COMPARISON OF ECOSYSTEM STRUCTURE AND FUNCTION OF CREATED AND NATURAL SEAGRASS HABITATS IN LAGUNA MADRE, TEXAS

Paul A. Montagna, Principal Investigator

Cooperative Agreement No. X-00658801-0

Technical Report Number TR/93-007

FINAL REPORT

COMPARISON OF ECOSYSTEM STRUCTURE AND FUNCTION OF CREATED AND NATURAL SEAGRASS HABITATS IN LAGUNA MADRE, TEXAS

by

Paul A. Montagna, Principal Investigator

from

University of Texas at Austin
Marine Science Institute
P.O. Box 1267
Port Aransas, Texas 78373

to

Dr. James H. Ratterree, Project Officer
Water Management Division (6W-QM)
U.S. Environmental Protection Agency, Region 6
1445 Ross Avenue
Dallas, Texas 75202-2733

Cooperative Agreement No. X-00658801-0

The University of Texas Marine Science Institute Technical Report Number TR/93-007

November 3, 1993

COMPARISON OF ECOSYSTEM STRUCTURE AND FUNCTION OF CREATED AND NATURAL SEAGRASS HABITATS IN LAGUNA MADRE, TEXAS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

COMPARISON OF ECOSYSTEM STRUCTURE AND FUNCTION OF CREATED AND NATURAL SEAGRASS HABITATS IN LAGUNA MADRE, TEXAS

ABSTRACT

There is increasing demand to mitigate the loss of submerged wetland habitats. This project is designed to identify the criteria for a successful mitigation project, and the time for a created seagrass bed to become a functional habitat. Two approaches are taken. The first is a synoptic study of mitigated sites of different ages, the second is monitoring of a recent mitigation site for one year. Ecosystem structure and function is assessed by measuring select variables. Community metabolism and nutrient regeneration are key variables, which indicate the functioning of an ecosystem. Benthic community structure is a key variable that indicates the habitat utilization of an ecosystem. The mitigation sites are compared to three natural reference sites. Above-ground, the mitigation sites resembled natural sites in terms of biogeochemical function, but there were large differences below-ground. The mitigation sites lack sufficient organic material in the sediment for the environment to be fully functional. Benthic community structure at the mitigation sites resembled disturbed environments with high number, diversity, and low evenness. There was also a discernible trend among sites of different ages, that suggest it may take longer than 14-17 years to fully recover. Since this is such a long time, monitoring for one year did not reveal these differences. Future projects to transplant seagrasses for mitigation should consider adding organic matter to the soil to speed the time it takes for the habitat to become fully functional.

INTRODUCTION

Seagrass habitats are important to desirable fish and wildlife species (Kikuchi, 1974). Yet, numerous seagrass habitats have been damaged or destroyed by discharges, dredging and marine construction in our nation's bays and estuaries. There have been many projects to mitigate these adverse impacts on fish and wildlife. The general goal of mitigation programs is to replace habitat or repair damage. National Marine Fisheries Service recommends that mitigation projects should attempt to reestablish wetland fishery habitats and their ecological function (Thayer *et al.*, 1986). Mitigation projects generally include the restoration or creation of new seagrass habitats, but monitoring or evaluation of the success of these projects is rarely done. When it is performed it is usually limited to describing the success of the plantings. For example, in south Texas estuaries four out of seven mitigation projects planted between 1978 and 1983 were judged successful (Cobb, 1987). Success was determined by comparing percent cover in the mitigated area versus a control area. Much less is not known on whether these mitigated habitats are functioning like natural seagrass habitats.

Biological interactions between plants, animals, and microbes have a profound effect on the success of any habitat creation project. After initial construction or planting, there is a succession of events leading to the climax, mature seagrass community. This process includes colonization of the unvegetated or transplanted area by microbes, epiphytes, and benthic invertebrates. The microbial community is important in maintaining the balance of available nutrients, which are necessary for plant growth. Invertebrate bioturbation plays an important role in irrigating sediments with water and oxygen, which can enhance nutrient cycling rates. Finally, a luxuriantly vegetated benthos can provide the habitat for a variety of vertebrate and invertebrate species. All these processes must occur before the mitigated environments become a functioning habitat in the sense of an ecosystem.

The objective of this study is to compare benthic metabolism, nutrient regeneration, and habitat utilization of created seagrass habitats of different ages with natural habitats. The goal of collecting this data is to determine how, and when created habitats become functioning ecosystems like natural systems. This information is necessary to define measures of success, and delineate how long it takes a planted system to provide the ecological functions that are provided by naturally occurring seagrass systems. This information can also be used to develop new criteria or methods for projects to create, enhance or restore seagrass habitats.

Figure 1. Upper Laguna Madre. Natural reference sites are in Baffin Bay (6), and the Laguna Madre (189). Mitigation sites are between the shorelines of the cities of Flour Bluff and Padre Isles.

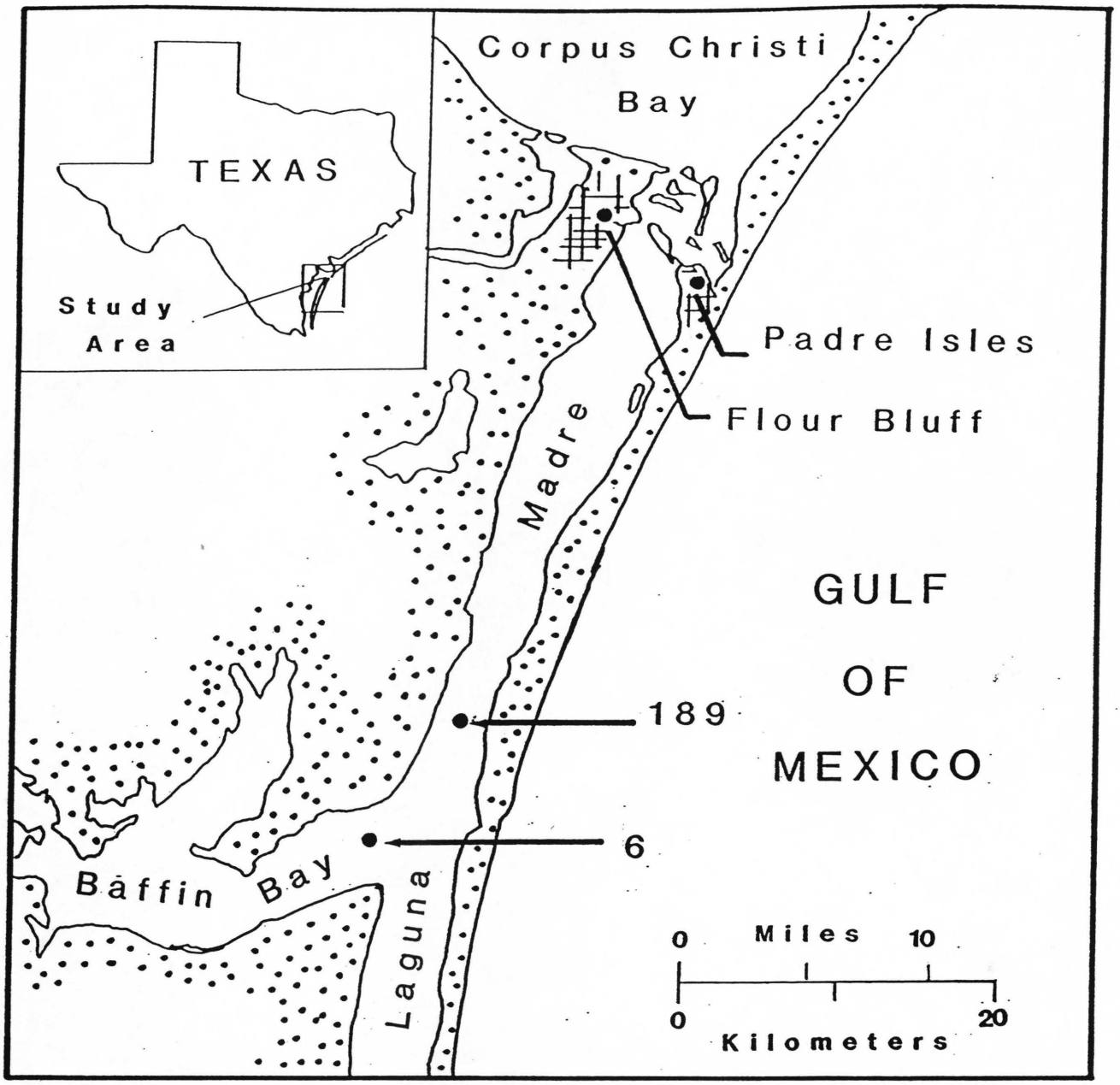
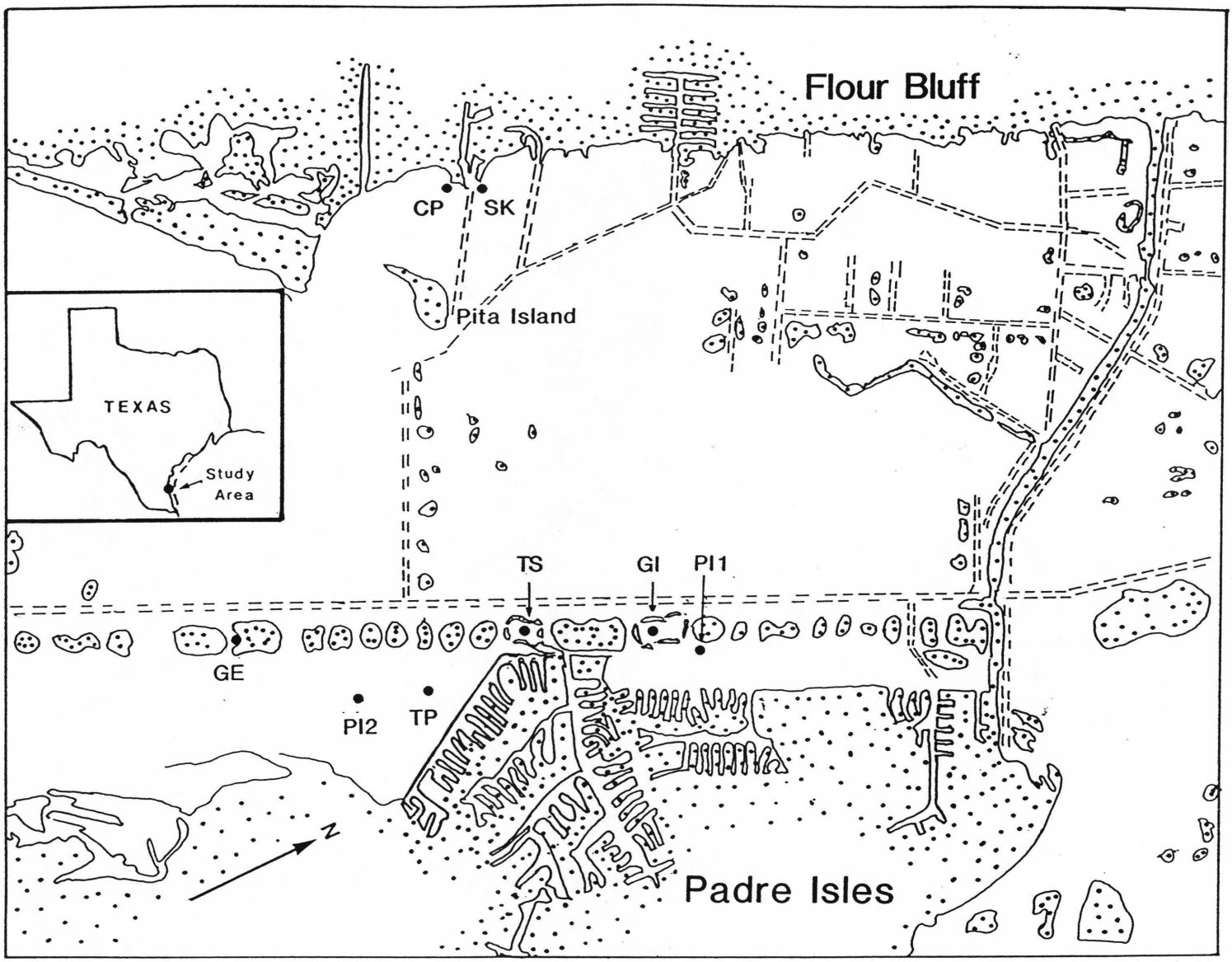

Corpus Christi
Bay
TEXAS
Study
Area
Padre Isles
Flour Bluff
Madre
GULF
OF
MEXICO
189
6
Baffin Bay
Laguna
0
Miles
10
0
20
Kilometers

Figure 2. Northern part of Upper Laguna Madre. Location of mitigation sites. Channels are shown in dashed lines.


Flour Bluff
CP
SK
Pita Island
TEXAS
Study Area
TS
GI
PI1
GE
PI2
TP
N
Padre Isles

METHODS

Study Design

Two studies were performed. One study was a synoptic sampling of 13 stations to compare community structure and rates of biogeochemical processes at natural, old and recent mitigation sites. Three stations were naturally vegetated sites, nine stations were in mitigation sites and one was in a muddy bottom of an open bay. Two of the mitigation sites were constructed in the mid-1970's and are about 14-17 years old. These are called "old sites". Three of the mitigation sites were constructed between 1990 and 1991 and were 1-2 years old when sampled. These are called "new sites". It is reasonable to assume that natural sites are much greater than 20 years old, so the natural sites represent the oldest sites. An important feature of the study design is that we are replicating sites, that is replicating at the treatment level to avoid pseudoreplication. The 13 stations used for the synoptic study were sampled in April 1992.

The second study was performed to monitor seasonal variability in community structure at a natural and mitigation site. Four stations, two natural and two mitigation, were sampled quarterly throughout a one-year period.

Study Area

Ten study sites were chosen in the Upper Laguna Madre and Baffin Bay (Table 1). Two of the sites have been visited since 1989 as part of a long-term research project to determine the importance of seagrass beds in maintaining a productive finfishery (Figure 1). These sites are 189 in the southern upper Laguna Madre and 6 in Baffin Bay (Table 1). Eight of the sites were located in a small area in the northern Upper Laguna Madre between the Flour Bluff and Padre Isles shorelines (Figure 2).

In most cases there is only one station per site. At three sites, there are two paired station locations. One station is located in the grass bed, and one station is adjacent in a bare patch. These paired stations are located in sites 189, TS and GI. The suffix (-G) for the grass and (-S) for sand patch is used to name each site: 189G, 189S, TSG, TSS, GIG, and GIS. Only station 6, which was in mud, does not have a suffix added to the station name.

All stations were sampled during the synoptic study in April 1992. Four stations (189G, 189S, TSG and TSS), one at a natural site (189) and the other at a mitigated site (TS) were sampled in each of the four seasons during the temporal study.

Study Site Descriptions

Gulf Isles Limited (GI_), project #9009(08) is located east of Intracoastal Waterway Marker 49. The project scraped down a spoil island and created an area of submerged habitat approximately 320 m × 168 m with six circulation channels in April, 1991. Seagrass planting was not required. Natural colonization by *Ruppia maritima, Halodule wrightii* and *Halophila engelmannii* appears to have been successful. Two stations were sampled in the southern end of the excavation site at a depth of 0.4 m. One station was in a mixed bed of *H. engelmannii* and *R. maritima* (GIG) and the other was an adjacent bare sand patch (GIS). The sediment was firm in both areas composed of approximately 90% sand, 5% rubble, 2% silt and 3% clay.

Padre Isles Natural Site #1 (PI1G) was located in an open area east of the Gulf Isles site and west of the Padre Isles development. This site is protected from high wave action due to the surrounding land resulting in a low energy area. Most of this area is covered with a mixture of *H. wrightii* and *R. maritima* with few bare patches. Core samples were taken from a bed of *H. wrightii* at a depth of 0.5 m. The sediment was very soft and smelled of H_2S when disturbed. The upper 3 cm of sediment was composed of 10% rubble, 55% sand, 10% silt, and 25% clay while from 3 to 10 cm depth sand increased to 90%.

Padre Isles Natural Site #2 (PI2G) was located in the center of a seagrass flat east of the spoil islands adjacent to Intracoastal Waterway Marker 63 and west of Padre Island. The dominant seagrass at this site is *H. wrightii*. Samples were taken at a depth of 0.75 m in a bed of *H. wrightii*. The sediment was firm compared to PI1 with more rubble 14% and sand 74% and less silt 25% and clay 10%. The deeper sediment (3-10 cm) had higher sand content (89%).

Transco scrape-down (TS_) project #18853 is located in state land tract 64 on a spoil island east of Intracoastal Waterway Marker 55. Submerged habitat was developed by scraping down an existing spoil island, cutting three circulation channels and planting *H. wrightii*. Samples were taken from *H. wrightii* (TSG) and bare sand (TSS) in a water depth of 0.4 m. The sediment was very firm composed primarily of sand in the grass (88%) and the bare patches (95%).

Transco pipeline (TPG) project #18853 was an attempt to establish seagrass, *H. wrightii*, on the bare shoulders of a pipeline extending from Padre Island in state land tract #174, and 64 under the Intracoastal Waterway near Marker 59, and through state tracts 48, 47, 25 and 134 to the mainland. The site sampled was located east of the spoil islands adjacent to marker 59 near the area where the pipeline crossed the state tract boundary between state tracts 64 and 174. The water depth was 0.6 m and the dominant grass along this section of the pipeline was *R. maritima*. The sediment

was firm composed of 95% sand.

Central Power and Light Company (CPG) project #10444 is located on the west Laguna Madre shoreline adjacent to the CP&L mariculture ponds. The project resulted in the removal of dredged material covering submerged seagrasses and was described as being successful. The project site is in a small cove formed by a point of land to the north with the opening facing the southeast. The predominant southerly winds deposit dead seagrass along the shoreline and on the bottom. *Ruppia maritima* was the dominant seagrass and was sparse. The water depth was 0.55 m and the sediment was very soft. The upper 3 cm of sediment sampled was 9% rubble, 70% sand, 12% silt, and 9% clay and the 3-10 cm sediment layer was 10% rubble, 79% sand 1% silt and 10% clay.

Skyline Equipment, Inc. (SKG) project #12004 (03) is located on the west Laguna Madre shoreline just north and adjacent to the Central Power and Light project. The project created 0.14 ha (0.34 acre) of submergent habitat from uplands in 1978. The site is located on a point and is exposed to high energy southeast and northerly winds resulting in minimal dead seagrass deposition. The bottom was covered with approximately 25% *Ruppia maritima*, 25% *Halodule wrightii* and 50% bare sand. Core samples were taken in *H. wrightii* at a depth of 0.35 m. The sediment was composed mainly of firm sand (92%).

Marker 189 (189_) is a natural reference site in an open grass flat to the west of Intracoastal Waterway Marker 189. This site is vegetated with *Halodule wrightii* with scattered bare patches and very little drift algae and dead seagrass debris. The water depth is 0.8 m. Samples were taken from the grass (189G) and an adjacent bare patch (189S). The sediment in the bare patch sampled was firm composed of 21% rubble, 61% sand, 3% silt and 15% clay. The grass sediment was similar with 21% rubble, 50% sand, 4% silt and 19% clay. The amount of clay increased with depth (35%) in the sandy bare patches and the seagrass.

Genesis Petroleum (GES) project #15844 is located between two dredge spoil islands east of Intracoastal Waterway Markers 67. Approximately 0.4 ha (0.9 acre) of submerged wetland was created from the emergent spoil island. The site is in a small cove which faces southeast into the prevailing wind. Dead seagrass and detritus collect along the shoreline and on the bottom. Although *H. wrightii* was planted following the scrape-down, no living seagrass was found at the site. The water depth was 0.9 m. The surface sediment was 63% sand and 31% clay. Below 3 cm the sediment was 94% sand.

Marker 6 (BB6) is a control site located approximately 180° off of Marker 6 at the mouth of Baffin Bay. This site is in the open bay in 2.2 m water depth without seagrass. The sediment is soft mud predominantly silt (15%) and clay (81%).

Hydrographic Measurements

Salinity, conductivity, temperature, pH, dissolved oxygen, and redox potential were measured at each station during each sampling trip with a multiparameter instrument (Hydrolab Surveyor II). The sonde unit was lowered to just beneath the surface and to the bottom. The instruments allows us to collect a variety of water quality parameters rapidly. The following parameters are read from the digital display unit (accuracy and units): temperature (± 0.15 °C), pH (± 0.1 units), dissolved oxygen (mg/l ± 0.2), specific conductivity (± 0.015 - 1.5 mmhos/cm depending on range), redox potential (± 0.05 mV), depth (± 1 m), and salinity (ppt). Salinity is automatically corrected to 25°C.

Suspended sediments are measured as turbidity in nephelometric turbidity units (NTU) with a Hach photometer. Turbidity can be converted to suspended sediment concentration by making a standard curve of turbidity versus dry weight of filtered sediments. In most Texas bays there is a linear relationship between suspended sediment and turbidity (R^2 = 0.99): suspended sediment ($mg \cdot ml^{-1}$) = 0.038×NTU + 0.085 (Montagna, 1989).

Geological Measurements

Sediment grain size analysis was also performed. Sediment core samples were taken by diver and sectioned at depth intervals 0-3 cm and 3-10 cm. Analysis followed standard geologic procedures (Folk, 1964; E. W. Behrens, personal communication). Percent contribution by weight was measured for four components: rubble (e.g. shell hash), sand, silt, and clay. A 20 cm^3 sediment sample was mixed with 50 ml of hydrogen peroxide and 75 ml of deionized water to digest organic material in the sample. The sample was wet sieved through a 62 μm mesh stainless steel screen using a vacuum pump and a Millipore Hydrosol SST filter holder to separate rubble and sand from silt and clay. After drying, the rubble and sand were separated on a 125 μm screen. The silt and clay fractions were measured using pipette analysis.

Chemical Flux Measurements

Biogeochemical fluxes were measured in the same 6.7 cm diameter core tubes that were used to sample macrofauna. Samples were taken by hand to a depth of 10 cm by divers. Three replicates were taken within a 2 m radius. The water level was brought to the top with added station water. After settling for about 10 minutes the initial water subsample was taken. Then the cores were closed with rubber stoppers

that had an oxygen probe and a relief valve so that a tight seal could be obtained. Cores were incubated in the dark for two hours. Ice chest coolers were used as incubation chambers. The coolers had station seawater circulated through them, via a pump, to maintain the temperature as near to ambient conditions as possible. Three replicate cores were used to determine sediment metabolism and nutrient regeneration. One station water sample was incubated as a control for oxygen metabolism, and two control samples were incubated for nutrient regeneration. The controls were used to represent changes in the overlying water that were not due to the presence of the sediment.

Oxygen concentration changes were measured every 15 min using pulsed oxygen electrodes (Endeco, Inc., Marion, MA). These electrodes are of a recent design in which the measurement of oxygen concentration is flow-insensitive (Langdon, 1984). The electrodes are connected to a Pulsed D.O. Sensor™ that controls the timing of the electrical pulses sent to each probe. Data is interpreted by the Pulsed D.O. Sensor and logged automatically on a portable computer. Oxygen changes per unit time were estimated using linear regression analysis.

Water subsamples were taken from the overlying water in the cores after the two hour incubation period to measure changes in other chemical constituents. Dissolved inorganic nitrogen (DIN) concentrations of ammonia, nitrate, and nitrite and phosphate and silicate were measured from the water subsamples using highly precise autoanalyzer techniques (Whitledge *et al.*, 1986). Nutrient changes were estimated as the difference from initial and ending values. The mean of two replicates was used as the control value.

The flux (FLUX) for both oxygen and nutrients is calculated a function of the chemical change (CHANGE) with respect to time minus a control value, and was adjusted for the area of sediment (FACTOR) covered by the core and the volume (VOLUME) of water contained in the core:

$$FLUX_{mmol \cdot m\text{-}2 \cdot h\text{-}1} = VOLUME_{l} \times CHANGE_{mmol \cdot l\text{-}1 \cdot core\text{-}1 \cdot h\text{-}1} \times FACTOR_{m\text{-}2/core} \qquad (1)$$

Biological Measurements

Sediment was collected from the same 6.7 cm diameter core tube, that was used to measure chemical flux. The macrofauna were sectioned at depth intervals of 0-3 cm and 3-10 cm (Montagna and Kalke, 1992). Samples were preserved with 5% buffered formalin, sieved on 0.5 mm mesh screens, sorted, identified, and counted.

Each macrofauna sample was also used to measure biomass. Individuals were combined into higher taxa categories, i.e., Crustacea, Mollusca, Polychaeta, Ophiuroidea, and all other taxa were placed together in one remaining sample. Samples were dried for 24 h at 55 °C, and weighed. Before drying, mollusks were placed in 1 N HCl for 1 min to 8 h to dissolve the carbonate shells, and washed with fresh water.

Sediment organic matter was also measured from each core. The seagrass stems, roots, and detritus from each sample was collected on a 0.5 mm sieve, dried and weighed.

