FINAL REPORT

STABLE ISOTOPE COMPONENT

by

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In response to House Bill 2 (1985) and Senate Bill 683(1987), as enacted by the Texas Legislature, the Texas Parks and Wildlife Department and the texas Water Development Board must maintain a continuous data collection and analytical study program on the effects of and needs for freshwater inflow to the State's bays and estuaries. As part of the mandated study program. This research project was funded through the Board's Water Research and Planning Fund, authorized under Texas Water Code Sections 15.402 and 16.058(e), and administered by the Department under interagency cooperative contract No. 9-483-705, 9-483-706, 8-483-607.

INTRODUCTION

The purpose of this study was to evaluate the use of stable carbon and nitrogen isotope ratio variations[1] for detecting and quantifying the impact of freshwater inflow on three Texas bays. The study was divided into three objectives:

1. Measurement of $\delta^{13}C$ and $\delta^{15}N$ of resident plants, animals and sediment in the three bays.
2. Determine if unique end members of the parameters were present which could be used to measure mixing.
3. Compare the isotope data to environmental variables and to other parameters being measured by other components of the overall study.

Objective 1 was accomplished and a large database reported in final reports to the Texas Water Development Board (TWDB Contracts #55-61011 and #55-71003). Objectives 2 and 3 are reported in this document.

Some background information needs to be considered in order to appreciate the stable isotope approach. The stable isotopes of carbon and nitrogen have the following approximate ratios:

$$\frac{^{13}C}{^{12}C} = \frac{1.11}{98.89} \qquad \frac{^{15}N}{^{14}N} = \frac{0.37}{99.63}$$

Due to isotope effects in chemical and physical processes these

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[1] Stable isotope ratio data is expressed in δ units, the parts per thousand difference between a standard and a sample;

$$\delta^{13}C = \frac{(^{13}C/^{12}C)_{sample} - (^{13}C/^{12}C)_{std}}{(^{13}C/^{12}C)_{std}} \times 1000$$

The carbon standard is the PDB limestone. A similar definition can be written for $\delta^{15}N$ where atmospheric nitrogen is the standard.

ratios vary slightly depending on the history of the material. In fact, as a result of kinetic isotope effects in the bio-geochemical cycles of carbon and nitrogen a series of reservoirs of these elements with fairly well resolved values of $\delta^{13}C$ and $\delta^{15}N$ exist. The study of these variations and the use of the data in ecology is an established field of investigation. Isotope ecology, as the field is called, has been generally reviewed by N.J. van der Merwe (1982). The marine aspects were reviewed by Fry and Sherr (1984) and Fry, Macko and Zieman (1987). These papers and others confirm the rule "you are what you eat in terms of $\delta^{13}C$ to within ± 1.0." This rule is the basis for using $\delta^{13}C$ to trace food-webs. The $\delta^{13}C$ values of the end-members, or potential food sources, must be known if one is to quantify relative utilization of food resources. The major end-members and their generally observed ranges for the 3 bays studied include:

Reservoir	$\delta^{13}C$	Source
Higher plants using C_3 photosynthesis	-25 to -30	river transported
Seagrasses and C_4 plants	-6 to -12	bay edges
phytoplankton	-18 to -22	open bay
benthic algae	-13 to -20	bay

Like other approaches to food-web analysis the stable isotope one has its own strengths and weaknesses. Inspection of this source shows that mixing of reservoirs may be complex because more than two sources can be involved. This is especially a problem for samples with $\delta^{13}C$ values in the phytoplankton range. Thus a -20 value may be due to the phytoplankton or to a mixture of river borne C_3 plants and marsh C_4 plants. Sometimes this ambiguity can be resolved by simply noting that the survey indicates that C_4 plants are almost absent. The presence of gradients of $\delta^{13}C$ is a useful aid for assigning sources. On the other hand biota $\delta^{13}C$ values near either end of the range of reservoirs set firm limits as to the assimilation of carbon from other sources by that biota. A noteworthy strength of the stable isotope approach is the fact that $\delta^{13}C$ of biota records, not what an organism has ingested, but what it has assimilated into tissue. The $\delta^{13}C$ value of a sample, say a fish, gives no indication of the population size of that fish nor is the $\delta^{13}C$ value dependent on the size of the population. Of course one does assume that there is a population with that approximate $\delta^{13}C$ value and that replicate analyses will give a closer approximation of the true $\delta^{13}C$ value. Population data from other studies can be combined with isotope data for various species to estimate the relative importance of food sources.

The nitrogen cycle is very different from the carbon cycle with respect to stable isotope patterns. While $\delta^{13}C$ remains nearly constant as organic matter moves along trophic levels, $\delta^{15}N$ shifts 2 to 5 per mil in the positive direction at each trophic level. The exact magnitude varies according to the organism and is not well understood. This trophic shift is the result of a metabolic flow of nitrogen whereby light nitrogen is lost, probably as ammonia or urea, and the residual tissue is left slightly heavy (Checkley and Entzeroth, 1985.; Macko et. al, 1982). Even with this added complexity $\delta^{15}N$ is a useful ecological tracer. The trophic shift leads to a pattern of $\delta^{15}N$ where primary producers are well resolved from top carnivores, and in which the complete scale of $\delta^{15}N$ is dependent on the value of the source inorganic nitrogen. The data base for $\delta^{15}N$ in this study is small compared to $\delta^{13}C$ but useful and interesting comparisons are possible.

MATERIALS AND METHODS

The collecting methods have been described in detail in earlier reports to the TWDB which have been mentioned. In general fish, shrimp, crabs, etc. were taken with small mesh nets and sediment and infauna with a grab sampler. All isotope analyses were done on carbonate free samples. Biota measurements were done on whole organisms for small animals or on muscle tissue on larger organisms. The analytical error for $\delta^{13}C$ is ± 0.2 and for $\delta^{15}N$ is ± 0.3. This is less than the biological variability associated with a population as seen in Table 8.1 This biological variability reflects a degree of randomness in the utilization of isotopically dissimilar food. It is thus related to the degree of specialization in feeding as well as to the variability of the food source. The biological variability (± 0.3) approached the experimental error (± 0.15) in the case of captive shrimp which were offered a single, well mixed diet in our laboratory. Although it is known that the random variability is complex, being dependent on behavior and source, it is reasonable to generally discuss the complete dataset with a belief that values which are different by as much as ± 1.0 per mil are significantly different.

DISCUSSION

LAVACA, SAN ANTONIO, NUECES BAYS

These three bay systems are compared in this section with respect to two major questions.

First, what is the stable isotope evidence that river inflow has a detectable effect on the food-web of biota of the three bays.

Second, are there differences in the stable isotope patterns among the three bays which can be related to environmental characteristics such as river flow or urban development.

In this discussion use is made of the databases already reported and of some of the data analyses from those reports. LAV, NUE and SAB are used to refer to the overall bays studied.

SEDIMENT

The $\delta^{13}C$ value of the total organic matter of surface sediment is integrated with respect to time and source of material. Sediment is much less mobile than biota so $\delta^{13}C$ of TOC is a long term record. The San Antonio and Nueces systems were sampled for sediment on a broad grid as shown in Figs. 8.1 and 8.2. The Lavaca system was sampled on a more restricted basis as shown in Fig. 8.3.

<u>SAN ANTONIO AND LAVACA SEDIMENTS</u>: These bays have similar $\delta^{13}C$ patterns. The most negative, -23.6, organic matter at the river mouth suggests river borne carbon for SAB. The most positive, -16.9, is near a small seagrass bed. The bay center is in the -19 to -18 range. A well defined gradient in $\delta^{13}C$ is seen in the contour map of SAB data (Fig. 8.4) and the station plot of LAV data (Fig. 8.5). Elemental analysis of SAB sediment yielded C/N ratios which ranged between 12.8 to 7.4 with the carbon rich stations being near the river mouth (Fig. 8.6). Based on these data the sediments of both bays hold essentially marine organic matter which has been mixed near the river mouths with river borne higher plant, C_3, carbon and at the bay centers mixed with some benthic algae or seagrass carbon. Gearing et. al (1977) surveyed $\delta^{13}C$ of sediment on the Gulf of Mexico shelf from the Mississippi River to Veracruz, Mexico and reported values from -19 to -26.9. Like Texas bays the most negative values were near river mouths, especially the Mississippi/Atchafalaya system.

In their classical paper on coastal sediments Sackett and Thompson (1963) reported a strong $\delta^{13}C$ gradient in the Mississippi Sound area. The river-end of the gradient had values of -28.3 to -24.3, with an average of -26.2 while the Gulf of Mexico samples were between -19 and -21. They too attributed the trend to the transport of terrestrial carbon by rivers. The $\delta^{13}C$ signal was lost in the marine background over a distance of 10-20 miles in their study and in a few miles in our study with its much smaller river.

All samples used in our study were surface sediments. $\delta^{13}C$ data on cores would provide a history of the sources of organic matter in these bays. At the present time San Antonio and Lavaca Bays are fairly similar with respect to sedimentary organic matter. This similarity will also be seen in $\delta^{13}C$ of many biota.

<u>NUECES BAY SEDIMENT</u>: $\delta^{13}C$ of TOC of sediment ranged from -20.65 to -16.02 over the 36 stations. The more negative values found in SAB and LAV are absent and several stations are in the -16 to -17 range. The contour map of $\delta^{13}C$ indicates that river borne organic carbon is not a strong contributor to the sediment mix, especially when compared to SAB and LAV (Fig. 8.7). The map shows a clear input of more positive carbon near the mouth of the Laguna Madre. This probably represents seagrass carbon from the extensive beds in the Laguna. The contour map of C/N ratios for NUE does not show the high (10+) values that normally would be expected if river borne higher plant carbon were present (Fig. 8.8). The center of the Nueces/Corpus bay systems is normal marine in character. The influence of seagrass beds will be seen to be even more intense in the biota of NUE.

The two major questions posed at the beginning of the DISCUSSION can be answered for sediment. First, river flow does have a readily detectable effect on $\delta^{13}C$, %C, %N and C/N ratio of sediment for Lavaca and San Antonio Bays, but a much weaker signal in Nueces Bay. Second, this difference among the bays may be related to the modest and highly controlled rate of river inflow for NUE. The $\delta^{13}C$ pattern for NUE is certainly related to the nearness of the seagrass beds of the Laguna Madre.

PARTICULATE ORGANIC MATTER (POM)

POM is a mixture of living and detrital organic matter which is retained on a glass fiber filter. It is a general indicator of the nature of organic carbon in the water column, but it is highly influenced by day to day variations. Nevertheless it serves as an excellent carrier of the ^{13}C tracer in the $\delta^{13}C$ approach. The POM data for SAB is a case in point. POM - $\delta^{13}C$ data in Figure 8.9 indicates that river transported, higher plant POM dominates the system for the study period, one of river flood. If this same data is viewed by season as in Figure 8.17B a more refined picture is seen. The POM shifts from near marine values of -23 in JAN-86 to -25 to -26 in JUN-87. The river flood took place in APR-87. The very negative NOV-86 values also indicate a strong terrestrial signal but must be associated with an earlier inflow. Since inner and outer bay stations show the same trends in Figure 8.17B the POM is fairly well mixed.

Comparisons of the three bays suggests that NUE receives much less river borne POM than SAB and LAV (Fig. 8.9 and 8.10). All three bays have some phytoplankton signal at -18 to -20. SAB and LAV have strong terrestrial signals. This is so even when the river and bay stations in LAV are tabulated independently (Fig. 8.9). The POM $\delta^{13}C$ patterns for the three bays will be a repeated theme in the evaluation of the $\delta^{13}C$ data for biota.

BIOTA

The database for $\delta^{13}C$ of biota from the three bays is large and suitable for posing answers to the two general questions. For all three bays 830 $\delta^{13}C$ analyses were made on 25 species of fish over the four year study period. For this reason correlations, patterns and pathways have been sought in some detail from the fish measurements.

FISH: All data for $\delta^{13}C$ of fish are represented in Fig. 8.11. The absence of values more negative than -21 in NUE is striking. Seagrass and benthic algae are the source of the peak at -14 to -12, while phytoplankton mixed with these sources can account for the more negative fish at -21 to -15. River borne carbon is not significantly present in NUE fish. This seagrass shift for fish is seen despite the fact that little evidence of seagrass POM was seen in Figure 8.9. One must conclude that the fish (or fish-food) are moving out of seagrass dominated feeding areas which are remote from the sampling sites. This is seen in Figures 8.19A-C wherein seagrass stations and bay stations are all well within the seagrass influence. By contrast, in SAB the seagrass and bay stations are well resolved in $\delta^{13}C$.

SAB and LAV fish show a strong river influence. LAV fish are distributed around -20 in a pattern that is consistent with a strong phytoplankton signal, but with important river borne and benthic plant inputs. Figure 8.11 for LAV is plotted so that one can consider the bay and river stations separately. The bay stations average -19.92 ± 2.07 and the river -20.98 ± 2.79 which are different by the t-test. The peak for bay - only stations is about 1 per mil less negative than for all stations. However, fish which show a terrestrial signal are present at the bay stations so that the influence of the river is real. If only the bay stations are considered (Figure 8.12) only a slight, perhaps 10%, river signal is seen. SAB supports small seagrass meadows which, with benthic algae, are probably the source of the less negative carbon at -13 to -15. Once again the carbon cycle in NUE is distinct from that of LAV and SAB.

Table 8.2 is a summary of data for $\delta^{13}C$ of fish, by common name, which were found in all three bays or in any two bays. All stations are included, river and bay, but it should be noted that all of the fish are marine. In every three bay case, NUE fish are less negative than SAB or LAV supporting the stated generalizations for NUE. Several species, such as menhaden and silverside, show a 25 to 50% river signal. The species common to SAB and LAV all have very similar $\delta^{13}C$ values. The one case, Black drum, wherein NUE is more negative than SAB is interesting, but based on a single fish. LAV and SAB are fairly similar with regard to the fish foodweb based on $\delta^{13}C$ data. NUE is different, little influenced by river organic matter, but strongly shifted toward benthic plants and seagrass.

<u>SHRIMP</u>: Shrimp show the same shift in $\delta^{13}C$ for NUE as do fish, the seagrass influence. LAV and SAB are essentially planktonic in $\delta^{13}C$, but show modest benthic/seagrass and river input at the

two extremes (Fig. 8.13).

CRABS: Crabs show the shift toward seagrass in NUE. The influence of river borne carbon is somewhat stronger in SAB and LAV, but the overall pattern is that which is seen for other carbon reservoirs in these bays (Fig. 8.14).

INFAUNA: The infauna in SAB is strongly shifted toward river borne carbon, perhaps as a result of the flood conditions of the river followed by settling of detritus to the bay bottom (Fig. 8.15). LAV is essentially planktonic with a significant river contribution. Bay and river stations of LAV are treated separately in Figure 8.15 so that the influence of plankton on the bay stations is more obvious. The database for NUE is small and includes data from earlier work (Fry and Parker, 1979). No river influence is obvious for NUE. The impact of the river on LAV is seen in the gradient of $\delta^{13}C$ in Fig. 8.16B.

SEASONAL CHANGES IN $\delta^{13}C$ OF BIOTA: Large scale trends can be influenced by seasonal or rainfall changes. In order to evaluate these trends a number of specific comparisons have been made. Figures 8.17 A&B show such trends for SAB at inner and outer bay stations. The shift toward more negative values is due to high river flow which transported upland and marsh carbon into the bay. This response to terrestrial organic matter is most dramatic for decapods and fish including both inner and outer stations. Figure 8.18 shows similar plots for NUE, but the strong river signal seen in SAB is absent.

SEAGRASS BEDS: Figures 8.20 A&B show $\delta^{13}C$ of selected fish and invertebrates in relation to habitat and relative distance from river input in SAB. Seagrass sites (near the shore) are paired with a corresponding open-water site, with paired sites being less than 2 km apart. The seagrass does introduce a level of fine structure. Similar trends are seen for NUE in Figs. 8.19 A, B&C.

FEEDING GROUP EFFECTS: While $\delta^{13}C$ is an excellent tracer for detecting the importance of various plant types in foodwebs it is somewhat less useful for following these plant types through the complete foodweb. It loses resolution as one goes to higher levels. Nevertheless it is informative to attempt a feeding group analysis as in Figures 8.21 and 8.22. The groups shown in these figures are based in part on taxonomy and in part on generally held views of feeding relationships.

Animals were grouped by feeding type into 10 categories based on the known feeding behavior of these species: (1) pelagic fishes (bay anchovy, gulf menhaden, tidewater silverside), (2) benthic suspension feeders (bivalves),(3) amphipods (including zooplankton),(4) polychaetes, (5) omnivorous benthic fishes (croaker, goby, bay whiff, flounder, sea catfish, etc.), (6) decapods (blue and stone crabs), (7) omnivorous predatory fishes (killifish, pipefish), (8) herbivorous fish (mullet), (9) shrimp (white, brown, grass), and (10) benthic predatory fishes (drum, spot, pinfish, etc.) The herbivorous fishes are among the most ^{13}C enriched in both SAB and NUE while the pelagic fishes are the most ^{13}C depleted. If one accepts the terrestrial vs marine model then one can conclude that pelagic fish are more influenced by rivers. It is important to note that for both systems the inner bay always shows the river signal. The end members of plant materials are measured values with extreme values from single analyses dropped. Seagrass in SAB is somewhat more negative than usual, probably due to light CO_2 from the river.

