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A University of North Carolina
Sea Grant Program Publication
UNC-SG-74-15

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by

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This work was partially sponsored by Office of Sea Grant, NOAA, U. S. Department of Commerce under Grant number 04-3-158-40, and the North Carolina Department of Administration, Coastal Engineering Research Center, U. S. Army Corps of Engineers, and the Center for Coastal and Marine Studies. The U. S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright that may appear hereon.

SEA GRANT PUBLICATION UNC-SG-74-15 OCTOBER 1974

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ABSTRACT

Dredge spoil, sand and mud scooped from the bottom of navigation routes and piled high on channel edges has been successfully stabilized with plantings of North Carolina's dominant marsh grass, Spartina alterniflora.

Benefits of stabilizing spoil with Spartina, commonly known as smooth cordgrass, appear to be two-fold. In the short term, marsh grass slows erosion of spoil back into the waterways, thereby reducing the need for frequent and costly dredging with its wear and tear on the environment. In the long term, areas covered with Spartina come to look like natural marshlands. Marsh provides a vital source of nutrients and food for many young fish and shellfish and are therefore important to fishery resources.

Even though from outward appearance it looks like natural marsh, scientists aren't sure if spoil covered with Spartina has characteristics similar to nature's marsh beneath the surface. Natural marsh is more than a healthy stand of smooth cordgrass. It is habitat for animal life, or fauna, much of which is found nowhere else. Complex nutrient cycles involving the marsh fauna, sediments, grass and overlying waters are also found only in natural marsh.

The purpose of this research was to answer the general question: Does spoil covered with smooth cordgrass function similarly to natural marsh? Specifically, the research was aimed at determining differences

in animal life, or fauna, in spoil areas and natural marsh. Four objectives were carried out. They were: (1) To determine what fauna is found in transplanted spoil; (2) To compare spoil and natural marsh fauna; (3) To determine if spoil will ever resemble that of the natural marsh; (4) If the answer to (3) is yes, to determine how long after spoil is deposited animal life in the new marsh will become similar to natural marsh fauna. An additional objective was to investigate how the growth of Spartina may affect the development of animal life.

Two locations, one at Drum Inlet (Carteret County, N. C.) and one at Snow's Cut (New Hanover County, N. C.) were chosen for the study because of the difference in age of the spoil marsh and the range in environmental conditions. Sampling of the areas, both of which included bare spoil, artifical marsh and natural marsh, continued over a nine-month period, from March to November, 1973.

To determine factors affecting fauna at both locations, sediment particle size, organic carbon content, sediment temperature and Spartina biomass were analyzed. Measurements of faunal concentrations were taken regularly.

Two patterns of faunal development were found to occur at the sites. Fauna found in bare and planted plots at Drum Inlet were generally much alike. But a marked difference was found between fauna from these plots and that from Drum Inlet's natural marsh. In contrast, at Snow's Cut, bare and planted plots differed greatly in faunal development. There, bare, more than planted marsh fauna, resembled that of the natural marsh.

Spartina, an effective spoil stabilizer, appeared to have only an indirect effect on faunal development. The marsh grass traps moving sediment, thus contributing to the build-up of sediment and an increase in elevation.

Elevation was suggested as a major factor affecting faunal development. At Drum Inlet, where elevation differences between bare and planted plots are small, fauna in the two areas were similar. At Snow's Cut, where elevation differences are great, fauna were distinctly different in the bare and planted plots.

The research indicates that planted spoil fauna at Drum Inlet will more quickly resemble the natural marsh than that at Snow's Cut, even though the Drum Inlet area has been developing for a shorter time. Two explanations are offered: (1) Sediment particle size at Drum Inlet was almost identical to that if the natural marsh, while particles at Snow's Cut were smaller than natural marsh sediment; (2) It is possible that because of periodic overwash the natural marsh at Drum Inlet was less mature than that at Snow's Cut. Less maturity could mean that faunal development would require less time to resemble that in the natural marsh than in a more mature system.

One indication of how long it will take spoil marsh to resemble natural marsh is the organic carbon content of the sediment. Using organic carbon content as an indicator, estimates are that Drum Inlet spoil will resemble that of natural marsh in approximately four years from the time spoil was last deposited. But at Snow's Cut, the process may take as much as 25 years.

In conclusion, the research shows that planting Spartina on dredge spoil can lead to the creation of salt marsh that resembles marsh built by nature. How long this takes depends on how closely spoil resembles the natural marsh sediment, the natural sedimentation rate of the area, the elevation and the maturity of the natural marsh compared to the area of spoil deposition.

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INTRODUCTION

Salt marshes along the Atlantic and Gulf Coasts have recently become the subject of intense investigation. Teal (1962), Day et al. (1973) and Nixon and Oviatt (1973) have published energy flows for entire marsh ecosystems in Georgia, Louisiana and Rhode Island, respectively. The value of these marshes to nearby estuarine and coastal systems in supplying nutrients, food in the form of detritus, and in serving as a nursery ground for many commercially important species has been recognized (Odum 1961; Teal 1962; Odum and de la Cruz 1967; Day et al. 1973; de la Cruz 1973). Gosselink et al. (1974) have estimated a value of $50,000 to $80,000 per acre when functions performed by the marshes such as tertiary waste treatment are included in the evaluation. Many of the coastal states have enacted laws intended to protect existing marshland from destruction (Wass and Wright 1969).

A project has been underway for the past five years in North Carolina to establish salt marsh on dredge spoil by planting *Spartina alterniflora* (Woodhouse et al. 1972, 1974a, 1974b; Seneca 1974). The immediate benefit has been stabilization of the dredge spoil thereby reducing the expense involved in repeated dredging. The long term benefit is expected to be the establishment of additional acres of marshland on spoil which would otherwise be wasteland.

After a period of only two years the artificially established marshes resembled natural marsh in both appearance and *Spartina* dry matter production (Woodhouse et al. 1974a). However, a natural marsh is much more than just a monospecific stand of *Spartina*. A distinct marsh fauna exists and many of the animals are found nowhere else (Teal 1962).

Complex nutrient cycles are known to exist which involve the marsh sediments and fauna as well as the Spartina and overlying water (Pomeroy et al. 1968). The establishment of a stand of Spartina is only one step toward marsh creation.

This study was undertaken to investigate the macrofauna of the spoil marshes. The objectives were: 1) to determine the composition of the spoil fauna; 2) to investigate the relation of the spoil fauna to the natural marsh fauna; 3) to determine whether the spoil fauna will ever resemble the fauna of natural marsh; and 4) if so, to determine how long a time period will be involved.

Kraeuter and Wolf (1974) suggested that there are several ways salt marsh plants may influence marine macroimvertebrates, for example by providing them with substrate, food and protection from predation, and by modifying the temperature, humidity and illumination at the sediment surface. An additional objective of this study was to investigate the effects of Spartina growth on the fauna by using for a control bare spoil areas adjacent to those areas that were planted.

DESCRIPTION OF THE STUDY AREAS

Two locations were chosen for this study, one at Drum Inlet and one at Snow's Cut (Fig. 1). These areas were chosen to represent distinct situations: there was a difference in the ages of the spoil marshes and they encompassed the greatest range in environmental conditions of the available sites.

Drum Inlet

The Drum Inlet study area was located just north of new Drum Inlet (Carteret County, 34°51'N, 76°19'W) which runs through Core Banks, one of the barrier islands of North Carolina. New Drum Inlet was cut through Core Banks by the Corps of Engineers in December 1971 after the natural inlet 4.5 km to the north had closed due to its southward migration combined with extensive shoaling (Godfrey and Godfrey 1974). The dredge spoil from this operation was deposited behind the island and graded to facilitate planting of _Spartina alterniflora_. At the time of deposition the spoil was composed of 98% sand, 0.4% silt and 1.6% clay (Woodhouse et al. 1974b). _Spartina_ was planted in May 1972 and at the beginning of this study had been growing approximately one year.

The barrier islands normally support a vigorous growth of marsh on the landward side relying on overwash material to supply surface for the marsh's expansion (Godfrey and Godfrey 1974). A narrow band of such natural marsh was present at Drum Inlet, adjacent to the site of spoil deposition.

Extensive hydrographic data was available for the waters around old Drum Inlet and they probably reflect quite closely conditions at

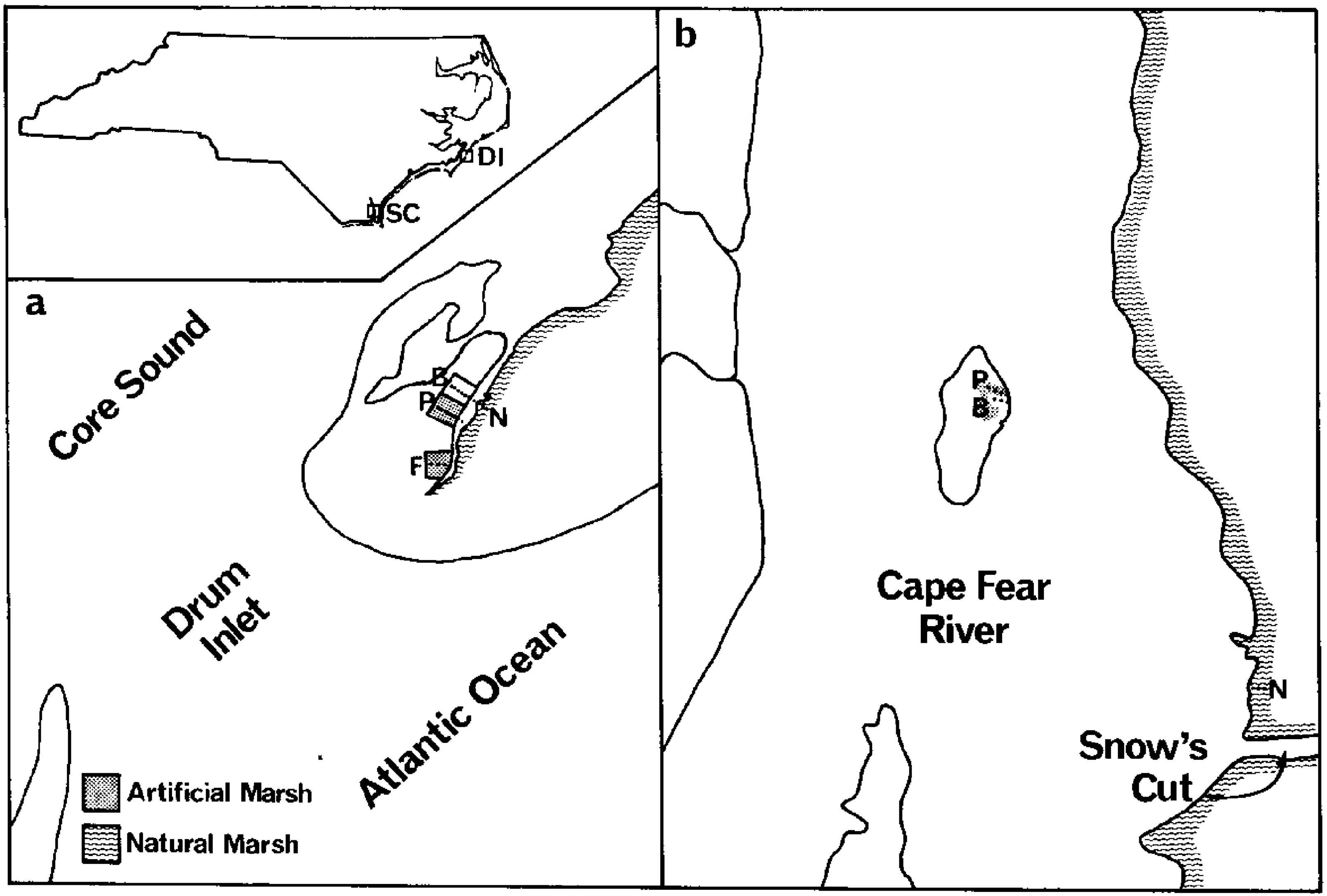

Figure 1. Location of the study areas: a) Drum Inlet, b) Snow's Cut. Letters represent transects: B (Bare), P (Planted), F (Fertilized), N (natural).

new Drum Inlet as well. The surface water near the inlet was near oceanic in salinity with average monthly values ranging from 28-35 ‰ , lowest in the winter and highest in the summer (Williams et al. 1973). Average monthly surface temperatures ranged from 9-27°C with highest temperatures recorded in August (Williams et al. 1973). Tidal range for Core Sound in this area is almost 1 m (Godfrey and Godfrey 1974) but the range appeared to be less than 0.5 m in the tidal creek which flooded the marsh.

Snow's Cut

The Snow's Cut study area was located on a spoil island lying in the Cape Fear River estuary (New Hanover County, 34°07'N, 77°56'W) approximately 24 km from the mouth. Fresh spoil was deposited about 60 days prior to the planting of *Spartina* which occurred in April 1971. The slope at this time was approximately 1.2-2.0% and the spoil was composed of 96% sand, 1% silt and 3% clay (Woodhouse et al. 1974a). At the beginning of this study the *Spartina* had been growing for two years.

Natural marsh occurs along the banks of the river in a narrow band generally less than 5 m wide. From the eroding peat banks facing the river it appears that wave action, possibly generated by the intense shipping traffic in the area, prevents the marsh from expanding into the river.

Salinity in this area is generally low, from 7-10 ‰ . Tidal amplitude is about 1.3 m.

METHODS

Sampling was carried out from March to November 1973; five samples were taken from Drum Inlet and four from Snow's Cut. The samples were taken from each area at 6-7 week intervals.

Three permanent transects were established at each site, one through the unplanted (Bare) plot, one through the artificially planted (Planted) plot, and one through the nearest natural marsh. Where Spartina was present the transects ran from the upper extent of its growth down to the center of the tidal creek at Drum Inlet or to just above mean low water at Snow's Cut. The transects through the Bare areas were set up parallel to the Planted transects.

In order to consider the effects of Spartina-mediated sediment accretion, permanent stations were established at Drum Inlet (Fig. 2a, 3a) by distance from the center of the tidal creek rather than by elevation. At Drum Inlet the Bare and Planted transects each had seven stations, 3.3 m apart, which were marked by stakes. The natural marsh had only four stations, 3.3 m apart, due to its narrower width. Due to the arrangement of the transects the lowest station of the Bare transect was also the lowest station of the natural marsh.