Statistical Analyses

Macrofauna diversity is calculated using Hill's diversity number one (N1) (Hill, 1973). It is a measure of the effective number of species in a sample, and indicates the number of abundant species. It is calculated as the exponentiated form of the Shannon diversity index:

$$N1 = eH' \tag{2}$$

As diversity decreases N1 will tend toward 1. The Shannon index is the average uncertainty per species in an infinite community made up of species with known proportional abundances (Shannon and Weaver, 1949). The Shannon index is calculated by:

$$H' = -\sum_{i-1}^{s}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right] \tag{3}$$

Where n_i is the number of individuals belonging to the ith of S species in the sample and n is the total number of individuals in the sample.

Richness is an index of the number of species present. The obvious richness index is simply the total number of all species found in a sample regardless of their abundances. Hill (1973) named this index N0. Another well known index of species richness is the Margalef (1958) index (R1). R1 is based on the relationship between the number of species (S) and the total number of individuals (n) observed:

$$R1 = \frac{S-1}{\ln(n)} \tag{4}$$

Although common, this relationship presupposes that there is a functional relationship

between S and n. This assumption may not be justified in all cases.

Evenness is an index that expresses that all species in a sample are equally abundant. Evenness is a component of diversity. Two evenness indices, E1 and E5, have been calculated. E1 is probably the most common, it is the familiar J' of Pielou (1975). It expresses H' relative to the maximum value of H':

$$E1 = \frac{H'}{\ln(S)} = \frac{\ln(N1)}{\ln(N0)} \tag{5}$$

E1 is sensitive to species richness. E5 is an index that is not sensitive to species richness. E5 is a modified Hill's ratio (Alatalo, 1981):

$$E5 = \frac{(1/\lambda) - 1}{N1 - 1}$$
$$where, \lambda = \sum_{i-1}^{S} \frac{n_i(n_i - 1)}{n(n-1)} \tag{6}$$

λ is the Simpson (1949) diversity index. E5 approaches zero as a single species becomes more and more dominant.

Statistical analyses to reveal differences among sampling periods, stations and sediment depths were performed using general linear model procedures (SAS, 1985). Analyses were performed on chemical flux and species abundance, biomass and diversity measurements. Two-way analysis of variance (ANOVA) models were used where sampling dates and stations were the two main effects or where stations and sediment depth were the main effects. One-way ANOVA was used to compare stations during the synoptic study of natural and mitigation sites in April 1992. Orthogonal linear contrasts were used to test five *a priori* hypotheses about the structure and function of the habitats studied (Kirk, 1982). The first hypothesis is that there is a difference between the means of all vegetated and all nonvegetated stations. The second hypothesis is that among seagrass stations, there is a difference between the means of the natural and mitigation sites. The third hypothesis is that there is a linear or temporal difference among ages of seagrass bed habitats; the natural sites are considered the oldest, CPG and SKG are considered the same age and designated "old" mitigation sites; and TPG, GIG, and TSG are considered as "new" mitigation sites. The fourth hypothesis is that there are differences among the means of the old and new mitigation sites. The fifth hypothesis is that there is a difference between the TRANSCO scrapedown (TSG) and pipeline seagrass sites (TPG). Tukey multiple

comparison procedures were used to find *a posteriori* differences among sample means (Kirk, 1982). The stations means are reported in a Tukey test, and those that are not different to the 0.05 level are joined by underlining. Multivariate ANOVA was used to test for treatment effects on species data. Factor analysis with rotated and unrotated factors was used to determine if communities were similar in different stations.

RESULTS

Synoptic Experiment

The stations were all hydrographically similar in April 1992 during the synoptic study (Table 2). Salinity and temperature averaged 24.6 ppt and 24.0 °C respectively at all stations. Dissolved oxygen and pH averaged 7.54 $mg \cdot l^{-1}$ and 8.97 respectively. There were some differences in oxygen concentration due to site differences and sampling at different times of the day. Baffin Bay was the only site with high turbidity.

There was considerable difference in sediment composition at all sites (Table 3; Figure 3). Baffin Bay was the only site dominated by mud, having a high silt and clay content. In the natural site of the southern part of the study area, station 189, sand composed half of the content of sediments. The southern natural site, 189, was no more than 55% sand. All the northern stations, natural and mitigation, were composed of at least 73% sand. Within sites, bare patches had 5-10% higher sand content than vegetated sediments. The seagrass obviously promotes settling of fine particles, since there was a higher amount of silt and clay at these stations.

Eh decreased with sediment depth at all stations (Table 4; Figure 4). There were dramatic differences among sites in sediment Eh profiles. Vegetated sediments (Figure 4A) were always much more negative than bare-patch sediments within sites (Figure 4B). There was a gradient of electronegativity from recent mitigation sites to older mitigation sties to natural sites. The two new sites (GI_, TS_, and TP) had almost no vertical differences in Eh. This indicates that there is a lack of reducing power in sediments of recent mitigation sites.

There was a considerable amount of seagrass-derived organic matter in all samples, except for the unvegetated sediments (linear contrast, P=0.0001, Figure 5). In the natural and old mitigation sites, most of this material was associated with the surface of the sediment (Figure 5). There was more material in natural sites (934 $g \cdot m^{-2}$) than in mitigation sites (438 $g \cdot m^{-2}$) (linear contrast, P=0.0001). There was also a significant difference with age of the mitigation site (linear contrast, P=0.0001). Old sites had 619 $g \cdot m^{-2}$, but new sites had only 317 $g \cdot m^{-2}$. New sites had proportionately lesser amounts of all components (Figure 6), but especially less below-ground material,

e.g., roots and detritus. The new total amount of material at new mitigation sites was not significantly different from unvegetated sediments (Tukey test). The general trend was for higher amounts of organic material in natural and newer mitigation sites and higher amounts in seagrass stations (mean dry weight in $g \cdot m^{-2}$, station name, and Tukey test):

985	952	876	793	445	357	326	267	220	165	18	12	5
PI1G	PI2G	189G	SKG	CPG	TPG	TSG	GIG	189S	GES	GIS	TSS	6

Oxygen measurements collected from the oxygen electrodes for calculating oxygen metabolism is given in Table 5. Mean oxygen flux was calculated using equation 1 and is presented in Figure 7. The average oxygen flux is negative indicating that the sediments were consuming oxygen in the dark. Seagrass bed samples had the greatest oxygen demand, -8.0 mmol $O_2 \cdot m^{-2} \cdot h^{-1}$ compared to -1.1 mmol $O_2 \cdot m^{-2} \cdot h^{-1}$ in non-vegetated sediments, because of the high biomass of the seagrasses themselves (linear contrast, P=0.0001). Average flux (mmol $O_2 \cdot m^{-2} \cdot h^{-1}$) at natural stations was -10.4, old mitigation sites was -7.2, and new sites was -6.5). There was a trend of higher oxygen consumption with age of the habitat (linear contrast, P=0.0001). The sand and mud stations were not significantly different from one another. The general trend was for higher amounts of oxygen consumption at seagrass stations, and less at mitigation sites (mean flux in mmol $O_2 \cdot m^{-2} \cdot h^{-1}$, station name, and Tukey test):

0.1	-0.9	-1.4	-1.7	-1.9	-4.8	-5.1	-5.4	-7.1	-7.7	-7.8	-9.7	-16.4
GIS	GES	6	189S	TSS	CPG	GIG	TSG	PI2G	TPG	189G	SKG	PI1G

Nutrient measurements for calculating nutrient regeneration is given in Table 6. Flux for all nitrogen components, DIN, phosphate and silicate were calculated. Total DIN flux was near zero at most stations (Figure 8). There was a great deal of sediment nitrogen uptake in the southern stations. However, variability was so great, that is it difficult to detect differences among stations (average flux in mmol $DIN \cdot m^{-2} \cdot h^{-1}$, station name, and Tukey test):

2.0	1.2	1.1	0.2	-0.8	-0.3	-0.9	-1.0	-1.0	-1.6	-5.7	-16.7	-26.3
GIG	TSS	PI1G	TSG	TPG	PI2G	CPG	189S	SKG	GES	GIG	189G	6

Ammonia flux was the greatest constituent of DIN. Ammonia flux was similar at all stations (Figure 9, average flux in mmol $NH_4 \cdot m^{-2} \cdot h^{-1}$, station name, and Tukey test):

2.3	2.3	2.2	0.9	0.1	0.07	-0.2	-0.3	-1.0	-1.1	-1.4	-16.8	-26.0
TSS	GIG	TSG	PI1G	189S	TPG	GIS	PI2G	CPG	SKG	GES	189G	6

Nitrite flux generally, was near zero, but on average there was efflux (0.084 mmol $NO_2 \cdot m^{-2} \cdot h^{-1}$). The only stations with a large amount of nitrite regeneration were the mud and natural seagrass station in southern Laguna Madre (Figure 10). Because of the high value at the mud site (station 6), there was more nitrite regeneration in unvegetated stations (0.20 mmol $NO_2 \cdot m^{-2} \cdot h^{-1}$) than in vegetated sediments (0.012 mmol $NO_2 \cdot m^{-2} \cdot h^{-1}$) (linear contrast, P=0.0096). Except for the high values at 6 and 189G, there were little differences among stations (average flux in mmol $NO_2 \cdot m^{-2} \cdot h^{-1}$, station name, and Tukey test):

1.12	0.64	0.09	0.03	0.03	0.02	-0.03	-0.04	-0.05	-0.06	-0.08	-0.28	-0.29
6	189G	TSG	PI1G	TPG	GIS	TSS	189S	CPG	GES	GIG	SKG	PI2G

Nitrate flux was also generally near zero, but on average there was uptake by sediments (-0.77 mmol $NO_3 \cdot m^{-2} \cdot h^{-1}$) (Figure 11). The only stations with a significant amount of nitrate uptake were generally unvegetated stations (-1.60 mmol $NO_3 \cdot m^{-2} \cdot h^{-1}$), which were different from vegetated stations (-0.26 mmol $NO_3 \cdot m^{-2} \cdot h^{-1}$) (linear contrast, P=0.0001). The only station with a large amount of nitrite flux was GIS (Figure 11, average flux in mmol $NO_3 \cdot m^{-2} \cdot h^{-1}$, station name, and Tukey test):

0.43	0.30	0.13	0.11	-0.16	-0.17	-0.21	-0.37	-0.52	-1.06	-1.08	-2.11	-5.33
SKG	PI2G	CPG	PI1G	GES	TPG	GIG	6	189G	189S	TSS	TSG	GIS

Phosphate flux was not significantly different at any of the 13 stations (P=0.3206, one-way ANOVA). The mean flux was -0.265 mmol $PO_4 \cdot m^{-2} \cdot h^{-1}$, and was not different from zero (Figure 12). On average silicate was generated by sediments (5.1 mmol

$SiO_4 \cdot m^{-2} \cdot h^{-1}$) (Figure 13). Silicate regeneration was higher in the natural seagrass sites (16.0 mmol $SiO_4 \cdot m^{-2} \cdot h^{-1}$) than in the mitigation seagrass stations (2.4 mmol $SiO_4 \cdot m^{-2} \cdot h^{-1}$) (linear contrast, P=0.0001). Silicate flux was high in seagrass bed stations (7.5 mmol $SiO_4 \cdot m^{-2} \cdot h^{-1}$) and low in non-vegetated stations (1.1 mmol $SiO_4 \cdot m^{-2} \cdot h^{-1}$) (linear contrast, P=0.0001). This trend was driven by large fluxes at two natural stations (Figure 13, average flux in mmol $SiO_4 \cdot m^{-2} \cdot h^{-1}$, station name, and Tukey test):

34.4	15.5	6.9	4.7	3.7	3.3	1.9	0.8	0.7	-0.3	-1.4	-2.0	-2.5
189G	PI1G	6	GIG	TSG	TPG	GES	TSS	CPG	SKG	GIS	PI2G	189S

Macrofaunal invertebrates were much more abundant in the top 3 cm of surface sediment (Table 7, Figure 14). There were on average 19,994 animals$\cdot m^{-2}$ in top 3 cm, and 3,831 animals$\cdot m^{-2}$ in the 3-10 cm depths. There were significant interactions among sediment depths and stations (2-way ANOVA, P=0.001), so it is difficult to determine if mitigation affected the vertical distribution of organisms. The percent of organisms present in the top 3 cm of sediment was calculated and a 1-way ANOVA indicated there were station differences (P=0.0069). Total percent abundance in surface was higher (linear contrast, P=0.0006) at all the seagrass sites (85%) than at the unvegetated sites (72%). The average biomass at all stations in the top 3 cm of sediment was 5.11 g$\cdot m^{-2}$, and 5.84 in the 3-10 cm section. Differences in vertical profiles among stations were found for biomass (Figure 15, 1-way ANOVA, P=0.0003). Again there was a higher percentage of the biomass found in vegetated sediments (63%) than in unvegetated sediments (38%) (linear contrast, P=0.0004). Natural sites had a higher percentage of the biomass in surface sediments (75%) than mitigation sites (55%) (linear contrast, P=0.0159). There was also an increased percentage of biomass in surface sediments with age of the seagrass bed; the old mitigation sites had 66% of the biomass in the surface, and the new sites had 48% at the surface (linear contrast, P=0.0228). The following is a Tukey test of the percent of biomass in the surface sediment:

87.5	82.1	80.2	73.0	61.1	58.6	55.9	49.2	45.0	39.1	26.7	24.7	11.3
PI2G	PI1G	6	CPG	TPG	SKG	189G	GIS	GIG	TSG	189S	GES	TSS

In general, vegetated sediments had higher total abundances to a depth of 10 cm (32,229$\cdot m^{-2}$) than unvegetated sediments (10,098$\cdot m^{-2}$) (linear contrast, P=0.0001).

Natural sites had higher abundances (40,781·m^{-2}) than mitigated sites (27,097·m^{-2}) (linear contrast, P=0.0005). Although there was no difference among old (28,932·m^{-2}) and new sites (25,874·m^{-2}) (linear contrast, P=0.4824), the trend of natural to old to new is significant (linear contrast, P=0.0006). Total macrofaunal density was highest in the vegetated (natural sites of the northern part of the study area (Tukey test, average number×10^3·m^{-2} to a depth of 10 cm, and station name):

55.8	41.1	29.0	28.8	27.1	27.0	25.4	25.4	25.1	9.1	6.1	4.3	3.8
PI2G	PI1G	SKG	CPG	GES	TSG	GIG	189G	TPG	189S	GIS	6	TSS

The average infaunal biomass in the top 10 cm of sediment was different only among vegetated and unvegetated sediments (Figure 15, linear contrast, P=0.0245). Although infaunal biomass varied by an order of magnitude there were few statistically significant differences among the stations (one-way ANOVA) (average biomass in g·m^{-2} to a depth of 10 cm, and station name):

21.3	19.1	18.8	16.4	14.2	13.3	10.6	9.6	5.2	4.6	4.2	2.6	2.5
TSS	GIG	SKG	TSG	CPG	189G	TPG	PI1G	PI2G	189S	GIS	GES	6

Community structure, in terms of major taxa, was different among the stations sampled (Figure 16). There were large differences among vegetated and unvegetated sediments (MANOVA, P=0.0001). Natural and mitigation sites were also different (MANOVA, P=0.0003). There were significant differences with respect to age of the vegetated sites (MANOVA, P=0.0006). The differences among sites was driven by changes in polychaete density, since they generally dominated the communities in all stations. Polychaetes generally dominated biomass also (Figure 17). Differences similar to abundance were found among vegetated and unvegetated sediments (MANOVA, P=0.0017), natural and mitigation sites (MANOVA, P=0.0053), and with respect to age of the vegetated sites (MANOVA, P=0.0146).

Community structure, in terms of species distributions was also different among the stations (Table 8). The most obvious factor that is related to changes in community structure is whether the station is vegetated or unvegetated (Figure 18). This factor, factor 1 in Figure 18, accounted for 53% of the variability in species distributions. The second factor, which accounts for 23% of the variability, seems to be related to the age of the mitigation site. All natural stations, the oldest mitigation stations (CPG and

SKG), and the pipeline site (TPG) group together in the center and left side of the second factor axis. The newer sites (TSG and GIG) group together with unvegetated sites on the right side of the second factor axis.

Species diversity is highest in seagrass systems (Figure 19, Table 9). The average N1 diversity for seagrass beds was 10.4 species compared to a 6.3 species for unvegetated stations (linear contrast, P=0.0001). Species diversity is highest in the recently disturbed environments. Natural sites had a lower average diversity (8.0) than mitigation sites (11.0) (linear contrast, P=0.0001). Diversity declined with age of the habitat (linear contrast, P=0.0001; new mitigation sites had a diversity of 12.6, old sites were 10.7, and natural sites were 8.0. The small difference between new and old sites was significantly different (linear contrast, P=0.0453). The average diversity at each site follows (N1, station name, and tukey test):

16.8	12.2	11.8	11.0	10.9	9.2	9.2	8.1	7.1	6.0	5.8	4.2	2.5
TSG	SKG	GIG	189G	189S	CPG	TPG	TSS	PI1G	GIS	PI2G	GES	6

Species evenness was different among stations (1-way ANOVA, P=0.0001, Figure 20, Table 9). The average E1 evenness index for seagrass beds was 0.80, which was not different from 0.77 for unvegetated stations (linear contrast, P=0.1173). Natural sites had a lower average evenness (0.70) than mitigation sites (0.82) (linear contrast, P=0.0002). Evenness declined with age of the habitat (linear contrast, P=0.0003; new mitigation sites had an evenness of 0.83, old sites were 0.79, and natural sites were 0.70. The average evenness index at each site follows (E1, station name, and tukey test):

0.97	0.91	0.88	0.85	0.83	0.83	0.80	0.77	0.76	0.74	0.68	0.62	0.57
TSS	189S	TSG	GIG	GIS	SKG	189G	TPG	CPG	6	PI1G	PI2G	GES

Evenness and diversity were correlated (Figure 21). As diversity increases evenness increases, i.e., dominance decreases. There appears to be a phase shift, or two separate relationships, for the non-vegetated sites versus the vegetated sites. The non-vegetated sites have higher evenness values than the vegetated sites. This indicates that there may be less dominance at non-vegetated sites.

Temporal Study

Two paired stations, one natural (189) and one created (TS), were monitored for one year to determine if change in the newly created habitat were discernible. There was always more material in the natural sediments (189) than in the mitigation site (TS) (Table 10, Figures 22-23). The relative proportion of organic matter in the surface 0-3 cm and bottom 3-10 cm sections of sediment did not change much over the year of monitoring (Figure 22). In general, the higher proportion of organic matter in the natural station (189) was due to higher amounts of material in both sections (Figure 22). At both sites, the organic material at the sand stations (-S) was composed entirely of detritus (Figure 23). There was much more detritus in the natural grass station (-G) than at the mitigation station (Figure 23). There was very little change at any station from April through October 1992.

Seasonal fluctuations in macrofaunal abundance (Figure 24) and biomass (Figure 25) did occur. The interaction between stations and dates was significant for biomass (2-way ANOVA, P=0.0428) and abundance (P=0.0028), indicating that changes in abundance and biomass were different at the mitigation and the natural site. Abundance at the natural sites increased throughout the year, but at the mitigation site there was a large decline during the spring and then a rise for the remainder of the year.

Figure 3. Sediment composition. Per cent dry weight of sediment components in each station. Samples taken in April 1992.

Laguna Madre Sediment Composition (% dry weight)

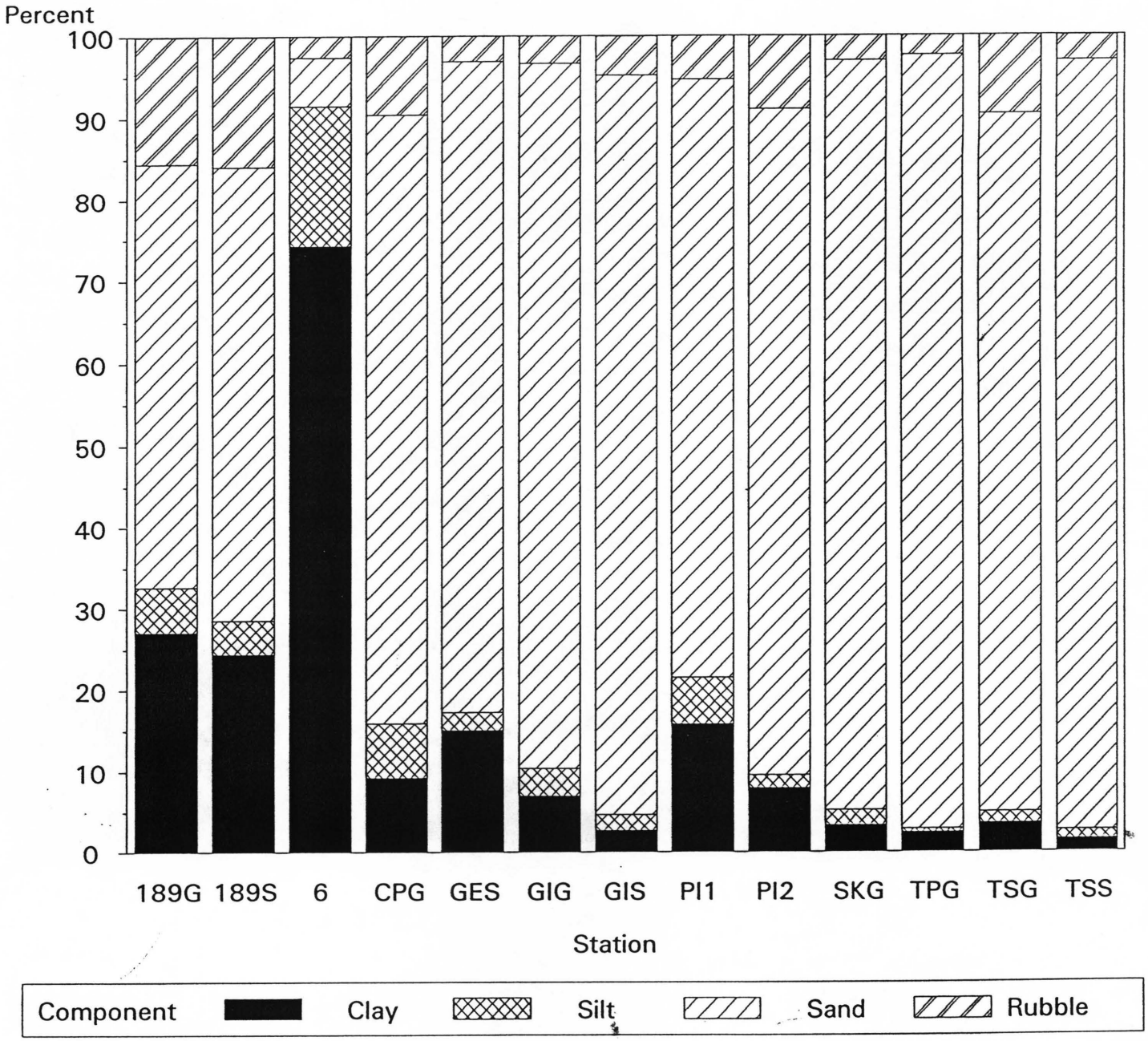


Figure 4A. Sediment eH profiles. Vegetated stations. Vertical distribution of eH measurements within each station. Samples were taken at each cm horizon. Samples taken in April 1992.

