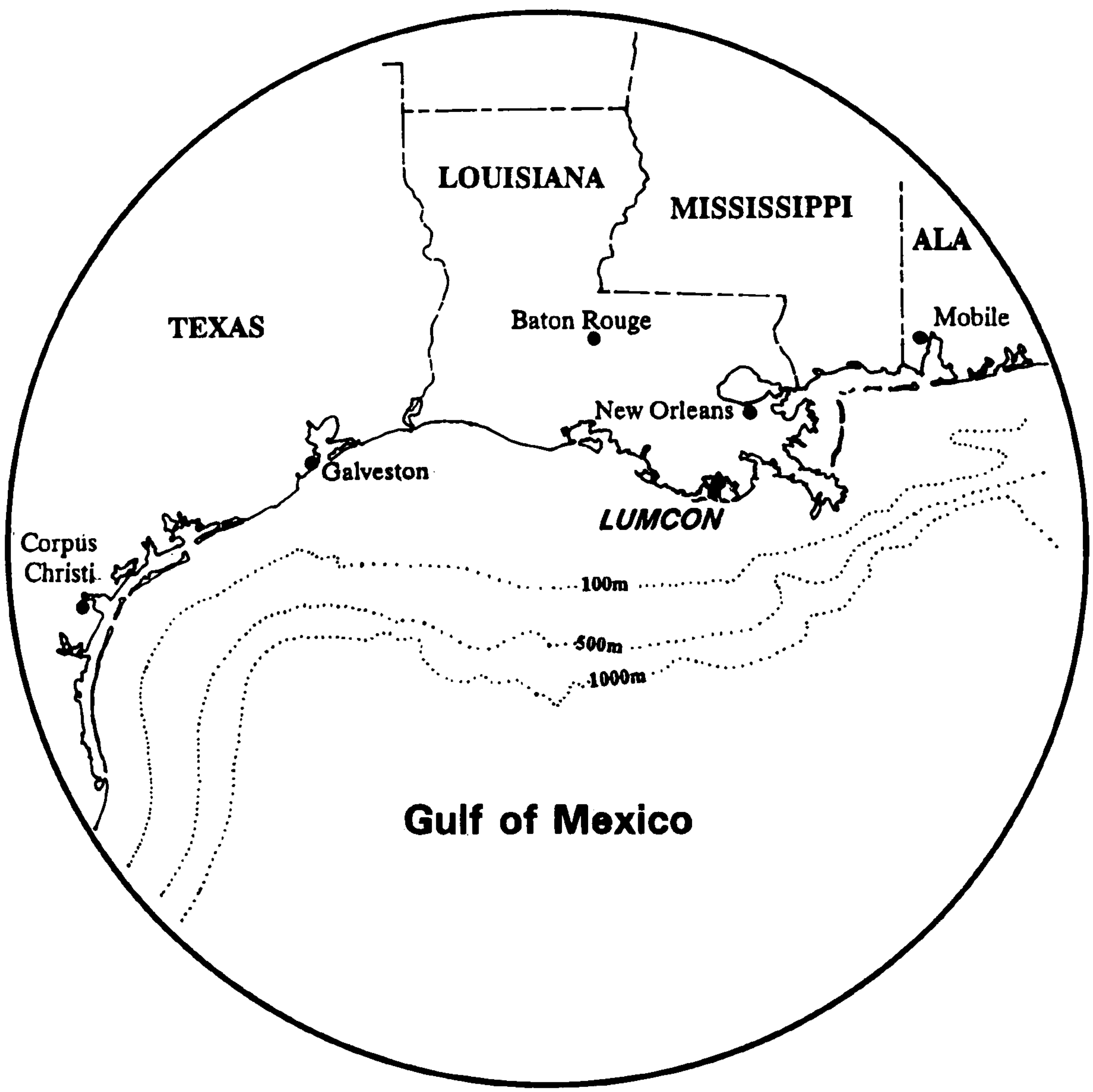
OCS Study
MMS 93-0061

University Research Initiative

Potential for Enhancement of Fisheries Habitat by Infilling OCS Pipeline Canals



MMS U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

Cooperative Agreement
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Potential for Enhancement of Fisheries Habitat by Infilling OCS Pipeline Canals

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ABSTRACT

The aerial coverage by canals and associated dredged-material levees is approximately 10% of total marsh area in coastal Louisiana, which is about the same coverage as natural channels. In addition to the direct loss of marsh habitat caused by the canals, the indirect effect of dredge material placement in levees has been associated with marsh deterioration. The restoration of productive fisheries habitat by infilling pipeline canals depends upon maximizing the area of shallow water in the canals and restoring as much of the adjacent marsh habitat as possible by removing dredged-material levees. The degree to which the canal can be infilled depends upon the amount of dredged material available and the bathymetry of the canal at the time of backfilling. Geomorphic survey and analysis was used to evaluate the potential result of infilling canals and the type of habitat which may result. Comparison of data for saline and brackish canal segments indicates that for both plugged and unplugged canals, canals in brackish areas have greater potential for infilling than those in saline areas. However, older brackish canals have a greater potential for the creation of shallow-water habitat than younger canals suggesting that changes in canal cross-section may be of a greater magnitude than changes in levee material. Our analysis demonstrated that simple survey techniques can be used to indicate the potential efficiency of canal infilling. We recommend that such surveys be used to evaluate both pipeline and disused location canals across the Louisiana coastal zone to determine the potential for increasing shallow-water habitat.