NITROGEN: A modest study of $\delta^{15}N$ of the three bay ecosystem was undertaken as part of this study. The data for all three bays shows the so called "trophic enrichment" whereby $\delta^{15}N$ increases 2-5 per mil at each foodweb junction (Figure 8.23). For LAV, $\delta^{15}N$ of sediment averages +5.4 ± 0.54 for five stations - a narrow range. This average is close to values for primary producers, +4.7 ± 1.9. The fact that the sediment is so near zero suggests that it is not prone to great exports of nitrogen which might shift it to more positive values. This is also the range that has been reported for many marine sediments, (Sweeney and Kaplan, 1980; Peters, et al, 1978). The SAB $\delta^{15}N$ values shown in Figure 8.23 follow a similar trophic pattern which indicates between 4 and 5 trophic levels. A noteworthy difference between SAB and LAV or NUE is that SAB values range up to +17 and are consistently more positive. Figure 8.24 demonstrates that SAB $\delta^{15}N$ is consistently heavy when compared to LAV or to a similar study at Sapelo Island, Georgia. This kind of shift suggests that inorganic nitrogen with an unusually positive $\delta^{15}N$ is present. Such nitrogen could be river derived or produced from within the system by some unknown process. This is a major departure from the usual and expected pattern which could be significant. However an in-depth study would be needed to approach a solution.

RIVER INFLUENCE: A central question for this study has been - what is the stable isotope evidence that the rivers are having a direct and significant influence on the foodwebs of the three bays which were examined? Further one would like some sense of the spatial and temporal extent of this influence. Partial answers to these questions have been given in the text of this report, but it is useful to summarize and generalize these relationships.

The isotope data base measured for these three bays is probably the largest one on record for such biological studies. The study covered about four years - two years in LAV and one each in NUE and SAB. The NUE and SAB were sampled on a well found grid, but only for one year each. LAV was sampled for two years but on a non-grid series of sampling stations, one-half of which were river stations. These are the constraints of the study. One further constraint is that we were never able to obtain a detritus free sample of phytoplankton so that our interpretation is based on a phytoplankton $\delta^{13}C$ end member of -20 ± 1 which is consistent with most studies of temperate waters (Fry and Sherr, 1984). In fact the benthic algae were close to this value when one excludes one rare red-alga which was an epiphyte in SAB. We have taken -26 ± 1 as the terrestrial, C_3, end member. With these end members a mixing line will be like the following:

Marine Carbon	25% TC	50% TC	75% TC	Terrestrial (C_3) Carbon (TC)
-20	-21.5	-23	-24.5	-26

Most of our discussions are based on averages but one should be aware that single observations - single samples - have meaning for the ecosystem.

SEDIMENT: The $\delta^{13}C$ and C/N data leave no doubt that there is a significant quantity of terrestrial carbon in the sediments of the LAV and SAB systems. The contour of $\delta^{13}C$ - SAB indicates that 50% of the total organic carbon (TOC) in the 2.5 mile long Guadalupe Bay (near the mouth of the Guadalupe River) is river transported terrestrial TOC (Figure 8.4). This strong river signal drops to slightly less than 35% terrestrial carbon in the next 2.5 miles down-bay. The balance of SAB sediment should be characterized as marine. Given that terrestrial carbon is entering the bay one wonders where it goes. The answer is that it is either metabolized to CO_2 and lost to the atmosphere and/or that it is present in some other carbon reservoir. LAV sediment data is difficult to compare to SAB and NUE for the reason stated - a different sampling plan. When all stations are considered for LAV the pattern is that of Figure 8.5. (Note: one bay sample at station 35/36 has been dropped.) Thus the system is being treated as if all stations were bay stations, and we know they are not. Nevertheless it is interesting that the curve is that of a mixing line of marine and terrestrial carbon. It may well be that the river bed at the time of sampling actually contained some marine carbon, or C_4 marsh plant carbon. If only the bay stations are plotted the curve indicates only marine carbon. NUE lacks the river mouth/delta terrestrial carbon seen in LAV and SAB in terms of $\delta^{13}C$ and C/N ratio. Either river transported terrestrial carbon is absent in NUE or it is over whelmed by the seagrass signal which is clearly seen in the contour (Figure 8.7). The river signal in sediment is quickly lost - within a few miles - or it is lost in the signal from seagrass and marine sources. One must look elsewhere for the river signal.

POM: The river signal seen in $\delta^{13}C$-POM for SAB firmly establishes the presence of river transported POM at every station (Figure 8.9 and 8.17A). The spring 1987 floods, which freshened SAB, probably flushed great quantities of POM into the bay. However, according to Figure 8.17A both the inner and outer bay held -26/-27 POM in Nov. 1986, prior to the spring 1987 floods. One must assume that earlier transport had been heavy. By Jan. 1987, both the inner and outer bays had shifted toward more marine values, but quickly moved to river-like values in the spring and summer as noted.

LAV also shows a strong river signal for POM (Figure 8.9). The bay and river stations are coded in the figure so that the river stations are seen to be richer in terrestrial organic matter, but bay stations account for almost one-half of the terrestrial shown. Figure 8.10 compares only the bay stations of LAV and shows a gradient from the outer most to the inner bay shore station. The inner bay stations (633 and 85), an area of about 36 square miles, are 60-70% terrestrial POM. In the distance between station 85 and 1505, ≈ 7 miles, the river signal falls to about 10%.

POM is probably the major mechanism for the transport of organic matter over long distances. Strictly speaking zooplankton are part of the POM, the living POM. They may also feed on the non-living POM including the river signal. We reported earlier in the LAV Bay Report that picked zooplankton and a specific zooplankton, <u>Acartia</u>, showed a river to bay gradient in $\delta^{13}C$. These figures and their data base are included herein as Figures 8.25 and 8.26 to support the POM data and to show the importance of single analyses (of many zooplankton). If one includes the zooplankton data in the POM then the river signal is bay wide at the 50% level.

INFAUNA AND FISH: Figure 8.15 demonstrates that the infauna in SAB is more than 50% river transported terrestrial organic matter. The importance of this, and perhaps the SAB study in general, is that it shows that terrestrial organic matter can be the dominant nutrient under conditions of flood and implies that it is highly significant in "normal" river flow. Figure 8.16B shows a gradient for infauna plus bivalves in LAV at the bay stations only. The pattern is much like the POM, a substantial signal in the inner bay grading into a marine signal in the outer bay.

INFLUENCES: The influence of river transported organic matter has clearly been demonstrated for SAB and LAV based on $\delta^{13}C$ data. For SAB the influence on reservoirs which respond quickly, as POM, is bay wide. For LAV it follows a gradient. NUE shows a gradient that is more related to input of carbon from the seagrasses of the Laguna Madre than the river. The data analysis in this report is based on using averages of many observations so that more general conclusions can be sought. However, from the point of view of the ecosystem specific observations or ranges may be equally important.

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TABLE 8.1

$\delta^{13}C$ OF ORGANISMS TAKEN IN THE SAME TRAWL (LAV).

Individual	Sta. 613 w. shrimp	Sta. 85 croaker
1	-21.39 (2)*	-22.46 (2.1)
2	-18.98 (2.5)	-23.24 (2.5)
3	-19.16 (3)	-23.18 (2.7)
4	-22.32 (3)	-23.13 (3.3)
5	-18.42 (3)	-22.28 (3.3)
6	-18.55 (3.5)	-22.52 (3.8)
7	-19.12 (3.5)	-22.27 (4.5)
8	-20.43 (6)	-20.10 (4.8)
x ± s.d.	-19.71 ± 1.52	-22.4 ± 1.01

* length in cm

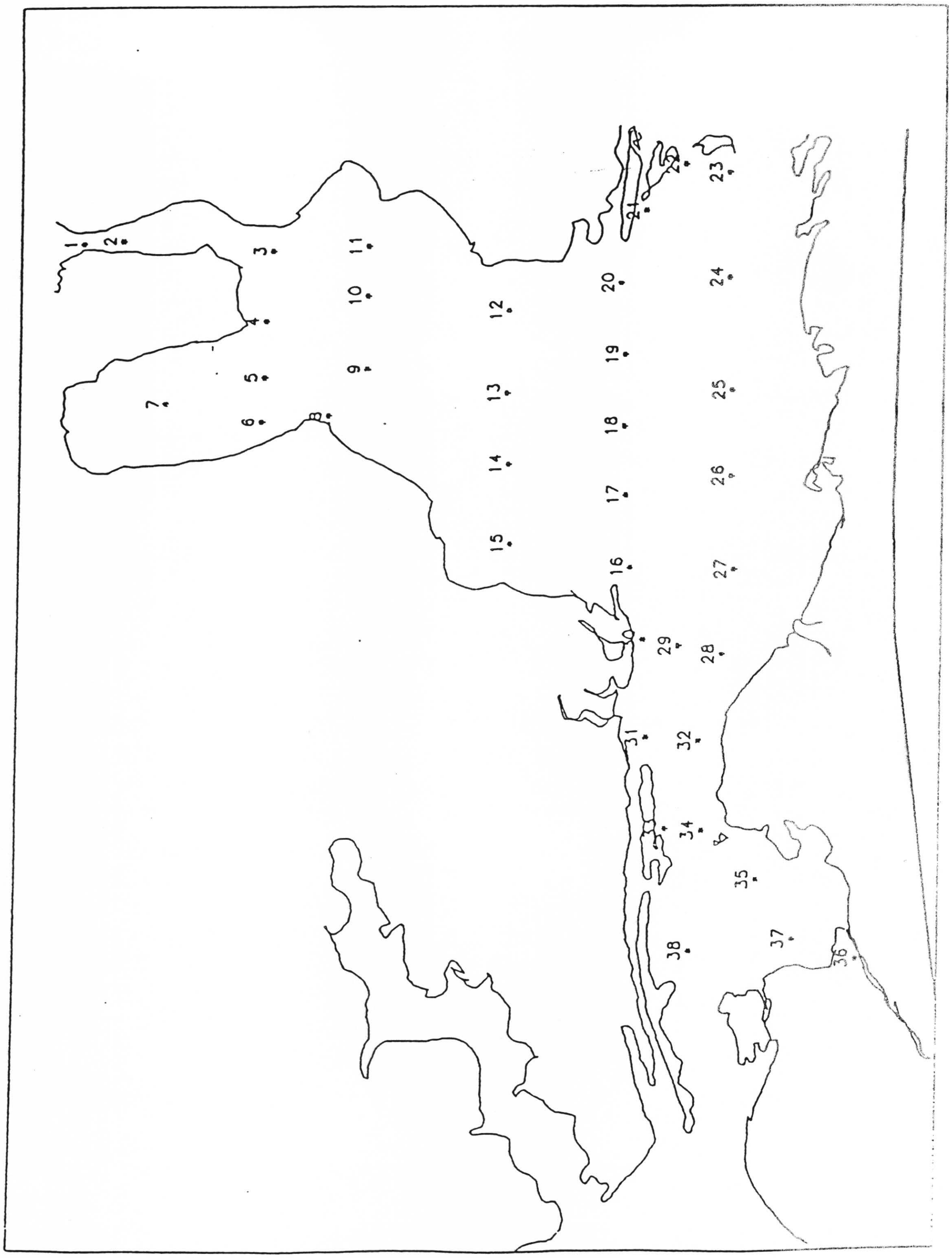


Figure 8.1 Station locations for sediment (SAB).

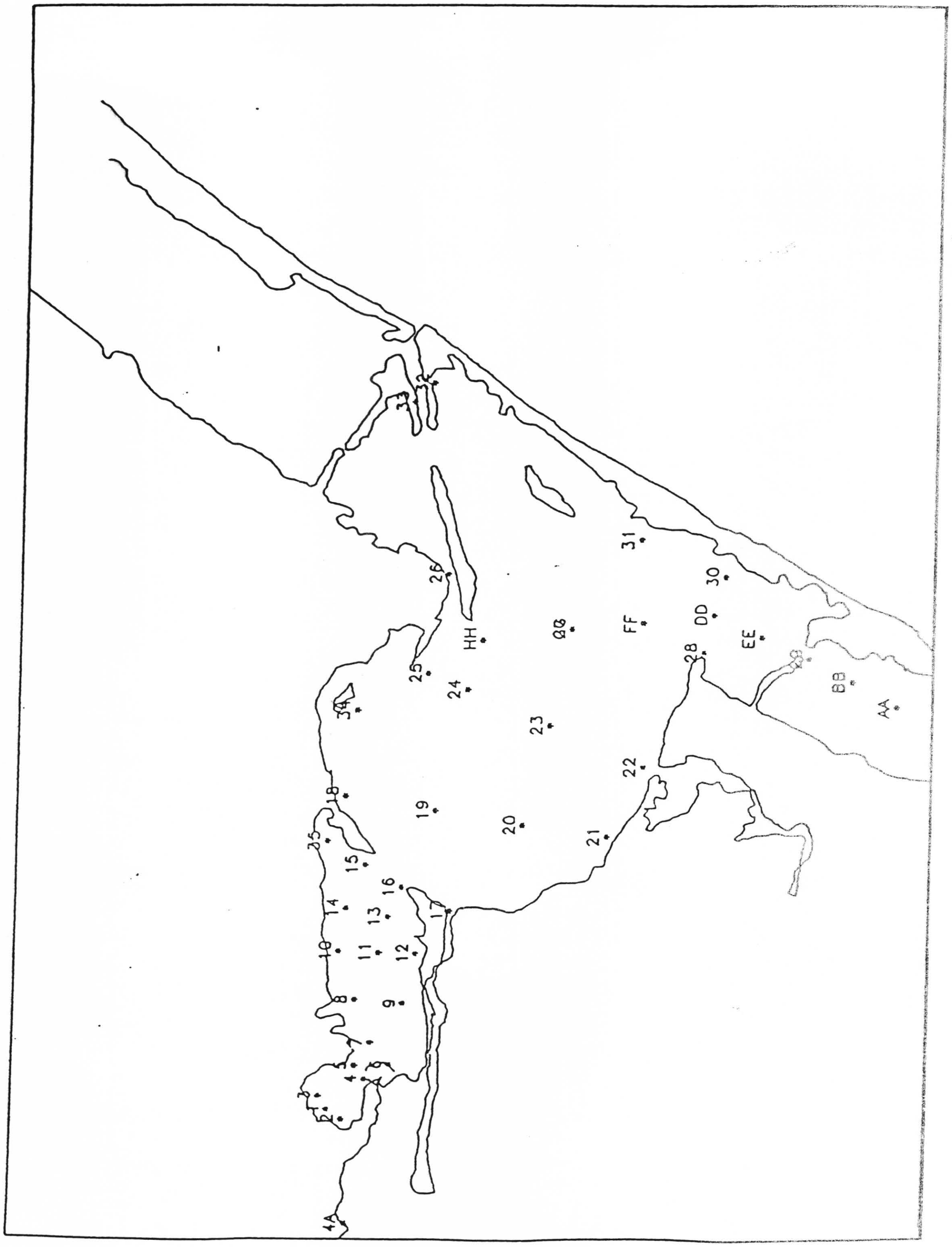


Figure 8.2 Station locations for sediment (NUE).