Laguna Madre eH Profiles
Habitat = Seagrass

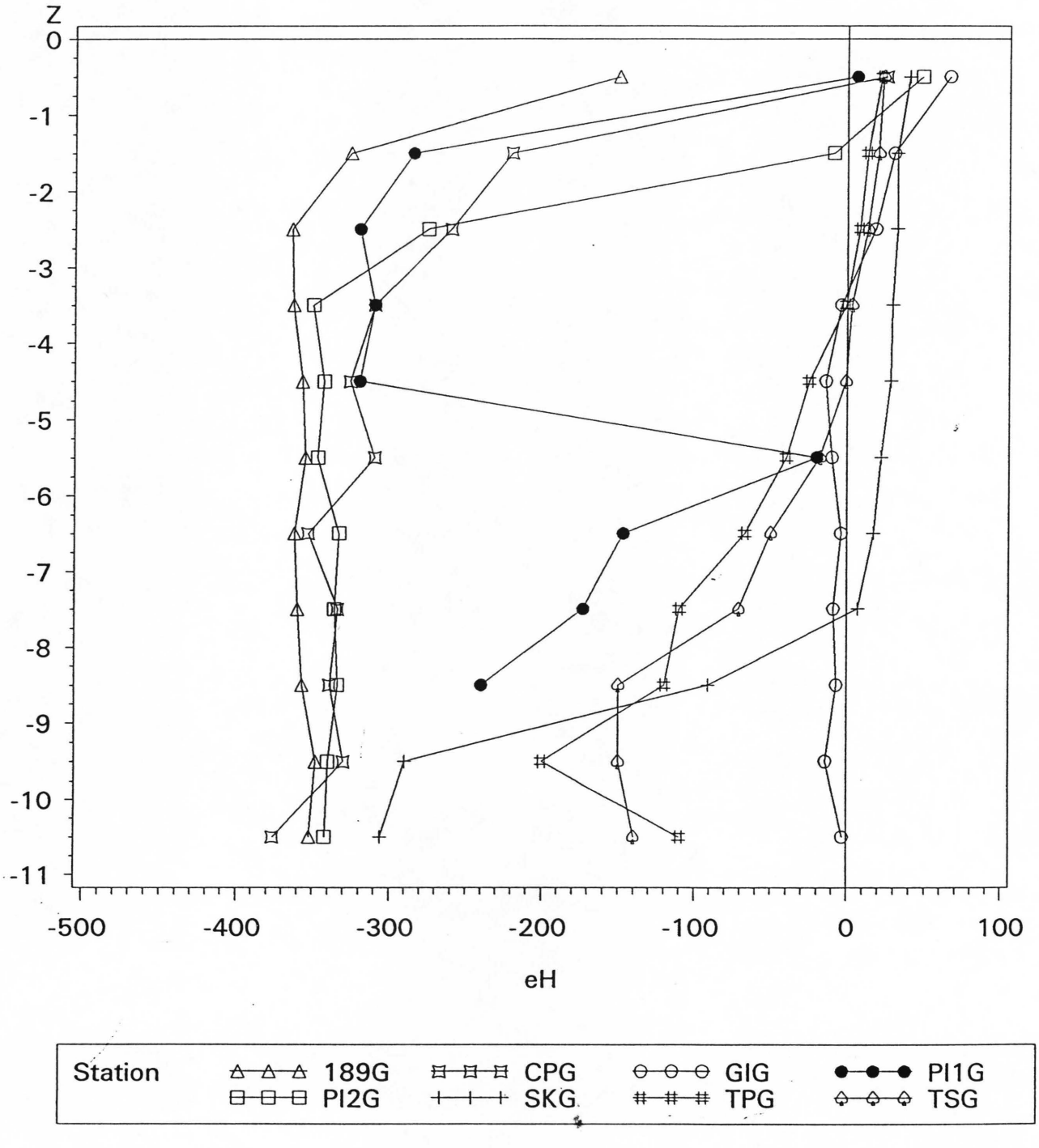


Figure 4B. Sediment eH profiles. Unvegetated stations. Vertical distribution of eH measurements within each station. Samples were taken at each cm horizon. Samples taken in April 1992.

Laguna Madre eH Profiles
Habitat = Unvegetated

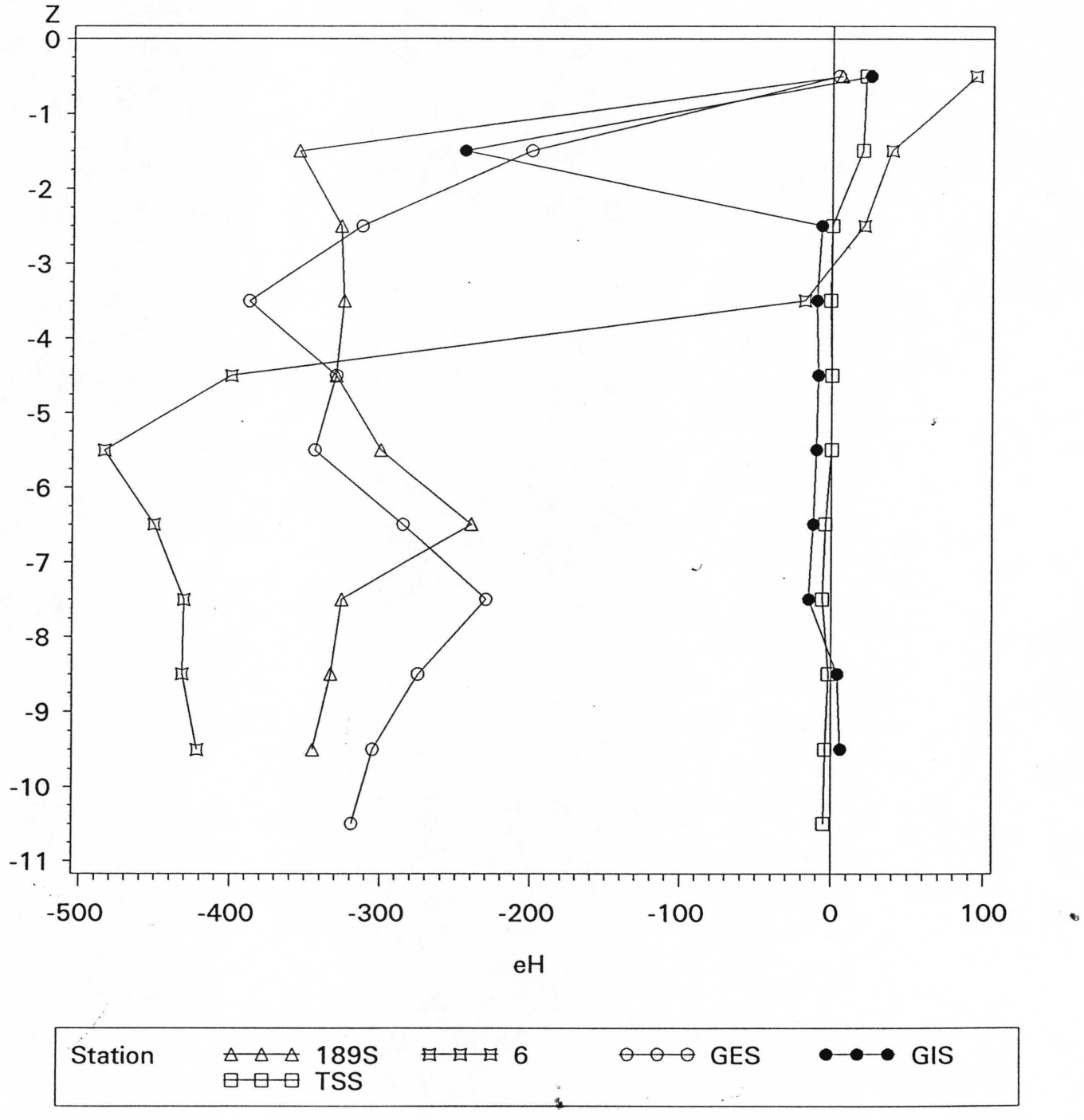


Figure 5. Sediment organic matter at two depths. Average from 3 replicate cores taken at each station in April 1992. Cores were sectioned into 0-3 cm 3-10 cm sections.

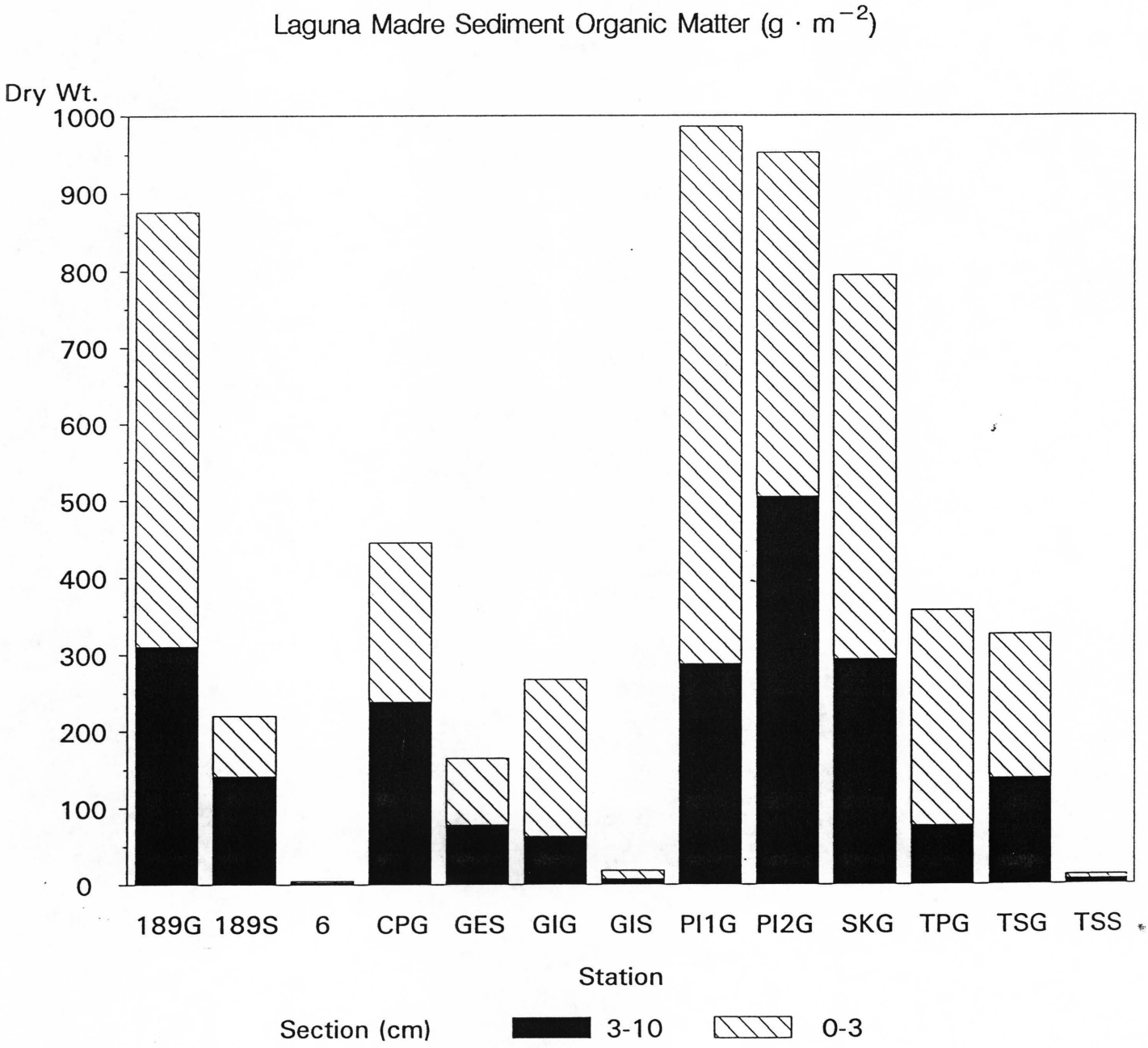

Laguna Madre Sediment Organic Matter (g · m^{-2})
Dry Wt.
1000
900
800
700
600
500
400
300
200
100
0
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station
Section (cm)
3-10
0-3

Figure 6. Sediment organic matter components. Average from 3 replicate cores to a depth of 10 cm. Samples taken at each station in April 1992. Plant material and detritus retained on a 0.5 mm sieve.

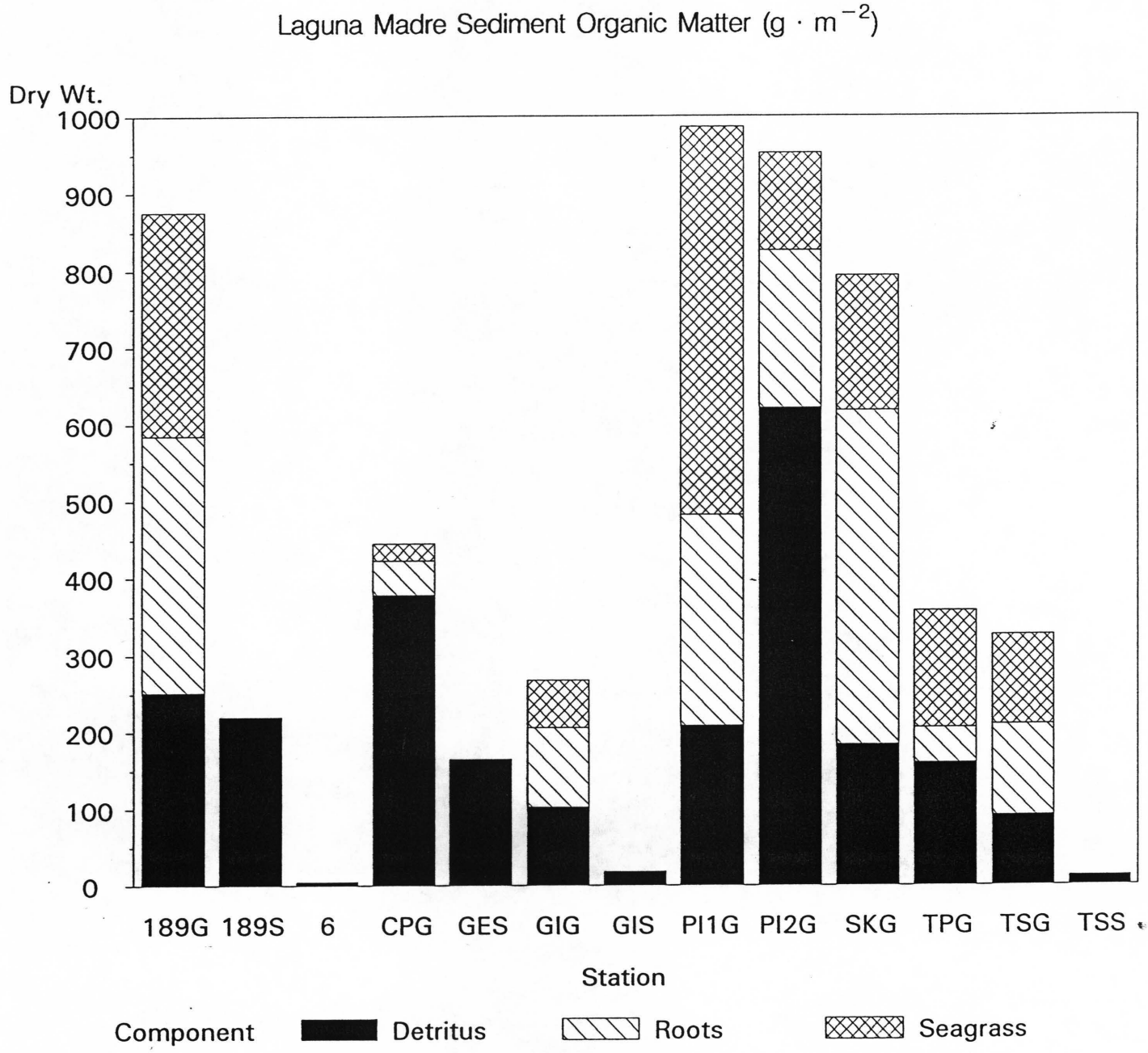

Laguna Madre Sediment Organic Matter (g · m⁻²)
Dry Wt.
1000
900
800
700
600
500
400
300
200
100
0
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station
Component
Detritus
Roots
Seagrass

Figure 7. Oxygen flux. Average flux from 3 replicate cores taken at each station. Samples taken in April 1992.

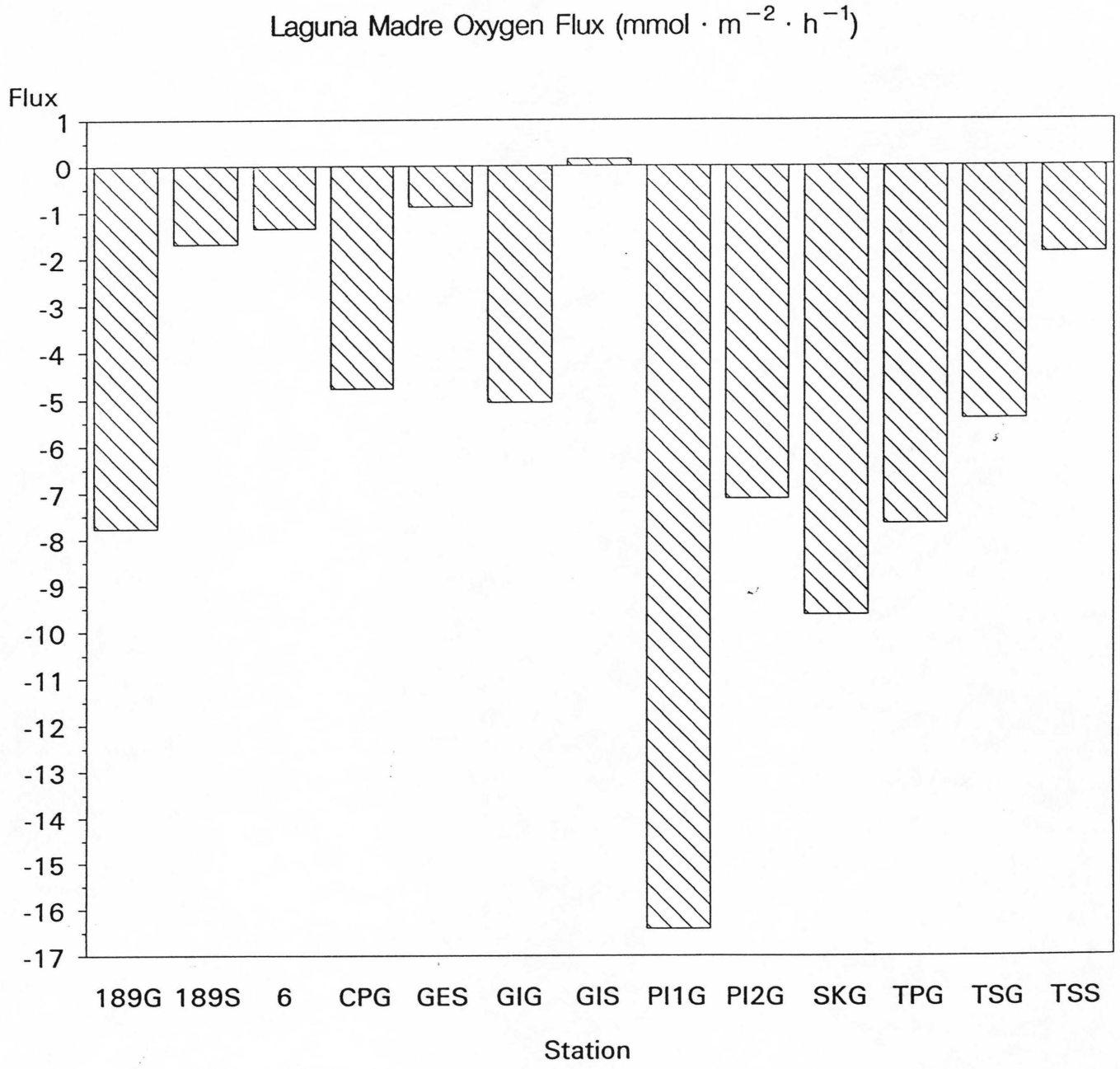


Figure 8. Total dissolved inorganic nitrogen flux. Average flux from 3 replicate cores taken at each station. Samples taken in April 1992.

Laguna Madre Dissolved Inorganic Nitrogen Flux (mmol · m^{-2} · h^{-1})

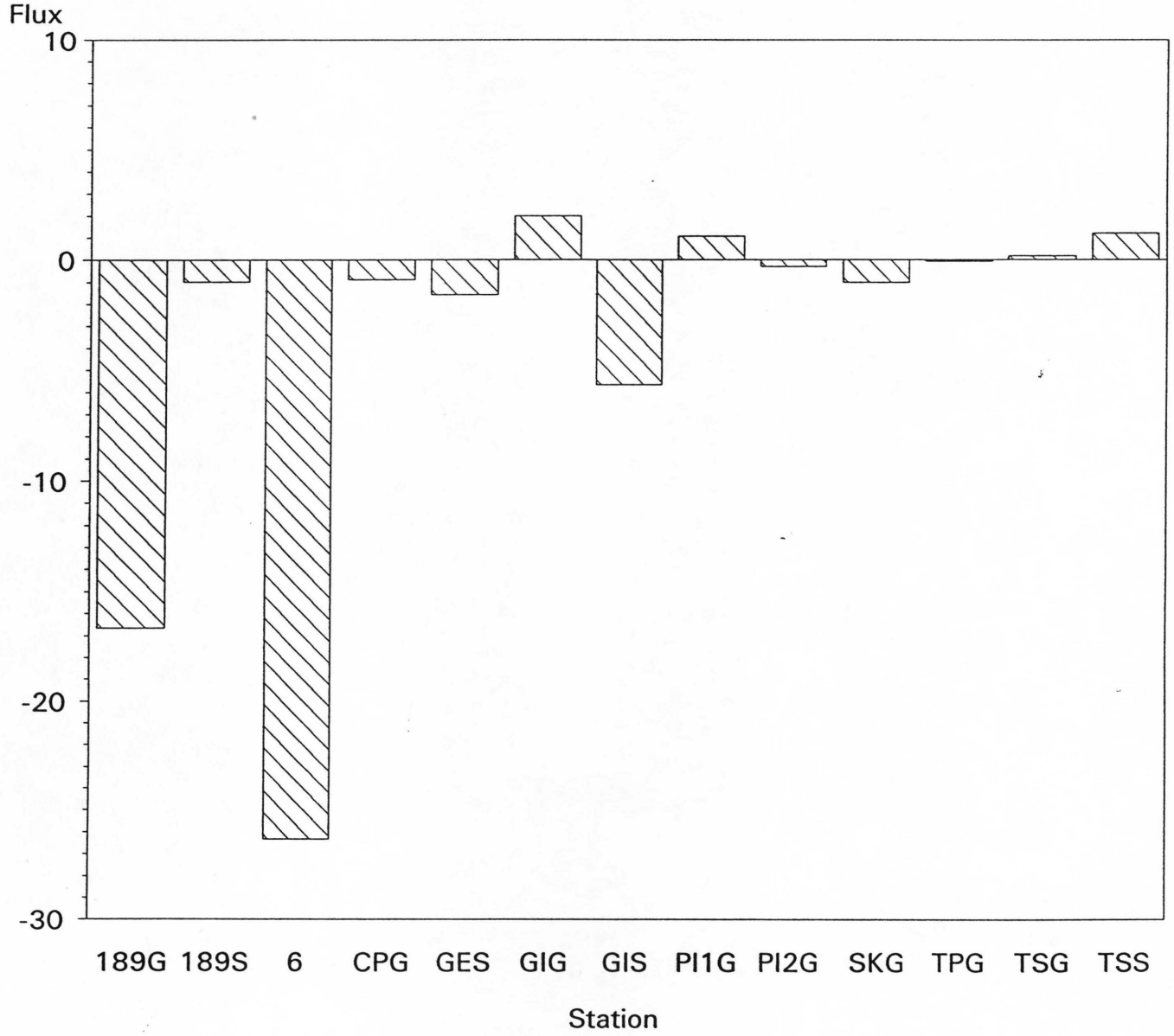


Figure 9. Ammonia flux. Average flux from 3 replicate cores taken at each station. Samples taken in April 1992.

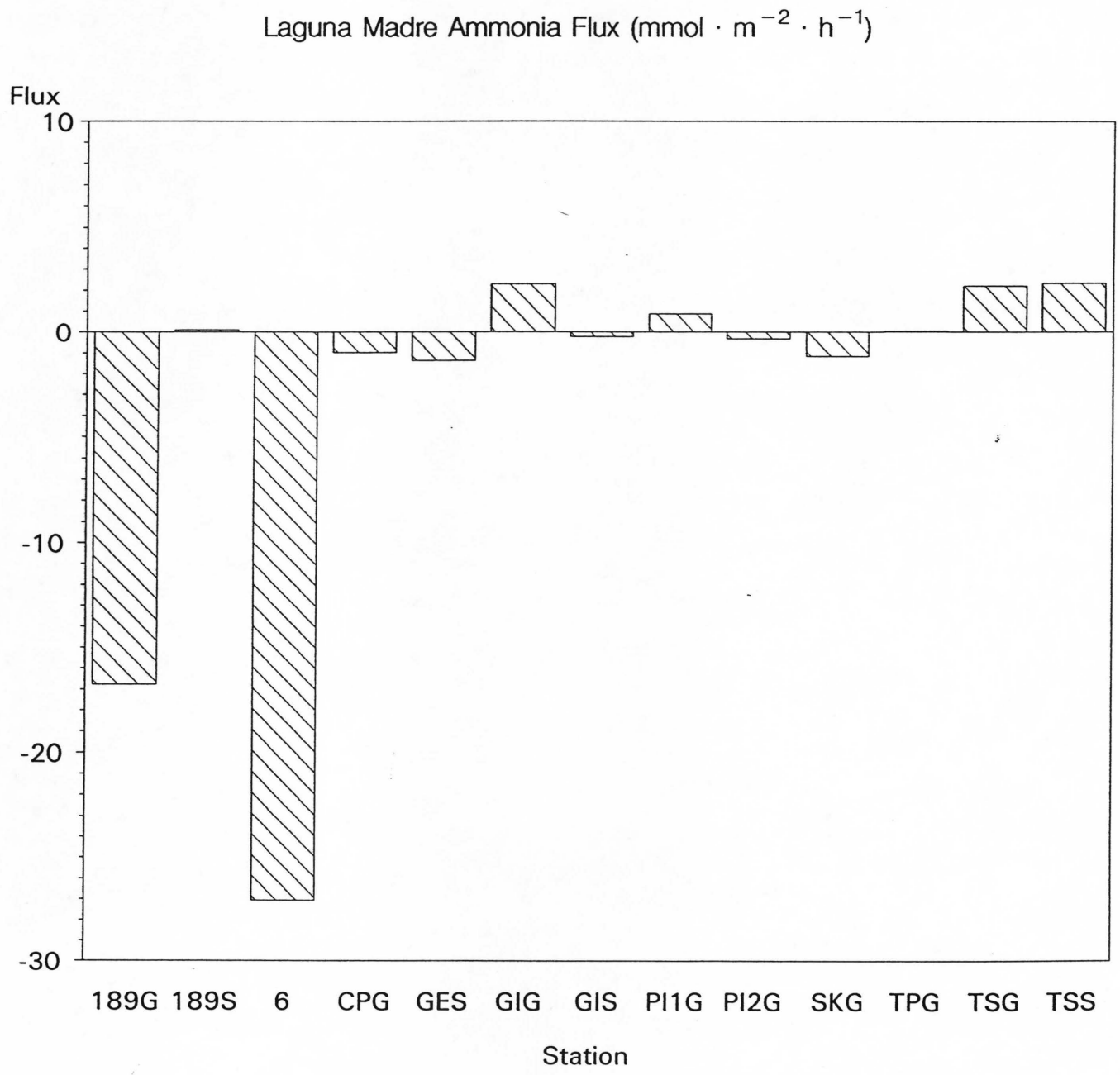

Laguna Madre Ammonia Flux (mmol · m^{-2} · h^{-1})
Flux
10
0
-10
-20
-30
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station

Figure 10. Nitrite flux. Average flux from 3 replicate cores taken at each station. Samples taken in April 1992.

