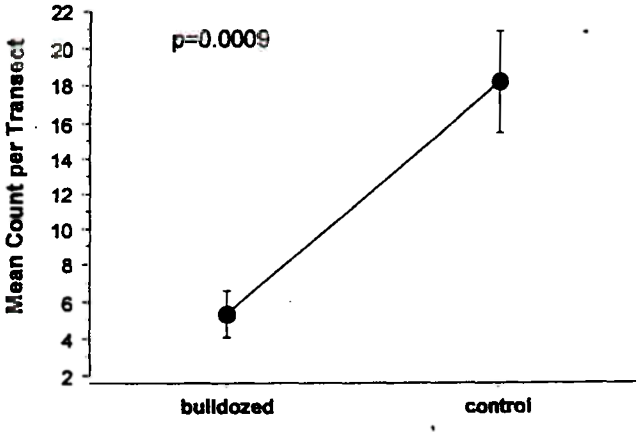


Figure 17. Result of two-way ANOVA testing the effects of treatment (bulldozed, control) and site on (log-transformed) total ghost crab abundances during August. Plot of the only significant effect is shown. Error bars represent one standard error.

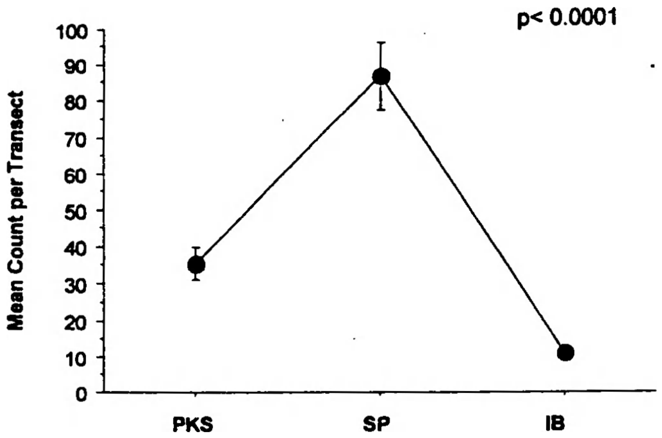


Figure 18. Result of two-way ANOVA testing the effects of treatment (bulldozed, control) and site on (log-transformed) total ghost crab abundances during September. Plot of the one significant effect is shown. Error bars represent one standard error.

A)

	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	.022	.022	.452	.5064
site	4	.218	.055	1.118	.3652
treatment * site	4	.505	.126	2.591	.0552
Residual	32	1.561	.049		

B)

	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	1.091	1.091	15.781	.0004
site	4	.804	.201	2.908	.0369
treatment * site	4	.797	.199	2.881	.0382
Residual	32	2.212	.069		

C)

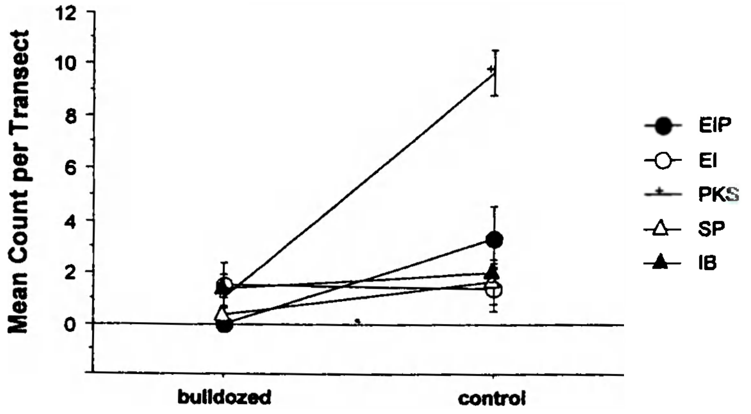


Figure 19. Results of 2-way ANOVA on log-transformed ghost crab abundances on A) the face of the dune and B) on the subaerial beach. All ghost crab data were collected in April. The interaction plot in C) illustrates the significant treatment x site interaction for ghost crab abundances on the beach. Error bars represent one standard error.

A)

	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	.599	.599	20.684	.0002
site	4	.517	.129	4.465	.0097
treatment * site	4	.379	.095	3.271	.0323
Residual	20	.579	.029		

B)

	DF	Sum of Squares	Mean Square	F-Value	P-Value
treatment	1	.054	.054	1.151	.2962
site	4	1.780	.445	9.517	.0002
treatment * site	4	.335	.084	1.791	.1703
Residual	20	.935	.047		

C)

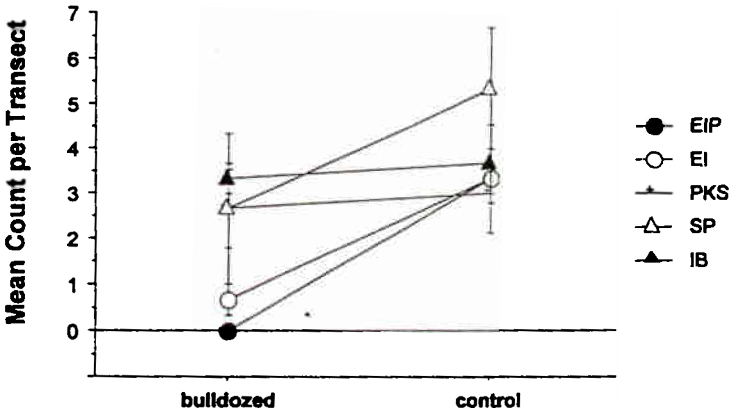


Figure 20. Results of 2-way ANOVA on log-transformed ghost crab abundances on A) the face of the dune and B) on the subaerial beach. All ghost crab data were collected in July. The interaction plot in C) illustrates the significant treatment x site interaction for ghost crab abundances on the face. Error bars represent one standard error.

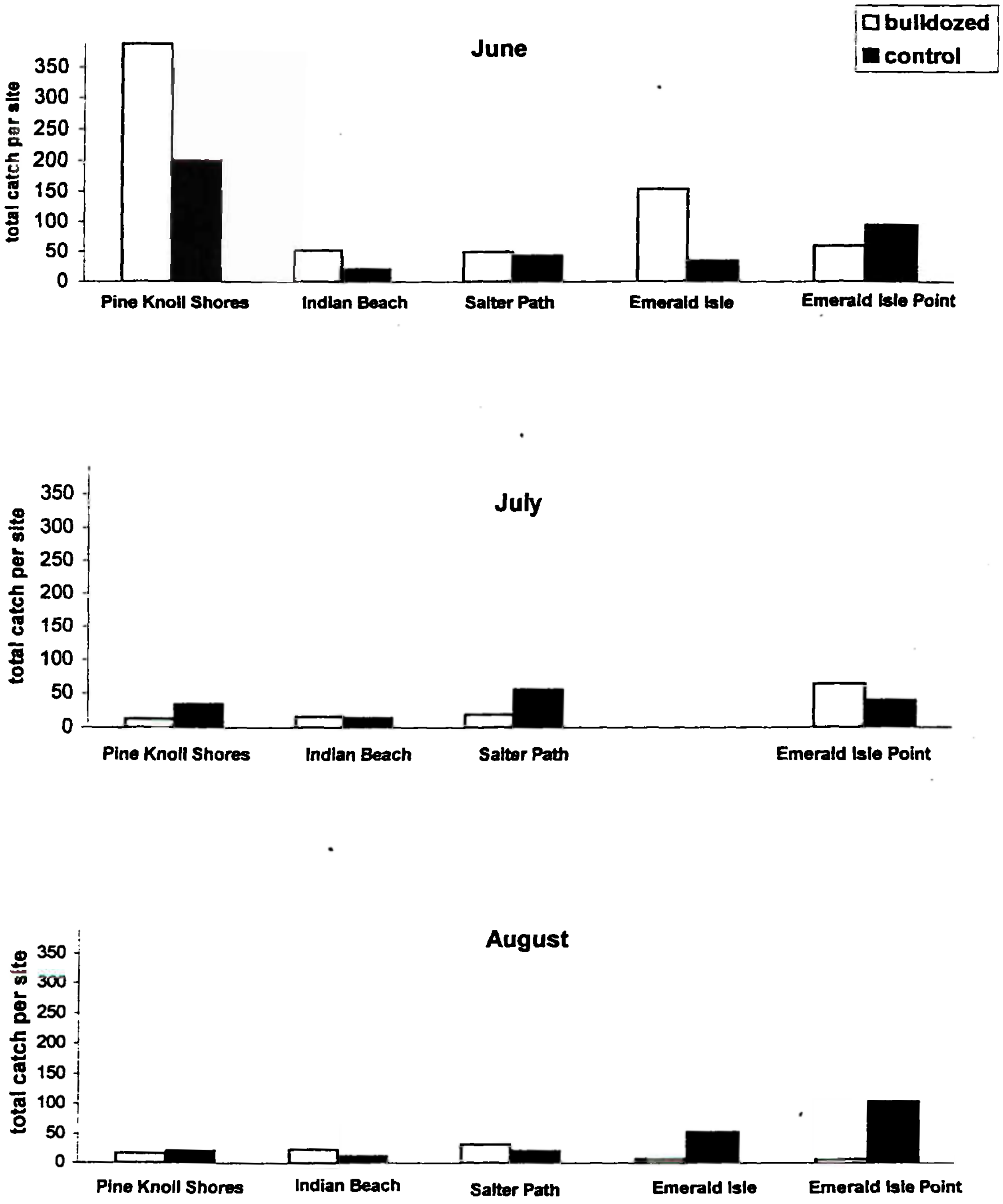


Figure 21. Total surf fish abundance for beach seine sampling conducted in June, July and August 1998 at all site pairs on Bogue Banks. Note that no sampling was conducted at the Emerald Isle site in July.

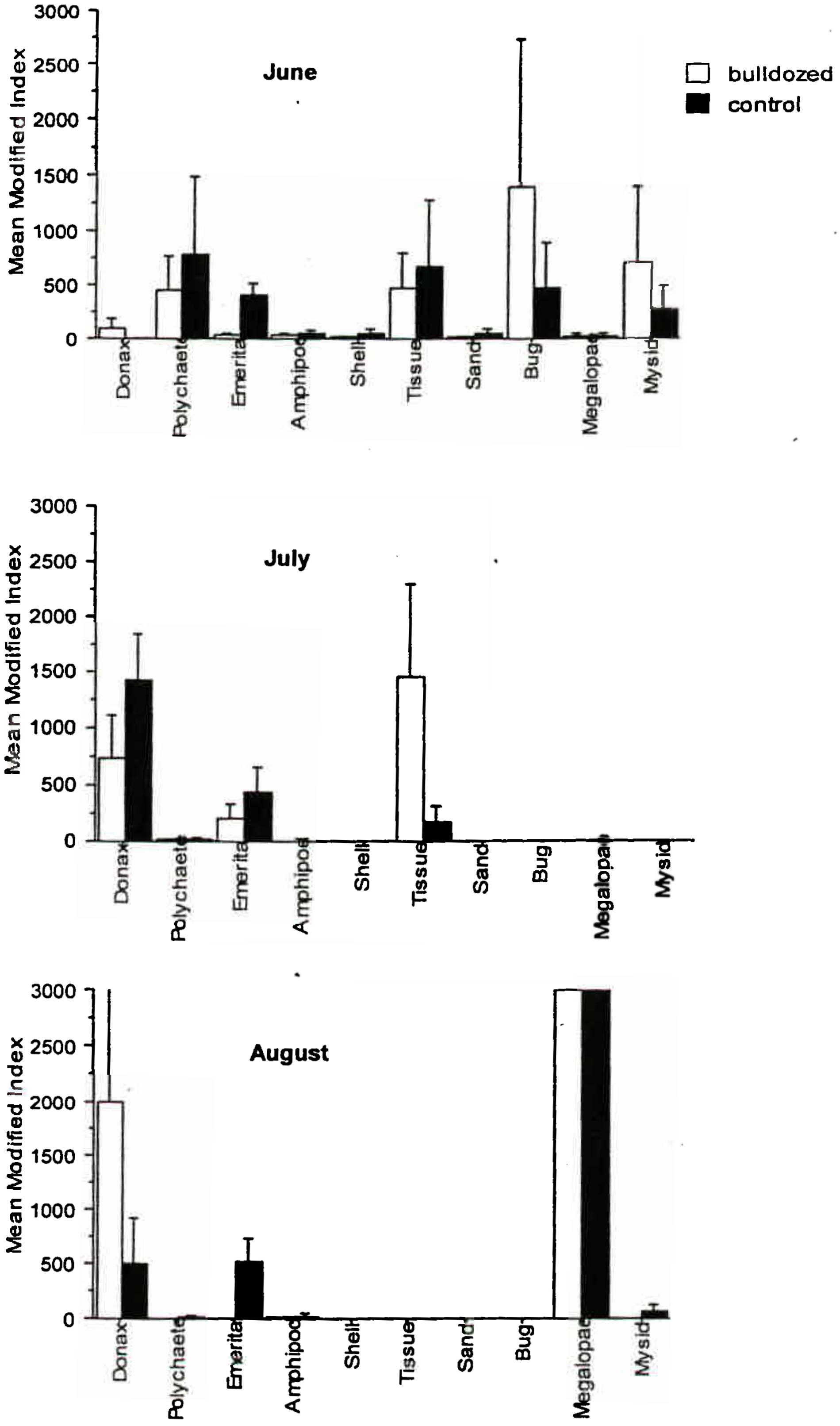
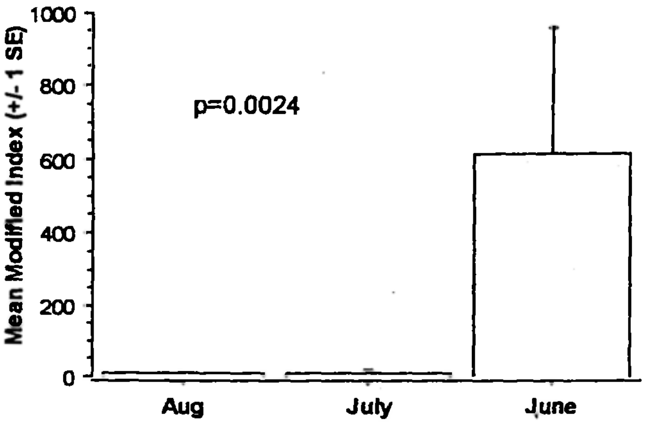


Figure 22. Mean Modified Index (Hyslop, 1980) by month for pompano stomachs collected during day seining at bulldozed and control sites on Bogue Banks (+/- 1 SE, N= 3- 5).

