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Beach restoration with offshore dredged sand: effects on nearshore macroinfauna

Carl H. Saloman

and

Steven P. Naughton

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U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
John V. Byrne, Administrator
NATIONAL MARINE FISHERIES SERVICE
William G. Gordon, Assistant Administrator for Fisheries

ABSTRACT

The effects of depositing dredged material from offshore on benthic macroinvertebrates inhabiting the swash zone and the first sandbar at Panama City Beach, Florida, are discussed. The dredged material was similar to existing beach material at most sites. The turbidity was relatively low, except near the area of deposition, because alongshore currents dispersed the turbid water.

The numbers of individuals at treated stations in the swash zone were reduced after deposition, and five to six weeks later, populations assumed levels comparable to untreated stations. No notable effects of deposition were observed on fauna inhabiting the sandbar. The significant differences in the number of species and individuals between treated and untreated stations both before and after deposition indicated that community composition, distribution, and abundance of macroinvertebrate fauna at similar stations (swash zone and sandbar) may differ naturally, even when the stations are located along the same beach.

INTRODUCTION

Hurricane Eloise passed over Panama City Beach, Florida, in September 1975, causing extensive beach erosion. Morton (1976), studying the effects of the storm, concluded that beach erosion was mainly due to storm surge, wave set-up, and beach scour. Wind and flood damages were considered minimal. The sand from the beach was transported westward. Saloman and Naughton (1977) found that the benthic fauna of the beach was minimally affected, and that the numbers of individuals were about the same after the storm as before. Numbers of species increased just after the storm, but quickly returned to previous levels.

At the request of the Federal Disaster Assistance Administration, the U.S. Army Corps of Engineers proposed a beach restoration plan to provide emergency protection for areas most vulnerable to additional wave damage. The proposal included the hydraulic dredging of offshore sand to create a 9.1 m wide berm, 1.8 m above mean sea level, at 23 selected sites. The Corps of Engineers estimated that 183,492 m^3 of sand would be required. Dredging began July 1, 1976 and was concluded August 8, 1976.

Studies on the effect of deposition of sand for beach restoration on the benthic fauna are scarce. Hayden and Dolan (1974) studied the effects of sand deposition on *Emerita talpoida* in Florida, and they concluded that the ecological impact was of short duration and involved redistribution of *E. talpoida*, rather than high mortality. Thompson (1973) concluded that no long-lasting effects can be seen from depositing offshore sediments on the beach. The objective of our study was to examine the effects of onshore dumping of hydraulically dredged offshore sand on the benthic macro-invertebrates inhabiting the swash zone and first offshore sandbar.

STUDY AREA AND STATIONS

Panama City Beach is located along the coast of northwestern Florida (Fig. 1). Houses and motels occupy most of the area on and behind the dunes. Undeveloped areas with sand dunes exist at St. Andrews State Park and at scattered points along the study areas. A sand dune backs the beach berm with elevations of 3.9 to 4.6 m above mean sea level (Wilson 1975).

The study area extended 41.7 km from the easternmost station, which was located in St. Andrews State Park (West Pass), to the westernmost station, which was located 7.4 km west of Phillips Inlet. The beach had an average width of 26 m before nourishment. Two sandbars occurred parallel to the beach, one about 15 m and another about 245 m offshore.

Twenty-three sites received dredged material from offshore (Fig. 1). Benthic sampling was conducted at three of these sites (treated stations) and at four other sites (untreated stations). Each sampling site had two stations, one in the swash zone and one on the first sandbar. The swash zone is the beach face or the sloping surface of the beach that is covered by the runup of water by waves (Russell 1969). The first sandbar is rarely exposed and then only during the lowest of low tides. The untreated sites were large beach areas backed by vegetated sand dunes. The three treated sites were narrow eroded beaches backed by concrete seawalls or large buildings, conditions typical of almost all of the sites that received dredged material.

METHODS

A stainless steel plug sampler that covered an area of 1/64 m^2 and penetrated to a depth of 23 cm was used for collecting benthic macro-invertebrates. Four plug samples were taken at each station. In a test of sampling adequacy, Saloman and Naughton (1978) determined that four plug samples in the swash zone sampled 100% of the benthic species at three different sites on Panama City Beach. During the study period (April 7 through December 6, 1976), 1,456 benthic samples were collected in 26 sampling trips. The samples were extruded into pans and seived through a stainless steel sieve with a mesh of 0.701 mm^2. The remnant portions were stained with Rose Bengal and preserved in 10% Formalin-seawater.

In the laboratory, the samples were rinsed in fresh water. The benthos were sorted into major taxa, placed in 70% isopropanol, and later identified to the lowest practical taxonomic level and enumerated.

Surface water temperature, salinity, and turbidity were recorded during each station visit. Frequency of sampling for hydrology at all stations started on a biweekly schedule, changed to weekly from April 26 through August 30, 1976, and then expanded to a biweekly and finally a monthly span. In addition, turbidity sampling only was conducted at the three treatment sites at more frequent intervals before, during, and after deposition. Four turbidity samples were taken during each site visit.

Temperature was measured with a mercury thermometer, salinity with a Goldberg refractometer[1/], and turbidity with a Hach laboratory turbidimeter, model 1860. Data were grouped into "before" and "after" deposition periods in zones (swash zone and first sandbar), and comparisons were made between treated and adjacent untreated stations using the Wilcoxon's signed rank test (Steele and Torrie 1960). The compared data consisted of the total number of individuals, the number of species, and the number of individuals of the most abundant species.

HYDROLOGY

From April through December 1976 water temperatures averaged 24.9°C and ranged from 14.0 to 30.9°C. Highest temperature occurred during August and lowest during December.

Salinities averaged 33.5‰ and ranged from 27.8 to 35.7‰. Values were slightly lower at the eastern portion of the study area because of lower salinity water issuing from St. Andrew Bay.

1/ Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Average turbidity recorded during the hydrology sampling schedule (April 7 through December 6, 1976) was 3.7 JTU and ranged from 0.6 to 32.0 JTU (Table 1). Turbidities collected at the three treated stations at more frequent intervals before and after deposition ranged as high as 86.0 JTU (Fig. 2). Turbidities increased along the beach during times of rough seas and in the vicinity of deposition. Turbidity was higher east of each deposition site, because the alongshore current was usually west to east.

The amount of turbidity was a result of the nature of the dredged material. At Station T-1, near Phillips Inlet, the deposited material was almost all clean white sand; the resulting turbidities during and immediately after deposition ranged from 1.3 to 7.7 JTU (Fig. 2). Offshore of Station T-2, the dredge encountered dark, muddy sediments with high organic content and produced the highest recorded turbidity (86.0 JTU). Turbidity at Station T-2 fell below 10 JTU 4 days after deposition, increased to 10.2 JTU 10 days after deposition, and then remained below 6.0 JTU during the remainder of the study (Table 1, Fig. 2). At Station T-3, near the eastern end of the study area, the deposited materials contained more white sand and less organic material than at Station T-2. Turbidities, however, ranged from 76.0 JTU during deposition to 8.2 JTU afterwards. A week after deposition (August 13), turbidities fell below 8 JTU (Table 1, Fig. 2).

INDIVIDUALS AND SPECIES

During the 9-month study period, 1,456 benthic samples from both the swash zone and the first sandbar contained 19,524 individuals belonging to 79 species.

