EFFECT OF FRESHWATER INFLOW ON MACROBENTHOS PRODUCTIVITY AND NITROGEN LOSSES IN TEXAS ESTUARIES

Paul A. Montagna, Principal Investigator
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FINAL REPORT

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PREFACE

The current contract is a continuation of a long-term study with the goal to determine the importance of freshwater inflow in maintaining benthic productivity in two Texas estuaries. Previous work has been performed with support, or partial support, by the Texas Water Development Board, Water Research Planning Fund, authorized under the Texas Water Code sections 15.402 and 16.058(e). This support was administered by the Board under interagency cooperative contract numbers: (1986-87) 0757, 8-483-607, 9-483-705, 90-483-706, 91-483-787, 92-483-300, 93-483-352, 94-483-003, 95-483-068, 96-483-132, 97-483-199, 98-483-233, 99-483-267, and most recently 2000-483-323.

This is a final interpretive report. Data is added to the time series based on previous reports, and the whole time series is reported so that year-to-year comparisons can be made. The report has two main sections: a synthesis of data collected over the entire study period, and appendices with data on biological, hydrographical, and sediment data on nitrogen losses compiled over the entire study period.

ACKNOWLEDGMENTS

I must acknowledge the significant contributions of Mr. Rick Kalke. Rick began the first sampling study of Lavaca Bay in 1984. He is an outstanding field person and taxonomist. The work reported on in this study could not have been performed without him. Carrol Simanek also provided significant help in data management. We obviously are collecting and processing a large amount of data. Input, proof-reading and maintenance of this large data set is a daunting task that Carrol handles very well. Dr. Steve Jarvis, Mr. Robert Burgess, Mr. Chris Kalke aided in field collections. This work has also benefitted by discussions with colleagues at the Texas Water Development Board (TWDB), e.g., William Longley (who retired), David Brock, and Gary Powell who have provided much help and guidance.

The Texas estuarine research reported here has been supplemented by many other projects. The most interesting trend is that we have moved from monitoring and evaluating freshwater inflows to using diverted, restored, or returned inflows to enhance and restore wetland areas of estuaries. Two such projects are currently under way. The U.S. Bureau of Reclamation has funded studies on the effect of freshwater diversion to Rincon Bayou to restore the Nueces Delta Marsh. The City of Corpus Christi has funded a biological monitoring program of the Allison Waste Water Treatment Plant diversion project to restore an area of the Nueces Delta Marsh with returned inflows. In these studies, we have built on past information and used the TWDB long-term data set in Nueces Bay as a baseline for comparisons.

From 1993 through 1996, the Lower Colorado River Authority contributed to the current study by funding data collection in two stations near the Colorado River. Since 1996, we have continued to fund data collection at these two stations with partial support form the University of Texas Marine Science Institute.

INTRODUCTION

The primary goal of the current research program is to define quantitative relationships between marine resource populations and freshwater inflows to the State's bays and estuaries. However, we know there is year-to-year variability in the population densities and successional events of estuarine communities. This year-to-year variability is apparently driven by long-term, and global-scale climatic events, e.g., El Niño, which affects rates of freshwater inflow. Therefore, this report documents long-term changes in populations and communities that are influenced by freshwater inflow. The best indicator of productivity is the change in biomass of the community over time.

A secondary goal of the current research is to quantify loss of nitrogen in Texas estuaries. Nitrogen is the key element limiting productivity. A simple budget would account for nitrogen entering the bay via freshwater inflow, how it is captured and transformed into biomass, and finally how it is lost from the ecosystem. One aspect of nitrogen loss is very poorly understood: How much nitrogen is buried in sediments and lost from the system? We report here nitrogen content changes with respect to sediment depth. Presumably nitrogen is labile in the upper, biologically active, layers of sediment and refractory at depth. Therefore, it is important to determine the sediment depth at which nitrogen content is at a low and constant value.

This study is a continuation of freshwater inflow studies that began in 1984. The goals have evolved over the years to reflect the synthesis of new information and the management needs of the Texas Water Development Board (TWDB). The original studies (1984-1986) were designed to determine the effect of inflow on Lavaca Bay. One station used during that study is still being sampled. San Antonio Bay was studied in 1987, and the Nueces Estuary (Nueces and Corpus Christi Bays) were studied in 1988. Long-term studies of the Lavaca-Colorado and Guadalupe Estuaries began in 1990. Our initial conclusions based on one to four years of data were that inflow does increase benthic productivity (Kalke and Montagna, 1991; Montagna and Kalke, 1992; 1995). However, later analysis of the data set over a 5-year period demonstrated that the largest effect may not be on productivity, but may be on community structure (Montagna and Li, 1996). This implies that reduced inflows may not only reduce productivity but may also change the composition of species in an estuary. The complete long-term record now extends over nine years. The completion of this research will take 12 to 20 years, because the trends are driven by long-term climatic events controlled by global climate patterns, e.g., El Niño.

METHODS

Study Design and Area

There are seven major estuarine systems along the Texas coast. Each system receives drainage from one to three major rivers. The northeastern most estuaries receive more freshwater inflow than the southwestern estuaries. Two estuarine systems were studied in detail (Fig. 1). Both systems have similar freshwater inflow characteristics, but the Lavaca-Colorado (LC) Estuary has direct exchange of marine water with the Gulf of Mexico via Pass Cavallo, whereas the Guadalupe (GE) Estuary does not. To assess ecosystem-wide variability stations in the freshwater influenced and marine influenced zones were chosen. Two stations, which replicate each of the two treatment effects (freshwater and marine) influence, were sampled. Generally these stations were along the major axis of the estuarine system leading from river mouth to the foot of the estuary near the barrier island. This design avoids pseudoreplication, where only one station has the characteristic of the main effect, and it is not possible to distinguish between station differences and treatment differences.

The Lavaca River empties into Lavaca Bay, which is connected to Matagorda Bay. Matagorda Bay also has freshwater input from the Colorado and Tres Palacios River. Over a 47-year period (1941-1987) the Lavaca-Colorado Estuary received an average of 3.800×10^9 m^3 y^{-1} with a standard deviation of 2.080 m^3 y^{-1} ($3.080 \pm 1.686 \times 10^6$ ac-ft y^{-1}) of freshwater input, and the freshwater balance (input-output) was 3.392×10^9 m^3 y^{-1} with a standard deviation of 2.345×10^9 m^3 y^{-1} ($2.750 \pm 1.901 \times 10^6$ ac-ft y^{-1}) (TDWR, 1980a; TWDB unpublished data).

Four Stations were occupied along the east-west axis of the system. Two stations were in Lavaca Bay (A and B), and two stations were in Matagorda Bay (C and D) (Fig. 1, Table 1). Depths of stations A, B, C, and D were 1.4 m, 1.9 m, 2.9 m, and 4.1 m, respectively. Four field trips were performed. Station A in Lavaca Bay was the same station 85 sampled in 1984-1986 (Jones et al., 1986). An additional two stations (E and F) were sampled along the north-south axis of Matagorda Bay to examine the effects of the Colorado River. Depths of stations E and F were 3.3 and 1.2 respectively. The stations D, E, and F area along a gradient from the pass to the river.

The San Antonio River joins the Guadalupe River that flows into San Antonio Bay. Over a 46-year period the Guadalupe Estuary received an average of 2.896×10^9 m^3 y^{-1} with a standard deviation of 1.597 m^3 y^{-1} ($2.347 \pm 1.295 \times 10^6$ ac-ft y^{-1}) of freshwater input, and the freshwater balance (input-output) was 2.624×10^9 m^3 y^{-1} with a standard deviation of 1.722×10^9 m^3 y^{-1} ($2.127 \pm 1.396 \times 10^6$ ac-ft y^{-1}) (TDWR, 1980b; TWDB unpublished data). This system was studied from January through July 1987 and sampling commenced again in 1990.

Four stations were occupied: freshwater influenced stations at the head of the bay (station A) and at mid-bay (station B), and two marine influenced stations near the Intracoastal Waterway, one at the southwestern foot of the bay (station C) and one at the southeastern foot of the bay (station D) (Fig. 1, Table 1). Stations were sampled five times in the first year. All stations were in shallow water. Depths of stations A, B, C, and D were 1.2 m, 1.8 m, 1.8 m, and 1.5 m, respectively.

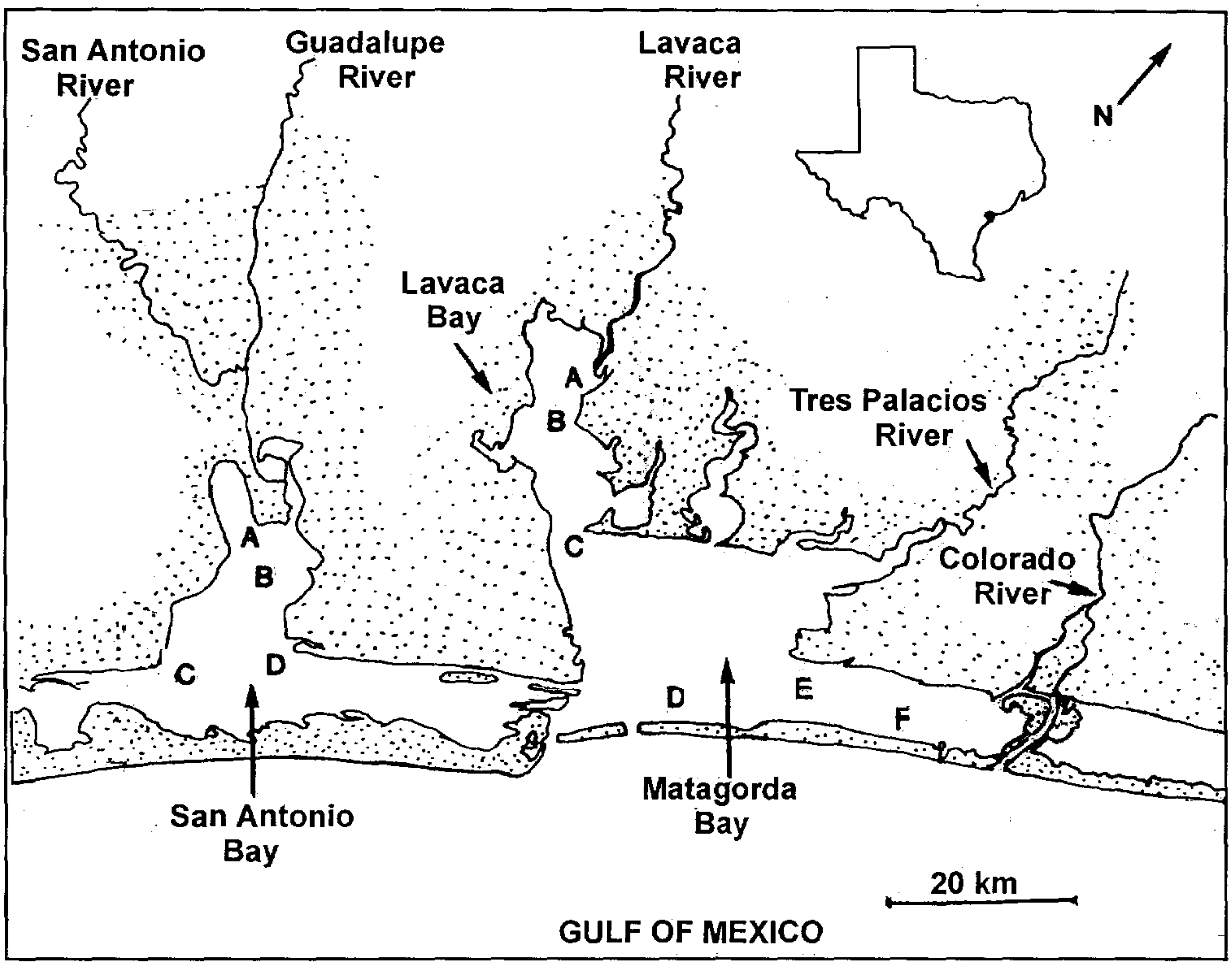

Figure 1. Map of the Guadalupe and Lavaca-Colorado Estuaries. Map shows major rivers, tidal inlets, and station locations.

Hydrographic Measurements

Salinity, conductivity, temperature, pH, dissolved oxygen, and redox potential were measured at the surface and bottom at each station during each sampling trip. Measurements were made by lowering a probe made by Hydrolab Instruments. Salinities levels are automatically corrected to 25 °C. The manufacturer states that the accuracy of salinity measurements are 0.1 ppt. When the Hydrolab instrument was not working, water samples were collected from just beneath the surface and from the bottom in jars, and refractometer readings were made at the surface.

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.

Biological Measurements

Sediment was sampled with core tubes held by divers. The macrofauna were sampled with a tube 6.7 cm in diameter, and sectioned at depth intervals of 0-3 cm and 3-10 cm. Three replicates were taken within a 2 m radius. Samples were preserved with 5% buffered formalin, sieved on 0.5 mm mesh screens, sorted, identified to the lowest taxonomic level possible, 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 Nitrogen Measurements

All Texas estuaries have been studied. The Sabine-Neches and Trinity-San Jacinto Estuaries were sampled in 1993. The Lavaca-Colorado and Guadalupe Estuaries were sampled in 1990, 1992, and 1996. The Nueces Estuary was sampled in 1991, 1994, and 1995. The Lower Laguna Madre was sampled in1998. The Upper Laguna Madre and Baffin Bay was sampled in1991, 1994, and 1999. Samples were taken in East Matgorda Bay during the current year

(Table 1). Our approach is to take sediments cores and measure nitrogen changes with respect to sediment depth. Cores are taken to a depth of 1 m. One-cm sediment sections are taken at the depth intervals listed. The sediment is dried, ground up, and homogenized prior to analysis.

Carbon and nitrogen content, as a percent dry weight of sediment, and carbon and nitrogen isotopic composition were measured. Samples were run using a Finnigan delta plus mass spectrometer linked to a CE instruments NC2500 elemental analyzer. This system uses a Dumas type combustion chemistry to convert nitrogen and carbon in solid samples to nitrogen and carbon dioxide gases. These gases are purified by chemical methods and separated by gas chromatography. The stable isotopic composition of the separated gases is then determined by a mass spectrometer designed for use with the NC2500 elemental analyzer. Standard material of known isotopic composition is run every tenth sample to monitor the system and ensure the quality of the analyses.

Table 1. Locations are given in degrees and decimal seconds format. Readings were made with a GPS unit using differential signal reception.

Estuary	Station	Latitude (N)	Longitude (W)
Lavaca-Colorado	A	28° 40.439′	96° 34.950′
	B	28° 38.192′	96° 34.985′
	C	28° 32.482′	96° 28.082′
	D	28° 28.661′	96° 17.230′
	E	28° 33.162′	96° 12.558′
	F	28° 35.767′	96° 02.456′
Guadalupe	A	28° 23.611′	96° 46.344′
	B	28° 20.866′	96° 44.744′
	C	28° 14.920′	96° 45.619′
	D	28° 18.126′	96° 41.061′
East Matagorda Bay	A	28° 39.000′	95° 56.000′
	B	28° 41.250′	95° 52.000′
	C	28° 42.667′	95° 49.000′
	D	28° 43.667′	95° 47.500′
	E	28° 44.583′	95° 46.283′
	F	28° 44.000′	95° 43.500′

RESULTS

Hydrographic Data

There is a salinity gradient in both the GE and LC estuaries (Table 2). The gradient extends to nutrient measurements as well. The salinity gradient in the GE is simple, long-term average salinities decrease from the Guadalupe River (station A) to the Intracoastal Waterway (ICW) (stations C and D). Station D, is north of station C and slightly more saline, because D is closer to the nearest inlet, Pass Cavallo in Matagorda Bay. The trend in LC estuary is more complex because of the presence of two major river sources. Salinity decreases from station A (near to the Lavaca River) to station D (near Matagorda Ship Channel inlet), then starts to decrease again from stations E to F, which is closest to the Colorado River diversion. As in GE, the nutrient gradients follow the salinity gradients.

Both estuaries appear to be a sink for dissolved inorganic nitrogen (DIN), because the concentration decreases more rapidly than salinity increases within the estuaries (Figs. 2 and 3). The GE estuary has much higher concentrations of DIN, phosphate and silicate than the LC estuary. The influence of the Lavaca and Colorado Rivers on nutrient concentrations are clear, because nutrient concentrations increase towards both sources (Fig. 3). For the most part, phosphate and silicate are conservatively mixed within both estuaries. The only exception is a tendency for phosphate to be a sink in LC in stations B and C, which are influenced by the Lavaca River. In contrast, stations E and F influenced by the Colorado River are conservatively mixed.

On average, the GE estuary is fresher (14 psu) than the LC estuary (20 psu) over all stations, depths, and sampling dates (Table 3). On average, nutrient concentrations are much higher in GE estuary than LC estuary. Although DIN is 3× higher in GE than LC, the difference is due almost entirely to higher nitrate concentrations. Nitrite and ammonium have very similar concentrations in both estuaries. Nitrogen species have differing percentage contributions, because of the differences in nitrate. Ammonium contributes 13% in the GE estuary, but 45% in the LC estuary.

Table 2. Hydrographic characteristics at stations in two estuaries. Average over all dates and depths, except depth which is bottom.

Lavaca-Colorado			STA=A		STA=B		STA=C		STA=D		STA=E		STA=F	
Variable	Units	N	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Refractometer	psu	69	14.6	8.7	16.3	9.0	21.3	8.7	24.6	7.3	22.2	7.9	17.8	8.5
Salinity meter	ppt	91	12.6	9.4	16.2	9.2	22.7	7.5	26.9	6.0	23.6	7.1	18.3	9.0
Temperature	°C	92	21.0	6.9	21.1	7.0	21.4	6.8	21.6	6.2	21.4	6.6	21.9	6.5
pH		79	8.308	0.887	8.235	0.653	8.133	0.414	8.113	0.428	8.160	0.558	8.220	0.556
DO	mg/l	89	8.32	1.73	8.19	1.71	7.75	1.66	7.38	1.85	7.53	2.25	7.98	2.56
Conductivity	uS/cm	90	20.143	14.413	25.906	13.853	35.861	10.950	46.662	48.220	37.233	10.391	29.342	13.408
ORP	mV	70	0.255	0.245	0.212	0.155	0.289	0.394	0.206	0.174	0.215	0.145	0.210	0.142
Depth	m	49	1.36	0.77	1.91	0.26	2.86	0.32	4.14	0.29	3.26	0.36	1.24	0337
PO_4	umol/l	68	1.658	1.380	1.383	1.181	1.036	0.716	1.005	0.815	1.334	1.064	1.822	1.470
SIO_4	umol/l	68	89.833	52.481	75.709	47.706	49.116	37.307	33.907	27.860	43.799	38.279	65.225	43.190
NO_2	umol/l	68	0.732	0.681	0.722	0.722	0.514	0.489	0.513	0.551	0.751	1.343	0.875	0.899
NH_4	umol/l	68	2.920	2.482	2.804	2.428	2.008	1.821	2.342	3.116	2.751	3.416	4.493	5.102
NO_3	umol/l	68	4.824	8.289	3.13	6.795	0.981	3.671	0.796	2.124	1.162	2.973	6.128	13.252
DIN	umol/l		8.476	11.452	6.656	9.945	3.503	5.981	3.651	5.791	4.664	7.732	11.496	19.253

Guadalupe			STA=A		STA=B		STA=C		STA=D	
Variable	Label	N	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Refractometer	psu	77	7.5	7.9	11.9	8.9	16.9	9.7	18.0	10.7
Salinity meter	ppt	101	7.3	7.5	12.1	8.6	16.9	9.4	17.8	9.8
Temperature	°C	102	22.2	6.5	21.7	6.8	21.8	6.7	21.9	6.5
pH		72	8.344	0.559	8.335	0.529	8.263	0.451	8.177	0.468
DO	mg/l	90	8.87	2.07	8.82	2.85	8.46	2.12	8.46	2.05
Conductivity	uS/cm	89	12.689	11.885	20.726	12.840	27.129	13.682	28.557	14.334
ORP	mV	63	0.177	0.056	0.232	0.271	0.948	6.001	0.220	0.318
Depth	m	56	1.18	0.26	1.68	0.33	1.83	0.32	1.45	0.24
PO_4	umol/l	79	4.914	3.530	3.422	2.890	2.729	2.152	2.362	1.979
SIO_4	umol/l	79	161.008	180.327	136.750	150.458	109.617	117.323	94.964	62.763
NO_2	umol/l	79	1.460	3.008	1.194	2.774	0.552	0.436	0.564	0.452
NH_4	umol/l	79	3.800	3.686	2.389	2.221	2.267	2.515	2.173	2.241
NO_3	umol/l	78	41.528	51.034	13.742	17.2	7.45	15.254	5.55	10.527
DIN	umol/l		46.788	57.728	17.325	22.195	10.269	18.205	8.287	13.22

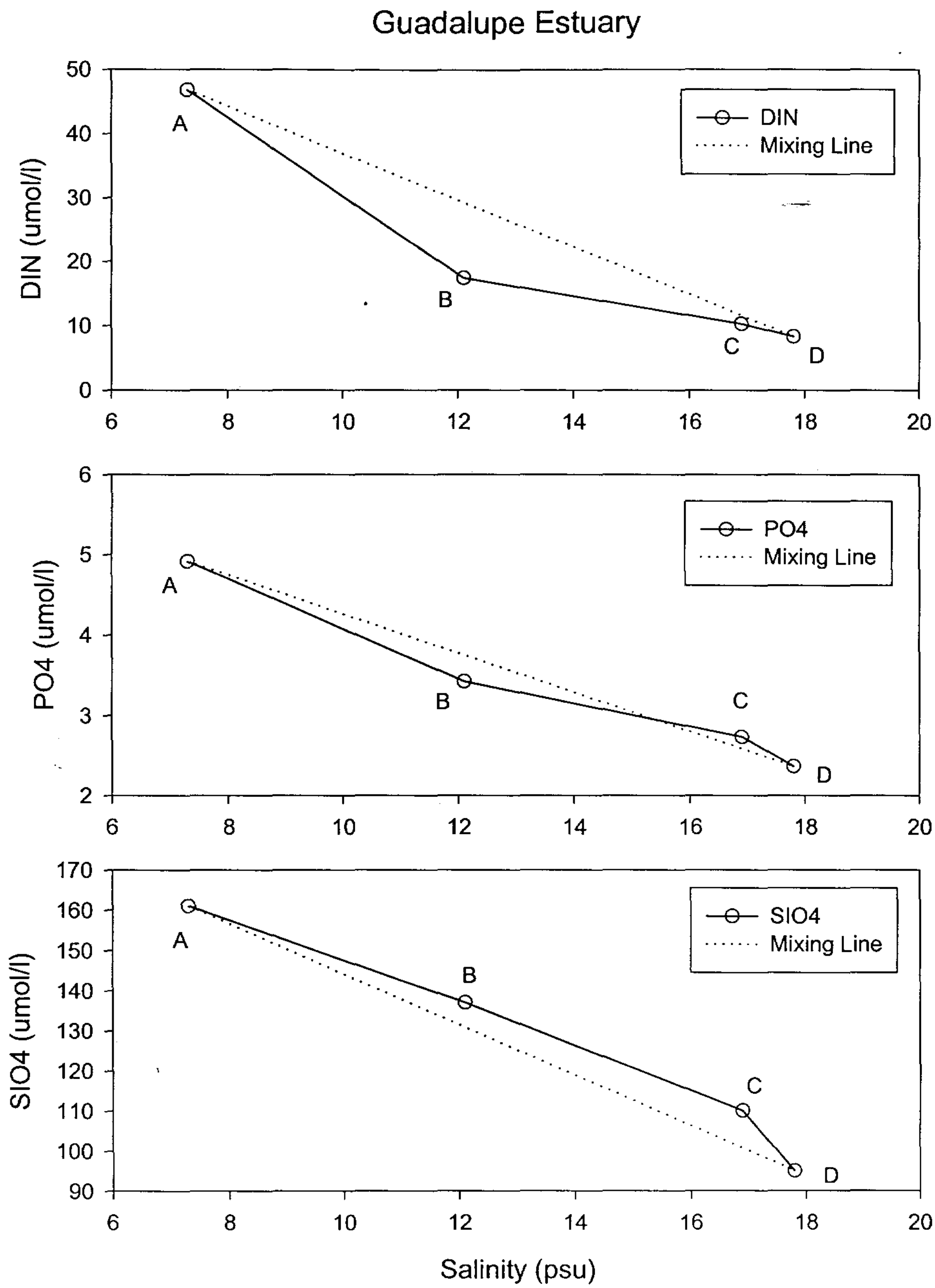

Figure 2. Mixing diagram of nutrient concentrations along the salinity gradient for stations in Guadalupe Estuary. Station averages over all dates and depths sampled.

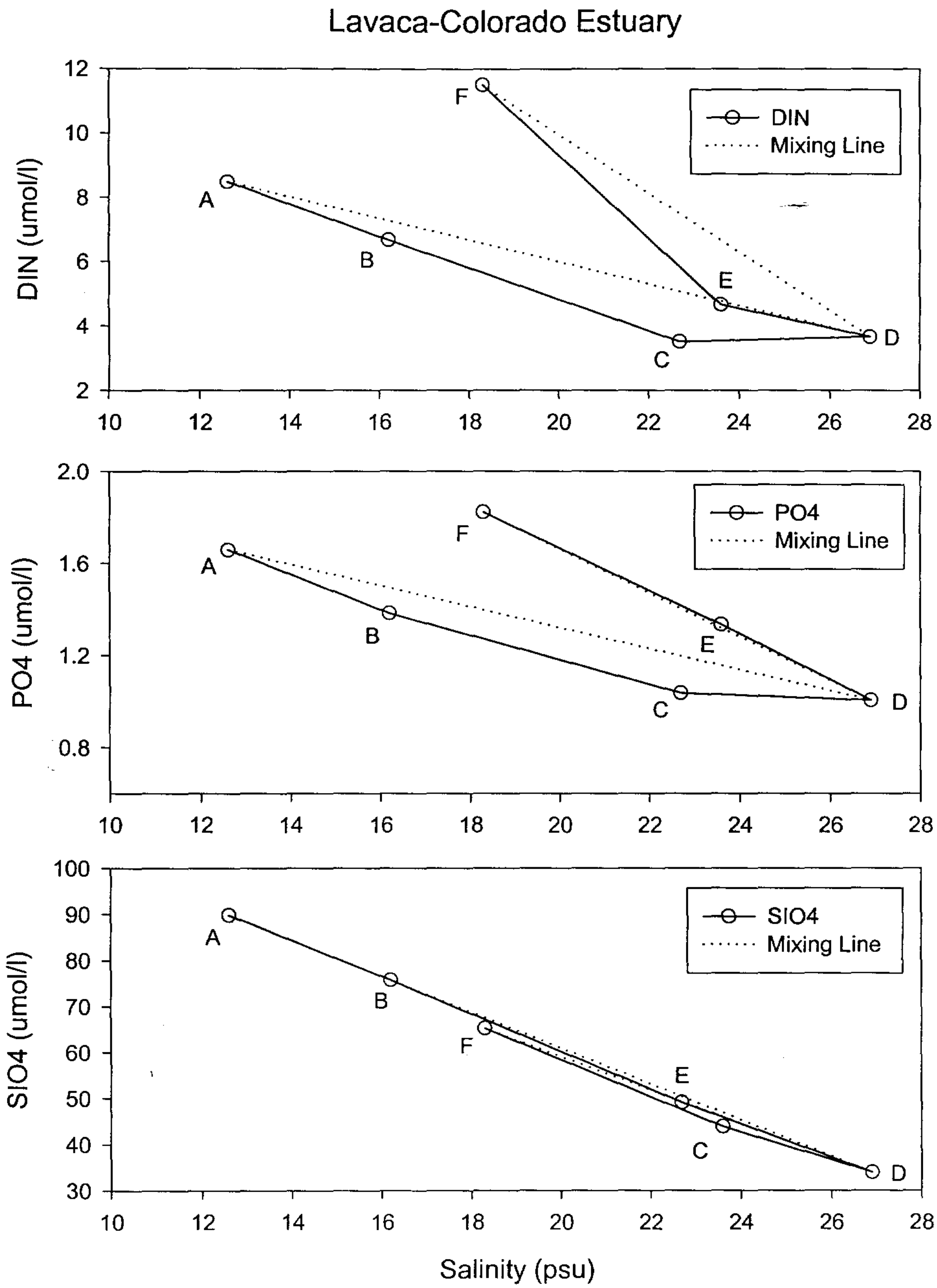

Figure 3. Mixing diagram of nutrient concentrations along the salinity gradient for stations in Lavaca-Colorado Estuary. Station averages over all dates and depths sampled.