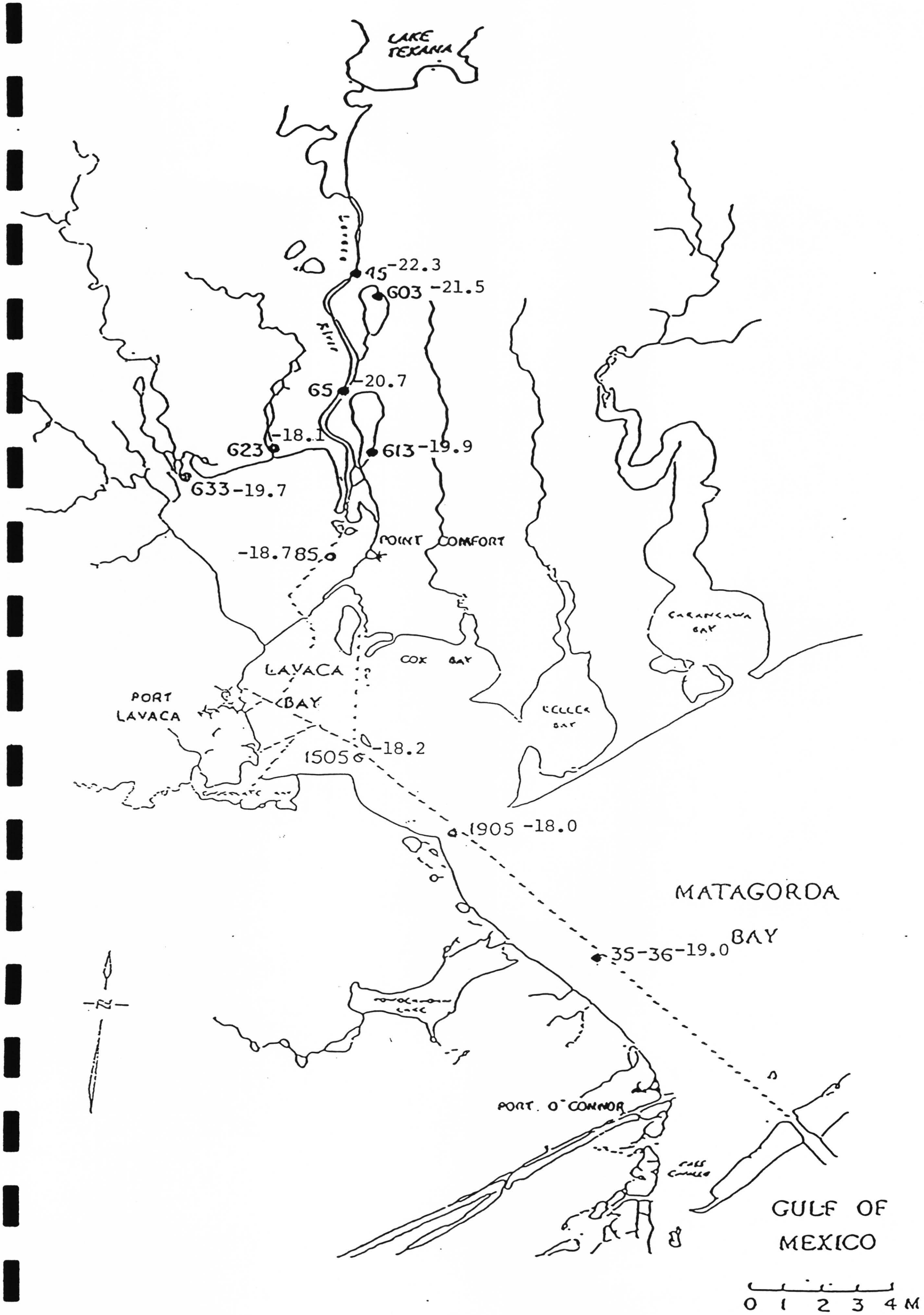
LAKE TEXANA
15 -22.3
603 -21.5
65 -20.7
623 -18.1
613 -19.9
633 -19.7
POINT COMFORT
-18.7 85
CARANCAWA BAY
COX BAY
LAVACA BAY
PORT LAVACA
1505 -18.2
1905 -18.0
MATAGORDA BAY
35-36 -19.0
N
PORT. O'CONNOR
GULF OF MEXICO
0 1 2 3 4 M

Figure 8.3

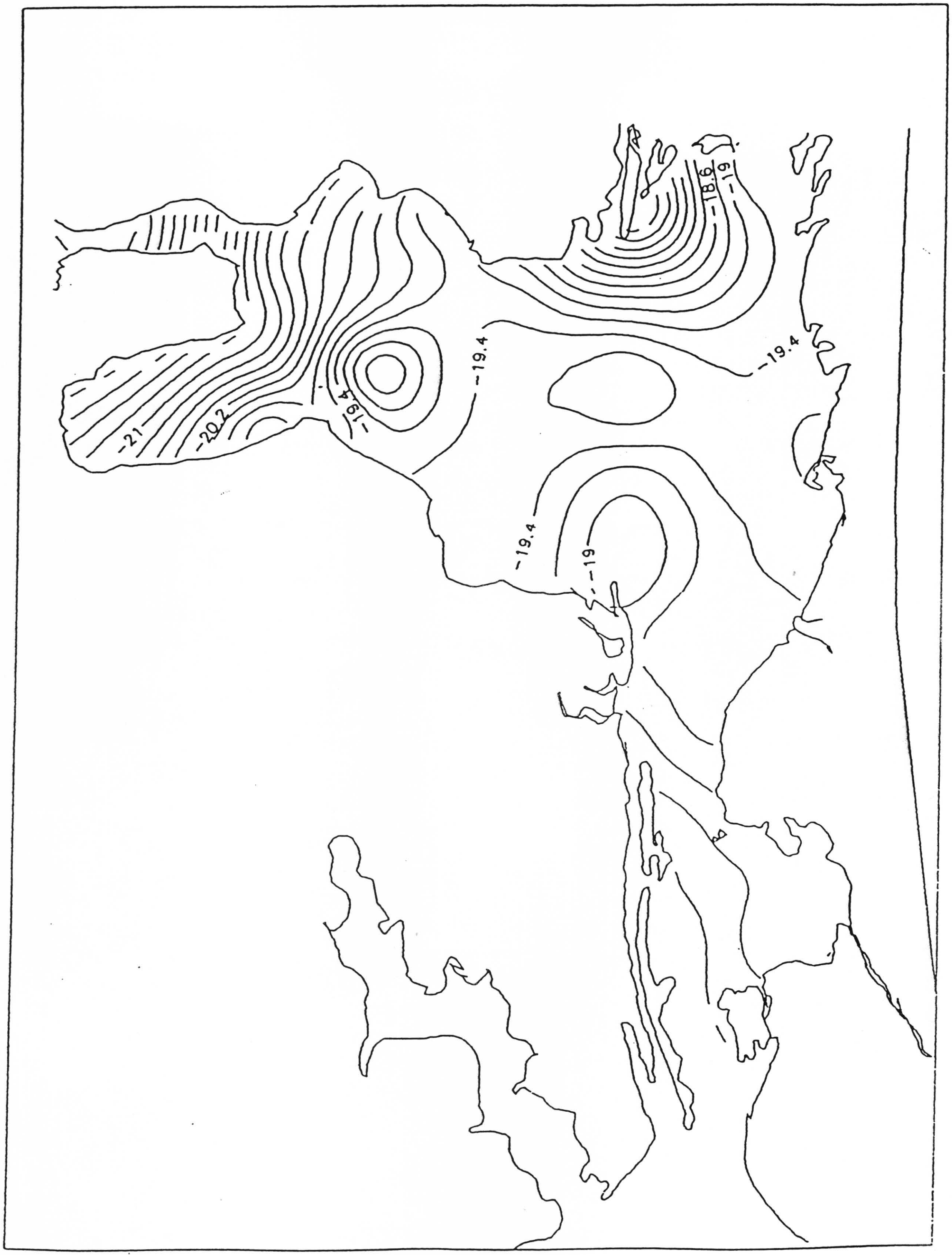
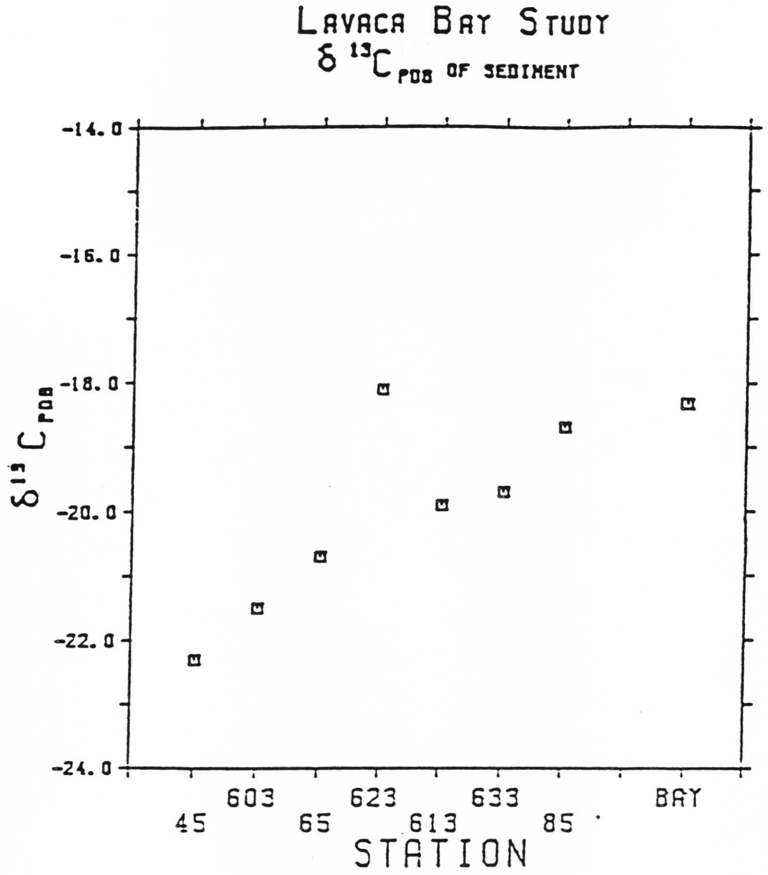


Figure 8.4 Contour of $\delta^{13}C$ for sediment TOC (SAB).


LAVACA BAY STUDY
δ 13C PDB OF SEDIMENT
δ13 C PDB
-14.0
-16.0
-18.0
-20.0
-22.0
-24.0
45
603
65
623
613
633
85
BAY
STATION

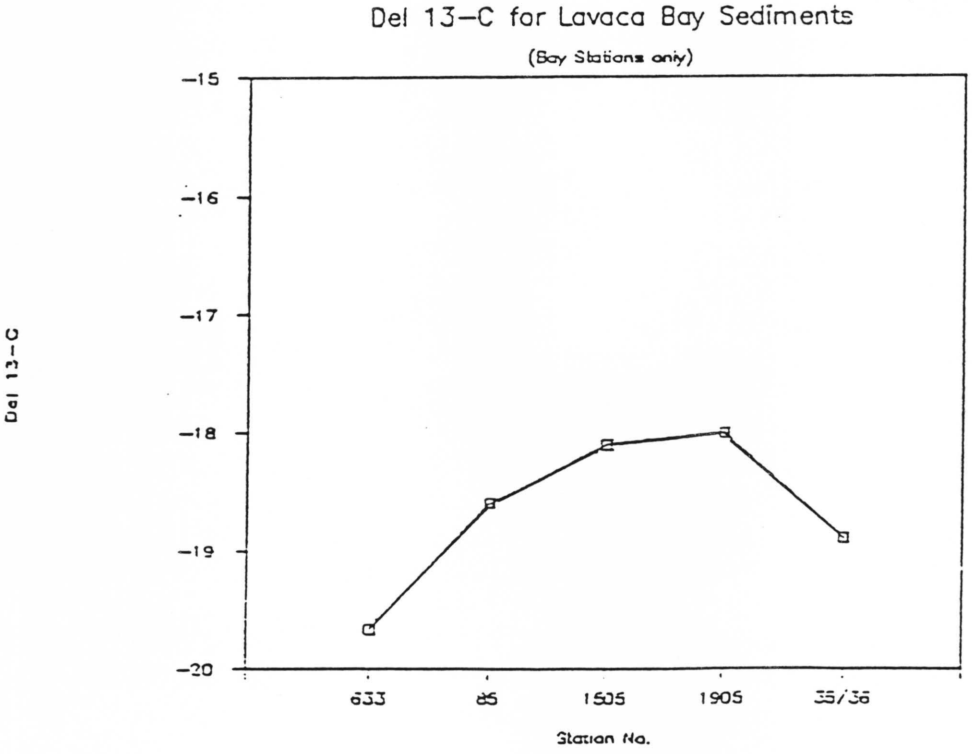

Del 13–C for Lavaca Bay Sediments
(Bay Stations only)
Del 13–C
–15
–16
–17
–18
–19
–20
633
85
1505
1905
35/36
Station No.

Figure 8.5

C/N Ratio – San Antonio Bay Sediments

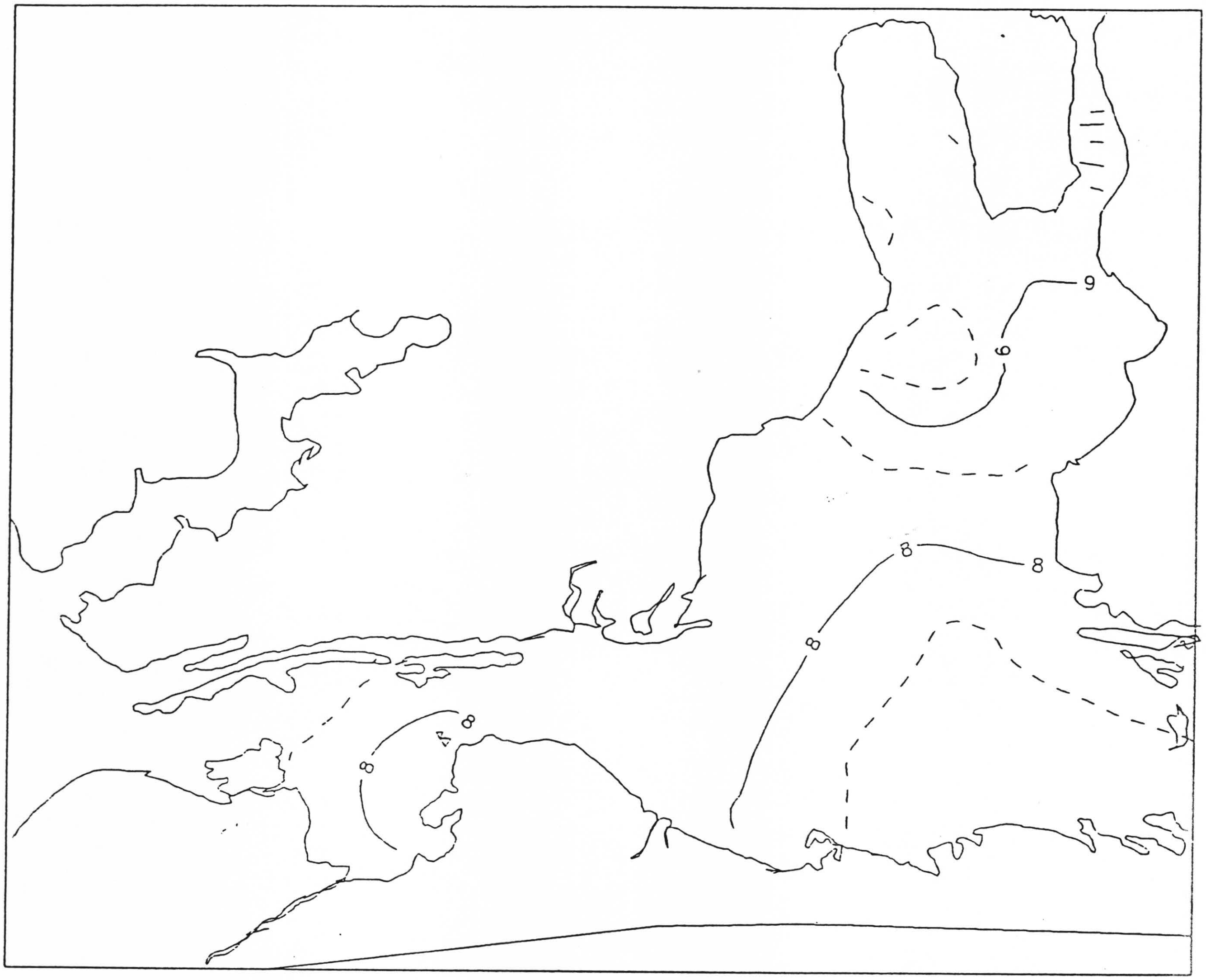


Figure 8.6

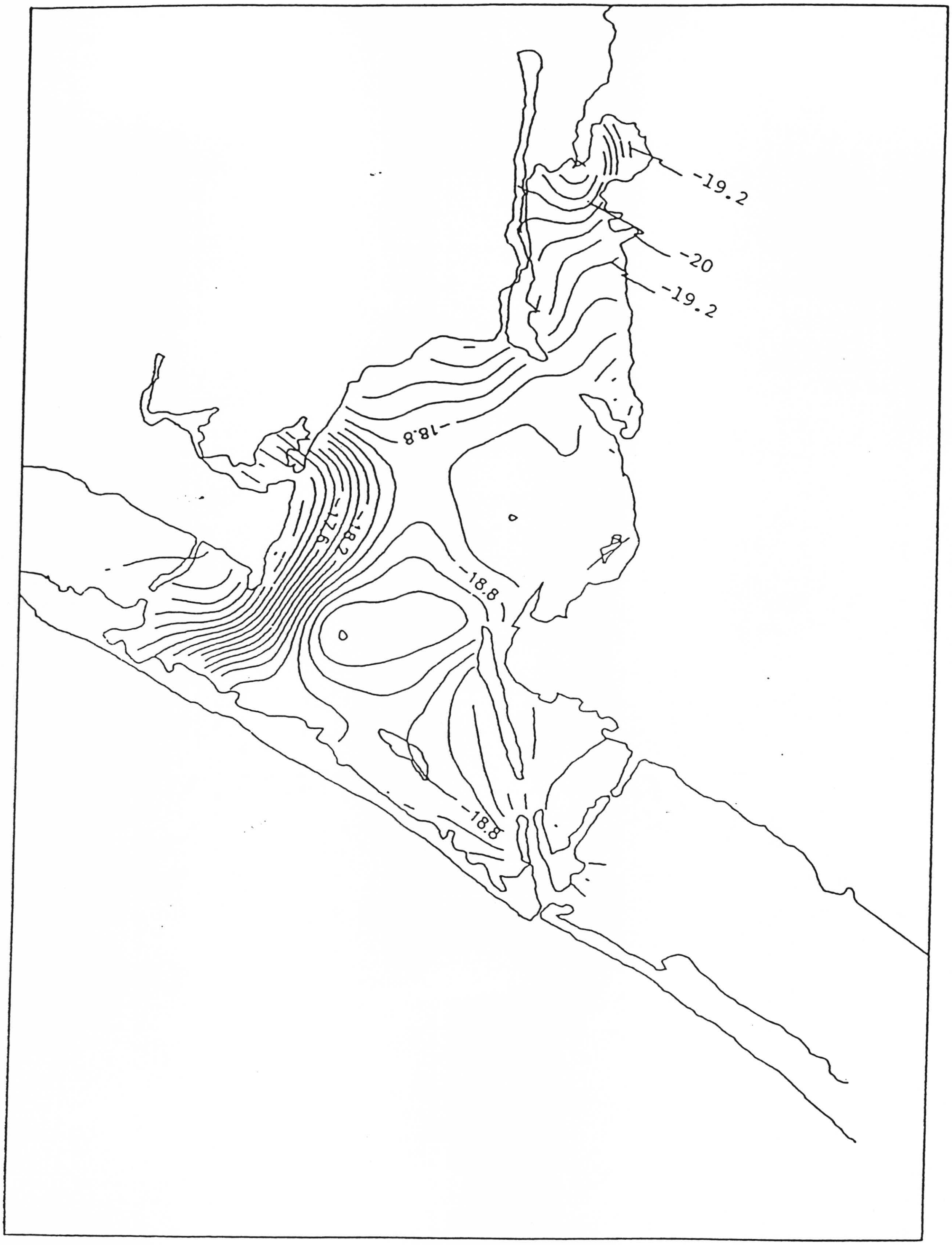


Figure 8.7 Contour of $\delta^{13}C$ for sediment TOC (NUE).

