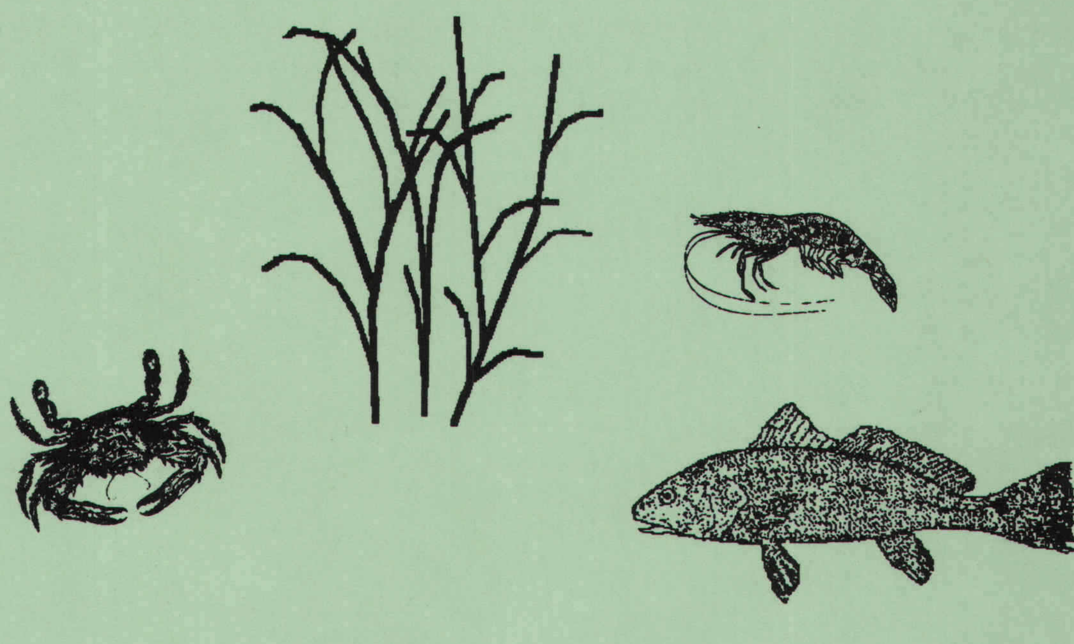
NOAA Technical Memorandum
NMFS - SEFC- 275

Habitat Availability and Utilization by Benthos and Nekton in Hall's Lake and West Galveston Bay



GALVESTON LABORATORY
SOUTHEAST FISHERIES CENTER
NATIONAL MARINE FISHERIES SERVICE
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JANUARY 1991

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By

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Abstract

Salt marsh habitats along the shoreline of Hall's Lake are threatened by wave erosion, but the reconstruction of barrier islands to reduce this erosion will modify or destroy nonvegetated habitats in West Bay. In order to provide information on the relative value of these estuarine habitats for fishery species, we identified the habitats present and sampled vegetation, sediments, and benthic and nektonic organisms in May 1990. In comparison with nonvegetated bottom, Spartina alterniflora marshes had higher sediment organic content and densities of infaunal crustacea, macrocrustacea (brown shrimp, grass shrimp, and blue crabs), and pinfish. Nonvegetated sites had greater numbers of forage fish such as anchovies. Both trawls and drop samples were used to sample nonvegetated bottom, and there appeared to be little difference among the nonvegetated sites. Mean densities of animals collected in trawls, however, were less than 50% of densites measured with the drop sampler. The value of salt marsh habitats for estuarine animals varied, and within Hall's Lake there was a significant correlation between marsh elevation and density of most macrofauna. In addition, densities of brown shrimp and pinfish were significantly greater in the well-established marshes of Hall's Lake compared with the narrow intermittent marsh present along the West Bay shoreline. Conclusions on relative habitat value based on samples collected at one point in time can be misleading, but data from historical samples, collected in the Hall's Lake marsh, suggest that densities of macrofauna observed in our study are not anomalous. In conjunction with other published data on habitat value in Galveston Bay, our results indicate that for most crustacea the Hall's Lake marshes are more valuable than the other habitats examined. The relative value of the habitats for fishes was highly dependent upon the species. A survey of the West Bay shoreline indicated that valuable salt marsh habitats could be established on created barrier islands if direction of exposure and shoreline slope were controlled.

Introduction

Barrier islands protect much of the Gulf Intracoastal Waterway (GIWW) from the erosional wave energy of West Galveston Bay. In the area of Hall's Lake, these islands have been worn away, and a narrow isthmus of land separating the lake from West Bay is threatened. The shoreline of Hall's Lake consists of salt marsh vegetation, and destruction of this habitat may result in the loss of valuable fishery and wildlife resources (Zimmerman and Minello 1984). Rebuilding of th barrier islands to reduce shoreline erosion, however, will destroy and alter open-water habitats in West Bay.

The objective of this baseline study was to determine the extent and distribution of the various habitat types present in the Hall's Lake area and measure relative use of these habitats by fishery species and other estuarine fauna. The habitats included fringe marsh, inner marsh, nonvegetated shoreline, and deeper subtidal bottom. Habitats were characterized by physical parameters, sediment texture and organic content, and vegetation density and biomass. Habitat utilization was assessed by measuring densities of fishery species and other organisms.

Study Area

Hall's Lake is a tertiary bay connected to Chocolate Bay which in turn is connected to West Galveston Bay. The lake is located approximately 16 miles west-southwest of Galveston, Texas (Figure 1). Hall's Lake is separated from the GIWW and West Galveston Bay by a 15-m isthmus of land. If this separation is breached by erosion, major circulation changes and habitat conversions are expected with possible changes in value of the area for fishery species and other natural resources. The lake shoreline consists of fringe marsh made up of mainly Spartina alterniflora and higher marsh consisting of shorter-height S. alterniflora and other salt marsh plants. Some of the southern shoreline of the barrier islands protecting the West Bay side of the GIWW is also vegetated with S. alterniflora, and superficially this habitat resembles the fringe marsh in Hall's Lake. Other habitats in the area do not support macrophytic vegetation and include intertidal shoreline of these barrier islands, shallows adjacent to the islands, and deeper subtidal bottom.

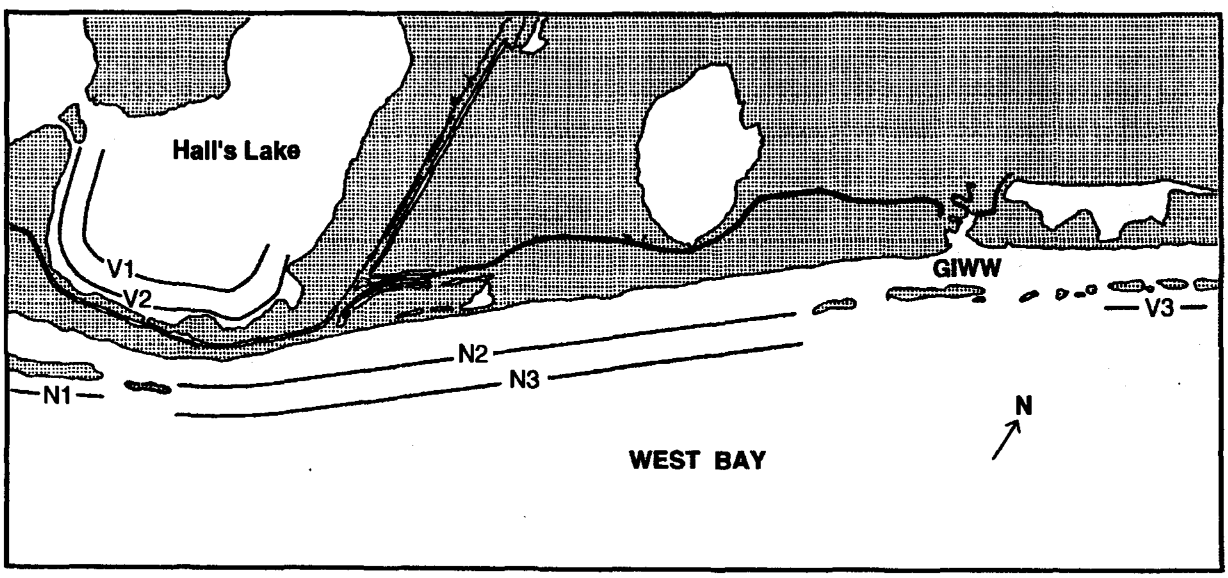

Figure 1. Drop sampling sites in Hall's Lake and West Galveston Bay. Sampl s w re collected along transects in three vegetated (V1-V3) and three nonvegetated (N1-N3) habitats.

Methods

Habitat Identification

The occurrence of various habitat types in the study area, with special attention to salt marshes, was determined from aerial photography and ground surveys using a level. Recent (1989) color infrared photography at a scale of 1:40,000 and 1:65,000 was used for portions of West Bay, and other photographs were obtained from the Galveston District Corps of Engineers. Measurements were made of overall marsh area, marsh width, elevation, and the species of plants present.

Field Collections

Abundances of macrofauna in these shallow-water habitats were mainly estimated using drop sampling methodology (Zimmerman et al. 1984). This method employs a large cylinder (1.8 m diam.) dropped from a boom on a boat to entrap organisms within a prescribed area (2.6 m^2) and is designed to sample fishes, crabs, and shrimps in marshes, seagrass beds and oyster reefs where methods such as trawls and seines are ineffective. Most of the macrofauna trapped in the sampler were captured using dip nets while the water was pumped out of the enclosure and through a 1-mm mesh net. When the sampler was completely drained, animals remaining on the bottom were picked up by hand. Animals collected were preserved in formalin with Rose Bengal stain.

Over a 2-day period (17-18 May 1990), 24 drop samples were collected in the study area during daylight hours on flood tide. Four samples were collected from each of six habitats or sites (Figure 1). The three vegetated sites (V1, V2, and V3) were intertidal; V1 was fringing marsh (within 1 m of the marsh edge) in Hall's Lake, V2 was inner marsh (5 m from the marsh edge) in Hall's Lake, and V3 was fringing marsh on the West-Bay side of an island along the GIWW. The nonvegetated sites (N1, N2, and N3) were both intertidal and subtidal; N1 was located along the West-Bay side of another island bordering the GIWW (intertidal and comparable to V3), N2 was in the lower intertidal of the erosional zone where islands had at one time been present, and N3 was subtidal in this erosional zone. This erosional zone is the region where islands may be rebuilt in the future.

Within each drop sample, we also collected samples of benthic infauna, sediment organics and grain size, and vegetation density and biomass. Benthic infauna was sampled with a 10-cm diameter core. At vegetated sites, the core was taken between clumps of vegetation. The upper 5 cm of sediment was sieved through a 0.5-mm mesh sieve, and material retained on the sieve was preserved in formalin with a Rose Bengal stain. An additional 10-cm diameter core was also collected for the analysis of sediment grain size and organic content. The upper 5-cm of sediment from this core was placed in a plastic bag and transferred to the laboratory on ice. A 0.2-M^2 subsample of the emergent plants in marsh samples was also placed in a plastic bag for laboratory processing. Other observations taken in conjunction with drop samples to characterize the different habitats included minimum and maximum water depth, temperature, salinity, dissolved oxygen, and turbidity. Water temperature and dissolved oxygen were measured using a YSI Model 51B meter, and salinity was measured using a refractometer. Water samples were collected for the analysis of turbidity in the laboratory.

Although drop sampling on nonvegetated bottom provides better density estimates for shrimp and probably other small crustaceans and fishes than trawls (Zimmerman et al. 1984, 1986), drop sampling is restricted to water less than 1 m in depth, may underestimate abundances of highly motile nekton, and cannot adequately sample low-density animals because of the relatively small area enclosed. Therefore, trawls were also collected in deep-water nonvegetated habitat and in some shallower habitats for comparison with drop samples. Three replicate trawls were collected at sites N2 and N3 and in adjacent deeper (> 1 m) water (Site N4). Trawls (13-mm stretch mesh) were towed for 3 minutes at a towing speed of around 1.5 mph. The area swept during a tow was approximately 450 m^2 (3.7-m mouth area x 121 m tow length). Trawl samples were preserved in formalin.

Laboratory Analyses

In the laboratory, all fishes and crustacea from drop samples and trawls were identified to species. Fish were measured to the nearest 1 mm in total length and counted in groups of 10-mm size intervals (1-10 mm, 11-20 mm, etc.). Decapod crustaceans were measured to the nearest 1 mm in total length for shrimps and carapace width for crabs and counted in groups of 5-mm size intervals (1 to 5 mm, 6 to 10 mm, etc.). Individual sizes of penaeid shrimp were recorded. From benthic cores, amphipods, tanaids, and polychaet worms were identified to th speci s lev l, and remaining organisms were grouped into larger taxonomic categories.

Marsh plants were identified and counted, and then air-dried for the determination of biomass. Sediment samples were split, and grain size analysis of one subsample was conducted according to the procedures of Folk (1980). The other subsample was wet- sieved through a 3-mm mesh sieve (to remove rocks, shell, and roots), dried to a constant weight at 100°C, and then burned for 3-h at 550°C. Weight lost on ignition was assumed to be representative of the sediment organic content (Dean 1974). Turbidity of water samples was measured using an HR Instruments Model DRT 100B nephelometer and a formazin standard.

Th Effect of Marsh Elevation

An additional analysis was conducted on data from sites V1 and V2 to examine the effect of marsh elevation in Hall's Lake. Within the lake, four samples were collected at the marsh edge (V1) and four from the inner marsh, 5 m from the edge (V2). Half of these samples (two edge; two inner) were collected on the western side of the lake, and the other half on the southeastern side of the lake. Shoreline slope was steeper along the western edge, and inner marsh samples were subsequently taken at a higher marsh elevation in the West compared with the Southeast. This arrangement of samples allowed us to conduct an analysis on the effect of marsh elevation. The elevation of each sample in relation to mean low water was estimated from water depth measurements taken at the time the samples were collected. Water depth was corrected for changes in tidal height during the sampling period and referenced back to a U.S. Army Corps of Engin ers staff gauge located at Alligator Point in the Hall's Lake area.

Data Analyses

The data were recorded on printed forms and entered in dBASE III Plus files using a microcomputer. Simple statistics were calculated and tables were constructed using Lotus 1-2-3. Differences among sites in sample parameters and log-transformed animal densities were statistically examined using Analysis of Variance (ANOVA) with PC SAS algorithms; sites wer considered to be diff r nt treatment levels in a 1-way ANOVA. Non-orthogonal contrasts were designed to compare nonvegetated vs vegetated habitats (N1 N2 N3 vs V1 V2 V3), fringe marsh vs inner marsh in Hall's Lake (V1 vs V2), marsh in Hall's Lake with marsh in West Bay (V1 and V2 vs V3), shallow nonvegetated bottom along an island vs shallow nonvegetated bottom in the erosional zon (N1 vs N2), and island shoreline without vegetation vs with vegetation (N1 vs V3). Additional unplanned comparisons of treatment means were conducted using the REGWQ (Ryan's Q) multiple range procedure in PC SAS (Day and Quinn 1989).

The effect of elevation in Hall's Lake was analyzed separately. Samples were classified as InnerSEast, FringeSEast, InnerWest, and FringeWest with two replicates in each group. A 1-way ANOVA was then conducted on the data considering each of these classifications as a treatment level. Contrasts were also examined comparing InnerWest (high elevation marsh) vs all six low marsh samples, InnerWest vs InnerSEast, and InnerWest vs FringeWest.