Table 3. Hydrographic characteristics in two estuaries. Average over all dates, stations, and depths, except depth which is bottom.

Variable	Units	N	Mean	Std Dev	Minimum	Maximum
Guadalupe Estuary						
Refractometer	psu	320	13.9	10.4	0	38
Salinity meter	ppt	416	13.74	9.83	0	35.16
Temperature	°C	420	22.0	6.5	8.29	31.5
pH		300	8.27	0.51	6.54	10.93
DO	mg/l	370	8.62	2.29	3.40	23.25
Conductivity	uS/cm	368	22.635	14.652	0.263	53.44
ORP	mV	262	0.39	2.97	0.051	48.2
Depth	m	221	1.54	0.38	0.19	2.3
PO_4	umol/l	321	3.311	2.859	0.071	18.551
SIO_4	umol/l	317	124.703	136.054	4.898	1230.32
NO_2	umol/l	321	0.931	2.077	0.034	20.97
NH_4	umol/l	321	2.663	2.799	0.006	24.728
NO_3	umol/l	320	16.658	31.528	0	282.96
DIN	umol/l		20.252	36.404		
%NH4	%		13.1%			
Lavaca-Colorado Estuary						
Refractometer	psu	414	19.6	9.1	0.5	35
Salinity meter	ppt	491	19.97	9.51	0	36.1
Temperature	°C	498	21.4	6.7	2.99	31.52
pH		418	8.20	0.61	6.45	12.53
DO	mg/l	481	7.87	1.95	0.12	16.36
Conductivity	uS/cm	484	32.452	25.310	0.14	492
ORP	mV	390	0.23	0.24	0	1.96
Depth	m	256	2.48	1.14	0.60	6.40
PO_4	umol/l	389	1.362	1.160	0	7.558
SIO_4	umol/l	387	59.967	46.068	0	200.632
NO_2	umol/l	389	0.677	0.816	0	9.11
NH_4	umol/l	389	2.846	3.233	0	26.876
NO_3	umol/l	389	2.791	7.360	0	89.979
DIN	umol/l		6.314	11.409		
%NH4	%		45.1%			

There are strong spatial and temporal trends in the hydrographic data. Salinity decreases in wet years and increases in dry years (Figs. 4 and 5). In the GE estuary, salinities were always lowest nearer the Guadalupe River at stations A and B (Fig 4). Salinities were generally highest at station D, but on three occasions the salinities were highest at station C. In the LC estuary, salinities were mostly lowest nearer the Lavaca River at stations A and B (Fig 5), once, they were lowest near the Colorado River at station F. Salinities were generally highest at station D, but on one occasion the salinities were highest at station E. The salinity range among stations was greatest at different times in the two estuaries. The two driest periods with the highest salinities occurred between 1988 through 1990 and 1995 through 1997. During these droughts, salinity range in the GE estuary was about 15 psu, but only about 5 psu in the LC estuary. During wet periods, the range was about 8 psu in the GE estuary, but about 20 psu in the LC estuary.

Dissolved oxygen (DO) concentrations are very important to benthos. The DO concentrations had a strong seasonal trend, decreasing in summer and increasing in winter, in both estuaries (Figs. 6 and 7). Hypoxia, where DO < 3 mg/l occurred only once in station B in Lavaca Bay, but there was not a general trend for low DO near rivers. In general, when DO was seasonally high, it occurred in the secondary bays near rivers, and when DO was seasonally low, it occurred in primary bays near ocean influences. The temporal trend was stronger than the spatial trend.

The temporal trend in salinity was very similar in the two estuaries (Fig. 8). For the most part, salinity rose or fell in synchrony. A few interesting exceptions occurred when a storm affected one watershed more than the other. For example, salinities dropped more in GE than LC in winter 1992 and throughout 1998 and winter 1999. Salinities in GE were almost always lower than in LC, except in spring and summer 1996. Seasonal trends are also apparent. Salinity is generally lowest in spring or early summer and highest in fall and winter (Table 4).

The temporal trend in DO is primarily seasonal, with little variation from year-to-year (Fig. 9). DO is also very similar in the two estuaries, but GE usually has higher winter concentrations than LC. DO is low in summers when temperatures are highest, and lowest in winter when temperatures are lowest (Table 4).

The relationship between salinity and DIN is not strong over time in either estuary (Figs. 10 and 11). This is in contrast to the trend described earlier where there is a strong spatial trend between salinity and DIN. The trend over time appears to indicate that high inflow and low salinity are related to high DIN concentrations. For example when salinity is low in GE in 1986 - 1987, 1992, and 1999, DIN increases or is at it's highest values (Fig. 10). This is also true in LC in 1992, 1993, 1994, and 1997 (Fig. 11). However, there is only a weak statistical relationship between salinity and DIN, $r^2 = 0.26$ for GE and $r^2 = 0.11$ for LC. The weak relationship is due to some low DIN values when salinity is low in 1987 and 1997.

Table 4. Monthly average salinity (psu), temperature (°C), and dissolved oxygen (DO) (mg/l) for bottom water over entire data set.

	Guadalupe Estuary				Lavaca-Colorado Estuary			
Month	n	Salinity	Temp.	DO	n	Salinity	Temp.	DO
1	45	14.6	12.6	10.4	56	21.9	12.7	9.4
3	8	5.0	16.1					
4	55	13.2	20.9	7.8	68	19.6	20.2	7.4
6	4	5.0	26.4	9.3				
7	53	11.3	29.9	7.0	70	21.1	29.4	6.0
8	4	7.6	29.6	6.0				
10	44	20.1	24.1	7.1	54	22.6	23.2	6.5
11	4	23.9	15.7	10.0	4	34.5	15.2	8.6
12	4	22.0	11.3	13.4	4		10.9	11.4

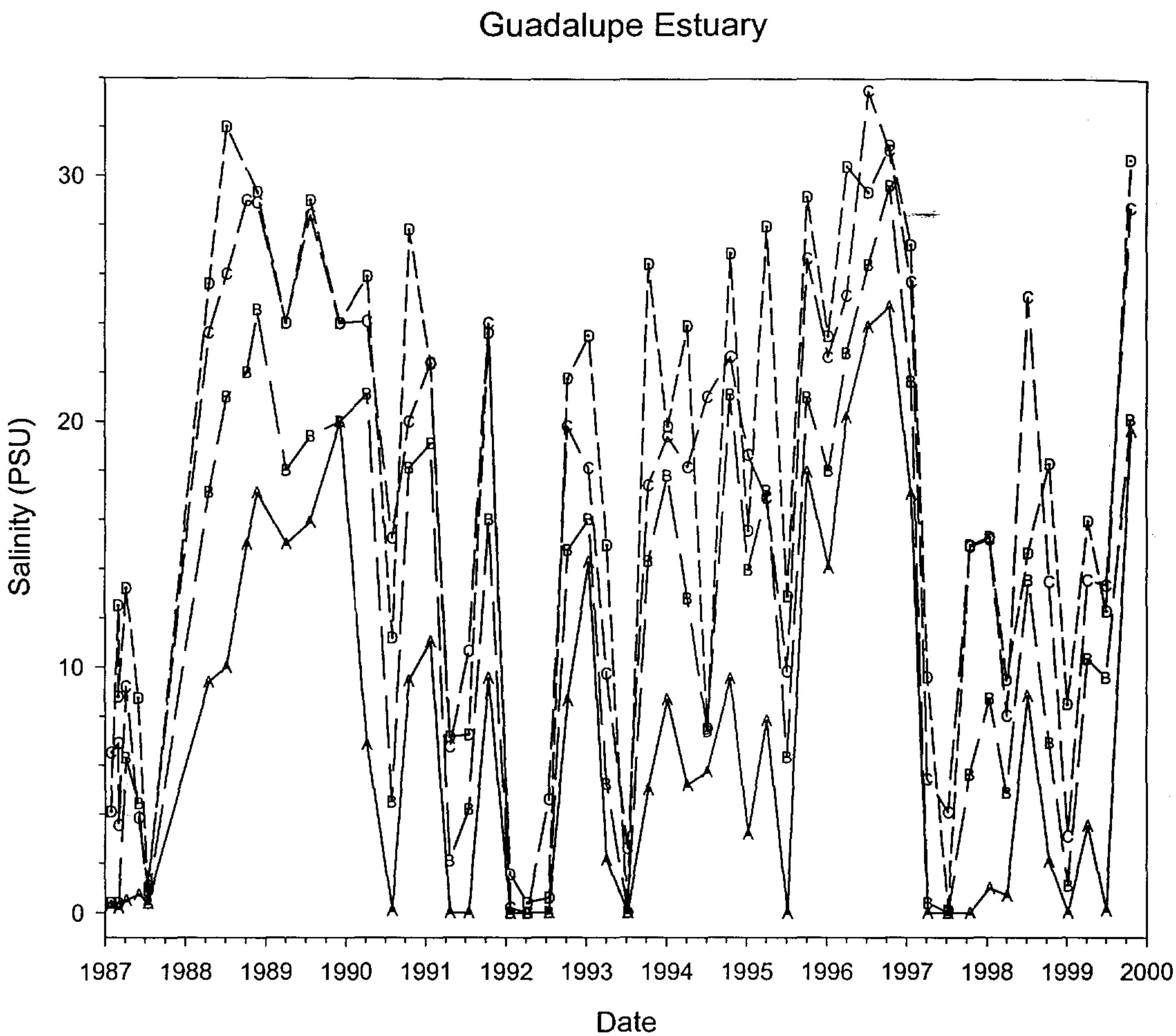

Figure 4. Salinity at stations in the Guadalupe Estuary over time.

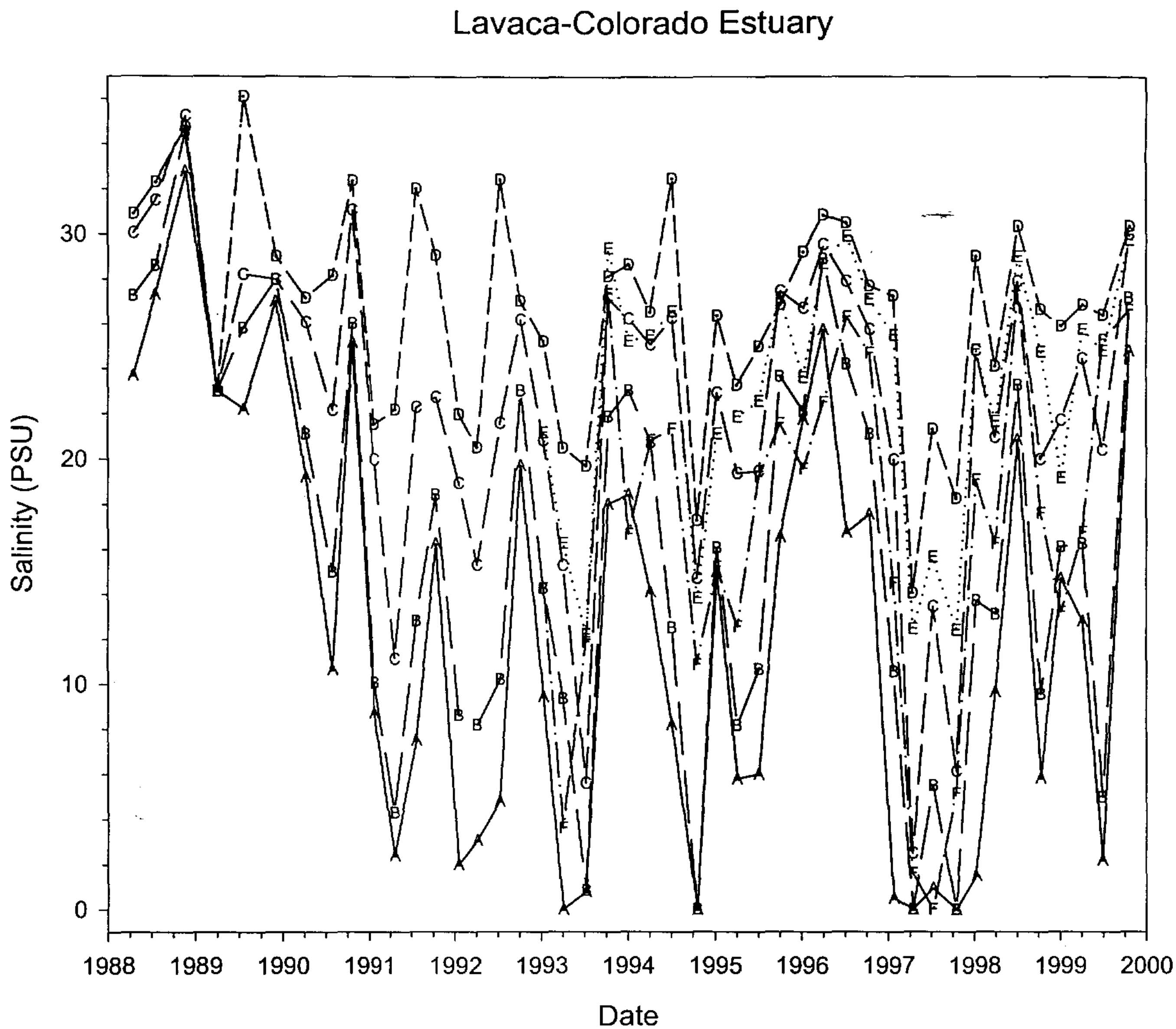

Figure 5. Salinity at stations in the Lavaca-Colorado Estuary over time.

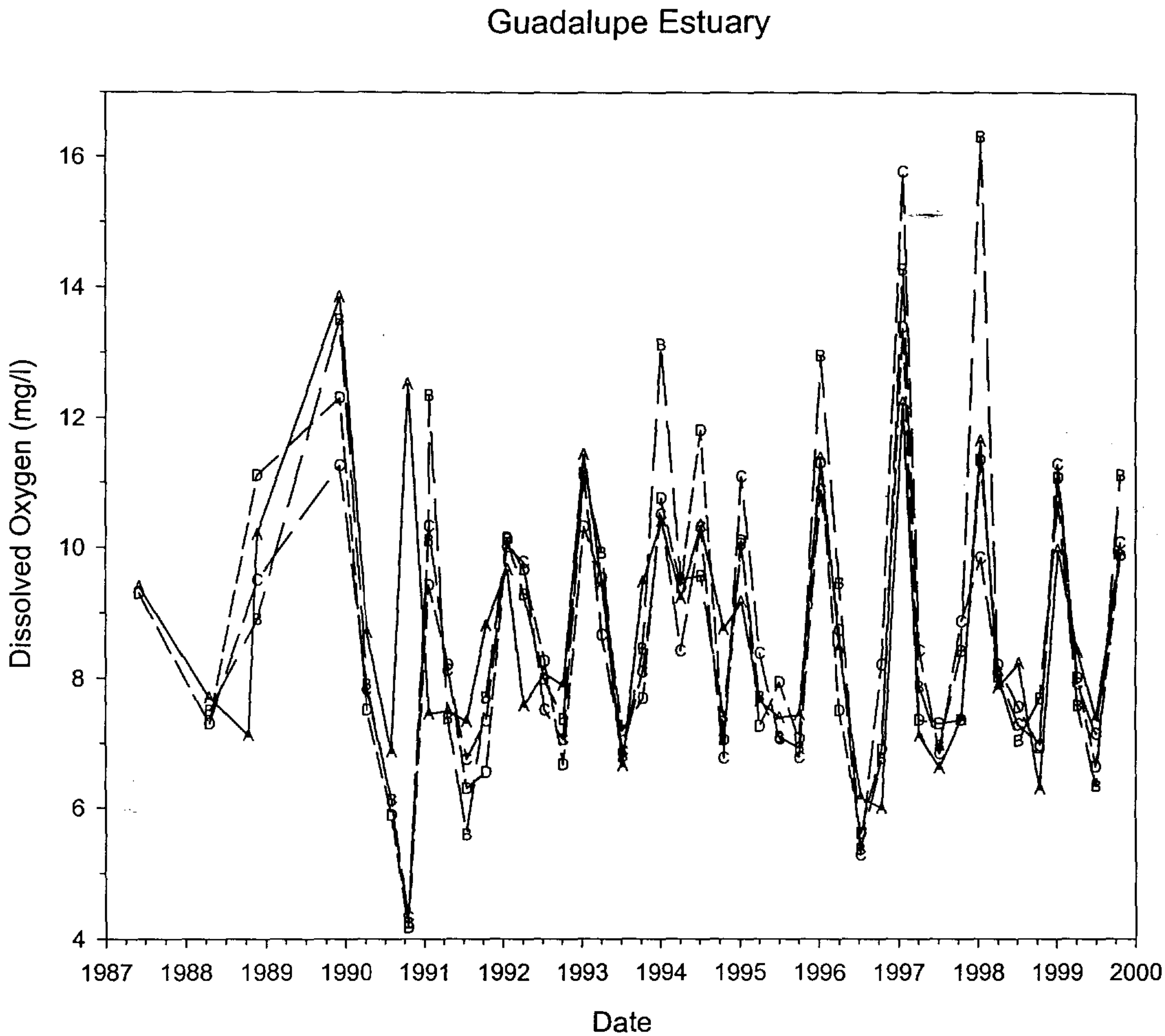

Figure 6. Dissolved Oxygen at stations in the Guadalupe Estuary over time.

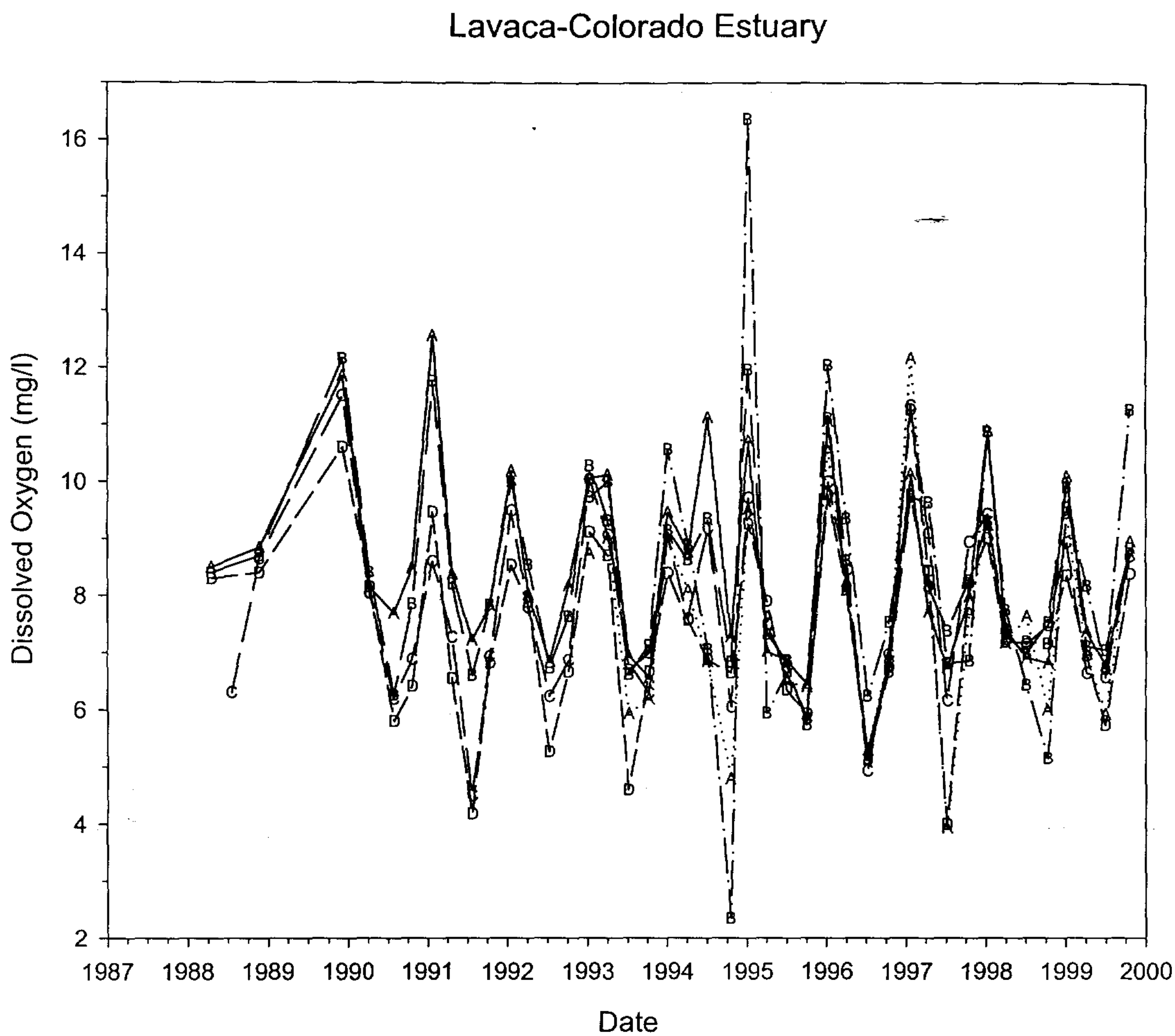

Figure 7. Dissolved Oxygen at stations in the Lavaca-Colorado Estuary over time.

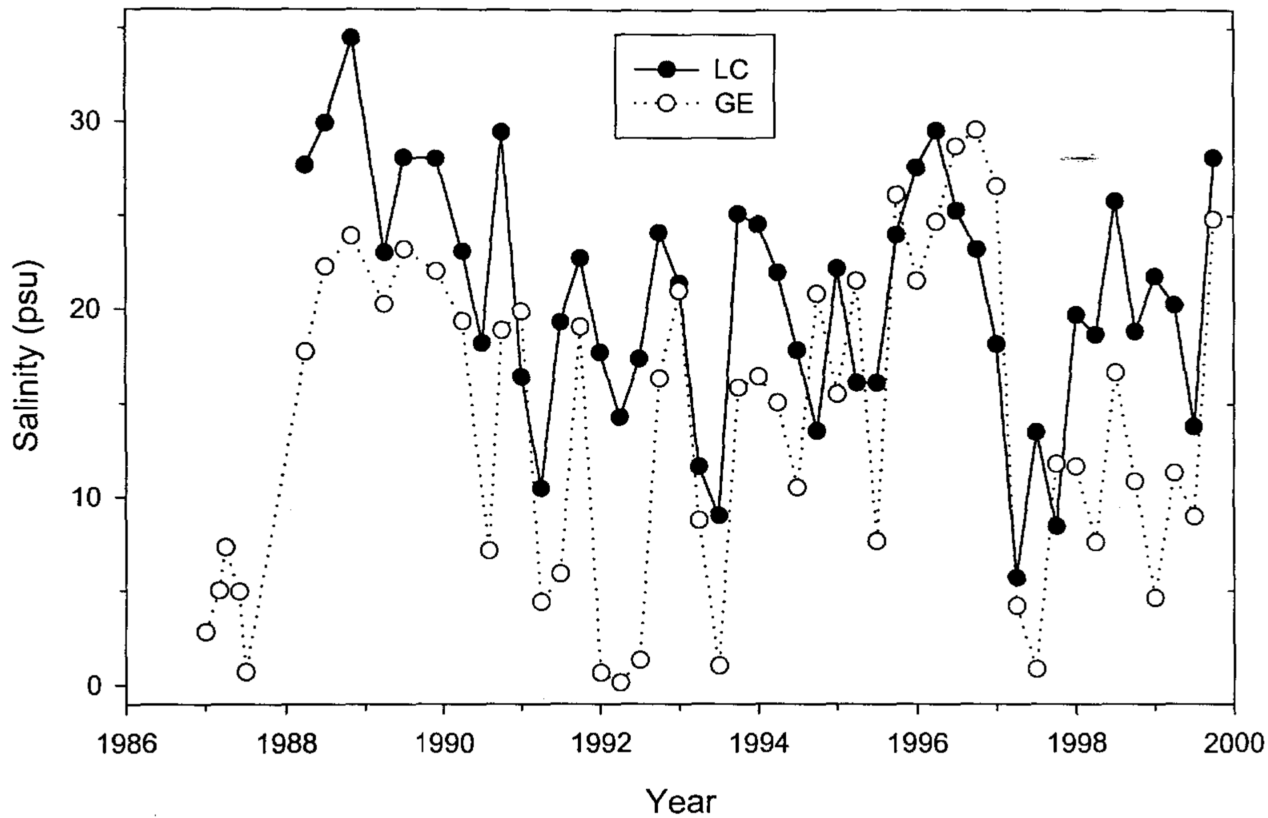

Figure 8. Long-term salinity change in the Lavaca-Colorado and Guadalupe Estuaries. Estuarine-wide average for stations A - D.