Subtidal habitats of pipeline canals in Louisiana brackish and saline marshes were sampled seasonally (Fall, spring and summer) between October 1991 and March 1993 to identify dominant natant species and test hypotheses relating habitat selection to water depth. In addition, we used topographic and tide gauge data collected in a saline pipeline canal to evaluate the potential change in marsh-surface habitat availability resulting from removing dredged material levees and backfilling canals. Daggerblade grass shrimp *Palaemonetes pugio*, bay anchovy *Anchoa mitchilli*, blue crab *Callinectes sapidus*, brown shrimp *Penaeus aztecus*, and gulf menhaden *Brevoortia patronus* were numerically dominant in both brackish and saline canals. Naked goby *Gobiosoma bosc*, rainwater killifish *Lucania parva*, and gulf pipefish *Syngnathus scovelli* were dominant only in brackish canals, whereas white shrimp *Penaeus setiferus* and Atlantic croaker *Micropogonias undulatus* were dominant in saline canals only. Varaiation in the abundance of numerically dominant species could not be related to maximum canal depth. However, the distribution of some species within pipeline canals was influenced by habitat depth. The degree of habitat segregation with depth was most pronounced in brackish canals during late spring and summer (May and June) when densities of both total fishes and total decapod crustaceans were significantly greater in shallow water. Naked goby, rainwater killifish, gulf pipefish, blue crab, and daggerblade grass shrimp were significantly more abundant in shallow water at this time. In saline canals, blue crabs selected shallow habitats in March and June, and daggerblade grass shrimp selected this habitat in March. Bay anchovy exhibited greater abundance in deep water seasonally in both brackish and saline canals. Selection of shallow subtidal habitats was greater in brackish canals where submerged aquatic vegetation (SAV) was present. Salinity may have affected the distribution of freshwater species (e.g., centrarchids) and limited their occurrence in saline canals. Increasing shallow subtidal habitat by backfilling canals may enhance the nursery habitat for some

species, especially in brackish canals where the area of subtidal habitat capable of supporting SAV could be expanded. Backfilling would also benefit species that use the marsh surface by restoring the area presently buried beneath dredged-material levees. Following levee removal, the hydroperiod of the area would be similar to the surrounding marsh, and therefore the habitat would once again be frequently available for use by nekton.

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ACKNOWLEDGMENTS

James Donovan, Derral Dupre, Zachary Caparros, G. Scott Longman and Dawn Boudreaux conducted the field survey for geomorphic evaluation. Marvin Goodly, G. Scott Longman, Timothy Baumer, Michael Van, Raymond Burditt, Maria Pattillo, Monica Daniels, Richard Jones, Derral Dupre and Brian Webster collected and processed the nekton samples. Nina De Luca analyzed the tide gauge and survey data. Brian Webster assisted with data analysis and prepared Figure 1. Peter F. Sheridan and Thomas J. Minello reviewed earlier drafts of this report. We acknowledge the support of OCS pipeline companies for their help in providing information for the canals database and allowing access to their sites for fieldwork. This research was supported by the Minerals Management Service, U.S. Department of the Interior, under MMS Agreement No. 14-35-0001-30470.

GEOMORPHOLOGICAL EVALUATION OF CANALS AND LEVEES

BACKGROUND

Since the development of oil and gas reserves in the Louisiana coastal zone began in 1926 in the Sweetlake field (Linstedt et al. 1991), Louisiana's extensive coastal wetlands have been dredged and filled for economic benefit. The original threat was from pipelines built for transport of oil to railroads, but with major discoveries of oil and gas in the wetlands during the 1920's and 1930's came improvements in technology which allowed drilling at any location from a barge. The impact of canals and their dredged-material levees on Louisiana coastal marshes has been assessed in a number of studies (Turner et al. 1982, Johnson and Gosselink 1982, Scaife et al. 1983, Turner and Cahoon 1987, among others). These studies have shown the magnitude of the direct impact of canal dredging. Turner (1987) estimates that the aerial coverage by canals and associated dredged-material levees is approximately 10% of total marsh area in coastal Louisiana, which is about the same coverage as natural channels. In addition to the direct loss of marsh habitat caused by the canals, the indirect effect of dredge material placement in levees on natural marsh hydrology can be dramatic (Swenson and Turner 1987) and has been associated with marsh deterioration.