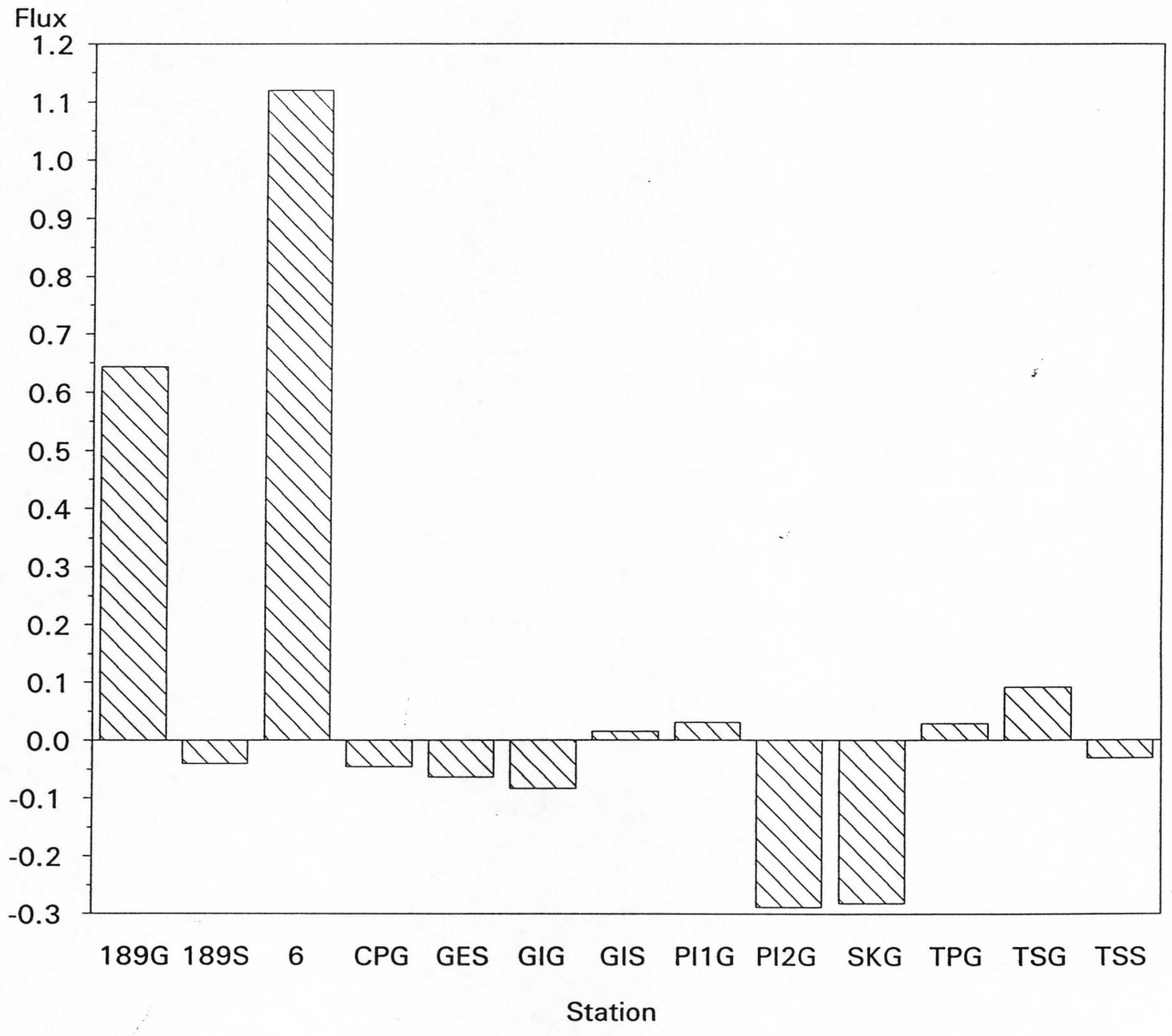

Laguna Madre Nitrite Flux (mmol · m^{-2} · h^{-1})
Flux
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station

Figure 11. Nitrate flux. Average flux from 3 replicate cores taken at each station. Samples taken in April 1992.

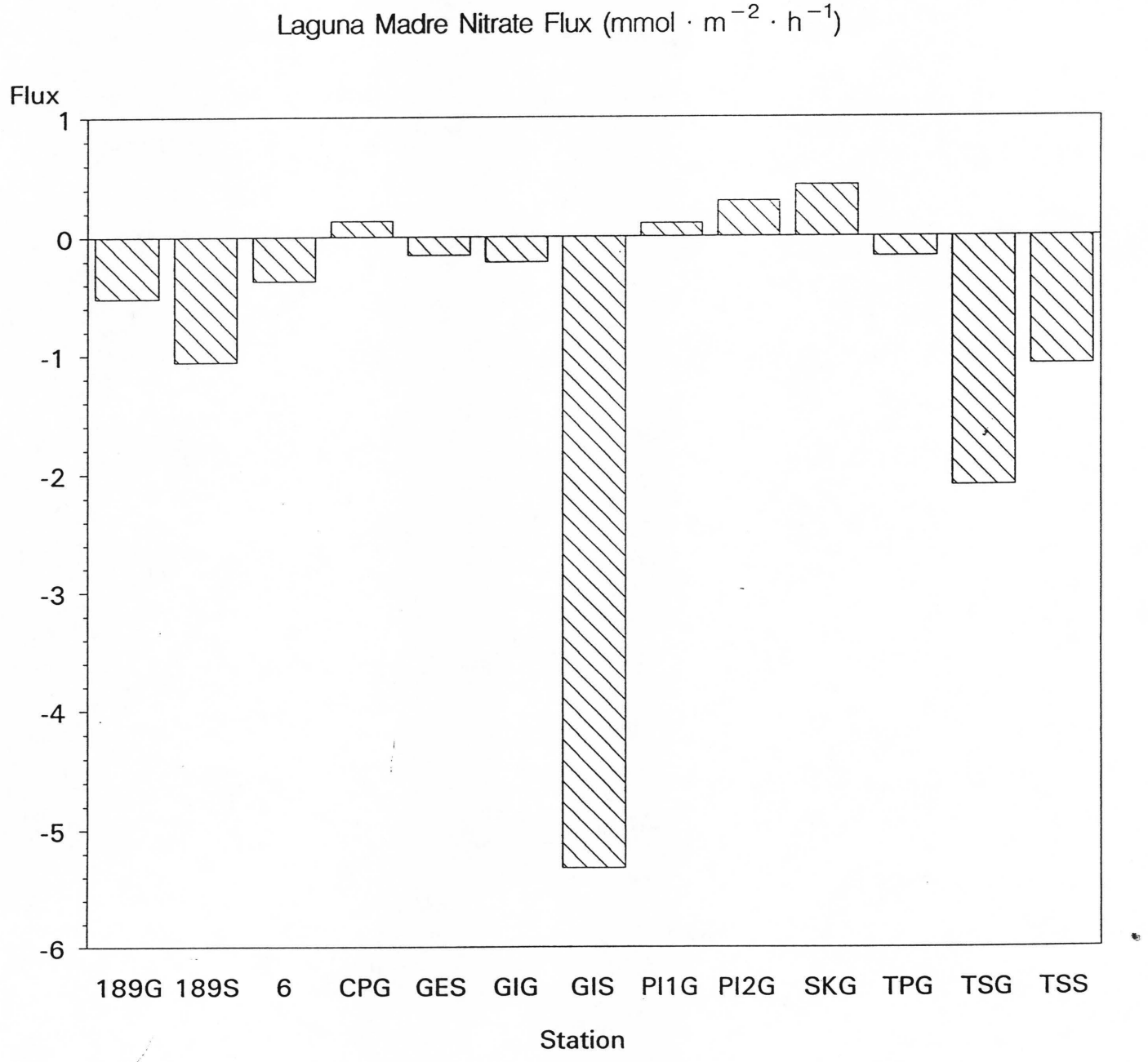

Laguna Madre Nitrate Flux (mmol · m⁻² · h⁻¹)
Flux
1
0
-1
-2
-3
-4
-5
-6
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station

Figure 12. Phosphate flux. Average flux from 3 replicate cores taken at each station. Samples taken in April 1992.

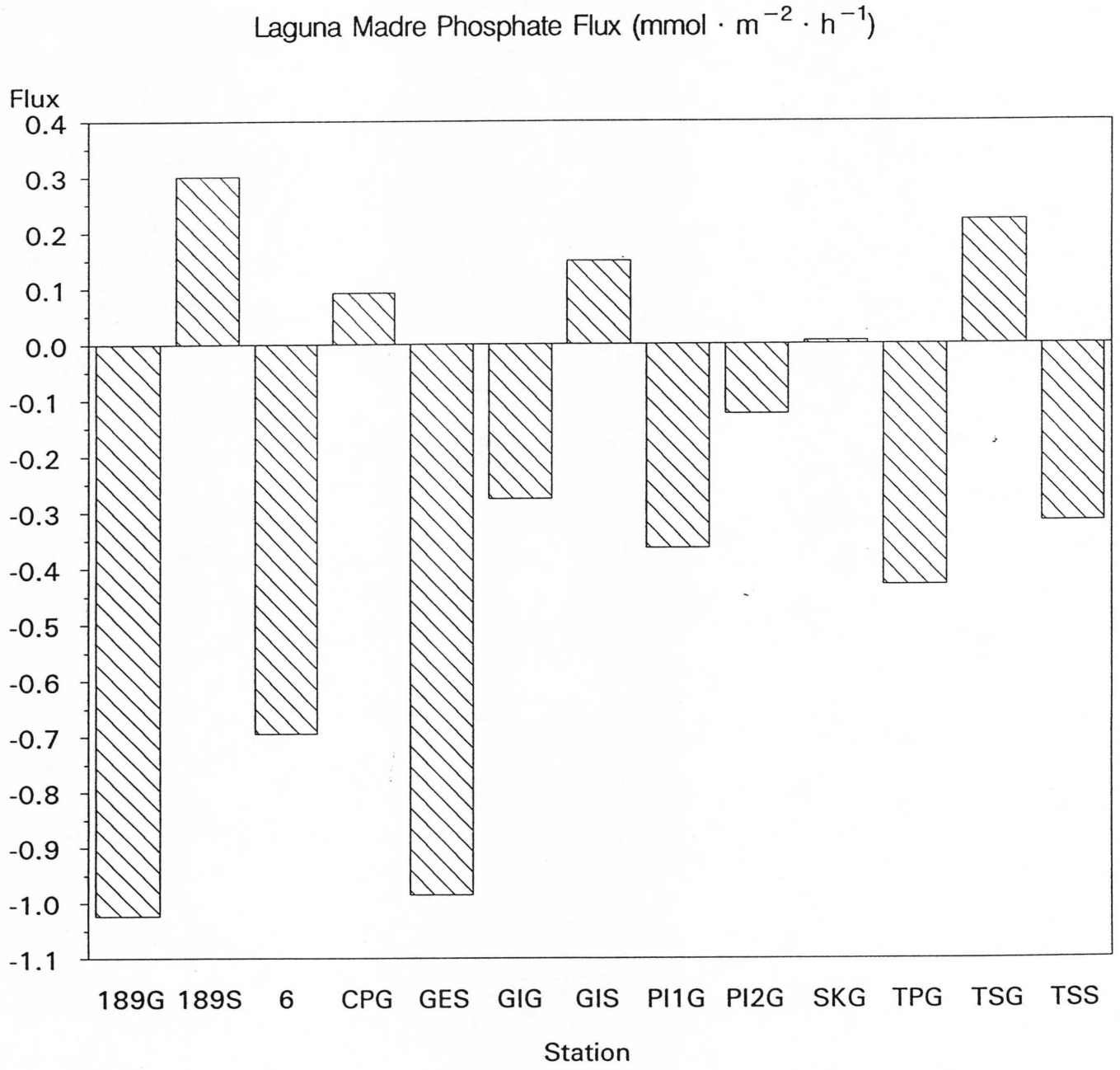

Laguna Madre Phosphate Flux (mmol · m^{-2} · h^{-1})
Flux
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station

Figure 13. Silicate flux. Average flux from 3 replicate cores taken at each station. Samples taken in April 1992.

Laguna Madre Silicate Flux (mmol · m^{-2} · h^{-1})

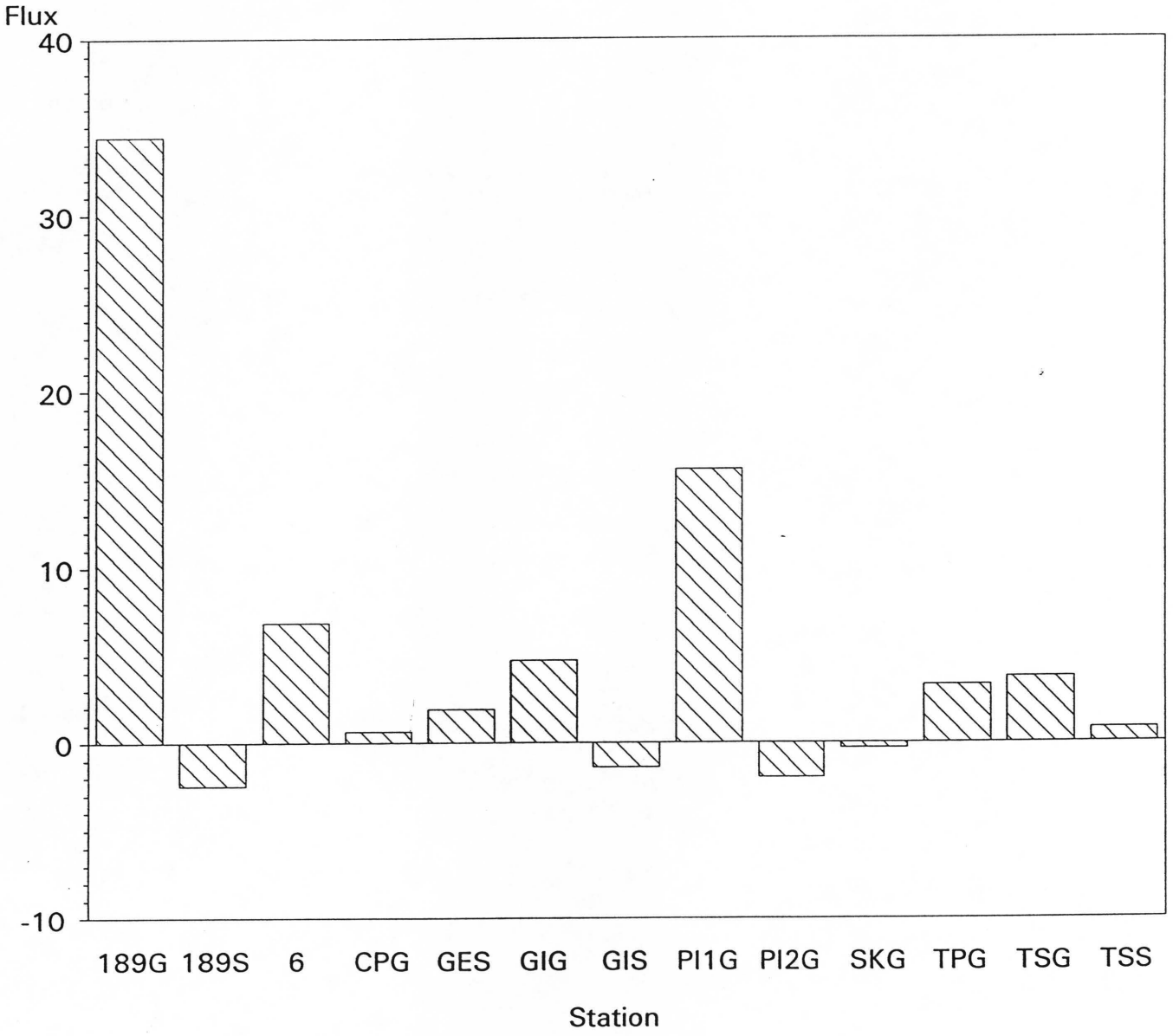


Figure 14. Macrofauna abundance at two sediment depths. Average number of individuals from 3 replicate cores taken at each station. Samples taken in April 1992.

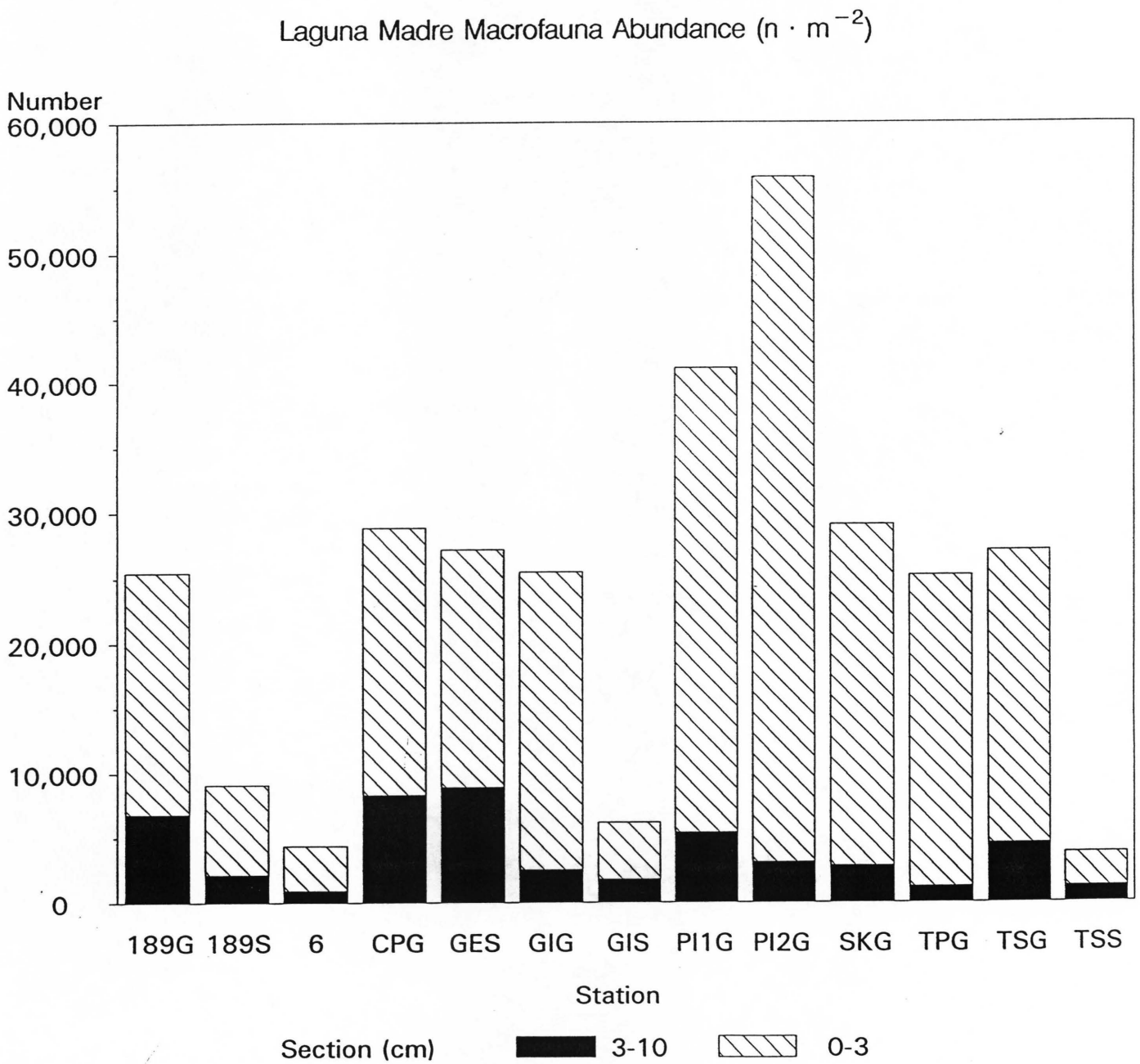

Laguna Madre Macrofauna Abundance (n · m $^{-2}$)
Number
60,000
50,000
40,000
30,000
20,000
10,000
0
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station
Section (cm)
3-10
0-3

Figure 15. Macrofauna biomass at two sediment depths. Average dry weight from 3 replicate cores taken at each station. Samples taken in April 1992.

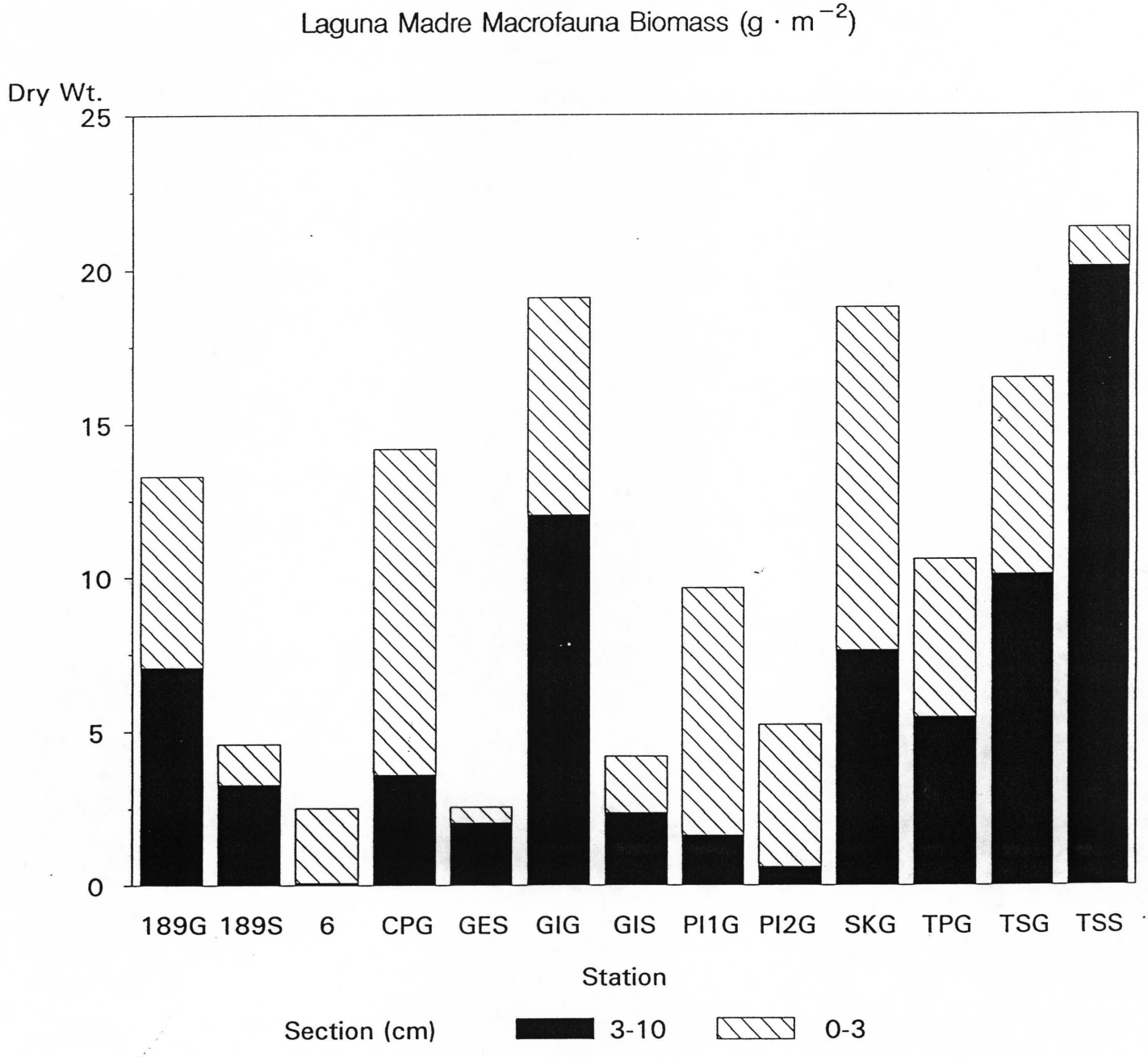

Laguna Madre Macrofauna Biomass (g · m $^{-2}$)
Dry Wt.
25
20
15
10
5
0
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station
Section (cm)
3-10
0-3

Figure 16. Macrofauna taxa abundance. Average number of individuals from 3 replicate cores taken at each station. Samples taken in April 1992.