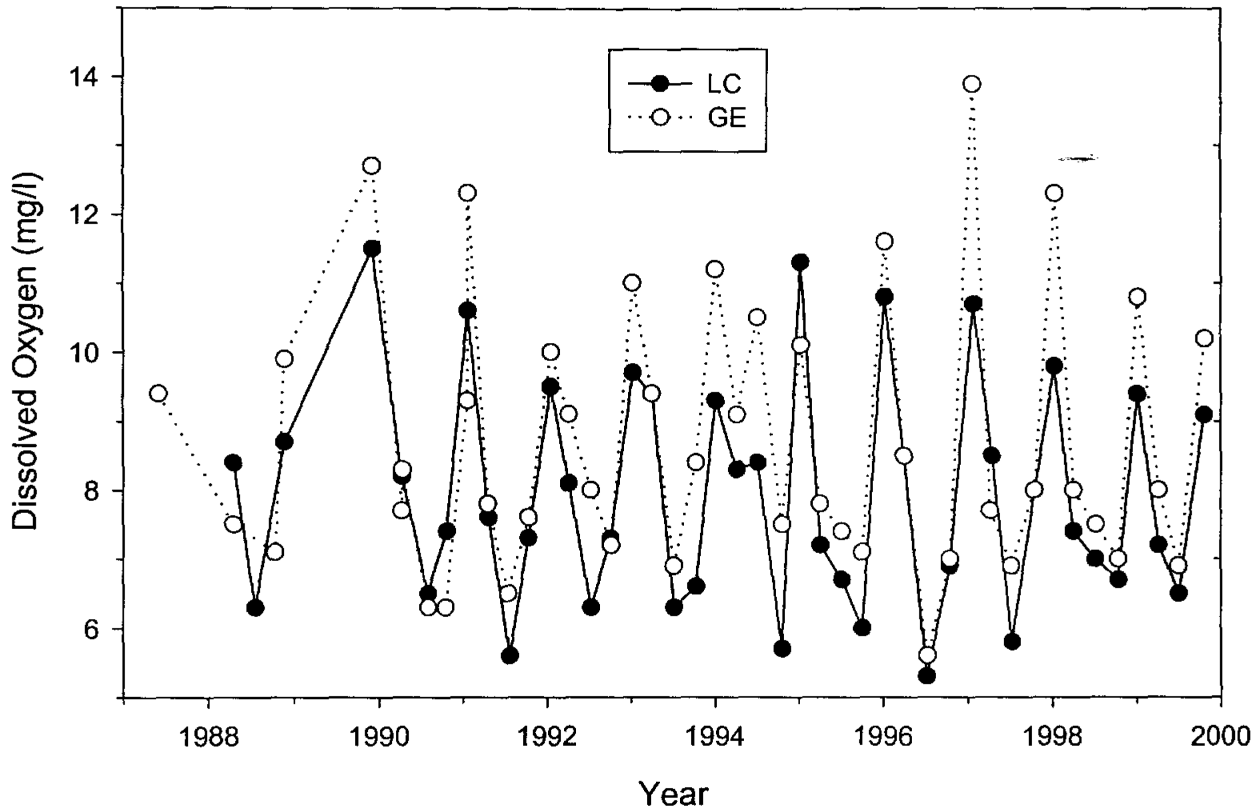

Figure 9. Long-term DO change in the Lavaca-Colorado and Guadalupe Estuaries. Estuarine-wide average for stations A - D.

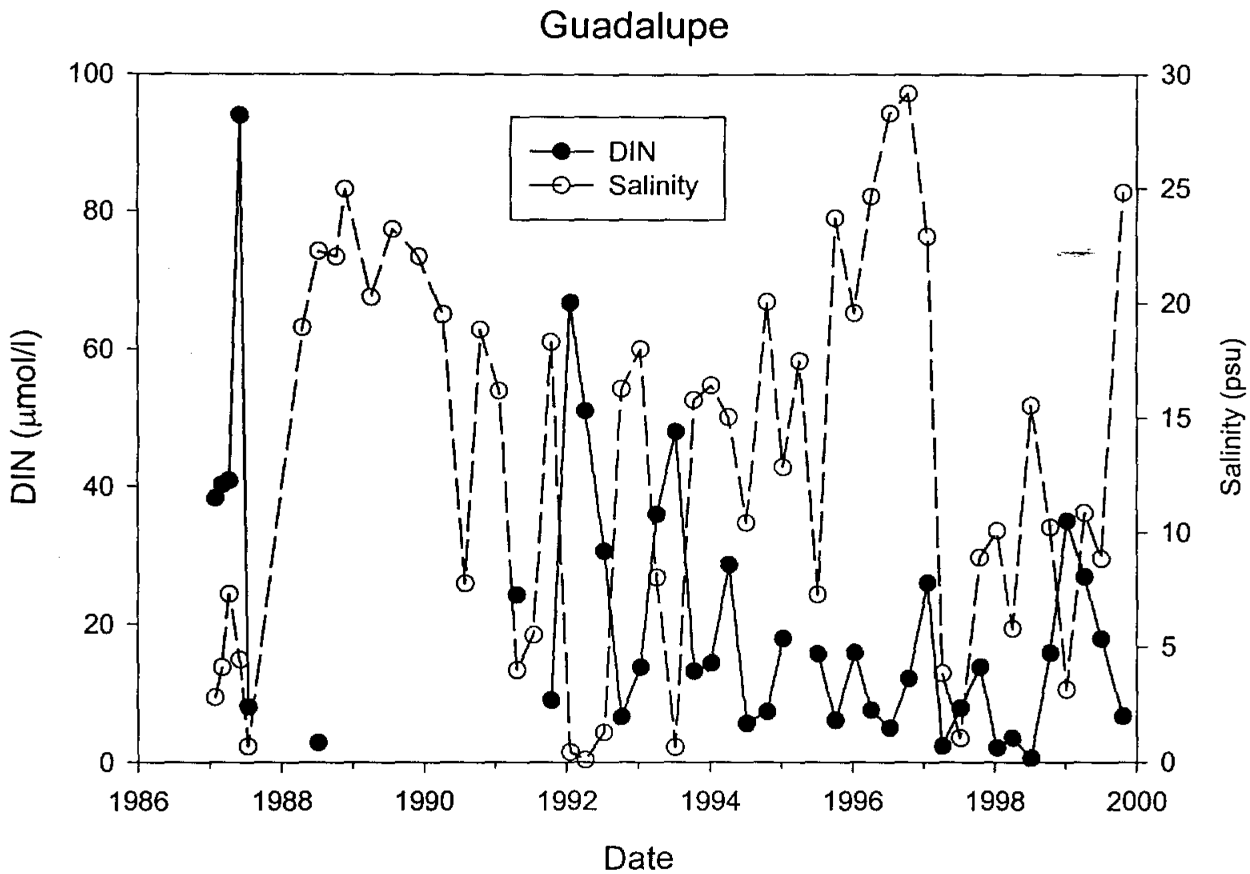

Figure 10. Long-term DIN and salinity change in the Guadalupe Estuary. Estuarine-wide average for stations A - D.

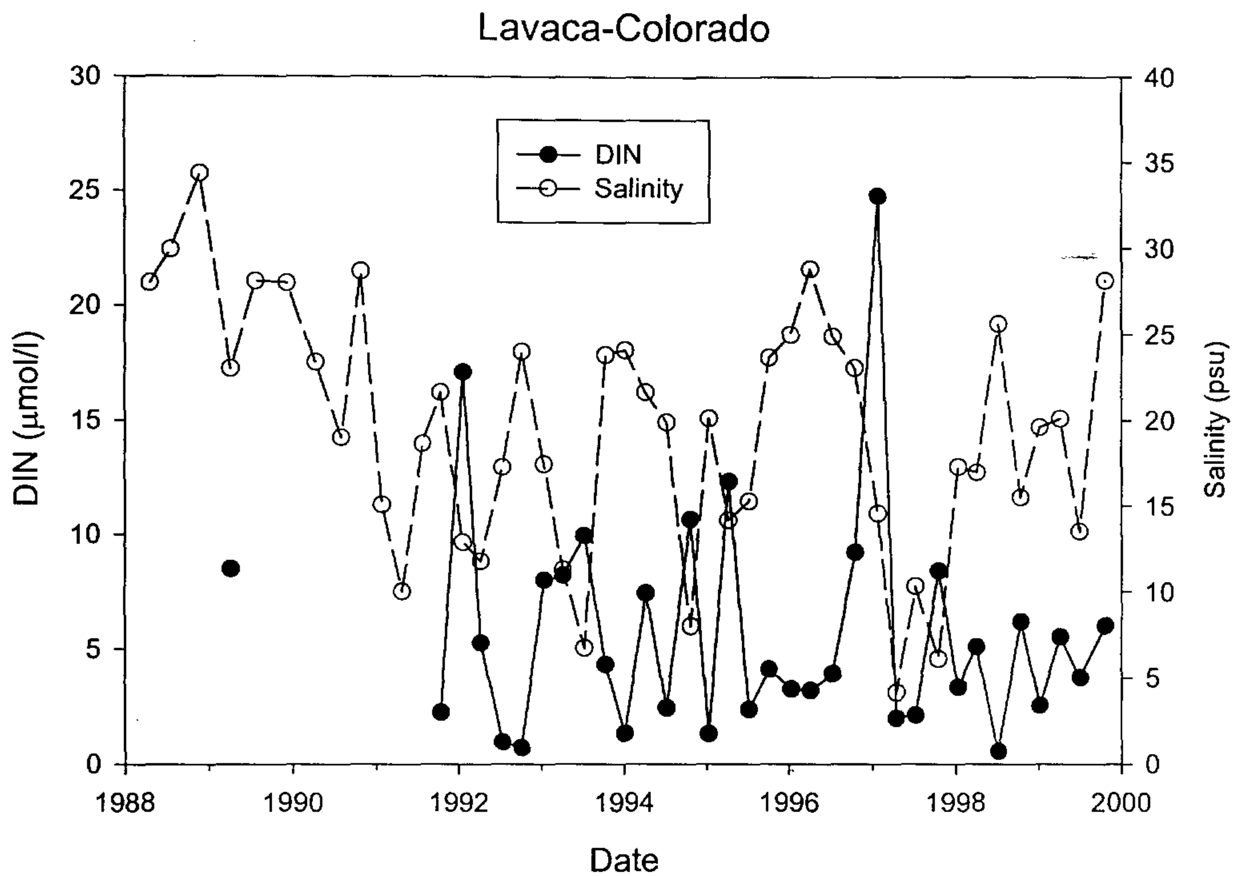

Figure 11. Long-term DIN and salinity change in the Lavaca-Colorado Estuary. Estuarine-wide average for stations A - D.

Macrofaunal Abundance and Biomass

One of the most fundamental measurements made on benthos is the total number(n) of individuals and total biomass found during each sampling period at each station. The range of values found was large. Abundance and biomass are sometimes correlated, but not always. This is especially true during recruitment events because a large number of small, new recruits can have a small biomass. In contrast, a low number of large individuals can have a high biomass. This is apparent in the GE estuary (Figs. 12 and 13). The highest abundance occurred in 1988 (Fig. 12), yet the highest biomass occurred in 1994 - 1995 (Fig. 13) when abundances were relatively low. Another curious feature is the dampening of abundance ranges and the decrease in abundance in GE estuary over the entire study period. Neither trend is apparent in the LC estuary. When abundances are high (Fig. 14), biomasses are high (Fig. 15). There is also no long-term trend for either abundance or biomass at the stations. In the GE estuary, there is a trend for higher abundances and biomasses at stations A and B relative to stations C and D. Again the opposite appears to be true in LC estuary, because stations C and D in Matagorda Bay often have the highest abundance and biomass.

The overall average abundance and biomass in the GE estuary changes with changing salinity regimes over long time scales (Fig. 16). This is best illustrated by examining the two dry periods: 1998 - 1990 and late 1995 - 1997. During both periods biomass abundance and biomass declined. In contrast, before both periods, and following both periods, biomass and abundance was higher or increasing. The same trend exists for the LC estuary (Fig. 17).

Even though there appears to be a linear relationship between salinity and biomass and salinity and abundance over time (Figs. 18 and 19), statistical significance is generally lacking (Table 5). Exponential, logarithmic, and linear models were examined, none gave a good fit. Models with lag salinity, or salinity change during the period did not yield good fits either. Only diversity had a significantly linear relationship with salinity.

Over the long-term, abundance patterns were very similar between the two estuaries (Fig. 20). The GE estuary was always slightly more dense, but the changes tracked one another. The biomass patterns were nearly as synchronous, and GE didn't always have the highest abundance.

Table 5. Linear regression relationships for curves in Figures 18 and 19. Benthic characteristics as a function of salinity (Sal). Data are averages over all stations for each sampling period (Figs. 16 and 17) where $n = 50$ for GE and 45 for LC. Abbreviations: P_{b0} = probability level for intercept = 0, P_{b1} = probability level for slope = 0, r^2 = coefficient of determination.

Estuary	Biomass (B)	Abundance (A)	Diversity (D)
GE	B = 2.29 + 0.257(Sal), P_{b0} = 0.0634, P_{b1} = 0.0011 r^2 = 0.200	A = 14777 + 315(Sal), P_{b0} = 0.0005, P_{b1} = 0.2024 r^2 = 0.034	D = 6.64 + 0.288(Sal), P_{b0} = 0.0001, P_{b1} = 0.0001 r^2 = 0.386
LC	B= 1.90 + 0.128(Sal), P_{b0} = 0.3067, P_{b1} = 0.1397 r^2 = 0.050	A = 5047 + 300(Sal), P_{b0} = 0.1294, P_{b1} = 0.0540 r^2 =0.084	D = 9.52 + 0.297(Sal), P_{b0} = 0.0006, P_{b1} = 0.0162 r^2 = 0.128

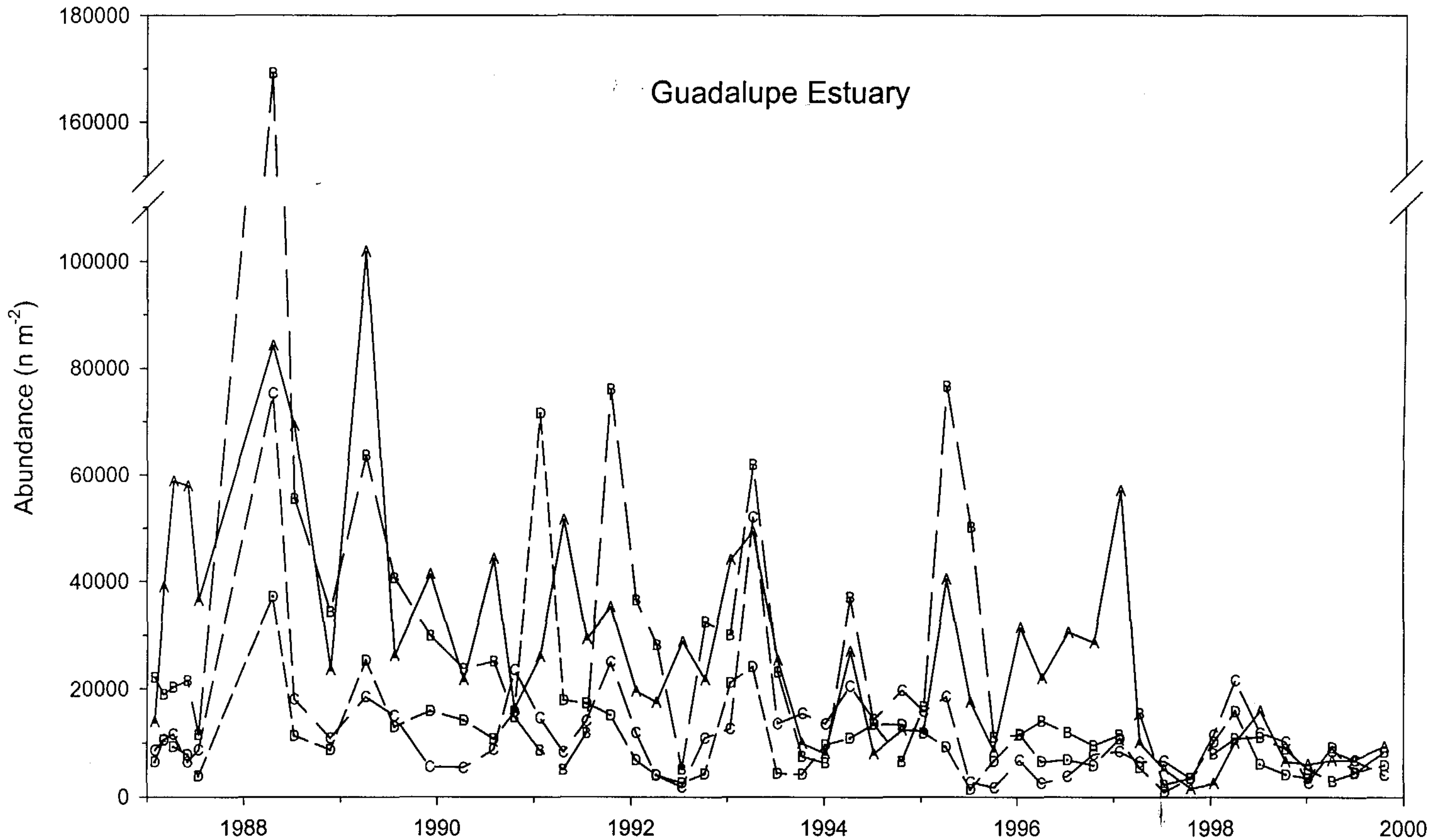

Figure 12. Abundance over time at stations in the Guadalupe Estuary.

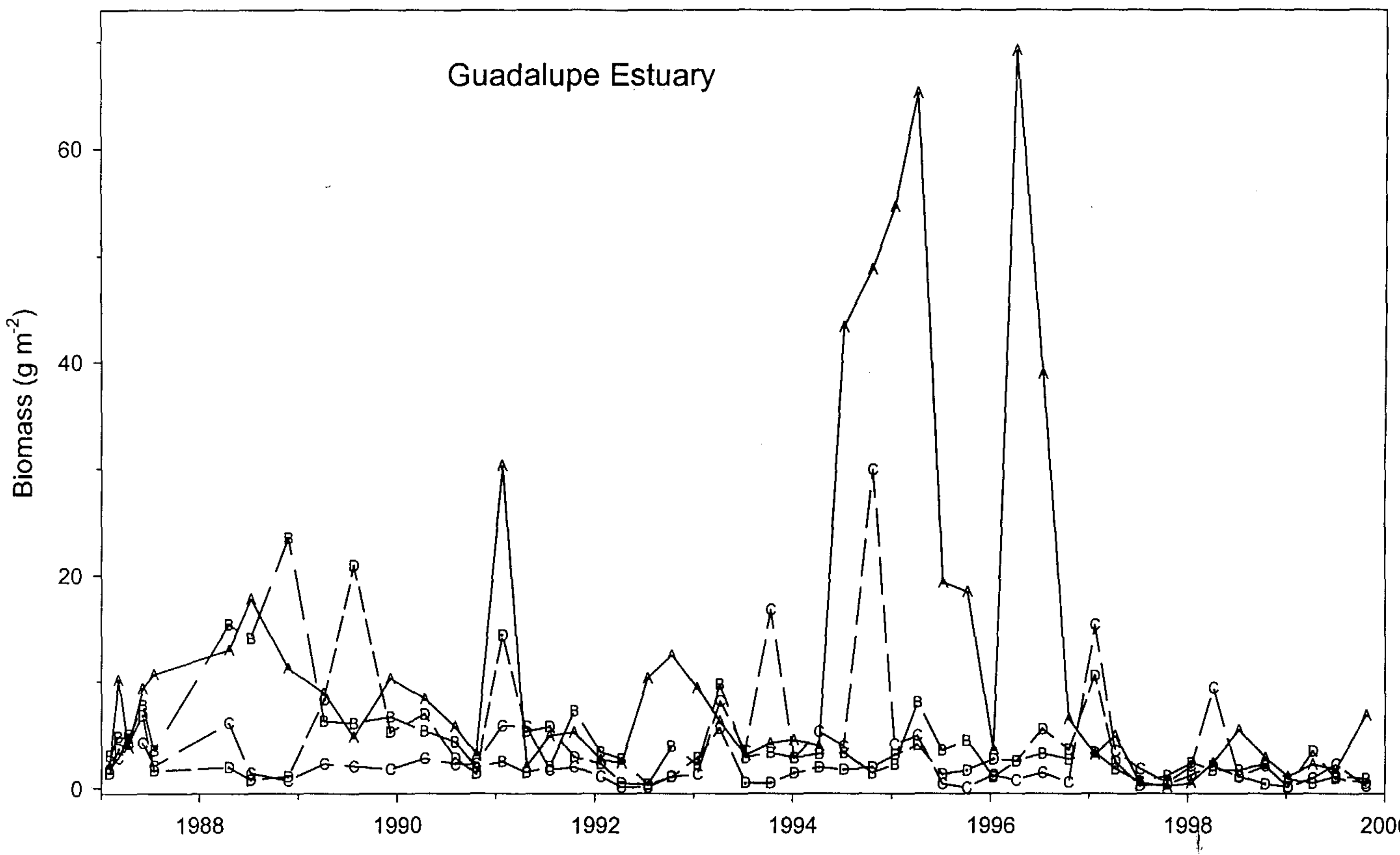

Figure 13. Biomass over time at stations in the Guadalupe Estuary.

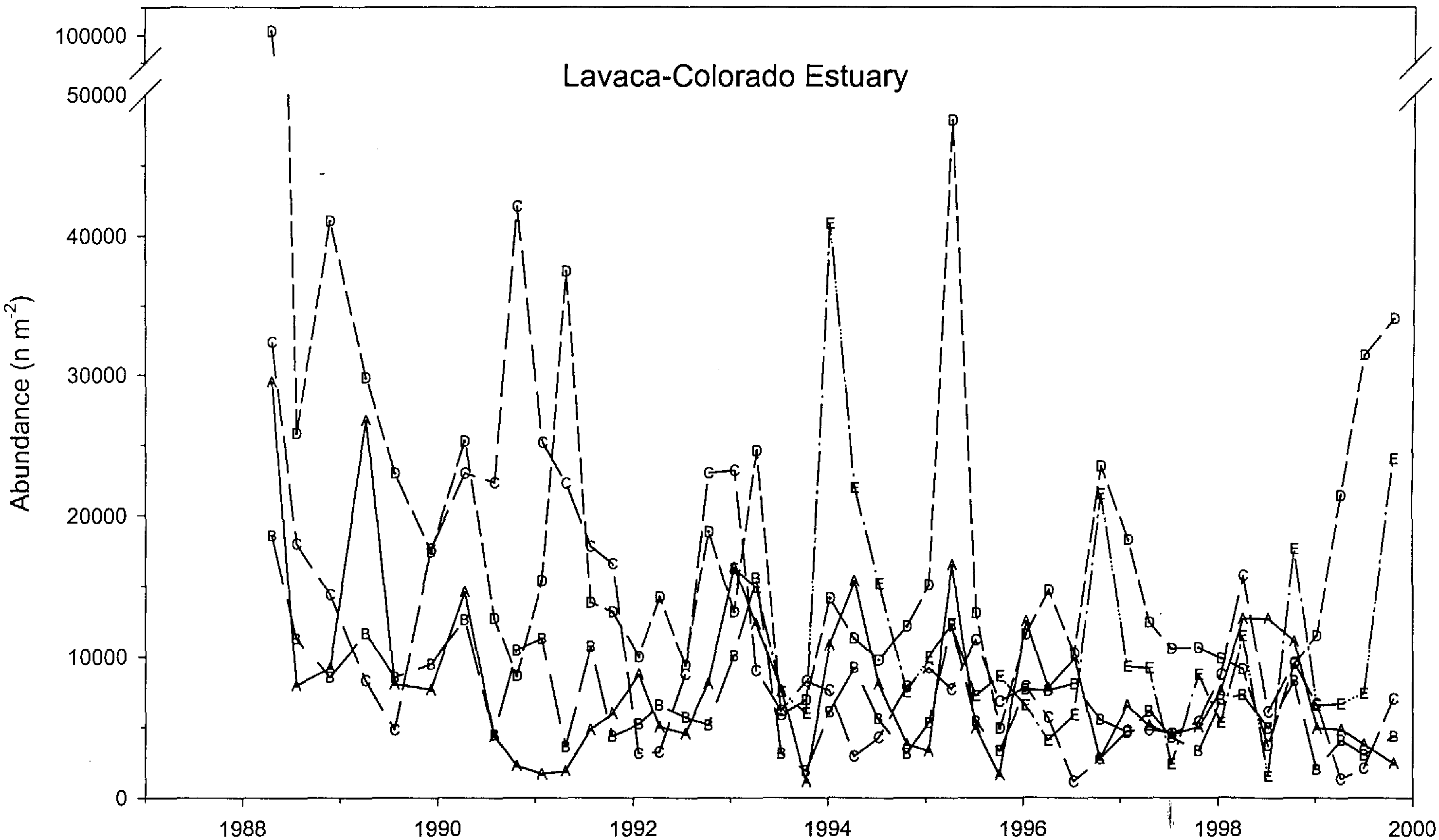

Figure 14. Abundance over time at stations in the Lavaca-Colorado Estuary.

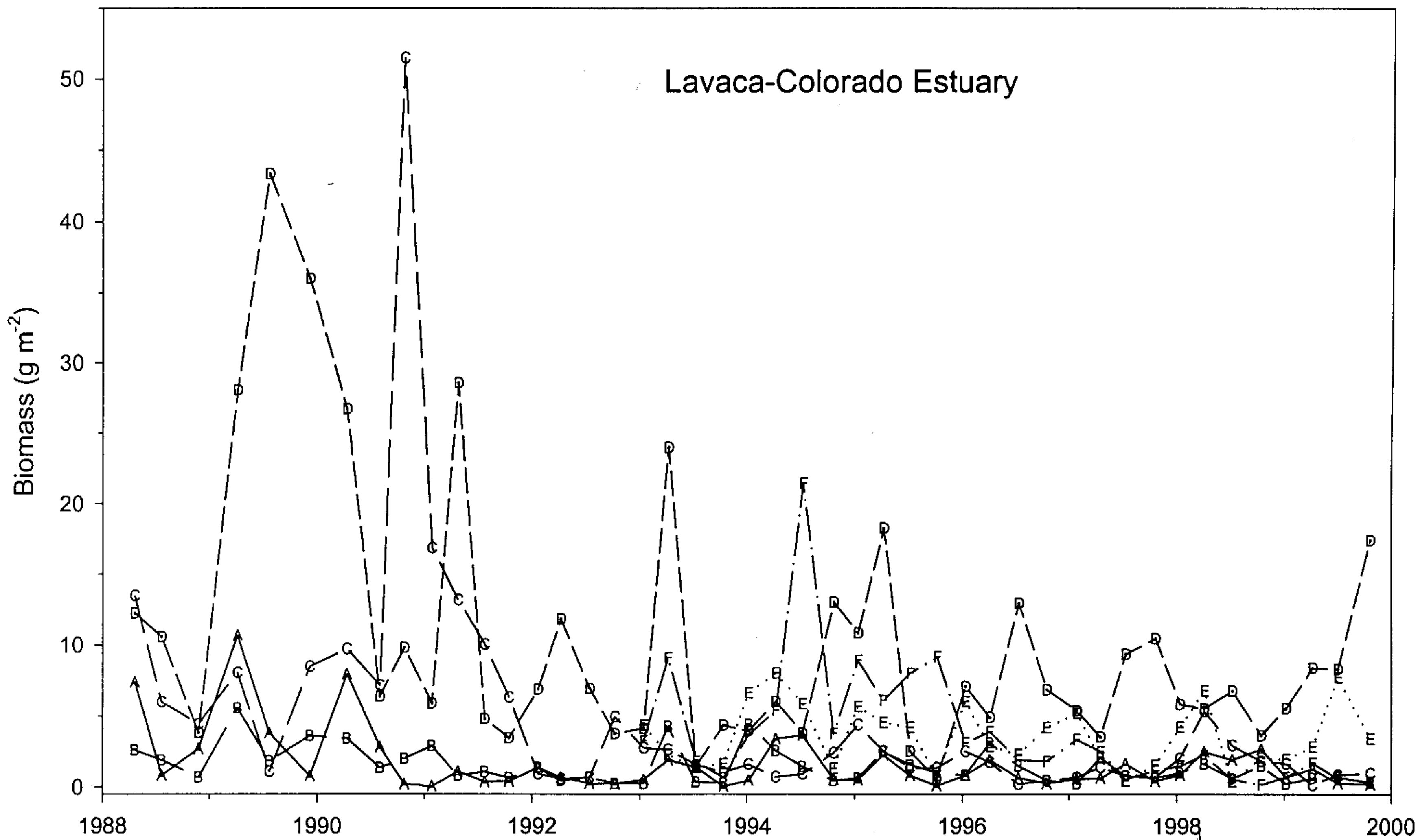

Figure 15. Biomass over time at stations in the Lavaca-Colorado Estuary.