Similarly, Snow's Cut stations (Fig. 2b, 3b) were located by distance from the water at low tide. Because of the greater length of the transects and the gentle slope, stations were placed 20 m apart. Stations in the Bare area were marked by stakes but the dense growth of Spartina made this impractical in the Planted area. Instead only the lower and uppermost stations were marked with stakes; the middle two stations were approximated each sampling period by determining the proper distance from the outer stakes and then walking into the middle of the

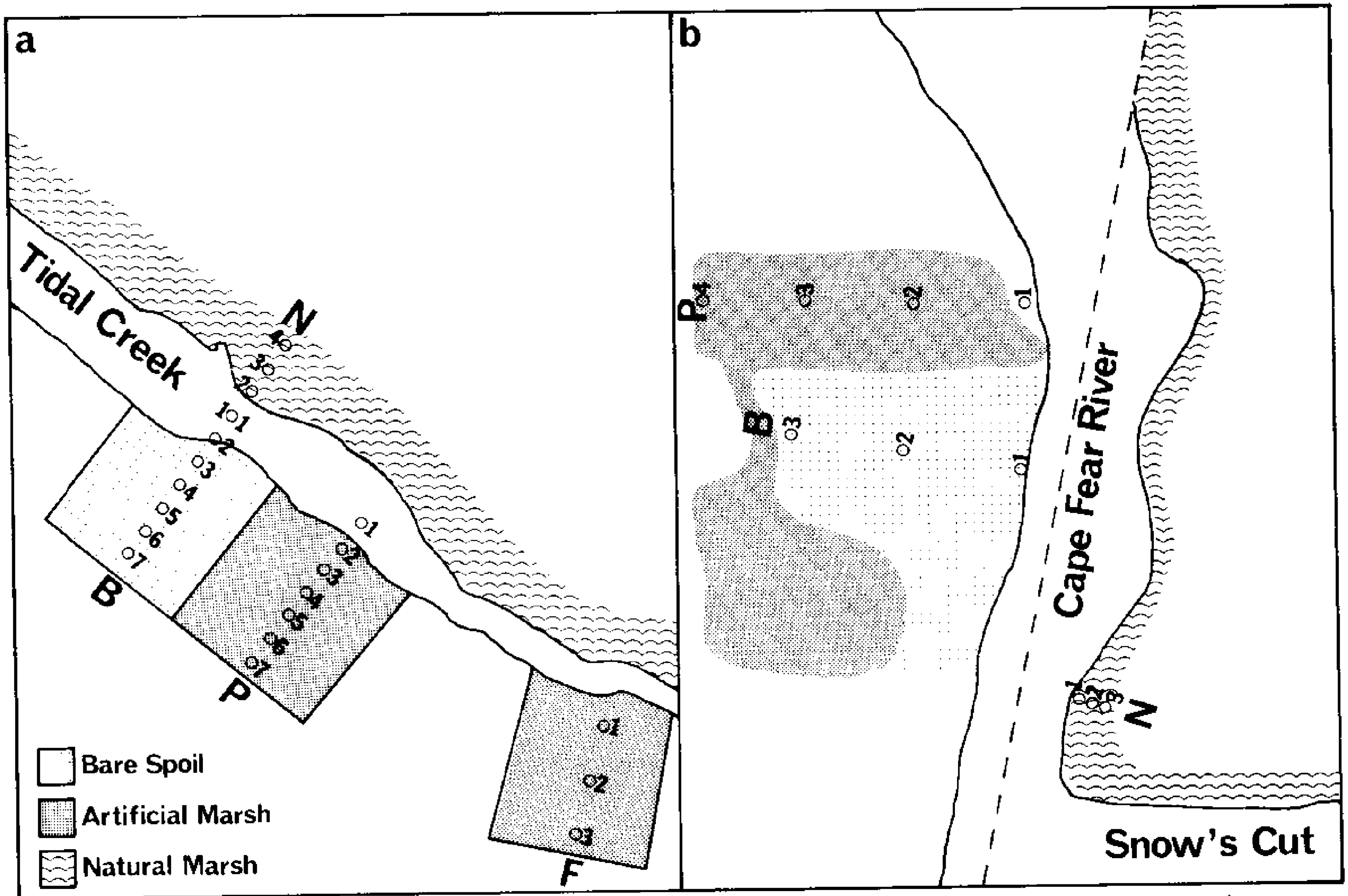

Figure 2. Location of the transects within the study areas: a) Drum Inlet, b) Snow's Cut. Letters represent transects: B (Bare), P (Planted), F (Fertilized), N (natural).

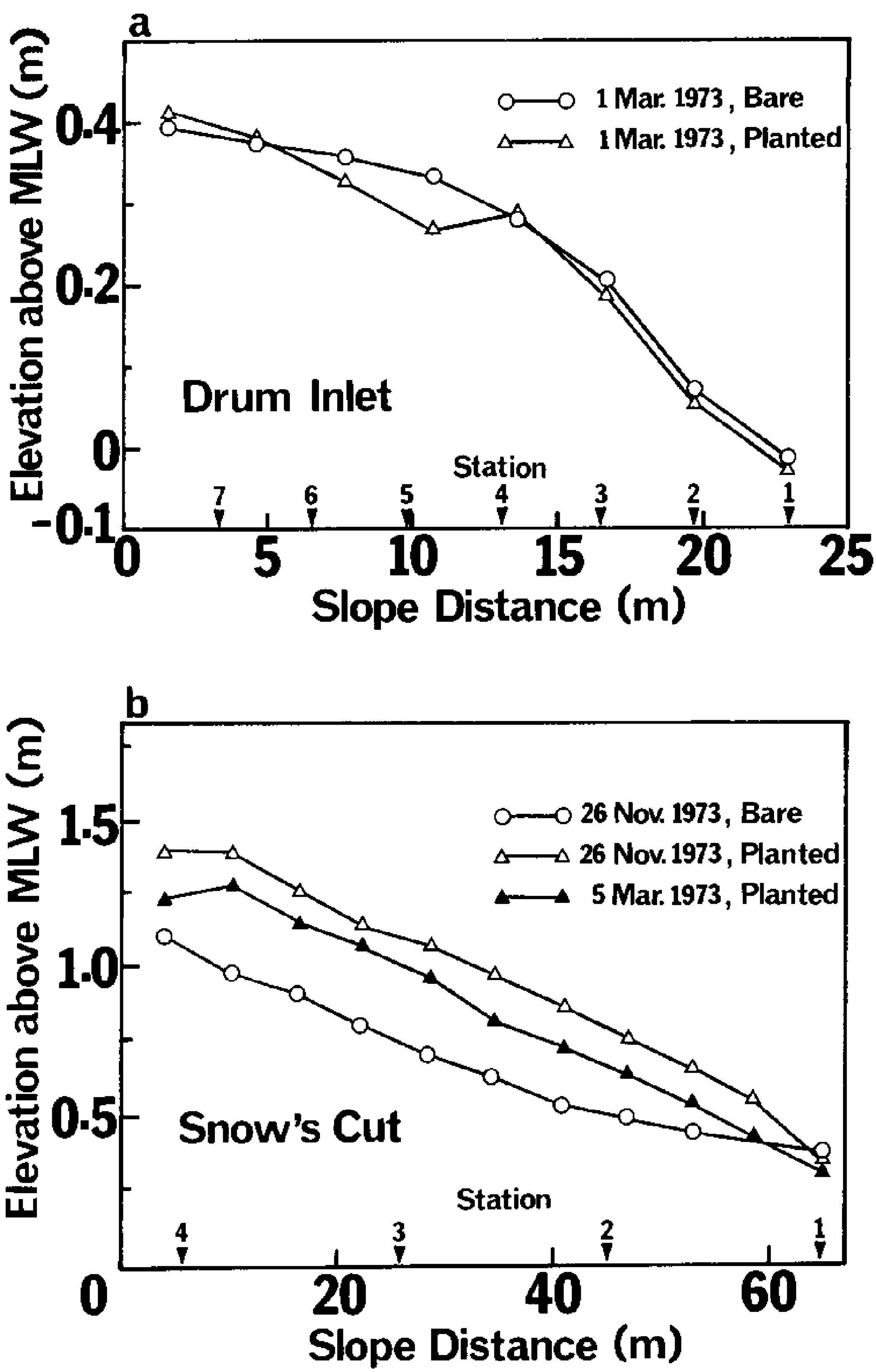

Figure 3. Elevation of the Bare and Planted transects: a) Drum Inlet, b) Snow's Cut (a, after Woodhouse et al. 1974b; b, S. W. Broome, personal communication).

plot. The Planted area had four stations, the Bare area three; this was because the Spartina extended about 20 m beyond the upper limit of the Bare area which was marked by encroaching vegetation from above (mainly Spartina). The natural marsh had only three stations, about 1.5 m apart, due again to its narrow width.

In addition one sample was taken at Drum Inlet from a section of spoil planted with Spartina and fertilized with the addition of N and P. Three stations were sampled, one from the lowermost growth of Spartina, one from the uppermost growth, and one from the middle.

Sampling was done with a stainless steel piston corer 9.5 cm in diameter (70.9 cm^2). Cores were taken to a depth of 13 cm and typically were taken in replicate pairs about 1 m apart from each station at low tide. Three replicates were taken from each station in the natural marsh and the Fertilized plot due to the smaller number of available stations. Cores were not taken from locations where evidence of previous sampling still remained.

Core samples were washed through a 1 mm sieve in the field and the remaining sediment, plant debris and animals were preserved in formalin-sea water. Howmiller (1972) found that weight loss occurred when invertebrates were stored in formalin prior to weighing; consequently the biomass figures from this study are probably underestimates of the true values. Animals were separated in the laboratory with sugar flotation (Anderson 1959). It was necessary to pick through the Spartina roots by hand but occasional use of staining showed that recovery was almost 100%.

All animals except insects were identified to species; insects could only be identified to family and for this reason the number of insect species was undoubtedly underestimated (G. Steyskal, personal communication). Molluscs were decalcified in dilute hydrocloric acid for 30 seconds to 1 minute and then all the animals were placed on tared aluminum foil planchets for drying. They were dried at 55°C for four days; no significant weight loss occurred after this time. The animals were then transported in a desiccator and weighed on a Mettler Micro Gram-atic balance to the nearest µg.

The method of sampling limited the fauna which could be sampled adequately. Adult insects such as leafhoppers and grasshoppers were not included in data analysis since they were collected so infrequently and were probably only incidentally associated with the sediment; the only adult insects included were the Staphylinid beetles which were extremely small (<4 mm), not very mobile and were collected in substantial numbers. *Uca pugilator*, the calico-backed fiddler crab, was too mobile to be adequately sampled and although numbers and biomass of those caught were included in the tables, they were not included in the calculation of totals or community diversity measures.

Two species of polychaetes, *Heteromastus filiformis* and *Capitella capitata*, were abundant but were fragmented by the sieving and preservation. Since it was not possible to distinguish the two species without the anterior segments, the posterior fragments could not be identified; the species were therefore identified to family only (Capitellidae) and were considered as one throughout the data analysis. Counts of individual Capitellids were not made for the March and May samples from Drum Inlet and these two samples were not included when average numbers were calculated.

Five aspects of community structure were calculated for each sample: the total number of species, the total number of individuals, the total biomass, the diversity by number of individuals and the diversity by biomass. The diversity index used was the Shannon-Weaver index

$$H'' = -\sum^{S} p_i \ln p_i$$

where p_i is the proportion of numbers or biomass the i^{th} species makes up of the sample total and S is the number of species present. H" is the maximum likelihood estimator of the true population diversity H' (Pielou 1966); its use with biomass was explained by Wilhm (1968). The Shannon-Weaver diversity increases as both the species richness (S) and the equitability of species abundance (J, see below) increase. For samples where no animals were present H" was assumed to be 0 since as $S \rightarrow 0$, $p_i \ln p_i \rightarrow 0$. Average values were calculated for each transect on each date and transects were compared using an overall F test for each measure. When more than two transects were compared with the F test, individual transect pairs were compared using the Least Significant Difference to test for significance (Steel and Torrie 1960).

Species data were combined and averaged over the entire sampling period and overall diversity, evenness and faunal affinity were calculated. Diversity was calculated as for individual samples and evenness, J, was calculated by

$$J = H''/H''_{max}$$

where H''_{max} is the maximum value H" can take for S species; J is maximum when all species are equally abundant. Faunal affinity was calculated using an index developed by Sanders (1960) to measure the relative similarity between two samples. The index is calculated by obtaining the percentage of the total sample represented by each species for each sample and then summing the smaller percentage for each species. As an example, if species A represented 50% of the biomass of sample 1 and 20% of the biomass of sample 2, then 20% of the total affinity between the samples would be attributable to species A. Results were expressed in separate trellis diagrams, one for Drum Inlet and one for Snow's Cut.

Sediment samples for particle size analysis and organic carbon determination were taken from all areas in September except the Snow's Cut natural marsh which was sampled in November. Two separate samples were taken from the spoil plots, one high intertidal and one low intertidal. Samples consisted of three cores (70.9 cm^2, 13 cm deep) from each plot which were later combined in the laboratory. The silt-clay fraction was determined by wet sieving and this value was then used to correct the percentages of the sand fractions which were determined by dry sieving with a graded series of sieves. The sediment was split into six grades according to the Wentworth scale: very coarse sand (>1.000 mm), coarse sand (0.500-1.000 mm), medium sand (0.250-0.500 mm), fine sand (0.125-0.250 mm), very fine sand (0.062-0.125 mm) and silt-clay (<0.062 mm). Sizes were converted to phi notation where ϕ = 0 when size = 1.000 mm, 1 when size = 0.500 mm, 2 when size = 0.250 mm, 3 when size = 0.125 mm and 4 when size = 0.062 mm. Median particle size was calculated both in mm (Md mm) and ϕ units (Mdϕ). To measure the spread of the particle sizes the quartile deviation of ϕ (QDϕ) was calculated by finding the diameters of the 25% ($Q_{25}\phi$) and 75% ($Q_{75}\phi$) points on the cumulative curve of sediment size and applying the formula

$$QD\phi = (Q_{75}\phi - Q_{25}\phi)/2 \quad .$$

A small spread between the quartiles indicates a "well sorted" sediment. To express the symmetry of the spread about the median, the quartile skewness of ϕ ($Sk_q\phi$) was calculated as

$$Sk_q\phi = \left[(Q_{25}\phi + Q_{75}\phi)/2\right] - Md\phi \quad .$$

A positive value indicates that the mean of the quartiles is greater than Mdϕ, a negative value indicates the mean is less than Mdϕ.

A dichromate wet-oxidation technique (Buchanan and Kain 1971) was used to analyze for organic carbon content. The three cores from each sample were split into six layers (the top five were 2 cm each and the bottom layer was 3 cm). Corresponding layers from the three replicate cores were then combined before analysis. Results were in percent organic carbon and this figure was then converted to organic carbon m^{-2} for a 2 cm layer by

$$\text{Org C } m^{-2} = \text{\% Org C} \times \text{Sediment Density} \times 20000$$

where 20000 is the number of cm^3 in a 1 m^2 x 2 cm layer.

Measurements of sediment temperatures were made from 0900-1800 (DST) on 1 July 1973 at Drum Inlet. The measurements were taken at 3-hour intervals along both the Bare and Planted transects using stations 1, 3, 5 and 7. Readings were taken at 1 cm above the surface (shaded), at the surface, and 1 cm, 5 cm and 10 cm below the surface with a thermistor probe connected to a YSI Model 46 TUC tele-thermometer. The thermistor was placed inside a glass pipette so that it could be pushed into the sediment.

Spartina biomass was determined for each plot at the end of the growing season. Three 0.25 m^2 quadrats were harvested from each plot by clipping and removing all the aboveground standing material. Two cores (70.9 cm^2, 13 cm deep) were then taken within each quadrat for determination of belowground biomass. The sediment was washed from the root material which was then dried, as was the grass, at 100°C for two days before weighing.