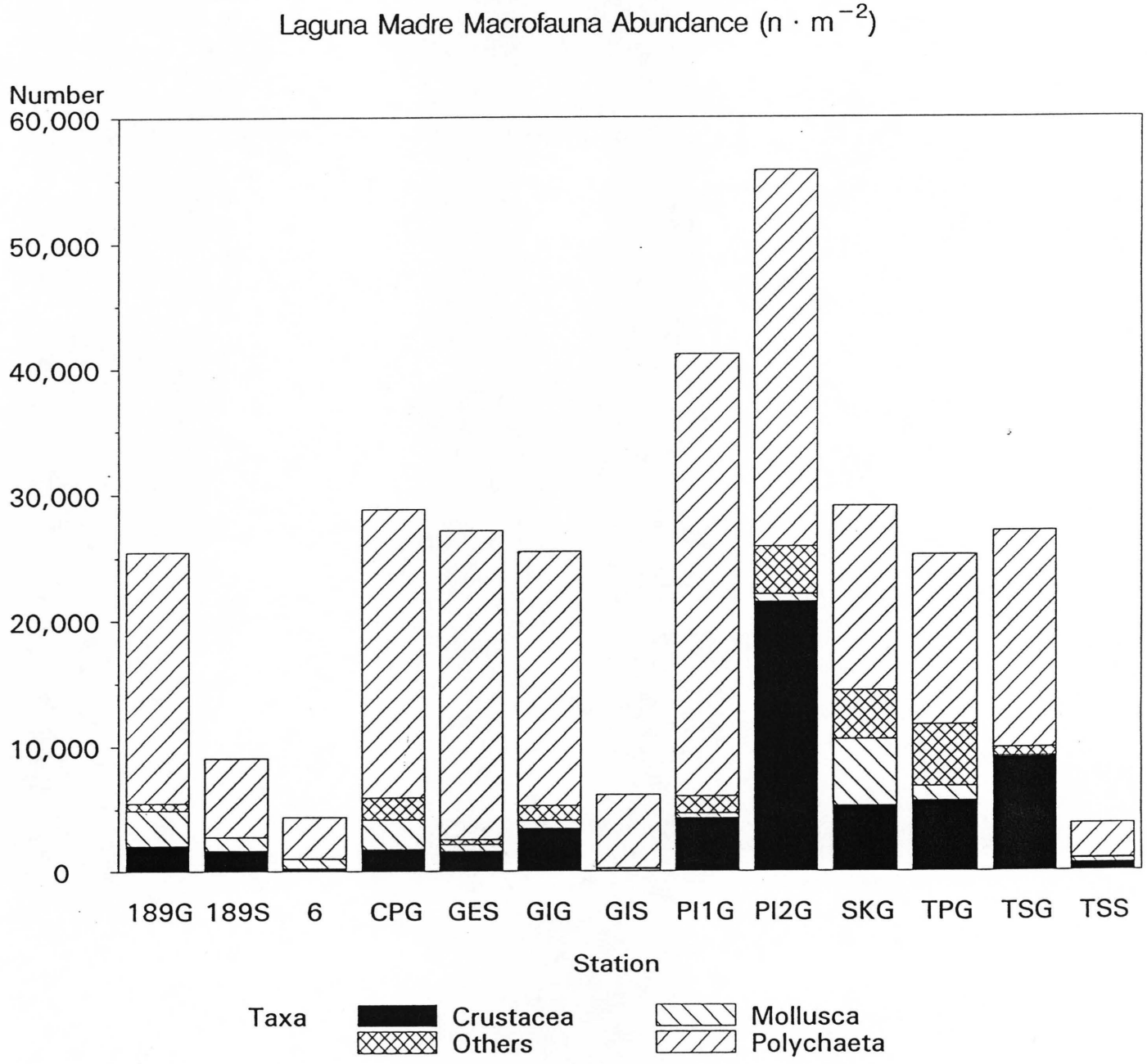

Laguna Madre Macrofauna Abundance (n · m^{-2})
Number
60,000
50,000
40,000
30,000
20,000
10,000
0
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station
Taxa
Crustacea
Others
Mollusca
Polychaeta

Figure 17. Macrofauna taxa biomass. Average dry weight from 3 replicate cores taken at each station. Samples taken in April 1992.

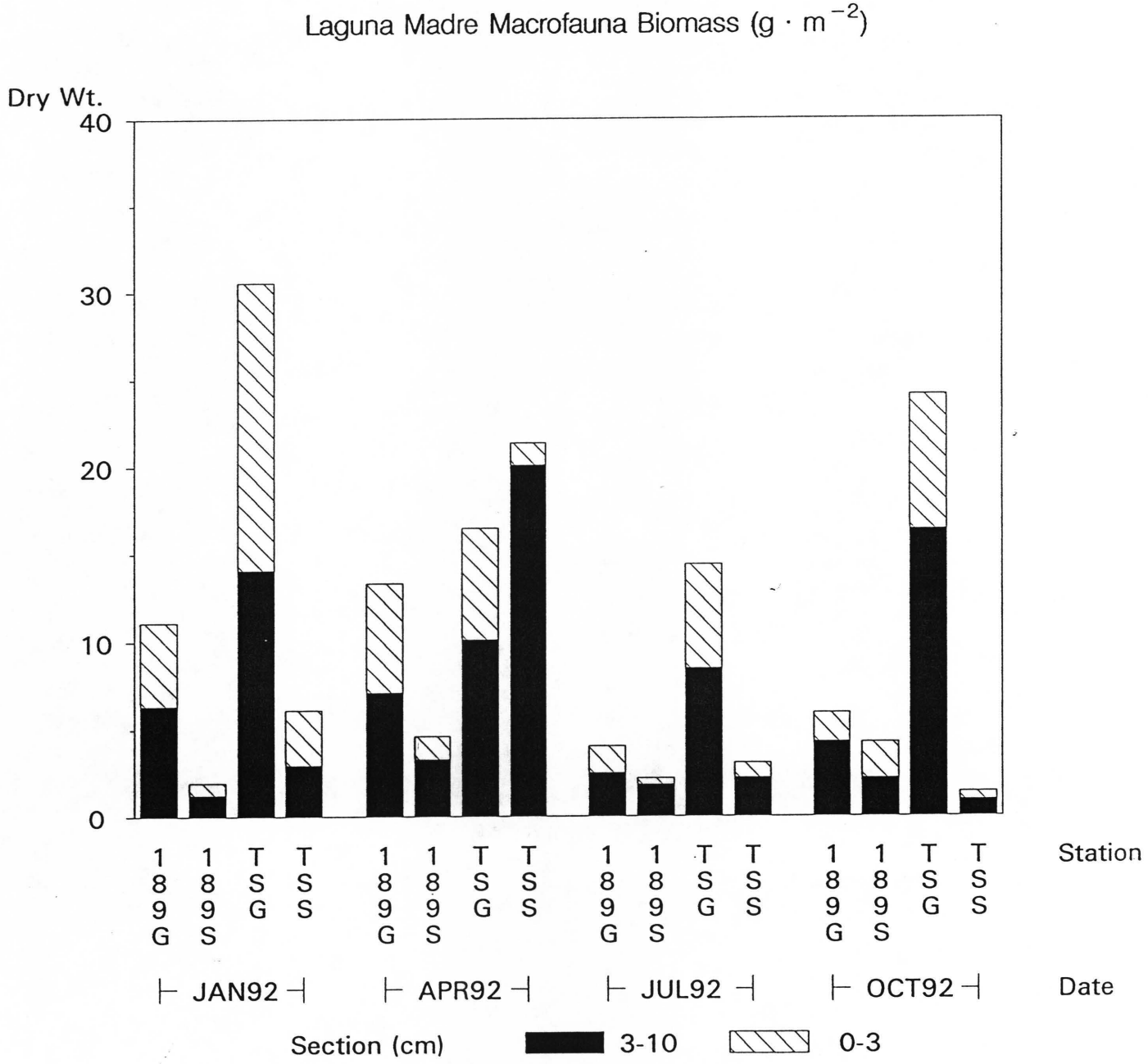

Laguna Madre Macrofauna Biomass (g · m^{-2})
Dry Wt.
40
30
20
10
0
189G
189S
TSG
TSS
JAN92
APR92
JUL92
OCT92
Station
Date
Section (cm)
3-10
0-3

Figure 18. Macrofauna species principal factor analysis. Samples taken in April 1992.

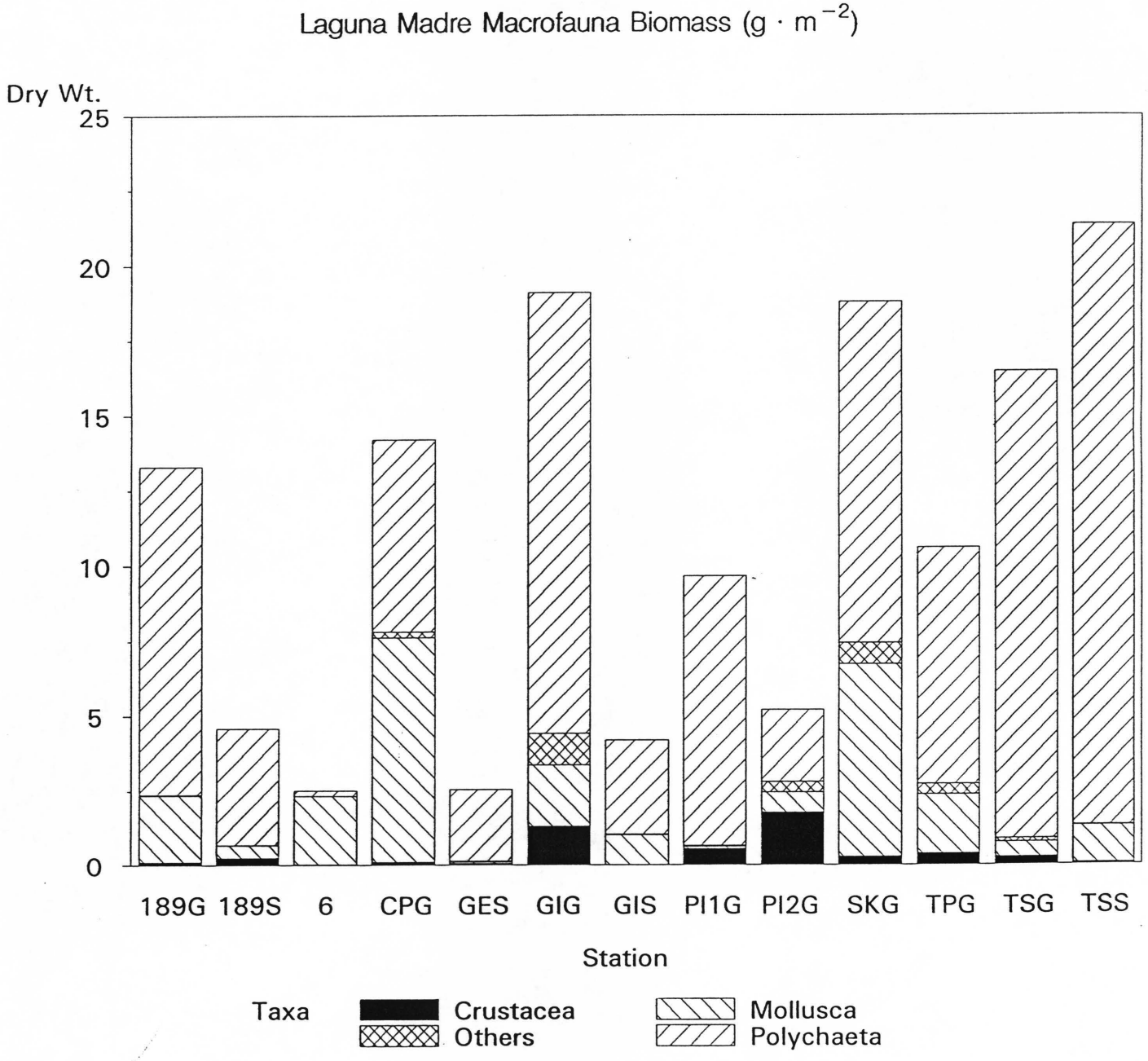

Laguna Madre Macrofauna Biomass (g · m^{-2})
Dry Wt.
25
20
15
10
5
0
189G
189S
6
CPG
GES
GIG
GIS
PI1G
PI2G
SKG
TPG
TSG
TSS
Station
Taxa
Crustacea
Others
Mollusca
Polychaeta

Figure 19. Macrofauna species diversity. Average Hill's index, N1, from 3 replicate cores taken at each station. Samples taken in April 1992.

Laguna Madre Macrofauna Species
Principal Factor Analysis

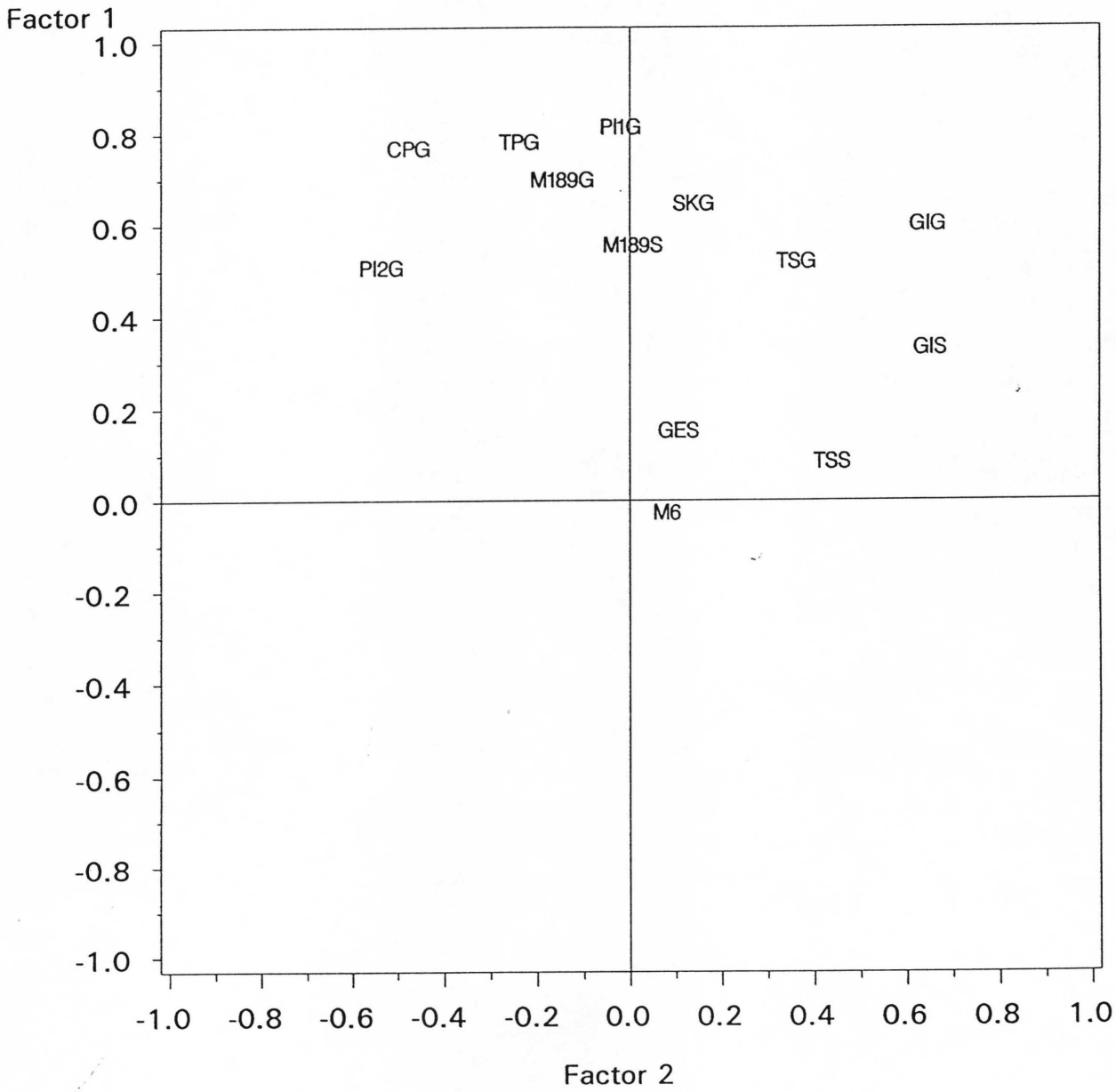


Figure 20. Macrofauna species evenness. Average Hill's index, E1, from 3 replicate cores taken at each station. Samples taken in April 1992.

Laguna Madre Macrofauna Diversity

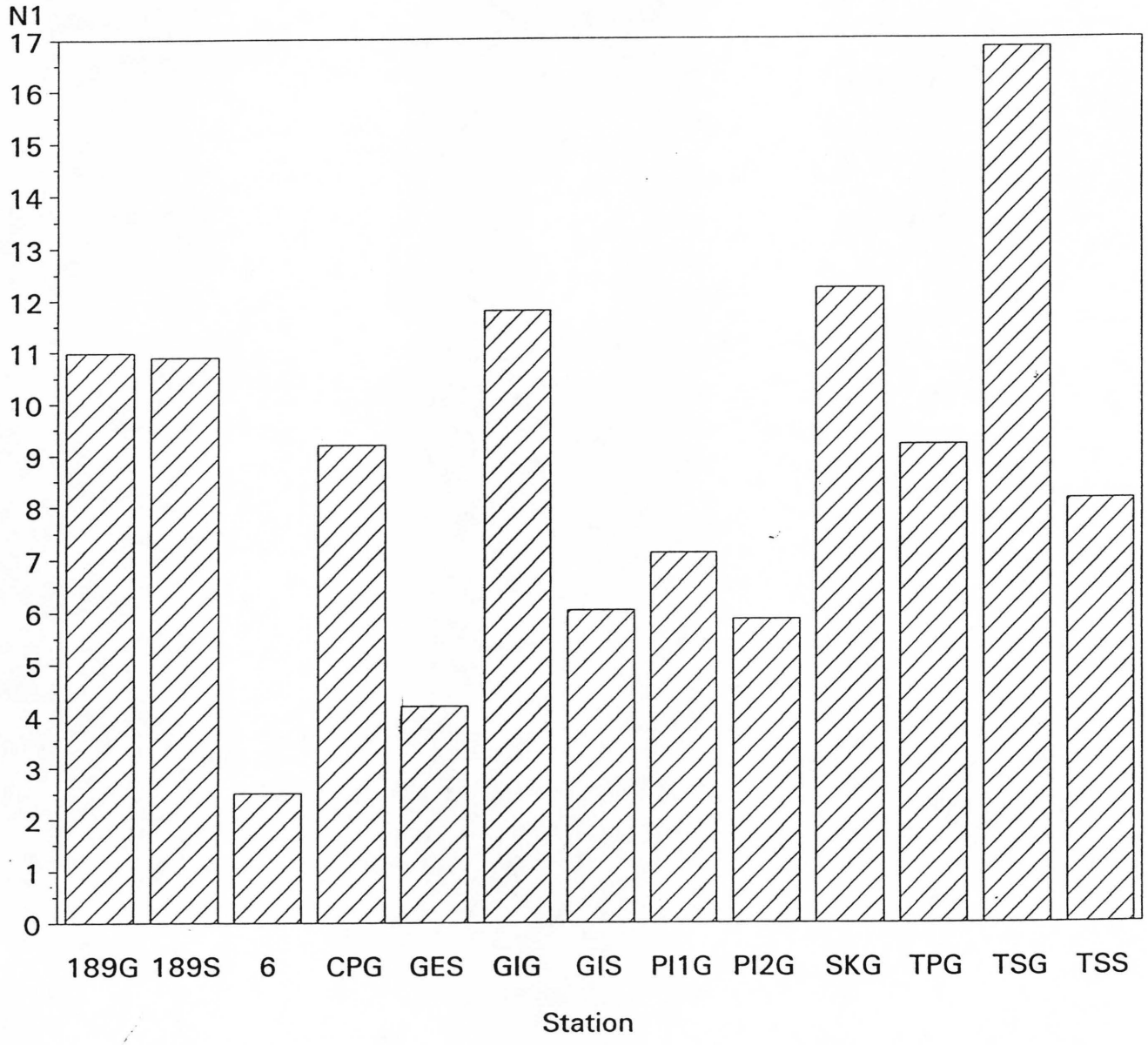


Figure 21. Relationship between species diversity and evenness. Average Hill's index, E1 and N1, from 3 replicate cores taken at each station. Samples taken in April 1992.

Laguna Madre Macrofauna Eveness

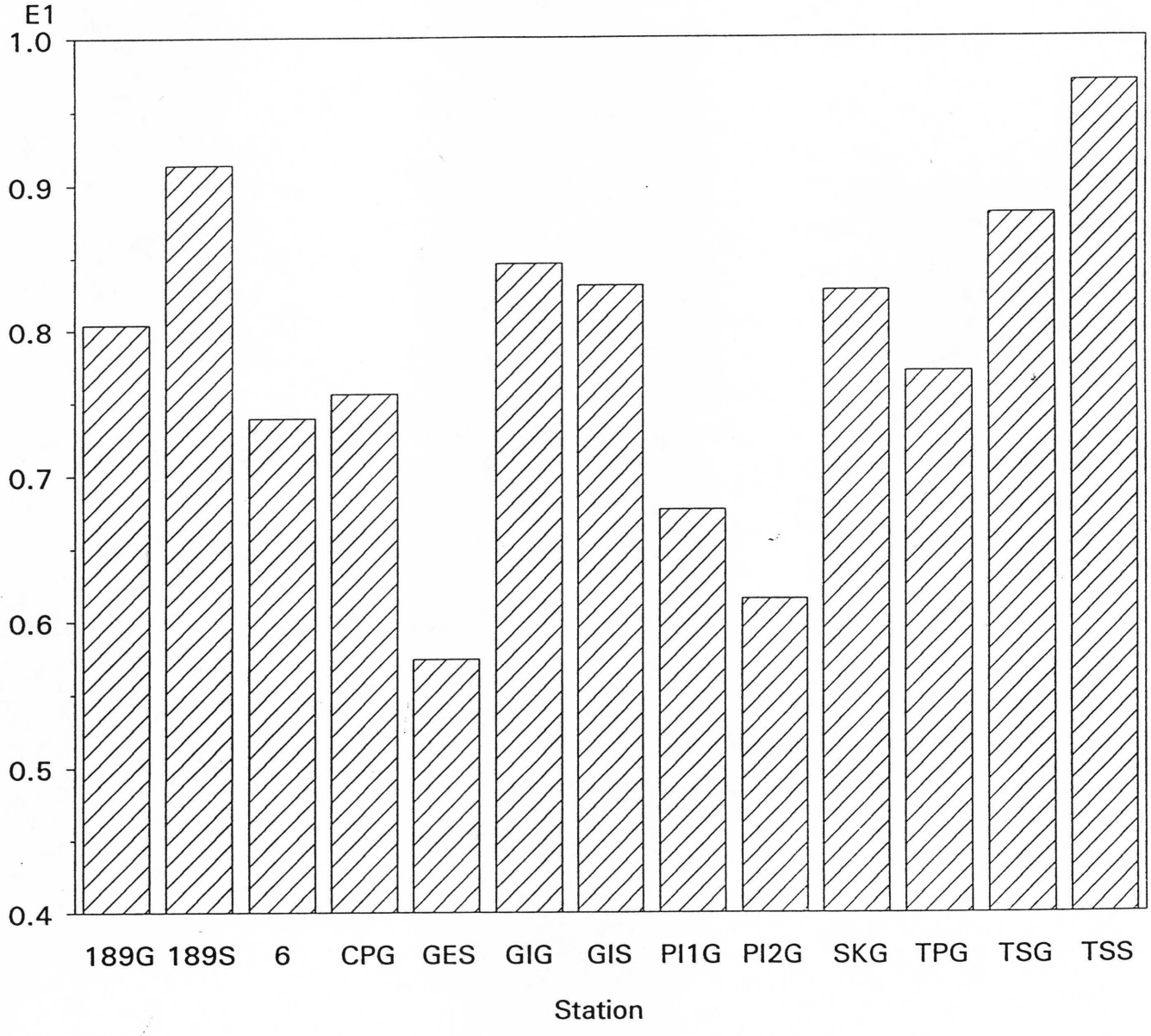


Figure 22. Sediment organic matter at two sediment depths over one year. Average number of individuals from 3 replicate cores taken at three stations.