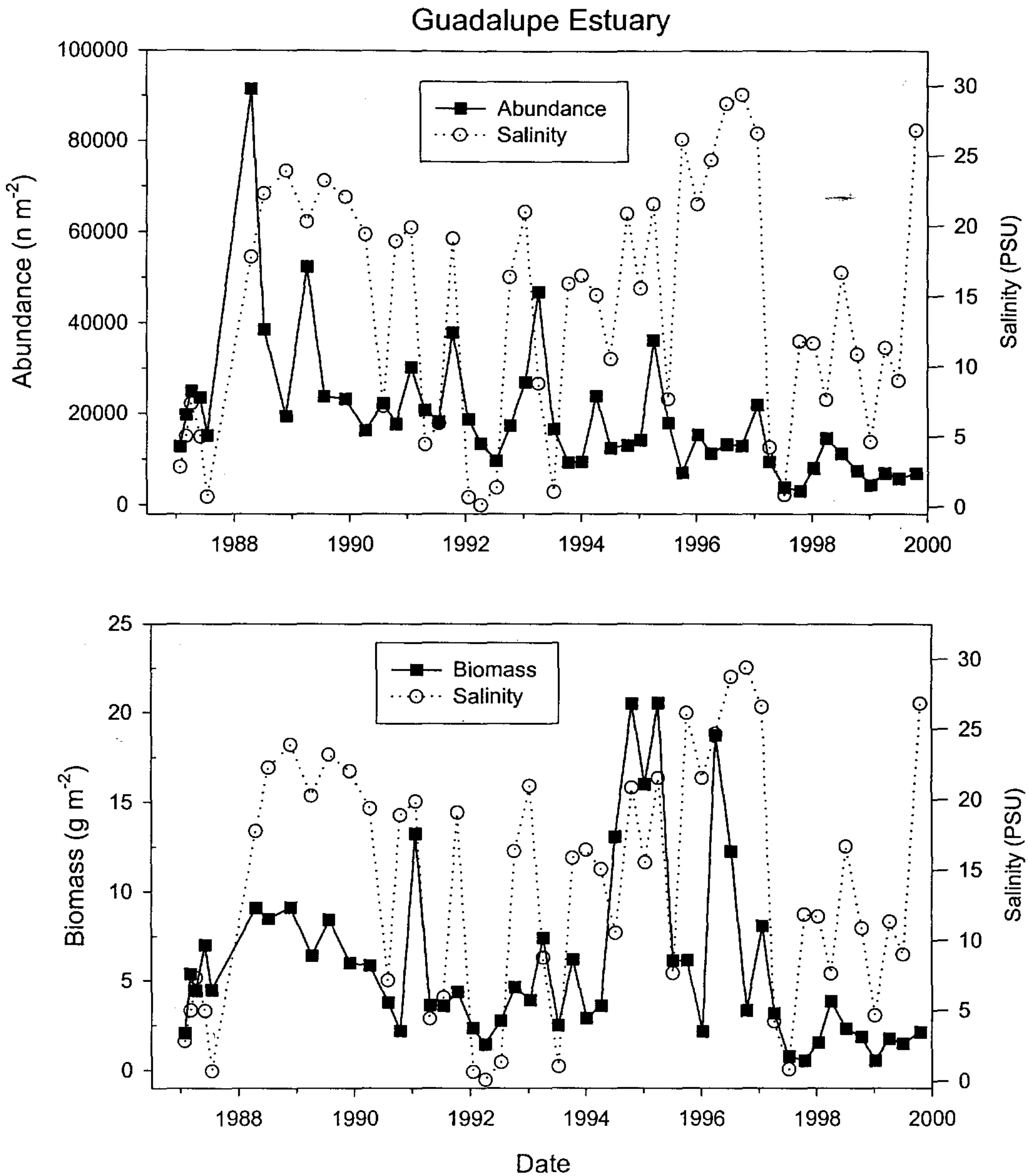

Figure 16. Long-term trend in abundance, biomass and salinity in the Guadalupe Estuary.

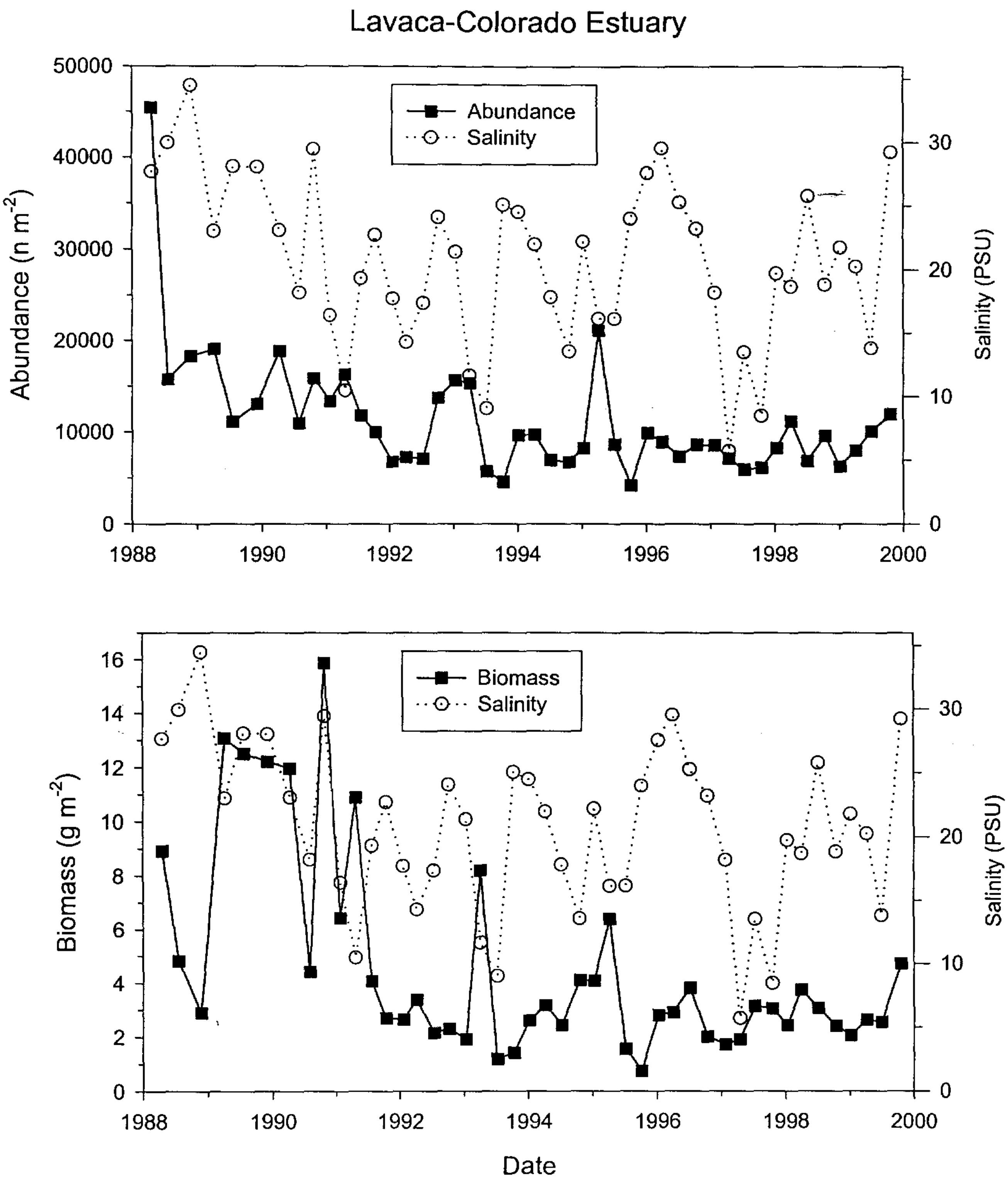

Figure 17. Long-term trend in abundance, biomass and salinity in the Lavaca-Colorado Estuary.

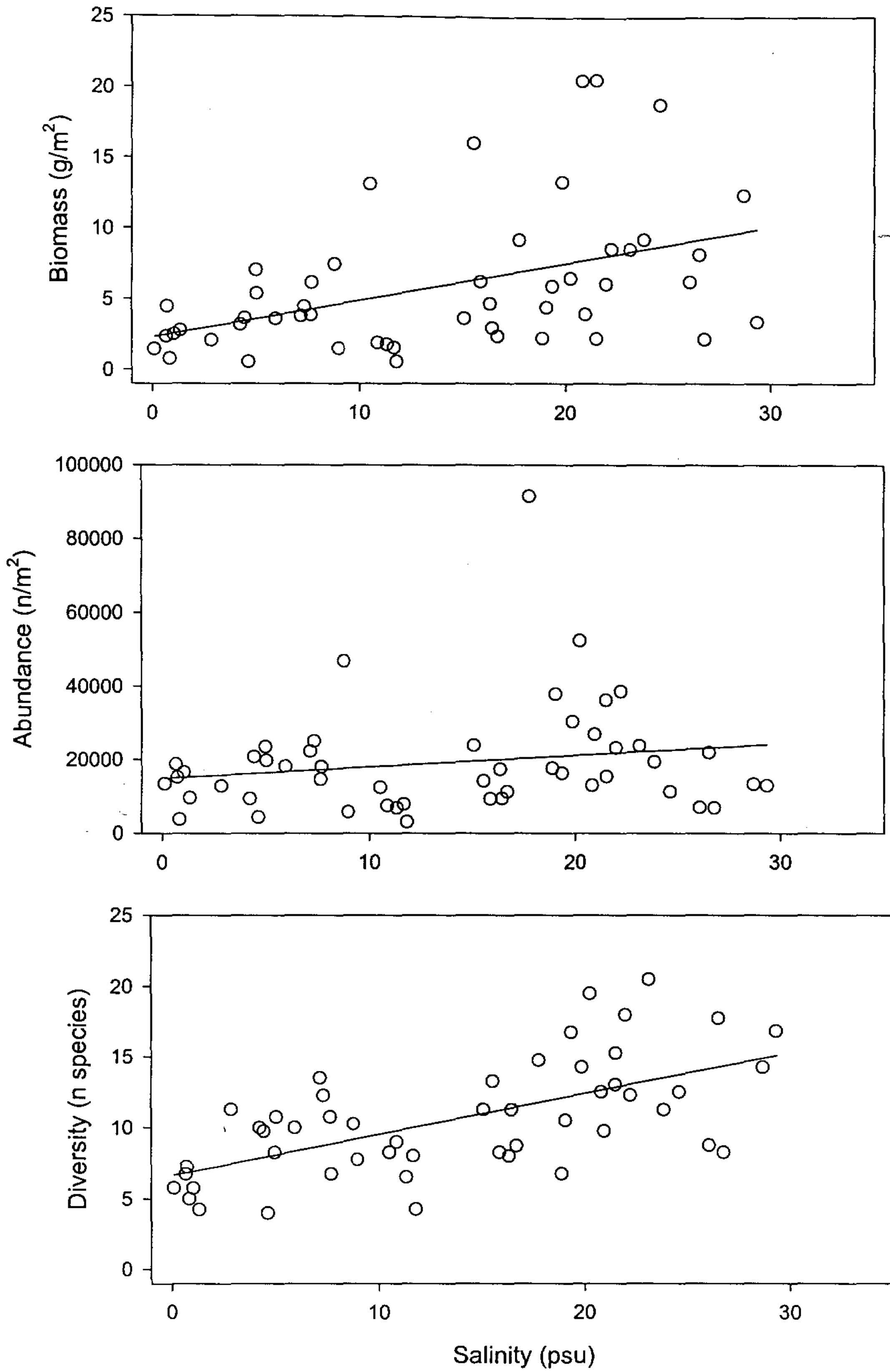

Figure 18. Salinity and organismal relationships in the Guadalupe Estuary (data from Fig. 16).

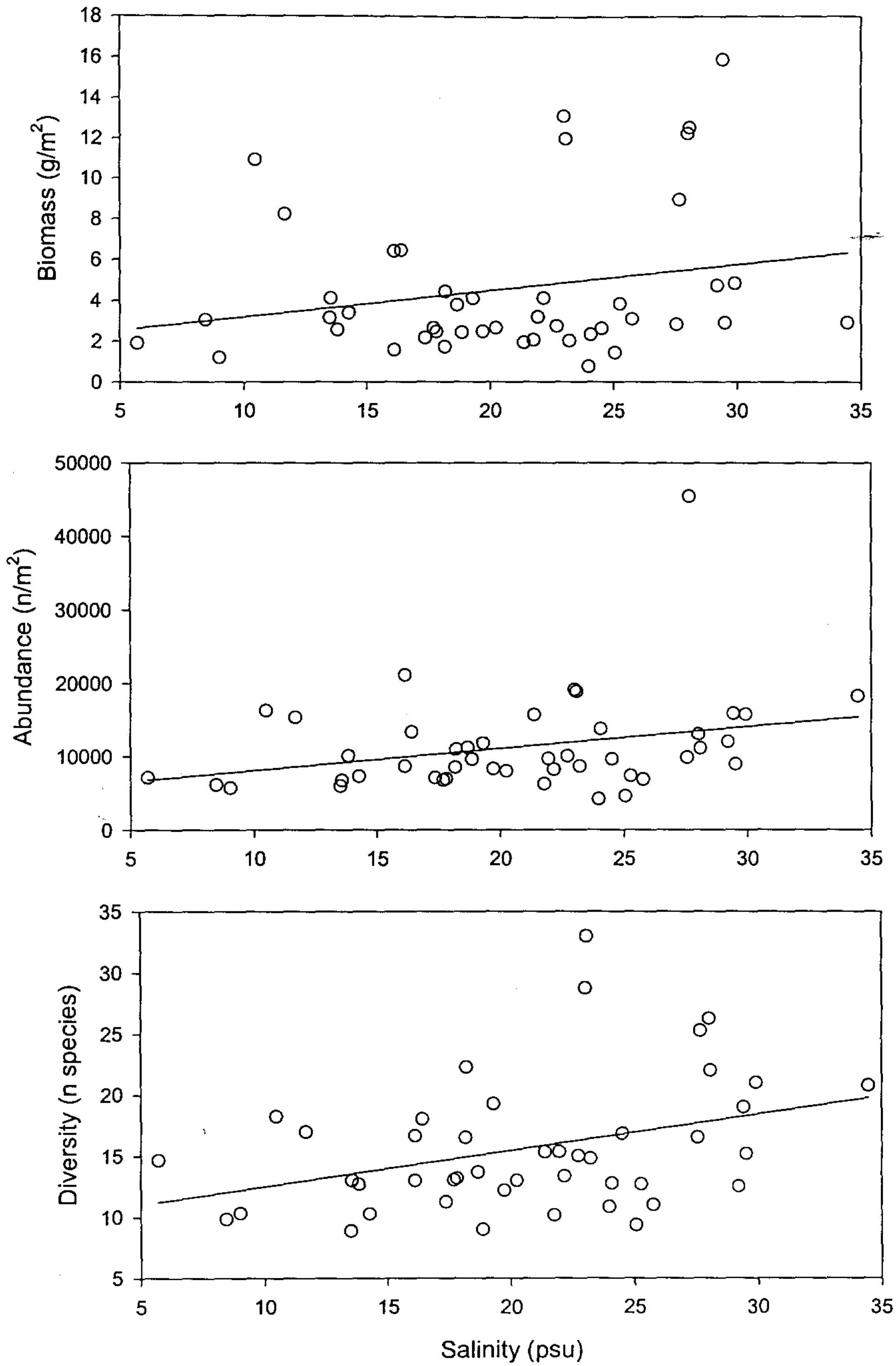

Figure 19. Salinity and organismal relationships in Lavaca-Colorado Estuary (data from Fig. 17).

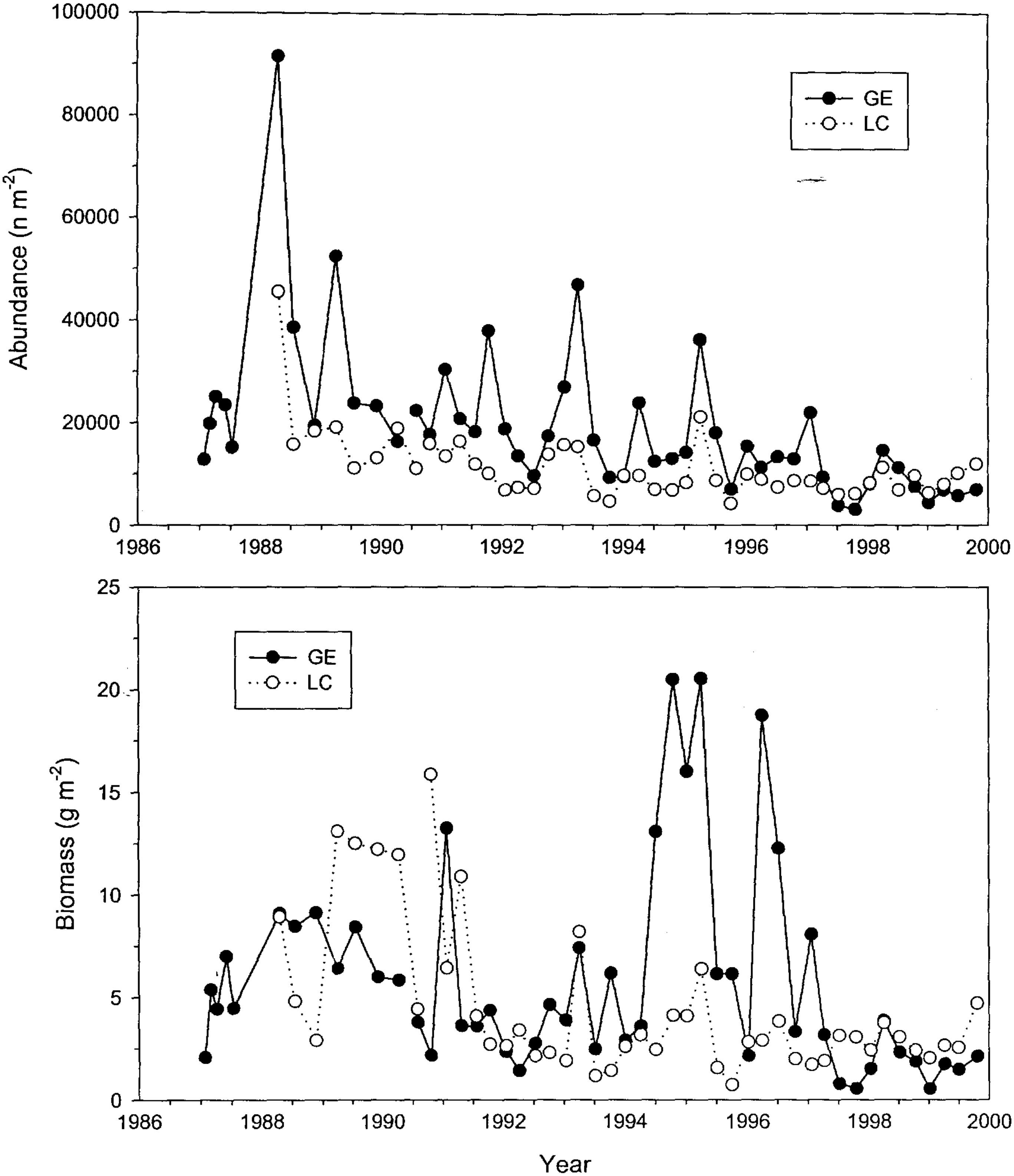

Figure 20. Comparison of estuarine-wide abundance and biomass over the long term.

Macrofaunal Community Structure

A total of 169 species were found in the GE estuary over the study period (Table 6). Many species were found primarily in one station or the other. The overwhelming majority of species were rare, occurring very infrequently (Table 7). There were two dominant species, the polychaetes *Mediomastus ambiseta* and *Streblospio benedicti*, that accounted for 59% of all organisms found. Seven species contributed to at least 1% of the fauna.

A total of 229 species were found in the LC estuary over the study period (Table 8). Many species were found primarily in one station or the other. The overwhelming majority of species were rare, occurring very infrequently (Table 9). There was one dominant species, the polychaete *Mediomastus ambiseta* that accounted for 40% of all organisms. *Streblospio benedicti* was the third dominant species. Twelve species contributed to at least 1% of the fauna.

Community structure was analyzed for the dominant species only using principal components analysis (PCA). The dominant species were defined as those contributing at least 0.75% of the community. This included the top 12 species in GE (Table 7) and top 13 species in LC (Table 9).

In GE, the polychaetes of the dominant community (S81, *Streblospio benedicti*, and S562, *Mediomastus ambiseta*) loaded highly on PC axis 2 (PC2) (Fig. 21). The third most dominant species (S504, the gastropod, *Littoridina sphictostoma*) loaded highly on PC1, indicating it dominated when the other two species were low. There was some overlap between stations, but generally, station A had high PC1 scores indicating the station was dominated by the gastropod (Fig. 22A). Stations A and B had similar community structure and this was different from stations C and D. Stations A and B were composed primarily of the dominant community with high scores for both PC1 and PC2. The community changed with time (Fig. 22A), but there were no seasonal trends (Fig. 22B). It appears the gastropod was most abundant during wet periods, which generally had high PC2 scores (Fig. 22B). The dominant polychaetes appeared to dominate in dry periods (Fig. 22B).

In LC, the dominant species (S562, *Mediomastus ambiseta*), had very low loadings (Fig. 23). The second dominant species (S72, the polychaete *Polydora caullyeri*) loaded highly on PC axis 2 (PC2) (Fig. 23). Most other species, including the third most dominant species (S81, *Streblospio benedicti*) loaded highly on PC1, indicating it dominated when the second dominant species was low in abundance. Stations D, C, and E in Matagorda Bay were very similar, loading high on both PC1 and PC2 (Fig. 24A). The community changed with time (Fig. 24A), but there was no apparent patterns relating to seasons or wet and dry periods (Fig. 24B).

Table 6. Guadalupe Estuary macrofauna species list. Average abundance (n m^2) at each station over all samples.