A) polychaetes



B) *Emerita*

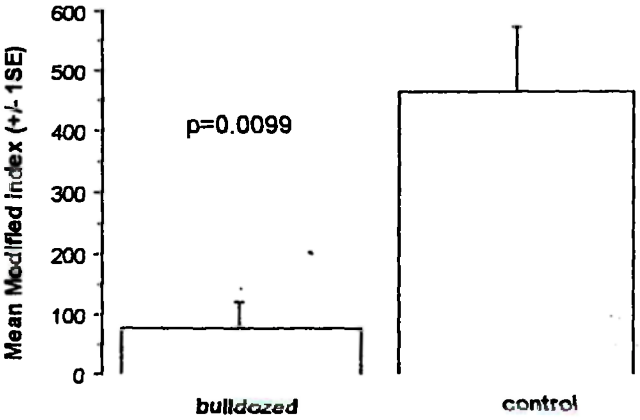


Figure 23. Significant effects of 2-way ANOVAs on modified importance (MI) values (Hyslop, 1980) of (A) polychaetes and (B) *Emerita* in stomachs of Florida pompano. (N = variable. See Table 7 for complete ANOVA results and text for details.) Polychaete MI values were significantly different among sampling months, and *Emerita* importance values were significantly different between the beach treatments, bulldozed and control.

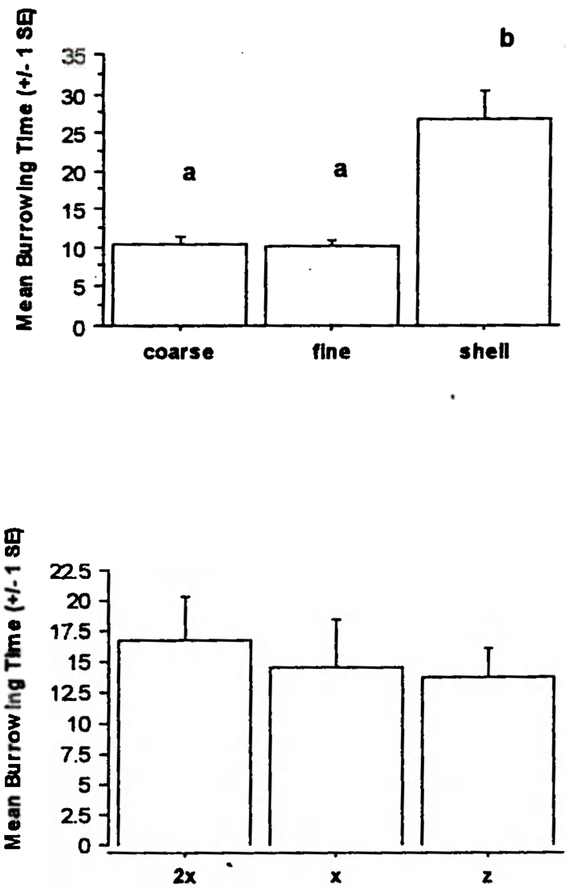


Figure 24. Main effect plots for 2-way ANOVA testing the effects of sediment type (coarse, fine, shell) and clam density (0, 123 and 146 clams per 30 cm-diameter, experimental arena) on burrowing speed of *Donax variabilis* (n=3). See Table 8 for complete ANOVA result. The main effect of sediment type was significant ($p<0.0001$), and results of post-hoc comparisons (Scheffe's F) are indicated. (Significant differences are shown by having different letter.) The main effect of density was not significant ($p=0.1796$), but a trend of slower burrowing rates at high clam densities was indicated. 2x = 246 clams, x = 123 clams and z= 0 clams.

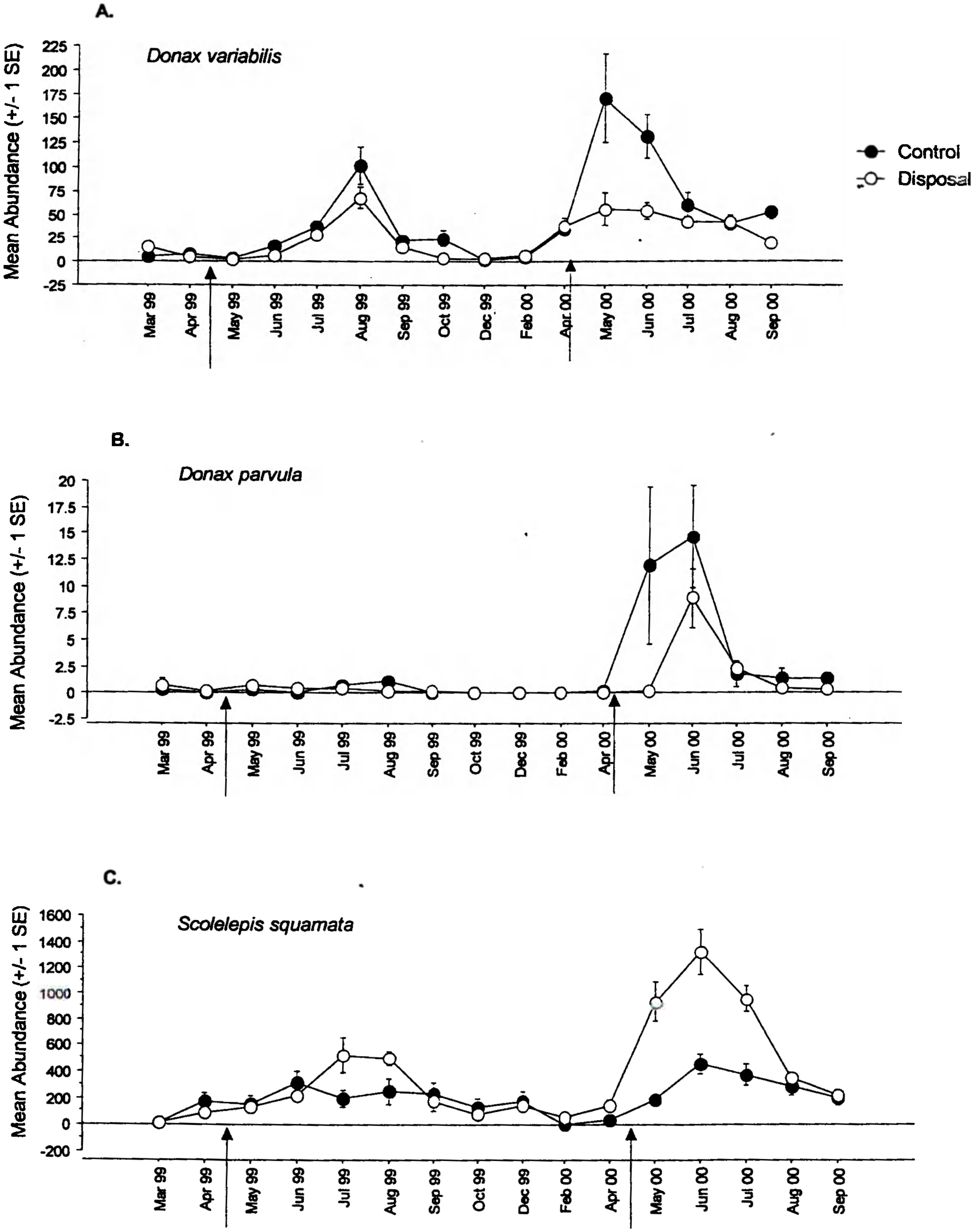
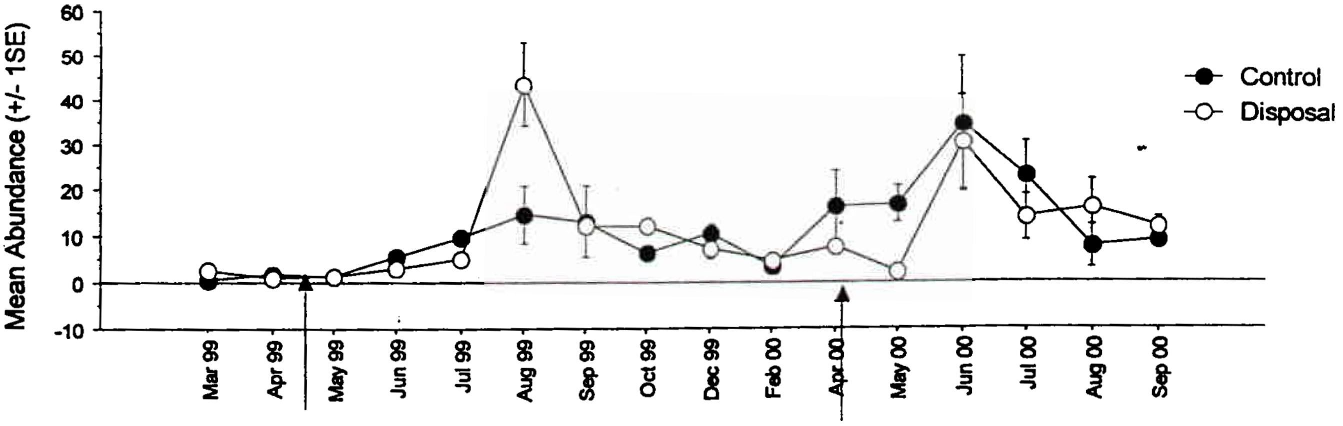


Figure 25. Mean abundances of the most common species occurring in benthic samples from N. Topsail over the course of the sampling period. Means were calculated using transect totals (n=6). Arrows on the x-axis indicate when beach disposal was initiated each year.

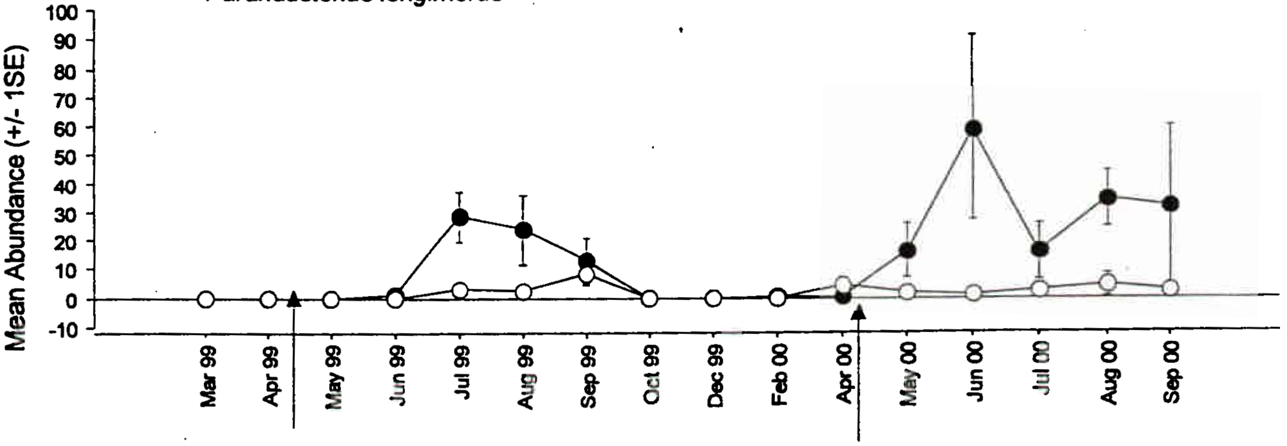
D.

Haustorius spp.



E.

Parahaustorius longimerus



F.

Amphiporeia virginiana

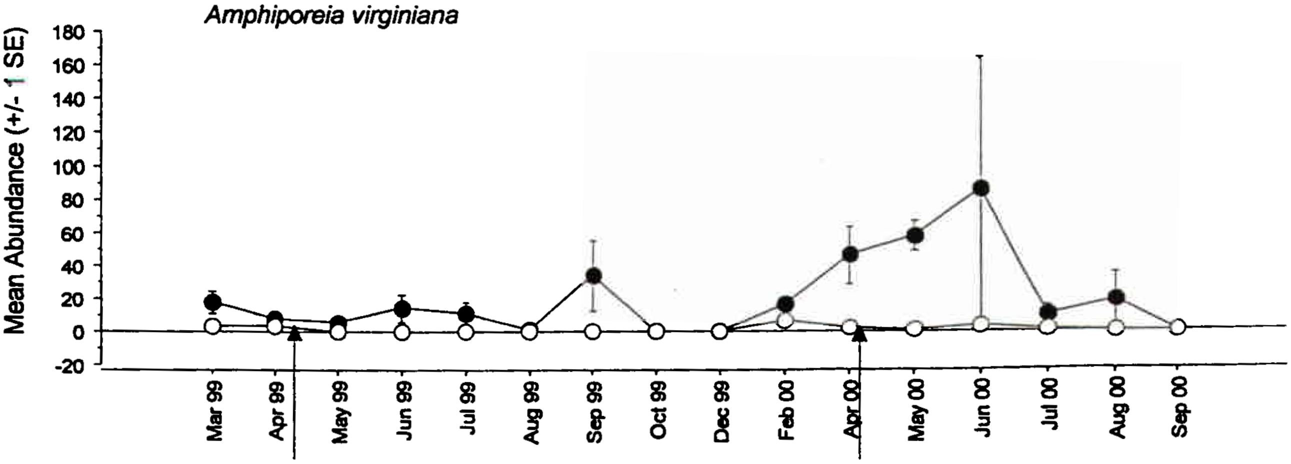


Figure 25. Continued.