Laguna Madre Diversity and Eveness

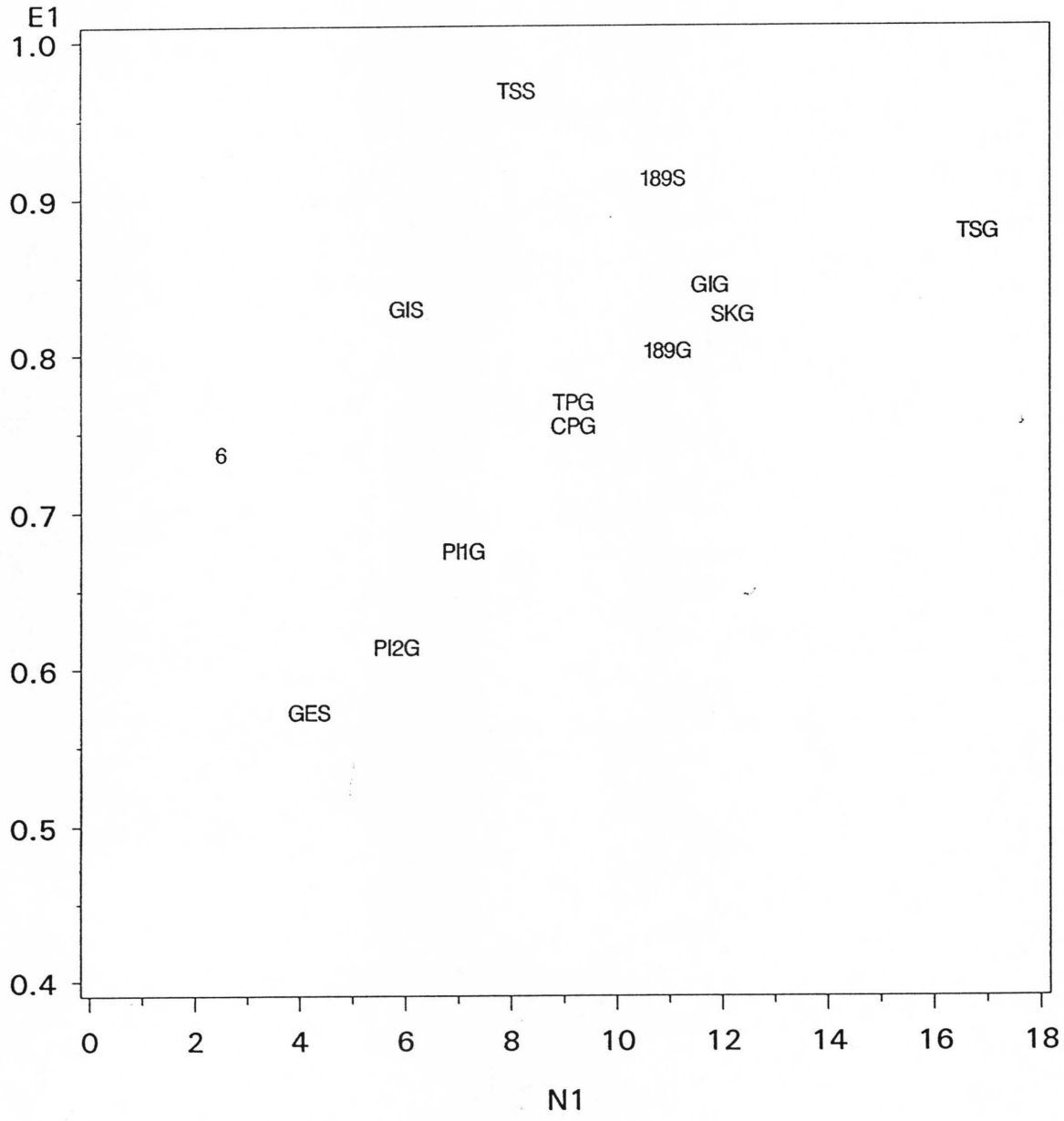


Figure 23. Sediment organic matter components over one year. Average dry weight from 3 replicate cores taken at three stations.

Laguna Madre Sediment Organic Matter ($g \cdot m^{-2}$)

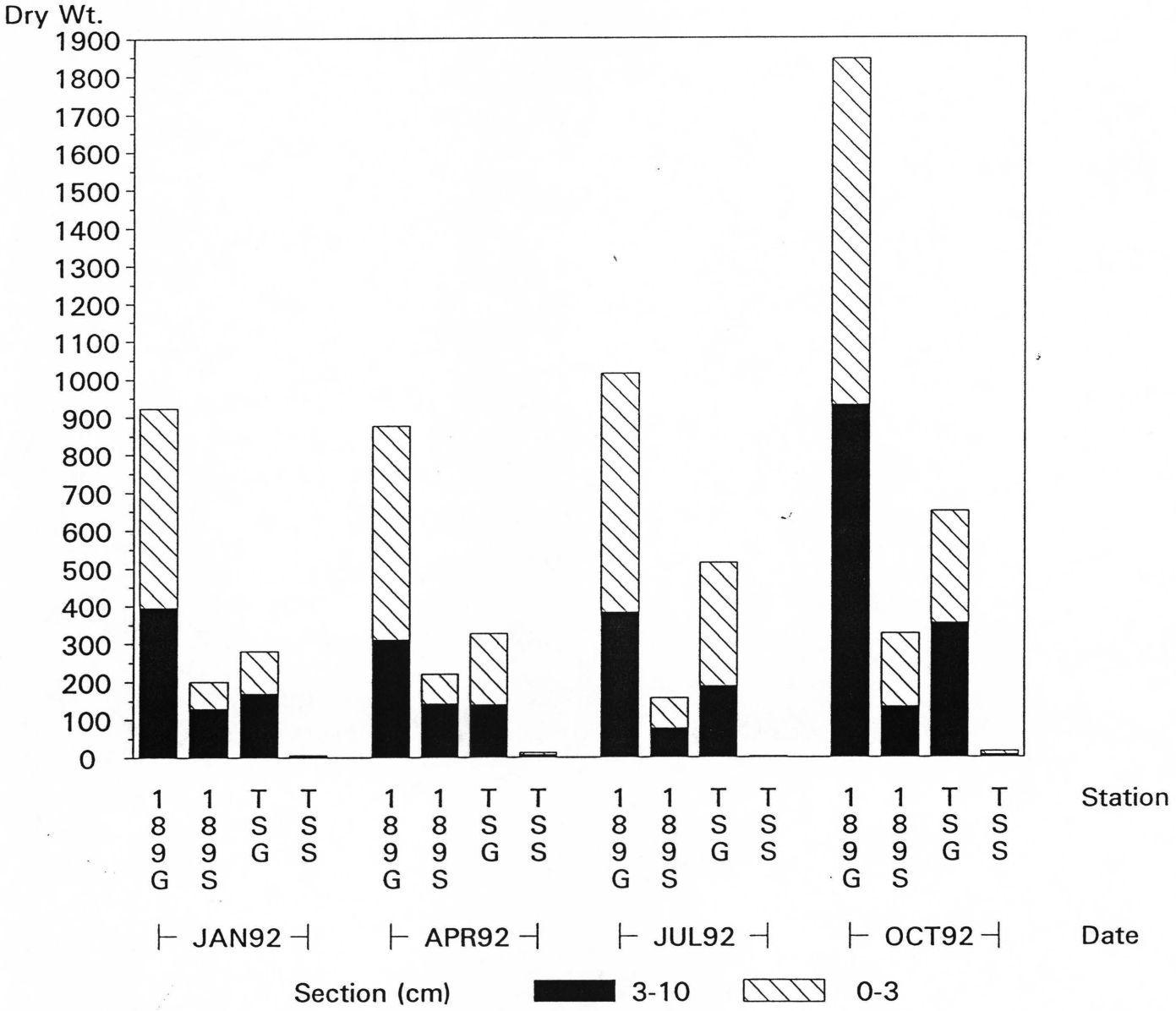


Figure 24. Macrofauna abundance at two sediment depths over one year. Average number of individuals from 3 replicate cores taken at three stations.

Laguna Madre Sediment Organic Matter ($g \cdot m^{-2}$)

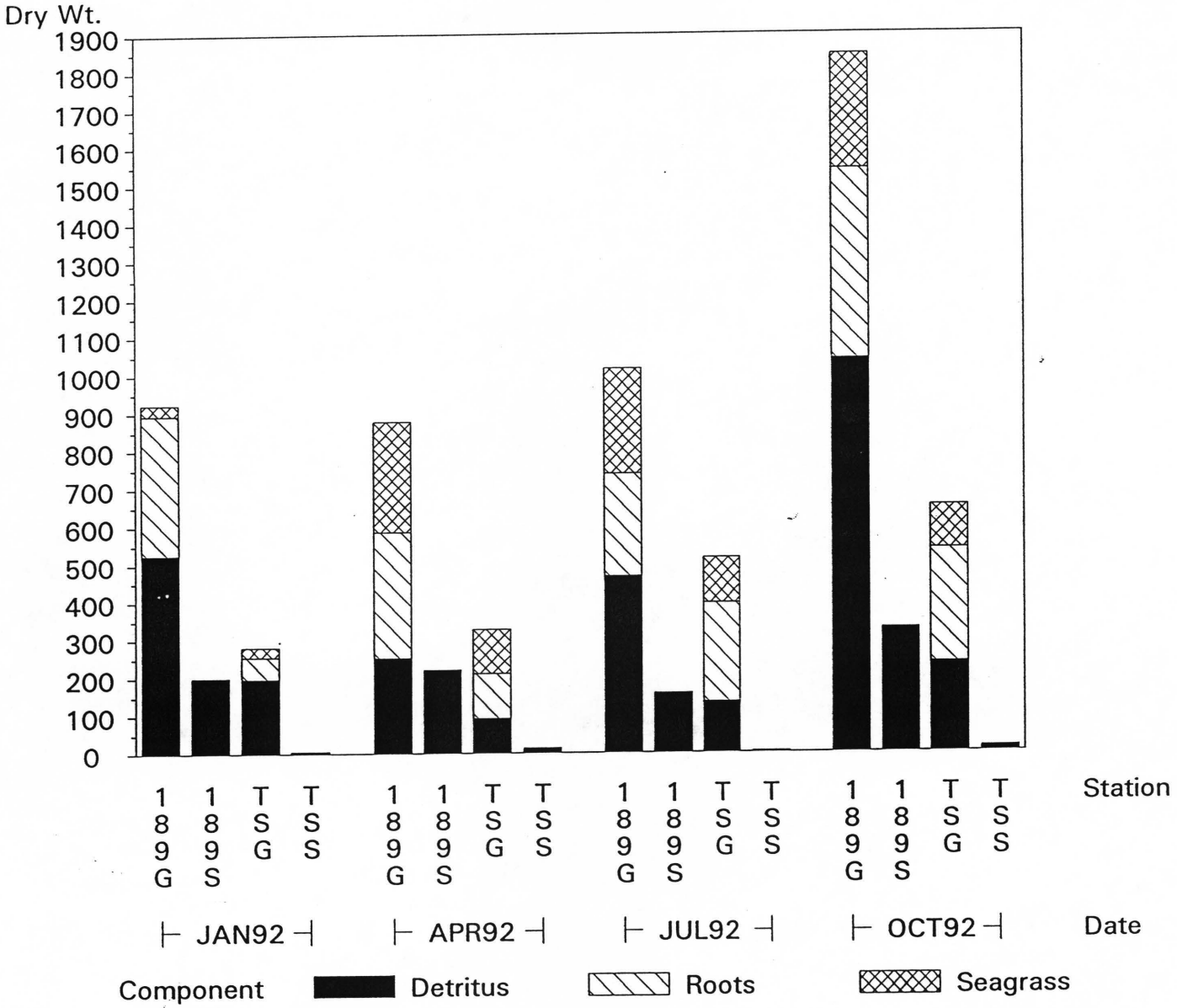
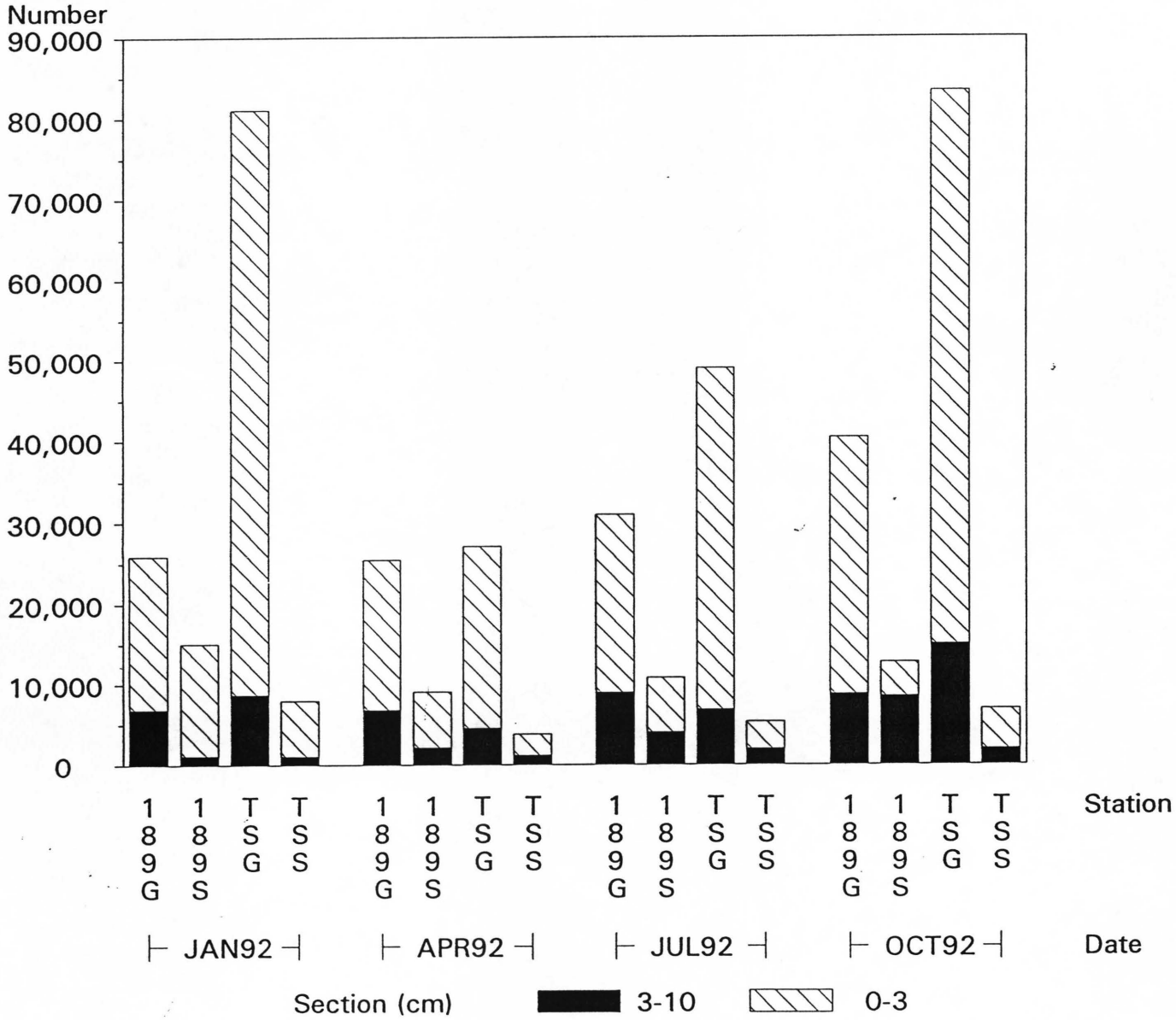


Figure 25. Macrofauna biomass at two sediment depths over one year. Average dry weight from 3 replicate cores taken at three stations.

Laguna Madre Macrofauna Abundance ($n \cdot m^{-2}$)



DISCUSSION

There is increasing demand to mitigate the loss of wetland habitats. Wetland loss is a recognized problem nationwide. Texas alone has lost over 240,000 ha of its original wetlands primarily to dredge and fill operations (Gosselink and Bauman, 1980). The problem is acute for seagrass beds, which are a submerged wetland habitat. Currently there is about 68,500 ha of seagrass beds in Texas estuaries (Duke and Kruczynski, 1992). Many of these habitats are at risk due to geomorphological changes by hurricanes, subsidence due to groundwater and hydrocarbon extraction, dredging for channels, filling and other development activities. Risk for seagrass loss is apparently higher in the northeastern Texas coast, because of higher population density and greater amounts of subsidence (White *et al.*, 1985). For example, in Galveston Bay, Texas, 95% of the seagrass beds have been lost since 1979 (Pulich and White, 1990). In contrast, seagrass beds in the southwestern coast, which includes the Laguna Madre, have changed less. Since 1965, there has been a gain of 130 km^2 of *Halodule wrightii* seagrass cover in the upper Laguna Madre, and a 330 km^2 loss in the lower Laguna Madre for a net loss of 200 km^2 (Quammen and Onuf, 1993). Current state and national policy requires mitigation for new habitat losses.

Mitigation projects have not always been successful. Of eight recent seagrass mitigation projects in south Texas, four failed to be effective (Cobb, 1987). Projects in this evaluation were judged as effective if seagrass grew back by either transplantation or natural revegetation. Recently, concern has been raised that these created or restored habitats may have grass cover, but are not functioning like a normal seagrass habitat (Quammen, 1986; Fonseca *et al.*, 1990). A new definition of "success" is the replacement of lost wetland function based on judgements that can withstand scientific review (Pacific Estuarine Research Laboratory, 1990). However, this could be difficult to implement. Any monitoring or sampling effort would be of limited duration and could be distorted by a R-selected or disturbance species, and we probably cannot replace the complex interactions that took up to centuries to evolve (Pacific Estuarine Research Laboratory, 1990). Much ecological research will be needed before we know what to measure, and how to interpret our measurements. We will also expect this research to provide recommendations for better planning of mitigation projects.

The current research is designed to identify some criteria for a successful mitigation project, and the time for a created or restored seagrass bed to become a functional habitat. Two approaches were taken. The first was a synoptic study of 10 mitigation sites of different ages, the second is monitoring of a recent mitigation site for a one year period. No one study can possibly examine all, or even most, of the

complex interactions in any ecosystem. These interactions can be grouped into two categories: structure and function. Structure refers to the composition of the ecosystem. The components are both biotic and abiotic. Function refers to the characteristic behavior of the system. Energy flow, trophic relationships and biogeochemical cycling are functional components that are unique to specific ecosystems. Seagrasses are benthic plants, so the creation or restoration of a seagrass habitat must duplicate the structure and function of an undisturbed benthic environment. In seagrass ecosystems, Ecosystem structure and function is assessed by measuring select variables. Community metabolism and nutrient regeneration are key variables, which indicate the functioning of an ecosystem. Benthic community structure is a key variable that indicates the habitat utilization of an ecosystem. The six mitigation sites are compared to three reference sites with seagrass and one open bay station.

Below ground, the Eh profiles show dramatic differences among natural and mitigation sites, and also suggest trends with mitigation site aging (Figure 4). Eh is a measure of the total electronegativity of the sediment. Reduced ions, e.g., NH_4 and H_2S are major contributors to Eh. These ions are evolved via anaerobic respiration during the decomposition of organic matter. So, Eh can be thought of as the total number of available electron donors. Low Eh values were typical of sediments in recent mitigation sites. This indicates there is might be low organic content in the mitigation sediments. This indication is supported by the measurements of sediment organic matter (Figures 5 and 6). Total oxygen consumption was also lower in mitigation sites (Figure 7). Both organic matter and oxygen flux exhibited increasing trends with habitat age. The mitigated ecosystems are not functioning biogeochemically like a natural ecosystem. The mitigation sites lack sufficient organic material in the sediment for the environment to be fully functional. It appears as if it may take up to 14-17 years for enough organic matter to accumulate at these sites for the processes to be occurring at similar rates to natural sites.

Above-ground, the mitigation sites differed from natural sites in terms of community structure. Utilization of mitigation sites by benthic macrofauna increases with age of the habitat (Figures 14-17). Both abundance and biomass increase along the gradient of new mitigation, old mitigation, and natural sites. Benthic community structure at the mitigation sites resembled disturbed environments with high diversity, and low evenness (Figures 19-21). There was also a discernible trend in diversity and evenness among sites of different ages. As with the biogeochemical data, the benthic invertebrate data suggests it may take longer than 14-17 years to fully recover. Since this is such a long time, monitoring for one year did not reveal these differences.

The lack of adequate biogeochemical functioning has been found at other locations. There were low amounts of sulfide and nitrogen in man-made salt marsh sediments of the Sweetwater River Wetlands, San Diego Bay, California (PERL, 1990). Benthic invertebrates were 54-55% less abundant in constructed than in natural habitats. PERL (1990) concluded that the man-made habitat was not functioning like a natural habitat.

Monitoring to determine success of a project can not be done over a short time scale. Monitoring to determine persistence of seagrass cover should occur for at least three years (Fonseca, 1989). Epifaunal colonization of eelgrass habitats in North Carolina can happen rapidly. Faunal abundances of fish and shrimp in a 1.9-year old transplanted bed and a 6-month old seed-developed bed were indistinguishable from mature natural seagrass beds (Fonseca *et al.*, 1990). This indicates that mobile fauna can establish themselves in mitigated habitats rapidly. In fact, most studies on the utilization of submerged vegetated habitats have focused on use by mobile invertebrates, megaepifauna (e.g., shrimp), or fish (Rozas and Odum, 1987a; 1987b; Fonseca *et al.*, 1990). If mobile species that colonize rapidly are studied then one can come to an erroneous conclusion that the ecosystem is functional. The current study focuses on the utilization of these habitats by infauna, and small seagrass epifauna (e.g., amphipods). The lack of mobility and reliance on a dispersal stage by macroinfauna, could explain why utilization of the mitigated habitats in the current study was not comparable to utilization of natural habitats. In Texas, macroinfauna were not as abundant in mitigated habitats that were one or two years old, as they were in natural habitats, or in habitats that were 14-17 years old. Therefore, it appears that monitoring for several years would be required to assess utilization by the benthic component.

A major contributing factor to the loss of seagrass habitats is the issuance of permits by the U.S. Army Corps of Engineers. The reestablishment of wetland fishery habitats and their ecological function is an important national goal of several federal agencies, e.g., the National Marine Fisheries Service (Thayer *et al.*, 1986). Some might argue, that the spoil islands are a beneficial use of dredge materials since they create bird habitat. However, many of these islands contain few birds, because predators (e.g., coyotes and rattlesnakes) can overrun these islands rapidly. So, there has been a value-judgement that bird habitat may be more valuable than seagrass habitat. In the upper Laguna Madre, where the current research took place (Figure 1), 6% of the seagrass habitat has been converted to spoil islands and channels (Montagna, unpublished data). This determination was made by calculating the surface area of these environments from aerial photographs. One of the mitigation projects

studied here (site TS_) is a scrapedown of a spoil island to revert the habitat back to a seagrass bed. This habitat is very well covered by seagrass, and probably will become a functioning habitat in time. Although it will take a long time, this project appears to be a good example of how federal agencies can meet their goals to restore fisheries habitats that have been lost. The restored habitats can contribute to enhanced productivity and fisheries habitats (Thayer *et al.*, 1982), therefore it seems reasonable to convert spoil islands back to their original habitat.

Recommendations: Future projects to transplant seagrasses for mitigation should consider adding organic matter to the soil to speed the time it takes for the habitat to become fully functional. Currently, without soil emendation, it probably requires 14-17 years for seagrass habitats to become fully functional. Monitoring must be long-term. Short-term monitoring is not the best approach to discern when a habitat acquires functional values. Annual sampling over four years would be a better monitoring plan for the same effort than quarterly sampling over one year. Benthic macrofauna abundance and biomass are good monitoring tools to determine community structure changes, since they are relatively fixed in space and have meaningful temporal scales of response. Total organic matter or Eh profiles are good, cost effective monitoring tools for ecosystem function. It is not useful to make routine measurements of nutrient regeneration, but oxygen consumption will indicate the biogeochemical status of the ecosystem in a relative sense. Comparison with natural undisturbed habitats is essential, but is important to replicate at the treatment level, i.e., replicate natural and mitigation sites are required to find differences related to mitigation success.

ACKNOWLEDGEMENTS

I would like to thank Mr. Rick Kalke, the University of Texas Marine Science Institute, for his invaluable help on all aspects of this project. The nutrient samples were analyzed under the direction of Dr. Terry Whitledge. Carol Simanek was responsible for all aspects of data management for the project. This project was funded in part by Cooperative Agreement no. X-0658801-0, from the Water Management Division of the U.S. Environmental Protection Agency, Region 6; and in part by grant no. 3658-264 from the Texas Advanced Technology Program.