Taxa	A	B	C	D
Cnidaria				
Anthozoa				
Anthozoa (unidentified)	6	2	15	4
Platyhelminthes				
Turbellaria				
Turbellaria (unidentified)	15	2	55	15
Rynchocoela				
Rhynchocoela (unidentified)	210	272	269	210
Phoronida				
Phoronis architecta	0	0	83	36
Mollusca				
Gastropoda Cuvier,1797				
Gastropoda (unidentified)	250	0	0	6
Acteocinidae				
Acteocina canaliculata	6	17	9	61
Calyptraeidae Blainville,1824				
Crepidula sp	0	0	0	0
Crepidula fornicata	0	0	2	0
Crepidula plana	0	0	151	0
Ctenobranchia Schweigger, 1820				
Hydrobiidae				
Assimineidae				
Littoridina sphinctostoma	9244	2171	853	214
Vitrinellidae				
Vitrinellidae (unidentified)	0	0	0	9
Caecidae Gray, 1850				
Caecum pulchellum	0	2	0	2
Caecum johnsoni	0	0	4	36
Nassariidae				
Nassarius acutus	0	0	8	8
Columbellidae				
Mitrella lunata	0	0	2	2
Dendronotoidea Odhner,1936				
Nudibranchia (unidentified)	2	4	2	2
Pleurobranchia Von Ihering,1922				
Acteonidae				
Rictaxis punctostriatus	0	4	2	2
Atyidae				
Haminoea antillarum	0	83	0	0
Entomotaeniata Cossman,1896				
Pyramidellidae				
Odostomia sp.	6	0	2	0

Pyrgiscus sp.	0	0	4	19
Pyramidella crenulata	4	2	9	6
Eulimostoma sp.	2	4	4	4
Pyramidella sp.	11	2	0	8
Boonea impressa	0	0	13	0
Pelecypoda				
Pelecypoda (unidentified)	2	2	4	17
Nuculoidea Dall, 1889				
Nuculanidae				
Nuculana acuta	0	0	0	19
Nuculana concentrica	0	0	0	2
Mytiloidea Férussac, 1822				
Mytilidae				
Brachidontes exustus	0	38	0	0
Ischadium recurvum	8	0	0	0
Pterioidea Newell, 1965				
Ostreidae				
Crassostrea virginica	0	0	8	0
Hippuritoidea Newell, 1965				
Kelliidae Forbes & Hanley,1848				
Aligena texasiana	0	0	2	32
Leptonidae				
Mysella planulata	2	0	0	64
Mactridae				
Mulinia lateralis	2855	2700	1231	679
Rangia cuneata	337	15	9	2
Cultellidae				
Ensis minor	0	2	6	25
Tellinidae				
Macoma tenta	0	0	0	2
Tellina sp.	0	2	0	2
Macoma mitchelli	79	164	108	129
Solecurtidae				
Tagelus plebeius	0	0	8	9
Veneridae				
Mercenaria campechiensis	0	0	2	2
Pholadomyoidea Newell, 1965				
Pandoridae				
Pandora trilineata	0	0	0	11
Lyonsiidae				
Lyonsia hyalina floridana	0	0	2	0
Periplomatidae				
Periploma cf. orbiculare	0	0	0	19
Periploma margaritaceum	0	0	2	4
Scaphopoda				
Dentaliidae				

Dentalium texasianum	0	0	0	0
Annelida				
Polychaeta				
Polychaete juv. (unidentified)	0	2	2	0
Polynoidae				
Malmgreniella taylori	0	0	0	0
Sigalionidae				
Sigalionidae (unidentified)	0	0	0	2
Palmyridae (= Chrysopetalidae)				
Paleanotus heteroseta	0	0	0	4
Phyllodocidae				
Eteone heteropoda	4	36	9	17
Paranaitis speciosa	0	0	0	2
Anaitides erythrophyllus	0	0	4	0
Pilargiidae				
Parandalia ocularis	134	21	36	166
Hesionidae				
Gyptis vittata	4	15	28	32
Podarke obscura	0	0	2	0
Hesionidae (unidentified)	0	0	0	2
Syllidae				
Sphaerosyllis cf. sublaevis	0	0	0	2
Exogone sp.	0	0	0	4
Sphaerosyllis sp. A	0	0	0	0
Nereidae				
Neanthes succinea	4	11	9	34
Ceratonereis irritabilis	0	0	0	2
Nereidae (unidentified)	0	0	6	9
Nephtyidae				
Nephtys magellanica	0	0	0	0
Glyceridae				
Glycera americana	0	0	2	15
Glycera capitata	0	0	0	2
Goniadidae				
Glycinde solitaria	8	30	127	138
Glycinde nordmanni	0	8	2	6
Eunicidae				
Lysidice ninetta	0	0	176	0
Onuphidae				
Diopatra cuprea	2	6	25	38
Lumbrineridae				
Lumbrineris parvapedata	0	0	0	2
Arabellidae				
Drilonereis magna	0	0	2	0
Dorvilleidae				
Schistomeringos rudolphi	0	0	0	6

Spionidae				
Polydora ligni	89	0	0	13
Minuspio cirrifera	0	0	0	4
Paraprionospio pinnata	0	11	55	64
Scolelepis texana	4	4	25	23
Polydora websteri	34	2	2	9
Polydora socialis	2	2	19	8
Streblospio benedicti	6017	9804	1530	1240
Polydora caulleryi	0	0	38	480
Polydora sp.	15	0	0	4
Scolelepis squamata	2	0	15	6
Spionidae (unidentified)	0	2	0	0
Magelonidae				
Magelona phyllisae	0	0	0	2
Chaetopteridae				
Spiochaetopterus costarum	0	2	72	1004
Cirratulidae				
Tharyx setigera	0	0	0	34
Cossuridae				
Cossura delta	0	0	42	85
Orbiniidae				
Haploscoloplos foliosus	45	142	134	85
Haploscoloplos fragilis	0	21	34	25
Scoloplos texana	0	0	0	4
Paraonidae				
Paraonidae Grp. B	0	2	0	0
Opheliidae				
Armandia maculata	0	0	0	2
Capitellidae				
Capitella capitata	227	163	49	28
Notomastus latericeus	0	0	0	4
Heteromastus filiformis	9	0	0	0
Mediomastus ambiseta	5869	8159	6887	5391
Capitellidae (unidentified)	0	0	0	6
Maldanidae				
Branchioasychis americana	0	0	0	2
Clymenella torquata	0	2	4	47
Asychis elongata	2	0	2	0
Asychis sp.	0	0	4	23
Euclymene sp. B	0	0	0	0
Axiothella mucosa	0	0	11	42
Maldanidae (unidentified)	0	0	17	76
Pectinariidae				
Pectinaria gouldii	0	6	19	6
Ampharetidae				
Isolda pulchella	0	0	0	2

Melinna maculata	4	23	28	13
Hobsonia florida	437	40	0	26
Terebellidae				
Pista palmata	0	2	38	6
Terebellidae (unidentified)	0	0	0	2
Sabellidae				
Megalomma bioculatum	0	8	6	8
Sabellidae (unidentified)	0	4	0	0
Serpulidae				
Eupomatus dianthus	0	0	2	2
Serpulidae (unidentified)	0	0	0	6
Oligochaeta				
Oligochaetes (unidentified)	168	365	9	2
Sipuncula				
Phascolion strombi	0	0	0	0
Crustacea				
Ostracoda				
Myodocopa				
Sarsiella texana	0	0	2	4
Copepoda				
Harpacticoida				
Tachidiidae				
Thompsonula sp.	9	2	2	6
Cyclopoida				
Cyclopidae				
Hemicyclops sp.	15	0	2	78
Lichomolgidae				
Cyclopoid copepod (commensal)	2	0	4	0
Calanoida				
Diaptomidae				
Pseudodiaptomus coronatus	2	2	9	4
Cirripedia				
Balanus eburneus	9	6	28	0
Malacostraca				
Natantia				
Ogyrididae				
Ogyrides limicola	0	0	0	2
Reptantia				
Callianassidae				
Callianassa sp.	15	4	6	11
Diogenidae				
Clibanarius vittatus	0	0	2	0
Xanthidae				
Neopanope texana	4	0	0	0
Pinnotheridae				
Pinnixa sp.	0	0	0	9

Pinnixa cristata	0	0	0	2
Pinnixa chacei	0	0	0	2
Pinnotheridae (unidentified)	0	0	0	2
Brachyuran Larvae				
Megalops	2	2	0	0
Mysidacea				
Mysidopsis bahia	2	0	2	11
Bowmaniella sp.	2	0	0	0
Mysidopsis sp.	9	2	0	4
Mysidopsis almyra	13	9	2	2
Cumacea				
Cyclaspis varians	70	49	121	130
Oxyurostylis sp.	17	28	23	21
Leucon sp.	0	4	19	0
Diastylis sp.	0	0	2	2
Oxyurostylis salinoi	0	6	6	6
Cyclaspis sp.	0	0	0	6
Oxyurostylis smithi	4	9	64	59
Amphipoda				
Ampeliscidae				
Ampelisca abdita	1049	79	4	13
Ampelisca verrilli	0	0	0	0
Gammaridae				
Gammarus mucronatus	6	0	6	0
Oedicerotidae				
Monoculodes sp.	121	72	76	28
Synchelidium americanum	0	0	0	9
Corophiidae				
Erichthonias brasiliensis	0	0	0	17
Corophium ascherusicum	0	4	0	2
Corophium louisianum	2	2	8	0
Microprotopus spp.	4	6	19	4
Grandidierella bonnieroides	0	0	0	0
Bateidae				
Batea catharinensis	0	0	23	13
Liljeborgiidae				
Listriella barnardi	0	0	2	13
Listriella clymenellae	0	0	0	0
Stenothoidae				
Parametopella sp.	0	0	0	2
Caprellidae				
Caprellidae sp.	4	0	34	8
Melitidae				
Elasmopus sp.	0	0	2	0
Melita nitida	2	0	6	2
Isopoda				

Anthuridae				
Xenanthura brevitelson	0	0	0	2
Idoteidae				
Edotea montosa	19	4	4	0
Sphaeromatidae				
Cassidinidea lunifrons	0	2	0	0
Tanaidacea				
Tanaidae				
Leptochelia rapax	0	0	0	2
Insecta				
Insect larvae (unidentified)	2	0	0	0
Pterygota				
Diptera				
Chironomidae				
Chironomid pupae	2	0	0	0
Chironomid larvae	129	21	4	2
Echinodermata				
Ophiuroidea				
Ophiuroidea (unidentified)	0	0	9	8
Chordata				
Urochordata				
Ascidiaceae				
Molgula manhattensis	0	0	0	4
Hemichordata				
Schizocardium sp.	0	0	0	2

Table 7. Guadalupe Estuary macrofauna dominance list. Average abundance (n m^2) and percent composition over all samples.

Rank	Taxa name	SP Code	Mean	%Mean
1	*Mediomastus ambiseta*	562	6,576	34.36
2	*Streblospio benedicti*	81	4,648	24.28
3	*Littoridina sphinctostoma*	504	3,120	16.30
4	*Mulinia lateralis*	162	1,866	9.75
5	*Ampelisca abdita*	197	286	1.50
6	*Spiochaetopterus costarum*	91	269	1.41
7	Rhynchocoela (unidentified)	7	240	1.25
8	Oligochaetes (unidentified)	8	136	0.71
9	*Polydora caulleryi*	72	130	0.68
10	*Hobsonia florida*	492	126	0.66
11	*Macoma mitchelli*	488	120	0.63
12	*Capitella capitata*	111	117	0.61
13	*Haploscoloplos foliosus*	95	102	0.53
14	*Cyclaspis varians*	192	93	0.48
15	*Rangia cuneata*	498	91	0.47
16	*Parandalia ocularis*	508	89	0.47
17	*Glycinde solitaria*	55	76	0.40
18	*Monoculodes sp.*	205	74	0.39
19	Gastropoda (unidentified)	377	64	0.33
20	*Lysidice ninetta*	56	44	0.23
21	*Chironomid larvae*	487	39	0.20
22	*Crepidula plana*	145	38	0.20
23	*Oxyurostylis smithi*	500	34	0.18
24	*Paraprionospio pinnata*	82	33	0.17
25	*Cossura delta*	110	32	0.17
26	*Phoronis architecta*	245	30	0.16
27	*Polydora ligni*	71	26	0.13
28	*Hemicyclops sp.*	460	24	0.12
29	*Maldanidae (unidentified)*	122	23	0.12
30	*Acteocina canaliculata*	256	23	0.12
31	*Oxyurostylis sp.*	553	22	0.12
32	*Turbellaria (unidentified)*	499	22	0.11
33	*Haminoea antillarum*	561	21	0.11
34	*Haploscoloplos fragilis*	96	20	0.10
35	*Gyptis vittata*	32	20	0.10
36	*Diopatra cuprea*	58	17	0.09
37	*Melinna maculata*	125	17	0.09
38	*Mysella planulata*	159	17	0.09
39	*Eteone heteropoda*	22	17	0.09
40	*Neanthes succinea*	44	15	0.08
41	*Scolelepis texana*	83	14	0.07
42	*Clymenella torquata*	119	13	0.07

43	*Axiothella mucosa*	118	13	0.07
44	*Polydora websteri*	69	12	0.06
45	Caprellidae sp.	200	11	0.06
46	*Pista palmata*	128	11	0.06
47	*Balanus eburneus*	187	11	0.06
48	*Caecum johnsoni*	533	10	0.05
49	*Brachidontes exustus*	403	9	0.05
50	*Batea catharinensis*	199	9	0.05
51	*Callianassa sp.*	501	9	0.05
52	*Tharyx setigera*	92	9	0.04
53	*Aligena texasiana*	161	9	0.04
54	*Microprotopus spp.*	365	8	0.04
55	*Ensis minor*	163	8	0.04
56	*Pectinaria gouldii*	124	8	0.04
57	*Polydora socialis*	70	8	0.04
58	*Asychis sp.*	121	7	0.03
59	Anthozoa (unidentified)	2	7	0.03
60	*Edotea montosa*	196	7	0.03
61	*Mysidopsis almyra*	493	7	0.03
62	Pelecypoda (unidentified)	358	6	0.03
63	*Leucon sp.*	399	6	0.03
64	*Pyrgiscus sp.*	279	6	0.03
65	*Scolelepis squamata*	507	6	0.03
66	*Pyramidella crenulata*	379	5	0.03
67	*Megalomma bioculatum*	131	5	0.03
68	*Pyramidella sp.*	503	5	0.03
69	*Thompsonula sp.*	506	5	0.02
70	*Periploma cf. orbiculare*	510	5	0.02
71	*Nuculana acuta*	155	5	0.02
72	*Polydora sp.*	73	5	0.02
73	*Glycera americana*	54	4	0.02
74	*Pseudodiaptomus coronatus*	183	4	0.02
75	Ophiuroidea (unidentified)	357	4	0.02
76	*Tagelus plebeius*	502	4	0.02
77	*Erichthonias brasiliensis*	297	4	0.02
78	*Oxyurostylis salinoi*	194	4	0.02
79	*Nassarius acutus*	258	4	0.02
80	*Glycinde nordmanni*	580	4	0.02
81	Nereidae (unidentified)	323	4	0.02
82	*Listriella barnardi*	254	4	0.02
83	*Mysidopsis sp.*	428	4	0.02
84	*Mysidopsis bahia*	453	4	0.02
85	*Boonea impressa*	566	3	0.02
86	*Eulimostoma sp.*	402	3	0.02
87	*Pandora trilineata*	311	3	0.01
88	*Corophium louisianum*	201	3	0.01

89	*Gammarus mucronatus*	202	3	0.01
90	Vitrinellidae (unidentified)	412	2	0.01
91	Nudibranchia (unidentified)	408	2	0.01
92	*Pinnixa sp.*	380	2	0.01
93	*Heteromastus filiformis*	114	2	0.01
94	*Melita nitida*	204	2	0.01
95	*Synchelidium americanum*	208	2	0.01
96	*Rictaxis punctostriatus*	557	2	0.01
97	*Ischadium recurvum*	904	2	0.01
98	*Crassostrea virginica*	470	2	0.01
99	*Odostomia sp.*	151	2	0.01
100	*Schistomeringos rudolphi*	68	1	0.01
101	*Sarsiella texana*	362	1	0.01
102	Cyclopoid copepod (commensal)	186	1	0.01
103	*Cyclaspis sp.*	409	1	0.01
104	*Corophium ascherusicum*	390	1	0.01
105	*Periploma margaritaceum*	179	1	0.01
106	Serpulidae (unidentified)	354	1	0.01
107	Capitellidae (unidentified)	343	1	0.01
108	*Caecum pulchellum*	424	1	0.00
109	*Mitrella lunata*	147	1	0.00
110	*Mercenaria campechiensis*	273	1	0.00
111	*Paleanotus heteroseta*	17	1	0.00
112	*Exogone sp.*	547	1	0.00
113	*Minuspio cirrifera*	85	1	0.00
114	*Scoloplos texana*	98	1	0.00
115	*Notomastus latericeus*	116	1	0.00
116	*Asychis elongata*	446	1	0.00
117	Sabellidae (unidentified)	353	1	0.00
118	*Eupomatus dianthus*	554	1	0.00
119	*Neopanope texana*	234	1	0.00
120	*Diastylis sp.*	531	1	0.00
121	*Molgula manhattensis*	419	1	0.00
122	Polychaete juv. (unidentified)	512	1	0.00
123	*Tellina sp.*	168	1	0.00
124	*Anaitides erythrophyllus*	26	1	0.00
125	*Megalops*	469	1	0.00
126	*Nuculana concentrica*	262	0	0.00
127	*Paranaitis speciosa*	24	0	0.00
128	*Sphaerosyllis cf. sublaevis*	322	0	0.00
129	*Ceratonereis irritabilis*	43	0	0.00
130	*Glycera capitata*	327	0	0.00
131	*Lumbrineris parvapedata*	62	0	0.00
132	*Drilonereis magna*	65	0	0.00
133	*Magelona phyllisae*	89	0	0.00
134	Paraonidae Grp. B	341	0	0.00

135	*Armandia maculata*	360	0	0.00
136	*Branchioasychis americana*	117	0	0.00
137	*Ogyrides limicola*	218	0	0.00
138	*Clibanarius vittatus*	224	0	0.00
139	*Pinnixa cristata*	240	0	0.00
140	*Pinnixa chacei*	540	0	0.00
141	*Parametopella sp.*	438	0	0.00
142	*Elasmopus sp.*	309	0	0.00
143	*Leptochelia rapax*	195	0	0.00
144	Insect larvae (unidentified)	574	0	0.00
145	Chironomid pupae	494	0	0.00
146	*Schizocardium sp.*	249	0	0.00
147	*Crepidula fornicata*	144	0	0.00
148	*Macoma tenta*	165	0	0.00
149	*Lyonsia hyalina floridana*	180	0	0.00
150	Sigalionidae (unidentified)	316	0	0.00
151	*Podarke obscura*	34	0	0.00
152	Hesionidae (unidentified)	320	0	0.00
153	Spionidae (unidentified)	335	0	0.00
154	*Isolda pulchella*	126	0	0.00
155	Terebellidae (unidentified)	352	0	0.00
156	Pinnotheridae (unidentified)	356	0	0.00
157	*Bowmaniella sp.*	191	0	0.00
158	*Xenanthura brevitelson*	292	0	0.00
159	*Cassidinidea lunifrons*	505	0	0.00
160	*Crepidula sp*	836	0	0.00
161	*Dentalium texasianum*	154	0	0.00
162	*Malmgreniella taylori*	644	0	0.00
163	*Sphaerosyllis sp. A*	382	0	0.00
164	*Nephtys magellanica*	50	0	0.00
165	*Euclymene sp. B*	579	0	0.00
166	*Phascolion strombi*	244	0	0.00
167	*Ampelisca verrilli*	198	0	0.00
168	*Grandidierella bonnieroides*	396	0	0.00
169	*Listriella clymenellae*	203	0	0.00
	Total		19,125	99.78

Table 8. Lavaca-Colorado Estuary macrofauna species list. Average abundance (n m^2) at each station over all samples.

Taxa	A	B	C	D	E	F
Cnidaria						
Anthozoa						
Anthozoa (unidentified)	4	6	13	134	24	3
Platyhelminthes						
Turbellaria						
Turbellaria (unidentified)	4	13	38	32	51	47
Rynchocoela						
Rhynchocoela (unidentified)	105	97	319	620	203	176
Phoronida						
Phoronis architecta	0	21	6	34	3	17
Mollusca						
Gastropoda Cuvier,1797						
Gastropoda (unidentified)	2	2	4	0	0	3
Acteocinidae						
Acteocina canaliculata	46	46	15	4	91	44
Calyptraeidae Blainville,1824						
Cyclinella tenuis	0	0	0	2	0	0
Crepidula fornicata	0	0	0	6	0	0
Ctenobranchia Schweigger, 1820						
Hydrobiidae						
Assimineidae						
Littoridina sphinctostoma	36	4	0	0	0	0
Caecidae Gray, 1850						
Caecum pulchellum	0	0	0	0	0	3
Caecum johnsoni	0	0	25	11	34	24
Naticidae						
Polinices duplicatus	0	2	2	0	0	0
Nassariidae						
Nassarius acutus	11	11	13	13	7	7
Nassarius vibex	0	2	0	4	0	0
Columbellidae						
Mitrella lunata	0	0	2	0	0	0
Dendronotoidea Odhner,1936						
Nudibranchia (unidentified)	0	0	0	0	3	0
Pleurobranchia Von Ihering,1922						
Acteonidae						
Rictaxis punctostriatus	0	0	2	0	0	10
Atyidae						
Haminoea succinea	0	0	0	0	7	0
Haminoea antillarum	0	25	0	0	0	0
Entomotaeniata Cossman,1896						
Pyramidellidae						

Odostomia sp.	6	4	0	0	0	3
Pyrgiscus sp.	0	6	46	2	0	0
Pyramidella crenulata	6	27	4	0	51	3
Eulimostoma sp.	0	0	32	0	24	20
Pyramidella sp.	6	11	4	0	0	0
Eulimastoma cf. teres	2	0	0	0	0	0
Pelecypoda						
Pelecypoda (unidentified)	11	6	11	248	7	10
Nuculoidea Dall, 1889						
Nuculanidae						
Nuculana acuta	2	0	27	29	152	7
Nuculana concentrica	6	13	27	19	24	0
Arcidae						
Anadara ovalis	0	0	0	2	0	0
Mytiloidea Férussac, 1822						
Mytilidae						
Brachidontes exustus	2	2	0	0	0	3
Pterioidea Newell, 1965						
Ostreidae						
Crassostrea virginica	0	2	0	0	0	0
Hippuritoidea Newell, 1965						
Kelliidae Forbes & Hanley,1848						
Aligena texasiana	0	0	6	6	0	0
Leptonidae						
Mysella planulata	8	6	15	48	14	30
Lepton sp.	0	0	0	128	3	7
Solenidae						
Solen viridis	0	0	0	0	0	3
Mactridae						
Mulinia lateralis	445	311	479	32	1054	189
Rangia cuneata	23	0	0	0	0	0
Cultellidae						
Ensis minor	29	0	0	0	0	0
Tellinidae						
Macoma tenta	0	0	0	8	0	0
Tellina sp.	17	13	2	6	0	3
Tellina texana	0	0	0	2	0	0
Tellidora cristata	0	0	2	0	0	0
Macoma sp.	0	0	0	4	0	0
Macoma mitchelli	162	130	13	11	7	216
Semelidae						
Abra aequalis	0	0	0	53	3	0
Solecurtidae						
Tagelus plebeius	17	0	0	0	0	0
Veneridae						
Mercenaria campechiensis	0	0	0	2	0	0

Myoidea Stoliczka, 1870						
Myidae						
Paramya subovata	0	0	0	162	0	0
Corbulidae						
Corbula contracta	0	0	0	511	3	0
Hiatellidae						
Hiatella arctica	0	0	0	46	3	0
Pholadomyoidea Newell, 1965						
Pandoridae						
Pandora trilineata	0	6	8	2	7	0
Lyonsiidae						
Lyonsia hyalina floridana	0	0	4	0	0	0
Periplomatidae						
Periploma cf. orbiculare	0	0	36	618	24	0
Periploma margaritaceum	0	0	38	237	0	0
Scaphopoda						
Dentaliidae						
Dentalium texasianum	0	0	0	4	0	0
Annelida						
Polychaeta						
Polychaete juv. (unidentified)	0	4	6	17	0	0
Polynoidae						
Eunoe cf. nodulosa	0	0	0	36	0	0
Malmgreniella taylori	0	0	0	29	7	3
Polynoidae (unidentified)	0	0	0	4	0	0
Sigalionidae						
Sthenelais boa	0	0	0	8	3	0
Sigalionidae (unidentified)	0	0	15	17	0	0
Palmyridae (= Chrysopetalidae)						
Paleanotus heteroseta	0	0	38	162	0	0
Amphinomidae						
Paramphinome jeffreysii	0	0	4	0	0	0
Phyllodocidae						
Eteone heteropoda	6	2	2	4	7	0
Paranaitis speciosa	0	0	0	2	10	0
Anaitides erythrophyllus	2	0	8	2	0	0
Phyllodocidae (unidentified)	2	0	0	0	0	0
Pilargiidae						
Sigambra bassi	2	2	34	27	27	10
Sigambra tentaculata	0	0	17	109	84	0
Cabira incerta	0	0	4	0	0	0
Ancistrosyllis jonesi	0	0	2	27	14	0
Ancistrosyllis groenlandica	0	0	13	21	14	0
Ancistrosyllis papillosa	0	0	8	6	0	0
Parandalia ocularis	107	27	11	0	0	74
Ancistrosyllis cf. falcata	0	0	0	2	3	0

Sigambra cf. wassi	0	4	0	8	0	7
Pilargiidae (unidentified)	0	0	4	6	0	0
Hesionidae						
Gyptis vittata	6	15	252	185	409	152
Podarke obscura	0	0	4	11	37	3
Hesione picta	0	0	0	2	0	0
Syllidae						
Syllis cornuta	0	0	0	2	0	0
Sphaerosyllis cf. sublaevis	0	0	0	2	0	0
Sphaerosyllis erinaceus	0	0	2	2	0	0
Brania clavata	0	0	111	2	0	0
Sphaerosyllis sp. A	6	4	13	42	10	0
Syllidae (unidentified)	0	0	15	2	0	0
Nereidae						
Neanthes succinea	0	2	4	0	0	0
Ceratonereis mirabilis	0	0	0	0	3	0
Ceratonereis irritabilis	0	0	2	0	0	0
Laeonereis culveri	11	2	0	0	0	0
Nereidae (unidentified)	11	2	4	25	14	27
Nephtyidae						
Aglaophamus verrilli	0	0	0	4	0	0
Glyceridae						
Glycera americana	0	2	13	13	0	0
Glycera capitata	0	0	0	2	0	0
Glyceridae (unidentified)	11	2	0	0	0	0
Goniadidae						
Glycinde solitaria	107	71	191	90	111	78
Glycinde nordmanni	4	17	6	0	10	7
Onuphidae						
Diopatra cuprea	11	11	17	46	10	10
Onuphis sp.	0	0	0	2	0	0
Lumbrineridae						
Lumbrineris latreilli	0	0	0	8	0	0
Lumbrineris tenuis	0	0	0	2	0	0
Lumbrineris parvapedata	0	0	42	42	95	20
Ninoe nigripes	0	0	0	6	0	0
Arabellidae						
Drilonereis magna	0	2	332	48	3	0
Dorvilleidae						
Schistomeringos rudolphi	0	0	2	13	0	0
Schistomeringos sp. A	0	0	6	2	0	0
Dorvilleidae (unidentified)	0	0	4	0	0	0
Spionidae						
Polydora ligni	19	2	2	0	0	0
Minuspio cirrifera	0	0	147	1067	236	7
Paraprionospio pinnata	19	90	216	151	466	179

Apoprionospio pygmaea	0	0	4	0	17	0
Scolelepis texana	0	2	0	0	7	3
Polydora websteri	4	0	0	0	0	0
Polydora socialis	0	0	36	11	0	0
Streblospio benedicti	1240	1139	441	229	506	996
Polydora caulleryi	0	0	758	1004	1303	3461
Polydora sp.	0	0	0	6	0	3
Scolelepis squamata	4	0	0	0	0	0
Spionidae (unidentified)	0	0	13	134	0	0
Magelonidae						
Magelona pettiboneae	0	0	6	4	0	0
Magelona phyllisae	0	0	6	11	0	0
Chaetopteridae						
Spiochaetopterus costarum	11	8	82	6	24	14
Cirratulidae						
Tharyx setigera	0	2	405	15	0	3
Cossuridae						
Cossura delta	76	279	321	651	696	192
Orbiniidae						
Haploscoloplos foliosus	27	59	88	32	44	71
Haploscoloplos fragilis	4	8	15	0	17	34
Scoloplos texana	0	0	2	0	0	3
Naineris sp. A	0	0	8	242	0	3
Paraonidae						
Aricidea fragilis	0	0	4	0	27	0
Aricidea taylori	0	0	0	0	3	0
Cirrophorus lyra	0	0	4	6	20	0
Paraonides lyra	0	0	2	6	14	0
Aricidea catharinae	0	0	11	6	68	0
Paraonis fulgens	0	0	0	0	3	0
Paraonidae Grp. A	0	0	97	8	34	0
Paraonidae Grp. B	0	0	397	174	7	0
Aricidea bryani	0	0	15	0	64	0
Opheliidae						
Armandia maculata	0	0	2	32	34	0
Capitellidae						
Capitella capitata	63	25	11	0	0	47
Capitellides jonesi	4	0	0	0	0	0
Notomastus latericeus	4	0	4	15	0	0
Notomastus cf. latericeus	0	0	6	13	0	0
Heteromastus filiformis	29	8	0	0	0	0
Mediomastus ambiseta	4742	4171	4612	4964	4062	4748
Capitellidae (unidentified)	0	2	4	2	0	0
Maldanidae						
Branchioasychis americana	2	4	57	19	7	0
Clymenella torquata	4	0	27	11	0	0