Historical Data

Drop samples and associated benthic infauna samples from the fringing salt marsh habitats of Hall's Lake were collected on three separate occasions (March 26, 1986; June 1, 1988; and September 21, 1988) in conjunction with other sampling studies conducted by the NMFS Galveston Lab's estuarine ecology group. The macrofauna densities from these samples should be directly comparable to those measured at Site V1. Cores in the historical samples, however, contained a small clump (4-7 stems) of Spartina alterniflora. The microhabitat sampled for infauna, therefore, differed in the historical samples from the present study in which cores were collected between clumps of vegetation. Historical drop sample data and core data, however, can provide some background information on seasonal and annual variability within the Hall's Lake marsh, and the data are included here for comparison with samples collected in May 1990.

Results

Habitats in the Hall's Lake Area

Hall's Lake

The shoreline of Hall's Lake is composed of a continuous stand of Spartina alterniflora, but th width or depth of the marsh and th marsh elevation vari considerably around the lake. An arbitrary levation of 67 cm above MLW was

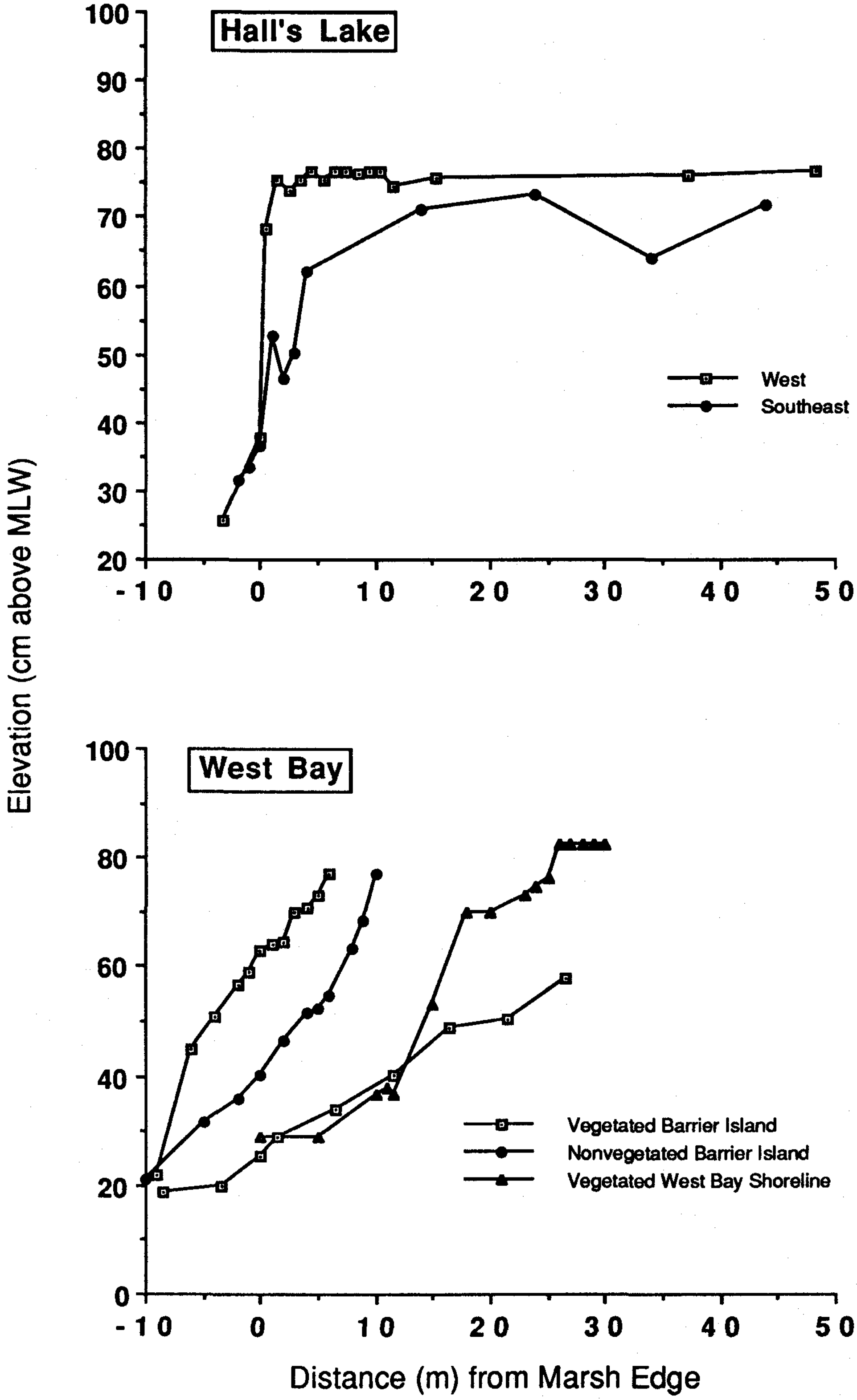

Figure 2. Typical shoreline profiles in the Hall's Lake area.

chos n to separat high marsh from low marsh. This separation roughly coincided with a distinct break in the elevation profile of most of the Hall's Lake marshes (Figure 2). High marsh was generally characterized by short S. alterniflora with the sporadic occurrence of other salt marsh plants such as Batis maritima, Salicornia bigelovii, and Borrichia frutescens. Low marsh was mainly taller S. alterniflora.

Most of the marsh around the lake was high marsh, and the band of low marsh was generally less than 10-m wide (Table 1). In the southeast portion of the lake, however, low marsh extended over 35 m in from the water's edge and comprised about 31% of the marsh present. This low marsh habitat is more frequently flooded at high and intermediate tides and therefore is more frequently available for exploitation by aquatic organisms.

West Bay

In contrast to the marshes in Hall's Lake, marshes in West Bay were small in overall area, narrow in width, and discontinuous (Table 1). Fetch length was also much greater for all of the West Bay marshes compared with the marshes of Hall's Lake. Most of the barrier island shoreline in the immediate vicinity of Hall's Lake was nonvegetated, and only 13.8 % of the island shoreline was vegetated. Along this shoreline, the closest smooth cordgrass marsh to Hall's Lake occurred to the East at our drop sampling site V3 (Figure 1). Overall elevation of these island marshes was low, and over 50% of their area was below 67 cm MLW. Smooth cordgrass on these island shorelines was frequently growing through a layer of oyster shell.

Further east along the West Bay shoreline (Appendix II, Sections C and D), marshes occurred more frequently, and 49.3% of the shoreline was vegetated. This shoreline had a southeastern exposure which was similar to the direction of exposure along the island shoreline near our sites N1 and V3. However, oyster shell was less abundant along the West Bay shorelin . Continuing to the east along the West Bay shoreline (Appendix II, Section E), marsh vegetation was again infrequently encountered, and only 9.4% of the shoreline was vegetated. This shoreline had an eastern exposure.

Comparison of Six Drop Sampling Sites

Physical and Chemical Characteristics

The six drop-sample sites represented a variety of shallow-water habitats (Tabl 2). Overall, there were no significant differences among the sit s in water temperatur , dissolved oxygen, or turbidity (Table 3). Some contrasts with dissolved oxygen were significant, but values were not low enough at any of the sites to negatively affect animal abundances (Table 2). There was a highly significant difference in salinity among the sites (Table 3), and salinities at the Hall's Lake sites were significantly lower than at the four sites in West Bay (Table 2, REGWQ multiple range test, 0.05 alpha). These low salinities were apparently due to a pulse of freshwater flowing into the lake from Hall's Bayou. The water was deepest at site N3 and shallowest at the inner marsh site in Hall's Lake (V2), although tidal changes over the sampling period affected this parameter to some ext nt.

Sediments

Overall, sediments at the six sites had a high percentage of sand and gravel (gravel is defined as anything retained on a 2-mm sieve). Sites N2 and N3 in West Bay had the highest mean percentages of sand and gravel (Table 4), and these sites were characterized by a great deal of shell and rock. Contrasts indicated that the percentage of sand and gravel along with the graphic mean particle size (size is inversely related to phi value) was greater at nonvegetated sites than at vegetated sites (Figure 3, Table 3). Sediments at nonveg tated

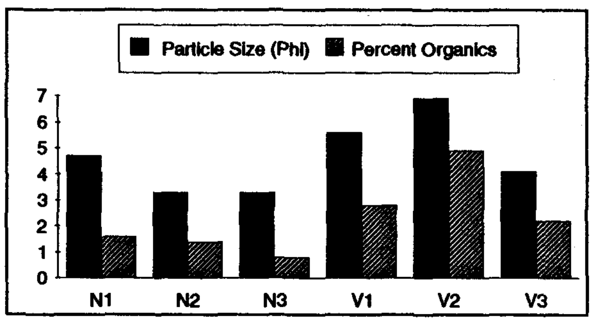

Figure 3. Sediment parameters at the six sampling sites. Particle size increases as phi decreases.

sites also had a significantly lower sorting value (more variability in particle size) and a lower organic content than vegetated sites. The contrast comparing vegetated sites in Hall's Lake with the vegetated site in West Bay (V1 + V2 vs V3) was marginally significant for three of the four sediment parameters analyzed, indicating that the marsh sediments in West Bay had a lower organic content and larger particle size than marsh sediments in Hall's Lake. There w r no significant differences in sediments betw n the inn r marsh and fring marsh in Hall's Lak or between the vegetated shoreline

(V3) and nonvegetated shoreline (N1) of islands in West Bay.

Macrophytes

Most of the macrophytes at the three vegetated sites were Spartina alterniflora. Other macrophytes (including Batis maritima, Salicornia bigelovii, and Borrichia frutescens) only occurred at the inner marsh site in Hall's Lake (V2) making up 39% of the vegetation density and 27% of the vegetation biomass. All three vegetated sites were significantly different on the basis of total macrophyte density and biomass with the greatest values occurring at the inner marsh in Hall's Lake and the lowest values in the West Bay marsh (Tables 3 and 5). Although a similar pattern occurred for density and biomass of Spartina alterniflora (Table 5), the large variability within sites prevented the detection of significant differences among the sites (ANOVAs, 2,9 df, $P > 0.10$).

B nthic Infauna

Overall, densities of peracarid crustacea (amphipods and tanaids) in benthic cores were low (Figure 4, Table 6), but there was a significant difference among sites (Table 3).

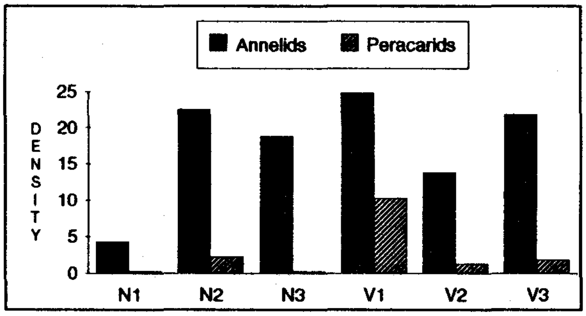

Figure 4. Mean number of benthic infauna per core (78 cm²) at the six sampling sites.

These infaunal crustacea were much more abundant in the fringe marsh of Hall's Lake than at any of the other sites. Much of this difference was due to the presence of the tanaid Hargaria rapax in the fringe marsh samples. The lowest densities of peracarids occurred at the deeper nonvegetated sites in West Bay. Annelid worms w re the most abundant of the infaunal organisms (Figure 4), and polychaetes were by far the most abundant annelids. Thirty species of polychaetes were identified, but none appeared to dominate the samples (Table 6). Overall, densities of annelids did not significantly differ among the sites (Table 3).

Macrofauna

Macrofauna densities varied significantly among the sites examined (Figure 5, Tables 3 and 7). The comparison of all vegetated sites versus all nonvegetated sites indicated that most crustacea including brown shrimp Penaeus aztecus, grass shrimp Palaemonetes pugio, and blue crabs Callinectes sapidus were found in significantly greater numbers in vegetated habitats along with some fish such as the pinfish, Lagodon rhomboides. Other relatively abundant fish, however, such as Anchoa mitchilli were never found in marsh habitats. The most

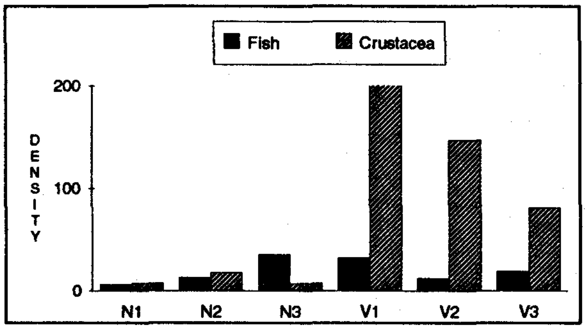

Figure 5. Mean number of macrofauna per drop sample (2.6 m²) at the six sampling sites.

abundant mollusc at marsh sites was the marsh periwinkle Littorina irrorata while the dwarf surf clam Mulinia lateralis was most abundant at nonvegetated sites. Density estimates of this clam were undoubtedly low, however, because it typically is an infaunal organism. In addition to differences in animal abundance, habitat-related size differences were also apparent, and the mean length of brown shrimp was significantly less in vegetated habitats compared with nonvegetated habitats (Tables 3 and 7). Within West Bay, the comparison of island shoreline with vegetation (V3) versus shoreline without vegetation (N1) indicated significant differences in densities of total macrofauna and crustacea (Table 3). Grass shrimp and blue crabs were much more abundant along the vegetated shoreline, while the lesser blue crab Callinectes similis was found in similar numbers in both habitats (Table 7). Brown shrimp densities were similarly low within both habitats, but the mean size of this species was significantly smaller along the vegetated shoreline (Table 7).

Comparisons among the vegetated sites indicated that more animals were present in the fringe marsh of Hall's Lake (V1) than the inner marsh (V2). A more detailed xamination of the marsh samples within Hall's Lake is presented in a following section. The West Bay marsh had significantly lower d nsiti s of pinfish and brown shrimp than th Hall's Lake marshes and significantly higher densities of the lesser blue crab. On the basis of overall density of large taxa such as fish, crustacea, and mollusca, however, there did not appear to be any significant differences between the Hall's Lake marsh s and the West Bay marsh (Table 3).

Densities of major taxa of macrofauna were not significantly different among the three nonvegetated sites in West Bay (Table 3, REGWQ Procedure). Mean fish densities were largest at N2 the deepest site (Table 7), but variability among samples prevented the detection of statistically significant differences at the 5% level.