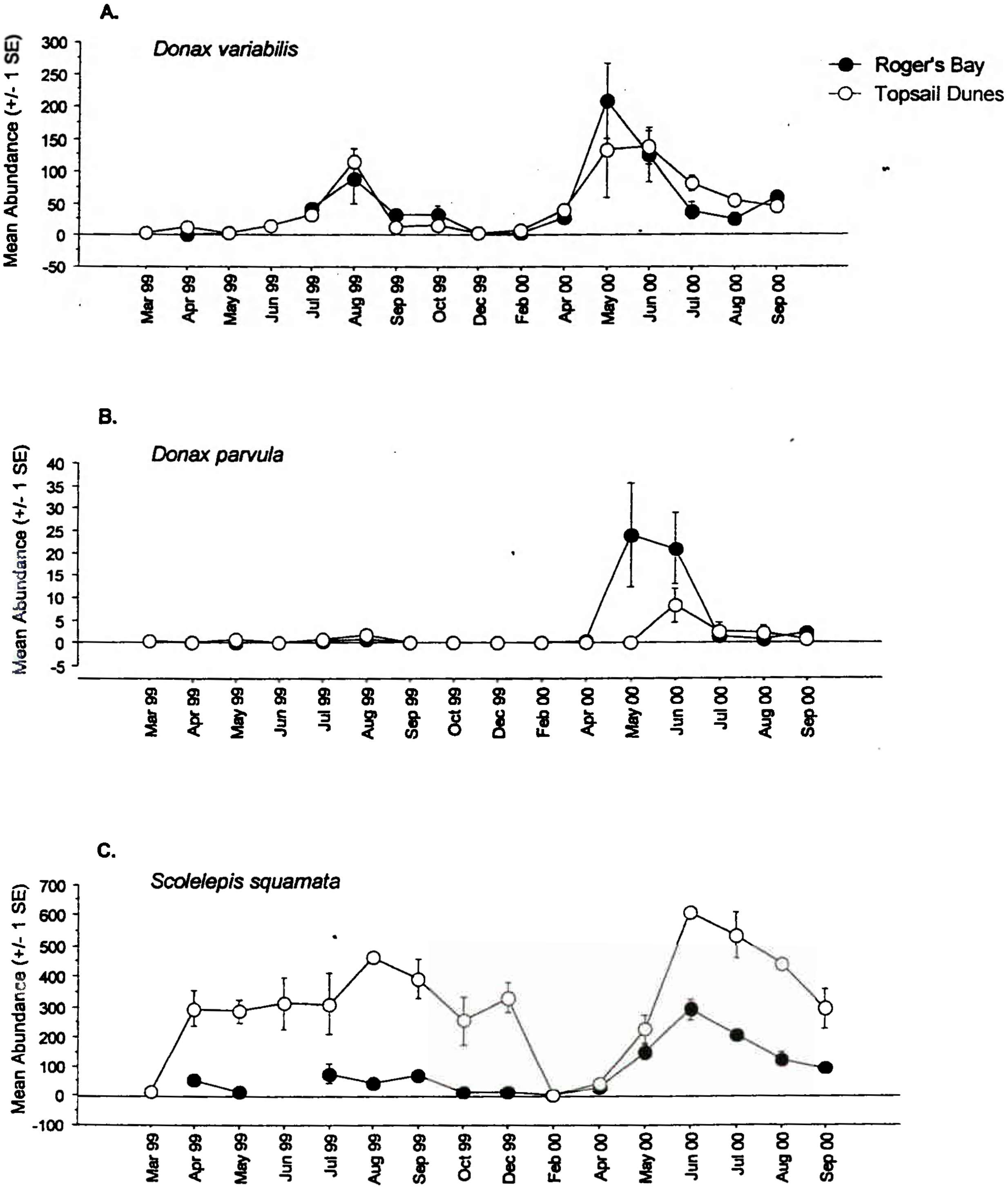


Figure 26. Mean abundances of the most common species occurring in benthic samples collected at the two control areas over the course of the sampling period. Means were calculated using transect totals (n=6).

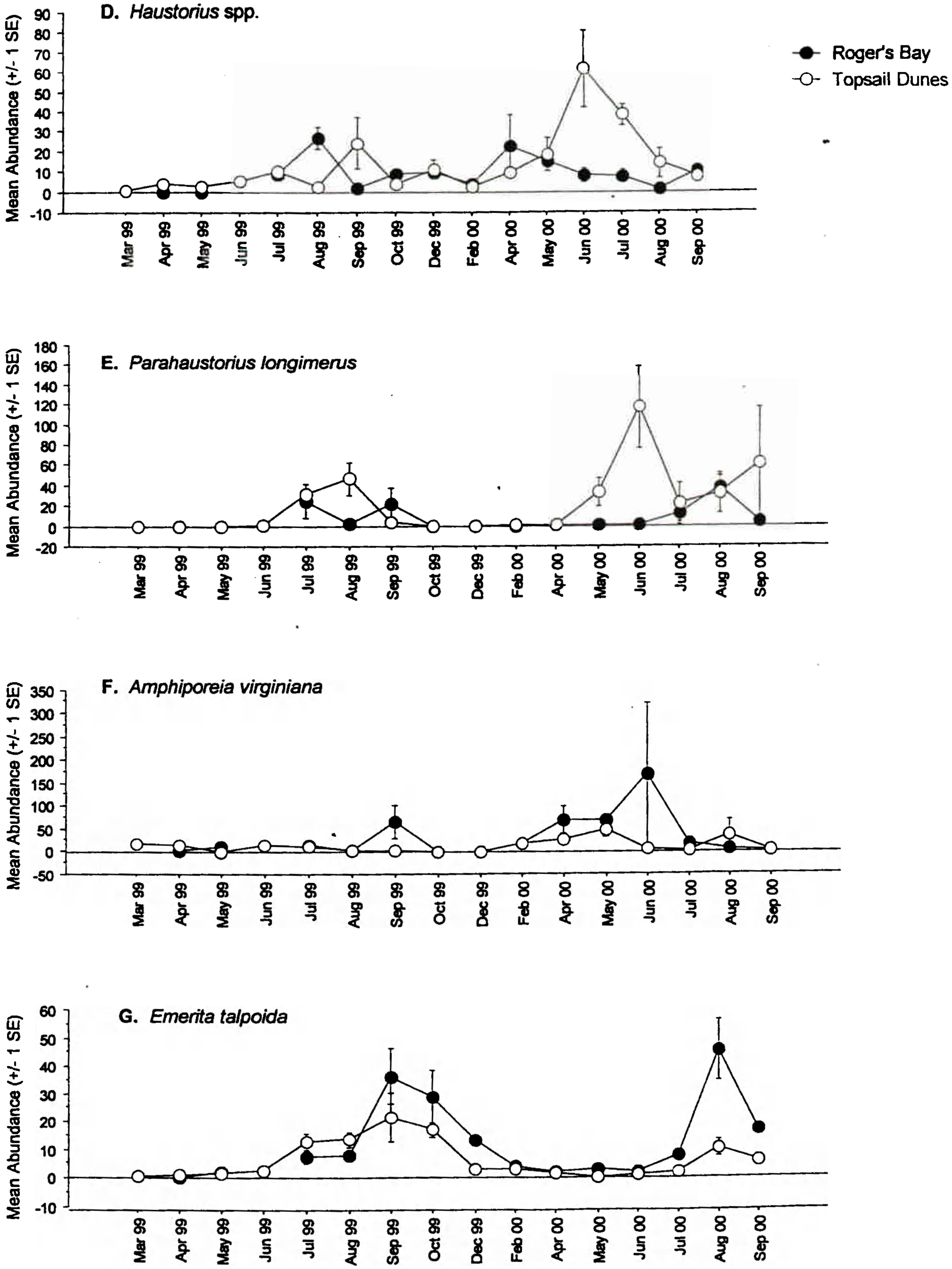


Figure 26. Continued.

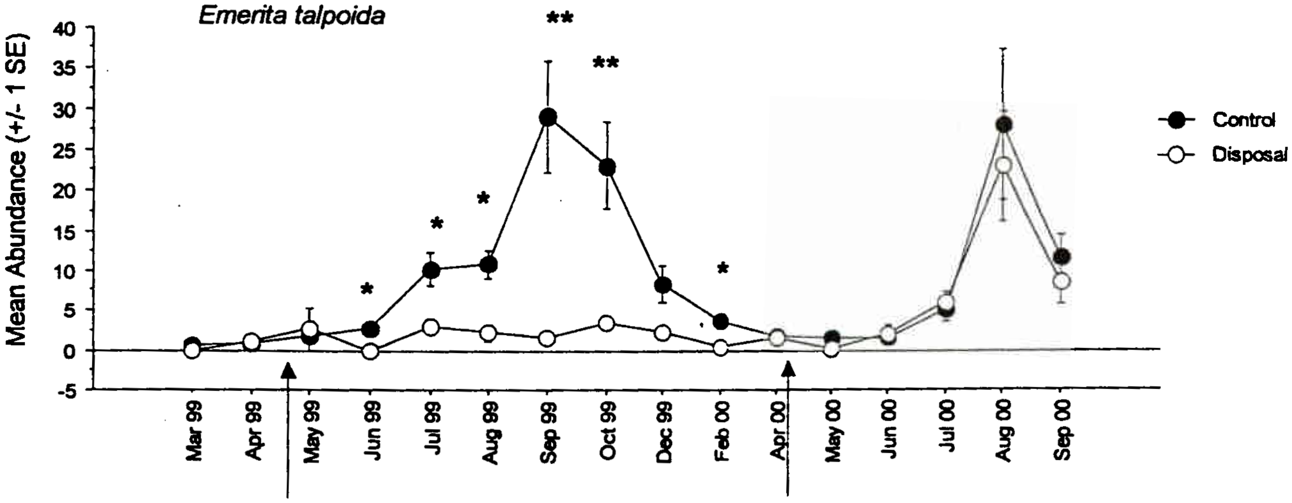
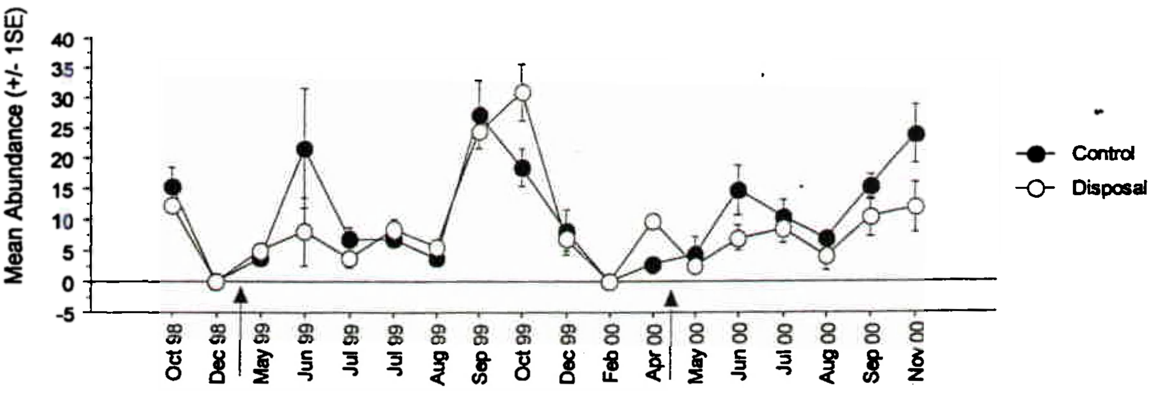
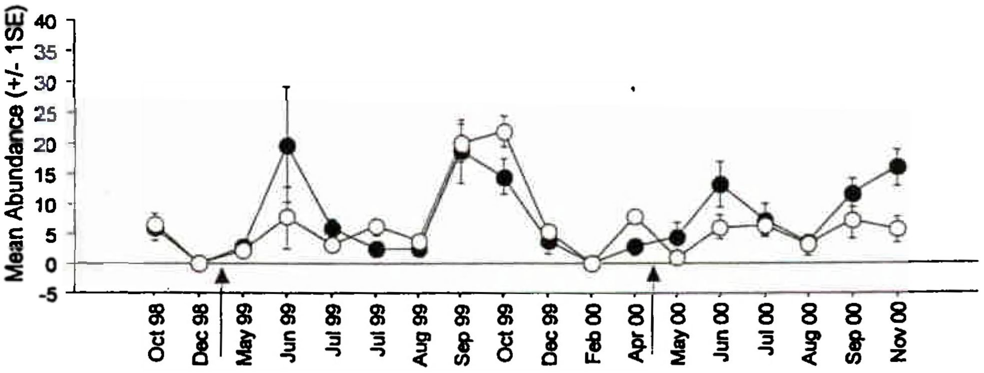


Figure 27. Mean abundance of the mole crab, *Emerita talpoida*, at control and disposal areas during the study period. Mean abundances were calculated using transect totals (n=6). Arrows on the x-axis indicate when disposal was initiated in each year. Asterisks indicate months in which significant differences between control and disposal means were found by Mann-Whitney U tests (* = $p<0.05$; ** = $p< 0.005$).

A. Total



B. Beach



C. Dune

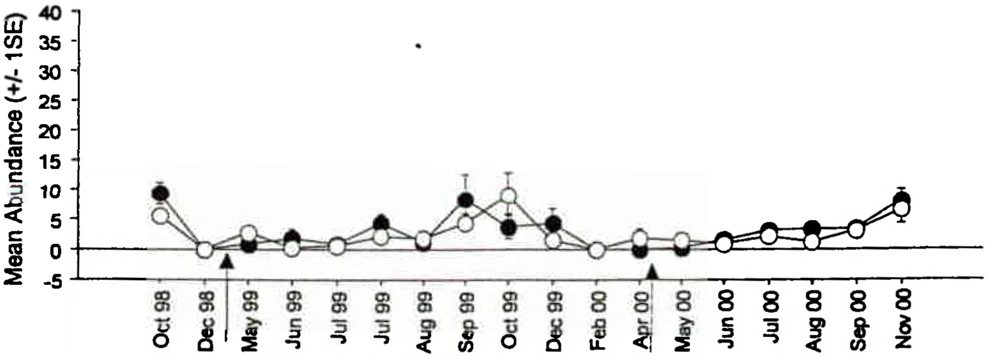
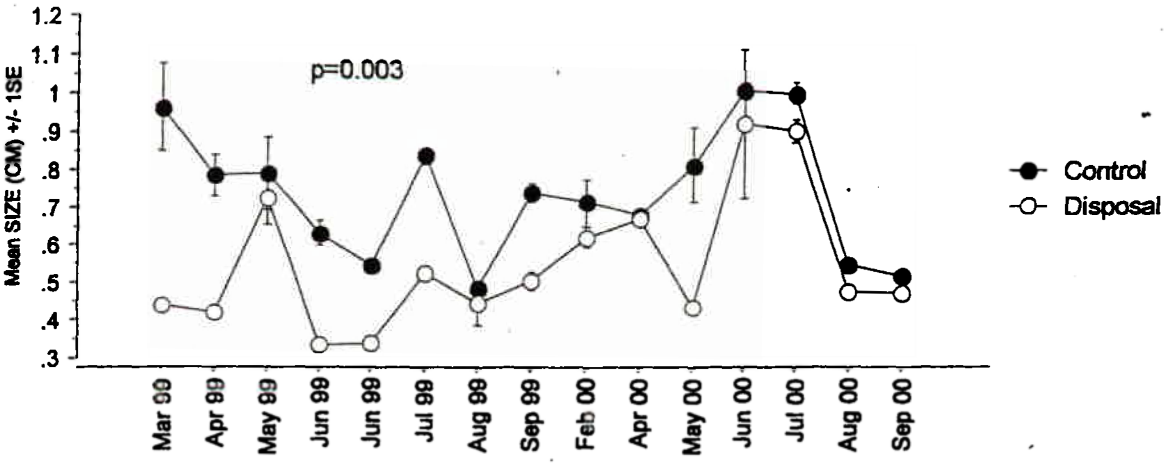


Figure 28. Mean ghost crab abundance at control and disposal areas over the course of the sampling period. Means were calculated from the total number of ghost crab burrows counted along each transect (n=6). Arrows along x-axis indicate when disposal was initiated in each year. Ghost crab counts are shown for (A) the total area censused and separately for burrows located on the beach (B) and on the dune face (C).