Swash Zone

Forty-four species consisting of 7,879 individuals were taken from the swash zone. Three species (*Scolelepis squamata*, 62.4%; *Haustorius* sp., 16.5%; and *Emerita talpoida*, 10.6%) comprised 89.5% of the individuals (Table 2). Polychaetes were the most abundant (5,079 individuals) and amphipods the most diverse (10 species). Species represented by only one or two individuals accounted for 57% of the species and 0.4% of the individuals.

The average number of individuals per m^2 for each sampling period varied from 130 to 2,135 (Table 2). The average number of individuals per m^2 during the entire sampling period was 693. Numbers of individuals were higher during the spring and gradually decreased toward the fall. The decrease was principally due to the lower numbers of *S. squamata* and *Haustorius* sp. in the fall (Table 2).

Sandbar

Seventy species consisting of 11,645 individuals were taken from the first sandbar. Four species (*Paraonis fulgens*, 34.7%; *Haustorius* sp., 34.1%; *Donax texasianus*, 7.5%; and *S. squamata*, 5.5%) comprised 81.8% of the catch (Table 3). Polychaetes were the most numerous (5,193 individuals) and diverse (16 species). Amphipods were second with 4,293 individuals and 14 species.

Average numbers of individuals per m^2 fluctuated during the sampling period with peaks of abundance occurring during June and mid-August. The increases were principally due to larger numbers of Haustorius sp. in June and P. fulgens during mid-August (Table 3). The average number of individuals per m^2 for each sampling period varied from 427 to 1,829 (Table 3). The average number of individuals per m^2 during the entire sampling period was 1,024 individuals.

EFFECTS OF DEPOSITION

The effects of depositing offshore sand upon the beach on the abundance and species composition of benthic organisms of the swash and sand bar zones were evaluated. Within each zone, the number of individuals, number of species, and total numbers of the most abundant species at treated areas were compared with untreated areas, both before and after deposition.

Swash Zone

In the pre-deposition period, one comparison out of six was statistically significant when the numbers of individuals at treated and untreated stations were compared. Numbers of individuals were more abundant at Station UT-1 than at Station T-1 on 10 of 11 sampling dates (Fig. 3).

After deposition, total numbers of individuals were generally lower at the treated stations for 5 to 6 weeks, but thereafter, the numbers were similar among treated and untreated stations. The only observed significant difference was between Stations T-2 and UT-3. Numbers of individuals at Station T-2 were lower than at Station UT-3 on 11 of 12 sampling dates (Fig. 3).

Before deposition the number of species and individuals at treated and untreated stations indicated a similar trend. In 8 of 41 comparisons, the numbers of individuals were higher at the treated stations. In 10 of 41 comparisons, the numbers of species were higher at the treated station. Before deposition, only one significant difference in numbers of species between stations was observed; the number of species at Station T-3 was greater than at Station UT-4 (Fig. 3).

After deposition, similar trends in comparisons of number of species and number of individuals were also evident. Comparisons of treated and untreated stations indicated that in 7 or 37 comparisons, the numbers of individuals and species were higher at the treated stations. After deposition, the numbers of species at Station T-1 were significantly greater than at Station UT-2 but, conversely, the numbers at Station UT-3 were significantly greater than at Station T-2 (Fig. 3).

To examine further the effects of beach restoration on the benthic fauna of the swash zone, the abundances of the three most prevalent species (S. squamata, Haustorius sp., and E. talpoida) were studied. The effect of deposition was different among the three species. Tests indicated that deposition of sand had an effect on the abundance of S. squamata as four of the six post-deposition comparisons were significantly different. In the four comparisons, numbers of S. squamata were higher at untreated stations than at treated stations (Fig. 4). In one of the four comparisons, a significant difference was present during both before and after deposition periods, because numbers of individuals at Station UT-1 were higher or equal to numbers of individuals at Station T-1 on 25 of 26 sampling dates (Fig. 4). The differences in the numbers of S. squamata in this instance are not attributed to deposition, because the differences in numbers of S. squamata between Station UT-1 and Station T-1 were present throughout the study period.

Haustorius sp. was also affected by deposition. Before deposition, no significant differences were found in the number of individuals when the treated and untreated stations were compared. In the post deposition period, two of six comparisons showed significant differences (Table 4). In both comparisons, the numbers of individuals were higher at the untreated stations.

Deposition of sand apparently had no effect on E. talpoida, because significant differences in the number of individuals before and after dredging were not observed (Table 4).

Sandbar

Before deposition, two comparisons out of six showed significant differences when the numbers of individuals at treated and untreated stations were compared. In both comparisons, numbers of individuals were more abundant at the treated stations than at the untreated stations (Fig. 5). After deposition, only one difference was statistically significant. The number of individuals at Station T-4 was the same or more abundant that at Station UT-5 on 12 of 15 sampling dates. During August 16-23, a distinct increase in the number of individuals occurred at the treated stations (Fig. 5). This was due mainly to increases of P. fulgens.

Before deposition, only one significant difference in the number of species between treated and untreated stations was observed. The number of species at Station T-6 was significantly greater than at Station UT-8 (Fig. 5). After deposition, significant differences were not found between treated and untreated stations.

The most abundant species on the first sandbar were P. fulgens, Haustorius sp., and D. texasianus (Table 3).

Before deposition two significant differences were found between stations for P. fulgens. Numbers of individuals were higher at Station T-4 than at Station UT-5 on 8 of 11 sampling dates. Conversely, the numbers of individuals were higher or the same at Station UT-6 than at Station T-5 on all sampling dates (Fig. 6).

After deposition, only one comparison was significantly different. The number of individuals of P. fulgens was higher or the same at Station T-4 than at Station UT-5 on 13 of 15 sampling dates (Fig. 6).

Before deposition, four differences were significant when the numbers of individuals of Haustorius sp. at treated and untreated stations were compared. At three of these (T-5 vs. UT-6, T-5 vs. UT-7, and T-6 vs. UT-8), the number of individuals was more abundant at the treated station than at the untreated station (Fig. 7).

Tests indicated that deposition probably had no effect on Haustorius sp. In the one comparison that was significantly different (Station T-6 vs. Station UT-8), the number of individuals was higher at Station T-6 than at Station UT-8 on 7 of 10 sampling dates (Fig. 7). A significant difference was also present before deposition, as the number of individuals was higher at Station T-6 than at Station UT-8 on 12 of 16 sampling dates (Fig. 7).

Before deposition there were three significant differences concerning D. texasianus and zero significant differences after deposition (Table 5). In all these comparisons, numbers of individuals were higher at the treated stations than at the untreated stations. After deposition, the number of individuals in one of the three comparisons (UT-6 vs. T-4) was higher at the untreated station.

CONCLUSIONS

Depositing offshore sand on Panama City Beach had minor, short-term effects on the benthic macroinvertebrates. In the swash zone, a decrease in the number of species and individuals occurred for a 5-6 week period after deposition at the treated stations. After the 5-6 week period, populations appeared to stabilize and significant differences between treated and untreated stations were lacking.

The first offshore sandbar contained a higher number of species and individuals than in the swash zone throughout the study period. The effect of dredged material upon the shore had practically no effect on the benthic macroinvertebrates inhabiting the first sandbar.

In both sampling areas (swash zone and sandbar) more significant differences between the number of species, individuals, and certain species occurred between stations (treated vs. untreated) before deposition than afterwards. This indicates that community composition and distribution and abundance of macroinvertebrate fauna at similar stations (swash zone, sandbar) are highly variable, even when they occur along the same beach. Because of this variation, adverse effects of deposition on the benthic macroinvertebrates were not discernible, if, indeed, they existed at all.