Th Effect of Marsh Elevation in Hall's Lake

Marsh elevation was significantly higher at the InnerWest marsh than at the other marsh locations (Table 8), although both inner marsh locations had higher mean elevations than the fringe marshes. The ANOVA comparing these four marsh locations had limited power to detect differences, but the primary contrast of concern, comparing the InnerWest location with all other locations, was significant for most macrofauna taxa examined. This highest elevation marsh (InnerWest) had the lowest densities of total macrofauna, fishes, and crustacea. In addition, there were significant negative correlations between marsh elevation and the log transformed density of total macrofauna ($r= -0.74$, $P= 0.036$, $n= 8$), fish ($r= -0.74$, $P= 0.035$, $n= 8$), and crustacea ($r= -0.78$, $P= 0.022$, $n= 8$); indicating that marsh elevation could explain between 55% and 61% of the variability in these density estimates. A similar relationship was apparent for brown shrimp (Figure 6). In contrast, infauna densities did not differ significantly among the four marsh locations, and were not correlated with

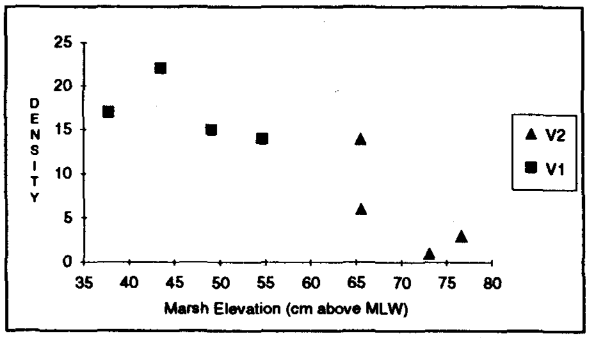

Figure 6. The number f brown shrimp per drop sample in relation to marsh elevation in Hall's Lake.

levation. M an d nsiti s of crustac a in the cores previously had been found to be lower at the inner marsh locations (Table 3; Contrast V1 vs V2), but the Southeast and West inner locations were comparable in density (Table 8).

In general, macrophyte biomass and stem density appeared lower on the west side of Hall's Lake (Table 8). Although the ANOVAs indicated a significant main effect of location for three of the four macrophyte variables examined, there was little evidence for a relationship with elevation.

Sediment parameters also differed among the four marsh locations in Hall's Lake, but the contrast comparing the highest marsh (InnerWest) with the other locations was not significant (Table 8). The outer or fringe marsh location on the western side of the lak appeared to have sediments of lower organic content and larger grain size than the other marsh locations, but these variables were not correlated with elevation ($P > 0.20$).

Trawl Collections

Catch from trawls taken at the three nonvegetated sites in West Bay (N2, N3, and N4) generally indicated similar animal abundances (Table 9). A comparison of log transformed catch of total fish, Anchoa mitchilli, total crustacea, and Penaeus aztecus showed no significant differences among the three sites (ANOVA; 2,6 df; all $Ps > 0.19$). The mean size of most animals at the sites also appeared similar, although the largest brown shrimp were collected at the deepest locations (Table 9).

A comparison was also made of density estimates obtained with trawls and drop samples for the two dominant species caught, Anchoa mitchilli and Penaeus aztecus, at Sites N2 and N3. Only animals greater than 40 mm TL were included in the comparison to remove problems with size-selective bias in the trawls. Catches from both gear types were converted to numbers per 100 m^2, and the mean d nsities from eight drop samples for A. mitchilli and P. aztecus were 24.1 (SE=24.1) and 24.0 (SE=14.4), respectively. In the six trawls taken at these sites, mean densities of A. mitchilli and P. aztecus were 1.7 (SE=0.8) and 11.7 (SE=2.1) per 100 m^2, respectively.

Historical Samples

Th drop samples from March 1986, June 1988, and Sept mber 1988 w re collected within th fringe marsh of Hall's Lak , and the macrofauna densities (Table 10) can be compared to densities measured in the present study at Site V1. Densities of fish and crustacea in June and September 1988 were substantially lower than the densities we observed in May 1990, while densities recorded in March 1986 were similar. All spring samples were similar in the sense that pinfish dominated the fish population in the marsh, and grass shrimp and brown shrimp were the most abundant crustacea. Grass shrimp were less abundant in the September samples, and the dominant penaeid was the white shrimp P. setiferus. Field notes from the June 1988 sampling indicate that the marsh elevation was relatively high in the *fringe marsh* where the samples were taken, and the abundance of fiddler crabs (Uca) in the samples (Table 10) would seem to corroborate this elevation difference. Marsh elevation may have been partially responsible for the low macrofauna densities observed in the June 1988 samples.

Infauna densities between the historical cores and the cores taken in the present study are not directly comparable because historical cores included a clump of S. alterniflora. The densities of infauna and epifauna are generally higher in cores with vegetation because of the increased structural complexity and habitat space provided by the stems and roots. Historical cores, however, do indicate a decline in benthic infauna numbers over the spring (Table 11) which we have observed in other marsh habitats of Galveston Bay. This decline is likely due to the impact of predation by juvenile fishes through the spring months, and a similar phenomenon may be responsible for the relatively low densities observed from cores collected in May 1990.

Discussion

The six habitats or sites examined in the Hall's Lake and West Galveston Bay were generally similar on the basis of the water parameters measured. Salinity was lower in Hall's Lake than in West Bay due to freshwater inflow from Hall's Bayou and the restricted outlet of Hall's Lake. It is unlikely, however, that this temporary salinity reduction affected animal abundances in the habitats examined (Zimmerman et al. 1990b). Sediments at the nonvegetated sites contained more sand and grav l and were lower in organic content than sediments from vegetated sites. Among the marsh sites, macrophyte density and biomass were generally greater in the Hall's Lake marshes compared with the marsh in West Bay.

Densities of macrofauna may not always reflect the value of a habitat in providing food for growth and protection from predation (Minello and Zimmerman in press), but in general, densities of fish and crustacea should be indicative of relative habitat value. Our results from drop samples suggest that for crustacea such as grass shrimp, brown shrimp, and blue crabs, the marsh habitats in the Hall's Lake area are of greater value than the nonvegetated habitats. Relative value of these habitats for fish, however, was highly dependent upon the species. These conclusions are consistent with those from other research on habitat selection and value in Galveston Bay (Zimmerman and Minello 1984, Minello et al. 1989, Zimmerman et al. 1989,1990a, Thomas et al. 1990). All marshes, however, are not alike. Although comparisons on the basis of large taxa such as total fishes or crustacea revealed no differences in the marshes (Table 3), significantly lower densities of pinfish and brown shrimp occurred in the marsh located in West Bay (V3) compared with the Hall's Lake marshes (V1 and V2). In contrast, the lesser blue crab was significantly more abundant in the West Bay marsh.

With the exception of the Southeast shoreline, most of the marshes within Hall's Lake were relatively high-elevation marshes with a relatively narrow band of fringing low marsh nearest the open water. Data from our drop samples indicated that marsh utilization by aquatic organisms was related to elevation; marsh elevation being negatively correlated with densities of fish and crustacea. W might expect higher-elevation marshes to be of lower value for aquatic fauna because these marshes are often unavailable due to a lower frequency of tidal flooding. In addition, however, it appears that even when these marshes are flooded, they support lower densities of macrofauna (Figure 6). Elevation alone, however, does not control marsh utilization. The low-elevation marsh on the barrier island of West Bay (V3, Table 1) was not utilized by fishes and crustacea to the same extent as the low marsh in Hall's Lake (Table 7). The marsh characteristics most important in determining utilization by macrofauna, should be related to the basic marsh functions of providing refuge and food. In addition to elevation, sediment characteristics, vegetation density, wave energy, and the distance to the marsh/water edge may all be important.

Macrofauna densities measured with drop samples wer generally similar among the three shallow nonvegetated habitats examined in

West Bay (Table 3). Trawl catches on both shallow and deeper water bottom also indicated that there was little detectable difference among nonvegetated sites. Trawls appeared to underestimate animal densities in relation to the drop sampler.

Speculation concerning habitat creation, development, and relative value is dangerous on the basis of a collection of samples taken during one time at one location. However, in conjunction with other information on animal abundances in vegetated and nonvegetated habitats of Galveston Bay (Zimmerman and Minello 1984, Zimmerman et al. 1989,1990a), the data collected in this study can be used to make some conclusions regarding the future of the Hall's Lake area. If erosional processes are not reduced in the area, it is likely that the isthmus separating Hall's Lake from the GIWW and West Bay will breach, and some of the marshes in Hall's Lake will be converted into nonvegetated habitats. Although elevation appears to be important in determining the density of macrofauna in these marshes, the marshes of Hall's Lake in general seem to support high densities of macrofauna, especially crustacea such as grass shrimp, brown shrimp, and blue crabs. The rapid conversion of the Hall's Lake marshes to shallow open water habitats will probably result in reduced abundances of crustacea in the area. Overall fish abundances may not be affected, although the dominant species may change from fish associated with salt marsh vegetation such as pinfish to more open-water fish such as anchovies.

One method of reducing erosion in the area is the creation of a new barrier island along the Gulf Intracoastal Waterway (GIWW) at the general location of our Site N2 (Figure 1). The shallow, rocky habitat at N2 will be replaced by upland, and our N3 habitat will be replaced by either shallow nonvegetated shoreline (N1) or shoreline vegetated with transplanted Spartina alterniflora which should eventually become similar to Site V3. Comparisons of the nonvegetated sites in this study, both with drop samples and trawls, indicate few differences, suggesting that the replacement of one nonvegetated site with another should not cause major changes in the productivity of the area. The transplanting of S. alterniflora along the shoreline of a new island also may increase abundances of both fishes and crustacea in the area, if our comparisons of Sites N1 and V3 can be used as indicators of the relative value of thes habitats.

Th pr senc of smooth cordgrass along the islands and shoreline of West Bay indicates that salt marsh vegetation can be established on newly created shoreline in the Hall's Lak area. In addition to its habitat value, this vegetation will function to prevent shoreline erosion. Shoreline elevation and direction of exposur appear to be important factors in marsh development in the Hall's Lake area. Mor extensive marshes can be established if the shoreline does not have a steep slope. If th se islands are built parallel with the GIWW, their southeast exposure should allow the establishment of stands of smooth cordgrass, as evidenced by shoreline growth of this vegetation to the east of the Hall's Lake area. Although marshes occur along this shoreline, the long fetch across West Bay appears to limit the extent of vegetation growth. Construction of wave barriers composed of rock, earth, or tir s on the north and east exposures could allow the establishment of more extensive marshes along this shoreline. In addition, the placem nt of oyster shell along the island shorelin may increase smooth cordgrass survival. Oyster shell was frequently present along shorelines supporting smooth cordgrass growth.

It should be emphasized that although vegetated habitats appear to support larger abundances of some animals, the species composition in vegetated habitats is frequently quite different from that in nonvegetated habitats. As an example Anchoa mitchilli was the most abundant fish at two of the three open water sites, but this species was not collected at the three marsh sites. In addition, marsh vegetation by its nature is intertidal, and not always available for exploitation. This periodicity in availability should be considered in determining habitat value. Marsh elevation and frequency of tidal flooding appear to be important characteristics controlling salt marsh value for many species.

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Appendix I.

Tabl 1. Shoreline characteristics and the amount of smooth cordgrass marsh at various locations in the Hall's Lake area.

Tabl 2. Summary of physical and chemical site characteristics in the Hall's Lake area.

Tabl 3. Results from 1-way ANOVAs with contrasts.

Table 4. Sediment characteristics at six sites in the Hall's Lake area.

Tabl 5. Density and dry weight (per sq. m) of macrophytic vegetation at the three vegetated sites near Hall's Lake.

Table 6. Densities (number per 78.5 sq. cm) of benthic infauna and epifauna collected in cores at six sites in the Hall's Lake area.

Tabl 7. Densities (number per 2.6 sq. m) of macrofauna and mean size (mm Total Length of Carapace Width) of selected species collected in drop samples at six sites in the Hall's Lake area on 17-18 May 1990.

Tabl 8. The effect of marsh elevation in Hall's Lake.

Tabl 9. Number caught and mean size of fish and crustacea collected in 3-minute trawl tows from study area.

Table 10. Macrofauna densities (No. / 2.6 sq. m), mean size of selected species, and physical parameters from historical samples collected in the fringe marsh of Hall's Lake.

Tabl 11. Densities (No. / 78.5 sq. cm) of benthic infauna and epifauna from historical samples collected in the fringe marsh of Hall's Lake.

Table 1. Shoreline characteristics and the amount of smooth cordgrass marsh at various locations in the Hall's Lake area. Low-elevation marsh is defined as marsh at elevations below 67 cm MLW. Shoreline marsh in West Bay was divided into an area just east of the barrier islands (Appendix II, Sections C an D) and an area near Carancahua Lake (Appendix II, Section E).

Area	Fetch (m)	Direction of Exposure	Degrees of Exposure	Presence of Shell/Rock	Shoreline Length (m)	Entire Marsh		Low Marsh		
						Width (m)	Area (ha)	Width (m)	Area (ha)	%
Hall's Lake Marshes										
West	1200	150-352	202	None	645	80	5.2	7.7	0.5	9.6
Southeast	850	220-330	153	None	495	114	5.6	35.7	1.8	31.3
South	725	80-320	240	None	610	8	0.5	5.2	0.3	65.0
East	1200	180-360	180	None	1179	121	14.3	0.5	0.1	0.4
North	850	40-240	200	None	2395	91	21.8	7.7	1.8	8.5
West Bay Island Zone										
Vegetated Island	5120	70-120	140	Frequent	320	15	0.5	7.9	0.3	52.7
Nonvegetated Island	5120	60-210	150	Frequent	2005	--	--	--	--	--
West Bay Shoreline (East of Islands)										
Vegetated Shoreline	5120	60-235	175	Occasional	1918	11.6	2.2	6.1	1.2	52.6
Nonvegetated Shoreline	5120	70-320	250	Occasional	1969	--	--	--	--	--
West Bay Shoreline (Near Carancahua Lake)										
Vegetated Shoreline	6000	10-210	200	None	185	13.2	0.2	7.2	0.1	54.5
Nonvegetated Shoreline	6000	10-190	180	Occasional	1796	--	--	--	--	--

Table 2. Summary of physical and chemical site characteristics in the Hall's Lake area. Means and standard errors were calculated from four replicate samples taken in conjunction with drop samples at each site (17-18 May 1990). See Fig. 1 for additional information.

Site	N1		N2		N3		V1		V2		V3	
Presence of Macrophytes	No		No		No		Yes		Yes		Yes	
Location	West Bay		West Bay		West Bay		Hall's Lake		Hall's Lake		West Bay	
Habitat	Shoreline		Open Water		Open Water		Shoreline		Inner Marsh		Shoreline	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Salinity (ppt)	11.0	0.71	11.8	0.25	12.3	0.25	6.3	0.48	6.3	0.75	13.0	0.71
Temperature (C)	28.9	0.63	28.4	0.43	28.1	0.57	29.2	0.45	29.5	0.21	29.1	0.43
Dissolved Oxygen (ppm)	6.4	0.31	7.0	0.13	7.0	0.23	7.2	0.20	7.1	0.09	7.6	0.43
Turbidity (FTUs)	34.5	10.71	30.3	9.21	17.3	5.62	22.8	2.78	37.0	12.12	25.8	9.93
Water Depth (cm)												
Minimum	53.8	4.19	32.0	2.58	65.5	4.73	21.0	7.19	10.3	1.31	20.3	5.78
Maximum	55.7	4.55	35.8	2.81	69.5	3.86	30.8	5.99	13.0	1.29	23.5	4.87

Table 3. Results from 1-way ANOVA's with contrasts. Degrees of freedom are total (23), main effect of Site (5), and residual error (18). F and P values are shown for the main effect while only P values are listed for the contrasts (various site combinations). Analyses on macrophyte parameters were run only on data from the vegetated sites (V1 - V3). Analyses on sediment grain size and sorting were conducted on data after gravel fraction had been removed (see Table 4). Log transformations were used on all animal densities and arcsin transformations on percentage data. Asterisks indicate a P < 0.001.