Asychis elongata	0	0	11	0	7	7
Asychis sp.	2	0	65	0	3	0
Euclymene sp. B	0	0	6	0	0	0
Axiothella mucosa	13	17	88	4	0	0
Axiothells sp. A	0	0	4	0	0	0
Maldane sarsi	0	0	0	0	3	0
Maldanidae (unidentified)	0	19	99	32	7	0
Oweniidae						
Owenia fusiformis	0	0	4	2	0	0
Flabelligeridae						
Brada cf. villosa capensis	0	0	0	2	0	0
Pectinariidae						
Pectinaria gouldii	0	0	11	15	3	3
Ampharetidae						
Isolda pulchella	0	0	0	2	0	0
Melinna maculata	4	8	19	11	3	0
Hobsonia florida	15	2	4	19	118	0
Terebellidae						
Amaenana trilobata	0	0	13	8	0	0
Pista palmata	0	0	6	0	0	0
Terebellidae (unidentified)	0	0	4	11	0	0
Sabellidae						
Sabella microphthalma	0	0	4	0	0	0
Megalomma bioculatum	0	2	6	0	0	0
Sabellidae (unidentified)	0	0	2	4	0	0
Serpulidae						
Eupomatus protulicola	0	0	2	0	0	0
Oligochaeta						
Oligochaetes (unidentified)	25	8	46	868	196	10
Sipuncula						
Phascolion strombi	0	0	11	55	3	0
Sipuncula (unidentified)	0	0	0	2	0	0
Crustacea						
Ostracoda						
Ostracoda (unidentified)	8	40	0	0	0	172
Myodocopa						
Sarsiella texana	4	0	4	2	0	0
Sarsiella spinosa	0	0	4	2	0	0
Copepoda						
Harpacticoida						
Canuellidae						
Ellucana secunda	0	0	0	0	20	0
Cyclopoida						
Cyclopidae						
Hemicyclops sp.	2	0	0	8	3	0
Lichomolgidae						

Cyclopoid copepod (commensal)	23	6	2	0	0	0
Calanoida						
Diaptomidae						
Pseudodiaptomus coronatus	4	8	19	19	14	10
Cirripedia						
Balanus eburneus	0	0	0	0	34	0
Malacostraca						
Natantia						
Ogyrididae						
Ogyrides limicola	0	8	4	6	7	10
Penaeidae						
Trachypenaeus constrictus	0	0	2	2	0	0
Reptantia						
Paguridae						
Pagurus annulipes	0	0	2	6	0	0
Paguridae juv.	0	0	4	0	0	0
Portunidae						
Callinectes similis	0	0	2	0	0	0
Xanthidae						
Xanthidae (unidentified)	0	0	2	0	0	0
Pinnotheridae						
Pinnixa sp.	0	0	4	23	0	0
Pinnixa cristata	0	0	4	0	0	0
Pinnixa chacei	0	0	8	34	0	0
Pinnixa retinens	0	0	4	0	0	0
Pinnotheridae (unidentified)	0	0	2	4	3	0
Brachyuran Larvae						
Megalops	0	2	0	4	0	3
Mysidacea						
Mysidopsis bigelowi	0	0	17	0	0	3
Mysidopsis bahia	4	2	8	6	3	0
Mysidopsis sp.	4	6	4	4	0	0
Mysidopsis almyra	4	2	2	0	0	3
Cumacea						
Cyclaspis varians	40	27	21	6	0	14
Oxyurostylis sp.	0	2	25	4	3	0
Leucon sp.	19	38	25	4	0	3
Diastylis sp.	0	0	2	0	0	3
Oxyurostylis salinoi	0	0	34	0	0	0
Oxyurostylis smithi	21	4	11	2	7	0
Eudorella sp.	0	11	13	23	20	0
Amphipoda						
Amphipoda (unidentified)	0	0	2	4	0	0
Ampeliscidae						
Ampelisca sp. B	0	0	2	11	0	0
Ampelisca abdita	387	46	15	4	10	108

Ampelisca verrilli	0	0	4	0	0	0
Gammaridae						
Gammarus mucronatus	2	0	0	0	0	0
Oedicerotidae						
Monoculodes sp.	8	6	13	0	3	0
Corophiidae						
Erichthonias brasiliensis	0	0	0	8	0	0
Corophium ascherusicum	0	0	0	2	0	0
Photis sp.	0	0	4	0	0	0
Corophium louisianum	6	0	0	0	0	20
Microprotopus spp.	6	6	2	4	3	0
Liljeborgiidae						
Listriella barnardi	2	2	13	44	24	14
Listriella clymenellae	0	0	4	0	0	0
Caprellidae						
Caprellidae sp.	2	0	4	4	0	0
Amphilochidae						
Amphilochus sp.	0	0	2	0	0	0
Isopoda						
Munnidae						
Munnidae sp.	0	0	0	2	0	0
Idoteidae						
Edotea montosa	17	0	2	0	0	7
Tanaidacea						
Apseudidae						
Apseudes sp. A	0	0	2	3800	7	0
Insecta						
Pterygota						
Diptera						
Diptera (unidentified)	2	0	0	0	0	0
Chironomidae						
Chironomid larvae	19	6	0	0	0	0
Ephemeroptera						
Potamanthidae (unidentified)	2	0	0	0	0	0
Echinodermata						
Ophiuroidea						
Ophiuroidea (unidentified)	0	0	107	408	138	14
Holothuroidea						
Thyome mexicana	0	0	0	4	0	0
Holothuroidae (unidentified)	0	0	0	2	0	0
Chordata						
Urochordata						
Ascidiaceae						
Molgula manhattensis	0	0	2	0	0	0

Hemichordata						
Schizocardium sp.	0	2	113	219	290	88

Table 9. Lavaca-Colorado Estuary macrofauna dominance list. Average abundance (n m^2) and percent composition over all samples.

Rank	Taxa Name	SP Code	Mean	%
1	Mediomastus ambiseta	562	4,550	40.36
2	Polydora caulleryi	72	1,088	9.65
3	Streblospio benedicti	81	759	6.73
4	Apseudes sp. A	509	635	5.63
5	Mulinia lateralis	162	418	3.71
6	Cossura delta	110	369	3.28
7	Rhynchocoela (unidentified)	7	253	2.25
8	Minuspio cirrifera	85	243	2.15
9	Oligochaetes (unidentified)	8	192	1.71
10	Paraprionospio pinnata	82	187	1.66
11	Gyptis vittata	32	170	1.51
12	Schizocardium sp.	249	119	1.05
13	Periploma cf. orbiculare	510	113	1.00
14	Ophiuroidea (unidentified)	357	111	0.99
15	Glycinde solitaria	55	108	0.96
16	Paraonidae Grp. B	341	96	0.85
17	Ampelisca abdita	197	95	0.84
18	Macoma mitchelli	488	90	0.80
19	Corbula contracta	174	86	0.76
20	Tharyx setigera	92	71	0.63
21	Drilonereis magna	65	64	0.57
22	Haploscoloplos foliosus	95	53	0.47
23	Pelecypoda (unidentified)	358	49	0.43
24	Periploma margaritaceum	179	46	0.41
25	Naineris sp. A	559	42	0.37
26	Acteocina canaliculata	256	41	0.36
27	Ostracoda (unidentified)	181	37	0.33
28	Parandalia ocularis	508	37	0.32
29	Nuculana acuta	155	36	0.32
30	Sigambra tentaculata	31	35	0.31
31	Paleanotus heteroseta	17	33	0.30
32	Lumbrineris parvapedata	62	33	0.29
33	Anthozoa (unidentified)	2	31	0.27
34	Turbellaria (unidentified)	499	31	0.27
35	Paramya subovata	568	27	0.24
36	Hobsonia florida	492	26	0.23
37	Maldanidae (unidentified)	122	26	0.23
38	Spionidae (unidentified)	335	25	0.22
39	Capitella capitata	111	25	0.22
40	Spiochaetopterus costarum	91	24	0.21
41	Paraonidae Grp. A	340	23	0.21
42	Lepton sp.	160	23	0.20

43	Axiothella mucosa	118	20	0.18
44	Mysella planulata	159	20	0.18
45	Brania clavata	39	19	0.17
46	Cyclaspis varians	192	18	0.16
47	Diopatra cuprea	58	17	0.15
48	Sigambra bassi	30	17	0.15
49	Listriella barnardi	254	16	0.14
50	Caecum johnsoni	533	16	0.14
51	Pyramidella crenulata	379	15	0.14
52	Leucon sp.	399	15	0.13
53	Nuculana concentrica	262	15	0.13
54	Branchioasychis americana	117	15	0.13
55	Aricidea catharinae	520	14	0.12
56	Nereidae (unidentified)	323	14	0.12
57	Phoronis architecta	245	14	0.12
58	Aricidea bryani	840	13	0.12
59	Haploscoloplos fragilis	96	13	0.12
60	Eulimostoma sp.	402	13	0.11
61	Sphaerosyllis sp. A	382	13	0.11
62	Pseudodiaptomus coronatus	183	12	0.11
63	Asychis sp.	121	12	0.10
64	Phascolion strombi	244	11	0.10
65	Armandia maculata	360	11	0.10
66	Eudorella sp.	564	11	0.10
67	Nassarius acutus	258	10	0.09
68	Abra aequalis	170	9	0.08
69	Podarke obscura	34	9	0.08
70	Pyrgiscus sp.	279	9	0.08
71	Hiatella arctica	389	8	0.07
72	Ancistrosyllis groenlandica	290	8	0.07
73	Polydora socialis	70	8	0.07
74	Melinna maculata	125	8	0.07
75	Oxyurostylis smithi	500	7	0.07
76	Glycinde nordmanni	580	7	0.07
77	Ancistrosyllis jonesi	28	7	0.06
78	Clymenella torquata	119	7	0.06
79	Pinnixa chacei	540	7	0.06
80	Tellina sp.	168	7	0.06
81	Littoridina sphinctostoma	504	7	0.06
82	Malmgreniella taylori	644	7	0.06
83	Heteromastus filiformis	114	6	0.06
84	Ogyrides limicola	218	6	0.05
85	Eunoe cf. nodulosa	12	6	0.05
86	Oxyurostylis sp.	553	6	0.05
87	Balanus eburneus	187	6	0.05
88	Oxyurostylis salinoi	194	6	0.05

89	Pectinaria gouldii	124	5	0.05
90	Sigalionidae (unidentified)	316	5	0.05
91	Cyclopoid copepod (commensal)	186	5	0.05
92	Aricidea fragilis	99	5	0.05
93	Cirrophorus lyra	901	5	0.05
94	Monoculodes sp.	205	5	0.05
95	Ensis minor	163	5	0.04
96	Pinnixa sp.	380	5	0.04
97	Glycera americana	54	5	0.04
98	Polychaete juv. (unidentified)	512	5	0.04
99	Corophium louisianum	201	4	0.04
100	Edotea montosa	196	4	0.04
101	Haminoea antillarum	561	4	0.04
102	Chironomid larvae	487	4	0.04
103	Mysidopsis bahia	453	4	0.04
104	Asychis elongata	446	4	0.04
105	Pandora trilineata	311	4	0.03
106	Rangia cuneata	498	4	0.03
107	Polydora ligni	71	4	0.03
108	Notomastus latericeus	116	4	0.03
109	Microprotopus spp.	365	4	0.03
110	Paraonides lyra	107	4	0.03
111	Eteone heteropoda	22	4	0.03
112	Apoprionospio pygmaea	84	4	0.03
113	Amaenana trilobata	563	4	0.03
114	Pyramidella sp.	503	4	0.03
115	Ellucana secunda	587	3	0.03
116	Mysidopsis bigelowi	188	3	0.03
117	Sigambra cf. wassi	552	3	0.03
118	Mysidopsis sp.	428	3	0.03
119	Notomastus cf. latericeus	344	3	0.03
120	Magelona phyllisae	89	3	0.02
121	Tagelus plebeius	502	3	0.02
122	Syllidae (unidentified)	321	3	0.02
123	Ancistrosyllis papillosa	29	2	0.02
124	Schistomeringos rudolphi	68	2	0.02
125	Terebellidae (unidentified)	352	2	0.02
126	Hemicyclops sp.	460	2	0.02
127	Odostomia sp.	151	2	0.02
128	Aligena texasiana	161	2	0.02
129	Laeonereis culveri	491	2	0.02
130	Anaitides erythrophyllus	26	2	0.02
131	Ampelisca sp. B	209	2	0.02
132	Glyceridae (unidentified)	326	2	0.02
133	Rictaxis punctostriatus	557	2	0.02
134	Paranaitis speciosa	24	2	0.02

135	Scolelepis texana	83	2	0.02
136	Sthenelais boa	15	2	0.02
137	Mysidopsis almyra	493	2	0.02
138	Gastropoda (unidentified)	377	2	0.02
139	Pilargiidae (unidentified)	319	2	0.02
140	Magelona pettiboneae	88	2	0.02
141	Sarsiella texana	362	2	0.02
142	Caprellidae sp.	200	2	0.02
143	Pinnotheridae (unidentified)	356	2	0.01
144	Megalops	469	2	0.01
145	Polydora sp.	73	2	0.01
146	Schistomeringos sp. A	334	1	0.01
147	Pagurus annulipes	225	1	0.01
148	Lumbrineris latreilli	64	1	0.01
149	Erichthonias brasiliensis	297	1	0.01
150	Megalomma bioculatum	131	1	0.01
151	Macoma tenta	165	1	0.01
152	Capitellidae (unidentified)	343	1	0.01
153	Brachidontes exustus	403	1	0.01
154	Haminoea succinea	152	1	0.01
155	Crepidula fornicata	144	1	0.01
156	Neanthes succinea	44	1	0.01
157	Ninoe nigripes	800	1	0.01
158	Euclymene sp. B	579	1	0.01
159	Owenia fusiformis	123	1	0.01
160	Pista palmata	128	1	0.01
161	Sabellidae (unidentified)	353	1	0.01
162	Sarsiella spinosa	551	1	0.01
163	Amphipoda (unidentified)	447	1	0.01
164	Nassarius vibex	149	1	0.01
165	Scoloplos texana	98	1	0.01
166	Diastylis sp.	531	1	0.01
167	Ancistrosyllis cf. falcata	550	1	0.01
168	Polinices duplicatus	146	1	0.01
169	Macoma sp.	411	1	0.01
170	Lyonsia hyalina floridana	180	1	0.01
171	Polynoidae (unidentified)	314	1	0.01
172	Paramphinome jeffreysii	252	1	0.01
173	Cabira incerta	270	1	0.01
174	Dorvilleidae (unidentified)	333	1	0.01
175	Polydora websteri	69	1	0.01
176	Capitellides jonesi	112	1	0.01
177	Axiothells sp. A	539	1	0.01
178	Sabella microphthalma	133	1	0.01
179	Trachypenaeus constrictus	211	1	0.01
180	Paguridae juv.	227	1	0.01

181	Pinnixa cristata	240	1	0.01
182	Pinnixa retinens	241	1	0.01
183	Ampelisca verrilli	198	1	0.01
184	Photis sp.	207	1	0.01
185	Listriella clymenellae	203	1	0.01
186	Thyome mexicana	837	1	0.01
187	Aglaophamus verrilli	47	1	0.01
188	Dentalium texasianum	154	1	0.01
189	Sphaerosyllis erinaceus	532	1	0.01
190	Scolelepis squamata	507	1	0.01
191	Caecum pulchellum	424	1	0.00
192	Nudibranchia (unidentified)	408	1	0.00
193	Solen viridis	420	1	0.00
194	Ceratonereis mirabilis	42	1	0.00
195	Aricidea taylori	102	1	0.00
196	Paraonis fulgens	303	1	0.00
197	Maldane sarsi	120	1	0.00
198	Pectinariidae	349	1	0.00
199	Cyclinella tenuis	805	0	0.00
200	Mitrella lunata	147	0	0.00
201	Eulimastoma cf. teres	780	0	0.00
202	Crassostrea virginica	470	0	0.00
203	Tellidora cristata	275	0	0.00
204	Hesione picta	567	0	0.00
205	Syllis cornuta	36	0	0.00
206	Glycera capitata	327	0	0.00
207	Onuphis sp.	60	0	0.00
208	Lumbrineris tenuis	294	0	0.00
209	Isolda pulchella	126	0	0.00
210	Eupomatus protulicola	565	0	0.00
211	Xanthidae (unidentified)	238	0	0.00
212	Corophium ascherusicum	390	0	0.00
213	Amphilochus sp.	296	0	0.00
214	Munnidae sp.	576	0	0.00
215	Diptera (unidentified)	854	0	0.00
216	Potamanthidae (unidentified)	795	0	0.00
217	Holothuroidae (unidentified)	393	0	0.00
218	Molgula manhattensis	419	0	0.00
219	Anadara ovalis	277	0	0.00
220	Tellina texana	167	0	0.00
221	Mercenaria campechiensis	273	0	0.00
222	Phyllodocidae (unidentified)	306	0	0.00
223	Sphaerosyllis cf. sublaevis	322	0	0.00
224	Ceratonereis irritabilis	43	0	0.00
225	Brada cf. villosa capensis	541	0	0.00
226	Sipuncula (unidentified)	372	0	0.00

227	Callinectes similis	422	0	0.00
228	Gammarus mucronatus	202	0	0.00
	Total		11,272	99.93

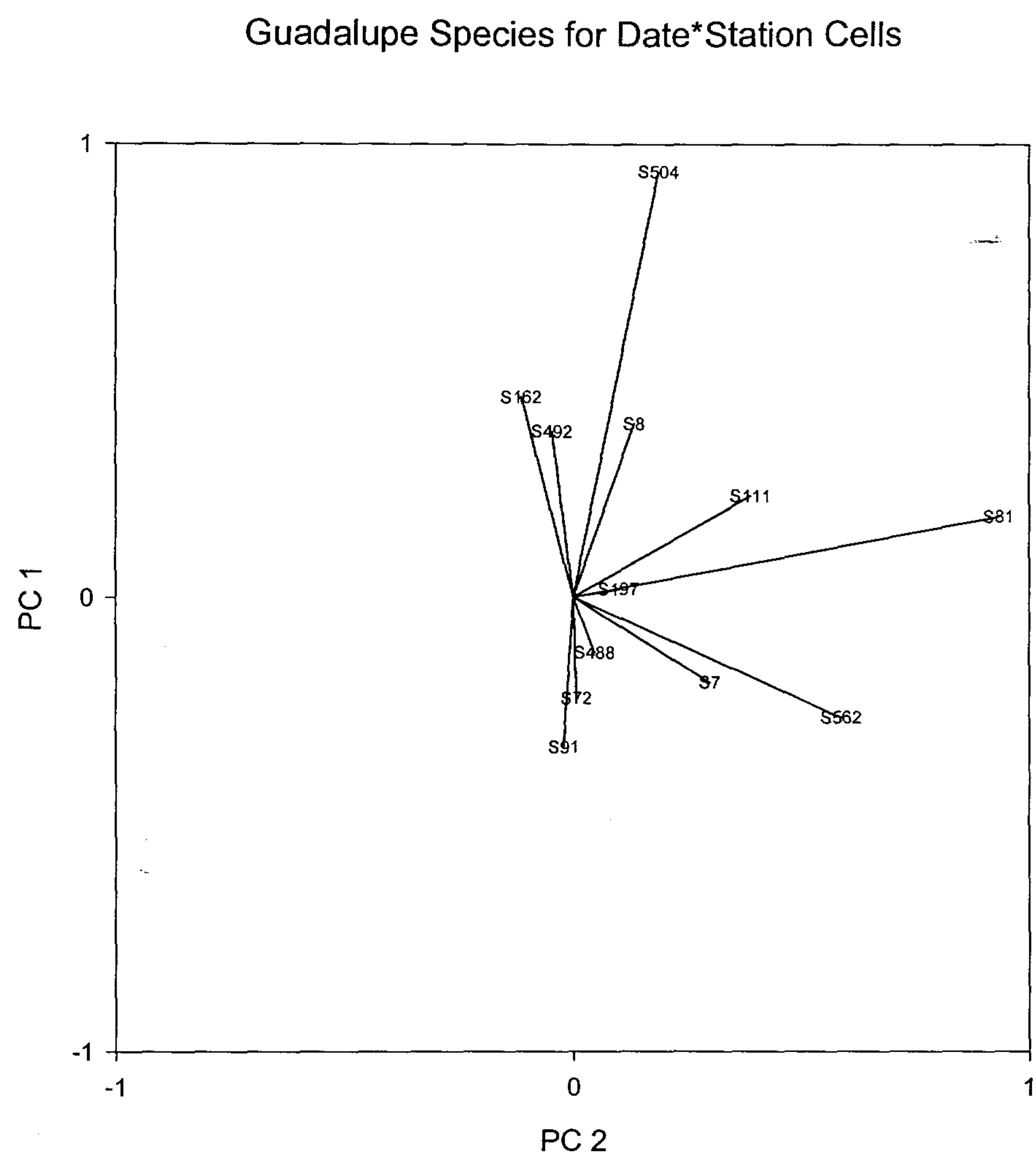

Figure 21. Loading vectors from a principal components analysis of dominant species in the Guadalupe Estuary. Numbers are species codes given in Table 7.

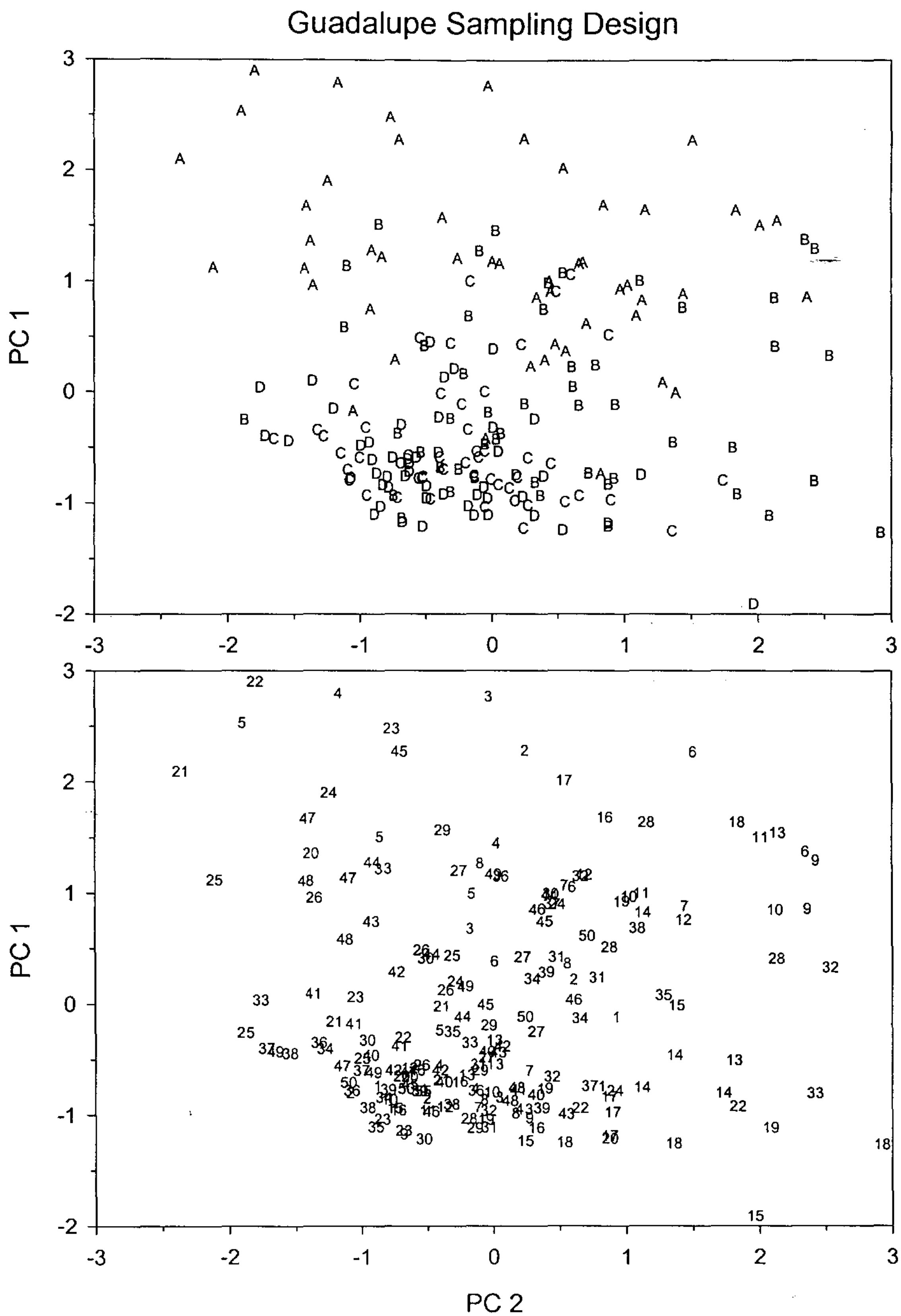

Figure 22A. Scores for dates and stations from a principal components analysis of dominant species in the Guadalupe Estuary. Top is station names, bottom is consecutive sampling periods as listed in Table 10.

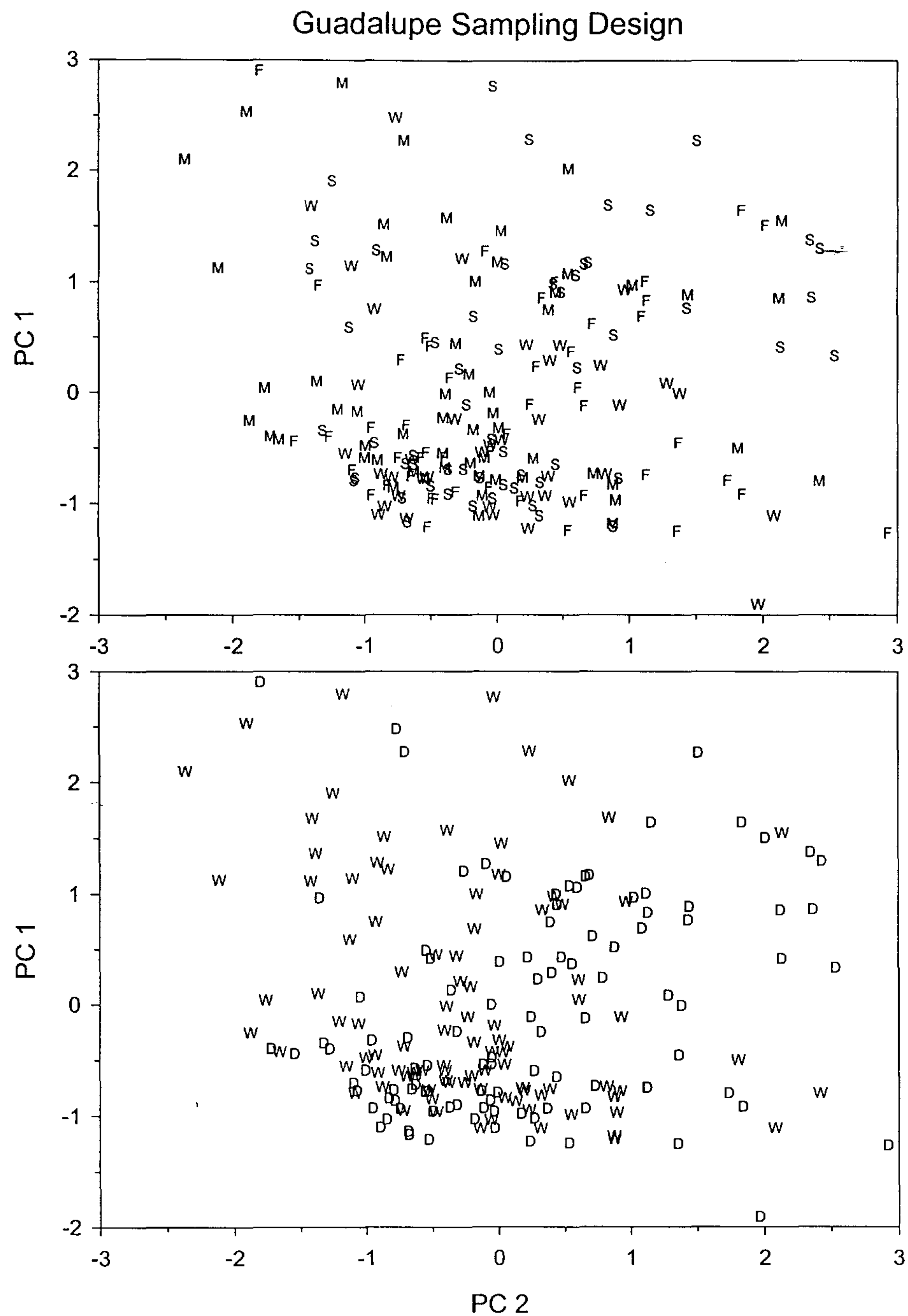

Figure 22B. Scores for seasons and period types from a principal components analysis of dominant species in the Guadalupe Estuary. Top is seasons (W=winter, S=spring, M=summer, F=fall), bottom is period types (W=wet, D=dry) as listed in Table 10.