The deposited material was observed to be similar to existing beach material at most sites. Turbidity was relatively low except when areas of organic mud and wood fibers were dredged and deposited on the beach. Alongshore currents carried turbid and discolored water generally from west to east, causing it to spread along the shore. The duration of turbid water at a particular site was principally governed by the duration of the depositing process, which occurred at 23 sites in a period of one month. Therefore, deposition duration at any one site averaged slightly more than one day. Heavy seas also increased turbidity by resuspending the fine sediments into the water.

The restoration of beaches by pumping dredged material from offshore sources onto eroding beaches is becoming a common practice along the coastline. In many cases, it is a temporary procedure to rectify temporarily existing erosion. It is evident from this study that the depositing of dredged material had only a short and minimal effect on the benthic macroinvertebrates in the swash zone and first sandbar. The results support the conclusion by Thompson (1973) that no harmful effects are evident from the depositing of offshore sediments on a beach, provided that the sediments are similar to those where they are placed.

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Table 1. Turbidity values at seven stations located in the swash zone of Panama City Beach, Florida. The solid lines separate the periods before and after deposition at the three treated stations.

Date	STATIONS						
	UT-1	T-1	UT-2	T-2	UT-3	T-3	UT-4
1976	JTU	JTU	JTU	JTU	JTU	JTU	JTU
4-7	1.4	1.3	2.8	2.1	2.1	1.8	1.3
4-26	2.4	1.5	4.8	2.2	5.3	5.8	4.7
5-3	1.9	1.5	1.4	1.3	2.1	1.8	2.0
5-10	1.3	2.2	1.8	1.9	1.3	2.1	0.9
5-17	3.1	3.7	2.2	5.7	2.2	1.5	1.9
5-24	14.0	13.3	9.5	11.4	11.3	18.9	16.0
6-1	4.9	5.3	4.2	4.4	1.8	2.0	1.7
6-7	1.2	0.6	0.8	1.2	1.1	1.0	1.3
6-15	1.4	1.3	0.7	1.7	1.1	1.8	1.3
6-21	1.2	0.8	0.8	1.2	1.7	1.0	0.6
6-28	1.0	1.5	0.9	0.8	0.8	1.0	1.2
7-6	1.3	2.7	2.3	5.7	1.9	1.4	0.6
7-12	2.4	2.7	2.1	26.2	6.4	2.0	1.8
7-19	1.7	3.9	1.2	2.4	2.9	3.4	3.6
7-26	1.5	1.6	1.3	20.5	1.8	1.2	1.5
8-2	1.7	3.1	3.0	10.2	23.7	20.5	9.3
8-9	1.8	2.3	2.1	3.0	1.7	32.0	10.4
8-16	2.7	1.3	1.7	3.2	2.7	5.0	1.8
8-23	2.2	3.7	2.6	2.9	3.7	7.0	8.2
8-30	2.7	2.3	3.3	5.7	2.0	2.8	1.4
9-13	2.5	2.5	3.7	4.3	3.3	2.9	2.1
9-27	4.0	7.0	4.0	4.4	2.7	2.3	2.8
10-12	2.9	1.8	2.3	3.8	2.2	6.4	1.8
10-26	2.9	2.5	3.1	5.2	6.3	7.8	7.0
11-8	1.4	1.6	1.5	1.8	6.6	6.8	7.4
12-6	3.4	2.2	2.0	3.0	1.9	3.1	2.6
Average	2.6	2.8	2.5	5.2	3.9	5.5	3.7

Table 2. Numbers of macroinvertebrates caught in the swash zone of Panama City Beach, Florida, from April through December 1976.

SPECIES	SAMPLING DATES (1976) 4-7	4-26	5-3	5-10	5-17	5-24	6-1	6-7	6-15	6-21	6-28	7-6	7-12	7-19	7-26	8-2	8-9	8-16	8-23	8-30	9-13	9-27	10-12	10-26	11-8	12-6	TOTAL	PERCENT
NEMERTINEA																												
Unidentified sp. A				3					1		29					2				1					2		38	0.5
Unidentified sp. B								22	64	36		2		1	6				1				1				133	1.7
NEMATODA																												
Unidentified sp.					7			10																1			18	0.2
POLYCHAETA																												
Dispio uncinata										1	2										1			1			5	0.1
Haploscoloplos fragilis																								1	1		2	0.0
Nephtys bucera			1																								1	0.0
Paraonis fulgens		1		2	1			7	17	2	8	3		5	3	3	5		4	3	12	6	14	10	32	10	148	1.9
Polydora ciliata																				1							1	0.0
Scolelepis squamata	539	835	458	346	358	414	166	209	119	153	17	126	51	276	105	133	78	119	104	142	30	22	13	5	2		4920	62.4
Spiophanes bombyx				2																							2	0.0
GASTROPODA																												
Hastula salleana					1																						1	0.0
Mitrella lunata														1													1	0.0
Nudibranch sp.									2																		2	0.0
PELECYPODA																												
Anadara floridana														1													1	0.0
Donax texasianus	3	11	8	3	1	12	9	9	12	8	13	12	4	7	7	3	5	6	6	2	9	20	8	2	1	8	189	2.4
Ervilia concentrica												1															1	0.0
XIPHOSURA																												
Limulus polyphemus																									29	30	59	0.8
OSTRACODA																												
Euconchoecia sp.											7						65	30				3	1	1			116	1.5
MYSIDACEA											3						2	1									6	0.1
Mysidopsis bigelowi		3	1	1		2	2																					
Praunus flexuosus																									1		2	0.0
CUMACEA													1			1	1				1	4	1	1		1	19	0.2
Cyclaspis varians	1																		2								2	0.0
Spilocuma salomani	5	1			1	1																						
Unidentified sp. A																	3	3					2				14	0.2
ISOPODA																											1	0.0
Ancinus depressus	2							4																			1	0.0
Edotea montosa						1																						
Scyphacella arenicola																								1			1	0.0
AMPHIPODA																												
Acanthohaustorius sp.							1																				1	0.0
Cymadusa compta					1																						1	0.0
Haustorius sp.	60	74	116	24	24	21	144	37	126	131	55	31	61	26	63	32	65	6	71	8	7	11	1	2	26	78	1300	16.5
Parahaustorius sp.								1																			1	0.0
Photis sp.					2																						2	0.0
Pseudohaustorius sp.																	1										1	0.0
Hyperia sp.									2			1										2			3		8	0.1
Talorchestia sp.													1						2								3	0.0
Monoculodes sp.														1													1	0.0
Microprotopus sp.															1												1	0.0
CARIDAE																												
Hippolyte pleuracantha																						1					1	0.0
CALLIANASSIDAE																												
Unidentified sp.														1													1	0.0
ANOMURA																												
Emerita benedicti									3																		3	0.0
Emerita talpoida	22	9	7		3	14	11	12	17	45	39	35	25	48	31	62	73	59	44	26	30	30	22	25	93	51	833	10.6
Lepidopa benedicti	1		3		2			1	1		2	1	2	1	4	1		1	3	1	1		1	3			29	0.4
Pagurus longicarpus								1			1																2	0.0
BRACHYURA																												
Pinnixa cristata																					1			4			5	0.1
CEPHALOCHORDATA																												
Branchiostoma floridae						1				1																	2	0.0
TOTAL	633	934	594	381	401	466	333	313	364	378	276	212	145	368	220	237	298	225	237	184	92	99	64	57	190	178	7,879	99.7
Average Number per m^2	1447	2135	1358	871	917	1065	761	715	832	864	631	485	331	841	503	542	681	514	542	421	210	226	146	130	434	407	-	-

Table 3. Numbers of macroinvertebrates caught on the first sand bar of Panama City Beach, Florida, from April through December 1976.