Dependent Variable	Main Effect of Site F	Main Effect of Site P	Contrasts V1+V2+V3 vs N1+N2+N3	V1 vs V2	V1+V2 vs V3	N1 vs V3	N1 vs N2
Macrofauna (Total)	6.34	0.002	***	0.158	0.092	0.022	0.645
FISHES	2.60	0.061	0.508	0.020	0.779	0.138	0.533
Lagodon rhomboides	14.75	***	***	0.015	0.001	0.067	1.000
Anchoa mitchilli	4.83	0.006	0.008	1.000	1.000	0.211	0.211
CRUSTACEA	10.78	***	***	0.096	0.228	0.004	0.590
Penaeus aztecus	8.33	***	***	0.024	0.003	0.952	0.214
TL of P. aztecus	4.43	0.022	0.001	0.566	0.168	0.006	0.760
Palaemonetes pugio	15.26	***	***	0.081	0.166	***	0.198
Callinectes sapidus	19.36	***	***	0.159	0.368	***	0.619
Callinectes similis	6.60	0.001	0.028	1.000	***	0.628	0.412
MOLLUSCA	1.80	0.163	0.933	0.024	0.626	0.742	0.422
Benthic Infauna	2.48	0.071	0.188	0.132	0.568	0.027	0.013
ANNELIDA	2.49	0.070	0.101	0.390	0.816	0.019	0.009
CRUSTACEA	3.81	0.016	0.109	0.005	0.209	0.632	0.185
Macrophytes							
Biomass (g dry wt/sq. m)	17.88	***		0.006	0.001		
Stem density (No./sq. m)	6.43	0.018		0.078	0.015		
Sediment							
Percent Organics	7.00	***	***	0.013	0.022	0.450	0.853
Percent Sand+Gravel	4.35	0.009	0.003	0.356	0.056	0.698	0.068
Mean grain size (phi)	3.25	0.029	0.012	0.266	0.039	0.625	0.235
Sorting	3.39	0.025	0.009	0.393	0.177	0.399	0.260
Physical Characteristics							
Salinity	28.93	***	***	1.000	***	0.022	0.360
Temperature	1.22	0.338	0.050	0.685	0.686	0.740	0.464
Dissolved Oxygen	2.45	0.073	0.024	0.839	0.140	0.003	0.091
Turbidity	0.68	0.641	0.875	0.277	0.712	0.500	0.742
Minimum Depth	20.76	***	***	0.124	0.434	***	0.004
Maximum Depth	25.18	***	***	0.008	0.755	***	0.003

Table 4. Sediment characteristics at six sites in the Hall's Lake area. Each mean and standard error (SE) was calculated from four cores taken within drop samples. Particles retained on a 2 mm sieve (-1 phi) were considered gravel. Graphic mean particle size is in phi; larger particles have smaller phi values. The sorting parameter shown is the Inclusive Graphic Standard Deviation of Folk (1980) and is a measure of the spread in the particle size-frequency distribution.

	N1		N2		N3		V1		V2		V3	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Whole Sample												
Percent Sand + Gravel	56.3	16.37	84.6	8.01	83.1	6.46	43.7	7.28	25.3	7.49	62.5	15.53
Percent Silt	31.7	11.76	10.3	4.71	13.4	6.45	29.8	4.00	38.7	3.70	25.6	8.71
Percent Clay	12.1	5.25	5.2	3.33	3.6	0.84	26.5	6.51	35.9	6.62	11.8	6.96
Graphic Mean Size	4.7	0.82	1.2	0.73	3.0	0.55	5.6	0.76	6.9	0.54	3.0	1.47
Sorting	1.9	0.70	2.7	0.57	1.4	0.34	2.9	0.46	3.4	0.22	3.0	0.36
Sample without Gravel												
Percent Sand	56.2	16.34	73.6	8.79	81.9	6.70	43.7	7.28	25.3	7.49	57.2	14.12
Percent Silt	31.7	11.73	18.0	4.83	14.3	6.78	29.8	4.00	38.7	3.70	30.0	7.60
Percent Clay	12.1	5.24	8.5	3.98	3.8	0.71	26.5	6.51	35.9	6.62	12.8	6.74
Graphic Mean Size	4.7	0.82	3.3	0.76	3.3	0.35	5.6	0.76	6.9	0.54	4.1	1.19
Sorting	1.9	0.71	2.6	0.38	1.1	0.24	2.9	0.46	3.4	0.22	2.4	0.43
Percent Organics	1.6	0.56	1.4	0.30	0.8	0.09	2.8	0.79	4.9	0.85	2.2	0.19

Table 5. Density and dry weight (per sq. m) of macrophytic vegetation at the three vegetated sites near Hall's Lake. Other macrophytes (live and dead combined) included *Batis maritima*, *Salicornia bigelovii*, and *Borrichia frutescens*.

	V1		V2		V3	
	Mean	SE	Mean	SE	Mean	SE
Total Macrophyte Density	165.8	52.3	284.4	47.7	71.4	17.8
Spartina alterniflora	165.8	52.3	173.5	74.0	71.4	17.8
Live	90.6	24.5	128.8	53.0	56.1	15.0
Dead	75.3	91.8	44.6	24.4	15.3	18.7
Other Macrophytes	0.0	0.0	111.0	75.9	0.0	0.0
Total Macrophyte Dry Weight (g)	298.5	64.5	613.1	79.6	93.1	31.8
Spartina alterniflora	298.5	64.5	448.0	162.4	93.1	31.8
Live	216.1	40.0	382.9	130.9	80.4	29.8
Dead	82.4	38.3	65.1	35.3	12.7	10.2
Other Macrophytes	0.0	0.0	165.1	95.3	0.0	0.0

Table 6. Densities (number per 78.5 sq. cm) of benthic infauna and epifauna collected in cores at six sites in the Hall's Lake area. Means and standard errors (SE) are from four replicate cores collected at each site on 17-18 May 1990.

	N1		N2		N3		V1		V2		V3	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
ANNELIDA	4.3	0.9	22.5	4.3	18.8	13.8	24.8	10.5	13.8	3.4	21.8	8.3
Polychaeta												
Aricidea (Acmira) philbinae	0.0		0.0		1.8	0.63	0.0		0.0		0.0	
Aricidea (Aricidea) fragilis	0.0		0.0		0.5	0.50	0.0		0.0		0.0	
Capitella capitata	0.0		0.3	0.25	0.0		3.8	2.39	8.5	2.87	0.8	0.48
Cerebratulus lacteus	0.0		0.0		0.0		0.0		0.0		0.5	0.50
Cirratulidae - unknown	0.3	0.25	0.0		0.0		0.0		0.0		0.0	
Eteone heteropoda	0.0		0.3	0.25	0.0		0.8	0.48	0.0		0.3	0.25
Genetyllis castanea	0.0		0.0		0.0		0.0		0.0		0.5	0.50
Glycera sp. C	0.3	0.25	1.0	0.71	0.3	0.25	0.0		0.0		1.3	0.25
Heteromastus filiformis	0.5	0.29	2.0	1.08	2.8	2.75	0.3	0.25	0.0		2.0	1.41
Hydroides protulicola	0.0		2.5	2.50	0.0		0.0		0.0		0.0	
Laeonereis culveri	0.0		0.0		0.0		5.0	1.08	1.8	0.75	0.0	
Marphysa sanguinea	0.0		0.0		0.0		0.0		0.0		0.3	0.25
Mediomastus californiensis	0.0		7.0	1.08	10.3	9.92	0.0		0.0		0.3	0.25
Mediomastus spp.	0.5	0.50	1.3	1.25	0.5	0.29	0.5	0.29	0.0		0.8	0.48
Megaloma spp.	0.0		3.0	1.91	0.0		0.0		0.0		0.0	
Nereidae, unidentified	0.0		0.0		0.0		0.0		0.3	0.25	0.3	0.25
Nereiphylla fragilis	0.0		0.0		0.3	0.25	0.0		0.0		0.0	
Nereis falsa	0.0		0.0		0.5	0.50	0.0		0.0		0.0	
Nereis (Neanthes) succinea	0.5	0.50	2.0	0.41	0.8	0.75	0.0		0.0		2.3	1.60
Neris (Neanthus) acuminata	0.0		0.0		0.0		0.3	0.25	0.0		0.0	
Parandalia fauveli	1.5	0.87	0.3	0.25	0.0		0.0		0.0		0.0	
Podarke cf. obscura	0.0		0.0		0.0		2.0	2.00	0.3	0.25	0.0	
Polydora cf. aggregata	0.0		0.5	0.50	0.0		0.0		0.0		0.3	0.25
Polydora ligni	0.0		1.0	0.41	0.0		5.5	3.23	0.3	0.25	0.5	0.50
Scoloplos fragilis	0.8	0.48	0.5	0.50	0.8	0.48	0.0		0.0		0.0	
Streblospio benedicti	0.0		0.0		0.0		0.5	0.50	0.0		11.5	8.89
Tharyx annulosus	0.0		0.3	0.25	0.3	0.25	0.0		0.0		0.0	
Tharyx marione	0.0		0.0		0.0		0.0		0.0		0.3	0.25
Tharyx marioni	0.0		0.5	0.29	0.3	0.25	0.0		0.0		0.3	0.25
Tharyx sp.	0.0		0.3	0.25	0.0		0.0		0.0		0.0	
Oligochaeta	0.0		0.0		0.0		6.3	2.72	2.8	2.10	0.0	
PERACARID CRUSTACEA	0.3	0.25	2.3	1.31	0.3	0.25	10.3	5.44	1.3	0.75	1.8	0.85
Amphipoda												
Ampelisca abdita	0.0		0.0		0.0		0.0		0.3	0.25	0.0	
Amphipoda, unknown	0.0		0.3	0.25	0.0		0.0		0.0		0.3	0.25
Corophium spp.	0.0		0.0		0.0		2.3	1.93	0.0		0.0	
Elasmopus cf. levis	0.0		0.3	0.25	0.0		0.0		0.0		0.0	
Gammarus mucronatus	0.0		0.0		0.0		0.0		0.5	0.50	1.0	1.00
Melita cf. nitida	0.0		1.8	1.18	0.3	0.25	0.0		0.0		0.5	0.50
Xenanthura brevitelson	0.3	0.25	0.0		0.0		0.0		0.0		0.0	
Tanaidacea												
Hargeria rapax	0.0		0.0		0.0		8.0	3.58	0.5	0.29	0.0	

Table 6 (continued)

	N1		N2		N3		V1		V2		V3	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
MOLLUSCA	2.3	0.48	3.3	1.25	1.3	0.95	0.0		0.0		3.8	1.80
Acteocina canaliculata	0.3	0.25	1.0	0.41	0.0		0.0		0.0		0.8	0.48
Anachis obesa	0.0		0.8	0.75	0.0		0.0		0.0		0.8	0.48
Lyonsia hyalina	0.0		0.0		0.0		0.0		0.0		0.3	0.25
Mulinia lateralis	2.0	0.41	1.0	0.71	0.8	0.75	0.0		0.0		0.3	0.25
Mysella planulata	0.0		0.0		0.0		0.0		0.0		0.3	0.25
Odostomia impressa	0.0		0.0		0.0		0.0		0.0		0.3	0.25
Odostomia spp.	0.0		0.0		0.0		0.0		0.0		0.3	0.25
Periploma margaritaceum	0.0		0.3	0.25	0.5	0.29	0.0		0.0		0.0	
Petricola pholadiformis	0.0		0.0		0.0		0.0		0.0		0.3	0.25
Pyrgocythara plicosa	0.0		0.3	0.25	0.0		0.0		0.0		0.3	0.25
Tagelus spp.	0.0		0.0		0.0		0.0		0.0		0.5	0.50
OTHERS												
Anemone	0.0		0.5	0.50	0.0		0.0		0.0		0.3	0.25
Insect larva	0.0		0.0		0.0		0.3	0.25	0.0		0.0	
Nemertean (unknown species)	0.8	0.25	0.5	0.29	0.8	0.25	0.3	0.25	0.0		0.5	0.50
Crustacea												
Callinectes sapidus	0.3	0.25	0.0		0.0		0.0		0.0		0.0	
Clibanarius vittatus	0.0		0.3	0.25	0.0		0.0		0.0		0.0	
Copepoda, Harpacticoida, unid.	0.0		0.0		0.0		0.3	0.25	0.0		0.0	
Cumacean, unidentified	0.5	0.29	0.0		0.3	0.25	0.0		0.0		0.0	
Larval crustacean, unidentified	0.0		0.3	0.25	0.0		0.0		0.0		0.0	
Panopeus turgidus	0.0		0.5	0.29	0.0		0.0		0.0		0.0	

Table 7. Densities (number per 2.6 sq. m) of macrofauna and mean size (mm Total Length or Carapace Width) of selected species collected in drop samples at six sites in the Hall's Lake area on 17-18 May 1990. Means and standard errors (SE) are from four replicate drop samples collected at each site.