A) ***Donax variabilis***



B) ***Emerita talpoida***

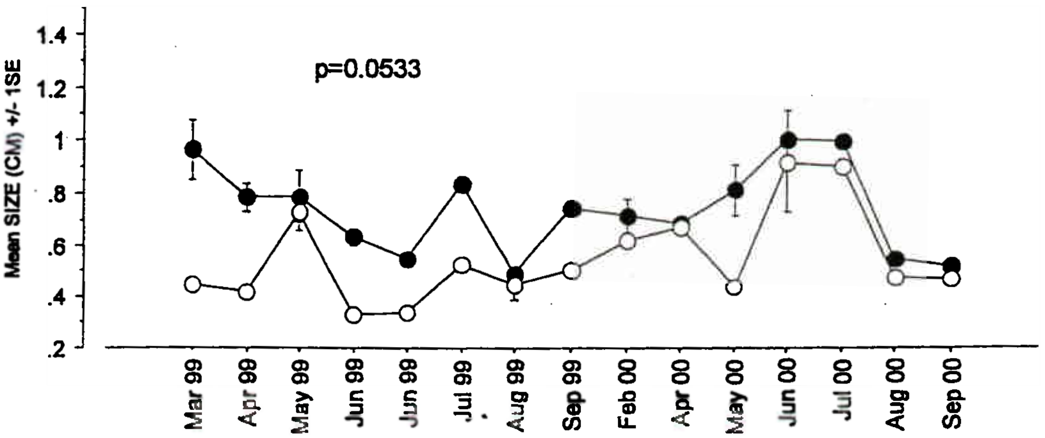


Figure 29. Mean size for *Donax variabilis* (A) and *Emerita talpoida* (B) during each sampling period. Means were calculated using total length measurements (anterior to posterior lengths) from all individuals collected at control and disposal areas for each time period. Sizes were compared by calculating the difference between mean control size and mean disposal size within each sampling period and then conducting a one sample t-test (two-tailed with hypothesized mean= 0) on the differences. Corresponding p-values are indicated on each plot and corresponding frequency distributions for each season of sampling are provided in Figures 30 & 31.

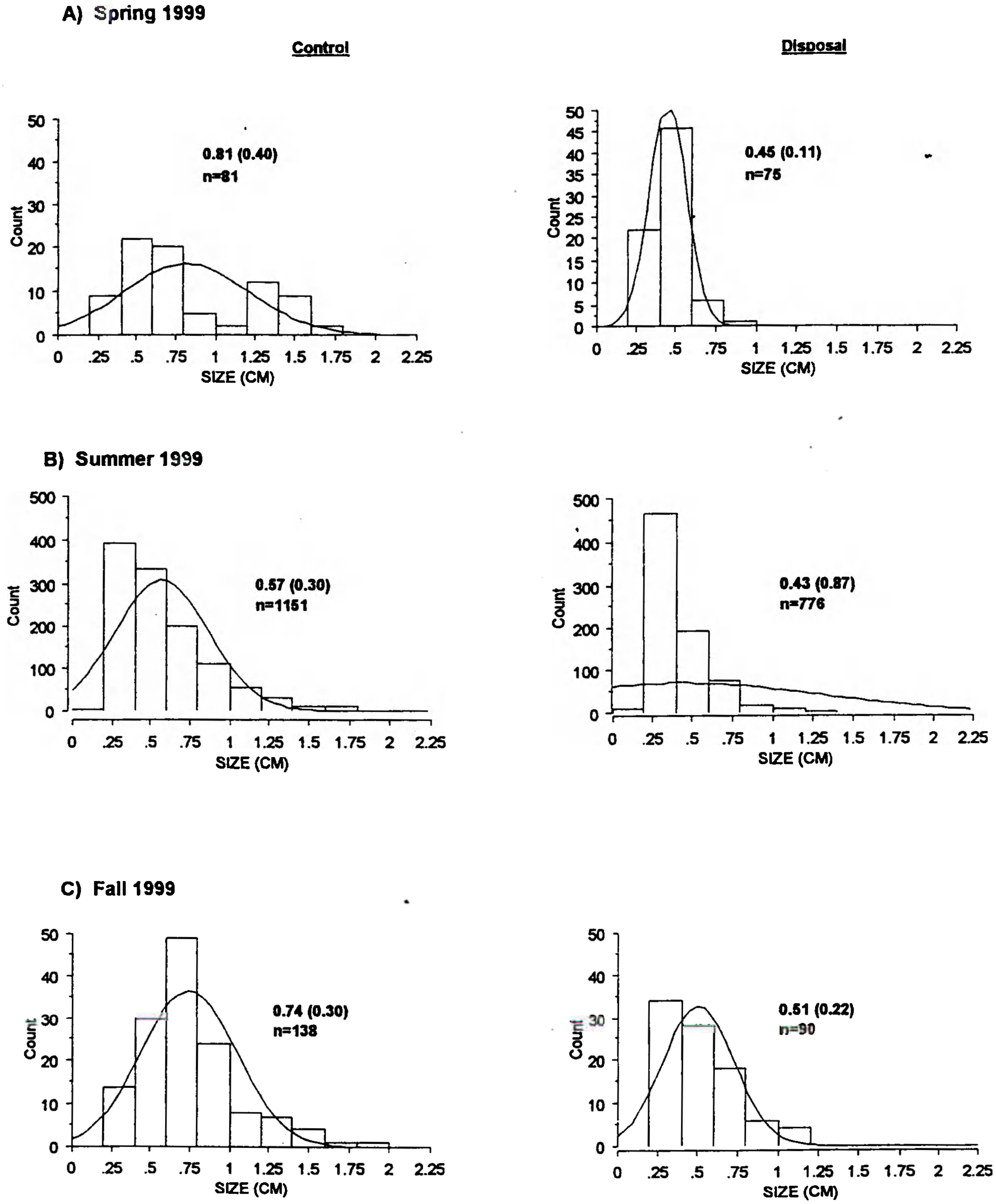
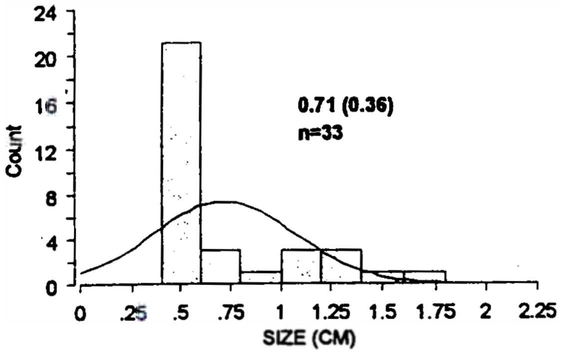
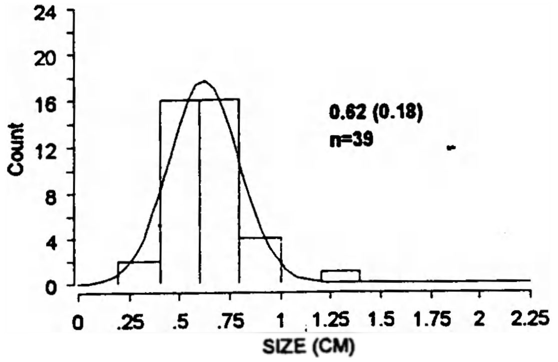


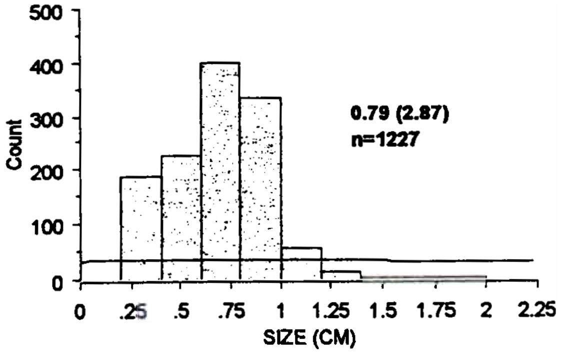
Figure 30. Frequency distributions of *Donax variabilis* size by season. Separate histograms for disposal (white) and control (gray) observations are provided for each season in each year of the study. Size represents the anterior-posterior length of the clam (measured to the nearest 0.01 cm). The curve in each plot represents the expected frequency curve for a normal distribution based on the mean and standard deviation of the data. Means and standard deviations are provided on each histograms.