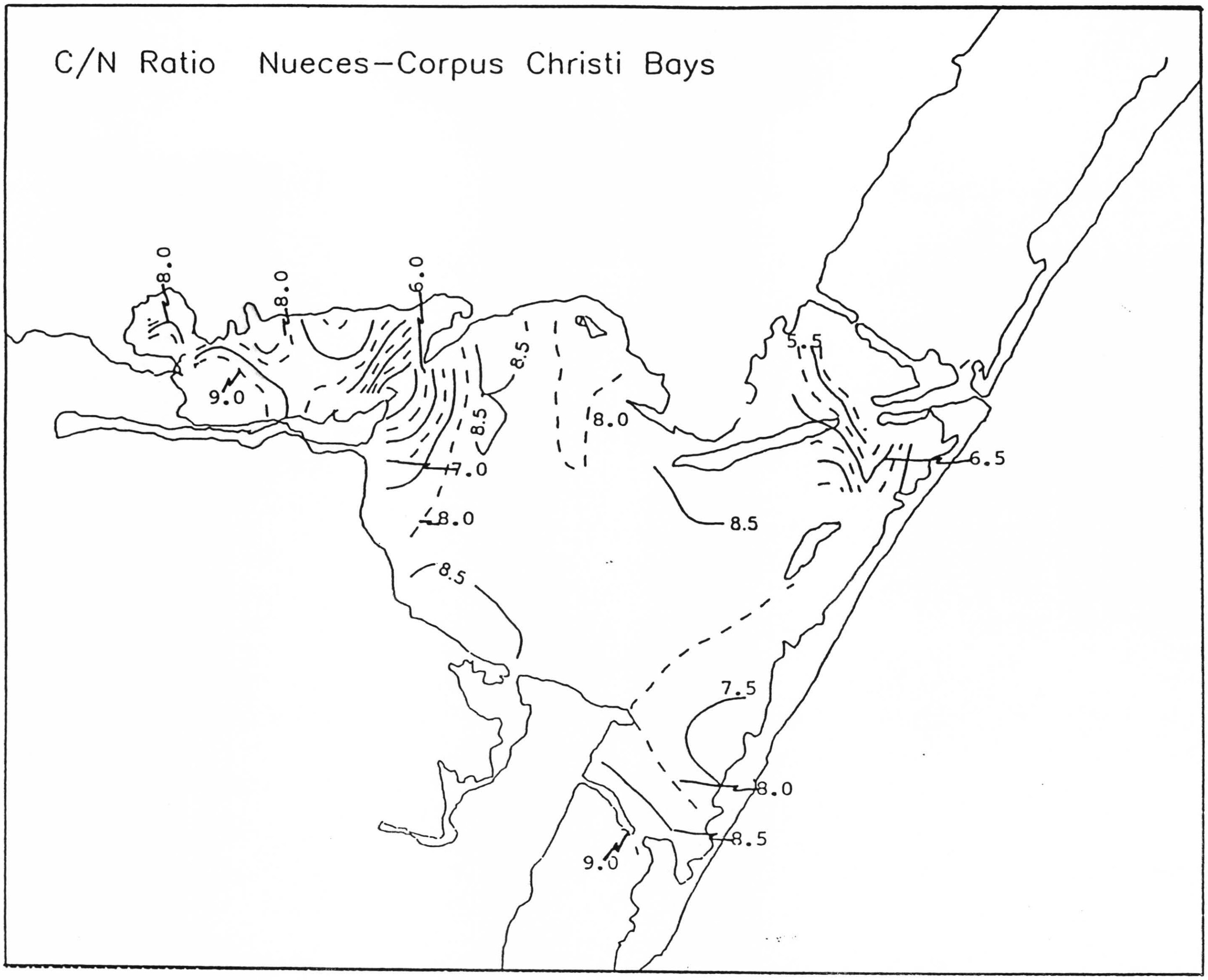

C/N Ratio Nueces–Corpus Christi Bays
8.0
8.0
6.0
9.0
8.5
8.5
8.0
5.5
6.5
7.0
8.0
8.5
8.5
7.5
8.0
8.5
9.0

Figure 8.8

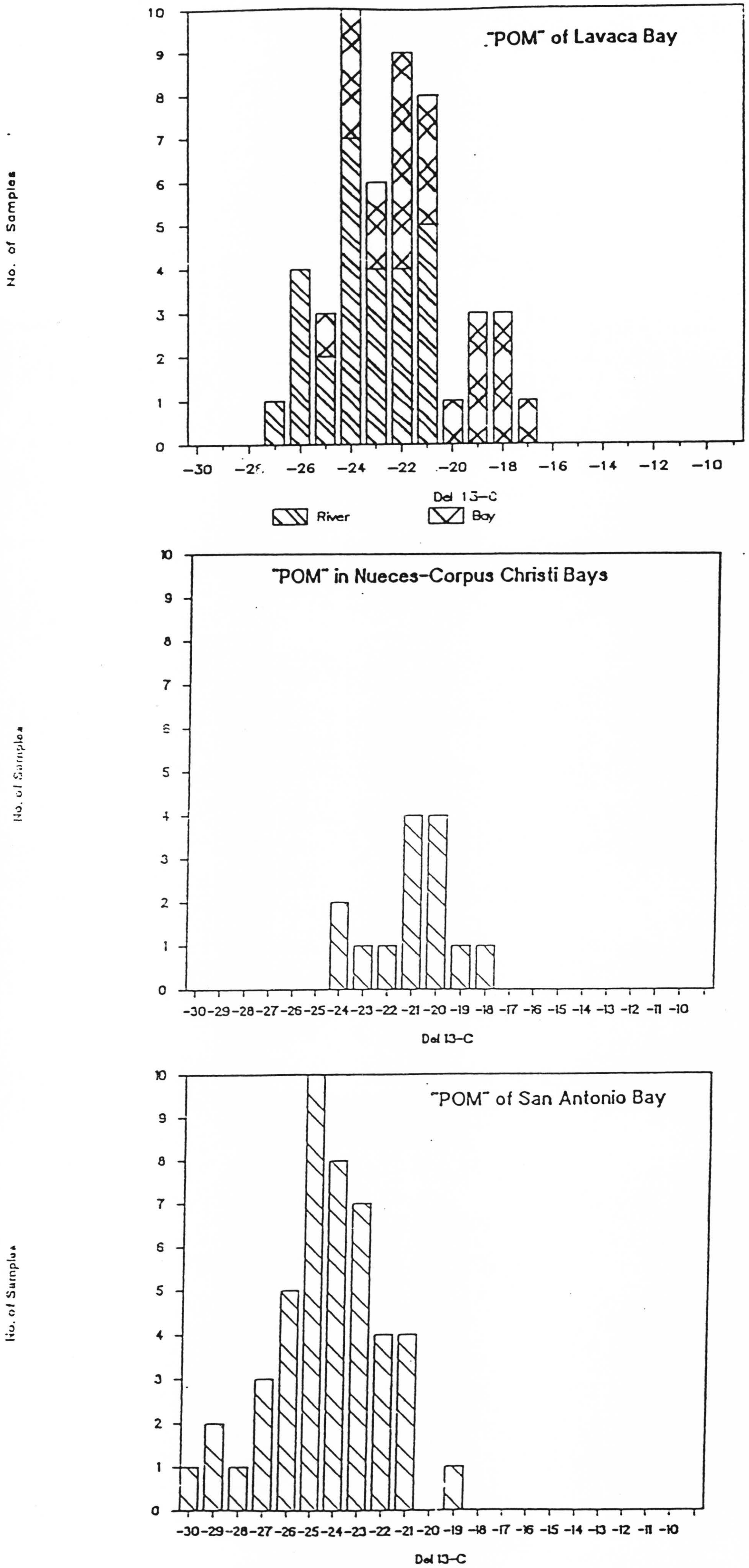


Figure 8.9 $\delta^{13}C$ of POM for all bays.

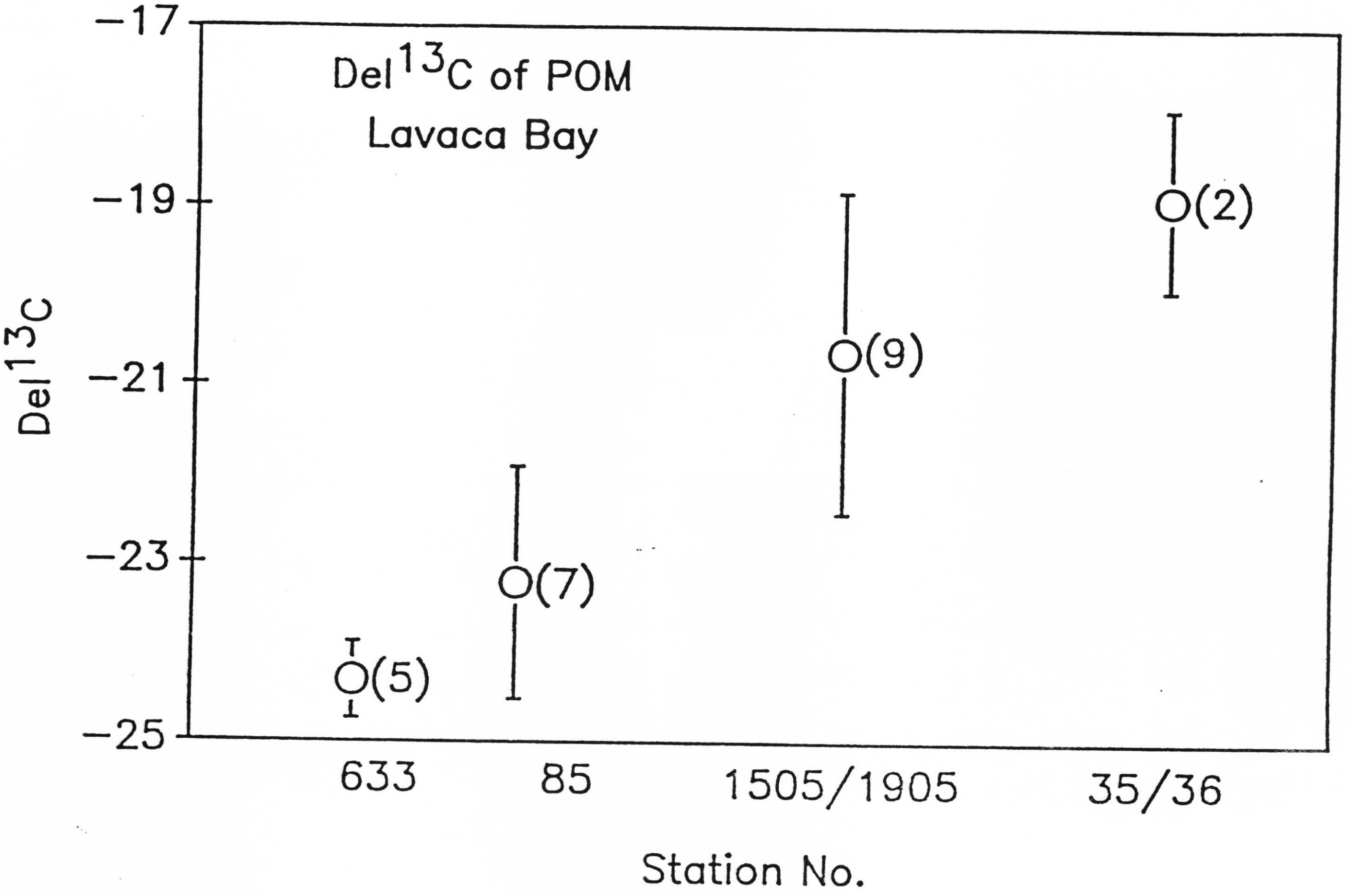

Del^{13}C of POM
Lavaca Bay
Del^{13}C
−17
−19
−21
−23
−25
(5)
(7)
(9)
(2)
633
85
1505/1905
35/36
Station No.

Figure 8.10

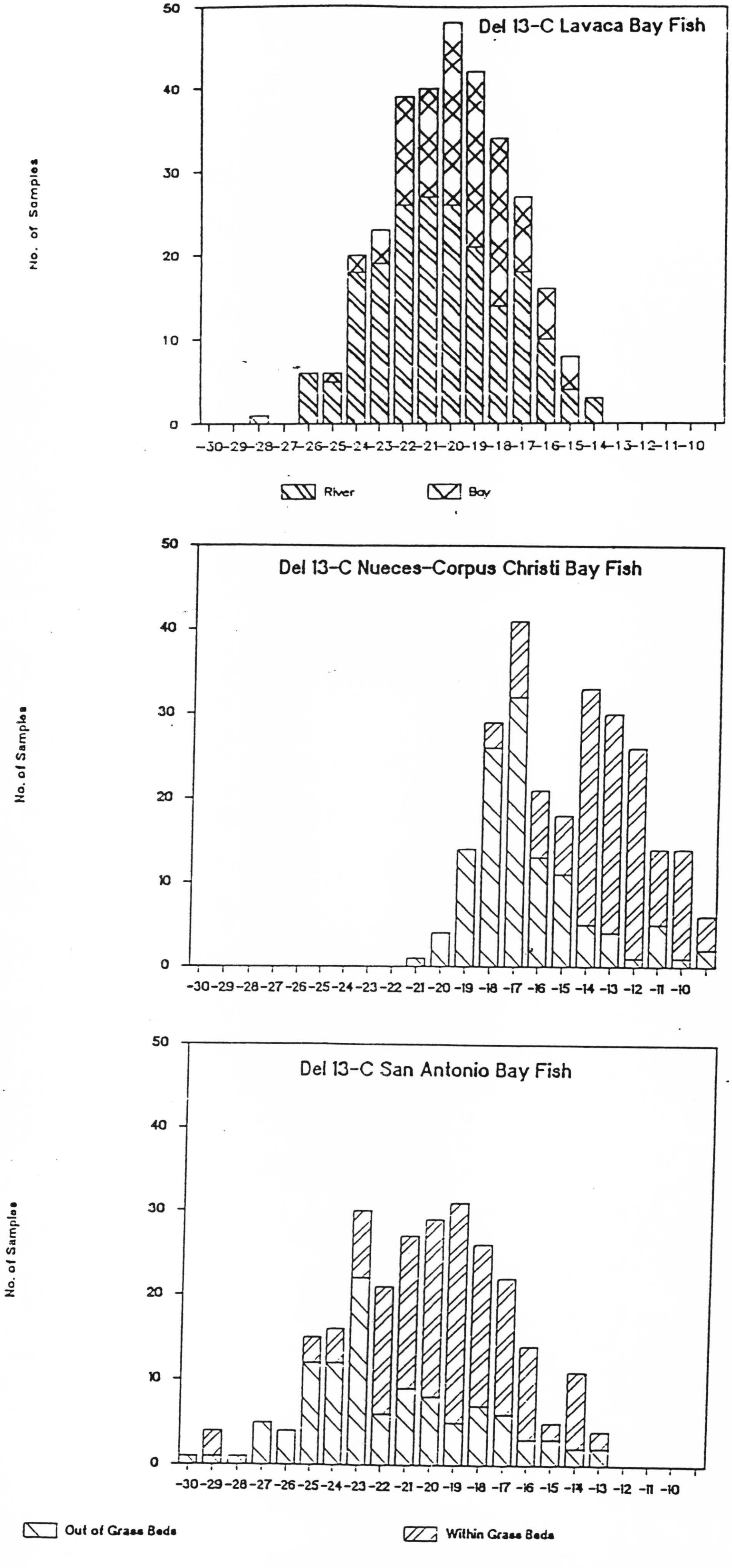

Del 13-C Lavaca Bay Fish
No. of Samples
0
10
20
30
40
50
-30-29-28-27-26-25-24-23-22-21-20-19-18-17-16-15-14-13-12-11-10
River
Bay
Del 13-C Nueces-Corpus Christi Bay Fish
No. of Samples
0
10
20
30
40
50
-30-29-28-27-26-25-24-23-22-21-20-19-18-17-16-15-14-13-12-11-10
Del 13-C San Antonio Bay Fish
No. of Samples
0
10
20
30
40
50
-30-29-28-27-26-25-24-23-22-21-20-19-18-17-16-15-14-13-12-11-10
Out of Grass Beds
Within Grass Beds