These dredging activities convert marsh and shallow subtidal habitat to a combination of uplands, on the dredged-material levees which are above the elevation of normal marsh flooding, and deep-water habitat. In addition aquatic organisms' access to the interior marsh surface is blocked by levees between the canal and backmarsh. Studies of nekton utilization of marshes alongside canals and natural channels have shown similar populations in both areas indicating that some species present within the canals use marsh-surface habitats (Rozas 1992a). However, during overmarsh tides, the organisms in natural channels can access extensive backmarsh areas which may not be available to organisms, depending upon the degree to which the marsh is isolated by dredged-material levees.

The success of infilling canals with the original dredged material has been examined by Neill and Turner (1987a) who noted that infilling was generally successful in reducing canal depth and restoring marsh vegetation in the area covered by the levee. However, such infilling does not restore emergent marsh vegetation in the canal because of the lack of remaining dredged material in the levees. Rather, shallow water bodies are produced, typically 0.5 - 1.5 m deep (Abernethy and Gosselink 1988, Neill and Turner 1987a).

The restoration of productive fisheries habitat for commercial, mainly transient, species by infilling pipeline canals may depend upon maximizing the area of shallow water in the canals and restoring as much of the adjacent marsh habitat as possible by removing dredged-material levees (Neill and Turner 1987b). The degree to which the canal can be infilled depends upon the amount of dredged material available above marsh elevation and the bathymetry of the canal at the time of backfilling. Neill and Turner (1987a) show inconclusive results regarding the relationship between levee age and depth of canal after infilling. The authors presumed this to be because canal bathymetry along with levee volume changed through time.

The purpose of this study is to elucidate the relationships between original canal dimension, marsh type, age and depth after infilling. Neill and Turner (1987a) conclude that shallow open water areas remaining after infilling may provide productive fisheries habitat, and as such may be as beneficial as the restoration of emergent marsh vegetation. In order for infilling to be effective as a mitigation option, assessment of the feasibility of producing productive shallow water habitat should be easy. We seek to establish simple techniques which can be used by managers to evaluate the potential result of infilling canals and the type of habitat which may result. This goal was achieved by a field survey of a representative sample of canals and geomorphic analysis.

STUDY AREA

The study was conducted in brackish and saline marshes in coastal Louisiana between the Atchafalaya River and Bayou Lafourche (Figure 1). This is the Terrebonne hydrologic basin of the Mississippi delta plain, and as such is relatively homogenous with respect to geological history and substrate character (Penland et al. 1988). Our study was restricted to pipeline canals which support Outer Continental Shelf (OCS) oil and gas activities. These pipelines usually extend from the Gulf of Mexico shoreline across the entire coastal zone. Our study area included a number of pipeline canals which cross both saline and brackish marsh zones.

METHODS

Canal Selection

In order to conduct our field sampling on a representative number of canals we compiled a database of all OCS pipeline canals within our study area. Initially attempts were made to obtain information on canals from permit applications to the Coastal Management Division of Louisiana Department of Natural Resources. It became apparent that this source included information on only a few pipeline canals as most pipeline canals in Louisiana were constructed before implementation of effective coastal zone management and regulatory practice. In order to identify canals about which we needed to obtain information, we used Penwell Map's "Pipelines of Louisiana" (Penwell 1986). This map identifies individual pipelines and their operators in Louisiana. Using this information we approached individual operating companies and requested their assistance in filling out a questionnaire about their pipelines and canals. Replies to all questionnaires were received within two months of our request, and several companies made special efforts to provide us with data in addition to that which we requested. As each completed questionnaire was received, the location of the canal and ownership was marked on U.S. Geological Survey 7.5 minute quad maps of the study area. Air photos were used to provide an updated view of the present status of the canals. Information on dredged-material levees, plugged-status, and canal width were also recorded on the quad maps. Data were also entered into a dBase III database designed for the project.

For field sampling purposes we wished to identify eight study sites in each of four types of canal: saline-plugged, saline-unplugged, brackish-plugged, and brackish-unplugged. Seven canals were identified in the database which carried OCS materials and which crossed both saline and brackish marsh types (as determined from local knowledge of the area and Chabreck and Linscombe (1978) map of Louisiana coastal marshes). One additional canal, which only crosses saline marshes, was included in initial site selection (Tennessee #3). The locations of these canals is shown in Figure 1. Each pipeline canal was divided into 1 km sections using the quad maps. These sections were designated as saline/brackish and plugged/unplugged. Frequently, the canal was actually divided into plugged/unplugged sections of less than 1 km in length and the character of the canal within each 1 km section was recorded. Random numbers were used to select three sections of canal of each of the four types. Although only one was included in the field study, three were chosen to allow for a second and third choice in the event that designations were found to be incorrect during field inspections. For example, it is difficult to determine from air photos how complete the plugs across canals are. If field inspection showed that a section selected as a plugged site was actually open to tidal exchange (i.e. unplugged) then the next plugged-selected section was inspected. In this manner, 30 canal segments were selected for study with two 'back-ups' for each segment.