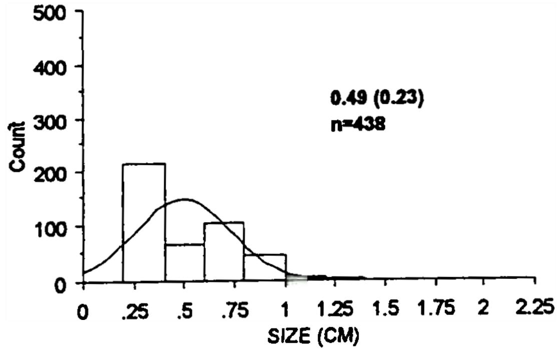
D) Winter 2000



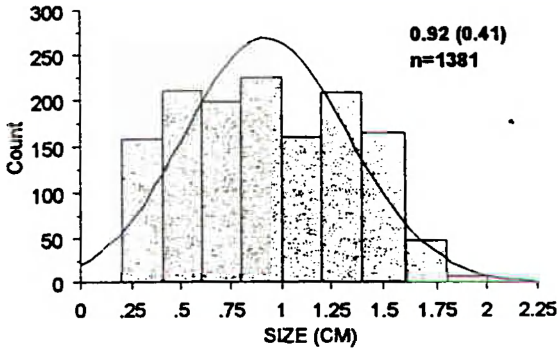


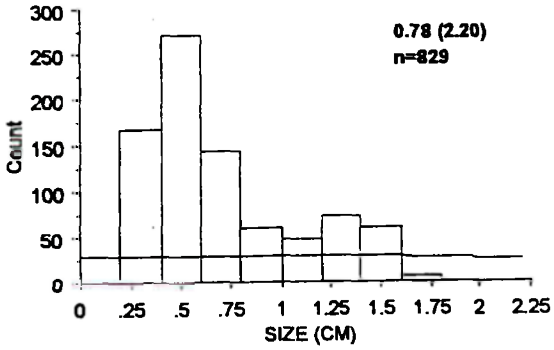
E) Spring 2000



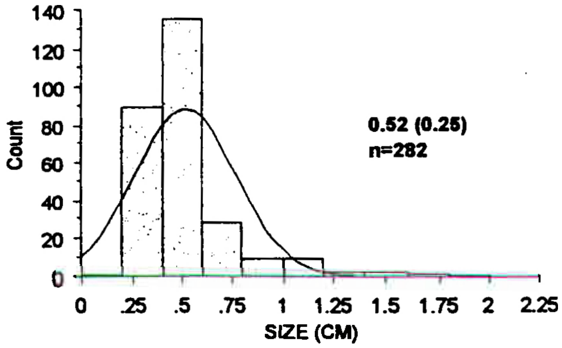


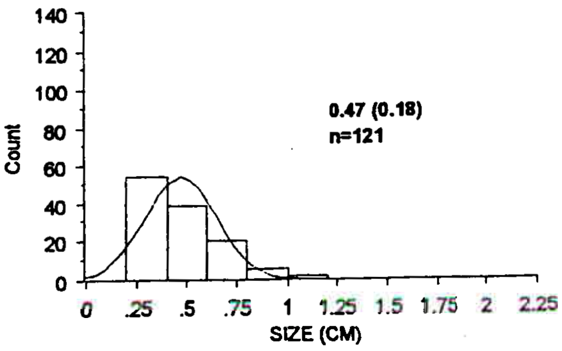
F) Summer 2000

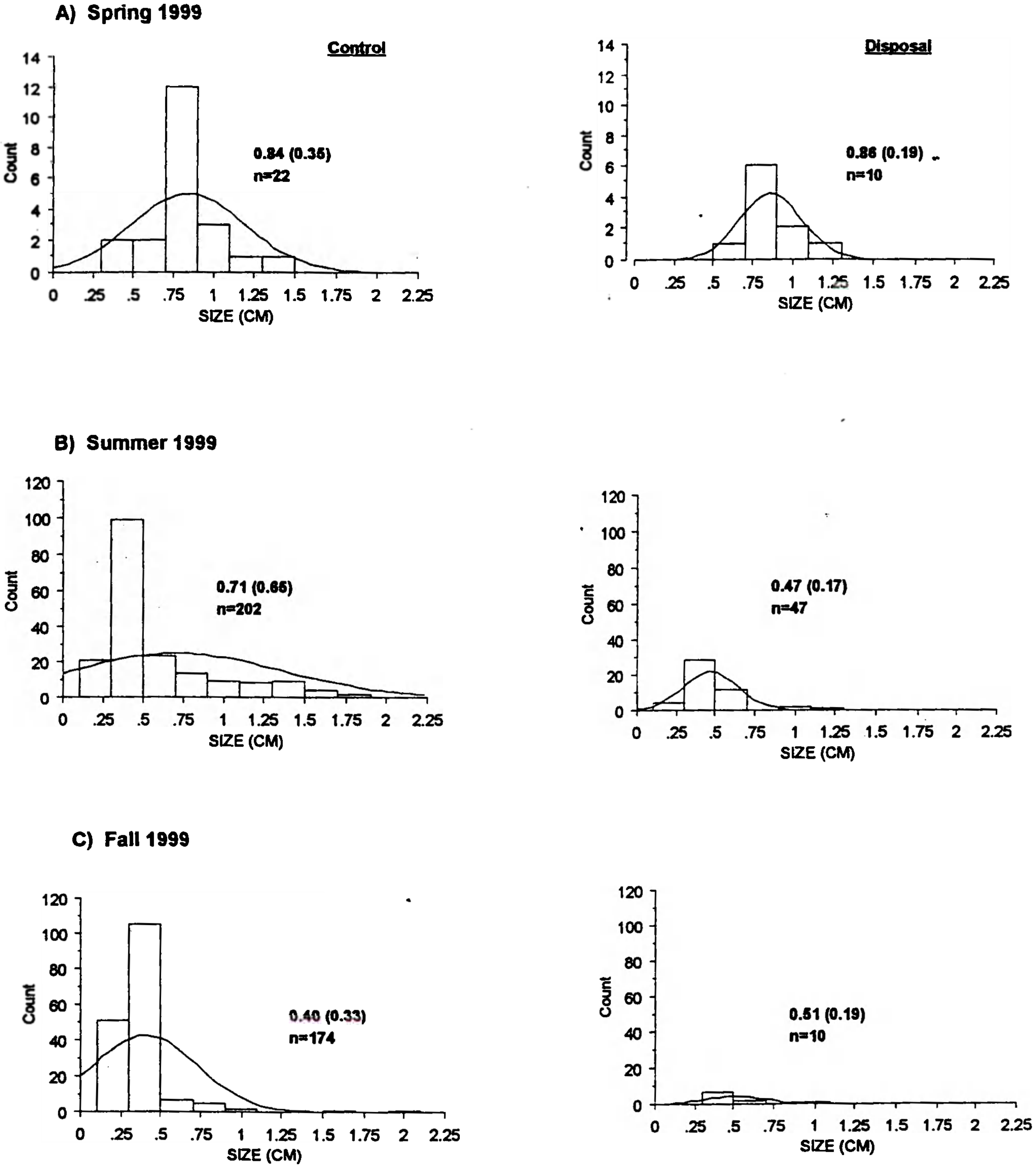




G) Fall 2000





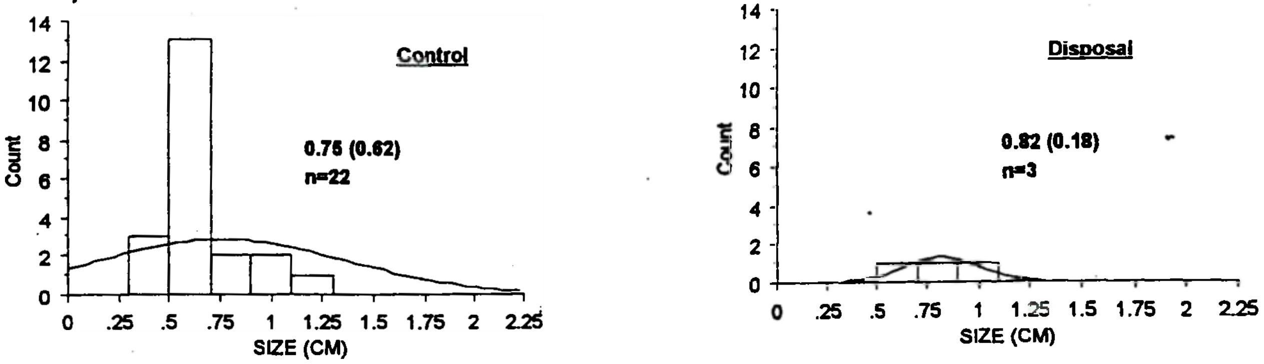

A) Spring 1999

B) Summer 1999

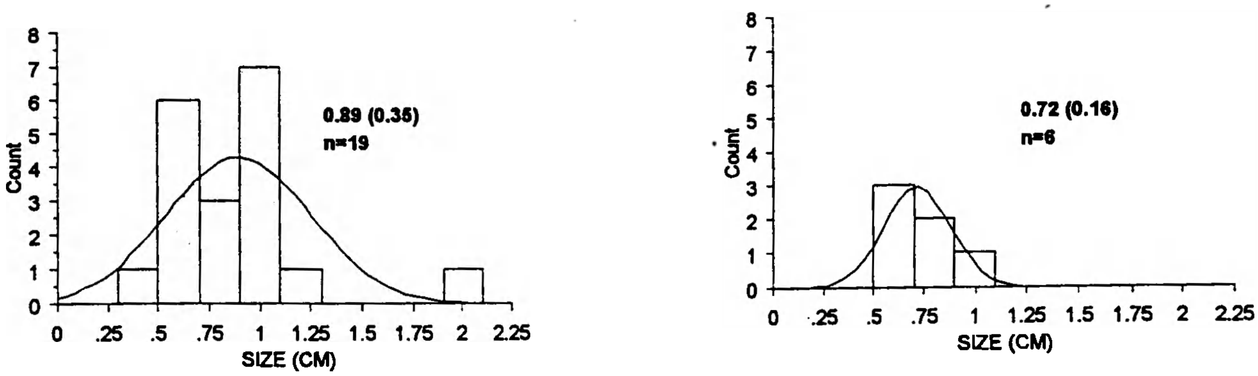
C) Fall 1999

Figure 31. Frequency distributions of Emerita talpoida size by season. Separate histograms for disposal (white) and control (gray) observations are provided for each season and year. Size represents the maximum anterior-posterior carapace length of a crab (measured to the nearest 0.01 cm). The curve in each plot represents the expected frequency curve for a normal distribution based on the mean and standard deviation of the data. Means and standard deviations are provided in each plot.

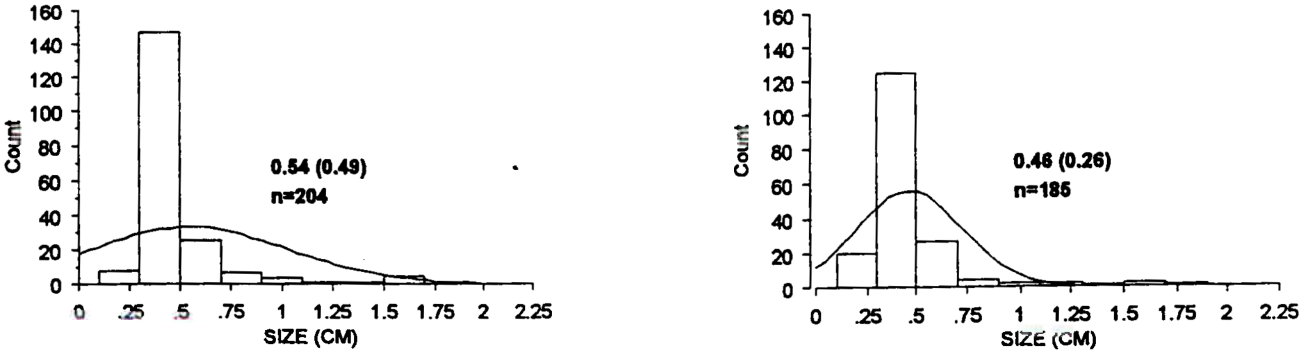
D) Winter 2000



E) Spring 2000



F) Summer 2000



G) Fall 2000

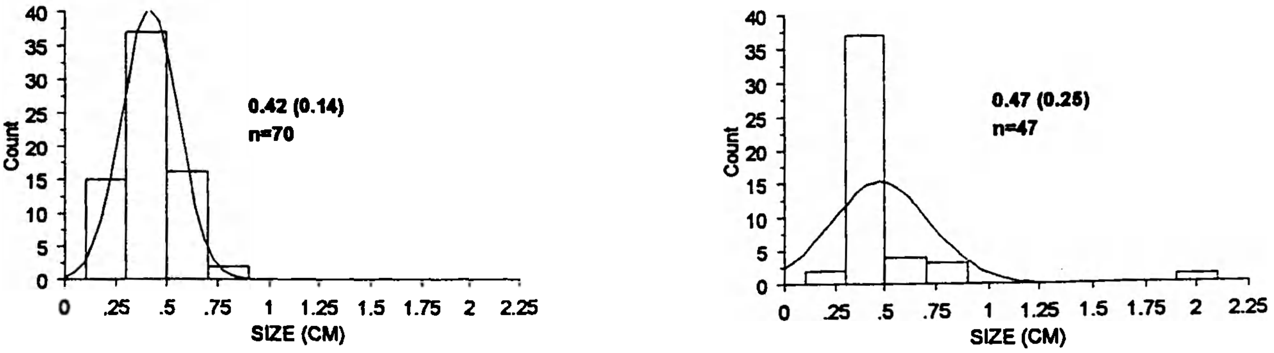


Figure 31. continued.

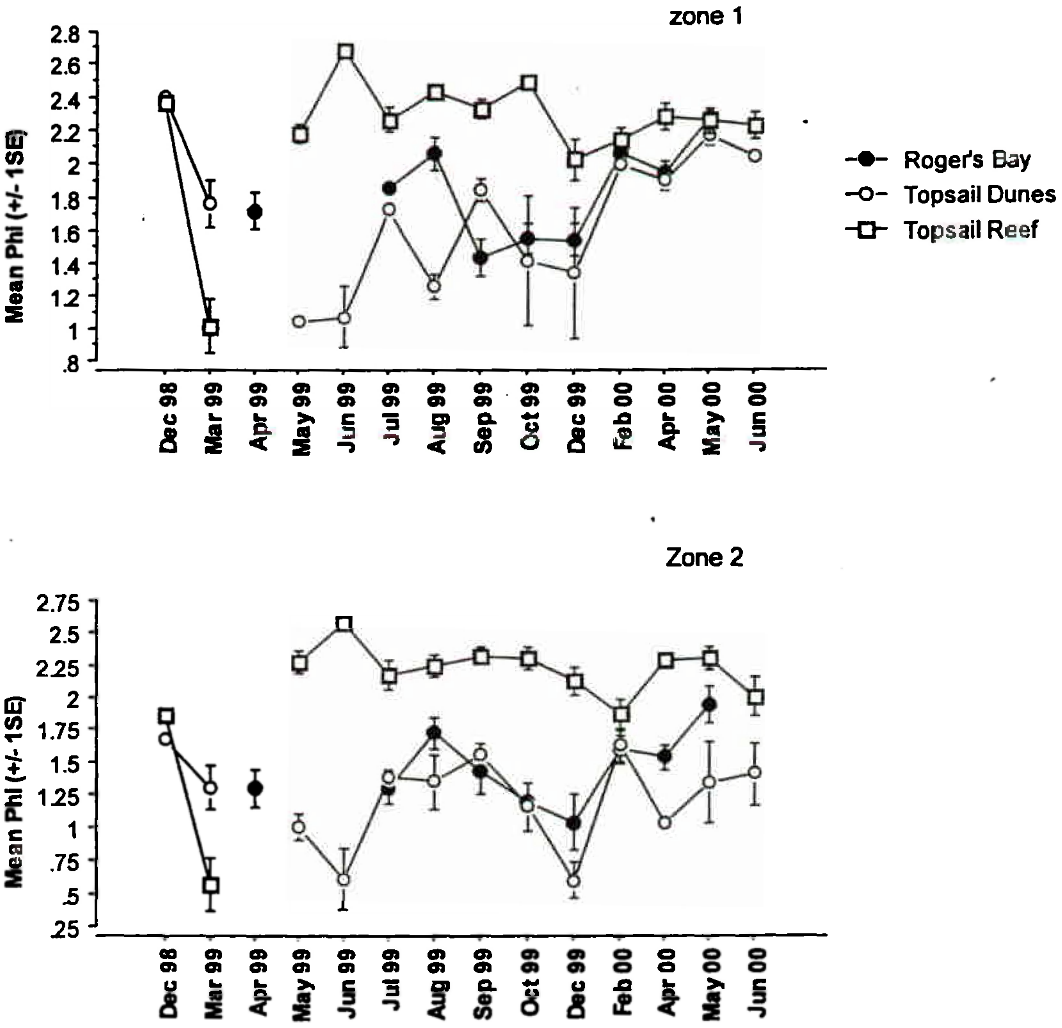
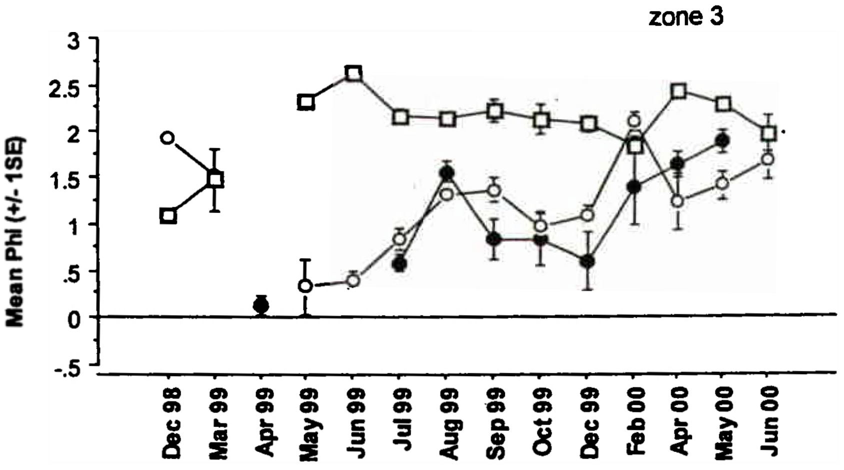
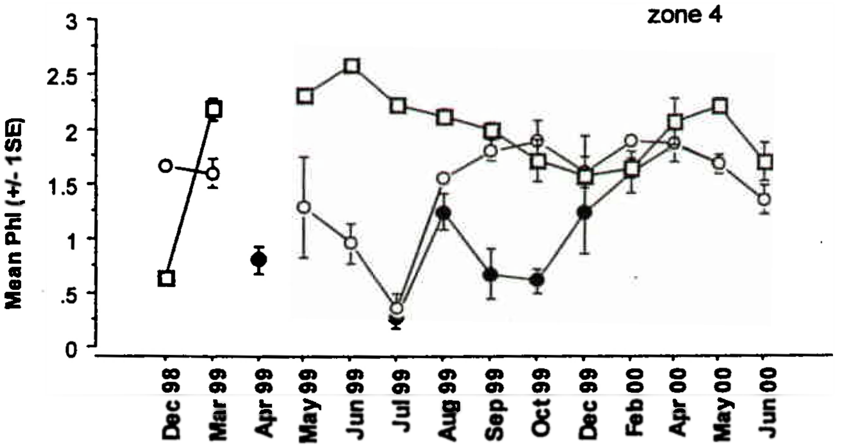
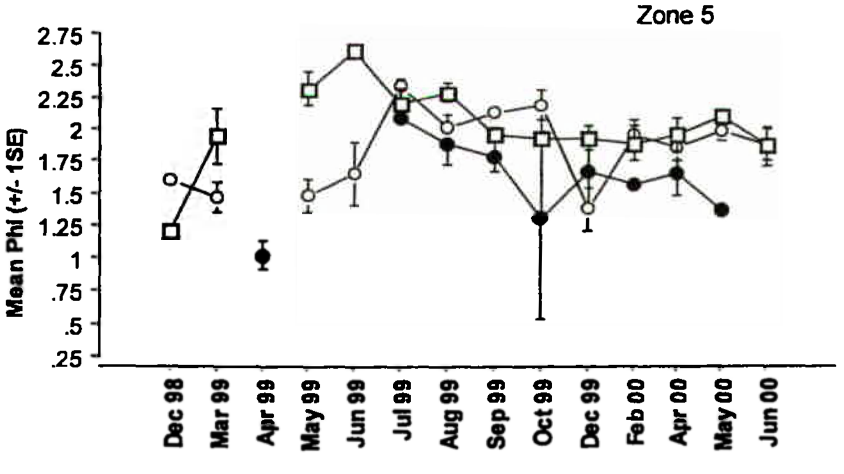