	SAMPLING DATES (1976)																											
Species	4-7	4-26	5-3	5-10	5-17	5-24	6-1	6-7	6-15	6-21	6-28	7-6	7-12	7-19	7-26	8-2	8-9	8-16	8-23	8-30	9-13	9-27	10-12	10-26	11-8	12-6	TOTAL	
TURBELLARIA																												
Unidentified sp. A																			1								1	0.0
NEMERTINEA																												
Unidentified sp. A	5	2	7	4	2	1	2	3	1						3	3	6	4	2	1	1		1		1	2	51	0.4
Unidentified sp. B								3		1				5	2				1								12	0.1
NEMATODA																												
Unidentified sp.	36				56	1	25	19																			137	1.2
POLYCHAETA																												
Armandia maculata																					3				1		4	0
Dispio uncinata	10	2		2			5	6	6	12	10	1	5	1	1	2	4	19	69	11	4		5	5	3	7	190	1.6
Eteone lactea							1																				1	0
Glycera oxycephala								2																			2	0
Glycera sp.																	1	1									2	0
Haploscoloplus foliosus				1				1	1	5	3	3								7							21	0.2
Haploscoloplus fragilis							1				1	1	3	5	2	2	3	2	35		10	6	12	18	45	5	151	1.3
Lumbrineris floridana																		11	9							1	21	0.2
Magelona riojai						3												1									4	0
Nephtys bucera	9	15	5	8	6	6	20	14	5	10	2	3	1	3	1			2	3	1			1		1	1	117	1.0
Onuphis nebulosa																			1								1	0
Paranaites speciosa	1																										1	0
Paraonis fulgens	26	20	37	82	16	29	53	129	118	95	156	127	104	190	169	157	219	484	486	276	102	136	155	163	285	224	4038	34.7
Poecilochaetus sp.						1																					1	0
Polydora ciliata																					1						1	0
Scolelepis squamata	41	153	43	45	46	36	20	18	14	24	37	42	23	32	9	19	3	19		5	4	3				2	638	
OLIGOCHAETA																												
Unidentified sp.																			1								1	0
GASTROPODA																												
Distoma varium														2													2	0
Hastula salleana		3		2	3		1	1	2								1			2			2				17	0.2
Mitrella lunata														2									1				3	0
Olivella mutica										1																	1	0
Polinices duplicatus		1		3			1	2	2	1			1	1		1											13	0.1
PELECYPODA																												
Donax texasianus	16	6	12	16	7	43	121	95	105	104	49	48	45	18	18	13	12	3	44	60	18	4	2	2	6	5	872	7.5
Pitar simpsoni																			1								1	0
Musculus lateralis																1											1	0
OSTRACODA																												
Euconchoecia sp.																									9	29	38	0.3
MYSIDACEA																												
Mysidopsis bigelowi		3	1	3	2	5	1	2					1				1		3	3		4	8	3		3	43	0.4
Praunus flexuosus	6	5	6	1		2	4	22	7	3	2		2	2	2		12	8	10	4	3	2	9	3	3	2	120	1.0
CUMACEA																												
Cyclaspis varians																									3		3	
Oxyurostylis smithi							1																				1	0
Spilocuma salomani	78	27	14	19	34	11	15	28	5	15	3	4	12	10	5		6	3	3	19	3	7	3	2	6	6	3318	2.9
Unidentified sp..A															1	1	1						2				5	0
ISOPODA																												
Ancinus depressus	20	1	4	6		3		7	8				4	9	9	6	11	11	3	33	3	5	11	1	9	2	166	1.4
Chiridotea excavata		2	1	4	1	1		4			1				2			4	10	1	2		1				34	0.3
Scyphacella arenicola											1																1	0
AMPHIPODA																												
Acanthohaustorius sp.	2	8	18	27	1	12	6	39	14	11	12							3	6								159	1.4
Ericthonius sp.					1																						1	0
Haustorius sp.	167	230	221	265	122	160	369	229	391	303	297	96	92	91	56	122	32	54	46	73	23	99	69	115	75	179	3976	34.1
Monoculodes sp.				1																							1	0
Parahaustorius sp.	4	8	6	6	2	4	6	10	4	3	7	3	2		2	3		4	5	4		1	1	2	1		88	
Photis sp.			1	1	2	1																					5	0
Protohaustorius sp.						1				1								2						1			5	0
Pseudohaustorius sp.			3												2		1		22	3					1		32	0.3
Synchelidium sp.		1		1		1	1	1			1				1			1	5								13	0.1
Hyperia sp.											1											1			3		5	0
Lembus sp.				1																							1	0
Microprotopus sp.						1													1		1			1			4	0
Talorchestia sp.															1							1					2	0
Nototropis sp.														1													1	0
CARIDEA																												
Hippolyte pleuracantha																											1	0

Table 3 (con't)

Species	4-7	4-26	5-3	5-10	5-17	5-24	6-1	6-7	6-15	6-21	6-28	7-6	7-12	7-19	7-26	8-2	8-9	8-16	8-23	8-30	9-13	9-27	10-12	10-26	11-8	12-6	TOTAL	%
Leptochela serratorbita																							1				1	0
Ogyrides alphaerostris		1																	1								2	0
CALLIANASSIDAE																												
Unidentified sp.									1																		1	0
ANOMURA																												
Albunea paretii								1																			1	0
Emerita benedicti			1						5	2		2	5	2	1	3		1					2	1			25	0.2
Emerita talpoida							2	6	1	6	5	12	1	4	6	5	2	5	24	2	3	1			9	2	96	0.8
Lepidopa benedicti	2	4	1		1		2		9	5	9	3	12	6	6	3	4	3	5	8	5	2			4	3	97	0.8
Paguristes hummi				1																							1	0
Pagurus longicarpus				1				2	6																		9	0.1
BRACHYURA																												
Ovalipes guadulpensis	1																										1	0
Pinnixa cristata		5	1	3		1	1		5	2	2				1	2		8	1		1	2		3	3	3	44	0.4
Portunus sp.										1								1	1								3	0
OPHIUROIDEA																												
Ophiophragmus moorei		1	1	1																							3	0
Unidentified sp. A								1																			1	0
ECHINOIDEA																												
Mellita quinquiesperforata		1									1								1								3	0
HOLOTHUROIDEA																												
Unidentified sp.A														1													1	0
CEPHALOCHORDATA																												
Branchiostoma floridae						1	2	1																1	3		8	0.1
TOTAL	424	499	383	904	302	324	661	646	710	605	600	345	313	385	300	343	319	694	800	514	187	274	286	321	471	475	11,645	99.4
Average Number per m^2	969	1145	875	1152	690	741	1511	1477	1623	1383	1371	789	715	880	686	784	729	1495	1829	1175	427	696	654	734	1077	1096	-	

Table 4. Comparisons of the numbers of *Haustorius* sp., and *Emerita talpoida* in treated and untreated stations in the swash zone using Wilcoxon's Signed Rank Test (n = number of observations and T - Wilcoxon's T value).