RESULTS

Sediment Analysis

Particle Size Distribution

Particle size analysis revealed that the dredge spoil at Drum Inlet was very similar to the natural marsh sediment (Table 1). Since the spoil was dredged from Core Banks itself and within 0.5 km of the natural marsh this similarity was not surprising. In general the sediment at Drum Inlet was well sorted medium to fine sand with little silt or clay. The relative proportions of sand and silt-clay had not changed appreciably since the spoil was deposited. Comparison of the Bare and Planted sediment showed no apparent differences that could be attributed to the growth of *Spartina*.

At Snow's Cut the natural marsh sediment was distinct from the dredge spoil (Table 1). While the spoil was similar to that found at Drum Inlet, the natural marsh sediment was more poorly sorted and the median particle size was larger. In addition the natural marsh sediment had a much higher silt-clay content due to a mud layer which began about 12 cm below the surface. Again there was no apparent change in the proportions of sand and silt-clay in the spoil since its deposition but the Planted plot had a smaller median particle size than the Bare plot. Within the plots the larger particle size was at the higher elevation. The *Spartina* served to trap sediment and the Planted plot had increased in elevation relative to the Bare plot (Fig. 3b); most of the newly-accreted sediment would have been finer than the spoil and this would have reduced the overall median particle size. The most likely explanation

Table 1. Sediment particle size analysis for the study areas.

Location	% Sand Fraction					%				
	Very Coarse	Coarse	Med.	Fine	Very Fine	Silt-Clay	MdØ	Md mm	QDØ	Sk_qØ
Drum Inlet										
Bare										
High	0.5	4.8	38.3	52.1	2.2	2.0	2.14	0.235	0.55	-0.04
Low	1.3	11.2	39.3	40.4	2.3	5.6	1.97	0.255	0.55	-0.02
Planted										
High	0.2	7.0	45.7	43.6	2.8	0.9	1.95	0.257	0.48	+0.03
Low	1.7	10.9	40.1	42.7	2.7	2.0	1.97	0.255	0.55	-0.02
Fertilized	1.4	8.9	37.8	44.6	2.4	4.9	2.06	0.240	0.58	-0.04
Natural	1.6	9.9	38.3	40.8	5.8	3.6	2.02	0.246	0.57	0.00
Creek	1.3	8.3	39.4	44.0	3.9	3.1	2.04	0.242	0.54	-0.03
Snow's Cut										
Bare										
High	0.7	11.6	49.2	31.7	2.5	4.2	1.78	0.288	0.55	+0.07
Low	0.4	6.8	37.4	46.0	6.4	3.1	2.09	0.233	0.56	0.00
Planted										
High	0.1	5.3	45.7	42.2	3.8	2.8	1.98	0.252	0.54	+0.04
Low	0.2	5.8	27.6	54.4	8.2	3.7	2.37	0.192	0.53	-0.09
Natural	3.0	29.9	34.9	12.4	2.7	17.3	1.48	0.355	0.85	+0.12

for the difference with elevation is that the finer particles were being winnowed out of the sediment at higher elevations and either carried away entirely or deposited at lower elevations.

Organic Carbon Content

At both Drum Inlet and Snow's Cut the high intertidal sediment had less organic carbon than the low intertidal sediment (Fig. 4, 5). This was expected since both benthic algal and Spartina production are greater in the low marsh than in the high marsh (Pomeroy 1959; Teal 1962). Additionally, differences among the Bare, Planted and Fertilized plots within each area were slight and inconsistent suggesting that it was the benthic algae and not the Spartina which had the greatest effect on the incorporation of organic carbon into the sediment.

There was, however, a major difference between the natural marsh of the two study areas in the distribution of organic carbon with depth. Although both natural marshes had similar concentrations in the top 4 cm, below that point there was a logarithmic decrease at Drum Inlet and a logarithmic increase at Snow's Cut. The similarity in surface values suggests that the same surface source was active for both locations; it is likely that this source was a combination of benthic algae and Spartina detritus. The difference in distribution in the deeper sediments was probably due to the organic-rich mud layer, found in the Snow's Cut marsh but not at Drum Inlet, overwhelming the amount of organic carbon coming from the surface.

In order to further quantify the variation of organic carbon with depth at Drum Inlet the relation was expressed as

$$\log_{10}[\text{Org C}] = \log_{10}k + B \log_{10}\text{Depth}$$

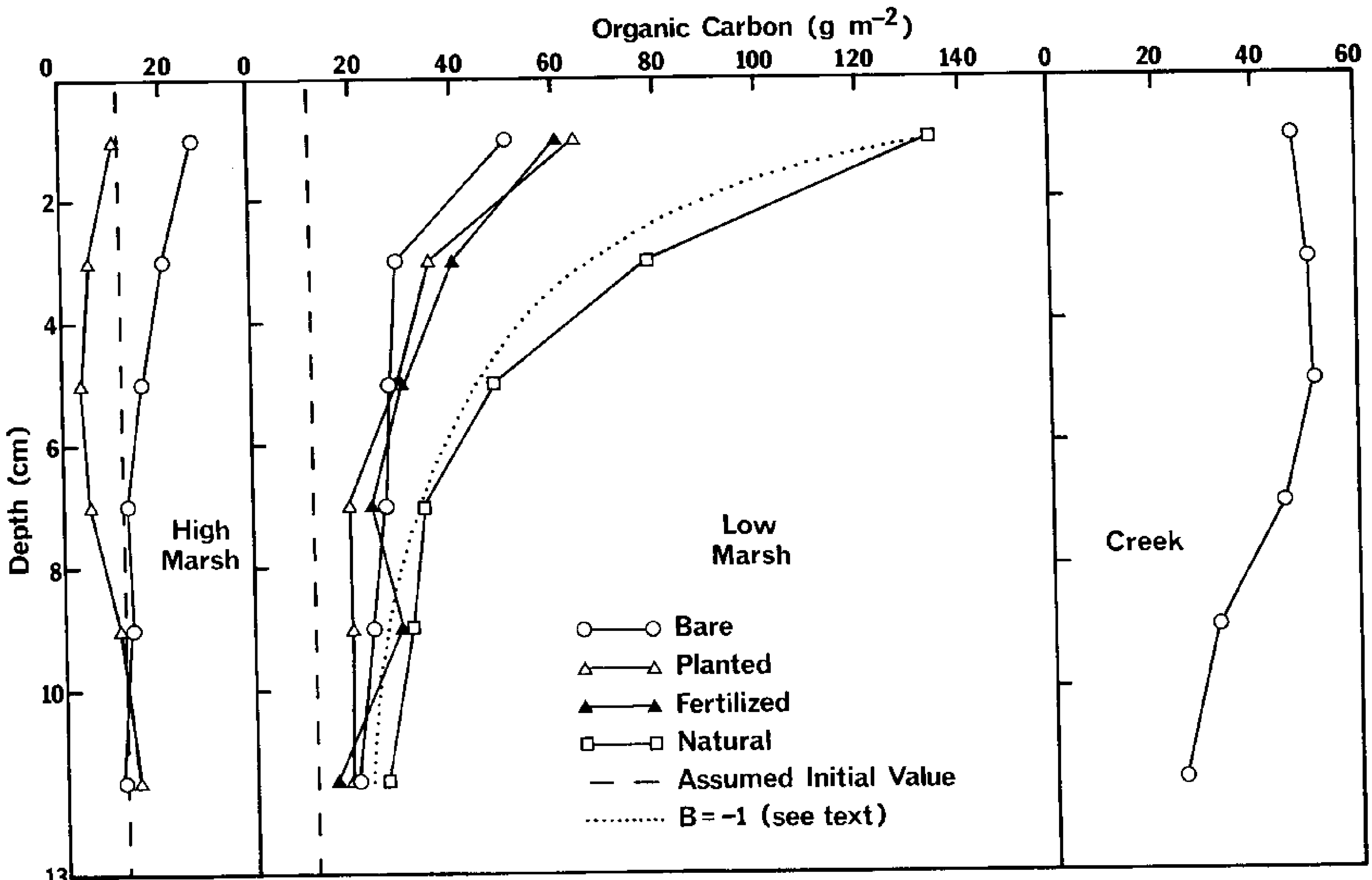

Figure 4. Distribution of sediment organic carbon with depth at Drum Inlet.

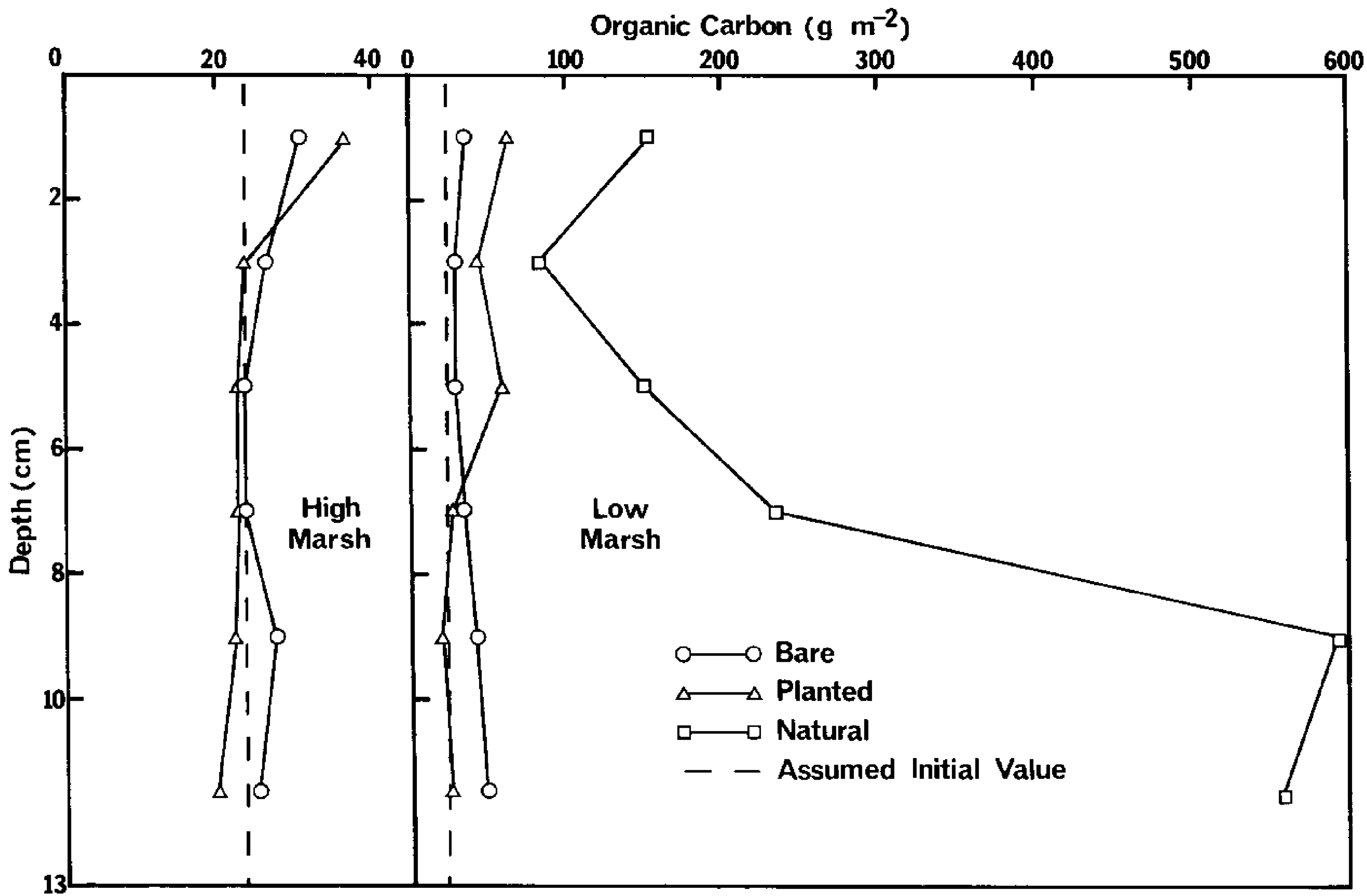

Figure 5. Distribution of sediment organic carbon with depth at Snow's Cut.

where [Org C] is the concentration of organic carbon in g m^{-2}, k is the hypothetical organic carbon concentration at the surface, and B is the extinction coefficient. Values of B were calculated for each low intertidal sample at Drum Inlet: Bare, B = -0.776 (r^2 = 0.93); Planted, B = -1.199 (r^2 = 0.93); Fertilized, B = -1.037 (r^2 = 0.83); natural, B = -0.954 (r^2 = 0.99). A value of B = -1 would indicate that the organic carbon concentration was inversely related to depth. The test for homogeneity of regression (Steel and Torrie 1960) showed that the values of B were not significantly different; this similarity supports the hypothesis that identical processes were causing the organic carbon distribution in all four plots at Drum Inlet. The only variable appeared to be the concentration of organic carbon at the surface; the presence of Spartina was not a factor.

It was necessary to assume some initial value of organic carbon at the time of spoil deposition so that changes after that time could be quantified. It is unlikely that the initial value was 0 and instead the average concentration of the deeper layers of the high marsh samples was taken as an initial value. It was shown above that the main input of organic carbon was from the surface; the deeper layers were more likely to represent the initial concentration. These values varied little with depth below 8 cm and were approximately the same for both the Bare and Planted plots within each area (Fig. 4, 5). The assumed initial values were 12.2 g C m^{-2} for Drum Inlet and 23.6 g C m^{-2} for Snow's Cut. No corrections were made for the presence of animals in the samples since they generally accounted for less than 1 g C m^{-2}.

By subtracting the assumed initial values of organic carbon and summing over the entire depth of the samples, the following values were calculated for the amount of organic carbon incorporated in the spoil since deposition for the low areas of the plots: DI Bare, 106.7 g m^{-2}; DI Planted, 116.0 g m^{-2}; DI Fertilized, 129.1 g m^{-2}; SC Bare, 77.0 g m^{-2}; SC Planted, 90.8 g m^{-2}. Organic carbon present in the samples from the natural marsh at Drum Inlet and Snow's Cut was 362.7 g m^{-2} and 2049.5 g m^{-2}, respectively.

Teal and Kanwisher (1961) found an average of 9.13% organic matter in a Georgia salt marsh, Chabreck (1972) reported an average of 12.32% organic carbon in Louisiana Spartina marsh, and Gray and Bunce (1972) reported an average of 8.4% loss on ignition from marsh sediments of Morecambe Bay, U. K. To facilitate comparison these values were converted to organic carbon where necessary by multiplying by a factor of 0.5 (Maciolek 1962) and expressed on a m^2 basis for a 13 cm layer by using a sediment density of 1.55 g cm^{-3} (the average value for the Drum Inlet and Snow's Cut sediments). The converted values for these three studies were, respectively, 9200 g C m^{-2}, 24800 g C m^{-2} and 8500 g C m^{-2}. The low values in the present study may have been due to the low percentage of silt-clay in the sediment; Wolff (1973) found a positive correlation between the percent organic matter and decreasing median grain size in sediments from the Delta area of the Netherlands and all of the above values were from sediments with over 20% silt-clay.

Since the spoil at Drum Inlet and Snow's Cut was deposited 16 and 30 months, respectively, before the samples were taken, it was possible to calculate the net rate of incorporation of organic carbon into the sediment: DI Bare, 80.1 g m^{-2} yr^{-1}; DI Planted, 87.0 g m^{-2} yr^{-1}; DI Fertilized, 96.8 g m^{-2} yr^{-1}; SC Bare, 30.8 g m^{-2} yr^{-1}; SC Planted, 36.3 g m^{-2} yr^{-1}.