Figure 32. Mean sediment grain size (phi units) at control beaches (Roger's Bay and Topsail Dunes) and at disposal beach (Topsail Reef). Mean grain sizes are shown separately for each tidal elevation sampled: the dry, supratidal beach (zone 1), the mid-intertidal (zone 2), the low intertidal (zone 3), the swash (zone 4) and the shallow sub-tidal beach (zone 5). All sediment samples were collected during low tide and were dry-seived according to Folk (1974). (n=3).


zone 3
Mean Phi (+/- 1SE)
3
2.5
2
1.5
1
.5
0
-.5
Dec 98
Mar 99
Apr 99
May 99
Jun 99
Jul 99
Aug 99
Sep 99
Oct 99
Dec 99
Feb 00
Apr 00
May 00
Jun 00


zone 4
Mean Phi (+/- 1SE)
3
2.5
2
1.5
1
.5
0
Dec 98
Mar 99
Apr 99
May 99
Jun 99
Jul 99
Aug 99
Sep 99
Oct 99
Dec 99
Feb 00
Apr 00
May 00
Jun 00


Zone 5
Mean Phi (+/- 1SE)
2.75
2.5
2.25
2
1.75
1.5
1.25
1
.75
.5
.25
Dec 98
Mar 99
Apr 99
May 99
Jun 99
Jul 99
Aug 99
Sep 99
Oct 99
Dec 99
Feb 00
Apr 00
May 00
Jun 00

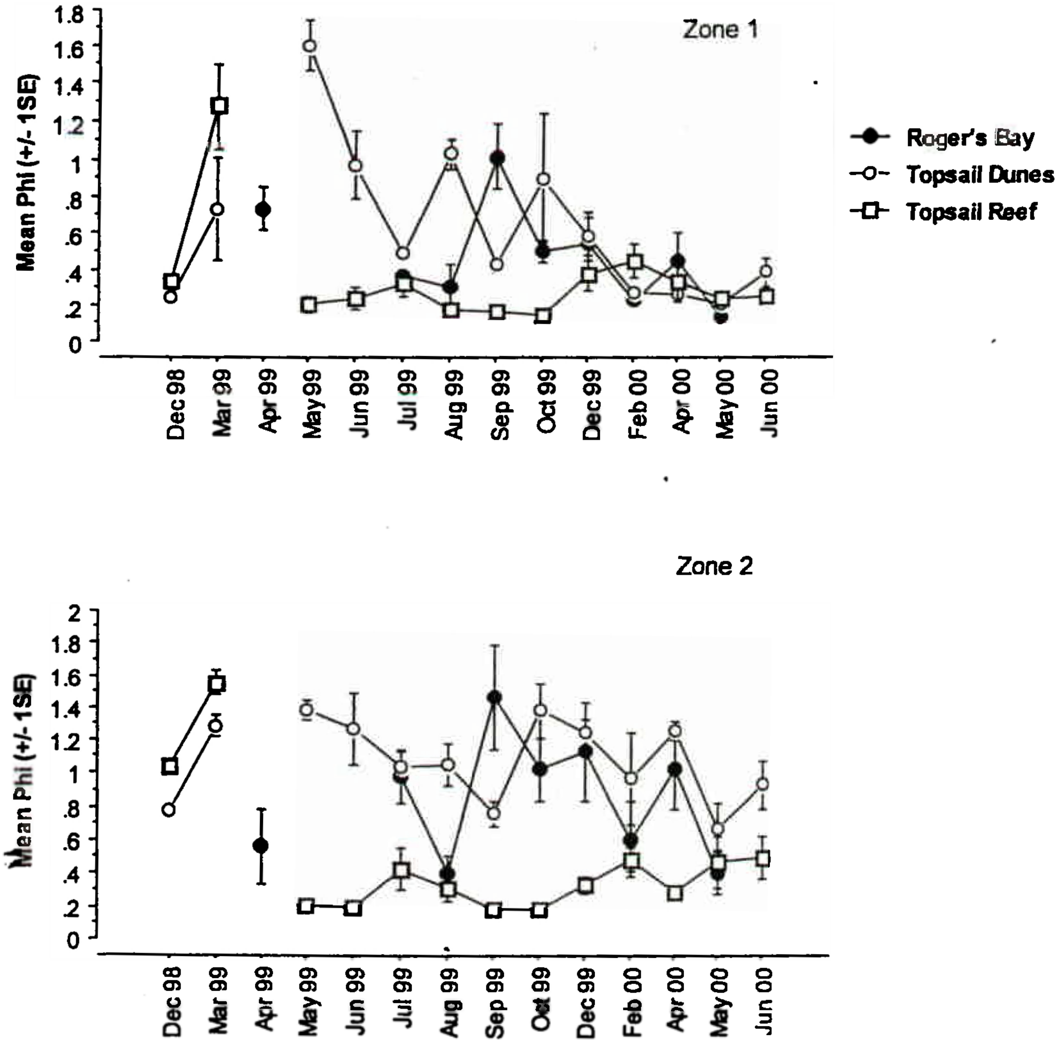
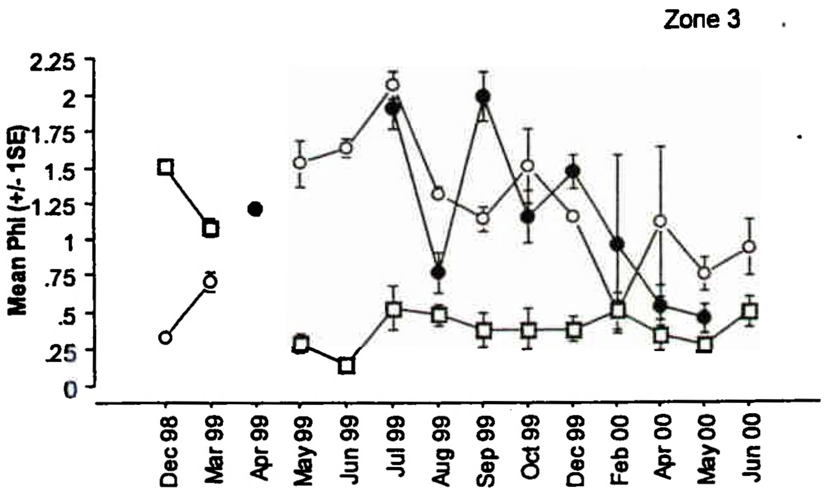
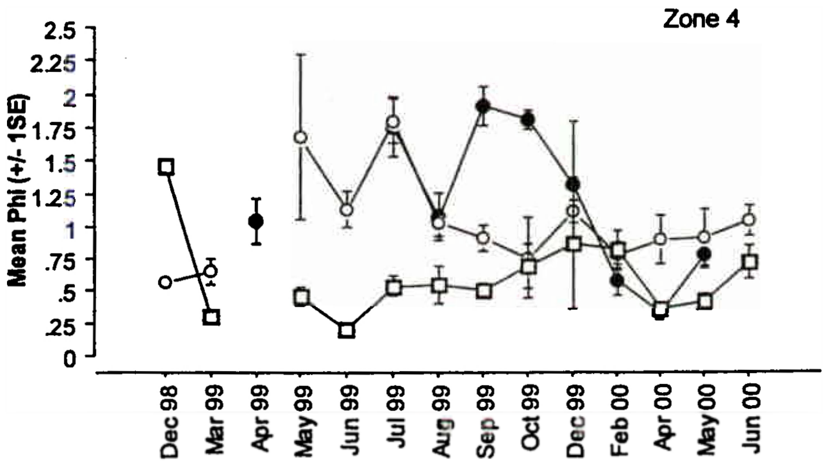
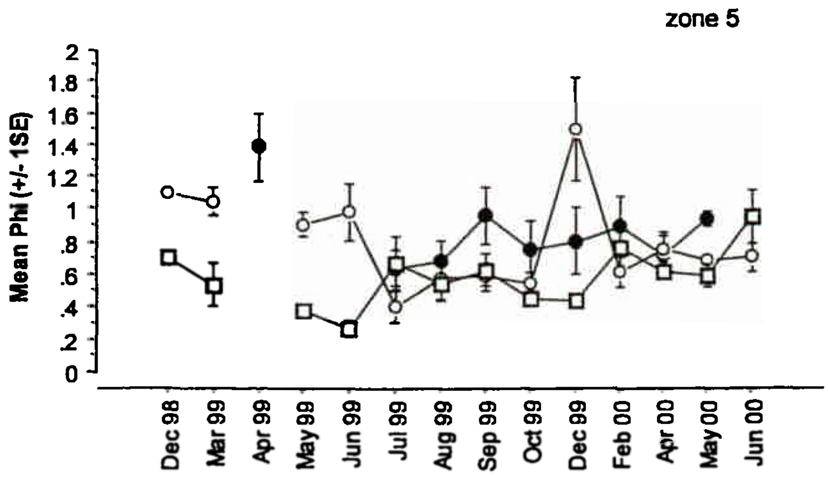


Figure 33. Mean sorting values (in phi units) for control beaches (Topsail Dunes and Roger's Bay) and disposal beach (Topsail Reef) over time (n=3). Sorting values are reported for each tidal elevation sampled: the dry, supratidal beach (zone 1), the mid-intertidal (zone 2), and low intertidal (zone 3), the swash (zone 4) and the shallow sub-tidal (zone 5). All sediments were collected during low tide.


Zone 3
Mean Phi (+/- 1SE)
2.25
2
1.75
1.5
1.25
1
.75
.5
.25
0
Dec 98
Mar 99
Apr 99
May 99
Jun 99
Jul 99
Aug 99
Sep 99
Oct 99
Dec 99
Feb 00
Apr 00
May 00
Jun 00


Zone 4
Mean Phi (+/- 1SE)
2.5
2.25
2
1.75
1.5
1.25
1
.75
.5
.25
0
Dec 98
Mar 99
Apr 99
May 99
Jun 99
Jul 99
Aug 99
Sep 99
Oct 99
Dec 99
Feb 00
Apr 00
May 00
Jun 00


zone 5
Mean Phi (+/- 1SE)
2
1.8
1.6
1.4
1.2
1
.8
.6
.4
.2
0
Dec 98
Mar 99
Apr 99
May 99
Jun 99
Jul 99
Aug 99
Sep 99
Oct 99
Dec 99
Feb 00
Apr 00
May 00
Jun 00

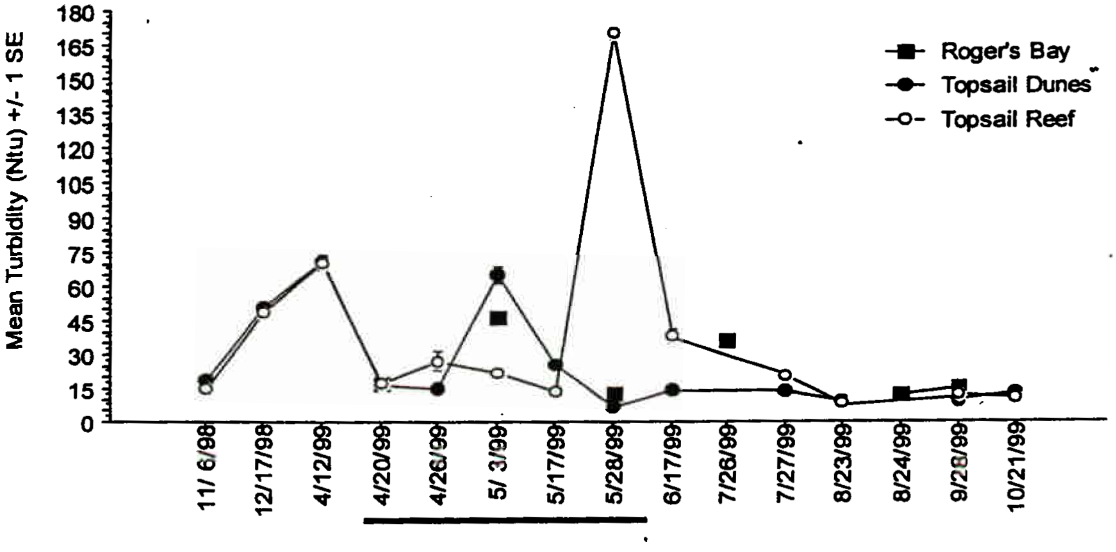


Figure 34. Mean turbidity at diposal and control areas before and after disposal activity in Spring 1999. Mean turbidity was calculated from six replicate water samples collected from the surf zone (1 m deep) except on 11/6/98 and 12/17/98 when only three replicates were collected. Bar below the x-axis indicates the time period of the disposal operation (during which time active pumping was intermittent).