Figure 8.11

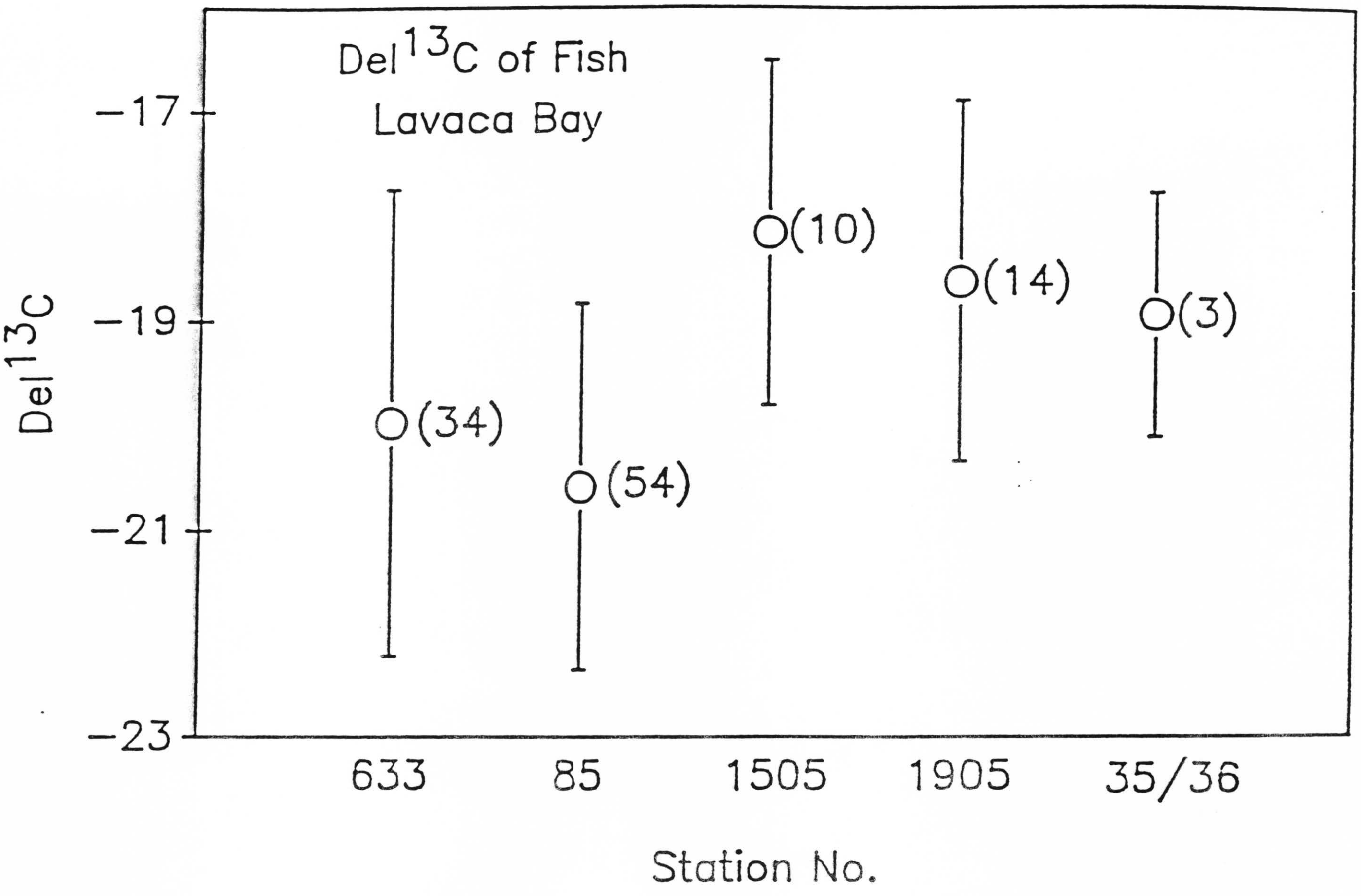

Del^{13}C of Fish
Lavaca Bay
Del^{13}C
-17
-19
-21
-23
(34)
(54)
(10)
(14)
(3)
633
85
1505
1905
35/36
Station No.

Figure 8.12

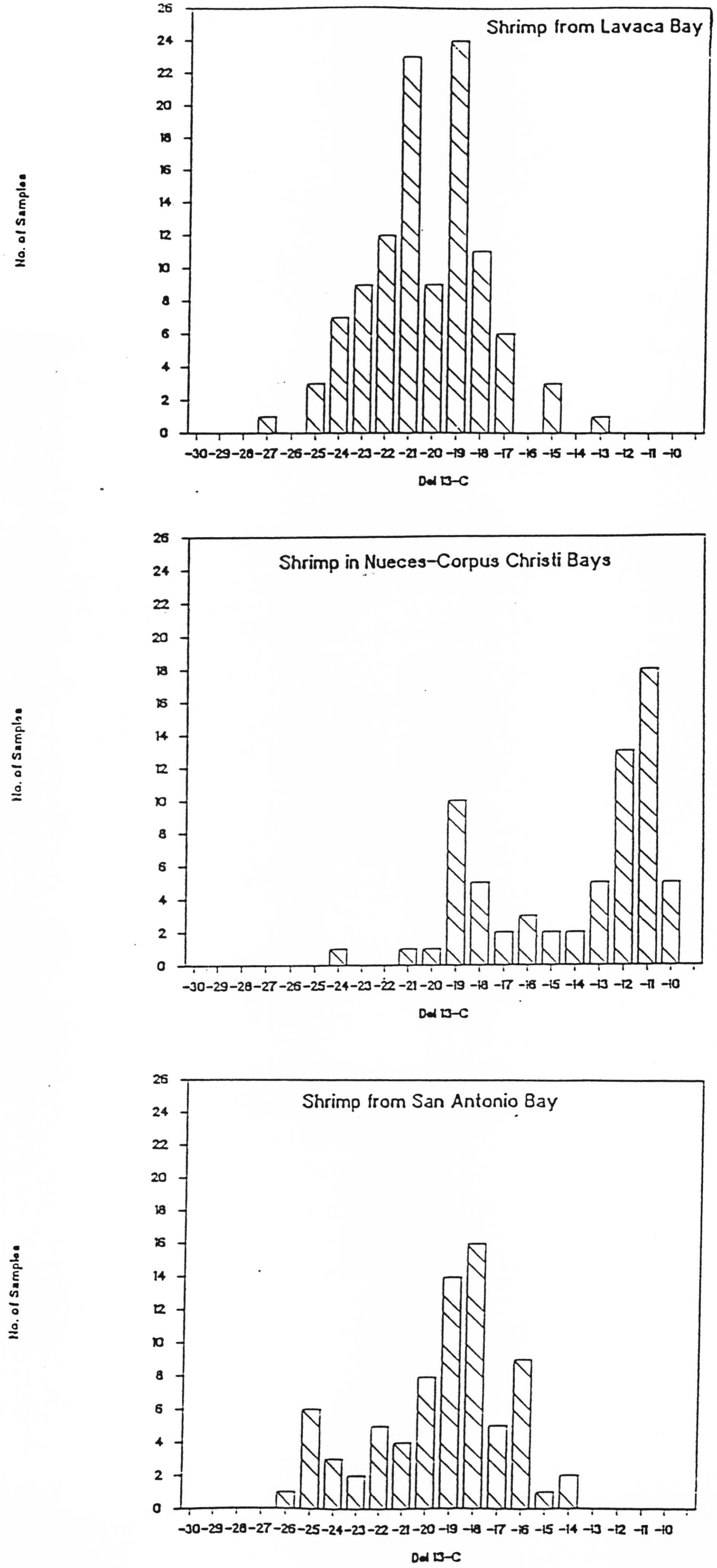

Shrimp from Lavaca Bay
Shrimp in Nueces-Corpus Christi Bays
Shrimp from San Antonio Bay
No. of Samples
Del 13-C
0
2
4
6
8
10
12
14
16
18
20
22
24
26
-30 -29 -28 -27 -26 -25 -24 -23 -22 -21 -20 -19 -18 -17 -16 -15 -14 -13 -12 -11 -10

Figure 8.13

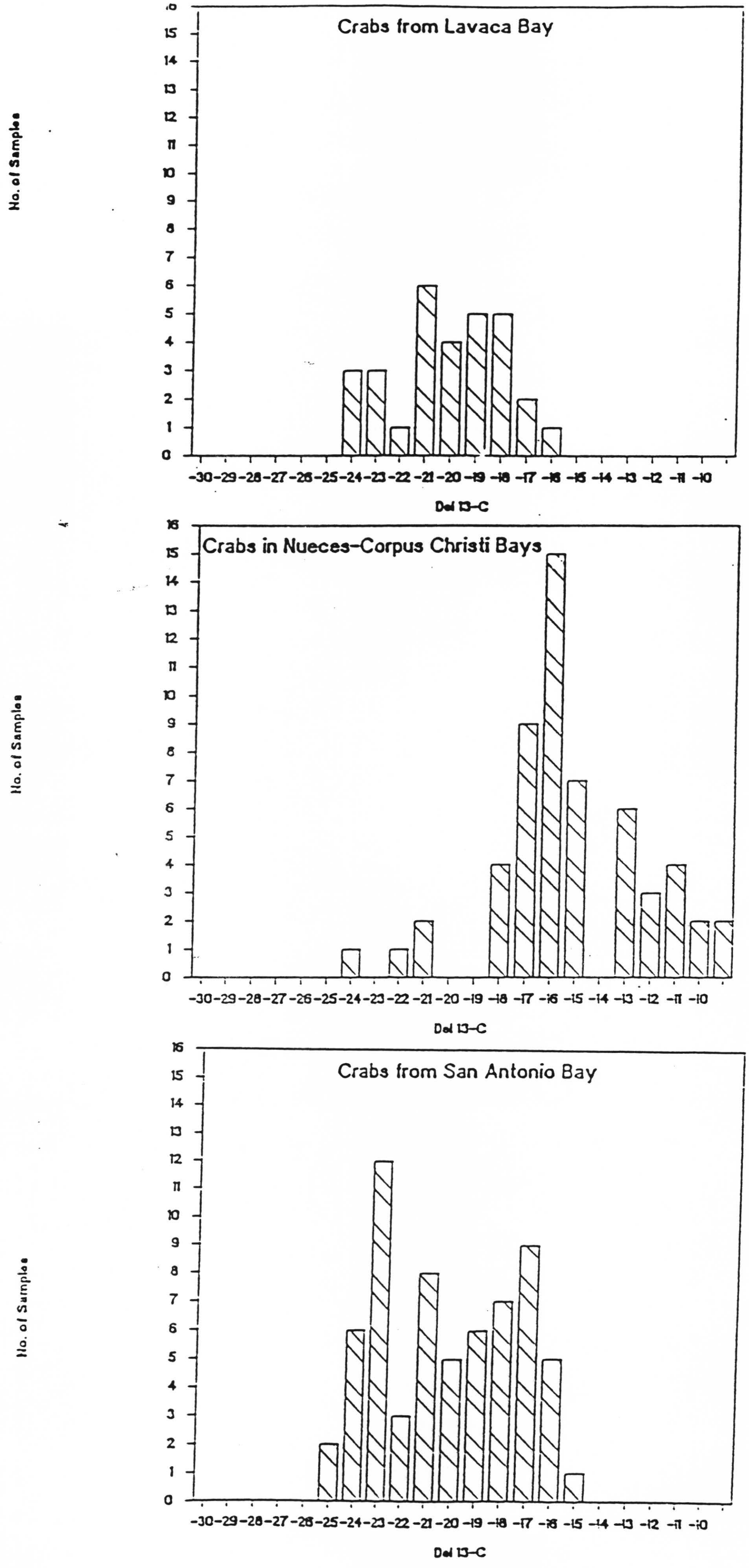

Crabs from Lavaca Bay
Crabs in Nueces-Corpus Christi Bays
Crabs from San Antonio Bay
No. of Samples
Del 13-C
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
-30
-29
-28
-27
-26
-25
-24
-23
-22
-21
-20
-19
-18
-17
-16
-15
-14
-13
-12
-11
-10

Figure 8.14

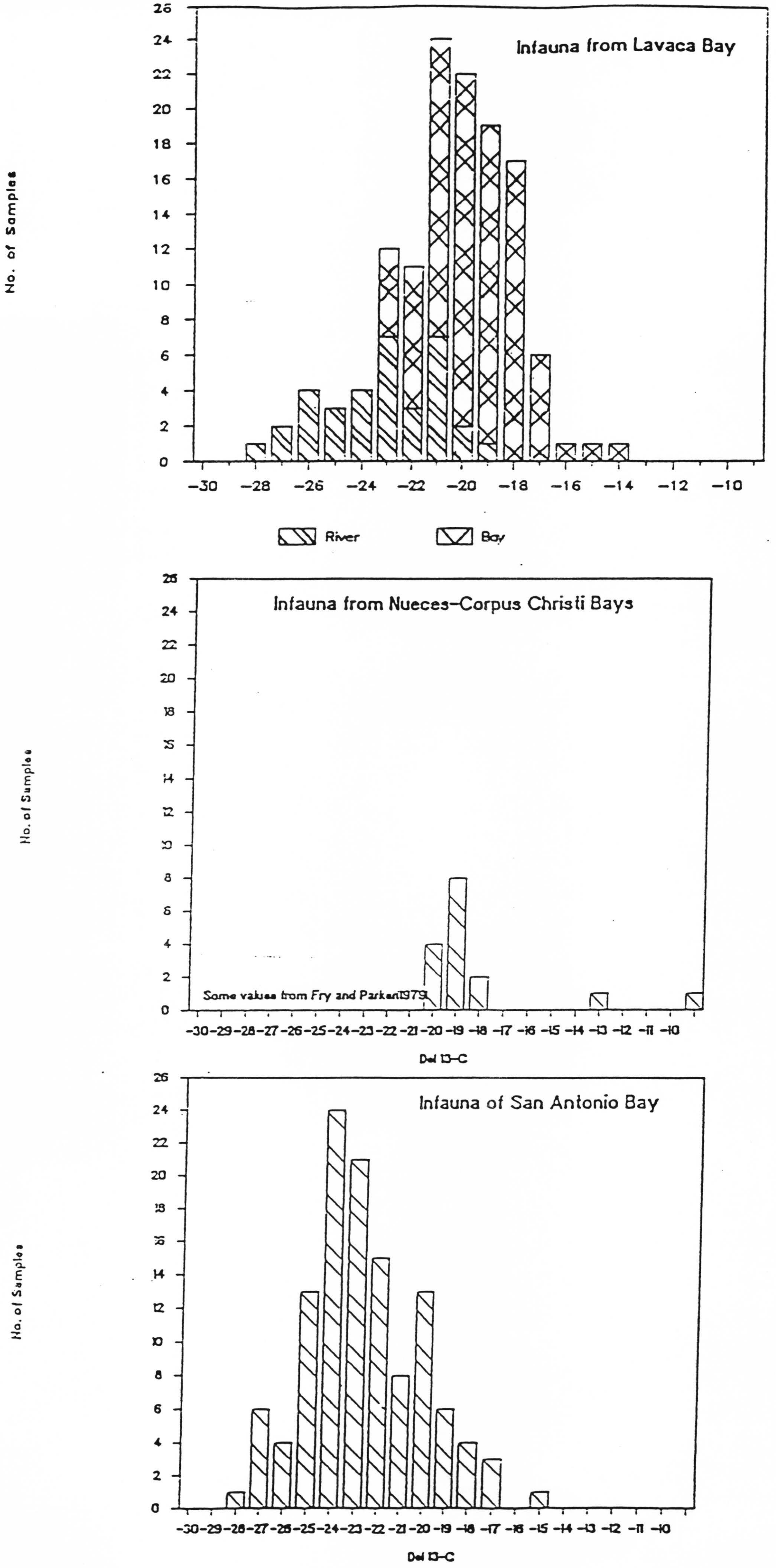

Infauna from Lavaca Bay
No. of Samples
0
2
4
6
8
10
12
14
16
18
20
22
24
26
−30
−28
−26
−24
−22
−20
−18
−16
−14
−12
−10
River
Bay
Infauna from Nueces-Corpus Christi Bays
No. of Samples
Some values from Fry and Parker 1979
-30 -29 -28 -27 -26 -25 -24 -23 -22 -21 -20 -19 -18 -17 -16 -15 -14 -13 -12 -11 -10
Del 13-C
Infauna of San Antonio Bay
No. of Samples
-30 -29 -28 -27 -26 -25 -24 -23 -22 -21 -20 -19 -18 -17 -16 -15 -14 -13 -12 -11 -10
Del 13-C