	N1		N2		N3		V1		V2		V3	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
FISHES	6.5	3.50	13.5	6.45	35.8	16.64	32.5	2.47	12.5	9.87	19.5	8.57
Anchoa mitchilli	3.8	3.42	0.0		28.8	16.74	0.0		0.0		0.0	
Arius felis	0.5	0.29	0.0		0.0		0.0		0.0		0.0	
Bairdiella chrysoura	0.0		0.0		0.0		3.0	3.00	0.0		0.0	
Brevoortia patronus	0.0		0.0		1.3	1.25	0.0		0.0		0.0	
Cynoscion arenarius	0.3	0.25	0.0		0.0		0.0		0.0		0.0	
Cyprinodon variegatus	0.0		0.0		0.0		0.0		0.3	0.25	0.0	
Fundulus grandis	0.0		0.0		0.0		0.3	0.25	0.8	0.75	0.0	
Gobiesox strumosus	0.8	0.48	9.0	4.02	2.5	1.85	0.5	0.50	0.0		15.0	8.03
Gobiosoma bosci	0.0		2.0	1.35	0.0		1.5	0.96	0.0		1.8	1.11
Lagodon rhomboides	0.0		0.0		0.0		22.0	5.43	11.0	8.38	2.0	1.08
Leiostomus xanthurus	0.3	0.25	0.0		0.0		0.0		0.0		0.0	
Menidia beryllina	0.5	0.29	2.3	2.25	2.5	2.18	1.0	0.41	0.0		0.8	0.48
Micropogonias undulatus	0.0		0.0		0.3	0.25	0.0		0.0		0.0	
Mugil cephalus	0.0		0.0		0.0		2.8	1.55	0.5	0.50	0.0	
Paralichthys lethostigma	0.0		0.0		0.0		1.0	0.41	0.0		0.0	
Syngnathus louisianae	0.3	0.25	0.3	0.25	0.0		0.0		0.0		0.0	
Syngnathus scovelli	0.0		0.0		0.3	0.25	0.3	0.25	0.0		0.0	
Unknown fish species	0.3	0.25	0.0		0.3	0.25	0.3	0.25	0.0		0.0	
CRUSTACEA	7.8	3.20	18.5	12.58	7.5	3.52	426.3	130.56	147.0	74.73	81.8	12.94
Alpheus heterochaelis	0.0		0.0		0.0		0.0		0.0		1.0	0.71
Callinectes sapidus	0.0		0.3	0.25	0.0		8.5	2.47	5.3	2.17	8.8	2.69
Callinectes similis	4.8	2.32	6.5	2.47	0.8	0.75	0.0		0.0		5.0	2.04
Callinectes spp. (pl)	0.3	0.25	3.0	3.00	0.3	0.25	0.0		0.0		0.0	
Clibanarius vittatus	0.8	0.75	1.3	0.95	1.0	0.71	7.0	4.06	1.3	0.75	8.8	4.59
Eurypanopeus depressus	0.0		0.0		2.0	2.00	0.0		0.0		1.8	1.44
Macrobranchium ohione	0.0		0.0		0.0		0.3	0.25	0.0		0.3	0.25
Palaemonetes intermedius	0.3	0.25	0.0		0.0		0.0		0.0		0.0	
Palaemonetes pugio	0.3	0.25	6.8	5.76	0.5	0.50	390.5	132.33	125.3	74.26	52.5	16.06
Palaemonetes sp. (pl)	0.0		0.0		0.5	0.50	0.0		0.0		0.0	
Palaemonetes vulgaris	0.0		0.0		0.0		0.0		0.0		1.0	1.00
Panopeus herbstii	0.0		0.3	0.25	1.3	1.25	0.3	0.25	0.3	0.25	0.3	0.25
Penaeus aztecus	1.5	0.65	0.3	0.25	1.0	0.71	17.0	1.78	6.0	2.86	2.5	1.89
Penaeus setiferus	0.0		0.0		0.3	0.25	2.8	1.31	0.0		0.0	
Rhithropanopeus harrissi	0.0		0.3	0.25	0.0		0.0		0.0		0.0	
Sesarma cinereum	0.0		0.0		0.0		0.0		1.5	0.96	0.0	
Sesarma reticulatum	0.0		0.0		0.0		0.0		2.0	1.68	0.0	
Uca longisignalis	0.0		0.0		0.0		0.0		5.5	2.47	0.0	

Table 7 (continued)

	N1		N2		N3		V1		V2		V3	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
MOLLUSCA	16.5	10.24	14.0	12.03	65.8	39.93	4.5	2.72	46.8	17.67	7.8	2.63
Amygdalum papyrium	0.0		0.0		0.0		0.0		0.3	0.25	0.0	
Brachidontes exustus	0.3	0.25	0.0		0.0		0.0		0.0		0.0	
Cerithidea pliculosa	0.0		0.0		0.0		0.0		0.5	0.29	0.0	
Crassostrea virginica	0.5	0.50	0.3	0.25	0.0		0.5	0.29	0.0		2.3	0.95
Crepidula plana	0.0		0.0		0.0		0.0		0.0		2.8	2.75
Cumingia tellinoides	0.0		0.0		0.3	0.25	0.0		0.0		0.0	
Diplothyra smithii	0.3	0.25	0.3	0.25	0.8	0.48	0.0		0.0		0.0	
Enis spp. (Minor)	0.3	0.25	0.0		0.5	0.50	0.0		0.0		0.0	
Littorina irrorata	0.0		0.0		0.0		4.0	2.83	46.0	17.76	0.8	0.75
Lyonsia hyalina	0.0		0.3	0.25	0.0		0.0		0.0		1.0	0.71
Mulinia lateralis	15.0	10.13	12.8	11.43	63.3	40.45	0.0		0.0		0.5	0.50
Nassarius acutus	0.0		0.0		0.3	0.25	0.0		0.0		0.0	
Nassarius vibex	0.0		0.3	0.25	0.3	0.25	0.0		0.0		0.0	
Petricola pholadiformis	0.0		0.0		0.0		0.0		0.0		0.3	0.25
Rictaxis punctostriatus	0.0		0.0		0.0		0.0		0.0		0.3	0.25
Semele proficua	0.0		0.0		0.3	0.25	0.0		0.0		0.0	
Sphenia antillensis	0.0		0.3	0.25	0.0		0.0		0.0		0.0	
Tagelus spp.	0.3	0.25	0.0		0.0		0.0		0.0		0.0	
Thais haemastoma	0.0		0.0		0.3	0.25	0.0		0.0		0.0	
MEAN SIZE												
Anchoa mitchilli	35.5	10.00			25.5	0.59						
Lagodon rhomboides							44.9	4.98	43.0	4.12	43.2	4.33
Callinectes sapidus							33.6	3.25	42.2	8.64	22.1	2.42
Callinectes similis	10.0	2.72	11.7	0.98							15.7	0.23
Palaemonetes pugio			12.9	0.09			30.5	0.77	29.4	0.55	20.0	1.93
Penaeus aztecus	59.1	6.16	62.0		58.3	3.67	41.0	3.49	44.4	3.89	33.2	6.19
Penaeus setiferus							16.1	4.49				

Table 8. The effect of marsh elevation in Hall's Lake. Means of two replicate samples at four marsh locations are shown with probability values from an ANOVA comparing the four marsh areas. Elevation is in cm above Mean Low Water.

	Means				ANOVA Results (P)			
	Inner Marsh (V2)		Fringe Marsh (V1)		Main Effect	Contrasts		
	SEast	West	SEast	West		InnerWest vs Rest	InnerWest vs InnerSEast	InnerWest vs FringeWest
Elevation (cm)	65.5	74.8	57.2	49.0	0.081	0.039	0.263	0.022
Macrofauna (Number / 2.6 sq m)	321.5	91.0	518.5	408.0	0.231	0.074	0.150	0.178
Fishes	23.5	1.5	32.5	32.5	0.061	0.016	0.060	0.022
Lagodon rhomboides	20.5	1.5	26.0	18.0	0.127	0.034	0.082	0.070
Crustacea	260.0	34.0	483.5	369.0	0.128	0.037	0.082	0.096
Palaemonetes pugio	237.0	13.5	447.5	333.5	0.132	0.038	0.073	0.115
Penaeus aztecus	10.0	2.0	18.0	16.0	0.027	0.007	0.031	0.011
Infauna (Number / core)	14.5	15.5	21.0	50.5	0.514	0.578	0.817	0.270
Annelids	13.0	14.5	16.0	33.5	0.747	0.787	0.790	0.468
Crustacea	1.5	1.0	4.5	16.5	0.173	0.179	0.872	0.062
Macrophytes (sq m)								
Density (stems)	293.3	275.5	244.9	86.7	0.249	0.427	0.857	0.112
Biomass (g dry wt)	713.1	513.1	409.9	187.1	0.023	0.382	0.104	0.027
Spartina alterniflora								
Density (stems)	293.3	53.6	244.9	86.7	0.046	0.040	0.019	0.627
Biomass (g dry wt)	713.1	183.0	409.9	187.1	0.014	0.030	0.005	0.967
Sediment								
Percent Organics	6.2	3.6	4.1	1.4	0.012	0.637	0.022	0.036
Mean grain size (phi)	7.6	6.2	6.9	4.3	0.030	0.879	0.104	0.049

Table 9. Number caught and mean size of fish and crustacea collected in 3-minute trawl tows from study area. Mean catch is calculated from three tows taken at each site, mean length is the mean of the mean lengths from each tow, and size range is from all animals collected at a site.

	N2				N3				N4			
Species	Catch		Total Length (mm)		Catch		Total Length (mm)		Catch		Total Length (mm)	
	Mean	SE	Mean	Range	Mean	SE	Mean	Range	Mean	SE	Mean	Range
FISH (Total Abundance)	12.7	4.81			28.0	8.39			24.3	3.48		
Anchoa mitchilli	7.7	4.33	44.8	24-85	17.3	8.82	40.1	20-82	12.3	4.37	31.7	22-74
Arius felis	0.0				0.0				0.3	0.33	120.0	120
Brevoortia patronus	2.0	1.15	54.0	35-80	3.7	2.19	63.4	39-87	0.0			
Chaetodipterus faber	0.3	0.33	72.0	72	0.3	0.33	125.0	125	0.0			
Lagodon rhomboides	2.0		67.5	58-79	2.7	0.88	75.7	66-85	0.7	0.33	68.5	67-70
Leiostomus xanthurus	0.3	0.33	64.0	64	2.0	1.15	75.7	63-87	8.3	4.48	76.8	65-90
Micropogonias undulatas	0.0				1.3	0.67	74.8	63-94	2.0	0.58	83.9	46-119
Orthopristis chrysoptera	0.3	0.33	178.0	178	0.0				0.0			
Peprilus berti	0.0				0.3	0.33	55.0	55	0.0			
Polydactylus octonemus	0.0				0.0				0.3	0.33	111.0	111
Prionotus tribulus	0.0				0.0				0.3	0.33	106.0	106
Sphoeroides parvus	0.0				0.3	0.33	30.0	30	0.0			
CRUSTACEA (Total Abundance)	47.7	18.85			58.3	9.06			80.7	25.46		
Callinectes sapidus	0.0				0.0				0.7	0.67	152.5	140-165
Palaemonetes pugio	0.3	0.33	29.0	29	0.0				0.0			
Penaeus aztecus	47.3	18.70	64.8	40-125	58.3	9.06	70.3	41-101	80.0	25.42	81.2	39-106
Species Diversity (Number of species)	8				9				9			

Table 10. Macrofauna densities (No. / 2.6 sq. m), mean size of selected species, and physical parameters from historical samples collected in the fringe marsh of Hall's Lake. Data are from drop samples collected on 26 March 1986, 1 June 1988, and 21 September 1988. Means and standard errors (SE) are calculated from four replicates. Habitat is comparable to Site V1.

	March 26 1986		June 1 1988		Sept 21 1988	
Species Name	Mean	SE	Mean	SE	Mean	SE
FISH	26.5	3.66	4.8	2.21	7.0	3.81
Adinia xenica	0.0		0.3	0.25	0.0	
Cynoscion nebulosus	0.0		0.0		1.3	0.63
Cyprinodon variegatus	0.3	0.25	0.0		0.0	
Fundulus grandis	2.0	0.82	0.0		0.0	
Fundulus similis	0.3	0.25	0.0		0.0	
Gobiesox strumosus	0.0		0.0		0.3	0.25
Gobionellus boleosoma	3.8	1.55	0.0		0.0	
Gobiosoma bosci	0.0		0.0		3.8	2.84
Lagodon rhomboides	20.0	3.24	4.3	2.02	0.3	0.25
Menidia beryllina	0.0		0.3	0.25	0.0	
Mugil cephalus	0.0		0.0		0.3	0.25
Orthopristis chrysoptera	0.3	0.25	0.0		0.0	
Paralichthys lethostigma	0.0		0.0		0.3	0.25
Symphurus plagiusa	0.0		0.0		0.5	0.50
Syngnathus scovelli	0.0		0.0		0.5	0.29
CRUSTACEA	423.8	117.89	24.5	6.14	290.8	106.86
Callinectes sapidus	12.0	1.29	1.0	0.41	27.8	5.27
Clibanarius vittatus	7.8	3.30	0.3	0.25	5.5	2.06
Palaemonetes intermedius	0.8	0.75	0.0		0.0	
Palaemonetes pugio	348.5	125.18	9.5	5.01	141.0	74.30
Palaemonetes vulgaris	0.0		0.0		10.0	7.15
Penaeus aztecus	54.8	13.98	1.3	0.25	31.3	9.11
Penaeus setiferus	0.0		0.0		74.5	24.42
Sesarma cinereum	0.0		1.8	0.75	0.0	
Sesarma reticulatum	0.0		0.3	0.25	0.0	
Uca longisignalis	0.0		10.5	4.70	0.3	0.25
Uca spp.	0.0		0.0		0.5	0.50
MOLLUSCA	15.8	6.75	44.8	30.52	57.3	27.46
Cerithidea pliculosa	0.0		0.5	0.50	0.8	0.48
Crassostrea virginica	8.3	8.25				
Littorina irrorata	6.3	1.75	44.3	30.02	56.5	27.06
Melampus bidentatus	1.3	1.25	0.0		0.0	
MEAN LENGTH						
Callinectes sapidus	15.2	1.65	15.9	9.84	55.0	6.99
Palaemonetes pugio	27.2	0.51	30.0	1.32	28.0	1.71
Penaeus aztecus	15.4	0.41	60.6	5.52	34.0	1.25
Penaeus setiferus					34.5	3.03
PHYSICAL PARAMETERS						
Salinity	25.5	0.29	23.3	0.25	18.0	1.22
Temperature	20.0	0.06	27.4	0.25	32.3	0.43
Dissolved Oxygen	8.5	0.35	6.5	0.42	10.2	0.83
Turbidity	28.0	4.92	16.3	4.52	7.3	2.98
Depth						
Minimum	12.3	1.97	27.3	1.38	20.3	1.11
Maximum	20.5	1.32	30.8	2.50	27.3	3.40

Table 11. Densities (No. / 78.5 sq. cm core) of benthic infauna and epifauna from historical samples collected in the fringe marsh of Hall's Lake. Cores included a small clump (4-7 stems) of Spartina alterniflora and were taken in conjunction with drop samples (Table 10). Means and standard arrors (SE) are calculated from four replicate cores.

Species Name	March 26 1986 Mean	March 26 1986 SE	June 1 1988 Mean	June 1 1988 SE	Sept 21 1988 Mean	Sept 21 1988 SE
POLYCHAETA	206.5	70.12	13.5	5.24	53.3	13.28
Capitella capitata	80.3	26.63	12.8	4.82	28.8	14.16
Eteone lactea	0.3	0.25	0.3	0.25	0.0	
Heteromastis filiformis	8.8	4.84	0.5	0.50	0.0	
Hobsonia gunneri	0.0		0.0		2.0	0.91
Laeonereis culveri	0.0		0.0		2.8	2.14
Nereidae, unidentified	0.0		0.0		2.0	1.22
Nereis (Neanthes) succinea	7.0	2.04	0.0		0.5	0.29
Polychaeta, unidentified	2.8	2.75	0.0		0.0	
Polydora ligni	7.0	7.00	0.0		3.0	1.47
Polydora spp.	16.8	10.16	0.0		0.0	
Streblospio benedicti	83.8	42.85	0.0		14.3	5.71
OLIGOCHAETA	23.3	11.63	39.5	16.95	17.8	4.21
AMPHIPODA	221.5	53.06	28.0	17.97	13.3	3.17
Corophium spp.	74.8	28.37	0.0		3.0	1.22
Gammarus mucronatus	138.3	58.91	22.5	16.53	6.8	1.80
Grandidierella bonneroides	8.5	3.28	0.0		2.0	0.71
Orchestia spp.	0.0		5.5	1.85	1.5	0.65
TANAIDACEA						
Hargeria rapax	41.3	28.57	3.3	3.25	17.3	11.37
OTHER						
Bivalve	1.3	0.48	0.0		0.0	
Callinectes sapidus	0.5	0.29	0.0		0.0	
Cassidinidea ovalis	6.3	2.84	0.0		0.8	0.48
Clibinarius vittatus	0.0		0.0		0.0	
Copepoda	0.3	0.25	0.0		0.0	
Edotea montosa	0.3	0.25	0.0		0.0	
Fish	0.3	0.25	0.0		0.0	
Gastropod	0.0		0.0		0.8	0.48
Insect larva	0.0		1.5	0.29	0.0	
Penaeus aztecus	0.3	0.25	0.0		0.0	
Sesarma cinereum	0.0		0.0		0.3	0.25

Appendix II.