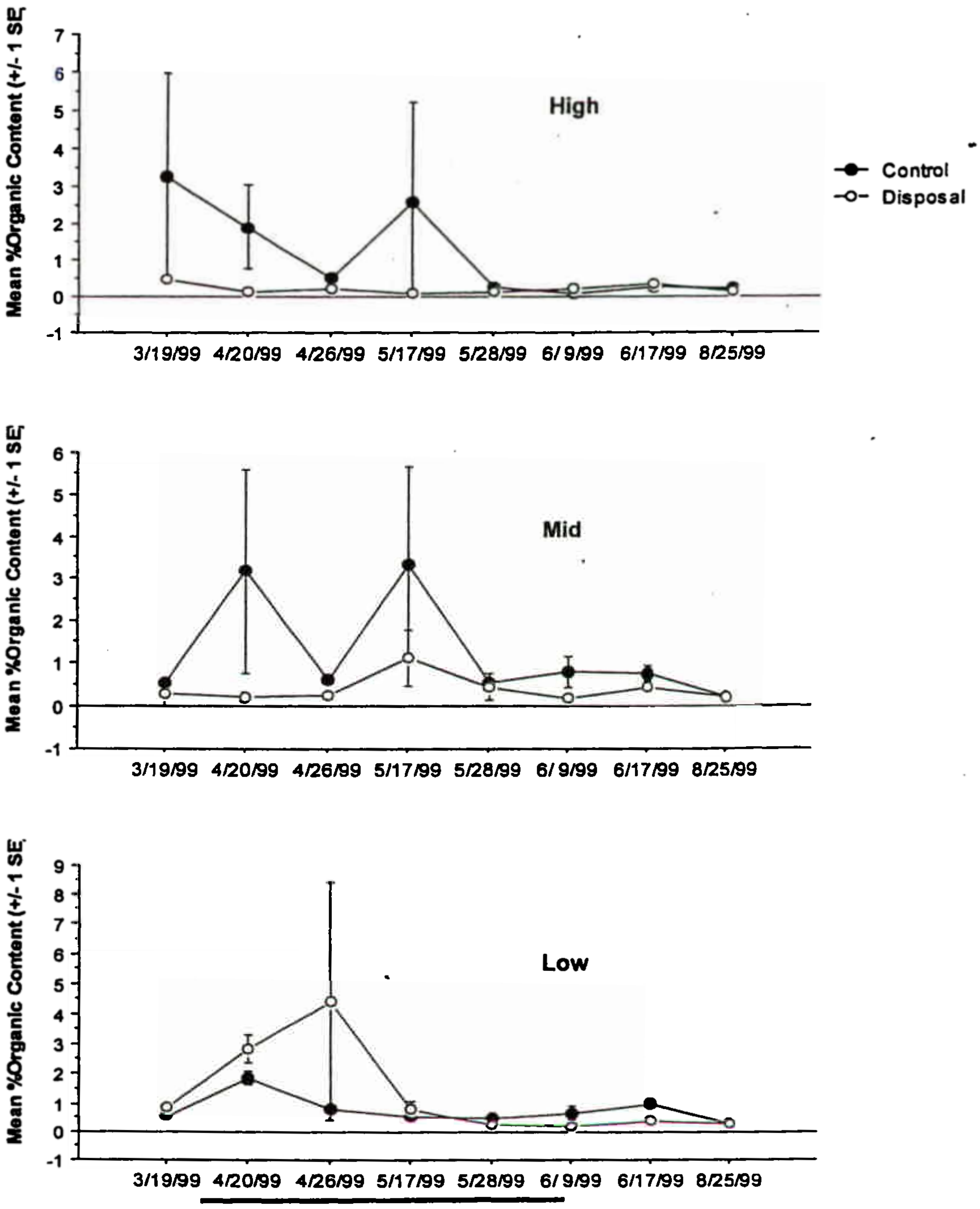


Figure 35. Organic content of sediments collected at control and disposal locations before and after beach disposal in 1999. Samples were collected at each of three tidal elevations. 'High' samples were collected just seaward of the dune toe, 'Mid' samples collected from the mid-intertidal beach (at low tide), 'Low' samples were collected from the swash zone (n=3). Bar below the x-axis indicates time period of the disposal operation.

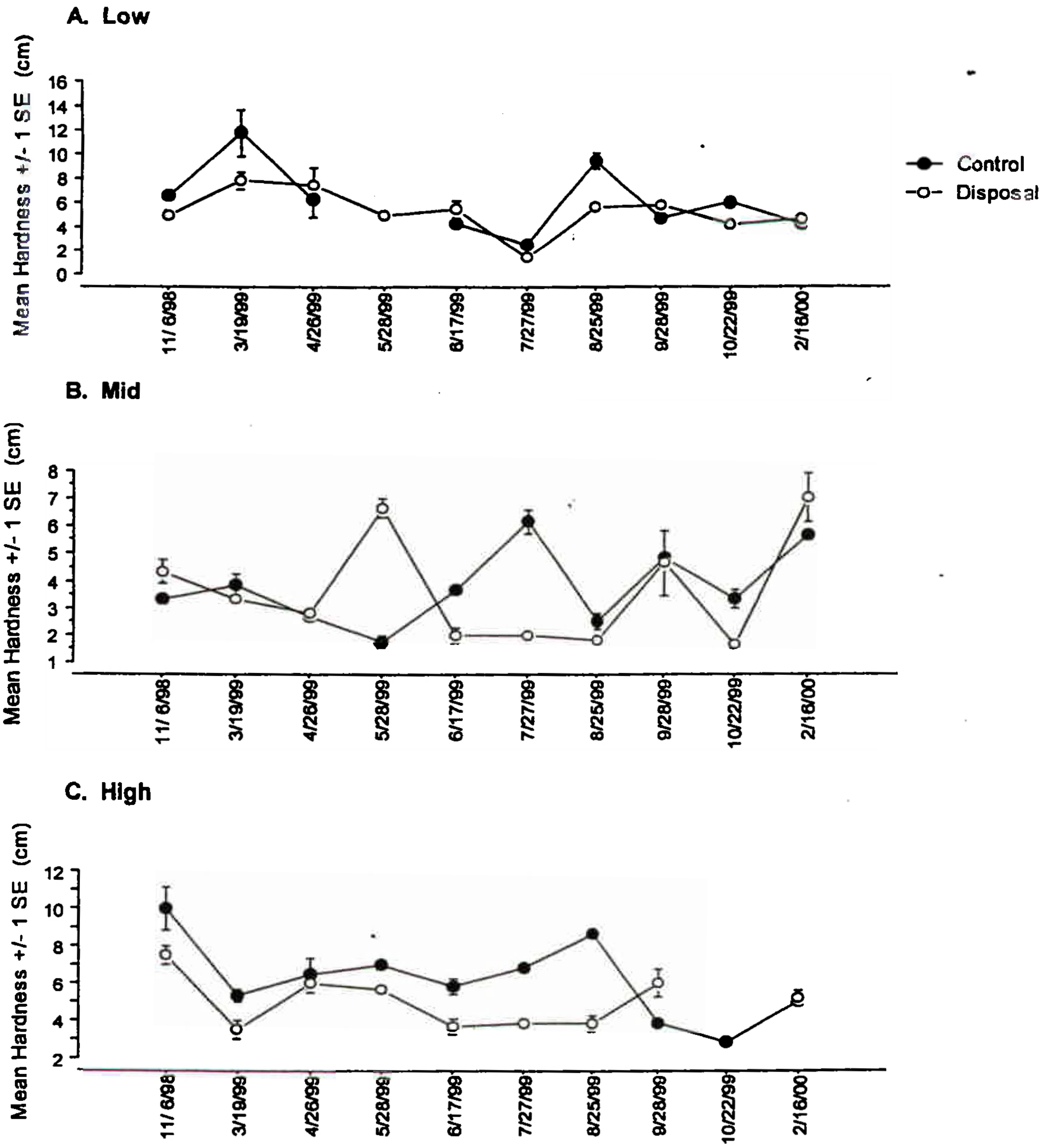
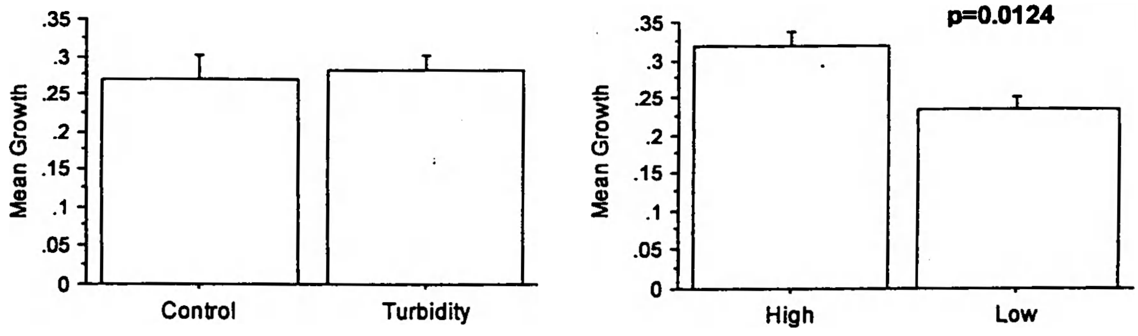
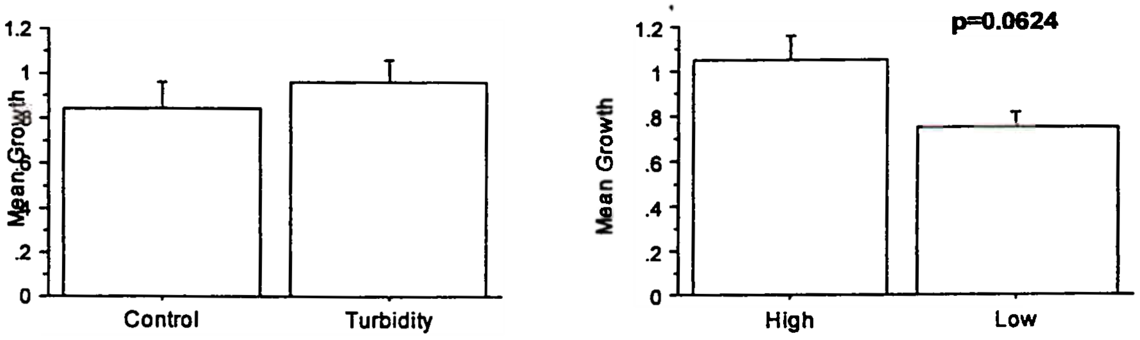


Figure 36. Mean beach hardness at control (Topsail Dunes) and disposal (Topsail Reef) beaches as measured by a penetrometer. Greater distances (cm) measured with the penetrometer indicate a softer, more penetrable beach surface. Means calculated from three replicate measurements at each tidal elevation (high, mid and low). The high tidal elevation was defined as the supratidal, dry sand; mid tide as the saturated zone during low tide; low tide as the nearshore edge of the swash zone.
Missing data points occur on dates when the penetrometer failed to work properly.

A) Proportional Length Change



B) Proportional Weight Change



C) Condition Index

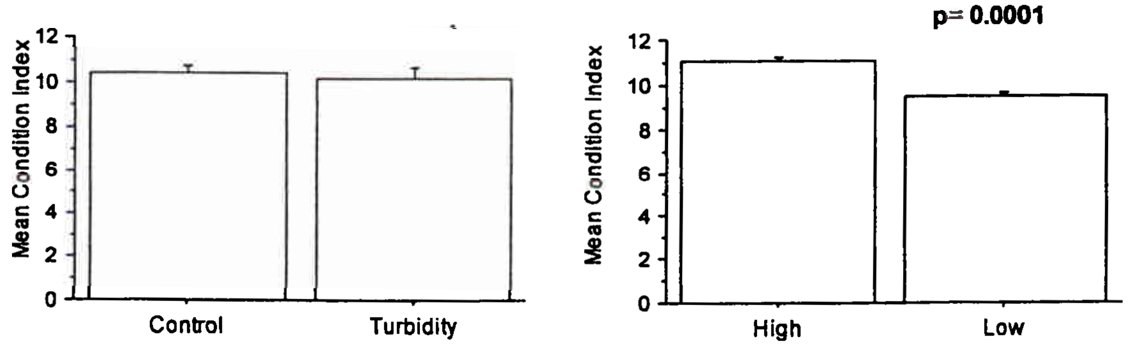
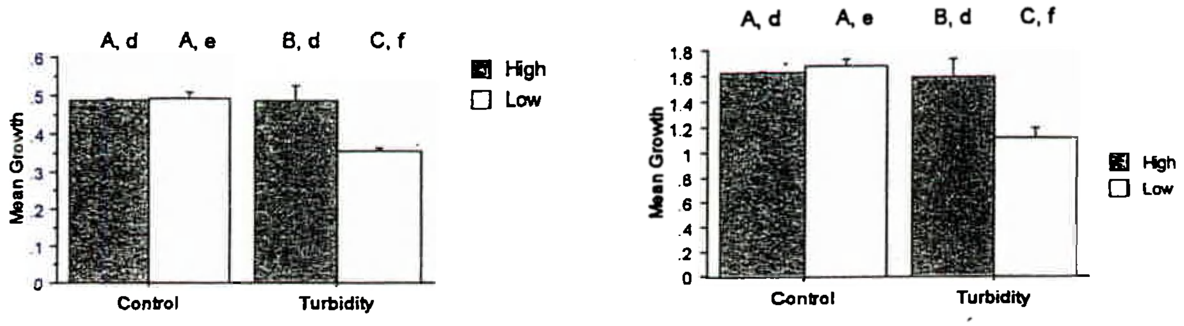
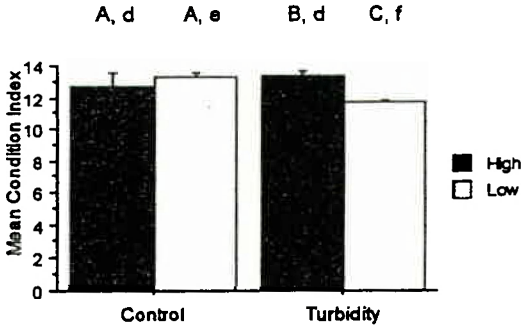


Figure 37. Bar plots illustrating results of two-way ANOVAs testing the effects of density (high vs. low) and turbidity (control vs. turbidity) on A) proportional length change, B) proportional weight change and C) condition index of *Donax variabilis*. Significant effects are labeled with corresponding p-values. ANOVA results are given in Table 13.