Stations	Before deposition		After deposition	
	Haustorius sp.			
	n	T	n	T
UT-1 vs T-1	10	18.0	13	35.0
UT-2 vs T-1	8	13.0	12	39.0
UT-2 vs T-2	12	14.0	7	1.5*
UT-3 vs T-2	13	43.5	7	0**
UT-3 vs T-3	15	56.5	4	3.0
UT-4 vs T-3	14	39.0	7	4.0
	Emerita talpoida			
UT-1 vs T-1	6	6.0	15	38.5
UT-2 vs T-1	9	15.0	12	18.0
UT-2 vs T-2	12	26.0	12	33.0
UT-3 vs T-2	11	30.5	11	31.5
UT-3 vs T-3	13	37.5	9	16.5
UT-4 vs T-3	12	34.0	10	24.5

* Significant at 0.05%
** Significant at 0.01%

Table 5. Comparisons of the numbers of _Donax texasianus_ in treated and untreated stations on the first sandbar using Wilcoxon's Signed Rank Test (n = number of observations and T - Wilcoxon's T value).

Stations	Before deposition		After deposition	
	Donax texasianus			
	n	T	n	T
C-5 vs T-4	10	23.5	9	12.0
C-6 vs T-4	11	10.5*	8	17.0
C-6 vs T-5	13	10.0*	10	9.0
C-7 vs T-5	14	18.5*	10	25.0
C-7 vs T-6	12	36.0	7	5.5
C-8 vs T-6	14	21.5	8	14.0

* Significant at 0.05%
** Significant at 0.01%

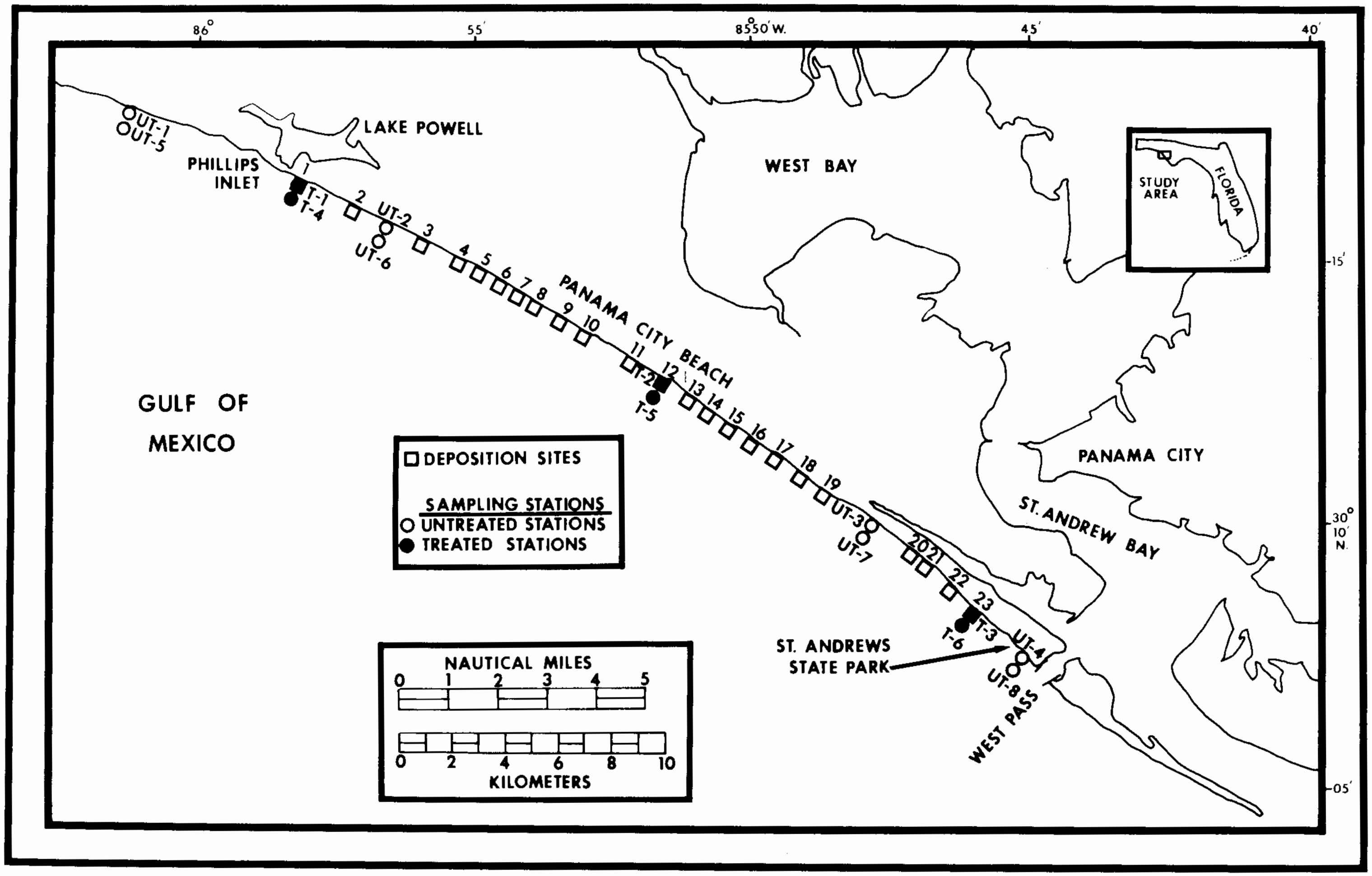


Figure 1. Locations of sampling stations and beach deposition sites.