Marsh locations along the northern shoreline of West Bay, and habitat changes between 1985 and 1990

Habitats Along th North rn Shorelin of West Bay

The northern shoreline of West Bay was examined to help determine the conditions necessary for growth of smooth cordgrass in this area. Most of the shoreline is a continuous island that separates the GIWW from West Bay (sections C-H). Near Hall's Lake (sections A-C) the island is breached and open-water areas occur along with smaller islands. Open water and small islands are also present at the opposite end of the surveyed area (sections I-J). Intermittent stands of smooth cordgrass are present along the shoreline of the main island (sections C, D, F, G, H, I, and J). On the smaller islands, small stands of smooth cordgrass occur near Hall's Lake (section C) while relatively large stands occur on the eastern islands (section I and J). Large areas of nonvegetated shoreline occur in sections A, E, and G.

Sections of bay shoreline varied in direction of exposure, and these differences appeared to be very important. Shorelines facing to the east and northeast are generally the areas least colonized with plants (section E, G, and J). In contrast, areas with a southwest exposure on islands along the GIWW near Tiki Island such as North and South Deer Islands (section J) have very extensive marsh habitats dominated by smooth cordgrass. These same islands generally have shell shorelines without vegetation on their shores with northeastern exposures. This distribution reinforces the concept that the northeast exposure is detrimental to marsh establishment.

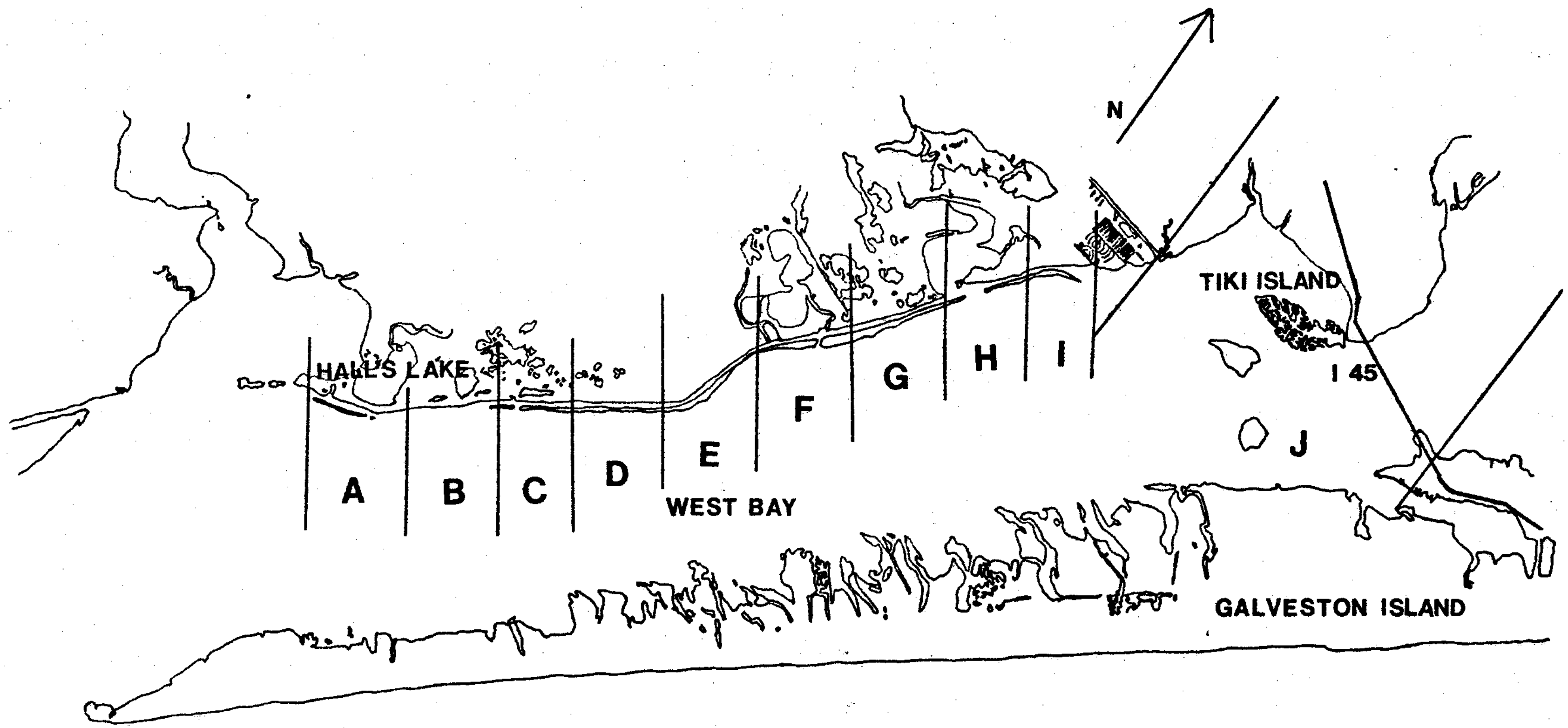
Shoreline elevation and slope on the islands near Hall's Lake appear to be important in regulating marsh development. The open water areas between the islands are presently too deep to allow smooth cordgrass to grow, and most of this area was submerged during our visits. Nonvegetated shoreline along the islands had relatively steep slopes leaving only a narrow band of shore with suitable elevation for colonization by smooth cordgrass. Because of these conditions, the smooth cordgrass marshes present on this shoreline are narrow. Oyster shell accumulation along the shoreline appears to be important in preventing erosion and allowing plants to survive in narrow bands.

Changes in Shoreline Habitats from 1985 to 1989-1990

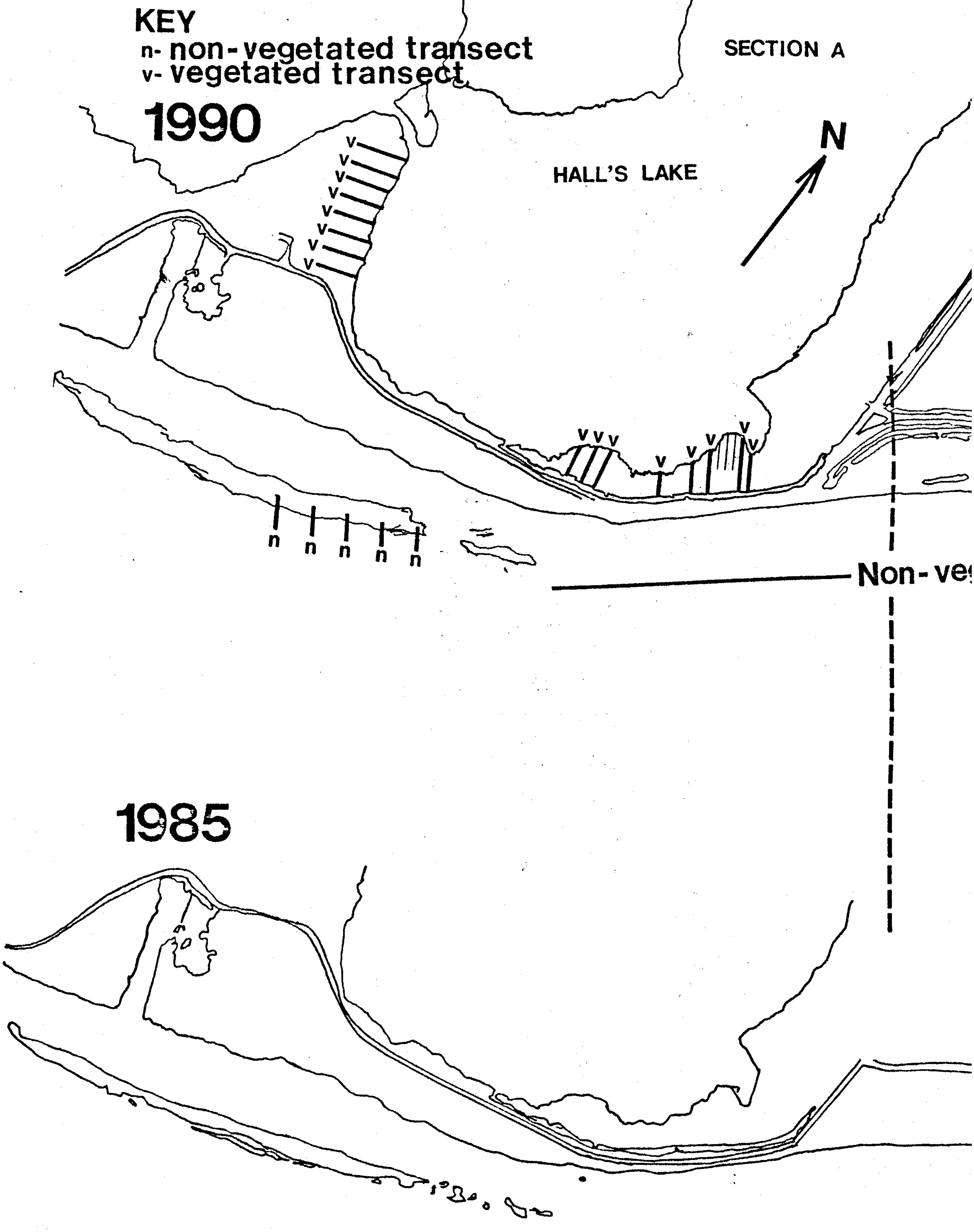
There was a considerable amount of marsh loss along the West Bay shoreline between 1985 and 1989-90. Some of the losses (marked with circles on figure) were easily detected from aerial photos taken in early 1989. Visual inspection of portions of the shoreline also revealed recent losses. Three hurricanes that passed through the Galveston area in the past two years may have caused some wave erosion in addition to normal erosion. Examples of differences in marsh configuration and size that appear to be associated with erosion are circled in Section D.

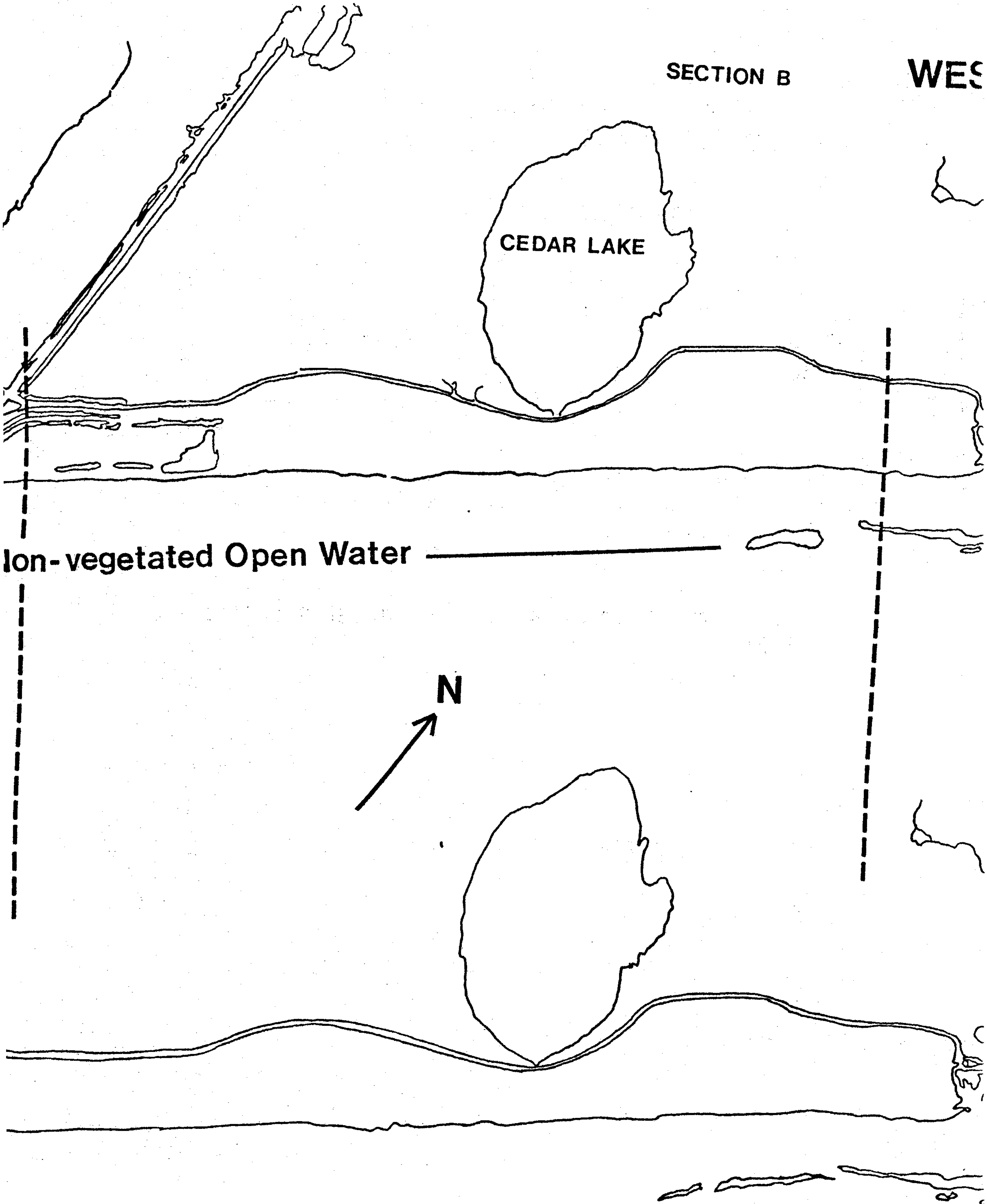
Losses and damage to existing marshes also occurred because of dredged material disposal during the last dredging cycle of the GIWW. Major losses of marsh were noted in sections F and G, and part of this loss appeared to be related to placement of dredged material on or near existing marshes. Habitat differences between 1985 and 1989-90 that appeared to be associated with dredged material disposal were also discernable in sections D, E, and H. Placement of the outfall pipe onto existing marshes resulted in burial of existing stands of smooth cordgrass. From the available photography it also appears that disposal at intervals along shorelines with intermittent stands of vegetation was detrimental to those stands. The reason for this loss of habitat when direct burial did not occur, however, was not readily apparent.