For a gross annual production of 200 g C m^{-2} by benthic algae Pomeroy (1959) estimated the total annual respiration of the sediment community (including the benthic algae) to be 100 g C m^{-2}. From these figures the net organic carbon incorporated into the sediment due to the benthic algae was 100 g C m^{-2} yr^{-1}. Loss due to tidal action washing out surface particles and loss to herbivores not considered as part of the sediment community would tend to reduce this figure and it is quite similar to the values calculated for the Drum Inlet plots. The low rates for the Snow's Cut plots may have been due to a low rate of benthic algal production or dilution of a comparable production by the rapid accretion of new sediment.

Finally, by making the assumptions that the natural marsh has reached a steady state where the organic carbon concentration is neither increasing nor decreasing and that the rate of incorporation of organic carbon into the sediment will remain constant as the spoil plots age, we can estimate the time it will take the spoil marshes to reach concentrations of organic carbon comparable to those of the natural marsh. These times were estimated to be 4.5 years for the Drum Inlet Bare plot, 4.2 years for the Planted plot and 3.7 years for the Fertilized plot from the time of deposition.

The same calculations may be made for the Snow's Cut spoil plots although the presence of the underlying mud layer in the natural marsh makes the assumption of steady state questionable. The estimated times to maturity for the Snow's Cut spoil plots were 26.6 years for the Bare plot and 22.6 years for the Planted plot.

Sediment Temperature

At all depths in the sediment and in the air 1 cm above the sediment all temperatures recorded from station 5 at Drum Inlet on 1 July 1973 were higher in the Planted plot than in the Bare plot (Table 2). There were no clouds present and insolation was probably near its maximum value for the year. The difference in temperature was maintained throughout the day and readings similar to these were found at the other stations followed throughout the day. Pomeroy (1959) found the same temperature difference between bare areas of a Georgia marsh and areas where dense stands of Spartina were growing and attributed it to a combination of greenhouse effect and reduced evaporation of water from the sediments. The maximum surface temperatures he recorded were about 36° and 40°C, respectively, similar to those from Drum Inlet.

Spartina Biomass

The aboveground biomass of Spartina in the spoil plots approached or surpassed that of the natural marsh at both Drum Inlet and Snow's Cut (Table 3) but the belowground biomass was less than half that of the natural marsh in both areas. Values of Spartina biomass in both areas were typical for southern marshes. The aboveground biomass fell within the range reported by Stroud and Cooper (1968) of 259-1320 g m^{-2} and by Williams and Murdoch (1966) of 250-2100 g m^{-2} for other North Carolina marshes. Gallagher (1974) found values of 4130 g m^{-2} for the belowground biomass in areas of medium Spartina in a Georgia marsh but his samples were 15 cm deep. Assuming distribution was uniform to the 15 cm depth, the top 13 cm would have had 3580 g m^{-2} and that value is within the range of values found in this study for the natural marshes.

Table 2. Sediment temperatures (°C) from station 5 at Drum Inlet on 1 July 1973; time is DST.

		Time (hr)			
Plot	Depth	0900	1200	1500	1800
Bare	Air (+1 cm)	31.6	35.2	32.3	28.0
Planted	"	32.7	35.6	32.7	29.3
Bare	Surface (0 cm)	31.6	36.9	35.4	29.2
Planted	"	33.5	37.7	36.0	29.9
Bare	-1 cm	31.2	36.8	35.6	29.6
Planted	"	33.0	37.5	36.4	30.1
Bare	-5 cm	29.4	35.3	35.2	30.9
Planted	"	30.8	35.9	36.1	31.1
Bare	-10 cm	27.6	32.4	33.7	31.3
Planted	"	28.6	33.1	34.5	31.7

Table 3. Standing crop of *Spartina alterniflora* in the study plots.

	Biomass ($g\ m^{-2}$)		
Location	Aboveground	Belowground	Date
Drum Inlet			
Bare	--	--	--
Planted	709.3	605.0	11 Sept.
Fertilized	1650.0	1348.1	11 Sept.
Natural	1056.1	3169.6	12 Sept.
Snow's Cut			
Bare	--	--	--
Planted	953.3	2388.4	18 Sept.
Natural	637.7	4966.0	26 Nov.

Faunal Analysis

All of the transects except the Drum Inlet Fertilized and the Snow's Cut natural were divided into two sections: an upper section made up of what were considered the "marsh" stations, and a lower section made up of the "creek" stations (Tables 4, 5). This was done after preliminary analysis of the data revealed an obvious change in total faunal biomass per sample between stations 2 and 3 at Drum Inlet and between stations 1 and 2 at Snow's Cut (Fig. 6). The change in biomass corresponded in each area to the true boundary of the *Spartina* marsh, the lower limit of *Spartina* growth. The "creek" at Drum Inlet was a true tidal creek while at Snow's Cut the "creek" was actually the Cape Fear River estuary (Fig. 2).

Drum Inlet

The trellis diagram for faunal affinity (Fig. 7) indicates that two main assemblages were present. One assemblage was made up of the creek stations and the natural marsh and the other was made up of the Bare and Planted spoil marsh. The Fertilized marsh did not seem to fit into either of these groupings but was closer to the other spoil plots than to the natural marsh. The dominant fauna of the creek-natural assemblage were polychaetes, *Laeonereis culveri* and the Capitellidae. Together they accounted for about 80% of the biomass of the three creek transects and about 60% of the natural marsh; in the Bare and Planted spoil marsh they were only about 36% of the biomass. The Bare and Planted marsh fauna was predominantly insect larvae which made up 56-63% of the biomass, as opposed to 7% for the natural marsh and less than 1% for the creek stations. The high faunal affinity between the Bare and

Table 4. Numbers and biomass (g) per m^2 of macrofauna collected at Drum Inlet. Numbers and biomass of *Uca pugilator* are included in the table but not in the totals (see Methods).

Species	Creek			Marsh			
	Bare	Planted	Natural	Bare	Planted	Natural	Fertilized
Annelida Total	3658.4[a] 9.6585[b]	2603.1 9.3253	5056.4 13.7723	220.9 0.1776	141.6 0.1389	1167.8 2.5095	297.9 0.1843
Capitellidae	2715.1 5.9048	1939.4 5.5198	3493.0 8.3653	206.8 0.1767	127.6 0.1264	964.0 1.9732	78.4 0.1724
Laeonereis culveri	766.9 3.4297	593.1 3.7054	1508.5 4.8202	5.6 0.0003	5.6 0.0104	109.7 0.2981	- -
Scoloplos fragilis	126.9 0.2445	14.1 0.0476	47.0 0.4236	2.8 0.0003	- -	- -	- -
Streblospio benedicti	28.2 0.0100	28.2 0.0312	- -	- -	2.8 0.0016	- -	- -
Paraonis fulgens	- -	- -	- -	- -	- -	7.9 0.0012	- -
Nereis succinea	7.1 0.0394	7.1 0.0146	7.9 0.1632	- -	- -	86.2 0.2370	- -
Eteone heteropoda	7.1 0.0091	- -	- -	- -	- -	- -	- -

[a]Numbers, [b]Biomass

Table 4. (continued).

Species	Creek			Marsh			
	Bare	Planted	Natural	Bare	Planted	Natural	Fertilized
Glycera sp.	7.1 0.0210	- -	- -	- -	- -	- -	- -
Paranais litoralis	- -	- -	- -	5.6 0.0003	- -	- -	- -
Henlea ventriculosa	- -	21.2 0.0067	- -	- -	2.8 0.0003	- -	- -
Enchytraeus albidus	- -	- -	- -	- -	- -	- -	141.0 0.0091
Tubificidae	- -	- -	- -	- -	2.8 0.0002	- -	78.5 0.0028
Arthropoda Total	28.3 0.1206	35.4 0.0403	0.0 0.0	1077.3 0.3100	371.4 0.2475	321.5 0.4846	752.4 0.9623
Acanthohaustorius millsi	- -	- -	- -	8.5 0.0010	- -	- -	- -
Orchestia grillus	- -	- -	- -	- -	2.8 0.0001	86.2 0.0163	15.7 0.0099
Gammarus palustris	- -	- -	- -	- -	- -	15.7 0.0025	- -
Sesarma cinereum	- -	- -	- -	- -	- -	23.5 0.1960	- -

Table 4. (continued).

Species	Creek			Marsh			
	Bare	Planted	Natural	Bare	Planted	Natural	Fertilized
Neomysis americana	7.1 0.0254	- -	- -	- -	- -	- -	- -
Argulus sp.	- -	7.1 0.0007	- -	- -	- -	- -	- -
Dolichopodidae	21.2 0.0952	21.2 0.0296	- -	138.0 0.0504	73.3 0.0468	54.9 0.0714	78.4 0.0081
Ephydridae	- -	- -	- -	758.7 0.1782	217.9 0.1686	15.7 0.0079	282.1 0.1623
Staphylinidae	- -	- -	- -	112.9 0.0352	33.8 0.0045	- -	15.7 0.0025
Muscidae	- -	7.1 0.0100	- -	42.3 0.0425	28.2 0.0227	- -	31.3 0.0122
Stratiomyidae 1	- -	- -	- -	- -	- -	62.7 0.1626	188.2 0.6844
Tabanidae	- -	- -	- -	2.8 0.0008	2.8 0.0014	54.9 0.0272	78.3 0.0550
Stratiomyidae 2	- -	- -	- -	2.8 0.0009	5.6 0.0031	- -	62.7 0.0279
Tendipedidae	- -	- -	- -	- -	- -	7.9 0.0007	- -

Table 4. (continued).

Species	Creek			Marsh			
	Bare	Planted	Natural	Bare	Planted	Natural	Fertilized
Hydrophilidae	-	-	-	11.3	3.5	-	-
	-	-	-	0.0010	0.0001	-	-
Melyridae	-	-	-	-	3.5	-	-
	-	-	-	-	0.0002	-	-
Mollusca	35.3	84.6	235.1	0.0	0.0	70.7	0.0
Total	1.8916	2.0892	3.1578	0.0	0.0	0.8208	0.0
Gemma	28.2	70.5	223.3	-	-	47.1	-
gemma	0.0051	0.0043	0.0139	-	-	0.0072	-
Tagelus	7.1	14.1	11.8	-	-	-	-
plebius	1.8865	2.0849	3.1439	-	-	-	-
Arcuatula	-	-	-	-	-	15.7	-
demissa	-	-	-	-	-	0.3440	-
Melampus	-	-	-	-	-	7.9	-
bidentatus	-	-	-	-	-	0.4696	-
Rhynchocoela	0.0	0.0	0.0	0.0	0.0	23.5	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0214	0.0
Uca	-	-	-	25.4	26.8	148.8	-
pugilator	-	-	-	0.0917	2.4125	0.9805	-
Overall	3722.0	2723.1	5291.5	1298.2	513.0	1583.5	1050.3
Total	11.6707	11.4548	16.9301	0.4876	0.3864	3.8363	1.1466

Table 5. Numbers and biomass (g) per m^2 of macrofauna collected at Snow's Cut. Numbers and biomass of Uca pugilator are included in the table but not in the totals (see Methods).

Species	Creek		Marsh		
	Bare	Planted	Bare	Planted	Natural
Annelida Total	674.0[a] 3.7061[b]	1030.4 7.7518	2177.9 6.7144	31.3 0.0127	579.9 1.3202
Capitellidae	282.1 1.2736	219.4 1.3800	78.2 0.3652	5.2 0.0013	31.4 0.0256
Laeonereis culveri	344.8 2.4059	795.3 6.3701	2013.4 6.3188	- -	141.0 0.5143
Streblospio benedicti	15.7 0.0009	15.7 0.0017	31.4 0.0037	- -	- -
Nereis succinea	15.7 0.0154	- -	- -	5.2 0.0090	391.8 0.7784
Scolecolepides viridis	15.7 0.0103	- -	54.9 0.0267	- -	15.7 0.0019
Enchytraeus albidus	- -	- -	- -	20.9 0.0024	- -
Arthropoda Total	345.0 0.1970	877.0 0.5237	305.8 0.3282	788.7 0.2473	13615.1 1.0343
Lepidactylus dytiscus	313.7 0.1371	767.3 0.4330	211.6 0.2313	480.5 0.1476	- -

[a]Numbers, [b]Biomass

Table 5. (continued).

Species	Creek		Marsh		
	Bare	Planted	Bare	Planted	Natural
Neomysis	-	-	-	73.1	-
americana	-	-	-	0.0118	-
Cyathura	31.3	47.0	39.2	10.5	13458.4
polita	0.0599	0.0715	0.0452	0.0066	0.8740
Gammarus	-	15.7	-	62.7	94.0
palustris	-	0.0016	-	0.0280	0.0432
Cassinidea	-	-	-	47.0	31.3
lunifrons	-	-	-	0.0061	0.0055
Sesarma	-	-	-	-	15.7
reticulatum	-	-	-	-	0.0260
Callinectes	-	-	-	-	15.7
sapidus	-	-	-	-	0.0856
Dolichopodidae	-	47.0	55.0	99.2	-
	-	0.0176	0.0517	0.0477	-
Ephydridae	-	-	-	5.2	-
	-	-	-	0.0019	-
Tendipedidae	-	-	-	10.5	-
	-	-	-	0.0006	-

Table 5. (continued).