Figure 8.15

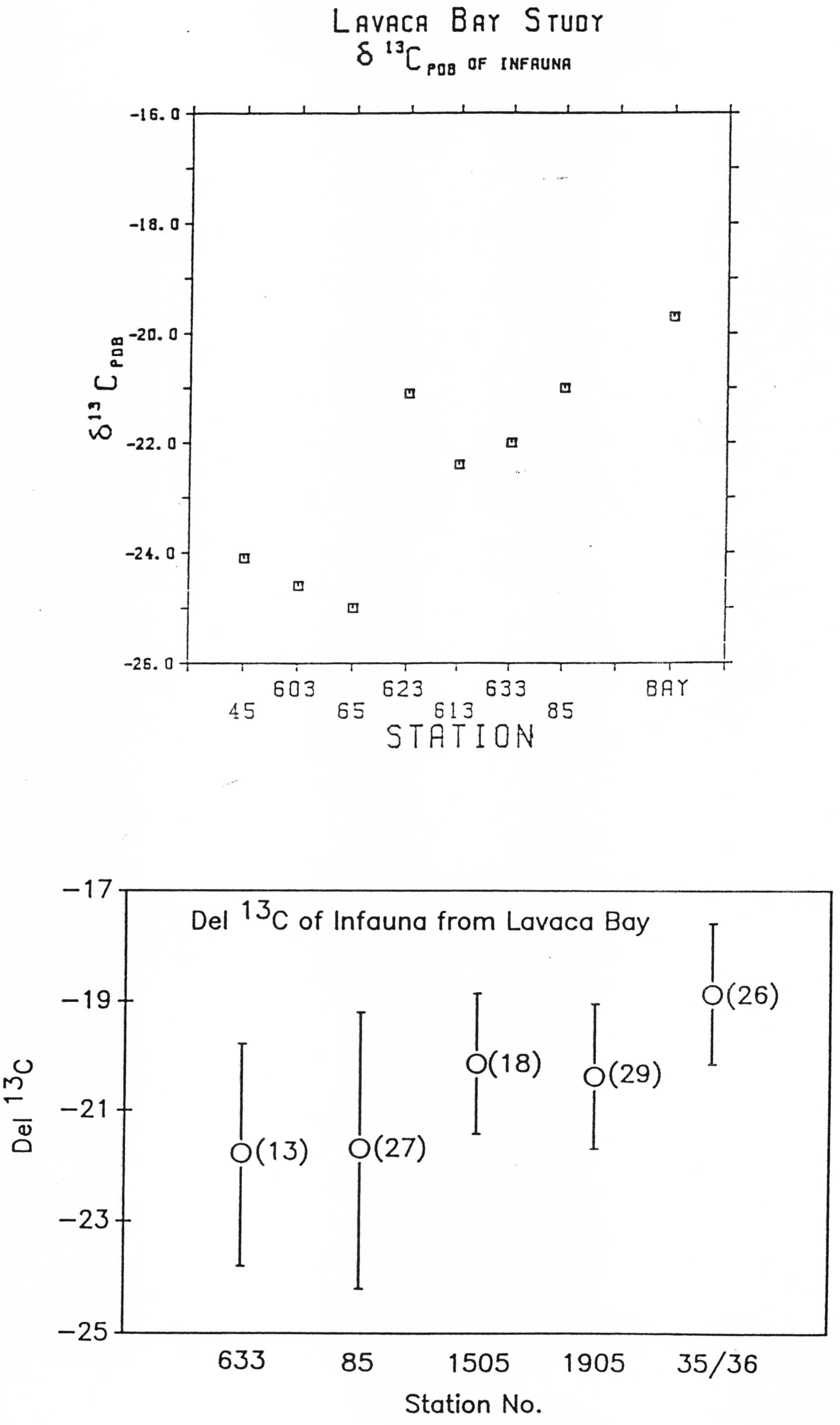
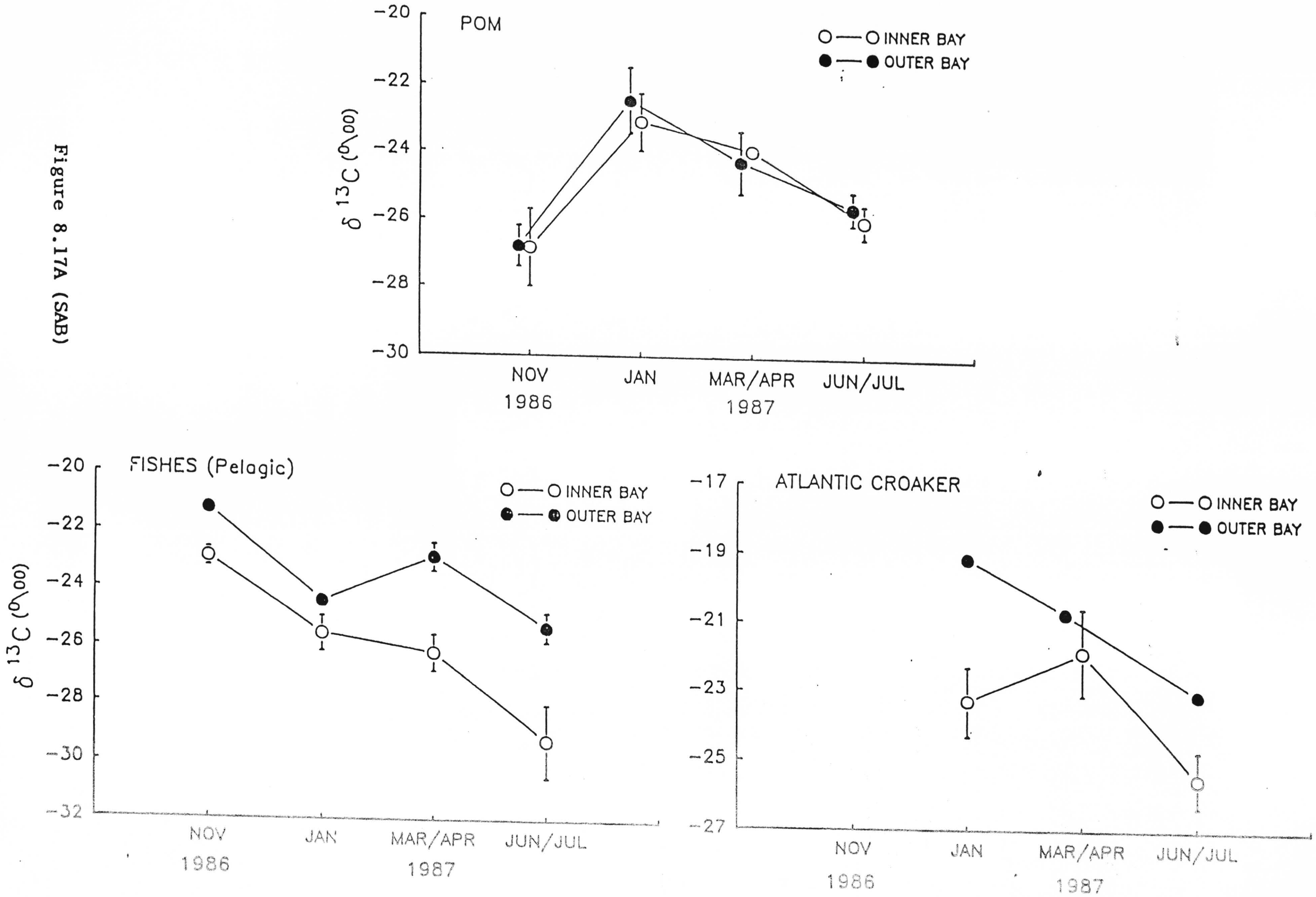

LAVACA BAY STUDY
$\delta^{13}C_{PDB}$ OF INFAUNA
$\delta^{13}C_{PDB}$
-16.0
-18.0
-20.0
-22.0
-24.0
-26.0
603
623
633
BAY
45
65
613
85
STATION
Del ^{13}C of Infauna from Lavaca Bay
Del ^{13}C
−17
−19
−21
−23
−25
(13)
(27)
(18)
(29)
(26)
633
85
1505
1905
35/36
Station No.

Figure 8.16

Figure 8.17A (SAB)



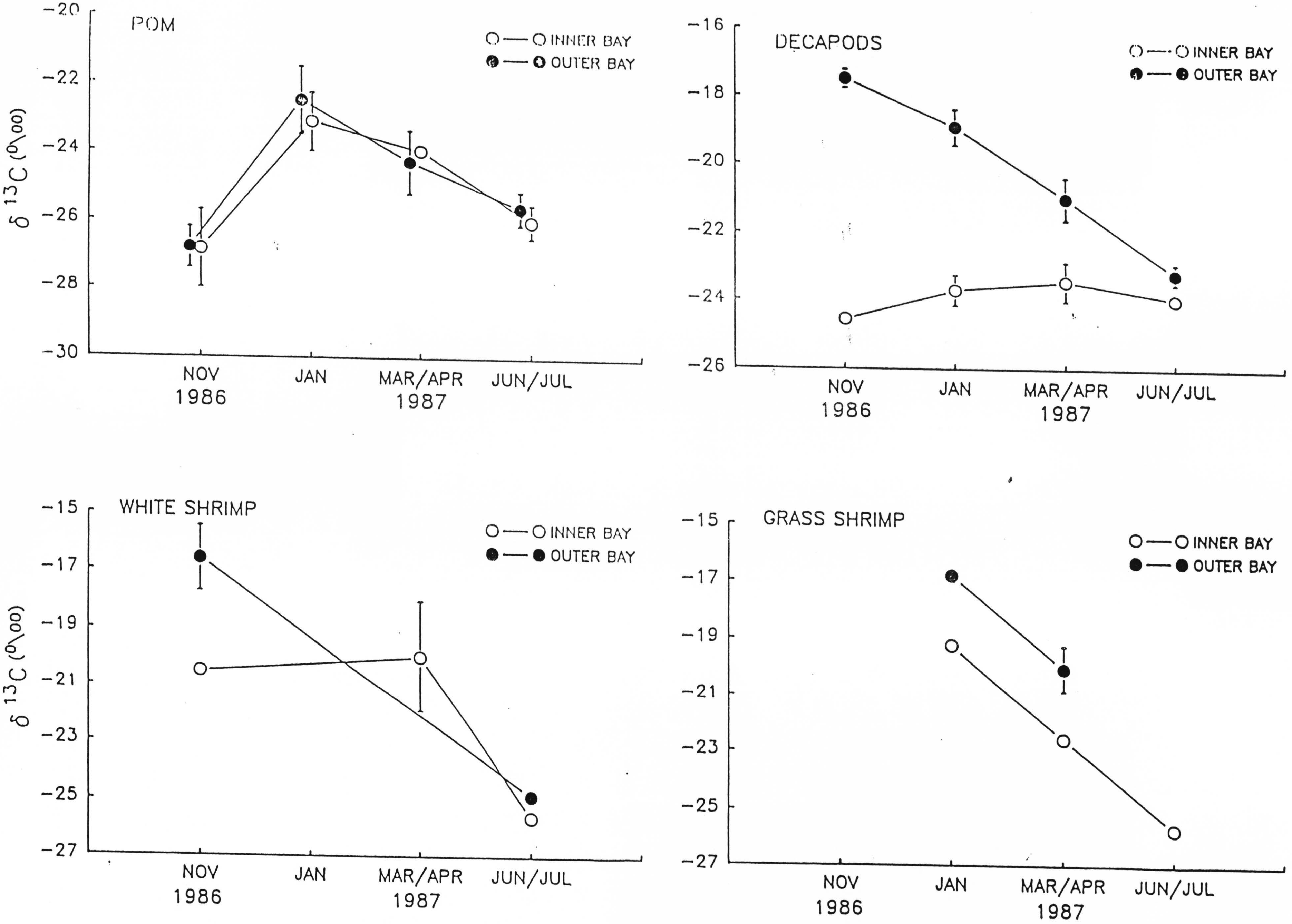


Figure 8.17B (SAB)

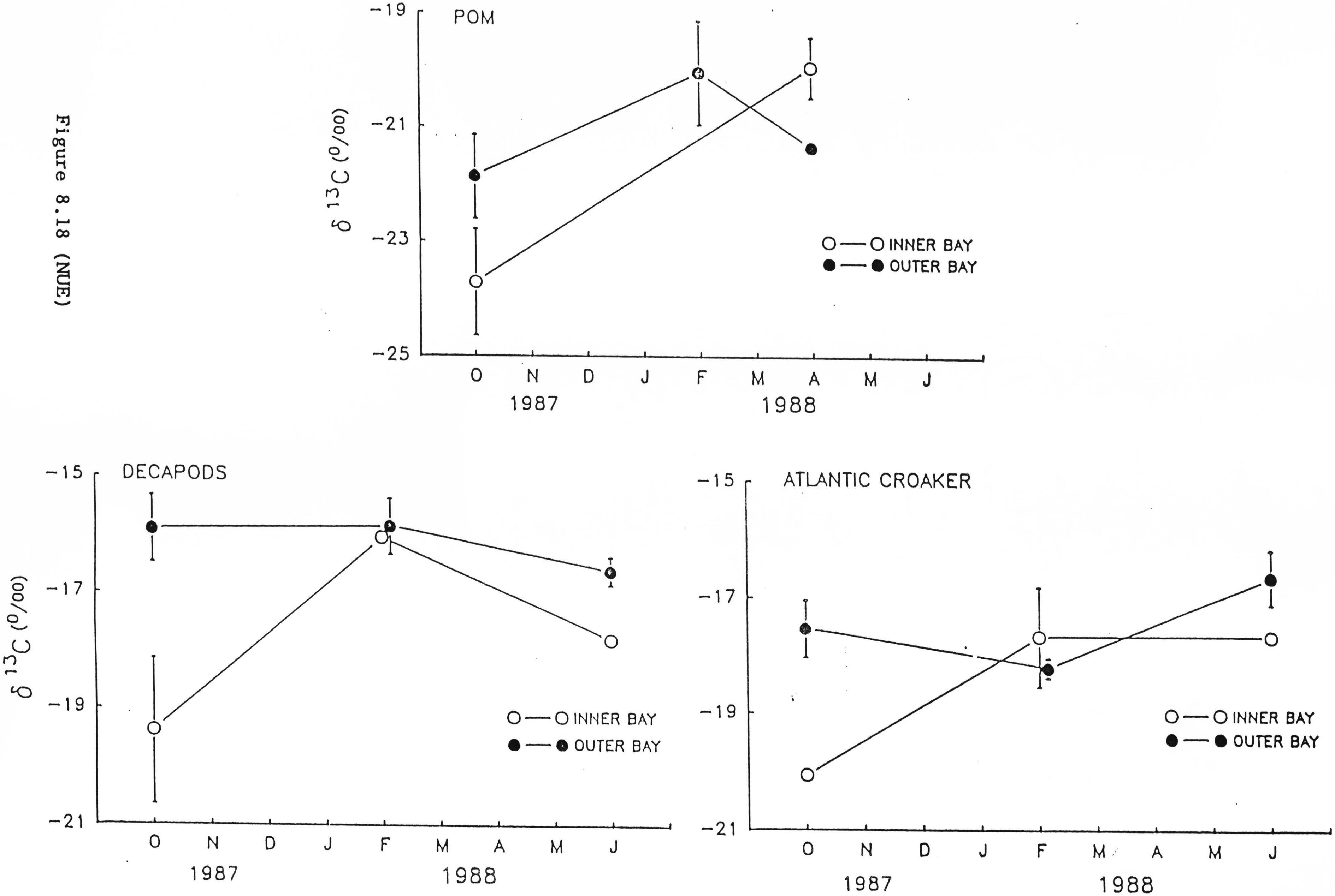
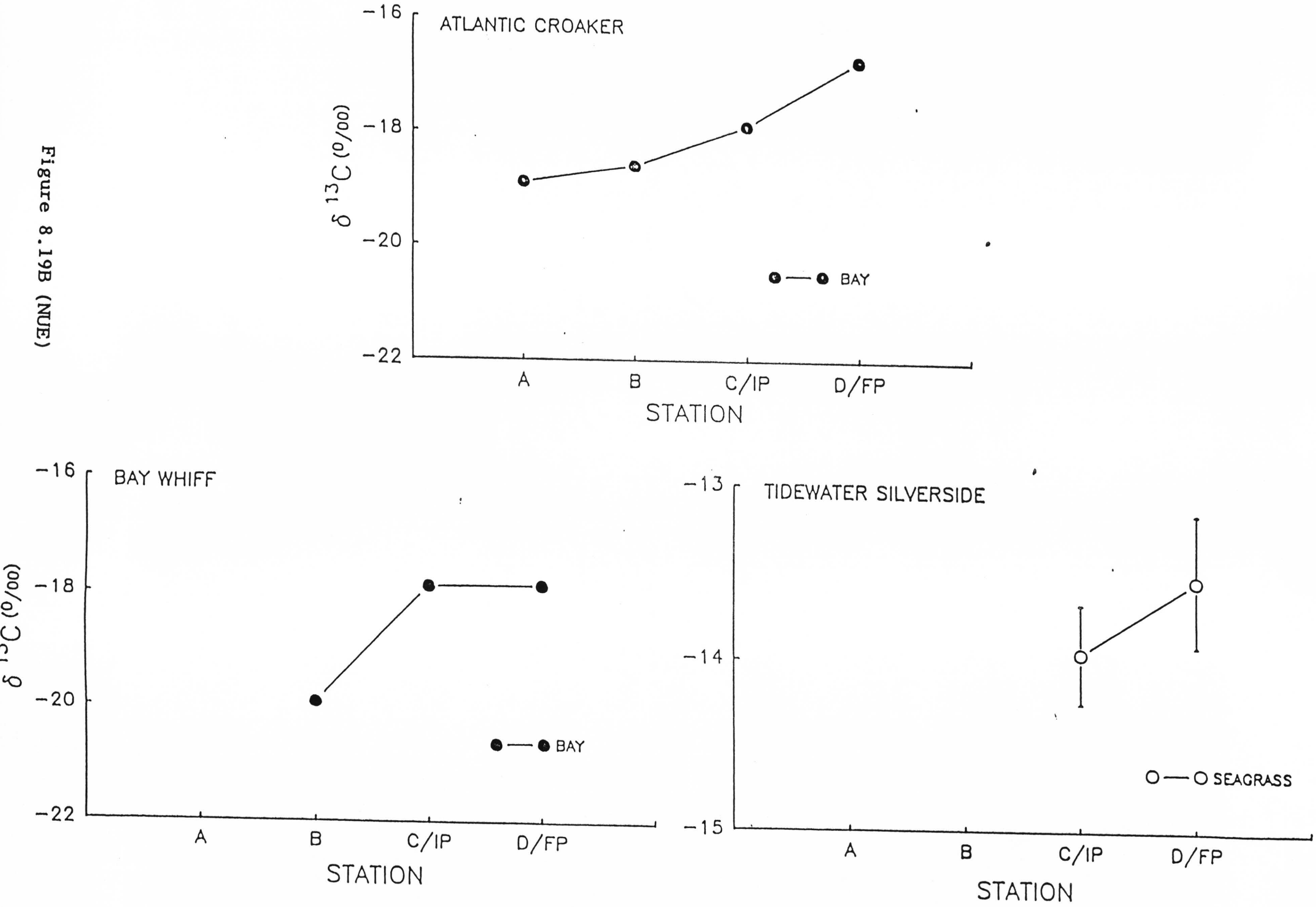