REFERENCES

Alatalo, R.V. 1981. Problems in the measurement of evenness in ecology. *Oikos*, 37:199-204.

Cobb, R. A. 1987. Mitigation evaluation study for the South Texas Coast, 1975-1986. Report to U.S. Fish and Wildlife Service. Corpus Christi State University, Corpus Christi, Texas, 88 pp.

Duke, T. and Kruczynski, W.L. 1992. The status and trends of emergent and submerged vegetated habitats of Gulf of Mexico coastal waters, U.S.A. Final Report to the U.S. Environmental Protection Agency, Gulf of Mexico Program, Habitat Degradation Subcommittee. Gulf Breeze, Florida. 161 pp.

Folk, R. L. 1964. Petrology of sedimentary rocks. Hemphill's Press, Austin, Texas. 155 pp.

Fonseca, M.S. 1989. Regional analysis of the creation and restoration of seagrass systems. In: Kusler, J.A. and M.E. Kentula (eds.). *Wetland creation and restoration: the status of the science. Volume I: regional reviews.* EPA/600/3-89-038a. Environmental Research Laboratory, Corvallis, Oregon. pp. 175-198.

Fonseca, M.S., W.J. Kenworthy, D.R. Colby, K.A. Rittmaster and G.W. Thayer. 1990. Comparisons of fauna among natural and transplanted eelgrass *Zostera marina* meadows: criteria for mitigation. *Marine Ecology Progress Series*, 65:251-264.

Gosselink, J.G. and R.H. Bauman. 1980. Wetland inventories: wetland loss along the United States coast. *J. Geomorphol. Supp.* 34:173-187.

Hill, M. O. 1973. Diversity and evenness: a unifying notation and its consequences. *Ecology*. 54:427-432.

Kikuchi, T. 1974. Japanese contributions on consumer ecology in eelgrass (*Zostera marina* L.) beds, with special reference to trophic relationships and resources in inshore fisheries. *Aquaculture*, 4:145-160.

Kirk R. E. 1982. *Experimental Design*. 2nd Ed. Brooks/Cole Publ. Co., Monterey, California, 911 p.

Langdon, C., 1984. Dissolved oxygen monitoring system using a pulsed electrode: design, performance, and evaluation. *Deep Sea Research*, 31:1357-1367.

Margalef, R. 1958. Information theory in ecology. *General Systematics,* 3:36-71.

Montagna, P.A. 1989. Nitrogen Process Studies (NIPS): the effect of freshwater inflow on benthos communities and dynamics. Technical Report No. TR/89-011, Marine Science Institute, The University of Texas, Port Aransas, TX, 370 pp.

Montagna, P.A. and R.D. Kalke. 1992. The effect of freshwater inflow on meiofaunal and macrofaunal populations in the Guadalupe and Nueces Estuaries, Texas. *Estuaries*, 15:307-326.

Nixon, S. A., C.A. Oviatt, J. Frithsen, B. Sullivan. 1986. Nutrients and the productivity of estuarine and coastal marine ecosystems. *Journal of the Limnological Society of South Africa*, 12:43-71

Pacific Estuarine Research Laboratory. 1990. A manual for assessing restored and natural coastal wetlands with examples from southern California. California Sea Grant Report No. T-CSGCP-021. California Sea Grant College, La Jolla. 105 p.

Pielou, E.C. 1975. *Ecological Diversity*. Wiley, New York.

Pulich, W.M., Jr., and W.A. White. 1990. Decline of submerged vegetation in the Galveston Bay system: chronology and relationships to physical process. Report to the Texas Parks and Wildlife Department, Austin, Texas. 27 pp.

Quammen, M.L. 1986. Measuring the success of wetlands mitigation. *National Wetlands Newsletter*, 8:6-8.

Quammen, M.L. and C.P. Onuf. 1993. Laguna Madre: seagrass changes continue decades after salinity reduction. *Estuaries*, 16:302-310.

Robinson, G. R., R. D. Holt, M. S. Gaines, S. P. Hamburg, M. L. Johnson, H. S. Fitch and E. A. Martinko. 1992. Diverse and contrasting effects of habitat fragmentation. *Science*, 257:524-526.

Rozas, L.P. and W.E. Odum. 1987a. Fish and macrocrustacean use of submerged plant beds in tidal freshwater marsh creeks. *Marine Ecology Progress Series*, 38:101-108.

Rozas, L.P. and W.E. Odum. 1987b. The role of submerged aquatic vegetation in influencing the abundance of nekton on contiguous tidal fresh-water marshes. *Journal of Experimental Marine Biology and Ecology,* 114:289-300.

SAS Institute, Incorporated. 1985. *SAS/STAT Guide for Personal Computers*, Version 6 Edition. Cary, NC:SAS Institute Inc., 378 pp.

Shannon, C. E. and W. Weaver. 1949. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, IL.

Simpson, E.H. 1949. Measurement of diversity. *Nature*, 163:688.

Thayer, G. W., M. S. Fonseca and W. J. Kenworthy. 1982. Restoration of seagrass meadows for enhancement of nearshore productivity. pp. 21-27. In N. L. Chao and W. Kirby-Smith (eds.), Proceedings of the Intnl. Symposium on Utilization of Coastal Ecosystems: Planning, pollution and productivity. Fundacao Unversidade de Rio Grande, Rio Grand.

Thayer, G. W., M.S. Fonseca, W.J. Kenworthy. 1986. Wetland mitigation and restoration in the Southeast United States and two lessons from seagrass mitigation. In: Estuarine Management Practices Symposium, Baton Rouge, LA, pp. 95-117.

White, W.A., T.R. Calnan, R.A. Morton, R.S. Kimble, T.G. Littleton, J.H. McGowen, H.S. Nance and K.E. Schmedes. 1985. Submerged lands of Texas, Galveston-Houston area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. Bureau of Economic Geology, Austin, Texas. 145 pp.

Whitledge, T.E., Veidt, D.M., Malloy, S.C., Patton, C.J. Wirich, C.D. 1986. Automated nutrient analysis in seawater. Brookhaven National Laboratory Report 38990. Upton, New York, 231 pp.

Table 1. Sampling locations. A. Station identification, location, habitat, date of planting, and project applicant and U.S. Army Corps of Engineer permit number. B. Locations determined by global positioning system (GPS). Abbreviations: ICW=Intracoastal Waterway, BB=Baffin Bay.

A.

Station	Location	Habitat	Date	Project
GIG	N Upper Laguna	Grass	APR91	Gulf Isles Limited 9009(08)
GIS	N Upper Laguna	Sand	APR91	Gulf Isles Limited 9009(08)
PI1G	N Upper Laguna	Grass	Natural	Padre Isles Site 1
PI2G	N Upper Laguna	Grass	Natural	Padre Isles Site 2
TSG	N Upper Laguna	Grass	APR90	Transco Scrape-down 18853
TSS	N Upper Laguna	Sand	APR90	Transco Scrape-down 18853
TPG	N Upper Laguna	Grass	APR90	Transco Pipeline 18853
CPG	N Upper Laguna	Grass	AUG75	Central Power and Light 100444
SKG	N Upper Laguna	Grass	1978	Skyline Equipment, Inc. 12004(03)
GES	N Upper Laguna	Sand	OCT83	Genesis Petroleum 15844
189G	S Upper Laguna	Grass	Natural	West of ICW Marker 189
189S	S Upper Laguna	Sand	Natural	West of ICW Marker 189
6	Baffin Bay	Mud	Natural	North of BB Marker 6 site

B.

Station	Latitude (N)	Longitude (W)	Error (m)
GI	27° 36' 32.6"	97° 15' 0.5"	±57
PI1	27° 36' 33.9"	97° 14' 49.6"	±74
PI2	27° 35' 6.3"	97° 15' 22.2"	±303
TS	27° 35' 56.0"	97° 15' 19.6"	±110
TPG	27° 35' 22.8"	97° 15' 9.7"	±81
CPG	27° 36' 28.5"	97° 17' 55.7"	±48
SKG	27° 36' 40.4"	97° 17' 46.1"	±101
GES	27° 34' 34.0"	97° 16' 3.5"	±20
189	27° 20' 53.7"	97° 23' 30.1"	±118
6	27° 16' 36.6"	97° 25' 39.2"	±14

Table 2. Hydrographic measurements. Abbreviations: STA=Station, Z=Depth, SAL(R)=Salinity by refractometer, SAL(M)=Salinity by meter, COND=Conductivity, TEMP=Temperature, DO=dissolved oxygen, and ORP=oxidation redox potential. Missing values show with a period.

Date	STA	Z (m)	SAL(R) (ppt)	SAL(M) (ppt)	COND (uS/cm)	TEMP (°C)	pH	DO ($mg \cdot l^{-1}$)	ORP (mV)	NTU
21JAN92	155	0.00	28	28.2	43.70	10.63	8.64	9.53	0.125	.
21JAN92	155	1.10	28	28.3	43.70	10.64	8.64	9.47	0.125	.
21JAN92	189	0.00	29	29.0	44.70	10.48	8.55	9.62	0.117	.
21JAN92	189	1.00	29	29.0	44.80	10.47	8.67	9.50	0.115	.
21JAN92	6	0.00	32	32.8	50.00	9.99	8.46	9.29	0.130	.
21JAN92	6	2.40	32	34.6	52.50	9.97	8.62	8.16	0.126	.
21JAN92	TS	0.00	24	24.7	39.00	12.65	8.52	9.78	0.131	.
08APR92	189	0.00	25	25.5	39.70	23.97	8.77	8.83	0.144	.
08APR92	189	1.00	25	25.5	39.70	24.00	8.77	8.76	0.142	.
08APR92	6	0.00	25	24.4	38.20	21.05	8.31	7.82	0.145	.
08APR92	6	2.20	25	24.6	38.70	20.75	8.57	6.30	0.136	.
22APR92	GIG	0.00	24	23.4	37.10	22.46	9.19	6.31	0.094	4.4
22APR92	GIG	0.10	24	23.5	37.20	22.51	9.09	6.25	0.097	4.4
22APR92	PI1	0.00	24	23.2	36.80	26.95	9.81	12.63	-0.055	.
22APR92	PI1	0.20	24	23.4	37.00	26.93	9.93	12.36	-0.026	.
23APR92	189	0.00	26	25.5	40.00	26.13	9.27	9.40	0.100	.
23APR92	189	0.80	26	25.5	40.00	26.07	9.52	8.92	0.098	.
23APR92	6	0.00	24	23.6	37.40	24.33	8.56	7.68	0.137	.
23APR92	6	2.20	24	27.0	42.10	23.90	8.85	5.20	0.130	.
24APR92	TPG	0.00	26	24.4	38.40	26.27	8.64	6.14	0.126	6.6
24APR92	TPG	0.60	26	24.5	38.50	26.29	8.77	6.07	0.126	6.3
24APR92	TSG	0.00	24	23.9	37.70	25.43	8.64	5.72	0.132	6.6
24APR92	TSS	0.40	24	23.8	37.70	25.15	8.60	4.21	0.149	6.6
27APR92	CPG	0.00	25	25.0	39.30	24.17	9.12	8.49	0.089	6.0
27APR92	CPG	0.55	25	25.0	39.30	24.17	9.12	8.49	0.089	6.0
27APR92	SKG	0.00	25	24.2	38.20	22.14	8.37	7.30	0.139	5.2
27APR92	SKG	0.35	25	24.2	38.20	22.14	8.37	7.30	0.139	5.2

28APR92	GES	0.00	25	24.8	38.30	21.78	9.19	5.13	0.108	19.0
28APR92	GES	0.90	25	24.7	38.30	21.76	8.93	4.96	0.289	19.0
28APR92	PI2	0.00	26	25.0	39.20	23.67	9.41	8.40	0.098	.
28APR92	PI2	0.75	26	25.0	39.40	23.65	9.44	8.38	0.100	.
08JUL92	189	0.00	20	18.8	30.40	29.80	9.03	8.25	0.187	.
08JUL92	189	0.70	20	18.8	30.60	29.80	9.03	8.20	0.182	.
08JUL92	6	0.00	18	16.8	27.60	29.14	8.73	8.51	0.208	.
08JUL92	6	2.00	18	24.4	38.50	28.90	8.34	3.29	0.227	.
08JUL92	TS	0.00	21	20.5	33.00	32.91	8.80	8.10	0.171	.
20OCT92	189	0.00	36	33.3	53.30	25.37	8.47	7.35	0.166	.
20OCT92	189	0.90	36	33.3	53.40	25.28	8.60	6.86	0.174	.
20OCT92	6	0.00	35	33.6	51.00	24.91	8.47	7.28	0.176	.
20OCT92	6	2.40	35	34.0	51.50	24.68	8.63	5.12	0.172	.
20OCT92	TS	0.00	38	31.8	48.50	26.45	8.55	8.52	0.177	.

Table 3. Sediment grain size in Laguna Madre. Percent dry weight of each sediment fraction.

Date	Station	Depth (cm)	Rubble (%)	Sand (%)	Silt (%)	Clay (%)
23APR92	6	3	1.4	3.3	14.7	80.6
23APR92	6	10	3.9	8.4	19.8	67.9
23APR92	189G	3	20.7	55.9	3.8	19.6
23APR92	189G	10	10.3	47.7	7.4	34.5
23APR92	189S	3	20.9	60.7	3.1	15.2
23APR92	189S	10	10.9	50.3	5.2	33.6
23APR92	GIG	3	4.3	83.1	4.2	8.5
23APR92	GIG	10	2.5	89.3	2.6	5.5
23APR92	GIS	3	5.0	90.7	2.1	2.1
23APR92	GIS	10	4.5	90.3	1.8	3.3
23APR92	PI1G	3	9.7	54.5	10.1	25.7
23APR92	PI1G	10	1.0	91.8	1.4	5.8
24APR92	CPG	3	8.8	70.2	12.3	8.7
24APR92	CPG	10	10.4	78.8	1.0	9.8
27APR92	GES	3	0.5	62.7	5.8	31.0
27APR92	GES	10	1.7	94.2	0.1	4.0
24APR92	PI2G	3	14.0	73.6	2.1	10.3
24APR92	PI2G	10	3.9	89.4	1.1	5.6
24APR92	SKG	3	4.0	91.2	0.4	4.5
24APR92	SKG	10	2.2	92.2	3.4	2.2
24APR92	TPG	3	2.2	94.5	0.4	2.9
24APR92	TPG	10	2.7	94.8	0.6	1.9
24APR92	TSG	3	4.6	87.6	2.0	5.8
24APR92	TSG	10	14.6	83.2	0.9	1.3
24APR92	TSS	3	2.4	94.5	1.0	2.0
24APR92	TSS	10	3.7	93.9	1.3	1.1

Table 4. Eh profiles in sediment cores. Values are the oxidation redox potential in mV at the sediment depth horizon. Missing values show with a period.

		Sediment Depth (cm)										
Date	Station	0	1	2	3	4	5	6	7	8	9	10
22APR92	GIG	66	30	18	-4	-14	-10	-4	-9	-7	-14	-3
22APR92	GIS	25	-245	-7	-10	-9	-10	-12	-15	4	6	.
22APR92	PI1G	6	-285	-320	-310	-320	-20	-147	-173	-240	.	.
23APR92	6	94	39	21	-18	-400	-484	-451	-431	-432	-422	.
23APR92	189S	6	-355	-327	-325	-330	-300	-240	-326	-333	-345	.
23APR92	189G	-150	-326	-364	-363	-357	-355	-362	-360	-357	-348	-352
24APR92	TSS	22	20	0	-1	0	0	-4	-6	-2	-4	-5
24APR92	TSG	23	20	13	3	-1	-18	-50	-71	-150	-150	-140
24APR92	TPG	22	13	8	-1	-25	-40	-67	-110	-120	-200	-110
27APR92	SKG	40	32	32	29	28	22	17	7	-91	-290	-306
27APR92	CPG	25	-220	-260	-310	-326	-310	-353	-334	-339	-330	-376
28APR92	GES	4	-200	-313	-388	-330	-344	-285	-230	-275	-305	-319
28APR92	PI2G	48	-9	-275	-350	-343	-347	-333	-336	-334	-340	-342

Table 5. Oxygen measurements in sample incubations. Oxygen units in μmole·l^{-1}. Missing values show with a period. Core 4 is a control with just station water.

Date	Station	Time	Core 1	Core 2	Core 3	Core 4
22APR92	GIG	10:25	213.9	277.9	359.9	311.2
22APR92	GIG	10:40	183.9	251.0	361.4	347.9
22APR92	GIG	10:55	163.3	226.4	328.9	344.4
22APR92	GIG	11:10	160.9	201.7	310.4	343.7
22APR92	GIG	11:25	129.8	163.4	281.1	341.5
22APR92	GIG	11:40	104.4	151.0	215.6	338.3
22APR92	GIG	11:55	102.8	132.6	222.9	339.2
22APR92	GIG	12:10	109.3	126.8	204.9	336.9
22APR92	GIS	12:40	304.3	356.9	446.2	400.4
22APR92	GIS	12:55	263.5	352.8	457.9	402.8
22APR92	GIS	13:10	281.0	357.4	456.5	404.7
22APR92	GIS	13:25	287.5	373.1	474.0	406.4
22APR92	GIS	13:40	299.6	381.0	482.4	405.7
22APR92	GIS	13:55	292.7	379.5	481.4	404.8
22APR92	GIS	14:10	285.1	375.6	471.5	402.6
22APR92	GIS	14:40	246.0	365.7	459.4	398.3
22APR92	PI1G	14:55	313.6	317.6	434.3	380.4
22APR92	PI1G	15:10	236.8	220.2	329.8	390.1
22APR92	PI1G	15:25	176.1	131.0	231.6	395.5
22APR92	PI1G	15:40	114.3	63.2	162.1	398.5
22APR92	PI1G	15:43	87.5	37.3	127.5	399.5
22APR92	PI1G	15:47	78.8	25.8	125.0	399.9
22APR92	PI1G	16:02	40.8	0.1	111.4	400.3
23APR92	BB6	10:42	178.7	279.3	343.1	342.8
23APR92	BB6	11:12	160.0	263.4	330.7	339.0
23APR92	BB6	11:27	160.0	260.5	294.7	335.4
23APR92	BB6	11:42	159.4	259.2	303.7	333.1

23APR92	BB6	11:57	160.3	260.3	315.7	331.8
23APR92	BB6	12:12	157.3	242.8	313.4	332.4
23APR92	BB6	12:27	153.5	217.3	292.0	333.9
23APR92	189G	13:27	305.7	343.8	443.8	382.9
23APR92	189G	13:42	260.4	296.3	412.4	382.8
23APR92	189G	13:57	177.3	251.3	370.8	382.2
23APR92	189G	14:12	120.4	243.9	290.8	381.5
23APR92	189G	14:27	48.3	243.6	210.7	380.7
23APR92	189G	14:42	40.9	190.1	143.6	380.4
23APR92	189G	14:57	10.1	159.5	128.6	380.7
23APR92	189G	15:12	0.0	162.0	123.2	379.8
23APR92	189S	15:27	278.7	346.7	457.2	379.0
23APR92	189S	15:42	256.5	344.7	441.4	378.5
23APR92	189S	15:57	252.5	344.1	437.7	378.3
23APR92	189S	16:12	242.8	338.6	430.8	377.4
23APR92	189S	16:27	234.7	337.4	428.9	377.4
23APR92	189S	16:42	227.8	323.5	422.5	376.4
23APR92	189S	16:57	213.7	312.9	408.3	375.1
23APR92	189S	17:12	208.0	310.2	400.2	374.6
24APR92	TSS	9:30	97.3	195.8	291.9	285.1
24APR92	TSS	9:45	85.5	174.8	282.1	280.0
24APR92	TSS	10:00	76.2	165.7	256.8	275.1
24APR92	TSS	10:15	70.8	138.7	260.4	275.2
24APR92	TSS	10:30	67.1	141.9	240.3	269.8
24APR92	TSS	10:45	64.9	134.0	227.7	270.0
24APR92	TSS	11:00	65.9	140.2	223.4	280.3
24APR92	TSS	11:15	58.6	147.4	214.7	281.4
24APR92	TSG	11:30	181.0	265.7	380.2	337.3
24APR92	TSG	11:45	96.8	142.2	260.9	342.1
24APR92	TSG	12:00	92.1	104.3	219.3	339.9
24APR92	TSG	12:30	32.1	54.5	182.8	329.9
24APR92	TSG	12:45	24.4	32.8	155.1	328.2
24APR92	TSG	13:00	31.6	19.6	146.7	327.9

24APR92	TSG	13:15	37.6	20.5	148.9	325.8
24APR92	TSG	13:30	27.4	19.7	145.7	325.4
24APR92	TPG	13:45	182.7	314.7	412.2	367.5
24APR92	TPG	14:00	111.3	280.0	221.3	364.6
24APR92	TPG	14:15	42.4	230.3	124.1	362.1
24APR92	TPG	14:30	23.6	175.5	122.2	358.5
24APR92	TPG	14:45	21.5	115.4	149.8	353.1
24APR92	TPG	15:00	13.0	76.0	138.7	349.9
24APR92	TPG	15:15	3.6	55.2	97.2	348.0
24APR92	TPG	15:30	0.0	39.3	73.5	345.4
27APR92	SKG	9:54	299.6	368.5	445.0	395.9
27APR92	SKG	10:09	218.2	263.0	351.5	391.3
27APR92	SKG	10:24	148.7	177.6	273.9	387.2
27APR92	SKG	10:39	77.8	125.8	176.7	382.6
27APR92	SKG	10:54	35.5	114.1	120.1	379.5
27APR92	SKG	11:09	16.4	97.4	77.8	378.7
27APR92	SKG	11:24	6.7	76.4	51.2	376.5
27APR92	SKG	11:39	9.8	50.5	36.7	374.3
27APR92	CPG	11:54	310.2	369.7	482.2	397.5
27APR92	CPG	12:09	197.6	317.1	425.5	399.7
27APR92	CPG	12:24	188.7	293.3	407.3	401.8
27APR92	CPG	12:39	184.8	282.9	381.8	401.6
27APR92	CPG	12:54	188.5	272.2	368.0	397.3
27APR92	CPG	13:09	160.3	258.3	346.9	398.1
27APR92	CPG	13:24	151.8	250.5	325.2	393.3
27APR92	CPG	13:39	66.4	235.9	311.6	391.6
27APR92	CPG	13:54	52.7	216.0	297.9	390.0
28APR92	GES	9:36	214.4	278.8	397.3	363.9
28APR92	GES	9:51	198.3	256.8	390.5	362.4
28APR92	GES	10:06	201.8	247.4	378.8	359.8
28APR92	GES	10:21	200.1	242.8	382.5	358.0
28APR92	GES	10:36	201.0	239.7	373.4	356.0
28APR92	GES	10:51	199.8	243.0	370.7	353.3

28APR92	GES	11:06	195.1	230.6	373.4	348.9
28APR92	GES	11:21	188.0	227.8	371.5	345.5
28APR92	GES	11:36	182.8	232.7	369.8	343.4
28APR92	PI2G	12:06	283.8	297.8	441.3	399.3
28APR92	PI2G	12:21	222.3	205.8	373.1	402.6
28APR92	PI2G	12:36	174.9	133.8	317.3	401.1
28APR92	PI2G	12:51	132.0	94.5	242.1	399.3
28APR92	PI2G	13:06	148.9	78.5	249.4	394.2
28APR92	PI2G	13:21	121.4	56.8	225.9	390.9
28APR92	PI2G	13:36	107.4	41.1	172.0	386.3
28APR92	PI2G	13:51	86.8	25.1	138.7	384.7

Table 6. Nutrient measurements in sample incubations. Nutrient units in μmole·l^{-1}. Missing values show with a period. Cores 4 and 5 are controls with just station water.