Species	Creek		Marsh		
	Bare	Planted	Bare	Planted	Natural
Mollusca Total	15.7 0.0047	0.0 0.0	0.0 0.0	0.0 0.0	47.0 0.5057
Tellina sp.	15.7 0.0047	- -	- -	- -	- -
Arcuatula demissa	- -	- -	- -	- -	47.0 0.5057
Rhynchocoela Total	31.3 0.0417	47.0 0.1144	31.3 0.1392	0.0 0.0	15.7 0.0028
Uca pugilator	- -	- -	- -	31.3 0.7659	31.3 1.7094
Overall Total	1066.0 3.9495	1954.4 8.3899	2515.0 7.1818	820.0 0.2600	14257.7 2.8630

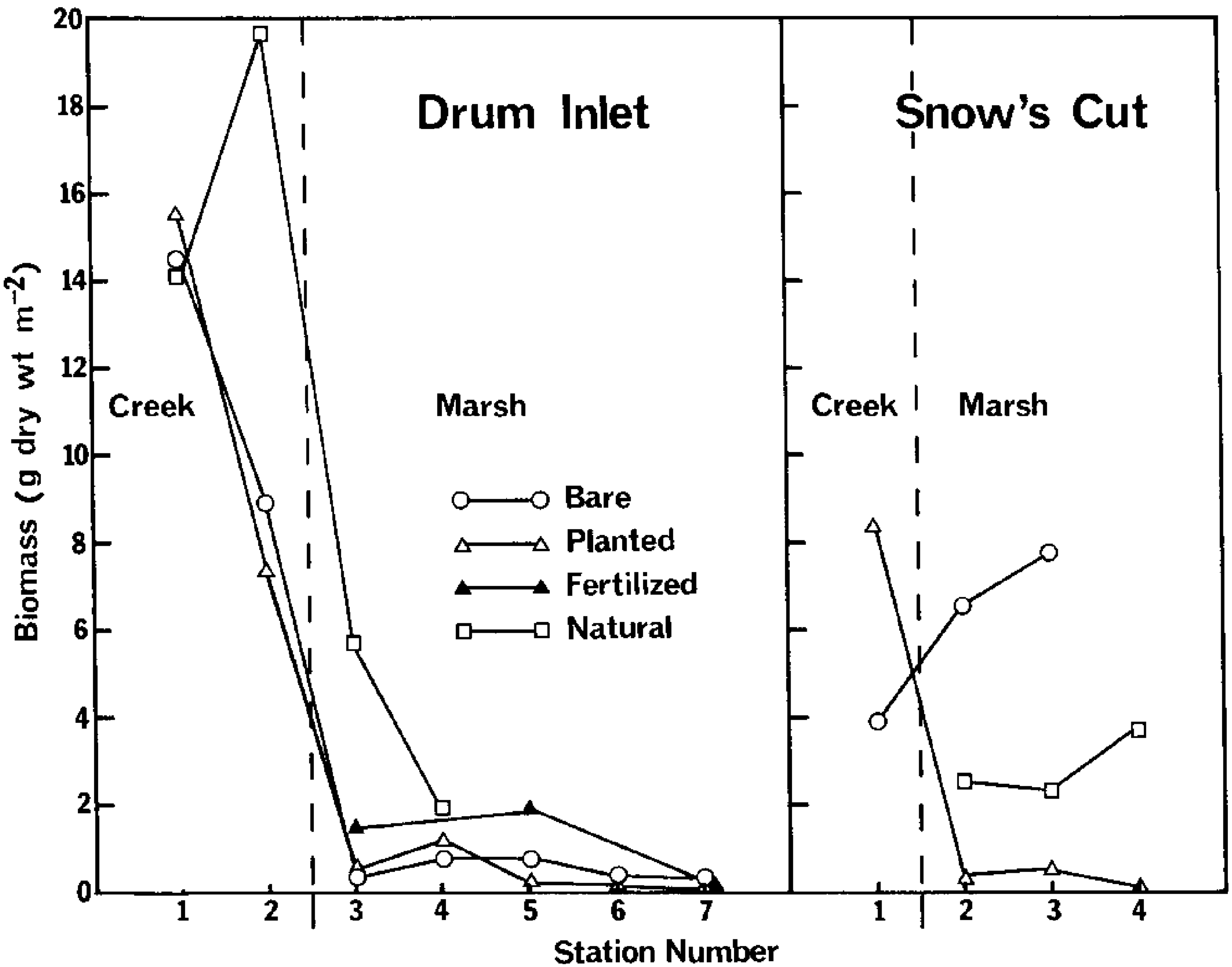

Figure 6. Change in faunal biomass between creek and marsh stations.

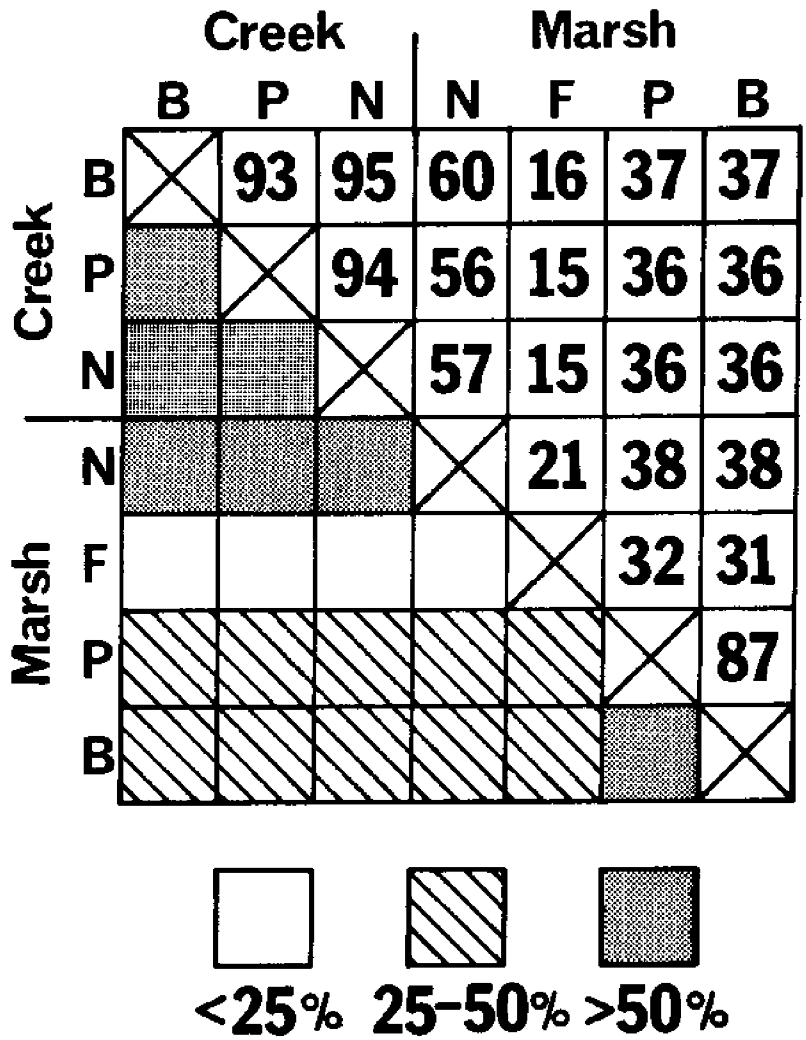

Figure 7. Trellis diagram of index of affinity between plots at Drum Inlet; letters represent plots: B (Bare), P (Planted), F (Fertilized), N (natural).

Planted plots indicated that the growth of the Spartina had not had a noticeable effect on the macrofauna. In the Fertilized marsh the two polychaetes accounted for 15% of the biomass while insect larvae made up 83%.

Teal (1962) and Wall (1973) listed species they found in salt marshes in Georgia and Massachusetts, respectively, and since most of the species collected in this study were included in their lists it was possible to classify the species into those normally occurring in salt marsh and those normally occurring in other habitats. "Marsh" species accounted for 14 of the 16 species found in the natural marsh (including Uca pugilator) and over 99% of the biomass. The natural marsh had eight species in common with the planted spoil (both the Planted and Fertilized plots) and those species made up 67% of the total natural marsh biomass and 94% of the Planted spoil biomass. Half the species found in the natural marsh had already colonized the spoil marsh and they were relatively more successful there than in the natural marsh; presumably this was due to the lack of competition from the eight other marsh species which had been unable to colonize the spoil.

Differences between the Bare and Planted plots in the average number of individuals per sample were apparent but the biomass remained similar throughout the summer (Fig. 8). Both plots had their greatest biomass in May due to a spring peak in the insect larval biomass (Fig. 9); by the end of June 90% of the insect larval biomass was gone due to the emergence of the adults. Although there was no significant difference between the plots for this peak biomass, the number of individuals was much greater in the Bare plot ($P < 0.05$). One insect family, the Ephydridae (brine flies), was responsible for this difference; while the average number of individuals present at stations 4, 5 and 6 of the Bare plot

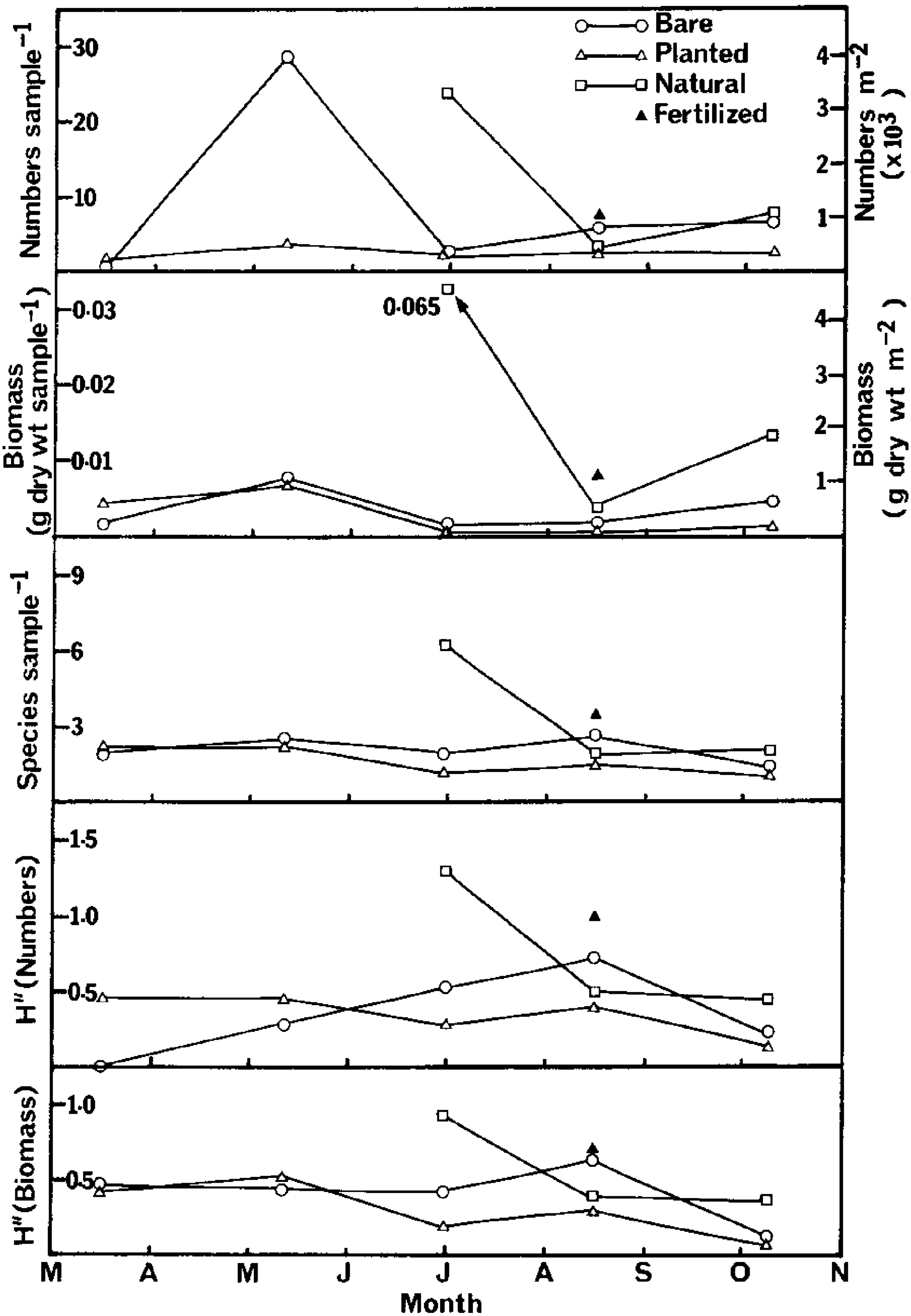

Figure 8. Seasonal variation of numbers, biomass and diversity measures for the macrofauna at Drum Inlet.

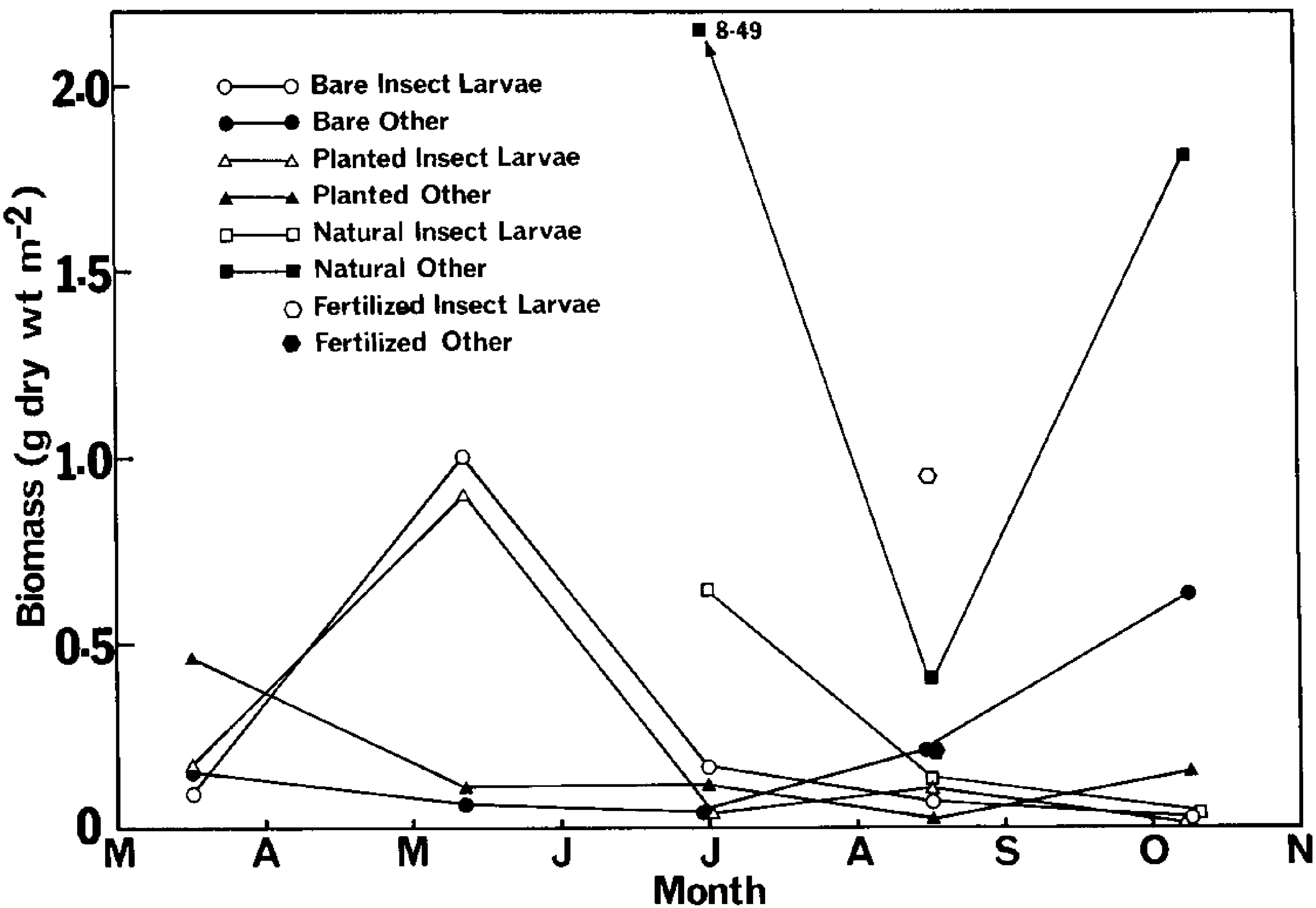

Figure 9. Seasonal variation of insect larval biomass compared with the biomass of other macrofauna at Drum Inlet.

was 11200 m^{-2}, there were only 1200 m^{-2} at the corresponding stations of the Planted plot. The August samples again showed that the Bare plot had a greater number of individuals ($P < 0.05$); this was due chiefly to an abundance of Staphylinidae (rove beetles) in concentrations averaging 480 m^{-2}, compared with 140 m^{-2} for the Planted plot. In October the Bare plot had significantly greater biomass and more individuals ($P < 0.05$); this difference could be attributed to the distribution of the Capitellidae, 780 m^{-2} with a biomass of 0.624 g m^{-2} in the Bare plot and only 210 m^{-2} with a biomass of 0.147 g m^{-2} in the Planted plot. On an overall basis, for the entire sampling period, there was no significant difference in biomass between the two plots; the Bare plot did appear to have a greater number of individuals but due to the spring peak there was a highly significant Transect x Date interaction (Table 6). The Spartina had no apparent effect on the total biomass of the spoil plots.