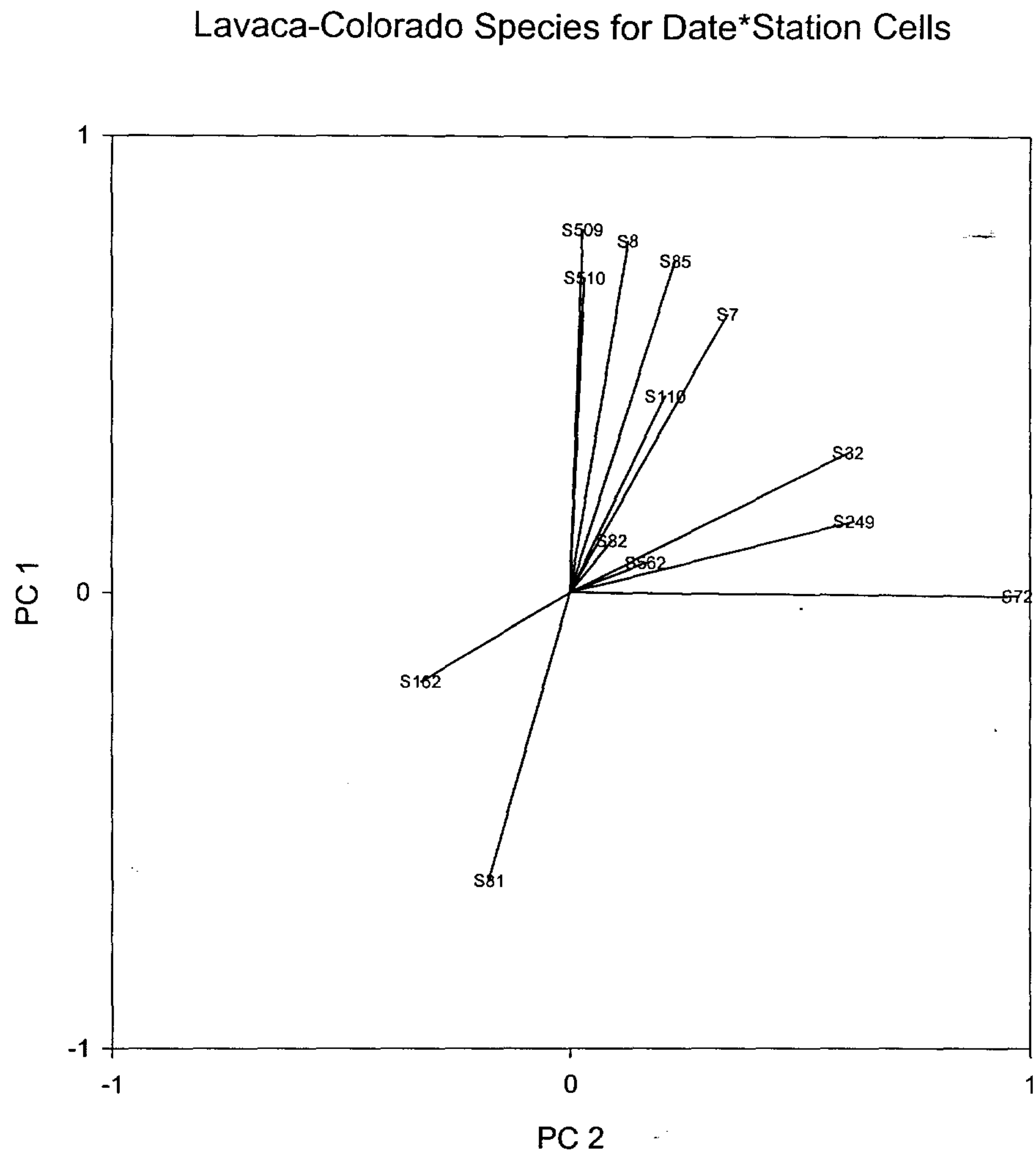

Figure 23. Loading vectors from a principal components analysis of dominant species in the Lavaca-Colorado Estuary. Numbers are species codes given in Table 9.

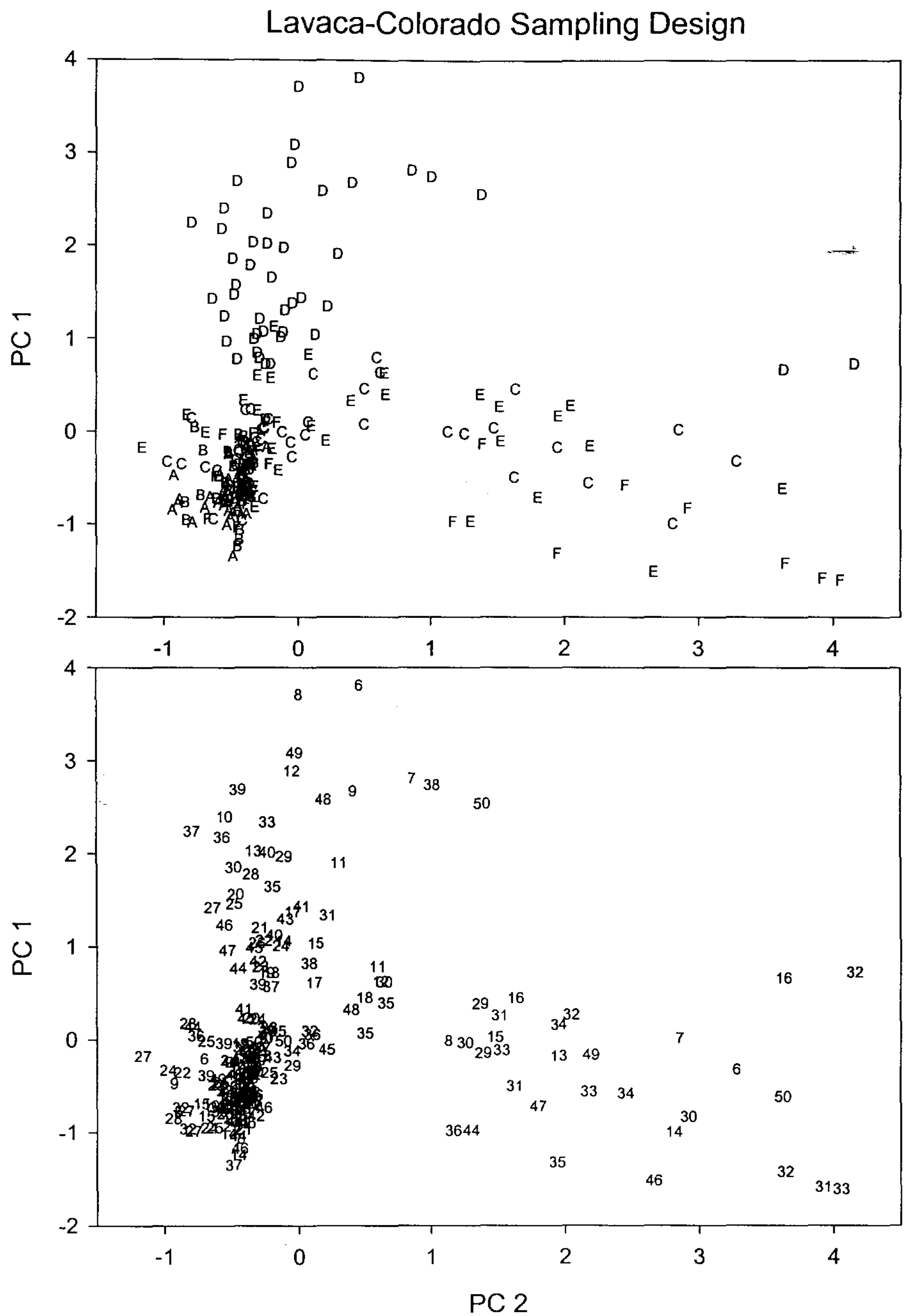

Figure 24A. Scores for dates and stations from a principal components analysis of dominant species in the Lavaca-Colorado Estuary. Top is station names, bottom is consecutive sampling periods as listed in Table 10.

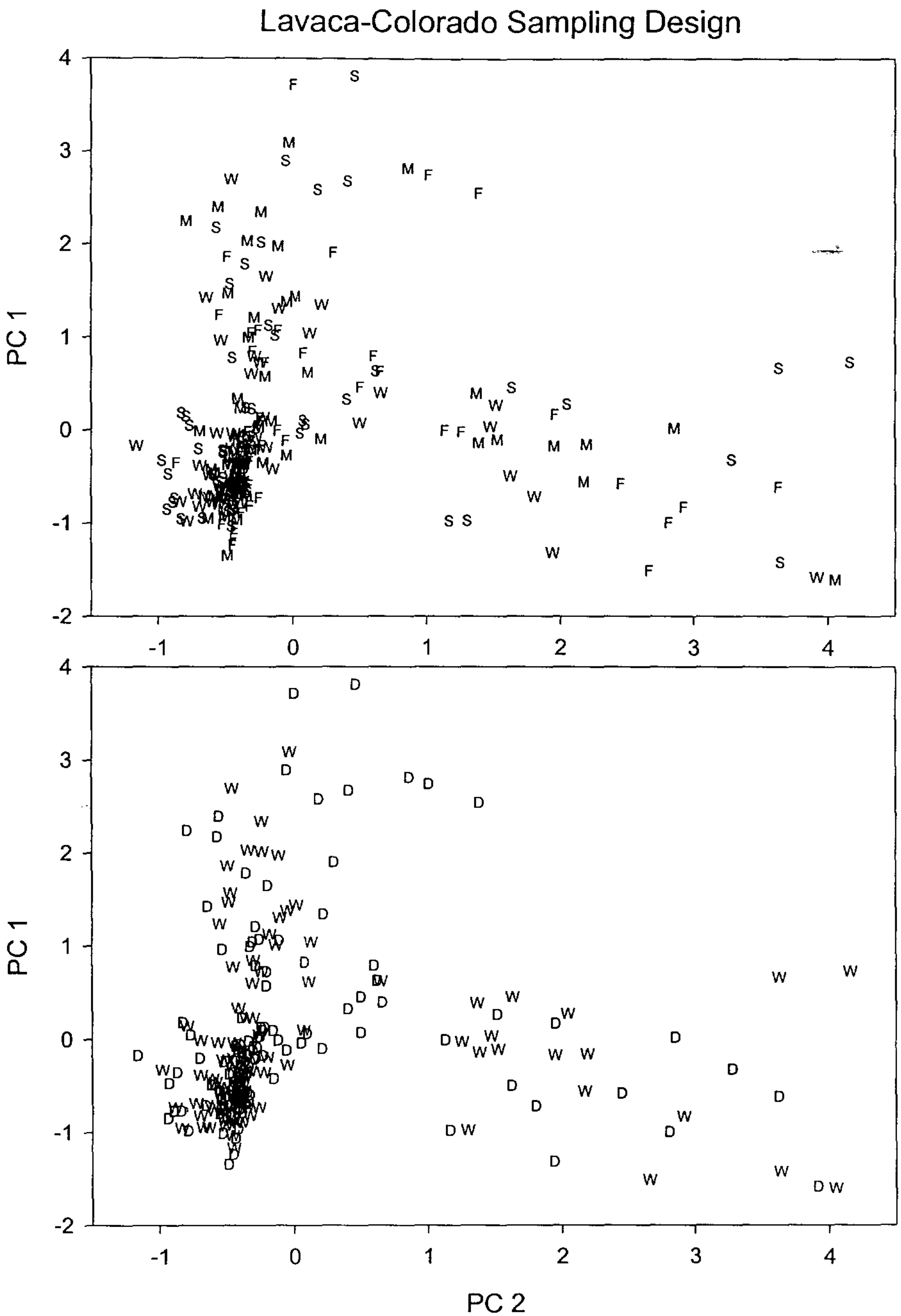

Figure 24B. Scores for seasons and period types from a principal components analysis of dominant species in the Lavaca-Colorado Estuary. Top is seasons (W=winter, S=spring, M=summer, F=fall), bottom is period types (W=wet, D=dry) as listed in Table 10.

Table 10. Codes for Figures 22 and 24. Abbreviations for sequential sampling periods, seasons (winter, spring, summer or fall), and type of climate during the period. Type is based on if salinity is lower (wet) or higher (dry) than average.

Guadalupe Estuary				Lavaca-Colorado Estuary			
Date	Period	Season	Type	Date	Period	Season	Type
28-Jan-87	1	W	W				
4-Mar-87	2	S	W				
8-Apr-87	3	S	W				
3-Jun-87	4	M	W				
15-Jul-87	5	M	W				
18-Apr-88	6	S	D	18-Apr-88	6	S	D
7-Jul-88	7	M	D	19-Jul-88	7	M	D
22-Nov-88	8	F	D	22-Nov-88	8	F	D
4-Apr-89	9	S	D	5-Apr-89	9	S	D
23-Jul-89	10	M	D	22-Jul-89	10	M	D
5-Dec-89	11	F	D	5-Dec-89	11	F	D
10-Apr-90	12	S	D	10-Apr-90	12	S	D
2-Aug-90	13	M	W	31-Jul-90	13	M	W
19-Oct-90	14	F	D	23-Oct-90	14	F	D
23-Jan-91	15	W	D	25-Jan-91	15	W	W
22-Apr-91	16	S	W	24-Apr-91	16	S	W
17-Jul-91	17	M	W	24-Jul-91	17	M	W
15-Oct-91	18	F	D	14-Oct-91	18	F	D
20-Jan-92	19	W	W	20-Jan-92	19	W	W
6-Apr-92	20	S	W	6-Apr-92	20	S	W
12-Jul-92	21	M	W	12-Jul-92	21	M	D
7-Oct-92	22	F	D	6-Oct-92	22	F	D
12-Jan-93	23	W	D	12-Jan-93	23	W	D
5-Apr-93	24	S	W	5-Apr-93	24	S	W
9-Jul-93	25	M	W	9-Jul-93	25	M	W
11-Oct-93	26	F	D	11-Oct-93	26	F	D
5-Jan-94	27	W	D	5-Jan-94	27	W	D
7-Apr-94	28	S	D	7-Apr-94	28	S	D
7-Jul-94	29	M	W	7-Jul-94	29	M	W
20-Oct-94	30	F	D	20-Oct-94	30	F	W
10-Jan-95	31	W	D	10-Jan-95	31	W	D
5-Apr-95	32	S	D	6-Apr-95	32	S	W
6-Jul-95	33	M	W	6-Jul-95	33	M	W
4-Oct-95	34	F	D	4-Oct-95	34	F	D
10-Jan-96	35	W	D	9-Jan-96	35	W	D
3-Apr-96	36	S	D	2-Apr-96	36	S	D
10-Jul-96	37	M	D	9-Jul-96	37	M	D
15-Oct-96	38	F	D	14-Oct-96	38	F	D
22-Jan-97	39	W	D	25-Jan-97	39	W	W
7-Apr-97	40	S	W	15-Apr-97	40	S	W

8-Jul-97	41	M	W	9-Jul-97	41	M	W
16-Oct-97	42	F	W	17-Oct-97	42	F	W
12-Jan-98	43	W	W	9-Jan-98	43	W	W
2-Apr-98	44	S	W	1-Apr-98	44	S	W
7-Jul-98	45	M	D	6-Jul-98	45	M	D
13-Oct-98	46	F	W	12-Oct-98	46	F	W
6-Jan-99	47	W	W	5-Jan-99	47	W	D
7-Apr-99	48	S	W	6-Apr-99	48	S	D
2-Jul-99	49	M	W	1-Jul-99	49	M	W
13-Oct-99	50	F	D	21-Oct-99	50	F	D

Nitrogen Losses in East Matagorda Bay

A great deal of nitrogen enters bays via river inflow. If this nitrogen is buried, then we would expect higher nitrogen values in sediments at the head of estuaries. This is because rivers empty into the secondary bay, and more nitrogen should be trapped in the upper reaches of the bay. The trends in all Texas estuaries confirm this hypothesis (Montagna 1997). East Matagorda Bay has little or no river influence, except for intermittent spill over from the Colorado River. The effect of even that intermittent flow is evident in that both nitrogen (Figure 25) and carbon (Figure 26) appear to have highest concentrations in sediments in at station A, nearest the river.

If nitrogen is utilized, or transformed in the biologically active labile zone, then there should be higher values in upper layers of sediment and lower values at lower layers in the refractory zone. This hypothesis is confirmed by the trends seen in the estuary-wide average nitrogen content. On average, there is a strong decrease in carbon and nitrogen values in the top 20 cm of sediment, and then values are relatively constant to 100 cm depth (Fig. 27). Thus, the labile zone appears to be limited to between 0 and 20 cm in East Matagorda Bay as it is in most Texas estuaries (Montagna,1997). Nitrogen content in most Texas estuarine sediment is 0.08 to 0.15 percent (%) at the surface, and declines to 0.04 to 0.08 %. East Matagorda Bay sediment is similar with about 0.07 % at the surface and declining to 0.05 to 0.04 %.

Man can influence another key component that affects nitrogen loss. In general, it is thought that the sedimentation rate in Texas estuaries is about 1 cm per 100 years (Behrens, 1980). However, recent water projects, particularly dams, have probably decreased this rate. An average nitrogen background level, i.e., the average content at about 40 cm is about 0.05 %. The average surface nitrogen content is about 0.1 %, so the change between the labile and refractory zone is a factor of 2. This implies that half of the nitrogen arriving at the sediment surface is lost to the system via burial.

This year, we used a new mass spectrometer that also measures isotopic values as well as elemental content values. East Matagorda Bay had lowest nitrogen ($\delta\ ^{15}N$) values in station A nearest the Colorado River (Fig. 28) and highest carbon ($\delta\ ^{13}C$) isotope values (Fig. 29) nearest the river in the top 20 cm of sediment. The differences indicate the importance of primary production in producing depositional particulates in the bay. On average, the vertical profile of nitrogen values declined 2 parts per thousand (‰) indicating a change through the sediment (Fig. 30). On average, the vertical profile of carbon values varied 2 ‰, decreasing mostly in the top 3 cm of sediment then increasing gradually to surface values. The change in carbon values at the surface verifies that the biogenic labile zone, which is dominated by fresh plant detritus, is limited to the top 20 cm.

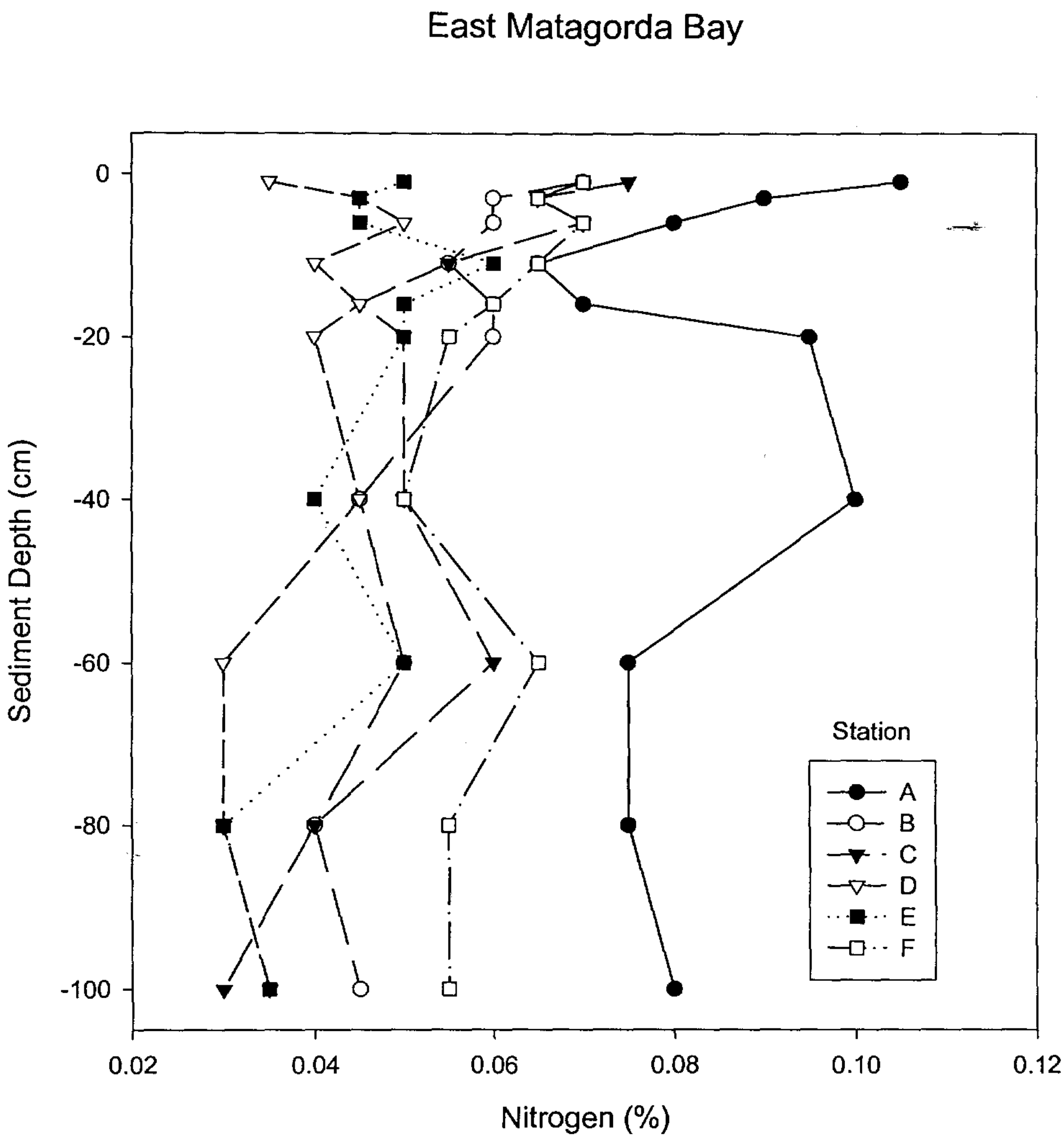

Figure 25. Nitrogen content of East Matagorda Bay sediments.

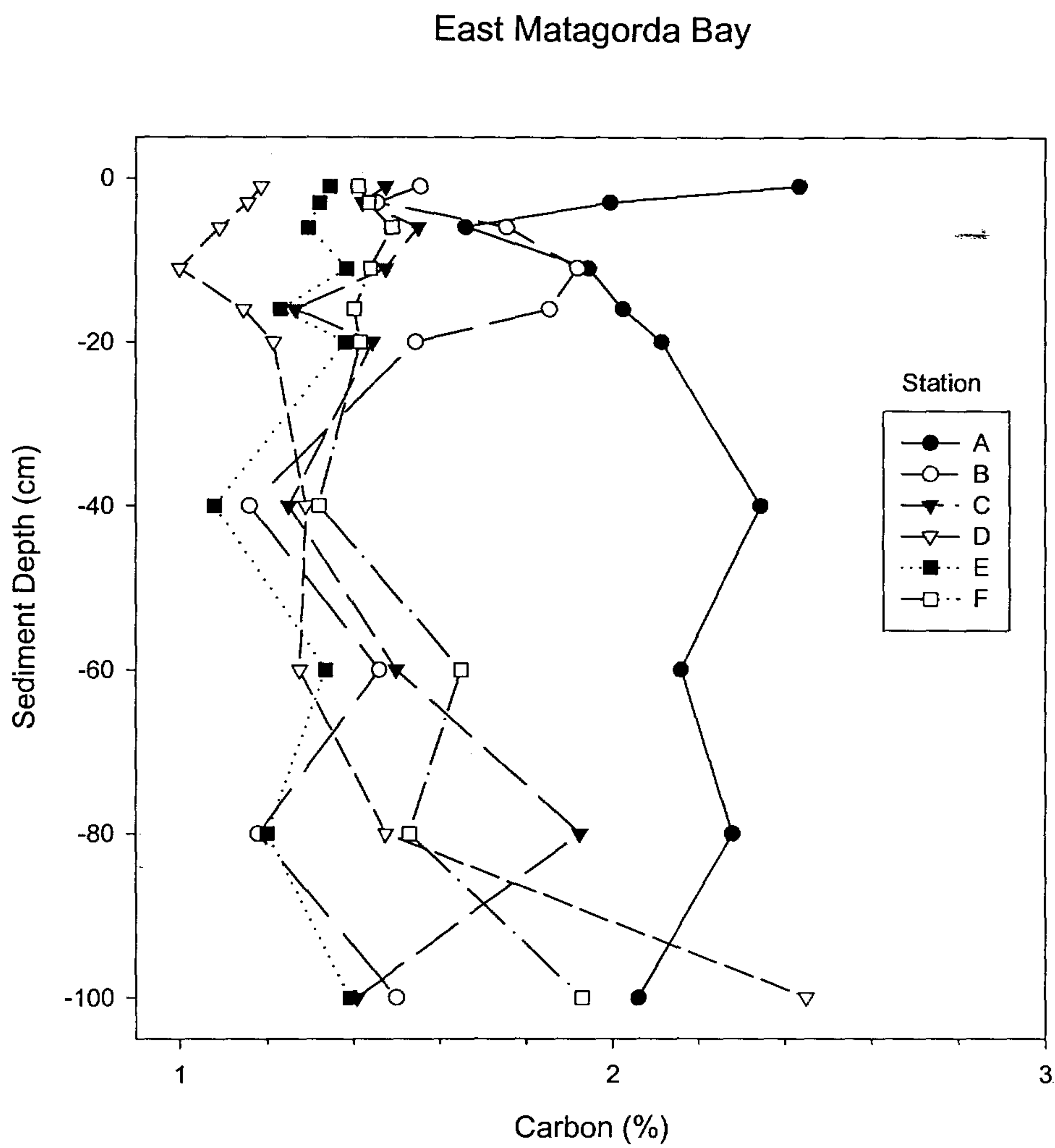

Figure 26. Carbon content of East Matagorda Bay sediments.