A) Length (p=0.0032)

B) Weight (p=0.0060)



C) Condition Index (p=0.0746)

Figure 38. Interaction plots for 2-way ANOVAs testing the effects of clam density (high, low) and turbidity conditions (control, turbidity) on A) proportional length change, B) proportional weight change and C) condition index of *Donax variabilis*. Corresponding p-values are given for each interaction, and ANOVA results are presented in Table 14. Results of post-hoc tests (Scheffe's, 1953) are indicated by letters in each plot. Capital letters refer to results of post-hoc comparison of high and low density treatments within the main effects control and turbidity. Where letters differ, a significant difference was found. Lower-case letters refer to post-hoc comparisons of control and turbidity treatments within each of the main effects high and low density.

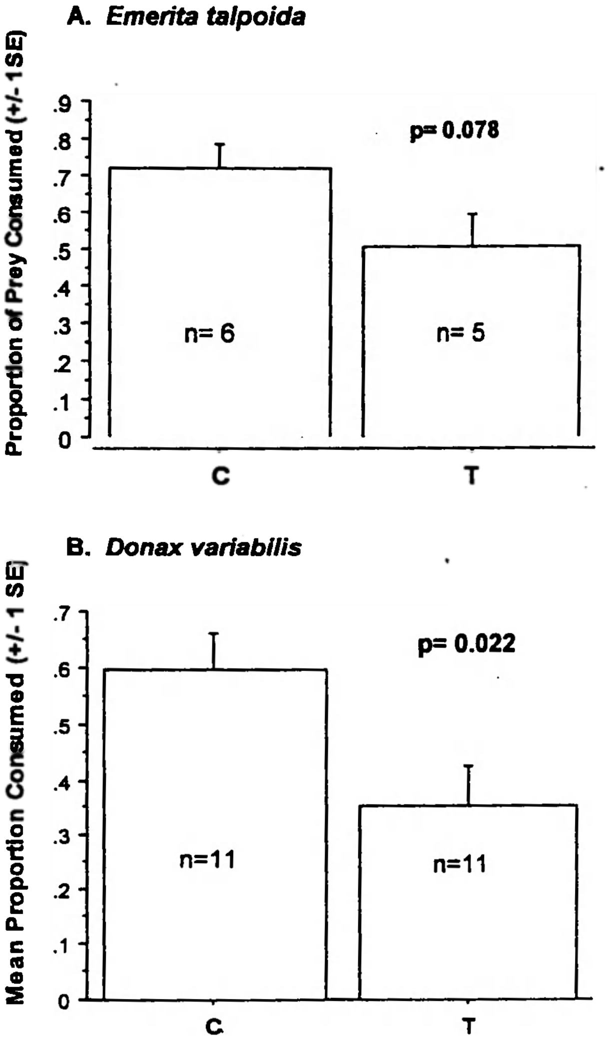


Figure 39. Proportion of mole crabs and coquina clams consumed by pompano in (separate) experiments designed to test the effect of turbidity on the ability of a visually foraging predator to capture prey. Bar plots show ANOVA results for the main effect of turbidity (T) vs. control (C) conditions. Corresponding ANOVA tables are presented in Table 15.

Appendix I. Results of surveying piers along Bogue Banks. Interviews with fishermen were conducted by a single observer in July, August, September and October, 1998 at early morning. In May and June survey forms were completed by fishermen on a volunteer basis. Monthly total catches were calculated for each pier as well as catch rates (i.e total # caught/ total # hours fished).

PIER	DATE	HOURS FISHED	TOTAL # CAUGHT	TOTAL # TAKEN	SPOT	PINFISH	BLUE-FISH	FLOUNDER	KING-FISH	SPANISH-MACKEREL	KING-MACKEREL	FL POMPANO	SHEEPS-HEAD	BLACKTIPSHARK	SANDPERCH	COBIA	HOGFISH	LIZARD-FISH	GRASS BASS	SEA BASS	BLACK DRUM	BLOWFISH	JACK	CROAKER	SPADEFISH
Bogue Inlet	05/21/1998	11	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	05/21/1998	7	17	17	3	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0
Bogue Inlet	05/23/1998	14.5	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Bogue Inlet	05/26/1998	5.5	6	6	0	0	5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	05/26/1998	11	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Bogue Inlet	05/27/1998	2.5	13	13	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	05/27/1998	9.5	5	5	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	05/27/1998	2	6	6	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	05/29/1998	4	10	10	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	05/29/1998	4	9	9	1	2	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0	0	0	0	0
totals		71	69		1	2	40			1		2			3	2	10								
rate		0.97			0.007	0.062	0.56			0.01		0.028			0.004	0.003	0.141								
Bogue Inlet	06/01/1998	12	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/01/1998	14	18	18	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/03/1998	14	21	21	0	0	17	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/03/1998	11	7	7	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/03/1998	12	7	6	0	0	6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/04/1998	13	6	6	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/04/1998	15	2	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/09/1998	12.5	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/09/1998	11.5	8	8	0	0	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/17/1998	9	38	38	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/18/1998	9	3	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/30/1998	9	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/30/1998	9	25	25	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	06/30/1998	6	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		150	124		55	0	62			6				1											
rate		0.827			0.367	0	0.413			0.04				0.0067											
Bogue Inlet	07/29/1998	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	07/29/1998	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	07/29/1998	2	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	07/29/1998	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	07/29/1998	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	07/29/1998	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	07/29/1998	4	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		22	5		0	2	0	1	1	1															
rate		0.227			0	0.090	0	0.045	0.045	0.045		0													
Bogue Inlet	08/05/1998	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	0.5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	1	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	0.5	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	0.1	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	0.5	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	0.5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	1.5	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	1.5	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	0.5	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	1.25	3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	1.5	4	4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	2.25	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	08/05/1998	0.25	3	2	0	2	0	1	0	0	0	0	1	0	0	0	0	2	1	1	0	0	0	0	0
totals		17.1	24		2	10	4	1					1					2	1	1					
rate		1.4			0.117	0.585	0.233	0.058					0.058					0.117	0.058	0.058					
Bogue Inlet	09/01/1998	1	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	09/01/1998	1	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	09/01/1998	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	09/01/1998	2.25	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	09/01/1998	1.75	6	3	3	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	09/01/1998	4.5	5	5	0	0	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	09/01/1998	2	2	2	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	09/01/1998	1.5	4	2	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
totals		13	24		13	4	3	1		2			2												
rate		1.85			1	0.308	0.231	0.080		0.154			0.154												
Bogue Inlet	10/15/1998	3	12	12	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	10/15/1998	1	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	10/15/1998	2.75	7	7	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	10/15/1998	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	10/15/1998	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	10/15/1998	3.75	3	3	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	10/15/1998	1.75	4	4	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	10/15/1998	5	7	3	0	0	4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	10/15/1998	5	7	7	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bogue Inlet	10/15/1998	2	4	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		26.5	46		22	12	5	2	5																
rate		1.74			0.83	0.453	0.189	0.075	0.189																
Sportsman	08/20/1998	2	4	3	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PIER	DATE	HOURS FISHED	TOTAL # CAUGHT	TOTAL # TAKEN	SPOT	PINFISH	BLUE	FLOUNDER	KING	SPANISH	KINGMACK	POMP	SHEEP	BLACKTIPSHARK	SANDPERCH	COBIA	HOGFISH	LIZARD	GRASS BASS	SEA BASS	BLACKDRUM	BLOWFISH	JACK	CROAKER	SPADEFISH
Sportsman	07/30/1998	1.5	5	4	0	0	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	0.75	5	5	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	1	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	1.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	2	2	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	2	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	3.5	5	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		17.5	21		5	2	12			2															
rate		1.2			0.286	0.114	0.686			0.114															

PIER	DATE	HOURS FISHED	TOTAL # CAUGHT	TOTAL # TAKEN	SPOT	PINFISH	BLUE	FLOUNDER	KING	SPANISH	KINGMACK	POMP	SHEEP	BLACKTIPSHARK	SANDPERCH	COBIA	HOGFISH	LIZARD	GRASS SHAD	SEA BASS	BLACKDRUM	BLOWFISH	JACK	CROAKER	SPADEFISH
Sportsman	07/30/1998	1.5	6	5	0	0	4	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	5.75	9	9	4	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	1	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	1.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	2	2	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	2	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	07/30/1998	2.5	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		17.5	21		5	2	12			2															
rate		1.2			0.286	0.114	0.686			0.114															
Sportsman	08/05/1998	2	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	3	10	9	3	5	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	1	4	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	3.25	8	7	2	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	2.5	6	5	3	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	2.5	4	3	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	1.75	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	0.5	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	0.5	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	0.75	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/05/1998	0.75	3	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		19.5	44		12	20	5	6	1																
rate		2.26			0.615	1.03	0.256	0.308	0.051																
Sportsman	08/01/1998	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/01/1998	1	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/01/1998	1	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/01/1998	2.5	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	08/01/1998	2.5	2	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		8	8		1	5	1					1													
rate		1			0.125	0.625	0.125					0.125													
Sportsman	10/15/1998	3	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	10/15/1998	2.5	35	25	32	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	10/15/1998	2.5	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	10/15/1998	4	6	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sportsman	10/15/1998	4	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		16	46		40			1		2		3													
rate		2.875			2.5			0.062		0.125		0.188													
Oceana	08/10/1998	3	3	3	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Oceana	07/30/1998	0.75	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	07/30/1998	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	07/30/1998	4	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	07/30/1998	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	07/30/1998	4	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		13.75	3		1	1	1																		
rate		0.218			0.073	0.073	0.073																		
Oceana	08/05/1998	4.5	9	8	3	4	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	3	5	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	2.5	5	4	1	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	3	4	4	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	2.5	11	0	3	4	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	2.5	8	7	3	2	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	4.25	3	2	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	4.5	7	6	0	0	4	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	3.5	7	6	2	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	3.5	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	1.25	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	3	5	5	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	0.5	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	08/05/1998	0.5	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		42.75	72		23	26	6	10		1	3	3													
rate		1.68			0.538	0.608	0.14	0.234		0.023	0.07	0.07													
Oceana	09/29/1998	1.25	5	4	2	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Oceana	09/29/1998	2.5	6	3	2	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	09/29/1998	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	09/29/1998	1.5	3	3	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	09/29/1998	3.5	12	6	2	5	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	09/29/1998	2.75	7	5	2	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		12.5	33		8	16	2	5					1					1							
rate		2.64			0.64	1.28	0.16	0.4					0.08					0.08							
Oceana	10/13/1998	1.75	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Oceana	10/13/1998	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	10/13/1998	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Oceana	10/13/1998	2.5	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Oceana	10/13/1998	2	2	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oceana	10/13/1998	2.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		11.5	8			1						2											3		1	1
rate		0.696				0.087						0.174											0.261		0.087	0.087

PIER	DATE	HOURS FISHED	TOTAL # CAUGHT	TOTAL # TAKEN	SPOT	PINFISH	BLUE	FLOUNDER	KING	SPANISH	KINGBACK	POMP	SHEEP	BLACKTIPSHARK	SANDPERCH	COBIA	HOGFISH	LIZARD	GRASS SHAD	SEA BASS	BLACKDRUM	BLOWFISH	JACK	CROAKER	SPADEFISH
Triple S	05/18/1998	2.5	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	06/09/1998	14	2	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	06/13/1998	3.5	3	2	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	06/13/1998	5.5	4	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Triple S	06/24/1998	2.5	4	4	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	06/25/1998	3	6	6	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	06/28/1998	8.5	4	4	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		37	23	21	1		4	1	1	15							1								
rate		0.622			0.027		0.108	0.027	0.027	0.405							0.027								
Triple S	07/30/1998	0.5	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	07/30/1998	0.5	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		1	3	2	2		1																		
rate		1.12			0.123		0.067																		
Triple S	08/01/1998	1.5	3	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/01/1998	0.5	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/01/1998	1	4	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/01/1998	1.5	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/05/1998	1.75	3	2	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/05/1998	2	11	11	6	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/05/1998	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/05/1998	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/05/1998	1.5	4	4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Triple S	08/05/1998	5	7	4	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Triple S	08/05/1998	4	7	5	2	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		20	44		12	15	9	3		1			1							3					
rate		2.2			0.6	0.75	0.45	0.15		0.05			0.05							0.15					
Triple S	08/03/1998	2.5	5	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/03/1998	0.5	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/03/1998	0.75	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/03/1998	1.75	5	4	1	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	08/03/1998	1	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
totals		6.5	16		6	8		1											1						
rate		2.46			0.923	1.23		0.154											0.154						
Triple S	10/13/1998	1	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Triple S	10/13/1998	1.5	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	10/13/1998	3	2	2	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	10/13/1998	4	20	20	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	10/13/1998	2	13	13	8	0	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	10/13/1998	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Triple S	10/13/1998	3	3	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	10/13/1998	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	10/13/1998	3	5	5	2	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Triple S	10/13/1998	3	4	4	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		22.5	52		13	1	3	1		20		11						1					1		
rate		2.31			0.578	0.044	0.133	0.044		0.889		0.489						0.044					0.044		
IronSteame	07/30/1998	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	07/30/1998	2.25	10	0	0	6	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	07/30/1998	2	17	17	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
IronSteame	07/30/1998	2	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	07/30/1998	1.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	07/30/1998	2.5	6	2	0	4	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	07/30/1998	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	07/30/1998	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	07/30/1998	3.5	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	07/30/1998	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	07/30/1998	2	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		23.25	38			29	1			1		6										1			
rate		1.63				1.25	0.043			0.043		0.258										0.043			
IronSteame	08/06/1998	3.25	5	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
IronSteame	08/06/1998	2.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	08/06/1998	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	08/06/1998	1.5	25	25	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	08/05/1998	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	08/06/1998	0.5	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	08/06/1998	2.75	4	2	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	08/06/1998	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	08/06/1998	0.5	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IronSteame	08/06/1998	2	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
totals		17.75	39		29	2		6									1			1					
rate		2.2			1.63	0.113		0.338									0.056			0.056					