Field Survey

The field survey of 32 canal segments selected according to the method described above was completed in Summer and Fall 1991. This survey consisted of four components:

(1) Three cross sections were chosen in the segment of the canal determined by the site selection procedure, usually located at each end of the canal segment and in the middle.

2) Rod and level techniques were used to survey the ground elevations across the dredged-material levees on both sides of the canal at each cross section.

(3) A recording fathometer was used to obtain a bathymetric profile of the canal at each cross section. In areas too shallow for use of the fathometer, depth profiles were determined by poling.

4) Soil samples were taken from the edge of each canal (either marsh or dredged material depending on levee proximity to canal), the middle of the dredged-material levee and the marsh behind the levee. These samples were analyzed for soil dry bulk density and organic matter content.

In practice, some selected sections of canal were impossible to access because of extremely shallow water or physical obstructions. In addition, field inspections found on several occasions that none of the three selected plugged sections of a particular canal were actually plugged. Where plugs were so deteriorated as to provide minimal obstructions to flow, no plugged section was surveyed. As a result of these field difficulties, the actual numbers of canal sections surveyed were 12 in saline marsh areas (5 plugged and 7 unplugged) and 9 in brackish areas (4 plugged and 5 unplugged).

Data Analysis

Fathometer records were used to calculate the canal depth at ten intervals across each canal cross section. These depths were combined in a computer program with the topographic survey data to calculate the difference in cross sectional area between the canal and the two dredged-material levees. This analysis was conducted for each of the three cross sections and averaged for each canal segment. The ratio between the area of the canal and the material in the spoil banks was calculated to provide an Infilling Index. This provides an indication of how much material is available in the dredged-material levees to infill the canal, and was used to estimate the resulting depth of the canal after infilling.

RESULTS AND DISCUSSION

Canal Selection

The canals database was used to compare the characteristics of the canals selected for study with all the canals in the study area for which data were available. Figure 2 shows the age distribution of the nineteen canals in the entire database compared with those selected for study. Most of these canals cross both saline and brackish coastal marshes zones. Clearly the peak in construction of OCS pipeline canals across this part of the Louisiana coastal zone was between 1955 and 1970. All of the canal sections selected for use in our study were originally constructed during this period, and the distribution of ages conforms well with that of the entire database.

Consideration of original canal depth also shows that the canals selected for sampling are representative of all the canals included in the database (Figure 3). Data on original depth are only available for 13 OCS pipeline canals in the study area. The median and modal depth for these canals is between 1.8 and 2.4 m. Depth information is available for seven of the canals selected for study, and the median and mode for this distribution are the same as for the entire database. This indicates that the canals selected for the field survey component of the study are representative of OCS pipeline canals in the study area.

Potential for Canal Infilling

Fathometer records and topographic survey data for the selected canals were combined to estimate the amount of material available in the levees and the amount of material required to fill in the canal. The results were combined into an Infilling Index (the mean ratio of levee cross section to canal cross section for the three sections measured in each canal segment). The results of this analysis and data on the original and present dimensions of the canal are shown in Table 1. Statistical analyses indicate no significant differences between the index values for plugged and unplugged canals for either saline or brackish marshes. The index values were used with the canal area and width information to estimate the depth of water which would remain after canal infilling. The results of this analysis are shown in Table 2.

The data in Tables 1 and 2 show that usually there was insufficient material to fill the canal completely. However, in two cases the values of the Infilling Index were greater than 1 indicating that there was more material than necessary to fill the canal. One of these segments, the saline plugged segment of Tennessee #5, was very shallow and narrow. The canal was constructed using flotation technology which requires the movement of a barge to lay the pipe (Wicker et al. 1989). As the remains of the canal are now little more than a shallow marsh channel we assume that the canal was backfilled immediately after the pipe was laid. The material surveyed in the 'levees' adjacent to the canal may represent the remains of material left after backfilling and the plugged shallow area has probably been infilled by natural marsh processes since then. The other canal with an Infilling index greater than 1 is also a saline plugged canal. However, the index varies from 0.705 to 2.15 from one end of the canal segment to the other (Transect A to Transect C) indicating considerable variability in both canal depth and levee cross-section along the length of the segment. Placement of dredged material along this canal may have been uneven for some reason, resulting in more material being available for infilling in some locations than in others.