The August sampling of the Fertilized plot revealed a greater biomass than for either of the other spoil plots ($P < 0.05$) and a larger number of individuals than the Planted plot ($P < 0.05$). This difference was due to the presence of large numbers of Stratiomyid (soldier fly) larvae, averaging 188 m^{-2} with a biomass of 0.684 g m^{-2}; in contrast no Stratiomyidae were ever found in the other spoil plots. For comparison the natural marsh had a peak Stratiomyid biomass of 0.437 g m^{-2} at the end of June but that figure had dropped to 0.038 g m^{-2} in August. Adult mosquitoes were not present during the day in any of the other areas sampled but in the Fertilized plot they were extremely abundant, suggesting that the dense growth of Spartina (see Table 3) reduced evaporation and kept humidity fairly high in the plot and this may have encouraged the growth of the Stratiomyidae; the fact that mosquitoes were

Table 6. Analysis of variance for faunal measures of the Bare and Planted marsh at Drum Inlet.

	Transect F values	Date F values	Interaction (T x D) F values
Numbers	19.40 ***	13.21 ***	7.64 ***
Biomass	0.24	3.17 *	0.46
No. of Species	3.89	3.61	0.79
H"(Numbers)	1.33	2.83 *	1.65
H"(Biomass)	2.73	3.77 **	1.11

* Significant at the 95% level

** Significant at the 99% level

*** Significant at the 99.9% level

not observed in the natural marsh indicated that the natural density of Spartina was not high enough to affect evaporation to this degree.

The natural marsh had a greater number of individuals and a higher biomass than the spoil plots at the end of June ($P < 0.01$) but by the end of the sampling period these differences had disappeared. The June biomass was about nine times that of the peak biomass of the spoil plots, which had occurred in May, and about 50 times the June spoil biomass. On an overall basis (Table 7) the natural marsh seemed to have significantly more individuals and a higher biomass than the spoil plots, but there was a significant Transect x Date interaction in each case. The interaction was due to the drop in both measures which occurred between the end of June and the middle of August (Fig. 8)

In order to estimate and compare the production of the spoil plots with that of the natural marsh it was necessary to make several assumptions. The Bare and Planted plots both had a generation of insect larvae and for that generation annual production was assumed to be equal to the peak standing stock, 1.01 and 0.89 g m^{-2}, respectively. The average standing stock for the rest of the invertebrates was 0.21 g m^{-2} for the Bare plot and 0.15 g m^{-2} for the Planted plot. Previous authors have estimated annual production by assuming it to be twice the average standing stock (Sanders 1956; Gerlach 1971; Day et al. 1973). Using this factor to estimate production of the other macroinvertebrates and adding in the insect larval production already calculated gives an estimated annual production of about 1.4 g m^{-2} for the Bare plot and 1.2 g m^{-2} for the Planted plot. In the same way the natural marsh annual production can be estimated from the peak insect larval biomass of 0.64 g m^{-2} and the average standing stock of the other macroinvertebrates, 3.57 g m^{-2}, and was about 7.7 g m^{-2}. Winter biomass of annelids and insect larvae

Table 7. Analysis of variance for faunal measures of the Bare, Planted and natural marsh at Drum Inlet.

	Transect F values	Date F values	Interaction (T x D) F values
Numbers	35.67 ***	6.45 **	27.50 ***
Biomass	34.92 ***	10.82 ***	19.88 ***
No. of Species	10.13 ***	3.12	5.04 **
H''(Numbers)	8.45 **	6.31 **	3.77 *
H''(Biomass)	6.41 **	5.50 **	2.83 *

* Significant at the 95% level

** Significant at the 99% level

*** Significant at the 99.9% level

may approach 1.7 times the summer biomass in Georgia marshes (Teal 1962); this suggests that the production estimates may be too low since no winter samples were taken in this study.

In addition to the functional attributes measured by the number of individuals and the biomass, a community also possesses certain structural attributes which may be expressed by various diversity indices. The average number of species per sample, the sample diversity computed with numbers of individuals [H"(Numbers)], and the sample diversity computed with biomass [H"(Biomass)] were followed throughout the sampling period for all the transects (Fig. 8). There were no significant differences between the Bare and Planted plots for any of the months sampled and there were no overall differences either (Table 6) showing that the *Spartina* had not yet affected the community structure. As was the case with numbers and biomass, the natural marsh was significantly greater than either of the spoil marshes in all the structural attributes that were measured in the June samples [$P < 0.05$ for H"(Biomass), $P < 0.01$ for the other measures], but by August the differences were gone. H"(Biomass) was greater in the natural marsh than in the spoil marshes in October ($P < 0.05$) but the other measures were not significantly different. On an overall basis the natural marsh appeared to be significantly different from the spoil marshes in all three of these measures; however, due to the decrease in all three measures between June and August significant Transect x Date interactions were present (Table 7). It appears then that in June, when biomass was at its peak, the natural marsh was a more diverse community with more niches occupied than for either the Bare or Planted spoil plots.

In addition to sample diversities, overall diversity and evenness were computed for each plot from the data of Table 4. These values, presented in Table 8, take into account not only the variation over space in the community structure (the sample diversity) but also the variation over time. Thus an area with an extreme seasonal peak in one species or group may have a low overall diversity or evenness even though values for both measures were high during the rest of the year.

There was a definite difference in diversity between the creek and marsh stations with the marsh stations generally having more species and higher values of evenness and thus higher values of H" (Table 8). Within the creek stations the natural creek had only about half as many species as the others but the greater evenness among the species caused the diversity to be about the same. Eight species were present in the Bare and Planted creek samples but not in the natural creek samples; however, five of the species were no longer present in June when natural creek sampling began and the remaining three were relatively unimportant, accounting for less than 1% of the Bare and Planted creek biomass. Since the creek was common to all three plots, the free tidal circulation was expected to obscure any plot effects, making the creek stations a control for the sampling method; the similarity of the creek samples tended to validate the sampling.

Within the marsh stations the Bare and Planted plots had similar values for H"(Biomass) and differed from the natural marsh but H"(Numbers) showed a similarity between the Planted plot and the natural marsh (Table 8). Wilhm (1968) pointed out that H"(Biomass) is a much better approximation than H"(Numbers) of the ideal diversity index which would use energy units as a basis for calculation. Although sampled over a shorter period of time than the spoil area the natural marsh still had more species than any of the spoil plots and given an equally long sampling period the total probably would have been higher. Evenness values were

Table 8. Overall faunal diversity and evenness for marsh and creek stations at Drum Inlet.

	Creek			Marsh			
	Bare	Planted	Natural	Bare	Planted	Natural	Fertilized
Total No. of Species (S)	11	11	6	12	14	16	11
H''(Numbers)	0.841	0.898	0.827	1.328	1.628	1.644	2.108
J(Numbers)	0.351	0.375	0.462	0.534	0.616	0.594	0.880
H''(Biomass)	1.175	1.105	1.164	1.442	1.404	1.666	1.295
J(Biomass)	0.490	0.461	0.650	0.579	0.531	0.601	0.540

generally similar for all the plots indicating that the spring insect larval peak in the spoil marshes had little effect. The Fertilized plot had the highest value of H"(Numbers) and the lowest value of H"(Biomass); this was because the dominant fauna, the Stratiomyidae, made up 60% of the biomass but only 18% of the individuals. Generally the results indicate that the natural marsh had a higher number of niches occupied over a longer period of time than the spoil marshes.

Snow's Cut

Three faunal assemblages were present at Snow's Cut (Fig. 10). The first was made up of the creek stations and the Bare marsh, the second was the Planted marsh and the third was the natural marsh. Just as at Drum Inlet the natural marsh was more closely related to the creek stations than to the Planted spoil. The dominant fauna of the creek-Bare marsh assemblage were the polychaetes Laeonereis and the Capitellidae which together accounted for 93% of the creek biomass and 93% of the Bare marsh biomass; they accounted for only 19% of the natural marsh biomass and 5% of the Planted marsh biomass. The Planted plot fauna consisted mainly of three species -- the amphipods Lepidactylus dytiscus and Gammarus palustris, and the Dolichopodidae (long-legged flies) -- which together made up 85% of the biomass. Four species were dominant in the natural marsh -- the polychaetes Laeonereis and Nereis succinea, the isopod Cyathura polita, and the ribbed mussel Arcuatula (=Modiolus) demissa; they accounted for 93% of the total faunal biomass.

At Drum Inlet the Bare and Planted plots had a high affinity (Fig. 7) but at Snow's Cut the affinity was only 5% (Fig. 10). The reason for the low affinity was the complete absence of Laeonereis, the

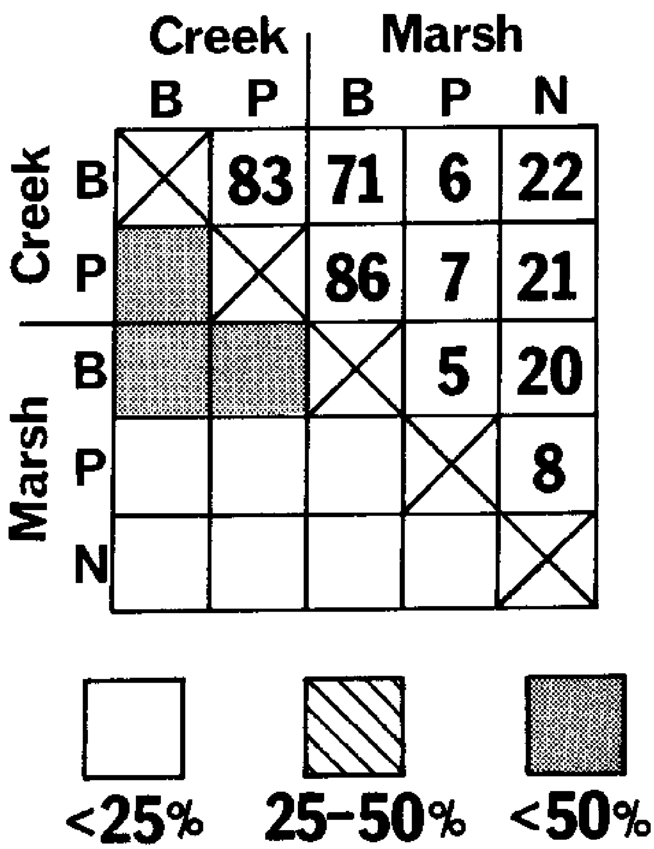

Figure 10. Trellis diagram of index of affinity between plots at Snow's Cut; letters represent plots: B (Bare), P (Planted), N (natural).

dominant species in the Bare marsh, from the Planted marsh. Laeonereis is most common "in sandy shoals at moderately low to very low water lines" (Hartman 1945); since the sediment of both plots was similar (Table 1) it appears to have been the difference in elevation between the two plots (Fig. 3b) that was significant in preventing Laeonereis from colonizing the Planted marsh as well as the Bare. Therefore the Spartina had a major, if indirect, effect on the fauna of the spoil plots by causing rapid sediment accretion in the Planted plot with a consequent increase in elevation.

Using the lists of Teal (1962) and Wall (1973) to classify the species, the natural marsh had 10 "marsh" species out of its total of 12 (including Uca) and the Planted marsh had 11 "marsh" species out of 12 total (also including Uca). However, on a biomass basis the "marsh" species made up over 99% of the natural marsh fauna but only 43% of the Planted marsh fauna. Evidently conditions were not yet favorable in the Planted plot for most of the natural marsh species.

In contrast to Drum Inlet the Bare and Planted marsh plots were consistently different in the number of individuals and total biomass present throughout the sampling period (Fig. 11). The Bare plot had significantly greater biomass in May ($P < 0.05$), July ($P < 0.01$), September ($P < 0.05$) and November ($P < 0.001$); numbers were significantly higher in May, September and November ($P < 0.05$). There appears to have been a peak in insect larval biomass in the Planted marsh in May (Fig. 12) but sampling was initiated too late in the year to be certain; in the May sample insect larvae made up about 83% of the total biomass but by July that figure had fallen to 8%. Most of the difference in numbers and biomass between the spoil plots was due to the difference in the population size of Laeonereis. The increase in numbers in the Bare plot in November

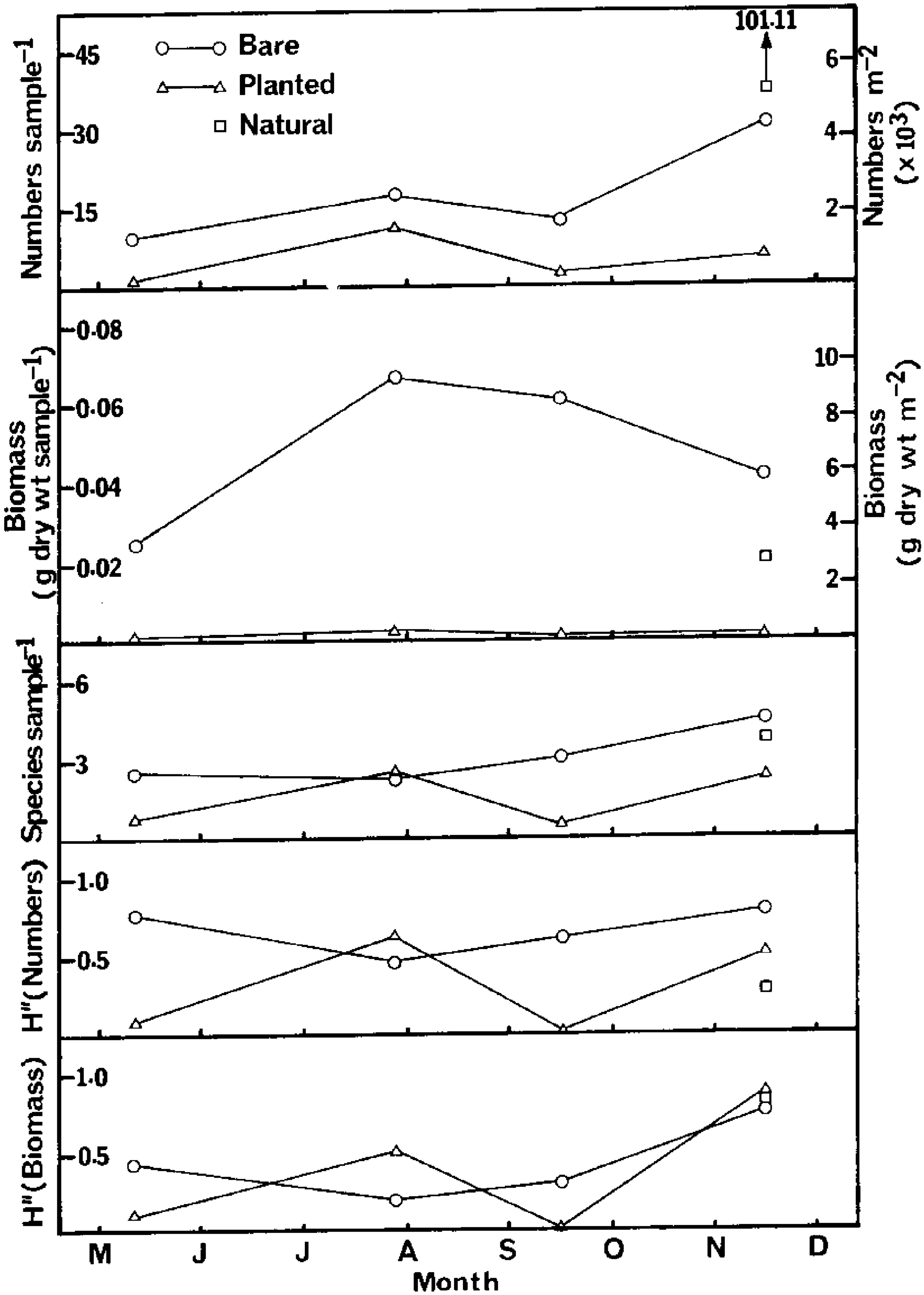

Figure 11. Seasonal variation of numbers, biomass and diversity measures for the macrofauna at Snow's Cut.