Figure 8.18 (NUE)

Figure 8.19B (NUE)



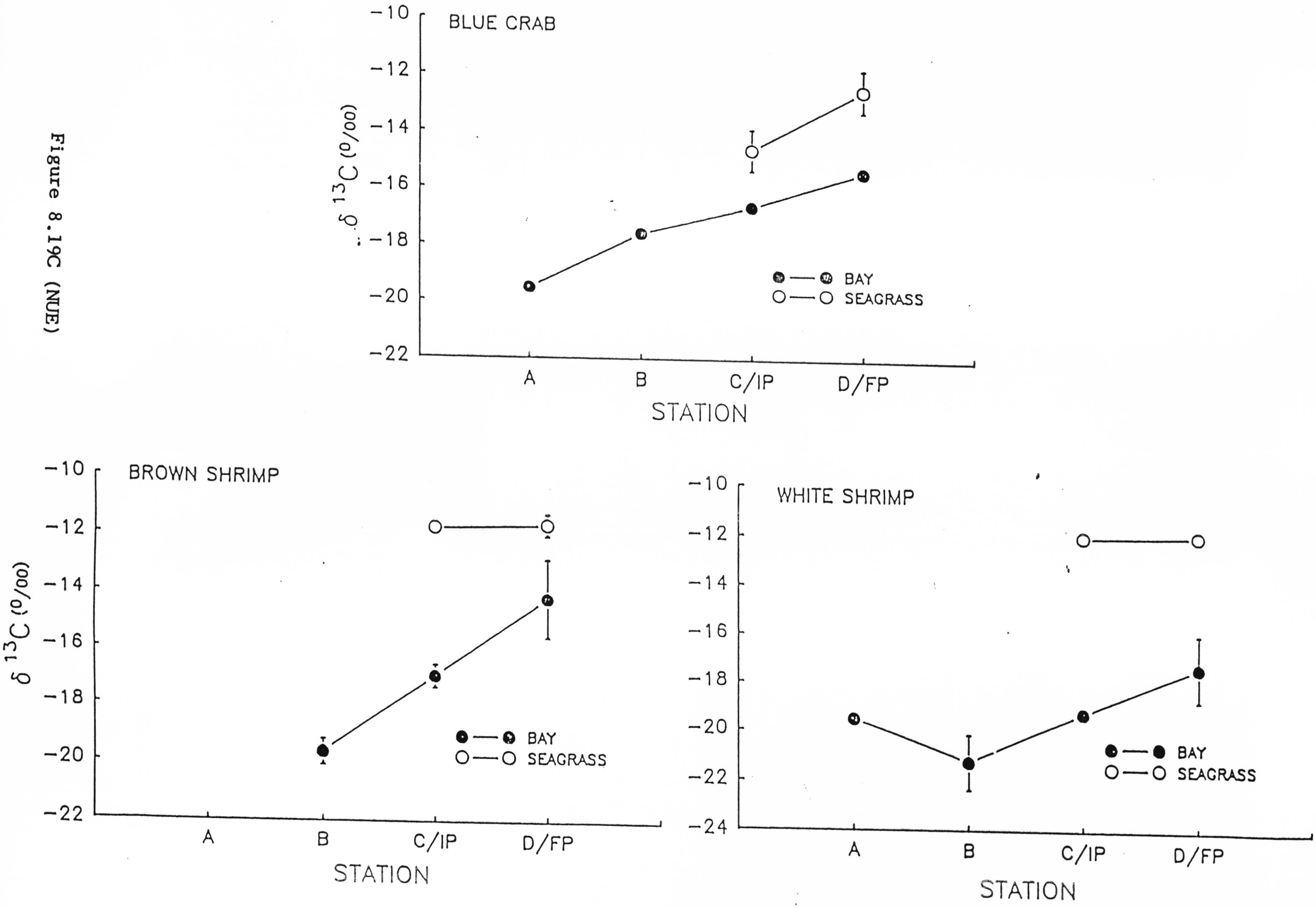


Figure 8.19C (NUE)

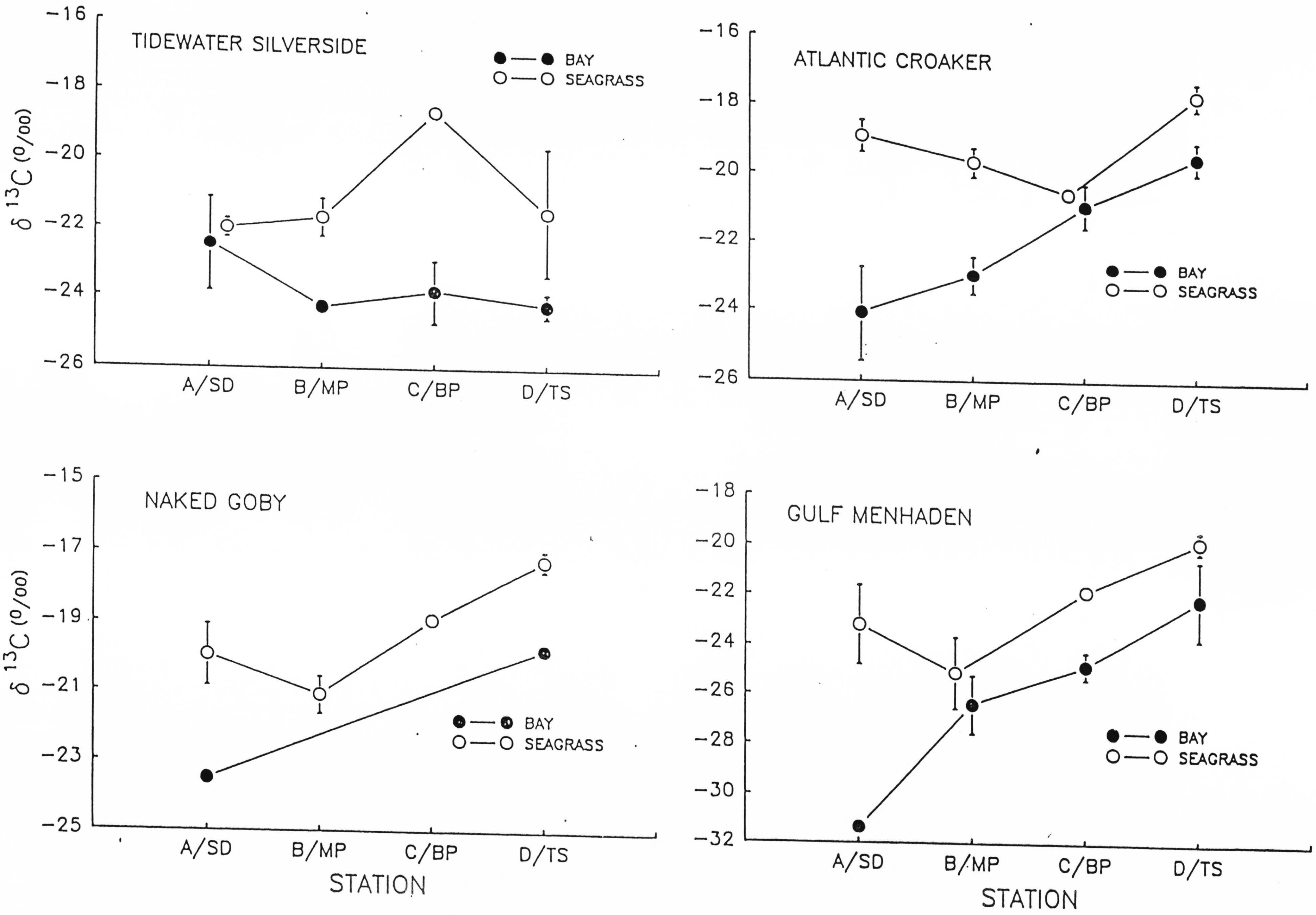


Figure 8.20A (SAB)

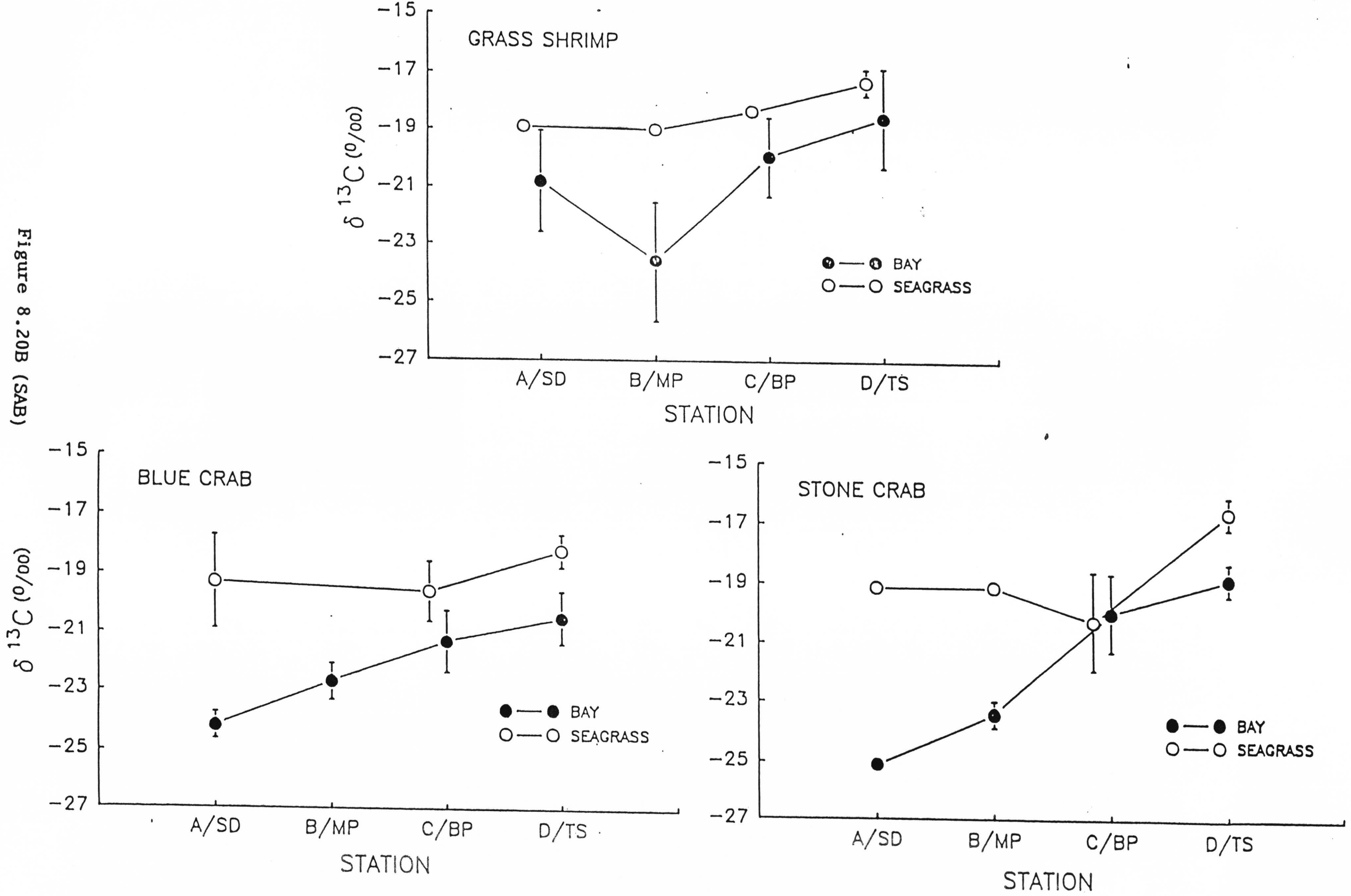


Figure 8.20B (SAB)

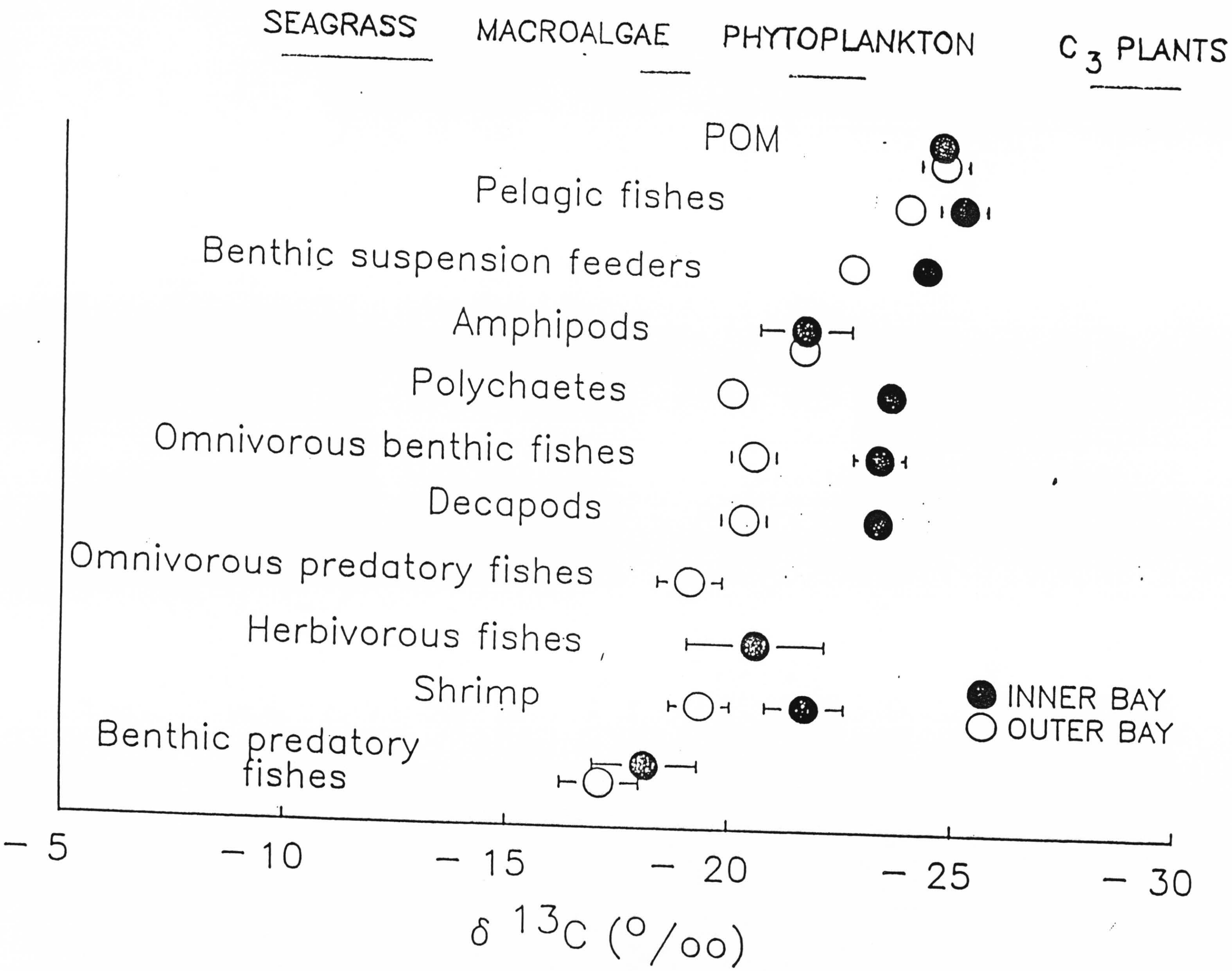


Figure 8.21 (SAB)