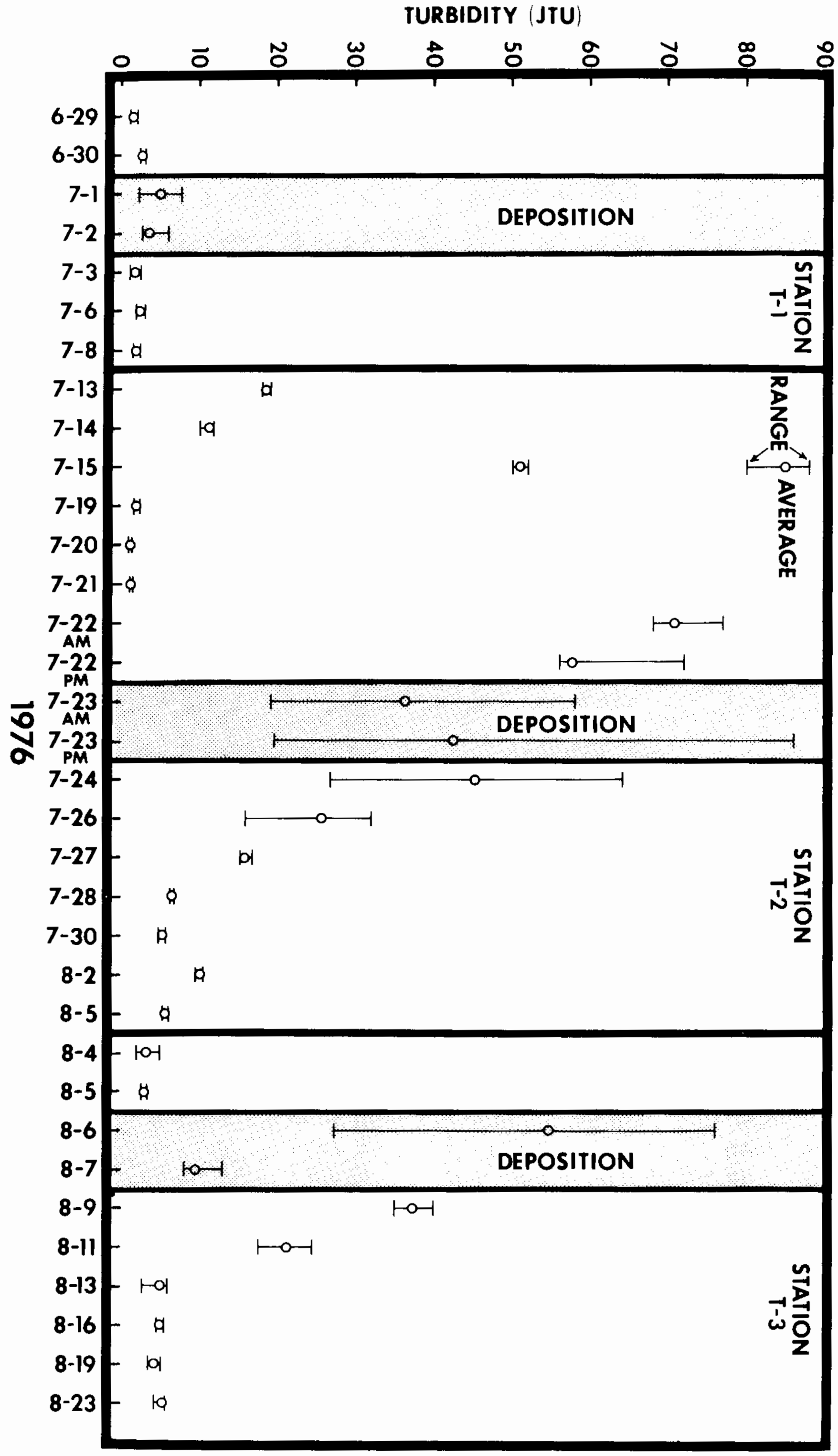


Figure 2. Turbidities at Stations T-1, T-2, and T-3 before, during, and after deposition.

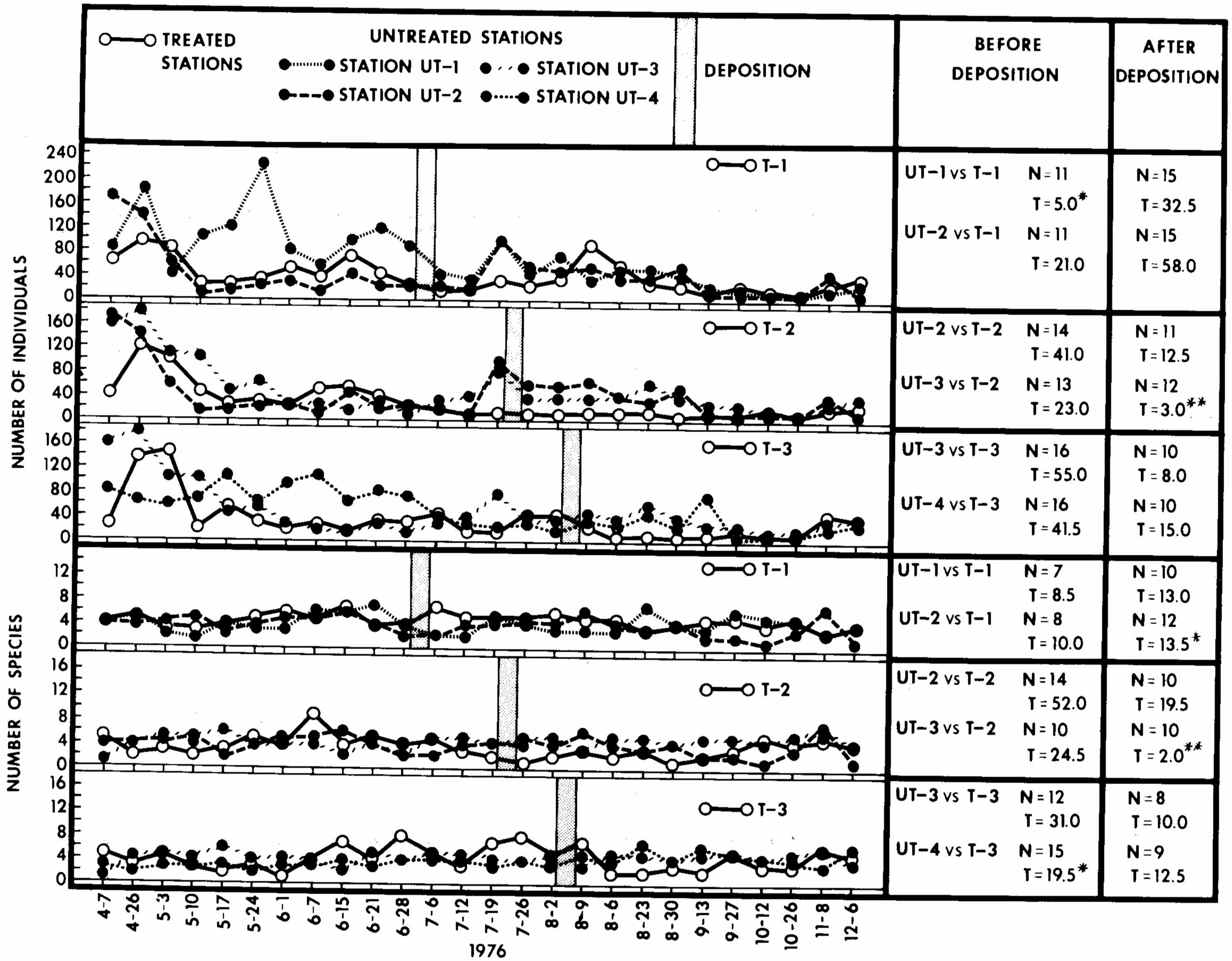


Figure 3. Comparisons of the numbers of individuals and species of benthic organisms between treated and untreated stations in the swash zone. Significant values of Wilcoxon's Signed Rank Test (n = number of observations and T = Wilcoxon's T value) are listed. A single asterisk means significant at 0.05% and double asterisk significant at 0.01%.