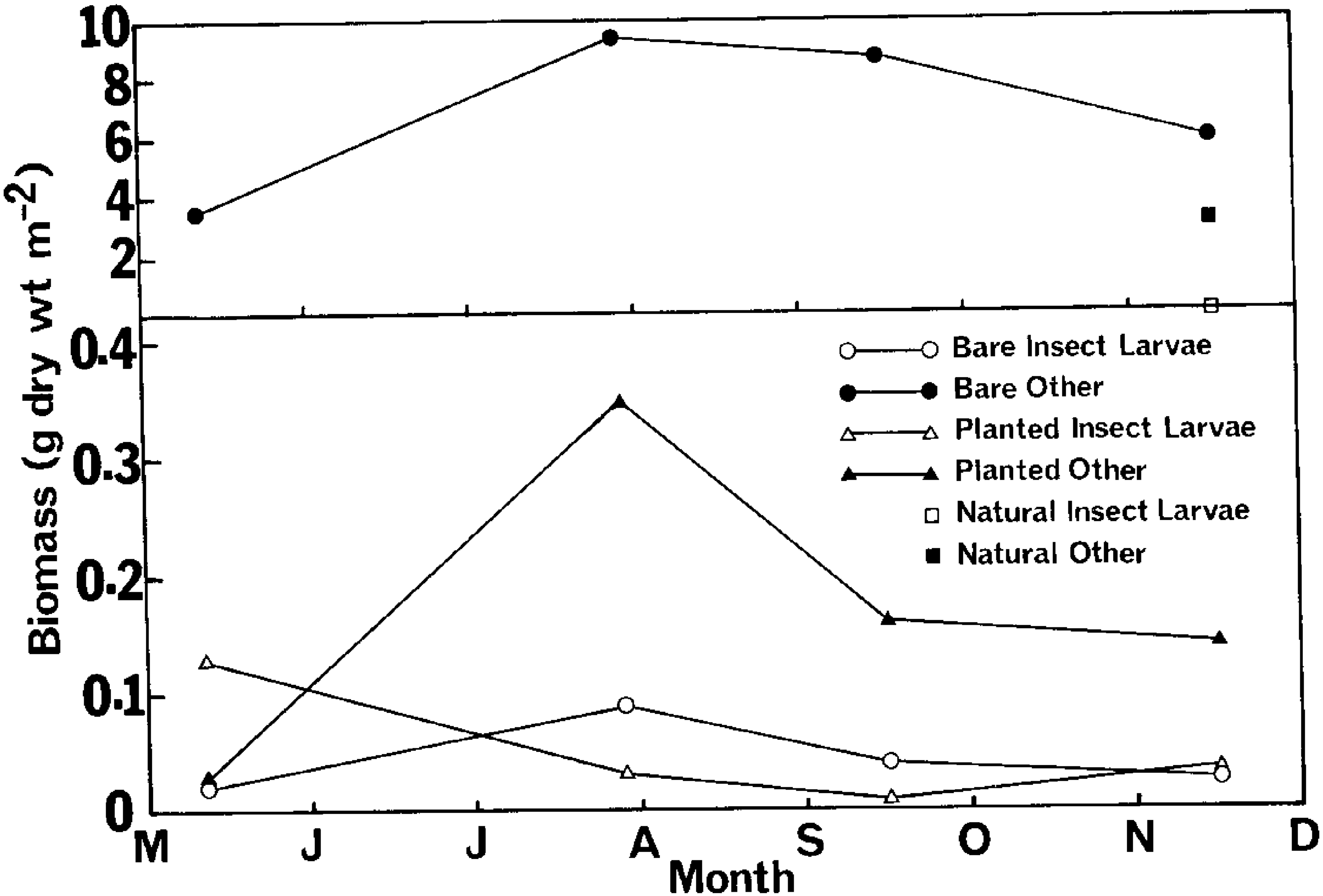

Figure 12. Seasonal variation of insect larval biomass compared with the biomass of other macrofauna at Snow's Cut.

was due to the collection of large numbers of juvenile Laeonereis, up to 8700 m^{-2}; these were probably the offspring from the spring spawning that had reached a size sufficient to be retained on the 1 mm sieve. An overall comparison of the two plots showed that the differences in numbers and biomass were highly significant (Table 9).

The November sampling of the natural marsh revealed a higher number of individuals than either of the spoil plots ($P< 0.01$) and a greater biomass than the Planted plot ($P< 0.01$) (Table 10); the Bare plot had a greater biomass than the natural marsh ($P< 0.01$). The high number of individuals was due to the large number of juvenile Cyathura that were present, as many as 21200 m^{-2}. No juvenile Cyathura were ever observed in the spoil plots during the course of this study.

Macrofaunal production was estimated in the same way as for Drum Inlet. Average biomass of the non-insect macrofauna for the Bare and Planted marsh plots was 6.85 and 0.17 g m^{-2}, respectively, and the peak standing stocks of insect larvae were 0.09 g m^{-2} for the Bare plot and 0.13 g m^{-2} for the Planted plot. Together these values give an annual macrofaunal production of 13.8 g m^{-2} for the Bare plot and 0.5 g m^{-2} for the Planted plot. Assuming the November biomass for the natural marsh was close to the yearly average, production there was 5.7 g m^{-2} yr^{-1}.

From these estimates it appears that the Bare marsh production was about 2.5 times that of the natural marsh and about 25 times that of the Planted marsh. The latter ratio is undoubtedly much too high; the peak biomass of insect larvae was not known for all the plots and since the percentage of insect larvae was greatest in the Planted plot, the relative underestimate of production probably was greatest there also. Again there was a systematic error introduced by the lack of winter sampling.

Differences in the structural community measures were present but

Table 9. Analysis of variance for faunal measures of the Bare and Planted marsh at Snow's Cut.

	Transect F values	Date F values	Interaction (T x D) F values
Numbers	14.58 ***	3.03 *	1.90
Biomass	54.45 ***	1.54	0.23
No. of Species	16.24 ***	2.26	1.97
H"(Numbers)	5.34 *	1.92	2.64
H"(Biomass)	0.66	3.08 *	3.37 *

* Significant at the 95% level

** Significant at the 99% level

*** Significant at the 99.9% level

Table 10. Analysis of variance for faunal measures for the November sampling of the Bare, Planted and natural marsh at Snow's Cut.

	Transect F values
Numbers	25.10 ***
Biomass	25.30 ***
No. of Species	3.51
H"(Numbers)	2.47
H"(Biomass)	2.16

*** significant at the 99.9% level

minor (Fig. 11). The only significant differences in the samples were in May when the Bare plot had higher values for all three measures ($P < 0.05$) but a significant Transect x Station interaction was present for the number of species per sample; this interaction resulted because no animals at all were present in the cores taken from the middle level (3) of the Planted marsh. An overall comparison, however, revealed that the Bare plot had significantly more species per sample and significantly higher values of H"(Numbers) (Table 9). There were no significant differences between the three structural measures for the November sampling of the natural marsh and spoil plots (Table 10).

The September Planted marsh samples showed an apparent drop in all the community attributes measured (Fig. 11) but this decrease was not significant for numbers and biomass. Four species were present in both the July and November samples but absent in September -- *Gammarus*, the isopod *Cassinidea lunifrons*, the oligochaete *Enchytraeus albidus*, and the Tendipedidae (midges); the only animals present in September were *Lepidactylus* and the Dolichopodidae. There was evidence that a severe storm had occurred since the July sampling; several large logs had been carried to the uppermost limit of the marsh resulting in some damage to the *Spartina*. The storm and its accompanying wave damage may have been the reason that only a small number of species were present. No significant effect on the fauna of the Bare plot was observed and this may have been because its lower elevation protected it from most of the wave damage which would have occurred during the high water level accompanying the storm.

The calculated values of overall biomass diversity (Table 11) show that the Planted plot and the natural marsh were more similar to each other than to the Bare marsh, in contrast to Drum Inlet where the two

Table 11. Overall faunal diversity and evenness for marsh and creek stations at Snow's Cut.

	Creek		Marsh		
	Bare	Planted	Bare	Planted	Natural
Total No. of Species (S)	9	8	8	11	11
H''(Numbers)	1.315	1.324	0.834	1.441	0.303
J(Numbers)	0.598	0.637	0.401	0.601	0.126
H''(Biomass)	0.943	0.774	0.537	1.416	1.611
J(Biomass)	0.429	0.372	0.258	0.591	0.672

spoil plots were quite similar. H''(Biomass) and H''(Numbers) differed greatly in the natural marsh where the large number of juvenile Cyathura made up 94% of the total numbers but only 31% of the biomass. This caused an extreme difference in the evenness and shows the correlation of H'' with J since S, the number of species, did not change (see DeBenedictis 1973). The creek stations had similar values for the indices and were intermediate between the Bare plot and the Planted plot and natural marsh values. The difference in H''(Numbers) and H''(Biomass) was due largely to Laeonereis which made up about 68% of the biomass of the creek samples but only 37% of the numbers.

It should be pointed out that the natural marsh was sampled only once, late in the fall, while the spoil marshes were sampled four times during late spring, summer and fall. This suggests that the overall diversity might have been underestimated since the total number of species found almost certainly would have been greater had samples been taken earlier in the year along with the spoil marsh samples.

Comparison with Other Studies

Comparison of this study with previous studies on salt marshes indicates that there may be less macrofaunal production in more northerly marshes. Production of polychaetes, mussels and snails in Louisiana was estimated as 26.6 g m^{-2} yr^{-1} by using twice the average standing stock (Day et al. 1973), while production of annelids and insect larvae, mussels and snails in Georgia was estimated to be about 7.6 g m^{-2} yr^{-1} [Teal 1962; to facilitate comparison with this study Teal's data were converted from kcal to dry weight using an average factor of 4.5 kcal per g decalcified dry weight for mussels, snails and polychaetes (Cummins and Wuycheck

1971)]. The estimated natural marsh production fom this study, 5.7 g m^{-2} yr^{-1} at Snow's Cut and 7.7 g m^{-2} yr^{-1} at Drum Inlet, was less than or about the same as that reported for Georgia and much less than that reported for Louisiana.

There was a significant lack of mussels and snails in the natural marshes of this study when compared with the Georgia and Louisiana marshes. Snails and mussels accounted for about 75 times as much production as the polychaetes in the Louisiana marsh (Day et al. 1973) and about three times as much production in the Georgia marsh (Teal 1962). In contrast, at Drum Inlet production of mussels and snails was less than one third that of the polychaetes and insect larvae and at Snow's Cut they accounted for less than half as much production. Of the two snails most common in southern marshes, *Littorina irrorata* and *Melampus bidentatus*, only one individual was found in either of the marshes investigated in this study. Their absence at Drum Inlet was quite unexpected simce in a preliminary survey of the natural marsh in the fall of 1972 both species were common; violent winter storms may be responsible for large year-to-year variations in the epifaunal populations there. The absence of the snails at Snow's Cut was probably due to the low salinity; both species are found in upper mesohaline or higher salinity (Wass et al. 1972) and Snow's Cut was lower mesohaline. Where salinity was higher, nearer the mouth of the Cape Fear River estuary (Copeland, Birkhead and Hodson 1974), both species were present (Seneca et al. 1974). For both study areas, then, the infauna were probably the major component of the macrofauna, in contrast to the other marshes which have been studied.

DISCUSSION

The biological monitoring of the two areas revealed that two different patterns of faunal development were occurring. At Drum Inlet the Bare and Planted plots were generally quite similar in all the community measures and seemed equally different from the natural marsh; at Snow's Cut, on the other hand, the Bare and Planted plots differed greatly in a number of aspects, the most obvious being biomass and overall diversity, and the Bare marsh fauna resembled the natural fauna more than the Planted fauna. At Drum Inlet most of the Planted marsh biomass was made up of species also found in the natural marsh; at Snow's Cut less than half the Planted marsh biomass was accounted for by species found in the natural marsh. Thus, there are three general observations to be accounted for:

1) There were only minor differences between the Bare and Planted plots at Drum Inlet,
2) There were major differences between the Bare and Planted plots at Snow's Cut, and
3) Even though it had been developing for a shorter period of time, the Planted spoil marsh fauna at Drum Inlet had a greater resemblence to the natural marsh fauna than did the Planted spoil fauna at Snow's Cut.

Several generalizations have been proposed for the changes occurring during succession in ecosystems (Margalef 1968); among these was an increase in diversity, leading to a reduction in the community response to external environmental fluctuations. The stability-time hypothesis of Sanders (1968) encompassed much the same concept (Johnson 1970). He presented the idea that two types of abstract communities are present: the "physically controlled community", where most adaptation is to the physical environment and diversity is low, and the "biologically accomodated community", where the physical environment is relatively stable and biological adaptation and hence diversity are high; these communities correspond to the immature and mature grades of Margalef's succession and most communities in nature fall somewhere between these extremes (Johnson 1970). Succession proceeds toward a biologically accomodated community under the local environmental conditions as it becomes possible for species associated with higher grade communities to colonize; thus the more eurytopic species will be low in the order of succession while the more stenotopic species will be relatively high in the order of succession. It will then be the stress produced by the physical environment on the higher grade species that limits the rate of succession. The fauna of a "new" environment similar to the surrounding environment would be expected to proceed toward biological accomodation more quickly than that of a "new" environment differing from the surrounding environment and the degree of similarity should determine the rate of succession.

The relative difference in elevation between the spoil plots can thus be employed to explain the first two general observations. The other factors of the macrofaunal environment which were measured were either similar for both the Bare and Planted plots at both study areas (sediment organic content and particle size) or differed to about the same degree between the spoil plots at both areas (aboveground and belowground Spartina biomass). Only by taking the differences in elevation into account can the faunal differences be explained. At Drum Inlet, where sedimentation was low and no elevation difference developed between the spoil plots, the fauna of the Bare and Planted spoil plots were similar; at Snow's Cut, where sedimentation was high and a significant difference in elevation developed between the spoil plots, the fauna of the Bare and Planted plots were dissimilar. It is a well-known fact that elevation has a profound effect on intertidal faunal communities; for example, the diversity of the fauna of a sandy beach has been shown to decrease with increasing elevation (Johnson 1970).