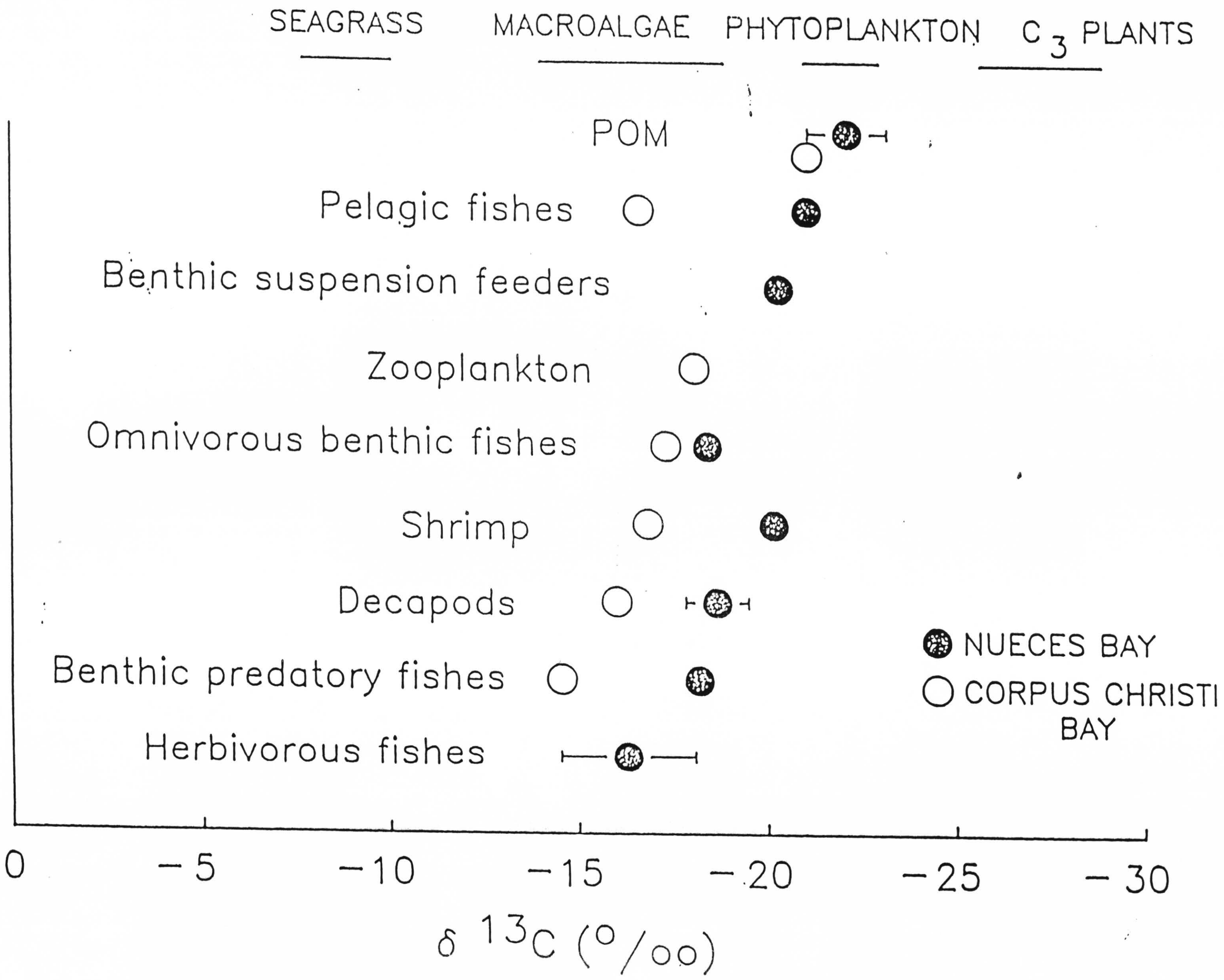


Figure 8.22 (NUE)

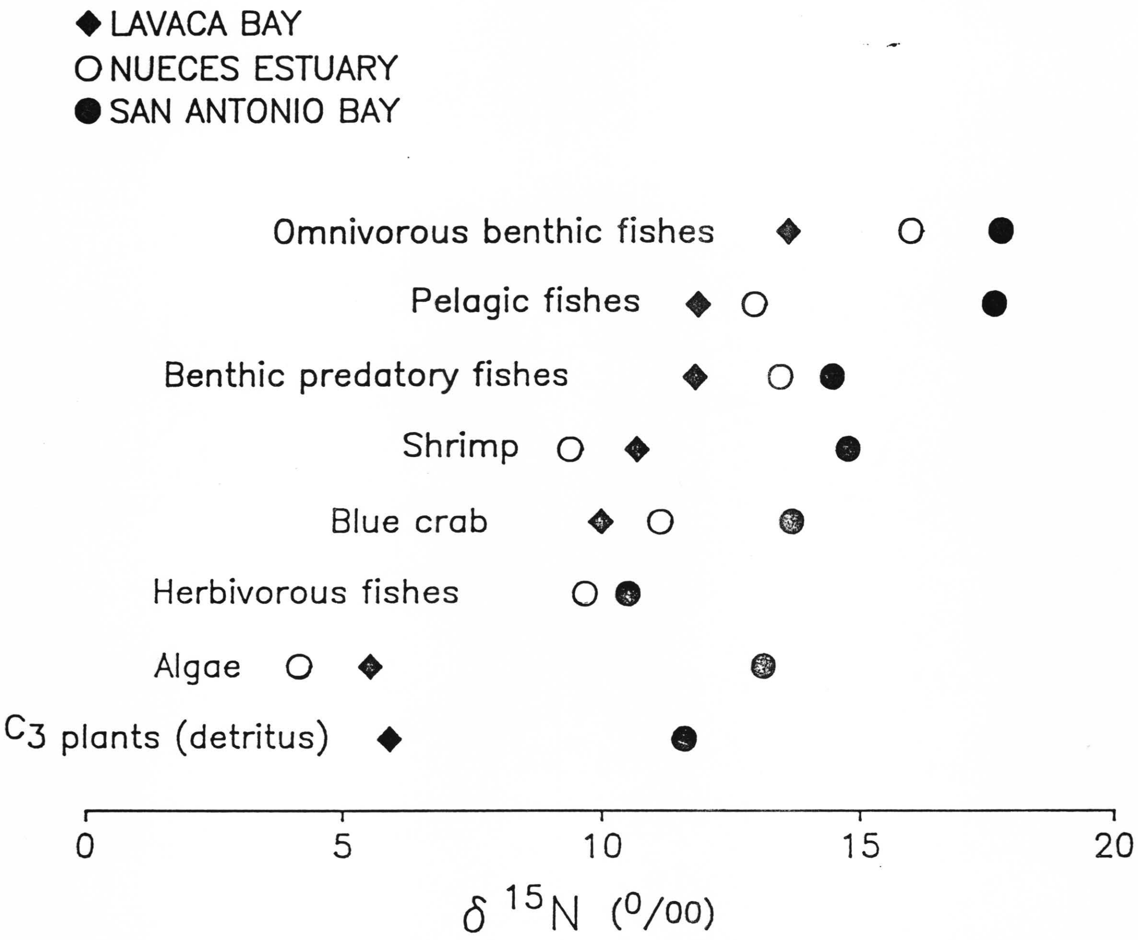
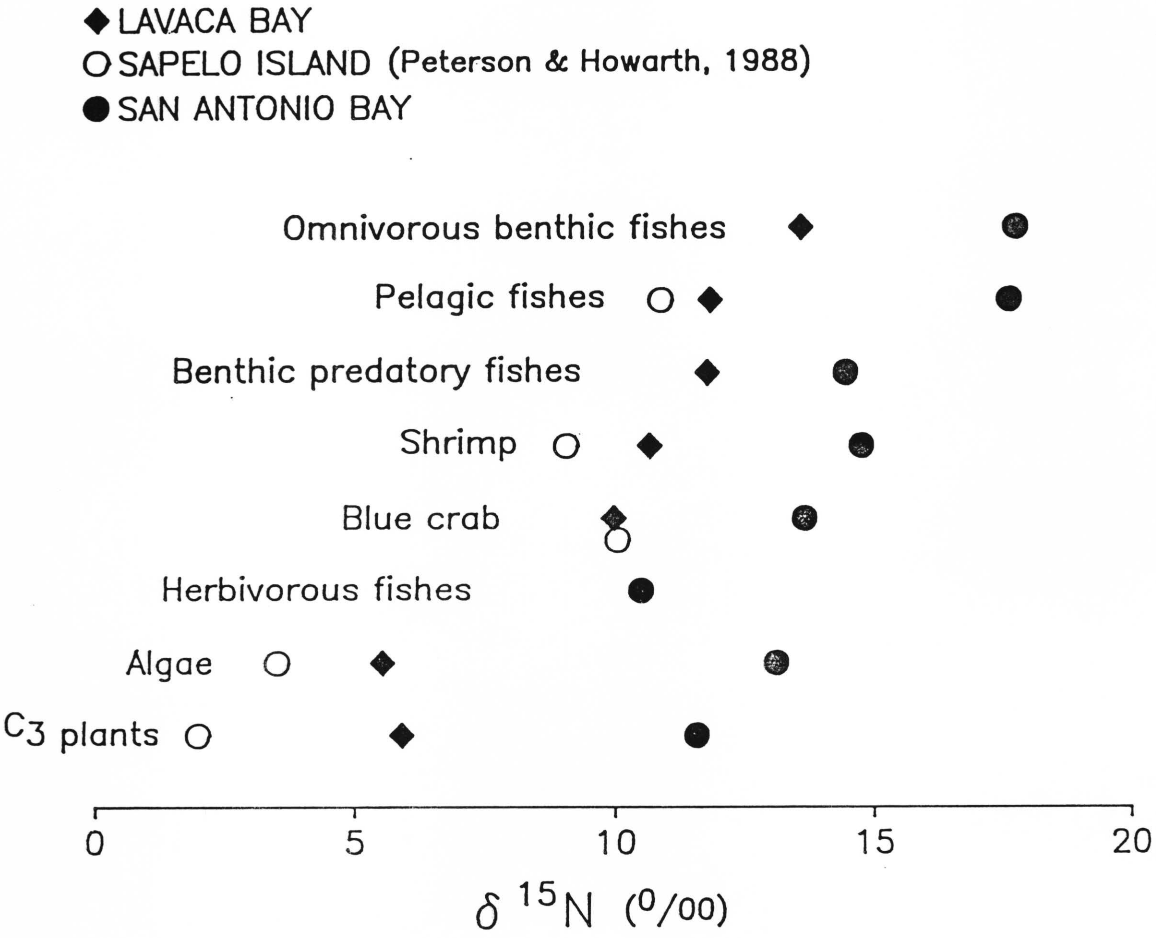
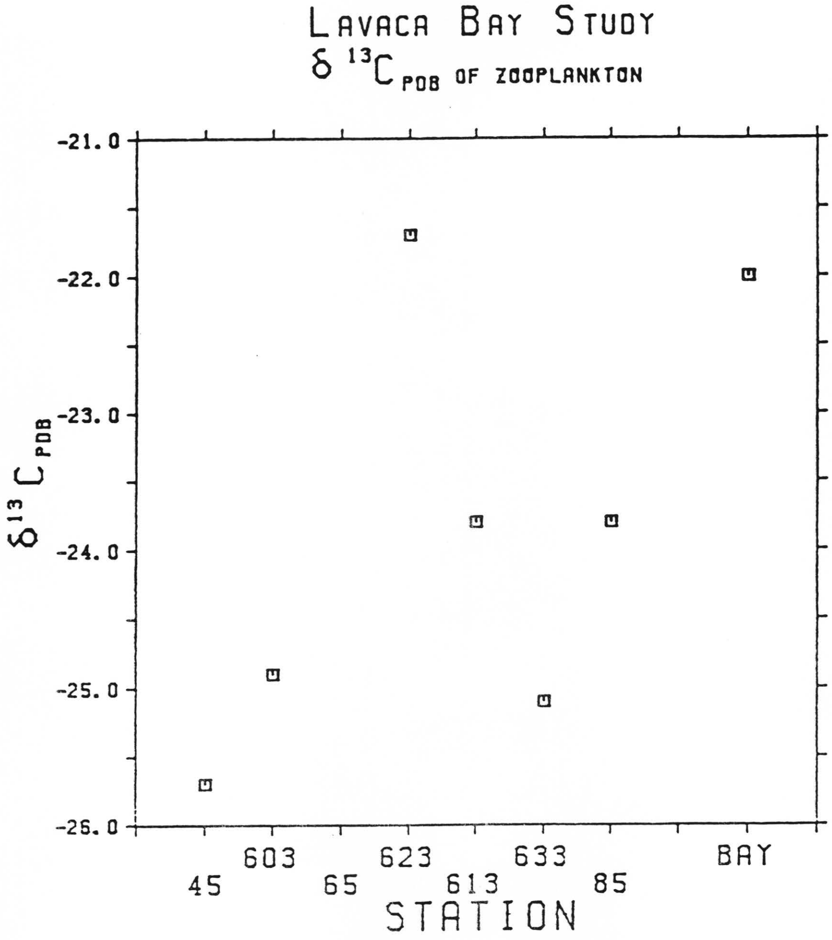

◆ LAVACA BAY
○ NUECES ESTUARY
● SAN ANTONIO BAY
Omnivorous benthic fishes
Pelagic fishes
Benthic predatory fishes
Shrimp
Blue crab
Herbivorous fishes
Algae
C_3 plants (detritus)
0
5
10
15
20
$\delta^{15}N$ ($^0/_{00}$)

Figure 8.23



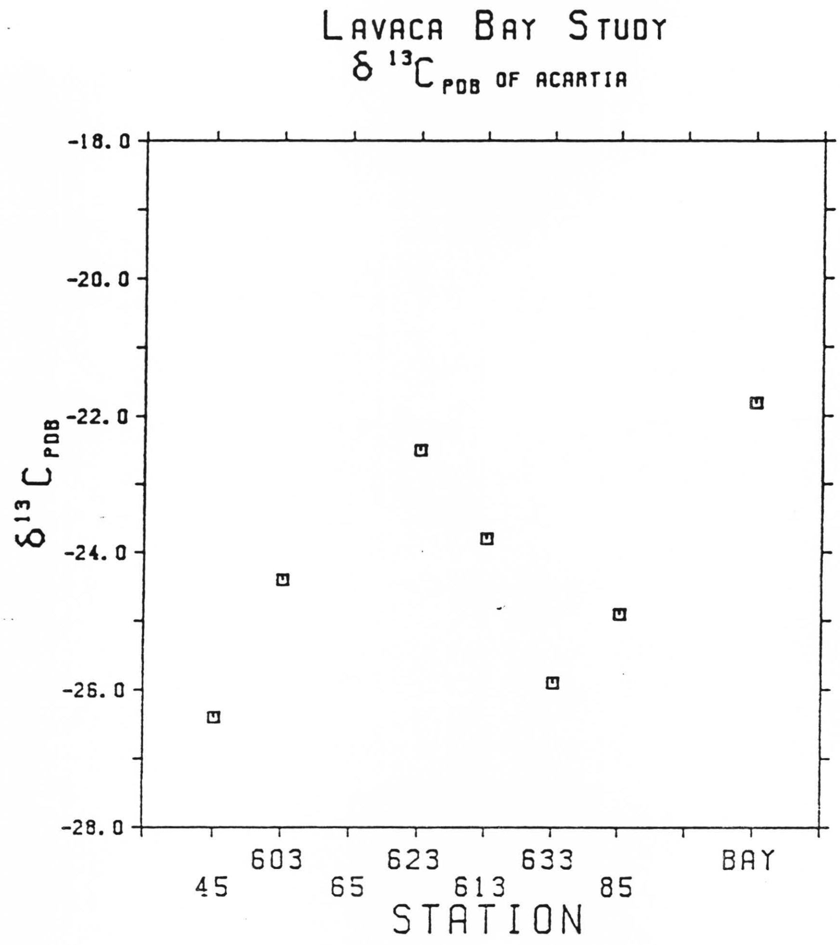
◆ LAVACA BAY
○ SAPELO ISLAND (Peterson & Howarth, 1988)
● SAN ANTONIO BAY
Omnivorous benthic fishes
Pelagic fishes
Benthic predatory fishes
Shrimp
Blue crab
Herbivorous fishes
Algae
C3 plants
0
5
10
15
20
δ 15N (0/00)

Figure 8.24



Station(s)	Average	Std. Dev.	Number
45	-25.7	0.79	7
603	-24.9	1.12	7
65			
623	-21.7	1.98	3
613	-23.8		1
633	-25.1	1.12	3
85	-23.8	1.88	8
Bay	-22.0	0.99	16
All	-23.5	1.97	45

Figure 8.25



Station(s)	Average	Std. Dev.	Number
45	-26.4	0.30	3
603	-24.4	1.26	4
65			
623	-22.5		1
613	-23.8		1
633	-25.9	0.08	2
85	-24.9		
Bay	-21.8	0.92	6
All	-24.0	1.90	20

Figure 8.26