Table 2 shows that for both brackish and saline canals, those that are left unplugged have shallower depths after infilling. However, neither of these comparisons is statistically significant. Only 7 of the 18 canal segments for which the depth calculation can be made will have depths of greater than 1 m after infilling. Three of these are on the Trunkline pipeline which was originally dredged to a depth of approximately 4 m according to the information provided by the pipeline company, much deeper than the other canals included in the field survey. In addition, although the canal was first constructed in 1958, a second pipeline was placed in the canal in 1980 resulting in very recent dredging activity. Tennessee #3 also shows greater depths after infilling than many other canals, and this also has been used for the laying of two pipelines. The original canal was constructed in 1968 but in 1977 the pipeline company laid another line in the same canal which required a second episode of dredging activity.

These two cases indicate the possible role of canal age in controlling the depth after infilling. Figure 4 shows the relationship between age of the canal, or time since most recent dredging activity, and the estimated depth after infilling for brackish canal segments. There is a strong negative relationship showing that infilling older canals is more likely to result in the creation of shallow water habitat than infilling younger canals. A similar, but less strong, relationship for saline canal segments is shown in Figure 5. Of the two main factors influencing the amount of material available and necessary for efficient canal infilling, decomposition and compaction of dredged material and natural canal infilling, it might be considered that both would change over time. One might expect that as the canal gets older there is less material available in the levee for infilling, but also that the canal has had an opportunity to naturally infill and so less material is required. These data indicate that these two factors do not both progress at the same rate, and that the amount of material available and the amount required converge with time. The data also indicate differences in these relationships between brackish and saline areas. Examination of soil samples from the dredged material and adjacent marshes provides more information on the response of the dredged material between marsh types.

Material Available for Infilling

Hatton et al. (1983) examined soil bulk density and organic matter content of various marsh types in the Barataria Basin, Louisiana which is immediately to the east of our study area. They found differences between streamside and backmarsh locations, and mean values for bulk density were 0.27 and 0.14 g/cm^3, respectively, for brackish marshes, and 0.35 and 0.29 g/cm^3, respectively, for saline marshes. There was a similar variation in soil organic matter content for brackish marshes with values of 22% and 42% but a consistent organic matter content of approximately 20% for saline marshes. Samples taken for our study show similar differences in soil organic matter content between saline and brackish areas (Figure 6), and values for backmarsh locations are within the range described by Hatton et al. (1983). In both marsh types, the marsh soils have higher organic matter contents than either the canal edge and mid-levee locations. These differences are not significant ($p = 0.05$) because of high levels of variation among canals which is presumably a result of the large differences in canal age. For both types of marsh the lowest organic matter contents are found on the mid-levee location. This is also the highest topographic point of the three, and for most levees is above the mean high water mark. The oxidation rates of the organic content in these better drained soils would increase, decreasing organic content as time passes All of the dredged-material levees included in the study were vegetated, and thus there is some active root growth contributing to present levels of soil organic matter.

However, the differences in soil dry bulk density between marsh types do not conform to the pattern identified by Hatton et al. (1983). For all sample locations, mean bulk density is greater in brackish marshes than in saline marshes (Figure 7). For both marsh types, bulk density is highest at the mid-levee location, and this difference is significant for the brackish marshes (edge vs. levee, $p = 0.005$; backmarsh vs. levee, $p = 0.02$). The increase in bulk density above marsh levels at the mid-levee location is most likely a result of higher rates of organic matter oxidation, as described above, and compaction as the soil dries. Nyman et al. (1990) examined the composition of marsh soils on a volumetric basis and found that on average pore space (water and gas) took up over 90% of soil volume in brackish marshes and almost 88% in saline marshes. When such marsh soils are dredged and placed above the level of mean high tide, drainage will reduce water content. This is one of the processes contributing to the lowering of levees through time and is reflected in the increase in bulk densities at the mid-levee locations shown in Figure 7.

Nyman et al. (1990) found little difference between the percent of soil volume taken up by organic matter in brackish and saline marshes (5.11% vs. 5.27%), but saline marshes had a greater percentage of their volume taken by mineral matter (6.89% vs. 4.03% for brackish marshes). In our study, bulk densities at mid-levee locations in brackish marshes are significantly higher ($p = 0.002$) than in saline marshes. This is difficult to explain but could reflect greater potential for oxidation and compaction, based upon the greater volume of organic matter and pore space, in these soils compared to saline marsh soils. Bulk densities of canal edge and backmarsh locations are very similar and there is no significant difference between brackish and saline soils at either of these locations. The bulk densities are higher than the values for natural marshes (Hatton et al. 1983), and this is probably a result of levee placement on the existing marsh surface. Suhayda (1987) examined the effect of levee placement on marsh soils and concluded that there was clear potential for compaction of marsh soils by the weight of the levee. A depression of the marsh surface was measured up to 15 m from levees placed on organic soils (Suhayda 1987). Such compaction would increase bulk densities of the marsh beneath and adjacent to the dredged-material levee above normal levels for the type of marsh. Such a process has likely resulted in the bulk density values between 0.4 and 0.6 g/cm^3 shown in Figure 7 for canal edge and backmarsh locations. Slightly higher bulk densities in brackish marsh soils may reflect their initially higher pore space and increased potential for compaction.