The difference in the relative maturity of the Planted spoil marsh in the two areas can be explained by the composition of the sediment. Species distributions are known to correlate with sediment particle size (Johnson 1971; Wolff 1973) but no such relationship has been found for sediment organic content (Tietjen 1969; Wolff 1973). At Snow's Cut the spoil had a smaller median particle size than the natural marsh sediment and this difference probably prevented some of the natural marsh species from colonizing the spoil. Elevation may also have had an effect since the natural marsh had a higher faunal affinity for the lower elevations of the Planted spoil. At Drum Inlet, though, the median particle size of the spoil was virtually identical to that of the natural marsh sediment and this similarity would have lessened the stress on natural marsh species attempting to colonize the spoil, allowing succession of higher grade species to occur sooner than at Snow's Cut.

The natural marshes of the two study areas may also have differed in relative maturity. The natural marsh at Snow's Cut appeared to be stable and fairly old. Snow's Cut was constructed by the Corps of Engineers in 1931 and the resulting spoil was deposited on the river bank; the present sediment consists of a 12-cm layer of muddy sand on top of a layer of mud suggesting that the marsh may have been created at that time. Since 1931 natural accretion has been occurring from the river-borne sediment. At Drum Inlet the natural marsh was fairly unstable; the main source of sediment for marshes on the Outer Banks is overwash material from the ocean side of the island (Godfrey and Godfrey 1974) and storms can frequently deposit large amounts of sand on the marshes. This type of intermittent, irregular stress tends to keep a community at a less mature stage than if the environment were stable or the stress followed a regular pattern (such as tidal flow) and thus tends to keep diversity low (Slobodkin and Sanders 1969). This leads to the prediction that the overall diversity of the natural marsh at Drum Inlet should be lower than the diversity of the natural marsh at Snow's Cut. In fact, though, H"(Biomass) was virtually identical at both areas. However, there area two additional considerations: 1) as previously stated the overall diversity of the natural marsh at Snow's Cut was probably underestimated, and 2) diversity of marine species generally decreases from the mouth of an estuary toward fresh water with a zone of minimum diversity occurring where the transition from marine to fresh water is most rapid (Carriker 1967). Taking these considerations into account it is quite possible that the diversity of the Snow's Cut marsh was actually much higher relative to the diversity of nearby environments than was the diversity at Drum Inlet; for comparable environments higher diversities would be expected near Drum Inlet than near Snow's Cut so although the diversities of the natural marshes were similar the Snow's Cut value represented a more mature stage of development. A developing marsh at Drum Inlet could have had relatively more low grade species in proportion to the total available species pool than at Snow's Cut and still have had a greater resemblence to the natural marsh fauna since the natural marsh also would have had a higher proportion of low grade species than at Snow's Cut.

The minimum order of time for the majority of salt marshes to reach maturity may be about 100 years if maturity is defined as the point where settlement balances accretion and no net change in elevation can occur

(Ranwell 1972). This time may be less for areas such as the spoil plots where sediment is already above the lower limit of growth of vegetation, as little as 10 years (Ranwell 1972) or a few decades (Redfield 1972); it seems likely that the development of the spoil marshes will be at least this rapid. However, in order for the fauna of the spoil areas to become a true marsh fauna not only must the elevation of the marsh have stabilized but the sediment must also become identical with that of natural marsh. In the case of the Drum Inlet spoil plots the sediment was virtually identical to natural marsh sediment at the time of sampling; at Snow's Cut, though, a difference was apparent between the two sediment types and before a true marsh fauna can develop, the sediment will have to develop into the characteristic marsh sediment of that area.

SUMMARY

1. Sampling of two artificially established *Spartina* marshes, one near Drum Inlet and one near Snow's Cut, N. C., was carried out from March to November 1973.

2. Based on the net rate of incorporation of organic carbon into the sediment it will take from 3.7-4.5 years from the time of deposition for the sediment of the Drum Inlet spoil marsh to reach the level of organic carbon concentration of the natural marsh; the corresponding time at Snow's Cut will be from 22.6-26.6 years. The major source of organic carbon to the spoil is probably the benthic algae since the rate was similar for both the Bare and Planted plots.

3. A positive correlation between the difference in elevation between the Bare and Planted plots and the difference between their invertebrate macrofauna was found. At Drum Inlet, where elevational difference between the plots was slight, the faunal communities were qualitatively and quantitatively similar. At Snow's Cut, where the difference in elevation was large, the faunal communities were dissimilar.

4. The greater difference in elevation between the plots at Snow's Cut was probably due to the high sedimentation rate there.

5. Even though it had been developing for a shorter period of time, the Planted spoil fauna at Drum Inlet had a greater resemblance to the natural marsh fauna than did the Planted spoil fauna at Snow's Cut. Two explanations were offered for this apparent contradiction: 1) The particle size

of the spoil at Drum Inlet was virtually identical to that of the natural marsh while at Snow's Cut the spoil had a smaller median particle size than the natural marsh sediment and this difference may have prevented some species from colonizing the spoil, and 2) It is possible that the natural marsh at Drum Inlet was relatively less mature than that at Snow's Cut and thus had relatively more lower grade species; they would be expected to be more successful at colonizing the spoil than the relatively higher grade species at Snow's Cut.

6. The Drum Inlet spoil fauna probably will come to resemble the natural marsh fauna much sooner than will the Snow's Cut spoil fauna. The increasing resemblence of the spoil fauna to the natural marsh fauna will be correlated with the increasing similarity between the spoil and the natural marsh sediment.

7. Based upon this study the technique of planting Spartina on dredge spoil can be used successfully to create new and functional salt marsh in areas where none previously existed. The length of time this will take depends on how closely the spoil resembles natural marsh sediment, the elevation of spoil deposition, the natural sedimentation rate in the area, and the relative maturity of the natural marsh community characteristic to the area of deposition.

LITERATURE CITED

Anderson, R. O. 1959. A modified flotation technique for sorting bottom fauna samples. Limnol. Oceanogr. 4:223-225.

Buchanan, J. B. and J. M. Kain. 1971. Measurement of the physical and chemical environment, p. 30-58. In N. A. Holme and A. D. McIntyre, eds. Methods for the study of marine benthos (IBP Handbook No. 16). Blackwell Scientific Publications, Oxford.

Carriker, M. R. 1967. Ecology of estuarine benthic invertebrates: a perspective, p. 442-487. In G. H. Lauff, ed. Estuaries. Amer. Assoc. Adv. Sci., Washington, D. C.

Chabreck, R. H. 1972. Vegetation, water and soil characteristics of the Louisiana coastal region. La. State Univ. Agric. Exp. Sta. Bull. 664. 72 p.

Copeland, B. J., W. S. Birkhead and R. Hodson. 1974. Ecological monitoring in the area of Brunswick nuclear power plant, 1971-1973. Report to Carolina Power and Light Co., Raleigh. 391 p.

Cruz, A. A. de la. 1973. The role of tidal marshes in the productivity of coastal waters. ASB Bulletin 20(4):147-156.

Cummins, K. W. and J. C. Wuycheck. 1971. Caloric equivalents for investigations in ecological energetics. Mitt. int. Ver. Limnol. 18:1-158.

Day, J. W., Jr., W. G. Smith, P. R. Wagner and W. C. Stowe. 1973. Community structure and carbon budget of a salt marsh and shallow bay estuarine system in Louisiana. Center for Wetland Resources Publ. LSU-SC-72-04. La. State Univ., Baton Rouge. 79 p.

DeBenedictis, P. A. 1973. On the correlations between certain diversity indices. Am. Naturalist 107(954):295-302.

Gallagher, J. L. 1974. Sampling macro-organic matter profiles in salt marsh plant root zones. Soil Sci. Soc. Amer. Proc. 38:154-155.

Gerlach, S. A. 1971. On the importance of marine meiofauna for benthos communities. Oecologia (Berl.) 6:176-190.

Godfrey, P. J. and M. M. Godfrey. 1974. The role of overwash and inlet dynamics in the formation of salt marshes on North Carolina barrier islands, p. 407-428. In R. J. Reimold and W. H. Queen, eds. Ecology of halophytes. Academic Press, New York.

Gosselink, J. G., E. P. Odum and R. M. Pope. 1974. The value of the tidal marsh. Center for Wetland Resources Publ. LSU-SG-74-03. La. State Univ., Baton Rouge. 30 p.

Gray, A. J. and R. G. H. Bunce. 1972. The ecology of Morecambe Bay. VI. Soils and vegetation of the salt marshes: a multivariate approach. J. appl. Ecol. 9:221-234.

Hartman, O. 1945. The marine annelids of North Carolina. Bull. Duke Univ. Mar. Sta. 2:1-54.

Howmiller, R. P. 1972. Effects of preservatives on weights of some common macrobenthic invertebrates. Trans. Amer. Fish. Soc. 101(4):743-746.

Johnson, R. G. 1970. Variations in diversity within benthic marine communities. Am. Naturalist 104(937):285-300.

Johnson, R. G. 1971. Animal-sediment relations in shallow water benthic communities. Marine Geol. 11:93-104.

Kraeuter, J. N. and P. L. Wolf. 1974. The relationship of marine macroinvertebrates to salt marsh plants, p. 449-462. In R. J. Reimold and W. H. Queen, eds. Ecology of halophytes. Academic Press, New York.

Maciolek, J. A. 1962. Limnological organic analyses by quantitative dichromate oxidation. U. S. Fish Wildlife Service Res. Rep. 60. 61 p.

Margalef, R. 1968. Perspectives in ecological theory. Univ. of Chicago Press, Chicago. 111 p.

Odum, E. P. 1961. The role of tidal marshes in estuarine production. N. Y. State Conservationist Jun-Jul:12-16.

Odum, E. P. and A. A. de la Cruz. 1967. Particulate detritus in a Georgia salt-marsh estuarine ecosystem, p. 383-388. In G. H. Lauff, ed. Estuaries. Amer. Assoc. Adv. Sci., Washington, D. C.

Pielou, E. C. 1966. Shannon's formula as a measure of species diversity: its use and misuse. Am. Naturalist 100:463-465.

Pomeroy, L. R. 1959. Algal productivity in the salt marshes of Georgia. Limnol. Oceanogr. 4:367-386.

Pomeroy, L. R., R. E. Johannes, E. P. Odum and B. Roffman. 1968. The phosphate and zinc cycles and productivity of a salt marsh, p. 412-419. In D. J. Nelson and F. C. Evans, eds. Proc. 2nd Symp. Radioecol. U. S. A. E. C., T. I. D. 4500.

Ranwell, D. S. 1972. Ecology of salt marshes and sand dunes. Chapman and Hall, London. 258 p.

Redfield, A. C. 1972. Development of a New England salt marsh. Ecol. Monogr. 42(2):201-237.

Sanders, H. L. 1956. Oceanography of Long Island Sound. X. The biology of marine bottom communities. Bull. Bingham Oceanogr. Coll. 15:345-414.

Sanders, H. L. 1960. Benthic studies in Buzzard's Bay. II. The structure of the soft bottom community. Limnol. Oceanogr. 5(2):138-153.

Sanders, H. L. 1968. Marine benthic diversity: a comparative study. Am. Naturalist 102(925):243-282.

Seneca, E. D. 1974. Stabilization of coastal dredge spoil with Spartina alterniflora, p. 525-530. In R. J. Reimold and W. H. Queen, eds. Ecology of halophytes. Academic Press, New York.

Seneca, E. D., L. M. Stroud, U. Blum and G. R. Noggle. 1974. An analysis of the effects of the Brunswick nuclear power plant on the productivity of Spartina alterniflora (smooth cordgrass) in the Oak Island, Dutchman Creek, Snow's marshes, Brunswick County, North Carolina, 1973-1974. First Annual Report to Carolina Power and Light Co., Raleigh. 68 p.

Slobodkin, L. B. and H. L. Sanders. 1969. On the contribution of environmental predictability to species diversity, p. 82-95. In Diversity and stability in ecological systems, Brookhaven Symposia in Biology No. 22. National Technical Information Service, U. S. Dept. of Commerce, Springfield, Va.

Steel, R. G. D. and J. H. Torrie. Principles and procedures of statistics. McGraw-Hill, New York. 481 p.

Stroud, L. M. and A. W. Cooper. 1969. Color-infrared aerial photographic interpretation and net primary productivity of a regularly-flooded North Carolina salt marsh. Water Resources Res. Inst. Rep. No. 14. Univ. of North Carolina, Raleigh. 86 p.

Teal, J. M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43(4):614-624.

Teal, J. M. and J. Kanwisher. 1961. Gas exchange in a Georgia salt marsh. Limnol. Oceanogr. 6:388-399.

Tietjen, J. H. 1969. The ecology of shallow water meiofauna in two New England estuaries. Oecologia (Berl.) 2:251-291.

Wall, W. J., Jr. 1973. The intertidal sand and salt marsh invertebrate fauna associated with the bloodsucking diptera of Cape Cod, Massachusetts. Environ, Entomol. 2(4):681-684.

Wass, M. L. et al. 1972. A check list of the biota of lower Chesapeake Bay. Spec. Sci. Rep. No. 65. Virginia Inst. Mar. Sci., Gloucester Point, Va. 290 p.

Wass, M. L. and T. D. Wright. 1969. Coastal wetlands of Virginia. Spec. Sci. Rep. No. 10. Virginia Inst. Mar. Sci., Gloucester Point, Va. 154 p.

Wilhm, J. L. 1968. Use of biomass units in Shannon's formula. Ecology 49(1):153-156.

Williams, A. B., G. S. Posner, W. J. Woods and E. E. Deubler, Jr. 1973. A hydrographic analysis of larger North Carolina sounds. Sea Grant Publ. UNC-SG-73-02. Univ. of North Carolina, Chapel Hill. 129 p.

Williams, R. B. and M. B. Murdoch. 1966. Annual production of Spartina alterniflora and Juncus roemerianus in salt marshes near Beaufort, North Carolina. ASB Bulletin 13:49.

Wolff, W. J. 1973. The estuary as a habitat: an analysis of data on the soft-bottom macrofauna of the estuarine area of the Rivers Rhine, Meuse, and Scheldt. Zool. Verhand. 126:1-242.

Woodhouse, W. W., Jr., E. D. Seneca and S. W. Broome. 1972. Marsh building with dredge spoil in North Carolina. N. C. State Univ. Agric. Exp. Sta. Bull. 445. 28 p.

Woodhouse, W. W., Jr., E. D. Seneca and S. W. Broome. 1974a. Establishing salt marsh on dredge spoil, p. 51-78. In 5th proceedings of WODCON world dredging conference. WODCON Assn., San Pedro, Calif.

Woodhouse, W. W., Jr., E. D. Seneca and S. W. Broome. 1974b. Propagation of Spartina alterniflora for substrate stabilization and salt marsh development. Tech. Mem. No. 46, Coastal Engineering Research Center. U. S. Army Corps of Engineers, Fort Belvoir, Va. 155 p.