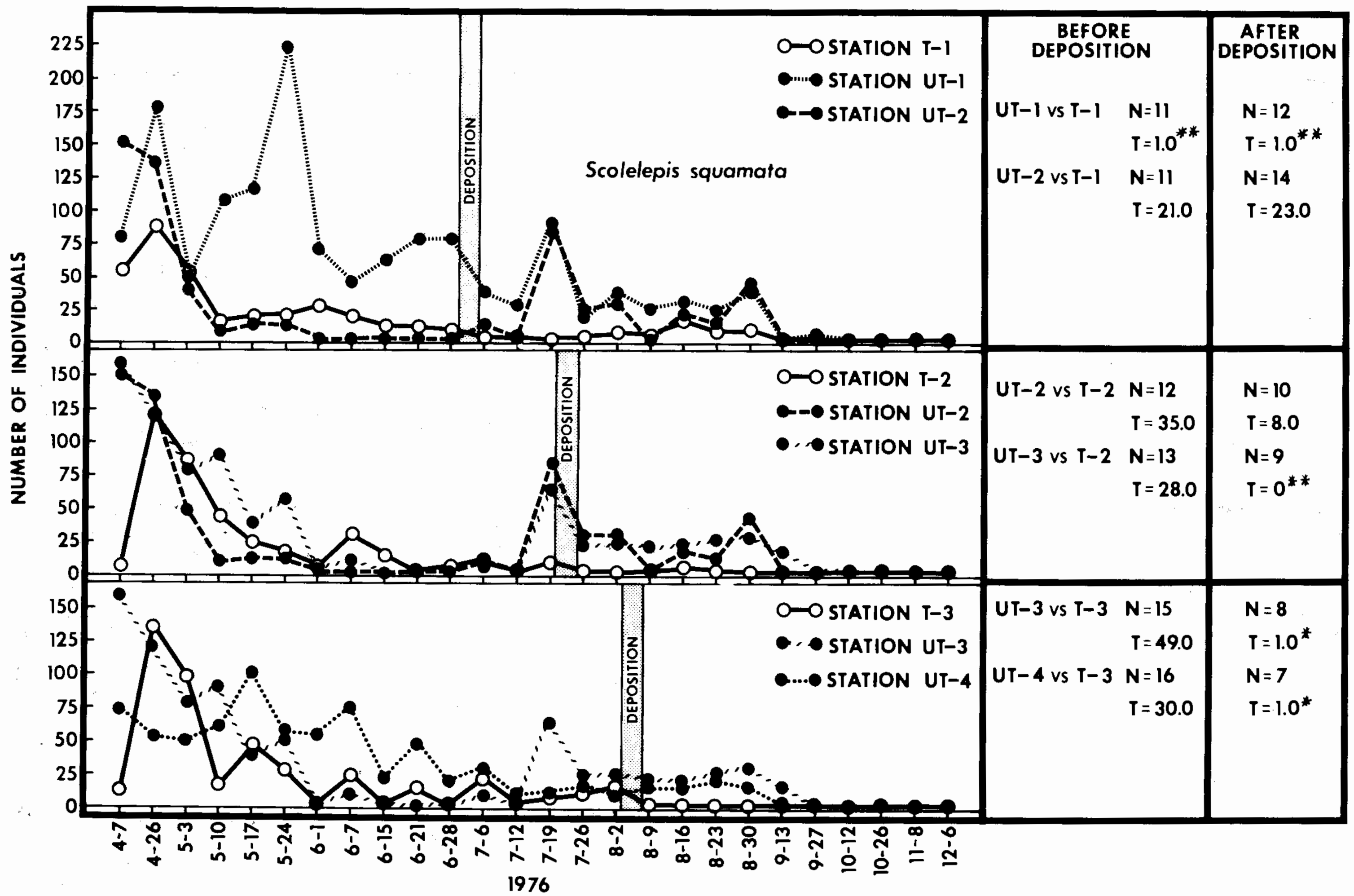
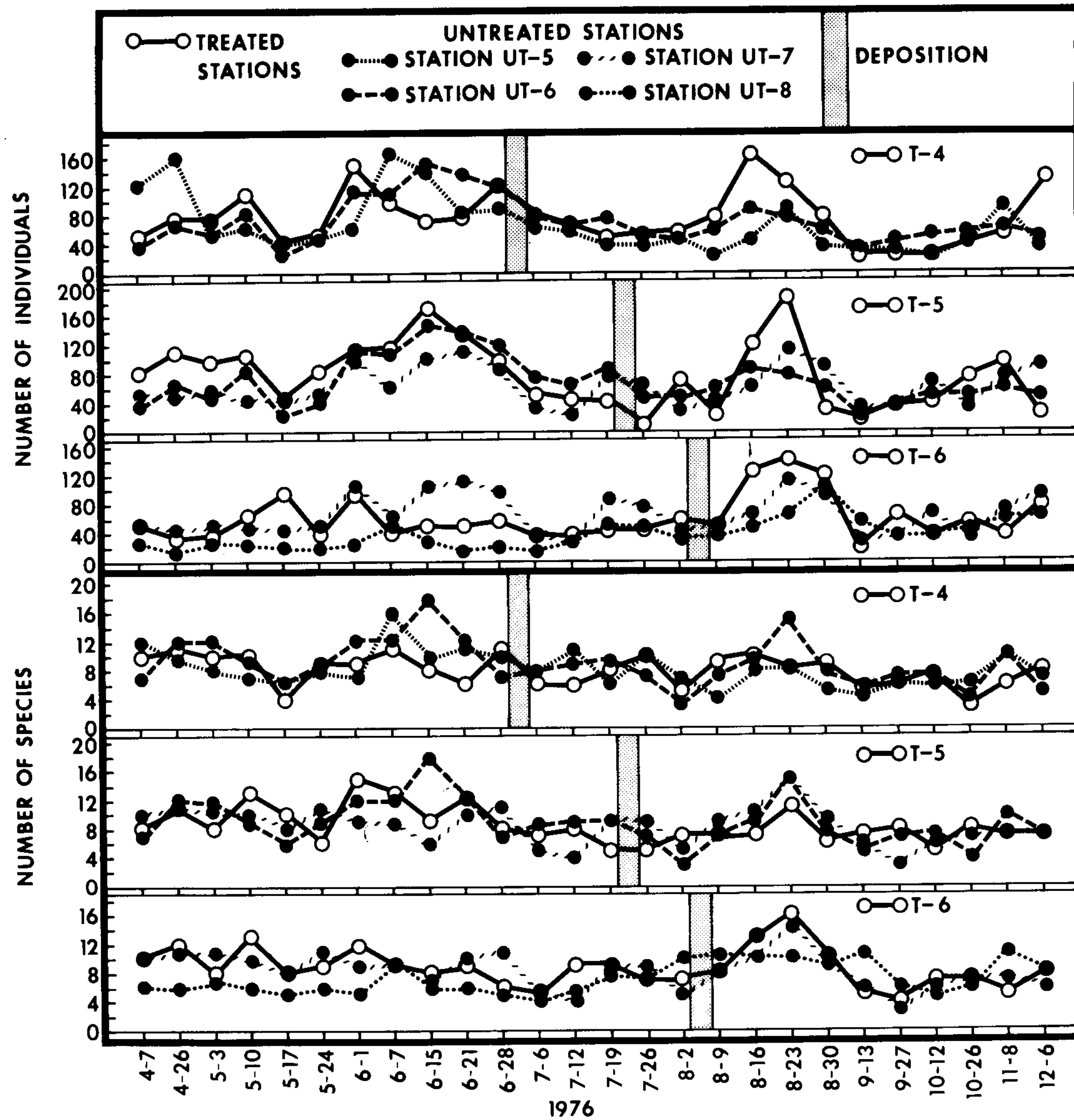
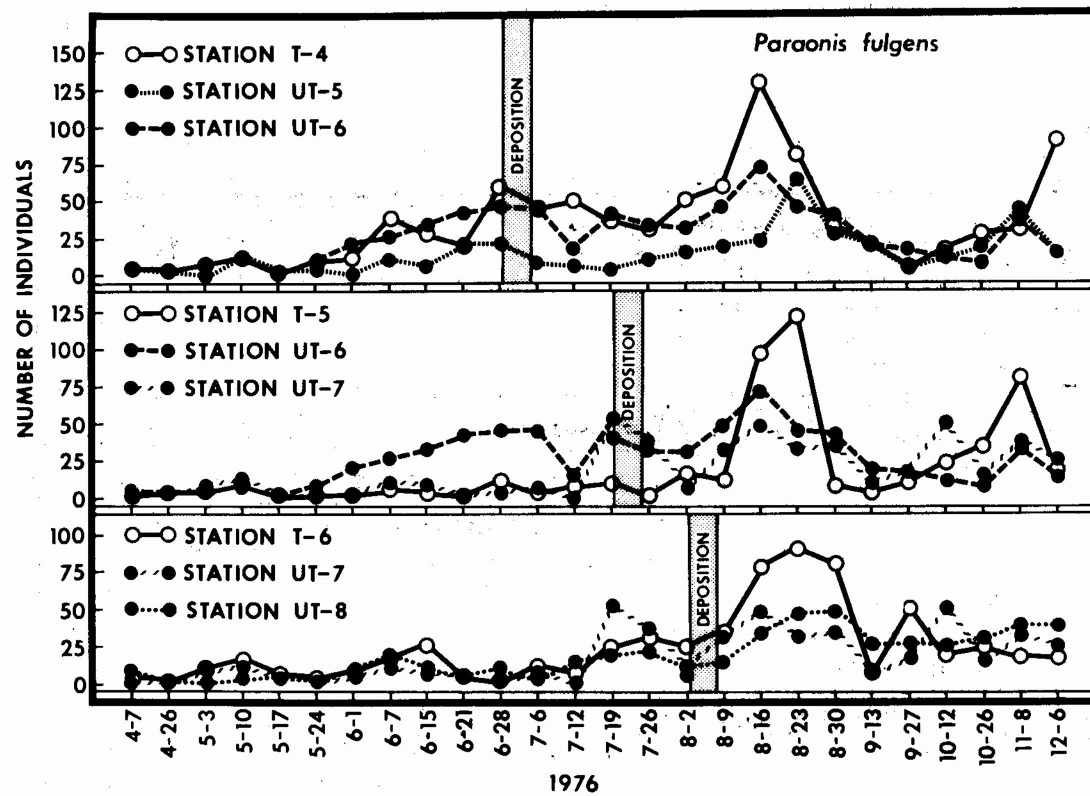