Predicting Restoration of Shallow-Water Habitat

Comparison of data for saline and brackish canal segments in Table 2 shows that for both plugged and unplugged canals, canals in brackish areas have greater potential for infilling than those in saline areas. Discussion of the soils data shows that the material available for infilling in brackish areas has both a higher organic matter content and a higher bulk density than that in saline areas. These two factors usually show an inverse relationship in Louisiana coastal marshes, and it is thought that greater potential for compaction, dewatering and decomposition may result in the surprisingly high soil bulk densities in brackish marshes. Such an increase in bulk density, and elimination of pore space, suggests that brackish canals may have less levee material available for infilling as these processes proceed through time. However, Figure 4 shows that older brackish canals have a greater potential for the creation of shallow-water habitat than younger canals suggesting that changes in canal cross-section may be of a greater magnitude than changes in levee material.

The accumulation of either organic or inorganic sediments within canals will result in gradual infilling through time. Within brackish areas, submerged aquatic vegetation, trees and shrubs on adjacent levees provide a local source of organic material for canal infilling. This is less abundant in saline marsh areas, and may be a factor contributing to the shallower depths after infilling in the brackish canal segments. In addition, the greater tidal amplitude in saline marshes might be expected to increase scour, or at least prevent the accumulation of material, in saline canal segments. This would also allow for greater infilling potential in relatively quiescent brackish areas. However, the differences for both marsh types between plugged and unplugged canals suggests that the flux of material into canals, rather than the *in situ* retention and accumulation of organic sediments, might also be an important influence on potential for infilling. The presence of plugs may reduce the erosion of levees by boat wakes, but will not impact decomposition and compaction within the levee material. However, the absence of plugs, although possibly exposing the canal to scour and material export during extreme events, apparently allows for the import and accumulation of material, reducing canal cross-section and increasing its potential for infilling. This may be especially important soon after canal construction. Where canals are dredged to depths greater than that of surrounding marsh channels, the deeper areas will become foci for material accumulation as both organic and inorganic sediments settle out in the relatively quiescent canal depths. In addition, our observations of canals before and after the passage of Hurricane Andrew across our study area in August 1992, indicated that considerable amounts of material, both organic and inorganic, accumulated in some canals, dramatically reducing canal depth. During tropical storm and hurricane events, when large quantities of sediment and organic debris are redistributed across the coastal zone, relatively deep canals with vegetated levees which interrupt deep overmarsh flows can become efficient traps for both organic and inorganic sediments.

CONCLUSIONS

This geomorphic evaluation of pipeline canals has shown that infilling the canals with dredged material from adjacent levees will rarely result in the restoration of vegetated marsh habitat except in the area where the levee is removed. However, there is frequently sufficient material available in levees to produce shallow-water habitat less than 1 m deep in the canal. Two factors influence the efficiency of the infilling process: (1) the amount of material available in the dredged-material levees at the time of infilling, and (2) the cross section of the canal at the time of infilling. Our study has shown that the efficiency of infilling increases with time after dredging for canals in both brackish and saline marsh areas. No significant difference in infilling potential was found between canals which had been plugged and those which had been left open, and that for canals which could be infilled to depths of less than 1 m, this was the case for both brackish and saline canal segments.

Examination of the levee material indicates that decomposition and consolidation are important processes within the levee soils. Decomposition is likely to be rapid after dredged material is initially placed on the levee in an aerobic environment and its net impact on the organic matter content of the levee will decrease in time as the rate of decomposition of the original organic material declines and vegetation growth on the levee introduces new organic material to the soil. Compaction and consolidation processes will also be rapid after initial placement of dredged material as the sediments drain and dewater.

All of the dredged-material levees examined in this study were at least 13 years old at the time of survey, and we conclude that none of them would still be undergoing this initial rapid phase of decomposition and dewatering. The other factor involved in the efficiency of canal infilling, decrease in canal cross-section, may also be more rapid immediately after canal construction, especially if the canal is deep relative to surrounding water bodies. However, the infilling process continues throughout the life of the canal. Our observations indicate the potential role of extreme events in canal infilling, and that material continuously accumulates in canals following construction. The relationships between age and potential canal infilling identified in this study, together with our understanding of the processes changing levee and canal with time, indicate that natural infilling of canals through time has a major influence on the type of habitat which can be produced by infilling with the remaining levee material.

Our analysis has demonstrated that simple survey techniques can be used to indicate the potential efficiency of canal infilling. We recommend that such surveys be used to evaluate both pipeline and disused location canals across the Louisiana coastal zone to determine the potential for increasing shallow-water habitat. Where canal infilling is found to be inefficient at present, we recommend that the canal be reevaluated at 5-year intervals as natural processes can greatly enhance the possibility of producing shallow-water habitat by infilling with the remaining levee material.