Consideration should be given to designing a research program to determine the best methods of avoiding marsh destruction during routine maintenance dredging operations. Closer monitoring of the disposal operation or precise instructions to contractors may be necessary to avoid future damage due to misplacement of outfall pipes. Disposal procedures may be developed that use dredged materials for protection or enhancement of existing marshes


N
HALLS LAKE
A
B
C
D
E
WEST BAY
F
G
H
I
TIKI ISLAND
I 45
J
GALVESTON ISLAND

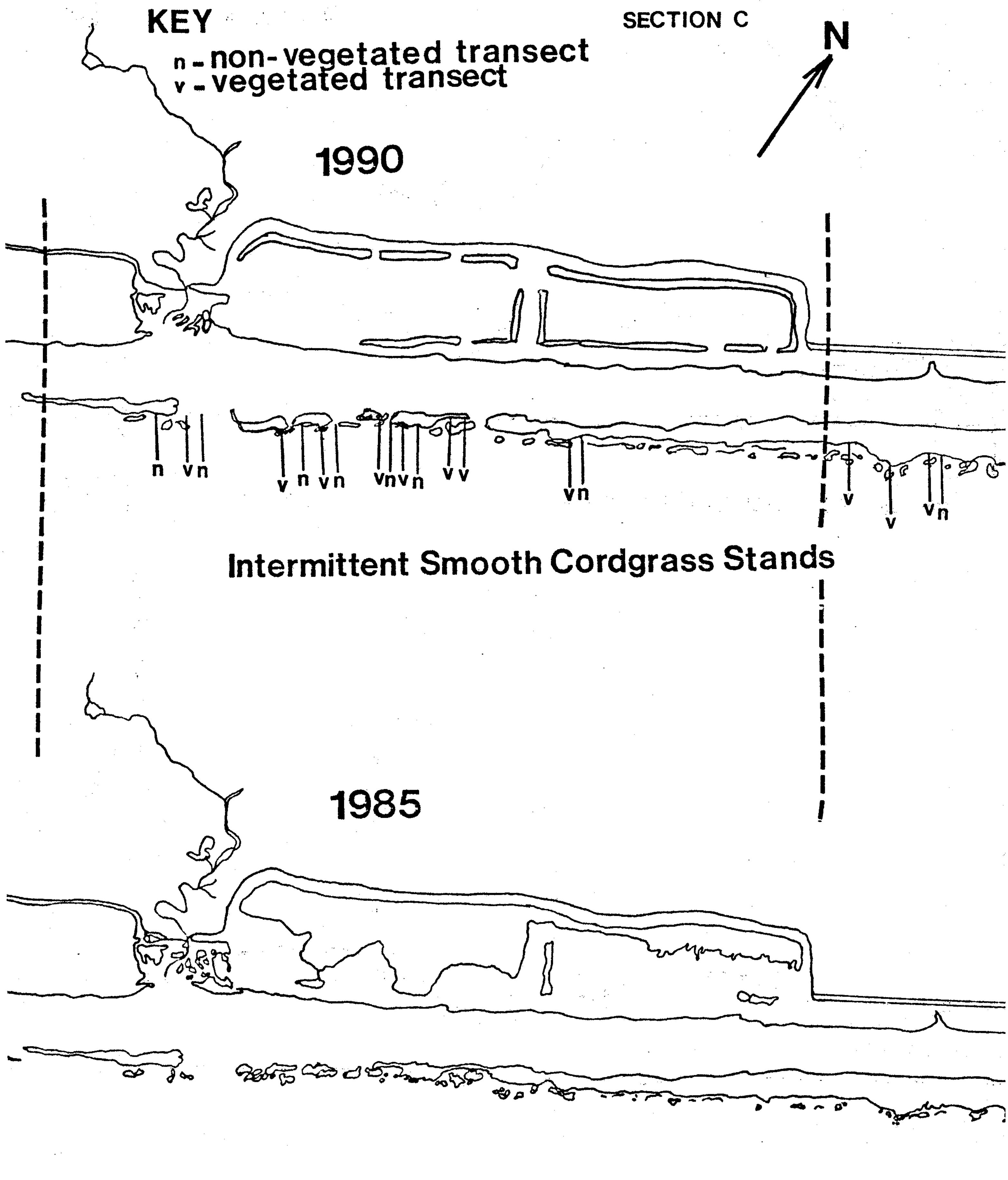
WEST BAY AT HALLS LAKE

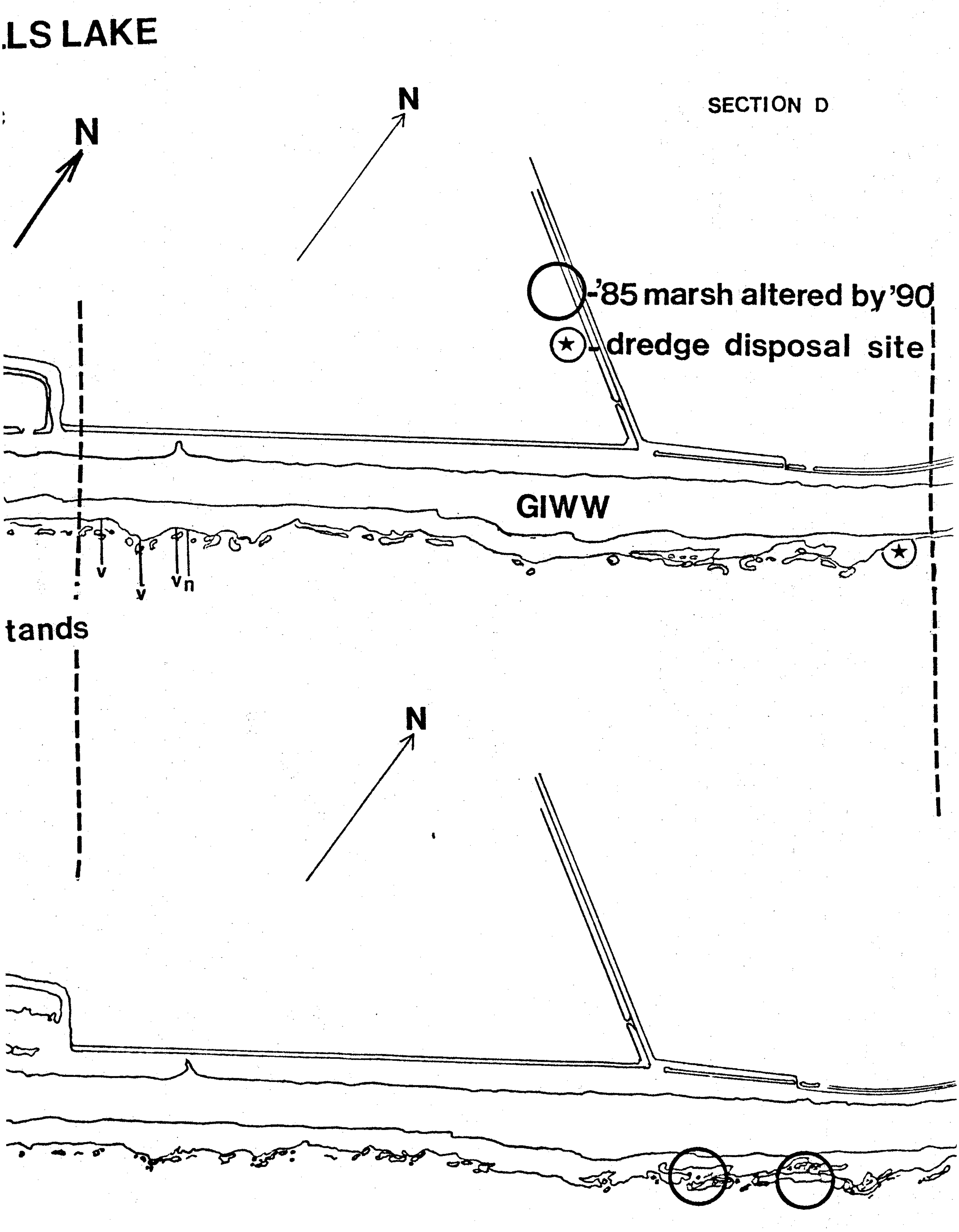


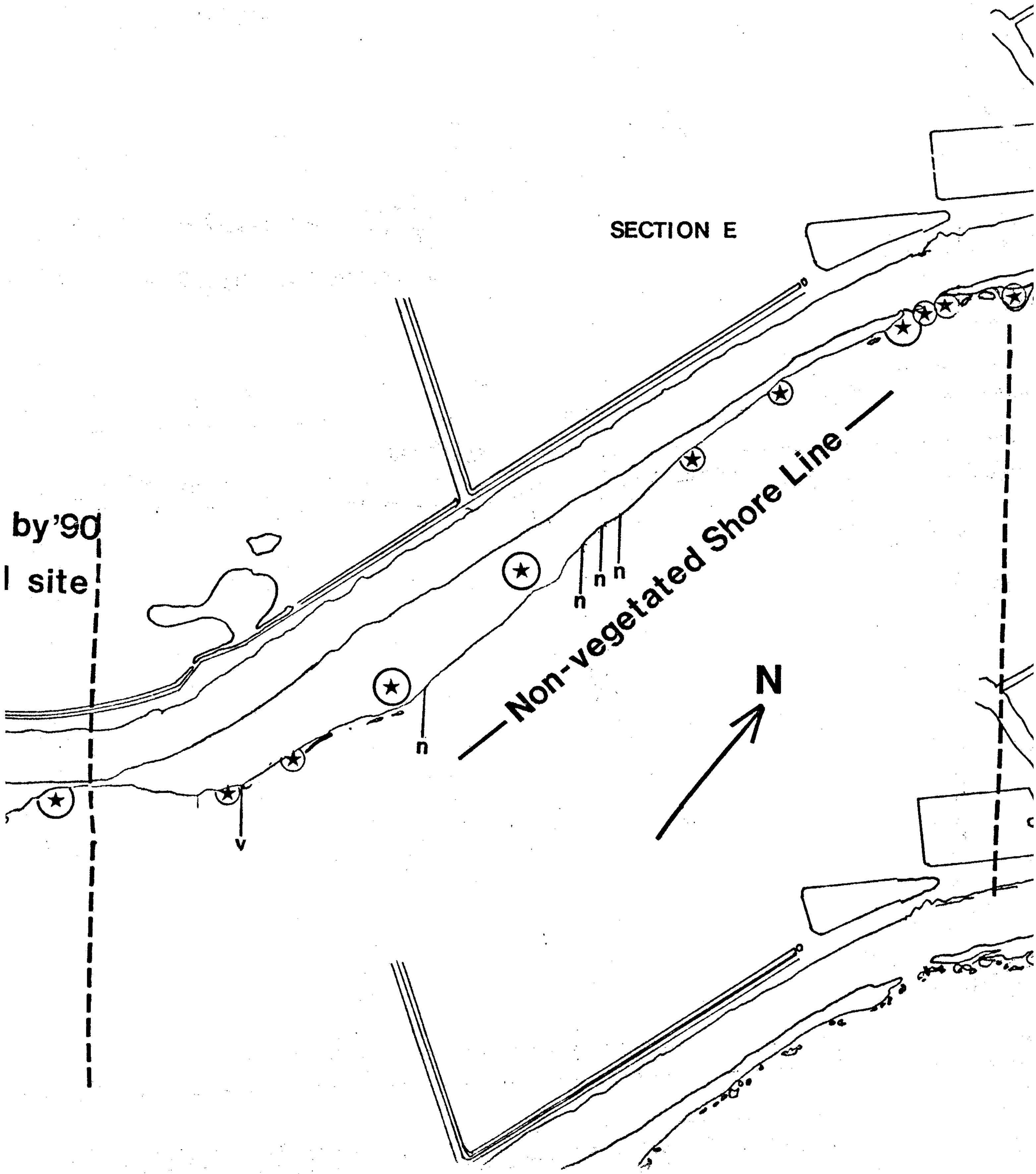