Date	STA	Core	Time	PO_4	SIO_4	NO_2	NO_3	NH_4
22APR92	GIG	1	10:20	0.721	141	0.412	0.924	1.960
22APR92	GIG	1	12:20	0.440	143	0.357	0.190	1.622
22APR92	GIG	2	10:20	0.693	141	0.456	0.151	2.507
22APR92	GIG	2	12:20	0.575	143	0.466	0.141	2.361
22APR92	GIG	3	10:20	0.687	141	0.354	0.435	1.819
22APR92	GIG	3	12:20	0.384	143	0.299	0.126	1.577
22APR92	GIG	4	10:20	0.409	142	0.194	1.080	2.202
22APR92	GIG	4	12:20	0.345	141	0.213	0.880	1.095
22APR92	GIG	5	10:20	0.370	142	0.198	0.955	2.131
22APR92	GIG	5	12:20	0.306	141	0.200	0.771	0.805
22APR92	GIS	1	10:20	0.289	141	0.236	0.006	.
22APR92	GIS	1	12:20	0.312	140	0.214	0.332	0.987
22APR92	GIS	2	12:30	0.424	140	0.256	0.169	1.310
22APR92	GIS	2	14:42	0.382	139	0.201	0.466	1.150
22APR92	GIS	3	12:30	0.418	140	0.227	0.319	1.198
22APR92	GIS	3	14:42	0.299	139	0.205	0.341	0.956
22APR92	GIS	4	12:30	0.433	141	0.264	0.404	1.251
22APR92	GIS	4	14:42	0.347	140	0.241	0.123	1.050
22APR92	GIS	5	12:30	0.503	140	0.267	0.461	1.318
22APR92	GIS	5	14:42	0.363	140	0.221	6.335	1.405
22APR92	PI1G	1	14:52	1.019	138	0.804	5.752	4.504
22APR92	PI1G	1	16:58	0.651	147	0.553	6.003	2.616
22APR92	PI1G	2	14:52	1.143	137	0.807	5.748	3.775
22APR92	PI1G	2	16:58	0.872	149	0.516	5.919	2.751
22APR92	PI1G	3	14:52	1.006	136	0.803	5.753	.
22APR92	PI1G	3	16:58	0.833	143	0.519	5.854	2.242
22APR92	PI1G	4	14:52	0.576	134	0.807	5.810	7.476
22APR92	PI1G	4	16:58	0.501	135	0.303	6.010	2.528
22APR92	PI1G	5	14:52	0.461	137	0.255	6.300	0.848
22APR92	PI1G	5	16:58	0.452	135	0.274	6.282	2.389

23APR92	BB6	1	10:33	2.972	168	0.410	0.554	18.640
23APR92	BB6	1	12:33	1.380	173	1.000	0.003	5.287
23APR92	BB6	2	10:33	2.017	166	0.279	0.454	7.971
23APR92	BB6	2	12:33	1.422	168	0.853	0.027	4.728
23APR92	BB6	3	10:33	1.062	176	0.779	0.049	39.448
23APR92	BB6	3	12:33	1.741	173	1.074	0.118	8.376
23APR92	BB6	4	10:33	1.062	161	0.738	0.184	5.200
23APR92	BB6	4	12:33	1.125	160	0.681	0.172	3.924
23APR92	BB6	5	10:33	1.295	162	0.820	0.306	4.842
23APR92	BB6	5	12:33	1.019	159	0.705	0.133	3.781
23APR92	189G	1	13:18	1.847	159	0.500	0.433	22.794
23APR92	189G	1	15:18	1.168	160	0.861	0.002	6.455
23APR92	189G	2	13:18	2.123	159	0.402	0.300	21.775
23APR92	189G	2	15:18	1.146	157	0.828	0.020	6.542
23APR92	189G	3	13:18	1.613	161	0.549	0.464	9.125
23APR92	189G	3	15:18	1.125	162	0.787	0.047	5.034
23APR92	189G	4	13:18	0.828	160	0.385	0.288	2.060
23APR92	189G	4	15:18	0.807	158	0.312	0.400	1.689
23APR92	189G	5	13:18	0.764	185	0.320	0.448	1.472
23APR92	189G	5	15:18	0.764	156	0.262	0.327	1.302
23APR92	189S	1	15:28	1.231	157	0.713	0.079	4.045
23APR92	189S	1	17:28	0.807	155	0.361	0.362	2.855
23APR92	189S	2	15:28	0.934	157	0.312	0.358	2.681
23APR92	189S	2	17:28	1.062	153	0.640	0.069	4.435
23APR92	189S	3	15:28	0.828	156	0.459	0.197	3.457
23APR92	189S	3	17:28	1.062	152	0.451	0.352	3.905
23APR92	189S	4	15:28	0.807	157	0.262	0.271	0.873
23APR92	189S	4	17:28	0.637	156	0.295	0.711	1.148
23APR92	189S	5	15:28	0.828	157	0.287	0.232	0.888
23APR92	189S	5	17:28	0.722	155	0.295	0.806	1.120
24APR92	TSS	1	9:24	0.442	171	0.364	0.402	3.427
24APR92	TSS	1	11:24	0.566	170	0.356	0.023	2.778
24APR92	TSS	2	9:24	0.365	172	0.395	0.199	2.596
24APR92	TSS	2	11:24	0.501	172	0.341	0.334	3.225
24APR92	TSS	3	9:24	0.392	171	0.372	0.208	2.738
24APR92	TSS	3	11:24	0.447	171	0.354	0.150	3.265
24APR92	TSS	4	9:24	0.304	171	0.339	0.070	2.413

24APR92	TSS	4	11:24	0.624	170	0.321	0.637	2.109
24APR92	TSS	5	9:24	0.366	171	0.333	0.060	3.650
24APR92	TSS	5	11:24	0.502	170	0.334	0.296	2.150
24APR92	TPG	1	13:40	0.604	193	0.358	0.106	2.880
24APR92	TPG	1	15:40	0.544	194	0.451	0.093	2.718
24APR92	TPG	2	13:40	0.977	194	0.427	0.178	2.596
24APR92	TPG	2	15:40	0.698	194	0.483	0.046	2.738
24APR92	TPG	3	13:40	0.970	194	0.403	0.656	2.312
24APR92	TPG	3	15:40	0.529	194	0.376	0.138	1.987
24APR92	TPG	4	13:40	0.467	195	0.370	0.205	2.251
24APR92	TPG	4	15:40	0.430	194	0.352	0.147	1.825
24APR92	TPG	5	13:40	0.494	195	0.374	0.186	2.211
24APR92	TPG	5	15:40	0.514	194	0.430	0.054	2.434
24APR92	SKG	1	9:49	0.694	185	0.472	0.230	0.293
24APR92	SKG	1	11:49	0.718	184	0.385	0.183	0.492
24APR92	SKG	2	9:49	0.775	185	0.467	0.221	0.670
24APR92	SKG	2	11:49	0.624	184	0.295	0.193	0.377
24APR92	SKG	3	9:49	0.753	186	0.353	0.255	1.309
24APR92	SKG	3	11:49	1.114	186	0.376	0.303	0.817
24APR92	SKG	4	9:49	0.424	186	0.254	0.272	0.314
24APR92	SKG	4	11:49	0.406	185	0.269	0.329	0.440
24APR92	SKG	5	9:49	0.453	185	0.249	0.605	0.230
24APR92	SKG	5	11:49	0.558	185	0.374	0.143	0.900
27APR92	CPG	1	11:56	0.833	186	0.541	0.099	1.361
27APR92	CPG	1	13:56	0.703	186	0.579	0.030	1.288
27APR92	CPG	2	11:56	0.903	185	0.599	0.028	1.518
27APR92	CPG	2	13:56	0.620	184	0.489	0.074	1.204
27APR92	CPG	3	11:56	0.677	185	0.500	0.046	1.413
27APR92	CPG	3	13:56	0.669	186	0.484	0.066	2.565
27APR92	CPG	4	11:56	0.573	185	0.276	0.121	0.733
27APR92	CPG	4	13:56	0.412	185	0.283	0.049	1.926
27APR92	CPG	5	11:56	0.520	185	0.279	0.105	0.722
27APR92	CPG	5	13:56	0.370	185	0.263	0.056	0.838
28APR92	GEN	1	9:28	0.766	182	0.503	0.035	1.014
28APR92	GEN	1	11:45	0.493	182	0.352	0.086	1.028
28APR92	GEN	2	9:28	2.145	182	0.490	0.042	3.714
28APR92	GEN	2	11:45	0.716	182	0.401	0.098	1.455

28APR92	GEN	3	9:28	1.223	181	0.414	0.043	2.320
28APR92	GEN	3	11:45	0.612	182	0.381	0.044	0.648
28APR92	GEN	4	9:28	0.680	181	0.347	0.036	0.957
28APR92	GEN	4	11:45	0.468	180	0.313	0.105	0.395
28APR92	GEN	5	9:28	0.494	181	0.271	0.105	0.652
28APR92	GEN	5	11:45	0.466	180	0.222	0.258	0.446
28APR92	PI2G	1	12:01	0.485	171	0.224	0.249	0.455
28APR92	PI2G	1	14:01	0.509	171	0.237	0.204	0.395
28APR92	PI2G	2	12:01	0.617	175	0.391	0.144	0.851
28APR92	PI2G	2	14:01	0.650	178	0.381	0.122	1.618
28APR92	PI2G	3	12:01	0.554	175	0.308	0.221	0.410
28APR92	PI2G	3	14:01	0.557	176	0.352	0.144	0.800
28APR92	PI2G	4	12:01	0.389	171	0.076	0.378	0.607
28APR92	PI2G	4	14:01	0.557	176	0.352	0.144	0.800
28APR92	PI2G	5	12:01	0.408	172	0.109	0.406	0.271
28APR92	PI2G	5	14:01	0.380	171	0.115	0.300	0.923
24APR92	TSG	1	11:34	0.521	172	0.379	0.221	2.697
24APR92	TSG	1	13:34	0.423	172	0.422	0.117	2.555
24APR92	TSG	2	11:34	0.460	172	0.439	0.019	3.123
24APR92	TSG	2	13:34	0.369	174	0.380	0.145	2.312
24APR92	TSG	3	11:34	0.502	171	0.420	0.634	3.407
24APR92	TSG	3	13:34	0.488	171	0.457	0.052	2.839
24APR92	TSG	4	11:34	0.610	172	0.396	0.486	2.758
24APR92	TSG	4	13:34	0.320	171	0.323	0.015	2.129
24APR92	TSG	5	11:34	0.349	173	0.335	0.063	2.393
24APR92	TSG	5	13:34	0.324	171	0.336	2.211	0.143

Table 7. Vertical distribution of macrofauna in April 1992. Mean biomass ($g \cdot m^{-2}$) and abundance ($n \cdot m^{-2}$) of taxonomic categories.

Station	Taxa	Section							
		0-3				3-10			
		$n \cdot m^{-2}$		$g \cdot m^{-2}$		$n \cdot m^{-2}$		$g \cdot m^{-2}$	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
189G	Crustacea	1891	433	0.093	0.026	189	328	0.018	0.031
	Mollusca	2742	1845	2.211	1.215	95	164	0.016	0.028
	Nemertea	473	433	0.029	0.037	95	164	0.012	0.021
	Polychaeta	13520	2542	3.880	2.496	6429	3059	7.036	6.814
189S	Crustacea	1607	164	0.234	0.156	95	164	0.023	0.039
	Mollusca	1040	867	0.414	0.673	0	0	0.000	0.000
	Polychaeta	4255	1725	0.652	0.517	2080	912	3.268	2.145
6	Crustacea	189	164	0.017	0.015	95	164	0.001	0.002
	Mollusca	756	164	2.311	1.995	0	0	0.000	0.000
	Polychaeta	2458	590	0.108	0.031	851	983	0.084	0.084
CPG	Crustacea	1229	1181	0.062	0.058	567	284	0.049	0.052
	Mollusca	1796	1074	7.020	3.706	567	284	0.498	0.738
	Others	473	433	0.012	0.011	1324	2293	0.172	0.298
	Polychaeta	17018	8608	3.481	1.156	5862	1889	2.890	1.509
GES	Crustacea	1513	819	0.058	0.065	95	164	0.002	0.003
	Mollusca	284	0	0.019	0.023	284	284	0.028	0.044
	Polychaeta	16451	3002	0.432	0.109	8131	2869	1.977	1.464

GIG	Crustacea	3120	2473	1.249	1.972	284	491	0.061	0.105
	Mollusca	473	590	0.195	0.301	189	328	1.845	3.195
	Nemertea	284	0	0.020	0.020	95	164	0.181	0.313
	Others	567	567	0.053	0.059	189	328	0.783	1.356
	Ophiuroidea	95	164	0.017	0.029	0	0	0.000	0.000
	Polychaeta	18342	4833	5.522	1.012	1796	1456	9.152	7.385
GIS	Mollusca	189	328	1.004	1.739	0	0	0.000	0.000
	Polychaeta	4160	1638	0.811	0.404	1702	750	2.327	1.929
PI1G	Crustacea	3404	1023	0.471	0.263	851	0	0.076	0.037
	Mollusca	189	328	0.071	0.123	189	328	0.002	0.003
	Nemertea	1040	819	0.015	0.014	95	164	0.002	0.003
	Others	189	328	0.005	0.008	95	164	0.016	0.028
	Polychaeta	30917	9360	7.430	1.953	4160	2293	1.544	1.083
PI2G	Crustacea	20138	15967	1.634	1.419	1324	328	0.135	0.088
	Mollusca	567	567	0.678	0.957	0	0	0.000	0.000
	Nemertea	945	590	0.042	0.051	0	0	0.000	0.000
	Others	2553	983	0.107	0.080	284	284	0.208	0.329
	Polychaeta	28459	433	2.132	0.684	1513	433	0.271	0.328
SKG	Crustacea	4916	2979	0.235	0.195	378	433	0.044	0.070
	Mollusca	4916	3691	6.433	6.032	284	0	0.006	0.000
	Nemertea	189	328	0.004	0.007	0	0	0.000	0.000
	Others	3593	1824	0.357	0.176	95	164	0.350	0.606
	Polychaeta	12575	2412	4.137	1.633	2080	164	7.197	3.723
TPG	Crustacea	5578	1181	0.395	0.067	95	164	0.002	0.003
	Mollusca	1135	1474	1.981	2.631	0	0	0.000	0.000
	Others	4822	3485	0.340	0.173	0	0	0.000	0.000
	Polychaeta	12386	9925	2.404	2.071	1135	851	5.446	7.147
TSG	Crustacea	8698	2166	0.253	0.089	378	433	0.019	0.028
	Nemertea	473	164	0.013	0.007	95	164	0.003	0.005
	Polychaeta	13331	2735	6.108	1.575	3876	590	9.462	3.427

TSS	Crustacea	662	590	0.056	0.051	0	0	0.000	0.000
	Mollusca	189	328	0.165	0.287	95	164	1.077	1.865
	Others	95	164	0.025	0.043	0	0	0.000	0.000
	Polychaeta	1607	590	0.999	1.101	1135	567	19.005	18.804

Table 8. Species distributions in April 1992. Average $n \cdot m^{-2}$ at each station to a depth of 10 cm.

Taxa	189G	189S	6	CPG	GES	GIG	GIS	PI1G	PI2G	SKG	TPG	TSG	TSS
Cnidaria													
Anthozoa													
Anthozoa (unidentified)	0	0	0	1796	284	851	0	284	2742	3593	4727	95	0
Platyhelminthes													
Turbellaria													
Turbellaria (unidentified)	0	0	0	0	0	0	95	0	0	0	0	0	95
Rynchocoela													
Rhynchocoel (unidentified)	567	0	0	0	95	378	0	1135	945	189	0	567	0
Mollusca													
Gastropoda													
Cerithiidae													
Diastoma varium	0	0	0	284	189	0	0	0	0	95	95	0	0
Ceritheum lutosum	567	0	0	1418	0	0	0	0	189	1702	284	0	0
Caecidae													
Caecum pulchellum	2175	284	0	189	0	0	0	0	189	0	95	0	0
Caecum glabrum	0	0	0	0	0	0	0	0	0	0	0	95	0
Pyramidellidae													
Sayella crosseana	0	0	0	0	0	0	0	0	0	95	0	0	0
Acteonidae													
Rictaxis punctostriatus	0	0	0	0	95	0	0	0	0	0	0	0	0
Crepidulidae													
Crepidula fornicata	0	0	0	189	0	0	0	0	0	3309	284	0	0
Nudibranchia													
Nudibranch (unidentified)	0	0	0	0	0	0	0	0	0	0	95	0	0

Pelecypoda													
Mytilidae													
Amygdalum papyrium	0	0	0	95	0	0	0	189	95	0	0	0	0
Brachidontes exustus	0	0	0	189	0	0	0	0	0	0	0	0	0
Tellinidae													
Tellina texana	95	0	0	0	0	95	95	0	0	0	0	0	0
Tellina tampaensis	0	0	0	0	0	473	0	0	0	0	189	95	284
Veneridae													
Anomalocardia auberiana	0	189	0	0	0	95	0	0	95	0	189	0	0
Chione cancellata	0	0	0	0	0	0	0	189	0	0	0	0	0
Mactridae													
Mulinia lateralis	0	567	756	0	284	0	95	0	0	0	0	0	0
Annelida													
Polychaeta													
Phyllodocidae													
Eteone heteropoda	0	0	0	0	0	0	0	0	0	378	0	378	189
Anaitides erythrophyllus	95	0	0	0	0	95	189	0	0	0	0	0	0
Pilargiidae													
Pilargiidae (unidentified)	0	0	0	0	0	95	0	0	0	0	0	0	0
Syllidae													
Sphaerosyllis cf. sublaevis	567	1418	0	0	284	4444	1229	3687	0	0	284	0	0
Brania furcelligera	945	0	0	2553	0	473	189	2458	567	1418	662	1229	0
Exogone sp.	2458	95	0	284	378	0	0	284	0	0	0	473	0
Sphaerosyllis sp. A	0	0	0	284	0	0	0	0	0	1324	0	2175	284
Opisthosyilis sp.	2553	1324	0	9549	0	378	189	5200	24109	473	4822	378	0
Syllidae (unidentified)	0	0	0	284	95	0	0	0	0	0	0	189	0
Nereidae													
Platynereis dumerilii	0	0	0	0	189	95	0	284	378	378	567	662	189
Nereidae (unidentified)	0	0	0	95	0	0	0	0	0	0	0	0	0
Goniadidae													
Glycinde solitaria	0	95	95	0	0	0	0	0	0	0	0	95	0

Dorvilleidae													
Schistomeringos rudolphi	0	0	0	284	0	0	95	0	0	95	0	0	0
Schistomeringos sp. A	0	95	0	0	0	0	0	0	0	0	0	0	0
Spionidae													
Polydora ligni	0	0	0	0	0	0	0	284	0	95	95	189	0
Prionospio heterobranchia	4444	284	0	2931	1324	3215	0	17018	945	6524	3876	4160	0
Scolelepis texana	0	0	0	0	0	0	0	0	0	0	95	0	95
Spiophanes bombyx	0	0	0	0	0	0	0	0	0	0	0	95	0
Streblospio benedicti	284	378	0	95	15884	1135	189	189	0	0	0	756	95
Spio setosa	0	0	0	0	0	0	0	0	0	0	378	189	284
Spionidae (unidentified)	0	0	0	0	0	0	95	0	0	0	0	0	0
Magelonidae													
Magelona pettiboneae	0	284	0	0	0	0	0	0	0	0	0	0	0
Chaetopteridae													
Spiochaetopterus costarum	0	0	0	0	0	95	0	0	0	0	0	0	0
Orbiniidae													
Haploscoloplos foliosus	0	0	0	662	95	95	189	0	0	0	0	189	95
Scoloplos rubra	95	378	0	0	0	0	0	0	0	0	0	0	0
Naineris laevigata	284	0	0	1040	0	0	0	378	2836	378	378	0	0
Capitellidae													
Capitella capitata	662	473	284	567	756	3782	2269	0	95	1891	1040	1607	378
Mediomastus californiensis	0	0	0	0	0	0	95	0	0	0	0	0	0
Heteromastus filiformis	567	284	0	95	0	0	189	0	0	378	945	1607	662
Mediomastus ambiseta	0	95	2931	0	473	284	189	0	0	0	0	378	0
Maldanidae													
Branchioasychis americana	378	0	0	0	284	1229	0	0	0	0	95	0	
Clymenella mucosa	0	0	0	284	0	2742	662	0	0	473	0	1607	473
Ampharetidae													
Melinna maculata	189	0	0	0	0	95	0	0	0	95	0	473	0

Sabellidae													
Fabricia sp.	0	0	0	0	0	0	0	0	473	284	0	0	0
Chone sp.	567	95	0	0	0	1513	0	662	95	473	189	284	0
Sabellidae (unidentified)	0	0	0	0	0	0	0	0	0	0	95	0	0
Polychaete juv. (unidentified)	0	0	0	95	0	0	0	0	95	0	0	0	0
Oligochaeta													
Oligochaete (unidentified)	5862	1040	0	3782	4822	378	95	4444	473	0	0	0	0
Crustacea													
Ostracoda													
Myodocopa													
Sarsiella zostericola	0	0	0	0	0	0	0	0	0	0	95	0	0
Copepoda													
Cyclopoida													
Lichomolgidae													
Cyclopoid (commensal)	0	0	95	0	0	0	95	0	0	0	0	0	0
Malacostraca													
Natantia													
Sergestidae													
Lucifer faxoni	0	0	0	0	0	0	0	0	0	0	95	0	0
Hippolytidae													
Hippolyte zostericola	0	0	0	0	0	95	0	0	0	0	0	0	0
Reptantia													
Brachyuran Larvae													
Megalops	0	0	0	0	0	0	0	0	95	0	0	0	0
Mysidacea													
Mysidopsis bahia	0	945	189	0	0	0	0	0	0	0	0	0	189
Cumacea													
Oxyurostylis sp.	0	0	0	0	95	0	0	0	0	0	0	0	0
Oxyurostylis salinoi	0	0	0	0	0	0	0	0	0	95	0	189	95
Amphipoda													
Ampeliscidae													
Ampelisca abdita	189	473	0	0	1513	378	0	0	0	0	0	756	284

Gammaridae													
Gammarus mucronatus	0	0	0	0	0	0	0	189	0	0	0	0	0
Corophiidae													
Cerapus tubularis	189	0	0	0	0	95	0	0	0	0	0	3404	0
Grandidierella bonnieroides	284	0	0	95	0	0	0	2647	0	567	95	0	
Caprellidae													
Caprellid	0	0	0	284	0	851	0	189	284	2269	756	1891	0
Amphilochidae													
Amphilochus sp.	0	0	0	0	0	0	0	0	1985	0	95	0	0
Amphithoidae													
Cymadusa compta	95	0	0	189	0	945	0	284	473	567	1418	1229	0
Melitidae													
Elasmopus sp.	756	95	0	378	0	0	0	0	13047	1229	756	0	0
Melita sp.	0	0	0	0	0	0	0	0	284	0	0	0	0
Isopoda													
Anthuridae													
Xenanthura brevitelson	0	0	0	0	0	0	0	0	0	0	0	95	95
Idoteidae													
Edotea montosa	284	189	0	0	0	0	0	284	0	95	0	0	0
Erichsonella attenuata	284	0	0	189	0	0	0	2742	473	567	1229	756	0
Sphaeromatidae													
Cymodoce faxoni	0	0	0	567	0	1040	0	95	2175	284	662	284	0
Tanaidacea													
Tanaidae													
Leptochelia rapax	0	0	0	0	0	0	0	378	0	0	0	0	0
Pycnogonida													
Pycnogonid (unidentified)	0	0	0	95	0	0	0	0	0	189	95	284	0
Echinodermata													
Holothuroidea													
Holothuroid (unidentified)	0	0	0	0	0	0	0	0	95	95	0	0	0
TOTALS	25435	9080	4350	25059	27139	25439	5959	43588	53137	29597	24775	26853	3786

Table 9. Laguna Madre Diversity and Evenness. Samples from April 1992. Average of 3 replicates.

	Diversity				Evenness			
Station	N1	SD	HPRIME	SD	E1	SD	E5	SD
189G	11.0	2.4	2.38	0.23	0.80	0.07	0.73	0.13
189S	10.9	0.1	2.39	0.01	0.91	0.02	1.17	0.20
6	2.5	1.0	0.87	0.39	0.74	0.10	0.80	0.15
CPG	9.2	1.5	2.21	0.17	0.76	0.03	0.61	0.10
GES	4.2	1.5	1.39	0.34	0.57	0.08	0.52	0.07
GIG	11.8	1.6	2.46	0.14	0.85	0.04	0.80	0.09
GIS	6.0	0.4	1.79	0.06	0.83	0.11	1.09	0.66
PI1G	7.1	0.9	1.96	0.13	0.68	0.03	0.56	0.08
PI2G	5.8	1.4	1.75	0.25	0.62	0.07	0.52	0.11
SKG	12.2	4.2	2.46	0.37	0.83	0.06	0.72	0.11
TPG	9.2	0.3	2.22	0.04	0.77	0.05	0.65	0.13
TSG	16.8	1.8	2.82	0.10	0.88	0.04	0.83	0.17
TSS	8.1	0.5	2.09	0.06	0.97	0.01	2.44	0.93

Table 10. Temporal changes in sediment organic matter. Samples from 1992, average of 3 replicates to a depth of 10 cm.

		Dry Weight ($g \cdot m^{-2}$)			
Date	Station	Seagrass	Roots	Detritus	Total
21JAN92	189G	28	369	525	923
21JAN92	189S	0	0	200	200
21JAN92	TSG	26	57	197	280
21JAN92	TSS	0	0	5	5
23APR92	189G	291	333	251	876
23APR92	189S	0	0	220	220
24APR92	TSG	116	118	92	326
24APR92	TSS	0	0	12	12
08JUL92	189G	278	270	466	1014
08JUL92	189S	0	0	157	157
08JUL92	TSG	120	260	134	514
08JUL92	TSS	0	0	3	3
20OCT92	189G	306	501	1036	1843
20OCT92	189S	0	0	327	327
20OCT92	TSG	114	300	236	650
20OCT92	TSS	0	0	13	13