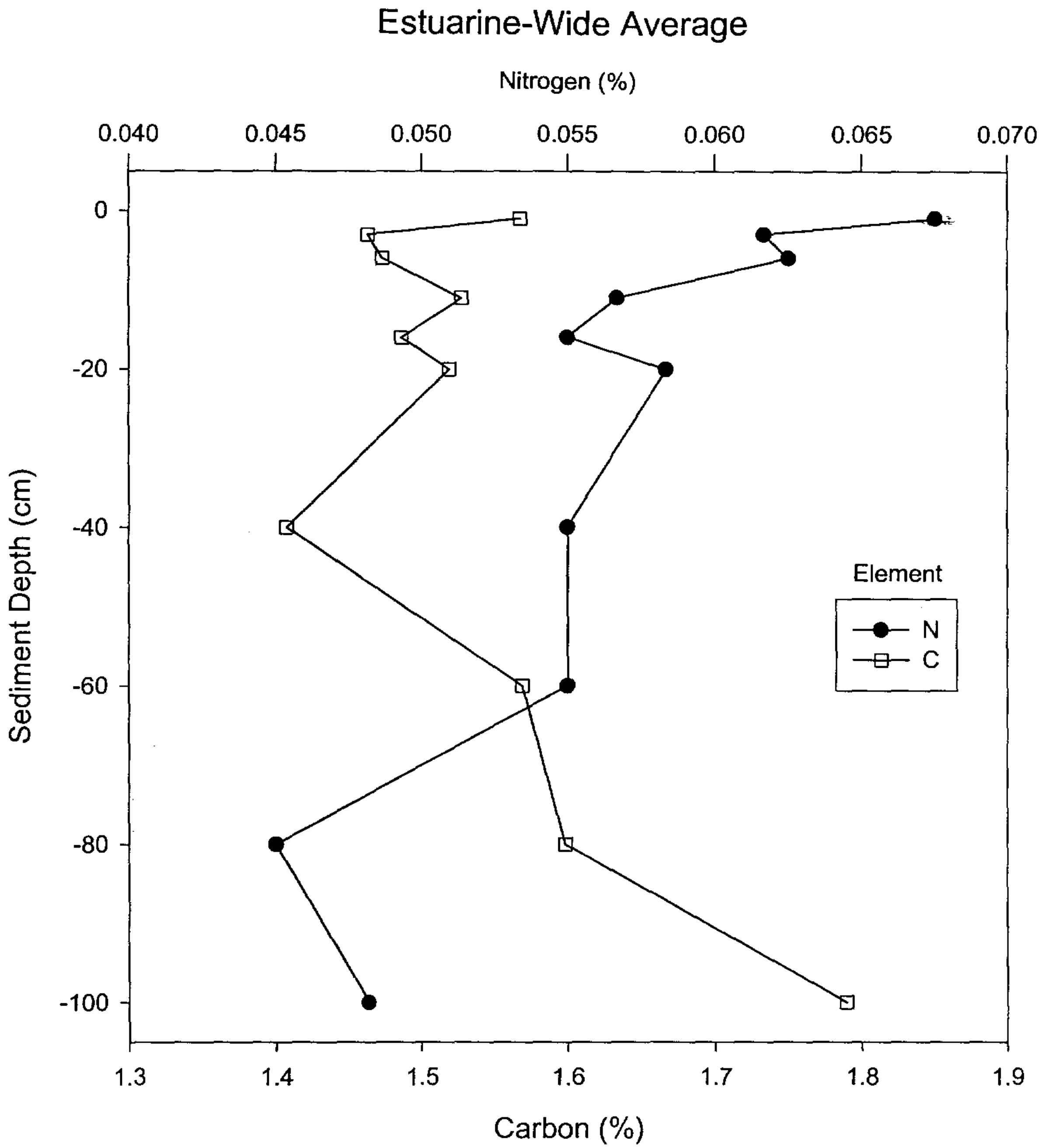

Figure 27. Average nitrogen and carbon content in East Matagorda Bay sediments.

East Matagorda Bay

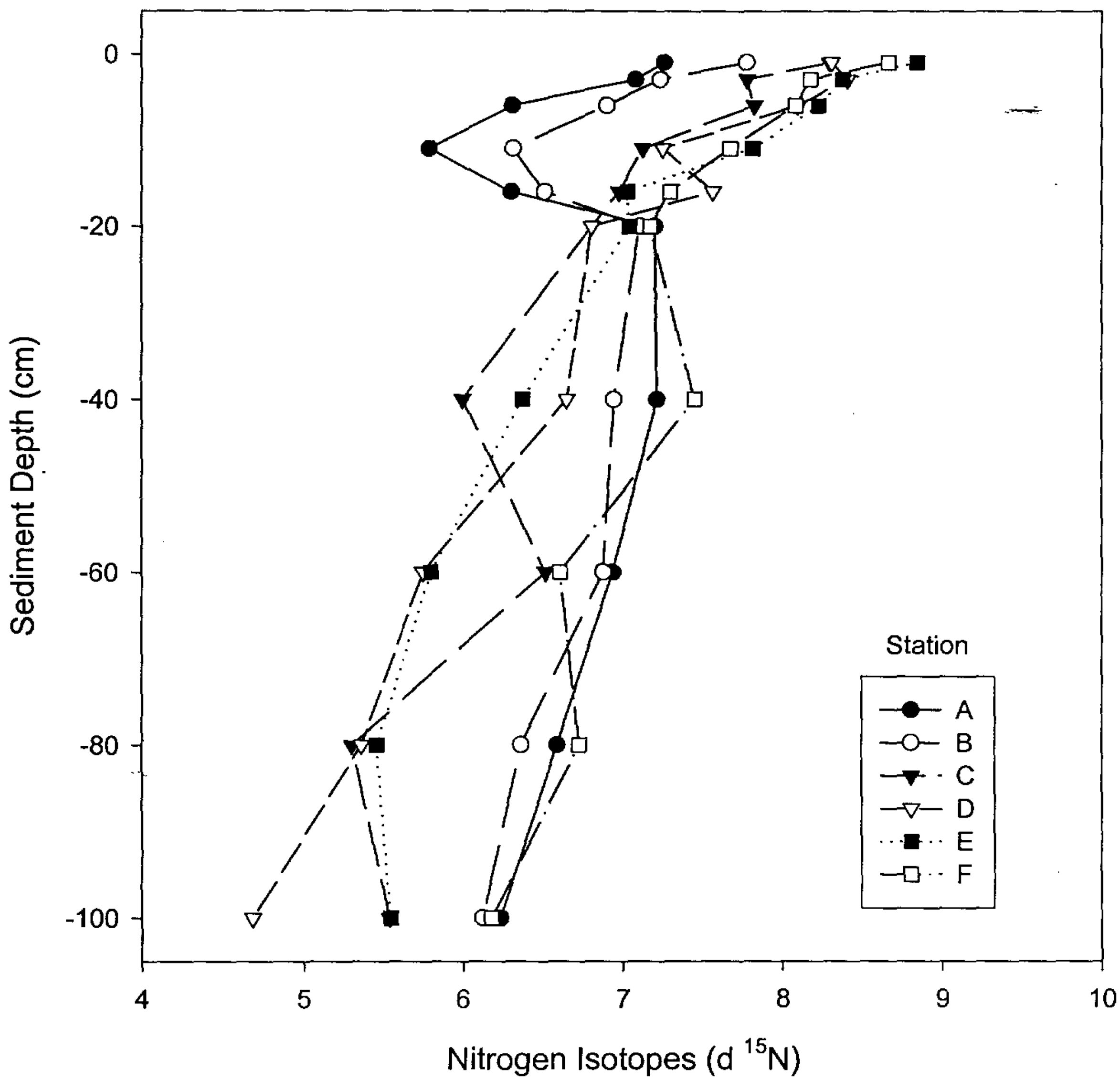

Figure 28. Profile of nitrogen ($\delta\ ^{15}N$) isotope values in East Matagorda Bay sediments.

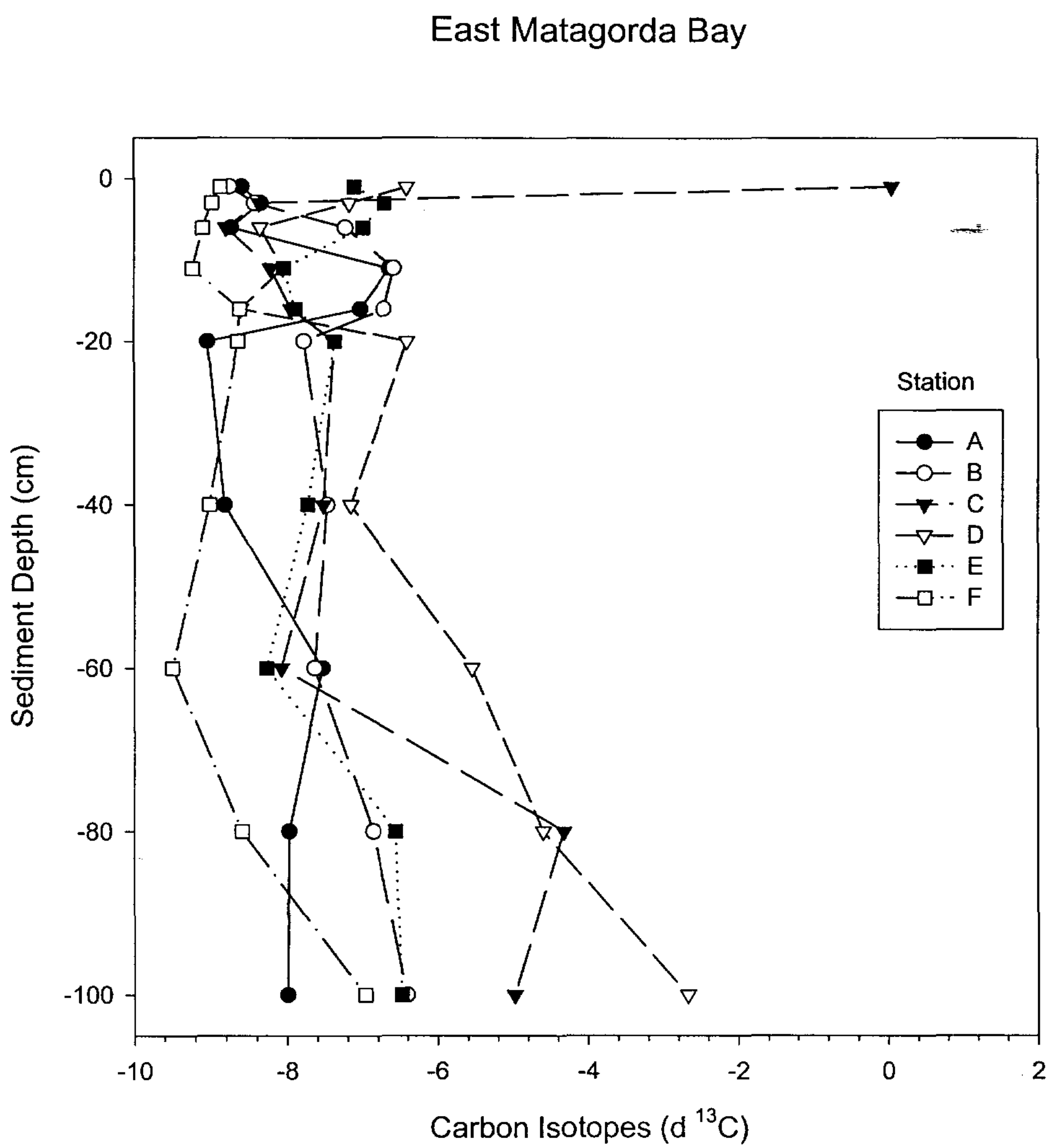

Figure 29. Profile of carbon ($\delta\ ^{13}C$) isotope values in East Matagorda Bay sediments.

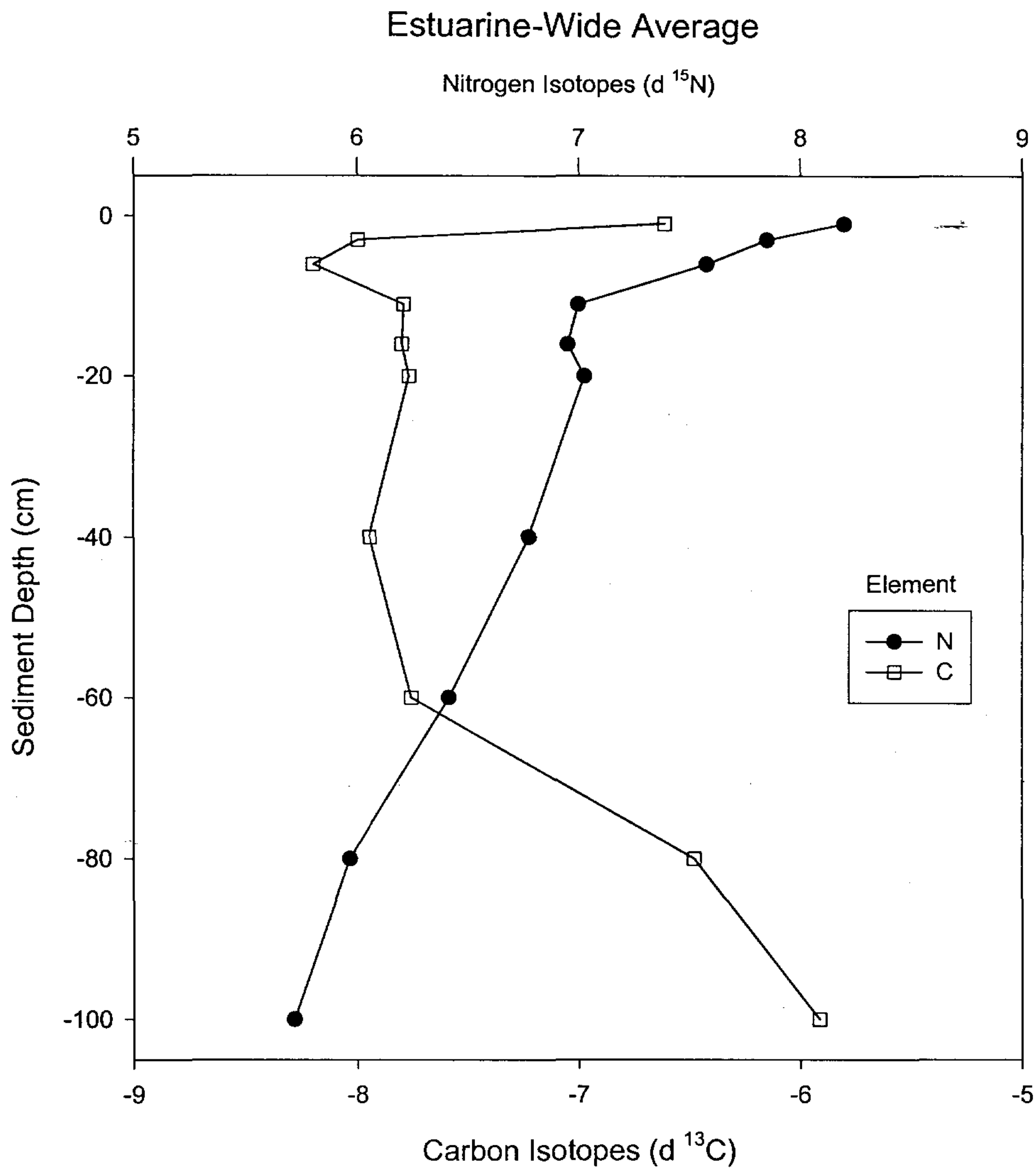

Figure 30. Average of nitrogen ($\delta\ ^{15}N$)and carbon ($\delta\ ^{13}C$)isotope values in East Matagorda Bay sediments.

DISCUSSION

Following an El Niño event in 1997, 1998 through 1999 was a dry period. Consequently, salinities were very high during summers of 1998 and 1999 (Figs. 4 and 5).

The Lavaca-Colorado and Guadalupe Estuaries are similar in the amount of freshwater inflow they receive, but different in two key attributes. The Lavaca-Colorado Estuary (910 km^2 at mean tide) is almost twice as large as the Guadalupe Estuary (579 km^2 at mean tide). The Lavaca-Colorado also has direct exchange of marine water with the Gulf of Mexico via Pass Cavallo and the Matagorda Ship Channel. In contrast, exchange in the Guadalupe Estuary is restricted by Cedar Bayou and is predominantly north-south exchange through the Intracoastal Waterway. The Lavaca-Colorado Estuary has higher estuarine-wide salinities (average 20.0 $\pm$ 9.5 psu from 1988-1999; Table 3) than the Guadalupe (average 13.7 $\pm$ 9.8 psu from 1987 - 1999; Table 3), which is smaller and has restricted exchange. This indicates freshwater inflow has a greater effect on the upper part of San Antonio Bay than on Lavaca Bay. This conclusion is supported by several pieces of data. At any given time salinities are lower in the Guadalupe than Lavaca-Colorado Estuary. This is true estuarine-wide and at stations A and B (nearest the river inflow source) in both estuaries. The amount of total carbon in sediments is much greater in the Guadalupe than in the Lavaca-Colorado (Montagna, 1991). Carbon content of Lavaca-Colorado sediments and Guadalupe-station D sediments are about 1%, but carbon content in the Guadalupe at station C is 3%, and at stations A and B around 4%. The carbon data indicates that organic matter is being trapped or not exported from the Guadalupe Estuary. Profiles of nitrogen content exhibit the same trends found in carbon, but there is less difference in total nitrogen content between the estuaries, both being about 0.05% (Montagna, 1991). Sediment texture is similar in both estuaries, and are characterized by silt-clay sediments, with increasing grain sizes from the upper to the lower parts of the estuaries.

Macrofauna abundance and biomass is generally larger in the Guadalupe Estuary than in the Lavaca-Colorado Estuary. The average biomass in the Lavaca-Colorado from 1988-1999 among all stations was 4.6 $\pm$3.8 $g \cdot m^{-2}$ and average abundance was 11,200 $\pm$6,800 individuals$\cdot m^{-2}$. The average biomass among all times and stations in the Guadalupe from 1987 - 1999 was 6.0 $\pm$5.0 $g \cdot m^{-2}$ and average abundance was 19,600 $\pm$14,900 individuals$\cdot m^{-2}$. The differences between the estuaries is probably due to the greater ratio of the volume of inflow relative to size of the bays. Diversity is generally greater in the Lavaca-Colorado Estuary (average 16 species found per station-date sampling period) than in the Guadalupe Estuary (average 11 species found per station-date sampling period). These results indicate that freshwater inflow is less diluted by marine water in the Guadalupe Estuary, so we find higher benthic productivity. The greater Gulf exchange in the Lavaca-Colorado leads to more oceanic species present in the that estuary, so we find higher diversity.

The long-term time series of salinity indicates there are large year-to-year fluctuations in both estuaries for freshwater inflow (Fig. 8). We have a continuous cycle of drought and flood conditions. The flood cycles are coincident with El Niño events in the western Pacific Ocean. So, climatic cycles in Texas are apparently caused by global changes. These cycles regulate freshwater inflow, and thus, directly affect the biological communities. The variability in the freshwater inflow cycle results in predictable changes in the estuary. The effects of recent El Niño events are obvious in the two estuaries. Salinities declined dramatically with the El Niño events in 1986 - 1987, 1992 - 1993, and 1997 -1998. The 1986 and 1992 events had larger effects in the Guadalupe Estuary, and the 1997 event had a larger effect in the Lavaca-Colorado

Estuary. The intervening dry periods are also different in the two estuaries. There have been two major dry periods with high salinities between El Niños: 1988 - 1992 and 1994 - 1997. We are currently in the third dry period, which began in 1998. The main difference between the two estuaries is that the smaller Guadalupe Estuary responds to flood with episodic periods of low salinity.

Whereas the effects of El Niño are seen in both estuaries, storms have more localized effects. The October 1998 is a good example. The long-term trend from mid-1997 through 1999 was a dry period with increasing salinities. However, the precipitation that caused the October 1998 flood occurred primarily in the Guadalupe watershed. Therefore, salinities in the Guadalupe Estuary were low through January 1999, whereas salinities in the Lavaca-Colorado Estuary increased.

Our study of the Lavaca-Colorado and Guadalupe Estuaries demonstrates the biological effects of this El Niño driven cycle. Flood conditions introduce nutrient rich waters into the estuary which result in lower salinity. This happened in the winter/spring of 1987, 1992 and 1997 in both estuaries. During those El Niño periods the lowest salinities and highest nutrient values were recorded. During these periods the spatial extent of the freshwater fauna is increased, and the estuarine fauna replaced the marine fauna in the lower end of the estuary. The high level of nutrients stimulated a burst of benthic productivity (of predominantly freshwater and estuarine organisms), which lasts about six months. This was followed by a transition to a drought period with low inflow resulting in higher salinities, lower nutrients, marine fauna, decreased productivity and abundances. At first, the marine fauna responded with a burst of productivity as the remaining nutrients are utilized, but eventually nutrients are depleted resulting in lower macrofauna biomass and densities. This was seen from 1989 to 1990, 1993 to 1995, and from 1997 through the present. Pulsed flood events, particularly in dry years, mitigates these patterns.

A longer record is available for station A in Lavaca Bay of the Lavaca-Colorado Estuary. These data illustrate that the long-term trend is more obvious, and that records of eight to ten years duration are much more revealing than records of only three years. There was a wet period in spring of 1985 that was of the same magnitude as the spring of 1991. To date, we have captured three wet-period cycles in the Guadalupe, and two in the Lavaca-Colorado, and two dry-period cycles in both estuaries.

CONCLUSION

The main difference between the Guadalupe and Lavaca-Colorado Estuaries relate to both size and Gulf exchange. Freshwater inflow has a larger impact on the smaller-restricted Guadalupe Estuary than in the Lavaca-Colorado. Both the smaller size and restricted inflow have synergistic effects, thus the Guadalupe is generally fresher and has higher carbon content than the Lavaca-Colorado. These conditions lead to higher benthic productivity in the Guadalupe Estuary. On the other hand, higher salinities and invasion of marine species is responsible for a more diverse community in Lavaca-Colorado Estuary. There is long-term, year-to-year variability in inflow. Higher inflow introduces higher values of dissolved inorganic nitrogen, which in turn stimulates primary production. The higher primary production, which is ephemeral and changes on very short time scales (days to weeks) drives benthic production, which changes over longer times scales (three to six months). Typically, nitrogen (which is derived from inflow and processed by estuarine organisms) is lost within the top 20 cm of sediment. Inflow also drives benthic community succession, due to different salinity tolerances of fresh, brackish, estuarine, and marine species. Due to the species changes and time scales of effects, the signal of inflow effects is easiest to measure and monitor using benthos as indicators. It is also apparent that long-term changes may be related to global climate cycles, e.g., El Niño events in the western Pacific Ocean. This study has benefitted by a statistical quirk (or trend) in climate data. There have been 11 El Niños in this century, three occurred in the first half and 8 have occurred in the second half. This short study (only 12 years) has captured three events. Because the long-term global cycles can vary from three to 20 years in length, long-term monitoring data will be required to develop reliable quantitative estimates of productivity versus inflow. Because the last few decades have been unusually wet, estimates based on the current study are likely to be over-estimates of the long-term average.

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December 13, 2000

Mr. Wayne K. Kuenstler, Director
The University of Texas at Austin
Office of Sponsored Projects
Austin, Texas 78713-7726

RE: Research Grant Contract Between the University of Texas at Austin (UT) and the Texas Water Development Board (Board), Contract No. 2000-483-323, Review of Draft Final Report "Effect of Freshwater Inflow on Macrobenthos Productivity and Nitrogen Losses in Texas Estuaries"

Dear Mr. Kuenstler:

Staff members of the Texas Water Development Board have completed a review of the draft report under TWDB Contract No. 2000-483-323. As stated in the above referenced contract, UT will consider incorporating comments from the EXECUTIVE ADMINISTRATOR shown in Attachment 1 and other commentors on the draft final report into a final report. UT must include a copy of the EXECUTIVE ADMINISTRATOR's comments in the final report.

The Board looks forward to receiving one (1) electronic copy, one (1) unbound single-sided camera-ready original, and nine (9) bound double-sided copies of the final report on this planning project. Please contact Dr. David Brock at (512) 936-0819 if you have any questions about the Board's comments.

Sincerely,

Tommy Knowles

Tommy Knowles, Ph.D., P.E.
Deputy Executive Administrator
Office of Planning

Cc: Dr. Paul Montagna, UTMSI
Dr. David Brock, Ph.D.

ATTACHMENT 1
TEXAS WATER DEVELOPMENT BOARD
Review of the Draft Final Report: Contract No. 2000-483-323
"Effect of Freshwater Inflow on Macrobenthos Productivity and Nitrogen Losses in Texas Estuaries"
Prinicipal Investigator – Dr. Paul Montagna, UTMSI

The reviewers have found that this report covers the objectives and required tasks of the contract. Some problems were noted with the report, which were likely due to the electronic transfer of the report to the agency. A change or further work on the analysis of community structure is suggested, to give full benefit of the data. Details of these and a few other minor changes are given below. With these changes, the report will be a very acceptable final product of this contract.

1. Figure 2, page 8, the title has lines typed over the top of each other. Also, the page number is sideways. This page may not be properly formatted, since the following page is blank. Please format properly.

2. The same problem occurs with Figure 3 as in Item 1.

3. Table 3 and 4 are jumbled and the page numbers are sideways. Perhaps the tables were imported from another program and did not properly transfer.

4. Figure 4 is missing a title. Please include.

5. Although the regressions presented on page 22 were not significant, it would be interesting to know how far the lines were from significance. The significance levels could be displayed in Table 5.

6. The title for Figure 19 is bumped off the page to the next page. Please correct.

7. In Figure 20, the legend in one graph is spelled out, while it is abbreviated in the other graph (and in most other figures). They should be made consistent.

8. One page 33, in the section describing the macrofaunal community structure analysis, the last sentences of the last two paragraphs are missing a verb or otherwise incomplete.

9. For the macrofaunal community structure analysis, an additional step to help get the most results from this approach is suggested. If the samples were identified by a letter or a code tied to season and/or inflow period, then the plot might give more insight. For example, the sample collection periods might be binned into inflow quadrants and warm/cool periods, and each bin given a code. These codes plotted against principal components might help illustrate your points.

10. On Page 65, the changes in carbon and nitrogen isotopes are presented in units of 0/00. There is an apparent inconsistency between the units in the text and the units given in the figures (0/0).