COMPARISON OF SUBTIDAL HABITATS IN PIPELINE CANALS

INTRODUCTION

In undisturbed marsh systems, shallow subtidal areas along the marsh-water interface provide essential habitat for fishery species (Baltz et al. 1993, Peterson and Turner 1994). Such areas are critical for aquatic organisms that use the marsh surface and retreat to nearby subtidal habitat when the marsh drains at low tide (Zimmerman et al. 1984, Peterson and Turner 1994). In addition, greater light penetration in these shallow waters is conducive to the growth of submerged aquatic vegetation (SAV) which enhances habitat value (Rozas and Odum 1988, Lubbers et al. 1990).

Pipeline canals constructed in coastal wetlands differ from natural subtidal areas in several important characteristics. Canals are usually straight, deep, and steep-sided; their average depth (1.8-3.6 m) is substantially greater than nearby natural tidal channels or ponds (Tabberer et al. 1985, Abernethy and Gosselink 1988, Wicker et al. 1989, Rozas 1992). Most of the subtidal area in canals is too deep for SAV development because of limited light penetration, even where turbidity and salinity are favorable for its establishment.

Deep canals may provide a refuge for large predators that would otherwise be constrained by the shallow water in natural marsh systems. These deep corridors may allow predators easy access to what little shallow subtidal habitat there is along canal shorelines. Consequently, the presence of large predators in canals may reduce densities of early life stages of nekton (fishes and decapod crustaceans), either by increasing mortalities or because potential prey avoid canals with high predator densities. Therefore, we hypothesized that densities of major species of nekton would be inversely related to canal depth.

Among the mitigation options available for pipeline canals in coastal Louisiana is backfilling, by removing the dredged material levee and returning the material to the canal (Neill and Turner 1987a). Backfilling of older canals has been used for mitigation on a number of occasions in Louisiana but has rarely been applied to longer pipeline canals. Although backfilling can return the entire levee to the canal, oxidation of the dredged material through time results in an insufficient amount of material to fully restore the marsh habitat that was originally destroyed. Rather, shallow water bodies typically <1 m deep are produced (Abernethy and Gosselink 1988, Neill and Turner 1987a). In addition to expanding shallow water habitat, infilling pipeline canals increases the availability of marsh surface habitat to nekton by converting the levee (high marsh/upland) back to low marsh and removing a potential barrier between the canal and marsh habitats.

In a recent survey of pipeline canals in coastal southeast Louisiana, we measured canal bathymetry and calculated the volume of dredged material contained in levees and available for backfilling (Reed and Rozas, Chapter 1). From these data, we estimated that backfilling the canals in our study area would decrease the average depth of most canals to

<1 m. Similar results were reported in studies of backfilled canals in coastal Louisiana (Neill and Turner 1987a, Abernethy and Gosselink 1988). Backfilling may enhance the nursery value of pipeline canals by expanding the area of shallow subtidal habitat and reducing the density of large predators (McIvor and Odum 1988, Baltz et al . 1993, Ruiz et al. 1993). Ideally one could test this hypothesis by comparing nekton densities in pipeline canals before and after backfilling. However, when we began this study, backfilling pipeline canals was rarely practiced in Louisiana, and the opportunity for collecting pre- and post-backfilling data did not exist. Therefore, we compared nekton use of shallow (<1 m) and deep (>1 m) subtidal areas in canals as a means of predicting the effect of backfilling on the nursery value of pipeline canals. We hypothesized that densities of nekton, and hence habitat utilization, would be greater in shallow than deep areas of canals.

The major goals of our study were to (1) identify the major species of nekton using subtidal habitats of pipeline canals within brackish and saline marshes of the Mississippi River deltaic plain, (2) determine whether the selection of subtidal habitat by nekton is influenced by maximum canal depth (Hypothesis 1), (3) determine whether subtidal habitat selection within pipeline canals is influenced by site-specific water depth (Hypothesis 2), and (4) evaluate the potential change in marsh surface habitat availability resulting from canal levee removal.

MATERIALS AND METHODS

Study Area.

We studied pipeline canals in the Terrebonne-Timbalier Basin of southeastern Louisiana (Figure 1). We separated canals into two types (saline and brackish) according to the marsh type in which they occurred (Chabreck and Linscombe 1991). Saline marshes were dominated by *Spartina alterniflora*, but *Juncus roemerianus*, *Distichlis spicata*, and *S. patens* were also present. Brackish marshes were dominated by *S. patens*. The system is microtidal. Tides are predominantly diurnal and have a mean range of approximately 0.4 m near the Gulf of Mexico, but tides are greatly diminished landward of the major bays, especially within brackish marshes (Shirzad et al. 1989).