SECTION B
WES
CEDAR LAKE
Ion-vegetated Open Water
N

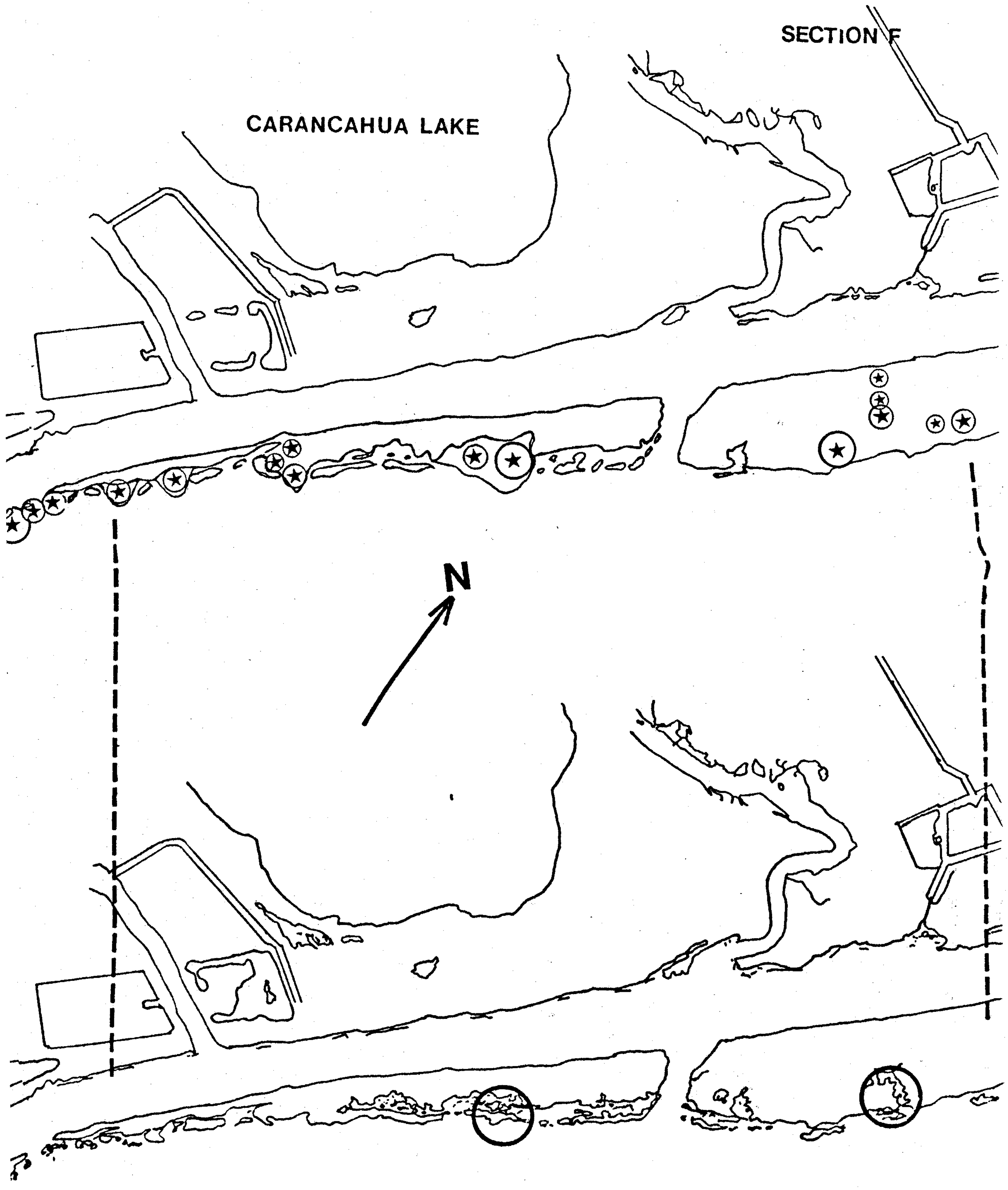
WEST BAY SHORE LINE EAST OF HALLS LAKE

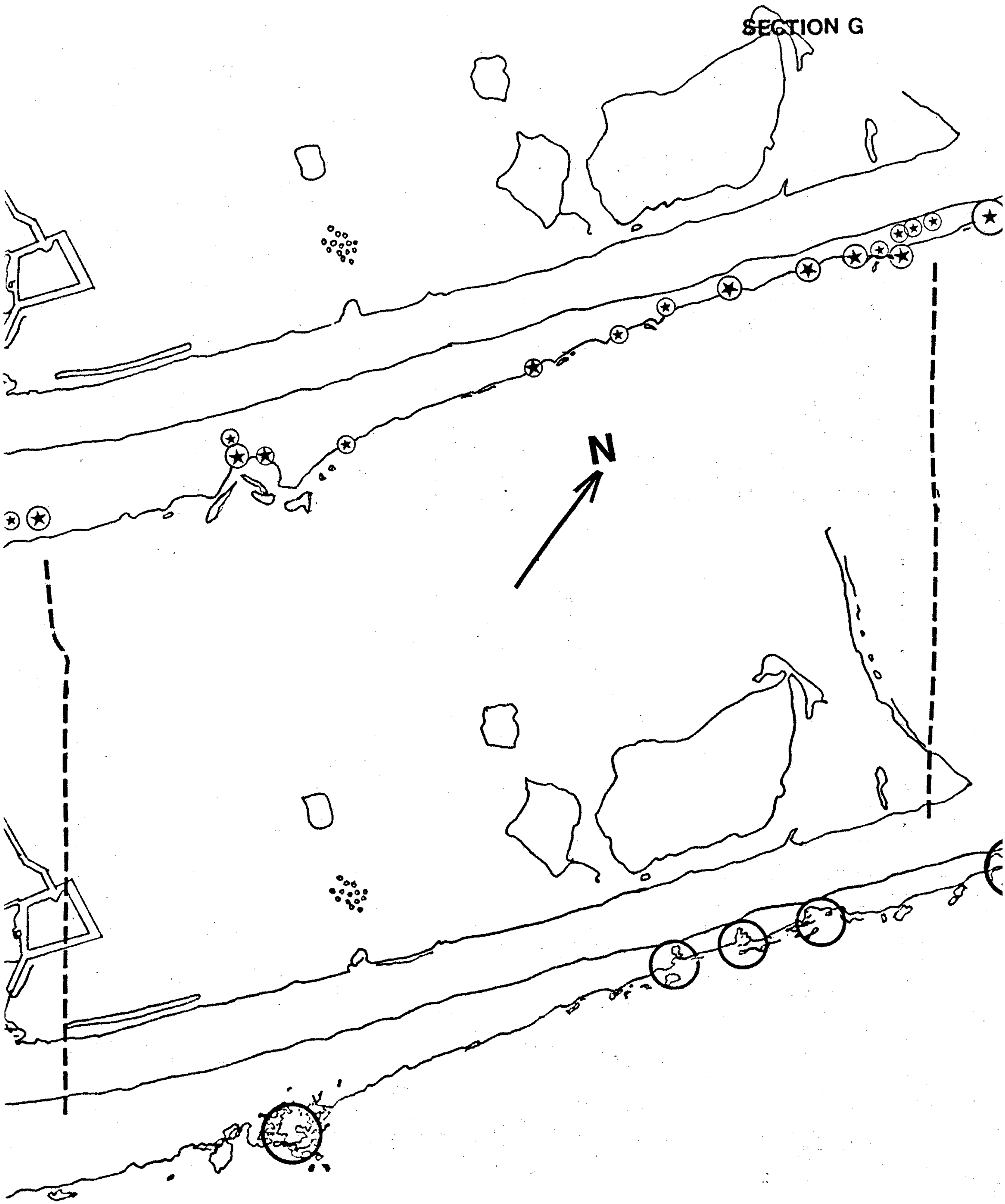



.LS LAKE
SECTION D
N
N
-'85 marsh altered by'90
-dredge disposal site
GIWW
v
v
v n
tands
N

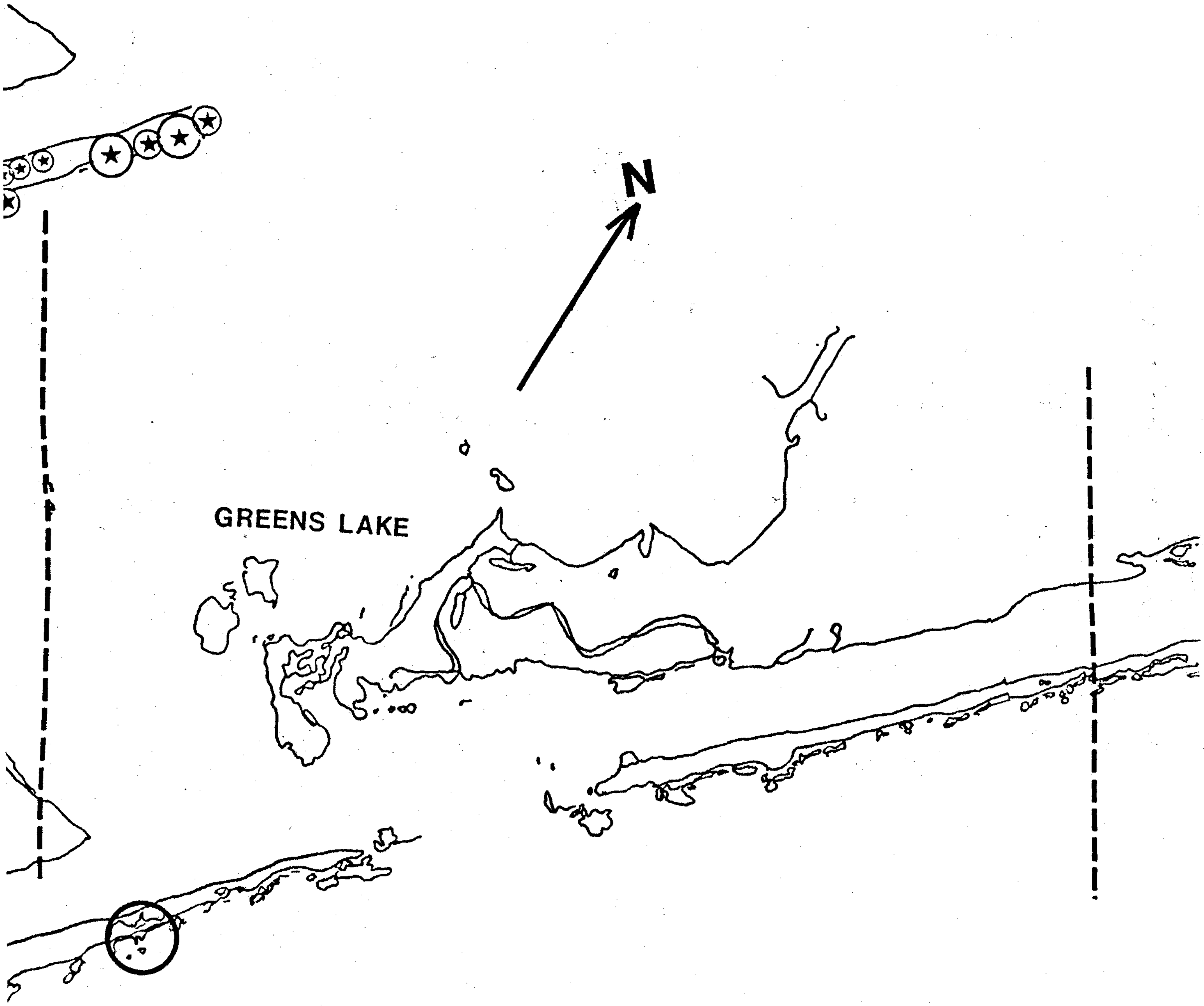


SECTION E
by'90
l site
Non-vegetated Shore Line
N
n
n
n
n
v

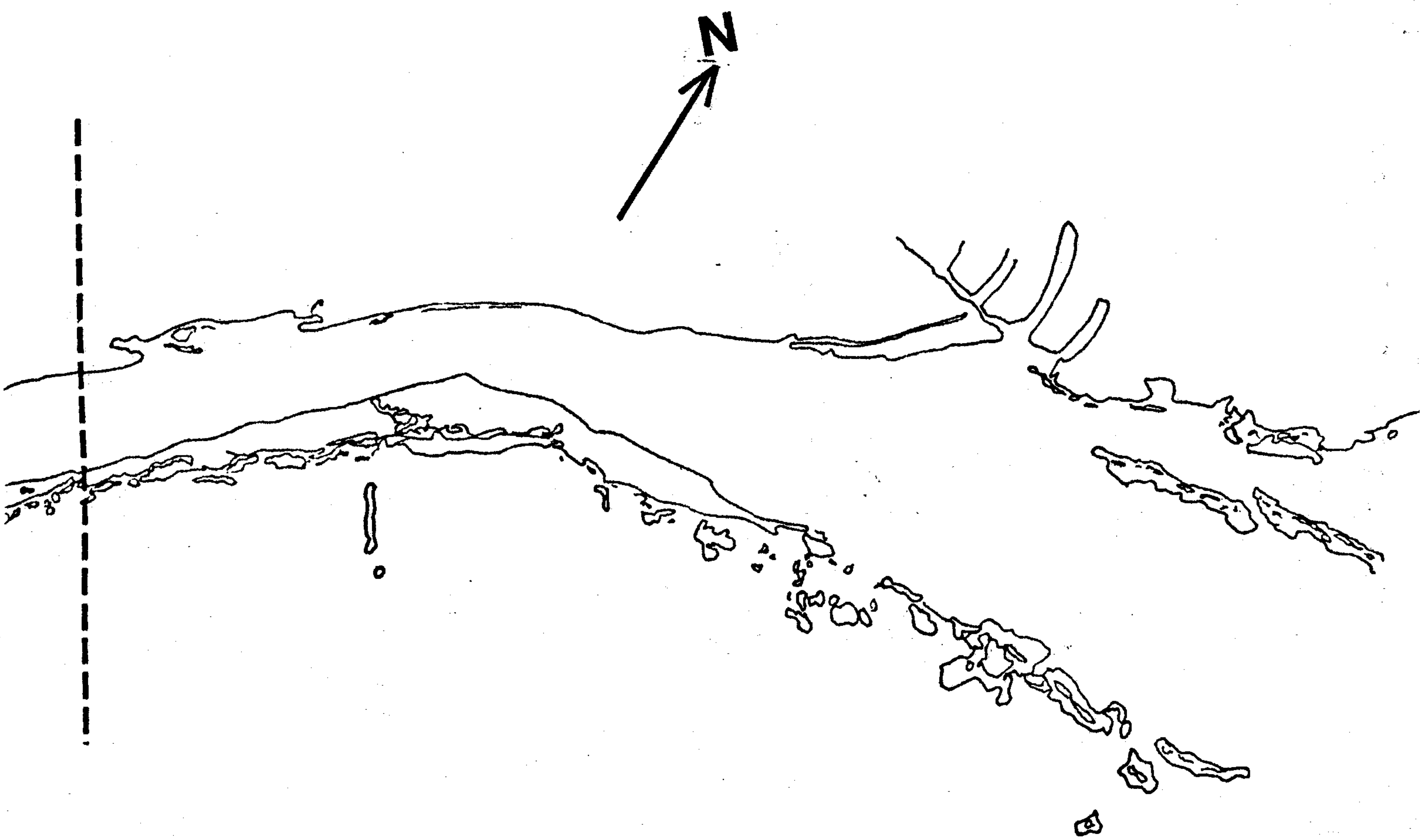

SECTION F
CARANCAHUA LAKE
N

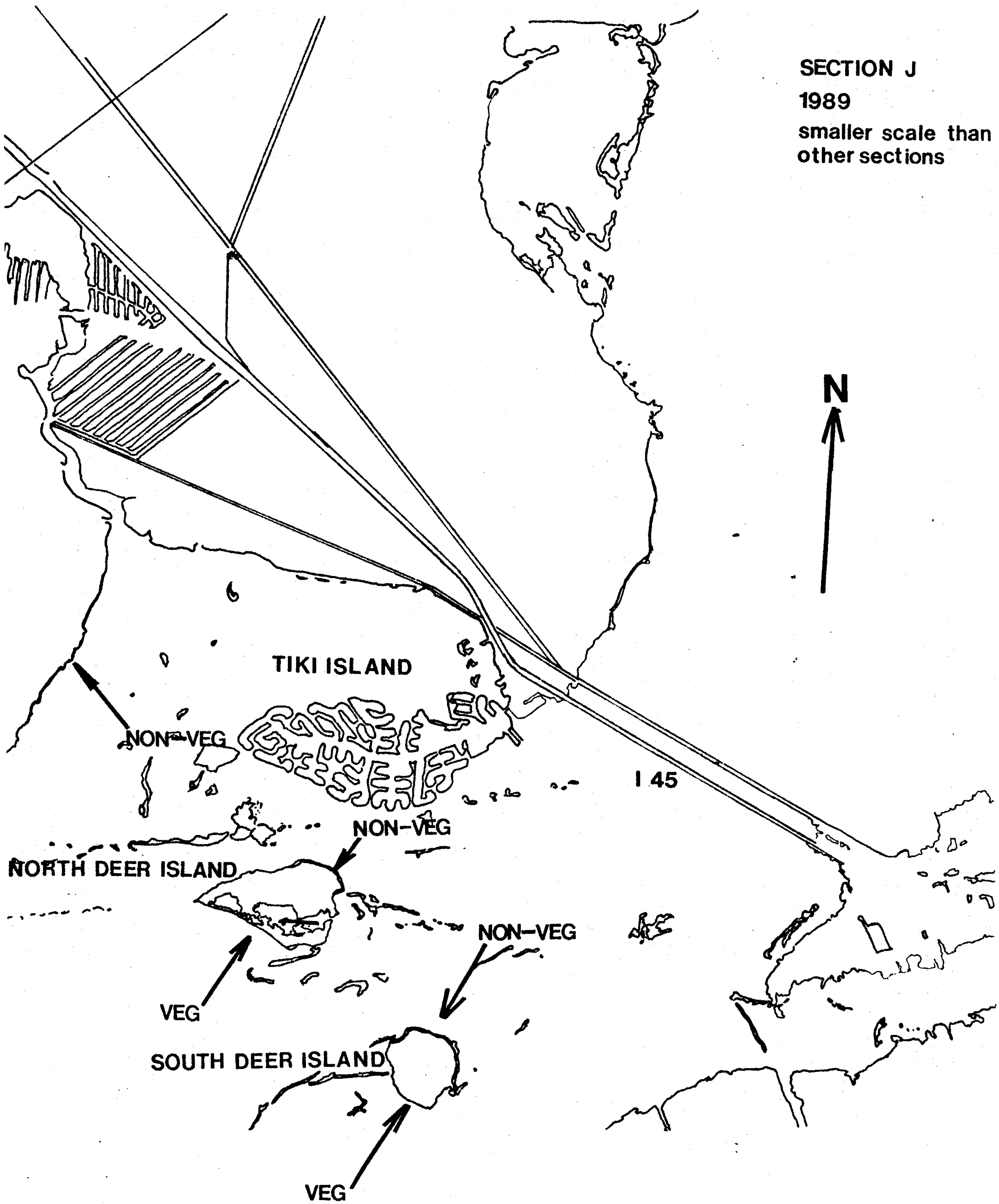

SECTION G
N

SECTION H



SECTION I





SECTION J
1989
smaller scale than
other sections
N
TIKI ISLAND
NON-VEG
I 45
NON-VEG
NORTH DEER ISLAND
NON-VEG
VEG
SOUTH DEER ISLAND
VEG