Figure 4. Numbers of individuals of Scolelepis squamata at the three treated stations compared with the untreated stations in the swash zone. Significant values of Wilcoxon's Signed Rank Test (n = number of observations and T = Wilcoxon's T value) are listed. A single asterisk means significant at 0.05% and double asterisk significant at 0.01%.



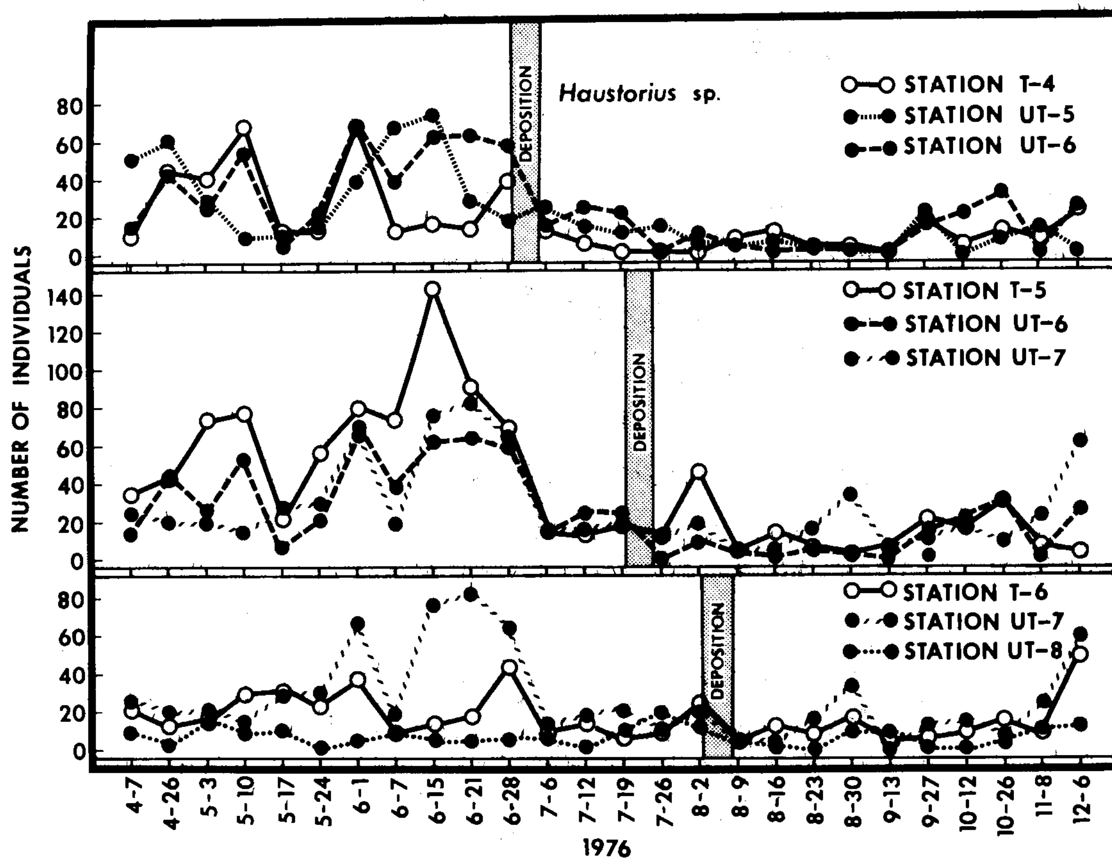
	BEFORE DEPOSITION		AFTER DEPOSITION
Number of individuals	UT-5 vs T-4	N=11 T=28.0	N=15 T=17.0
	UT-6 vs T-4	N=11 T=25.0	N=14 T=33.0
	UT-6 vs T-5	N=13 T=26.5	N=11 T=29.5
	UT-7 vs T-5	N=14 T=11.0	N=12 T=35.0
	UT-7 vs T-6	N=15 T=35.5	N=10 T=22.0
	UT-8 vs T-6	N=16 T=10.0	N=10 T=14.0
Number of species	UT-5 vs T-4	N=11 T=27.0	N=12 T=38.0
	UT-6 vs T-4	N=10 T=16.5	N=13 T=39.0
	UT-6 vs T-5	N=13 T=39.5	N=10 T=24.0
	UT-7 vs T-5	N=13 T=26.0	N=9 T=15.5
	UT-7 vs T-6	N=11 T=30.5	N=9 T=14.5
	UT-8 vs T-6	N=15 T=11.5	N=9 T=21.0

Figure 5. Comparisons of the numbers of individuals and species of benthic organisms between treated and untreated stations on the first sandbar. Significant values of Wilcoxon's Signed Rank Test (n = number of observations and T = Wilcoxon's T value) are listed. A single asterisk means significant at 0.05% and double asterisk significant at 0.01%.



BEFORE DEPOSITION		AFTER DEPOSITION
UT-5 vs T-4	N=11	N=14
	T=9.0*	T=10.0**
UT-6 vs T-4	N=9	N=14
	T=19.5	T=29.0
UT-6 vs T-5	N=14	N=12
	T=0**	T=38.0
UT-7 vs T-5	N=11	N=12
	T=19.0	T=36.0
UT-7 vs T-6	N=16	N=10
	T=35.5	T=16.0
UT-8 vs T-6	N=15	N=10.0
	T=39.0	T=16.5

Figure 6. Numbers of individuals of Paraonis fulgens at the three treated stations compared with the untreated stations on the first sandbar. Significant values of Wilcoxon's Signed Rank Test (n = number of observations and T = Wilcoxon's T value) are listed. A single asterisk means significant at 0.05% and double asterisk significant at 0.01%.



	BEFORE DEPOSITION	AFTER DEPOSITION
UT-5 vs T-4	N=11 T=27.5	N=15 T=43.5
UT-6 vs T-4	N=11 T=18.5	N=14 T=39.0
UT-6 vs T-5	N=13 T=7.5**	N=11 T=23.0
UT-7 vs T-5	N=14 T=11.5**	N=12 T=32.5
UT-7 vs T-6	N=16 T=17.0**	N=9 T=10.0
UT-8 vs T-6	N=15 T=11.0**	N=9 T=4.5*

Figure 7. Numbers of individuals of Haustorius sp. at the three treated stations compared with the untreated stations on the first sandbar. Significant values of Wilcoxon's Signed Rank Test (n = number of observations and T = Wilcoxon's T value) are listed. A single asterisk means significant at 0.05% and double asterisk significant at 0.01%.