Nekton Sampling.

Sampling trips were scheduled to coincide with equatorial tides, predicted periods of low water levels when nekton would be restricted to subtidal habitats and not dispersed over intertidal areas. Samples were collected using a 2 m^2 throw trap and a 2.4-m otter trawl. We used the throw trap only in subtidal habitats <2 m deep, which represented on average >80% of total canal area. The throw trap had 1.4 x 1.4 x 2.0 m high walls constructed of 3 mm mesh nylon netting. Four 1.3-cm diameter steel reinforcing rods were welded together to form a square and attached to the bottom of the net to make it sink rapidly in water. A chain inserted into sleeves sewn to the bottom of the net provided a 15-cm skirt that sealed the net bottom and prevented organisms from escaping beneath the net walls.

A floating collar made of 3.8-cm diameter plastic pipe and attached to the top of the net kept the throw trap vertical in the water column after it was deployed. When the net was deployed in water <2 m deep, the floating collar prevented most organisms from escaping over the net walls. However, on one occasion we observed large striped mullet escape by jumping over the collar.

We slowly approached each site in a small boat with the motor turned off by allowing the wind to push the boat near the sample area. When approximately 3 m away, two persons standing near the bow of the boat tossed the throw trap over the sample site. Every effort was made to sample subtidal sites at least 1.3 m from shore to eliminate the influence of the marsh edge on catch. Baltz et al. (1993) found that fish densities in open water were greater than expected when the sample site was ≤ 1.25 m from the marsh edge. After a sample was enclosed by the net, water temperature and salinity were measured at the site using a RS5-3 salinometer.

If present in the sample area, SAV was removed before organisms were collected. Vegetation was placed into sample bags, and transported to the laboratory in a cooler. Samples were washed in running water, dried to constant weight at 105 ^{o}C (48 h), and weighed (±0.1 g).

Animals were removed from the throw trap using a large clearing net. The clearing net was a 2.0 m deep bag (with a 1.8 x 2.3 m opening) made of 3-mm mesh nylon netting. A frame constructed with 1.9-cm diameter galvanized steel pipe was attached to the opening of the net for support. The throw trap was cleared by two persons placing the opening of the net against one side of the throw trap, then carefully pulling the net frame under and around the throw trap. Once the throw trap was engulfed, the clearing net and throw trap were lifted out of the water. The throw trap was then removed from the clearing net, and the contents of the clearing net were carefully washed to remove mud inadvertently collected along with the sample.

We supplemented throw trap samples in the first year of the study with otter trawl sampling to determine if species using canal habitats >2 m deep were adequately represented in throw trap samples. The otter trawl could be used to sample even the deepest areas of the pipeline canals in our study area, whereas the throw trap was limited to subtidal habitats <2 m deep. The otter trawl was constructed of treated nylon netting (1.3 cm "stretch"). The cod end was lined with 3-mm mesh netting. Door dimensions were 0.3 x 0.5 m.

Samples were preserved in 20% formalin for at least 72 h, washed in running water for 24 h, and placed into 70% ethanol for storage. Organisms were separated from detritus, identified, and counted; each (except for daggerblade grass shrimp, *Palaemonetes pugio* Holthuis) was also measured (i.e., standard length for fishes, total length for shrimp, and carapace width for crabs). All individuals of each species were weighed together to the nearest 0.1 g.

Hypothesis Testing

We collected data to test Hypothesis 1 (H_1: Densities of nekton are not related to maximum canal depth) from seven brackish and seven saline canals having a range of maximum depths (0.6-3.6 m) representative of those found in our initial survey (Reed and Rozas, Chapter. 1). We sampled each canal on two occasions, once between October 17 and 31, 1991 and again between March 2 and 19, 1992. On each occasion, we collected throw trap samples from three randomly selected shallow subtidal sites (usually ≤ 1 m) within each canal. We also collected a single otter trawl sample from each canal by towing the net for three minutes (distance=approximately 150 m) down the center of the canal.

Data for testing Hypothesis 2 (H_2: Densities of nekton are similar in shallow and deep subtidal habitats) were collected from a subset of the canals used to test Hypothesis 1. We selected three brackish and three saline canals, and sampled four depth zones (1=<0.5 m, 2=≥0.5m and <1.0 m, 3=≥1.0 m and <1.5 m, 4=≥1.5 m) in each canal with a throw trap. Canals were sampled during four months (May, June, and October 1992; March 1993) to capture seasonal variations in the peak abundance of nekton resulting from species differences in periods of recruitment to estuarine habitats.

To examine differences in habitat use patterns among species, we analyzed data for each numerically dominant species separately by canal type (brackish and saline) and sampling period. In addition, we used the variables total fishes and total decapods in the analyses. Numerically dominant species were defined as (1) estuarine residents collected at densities >1 individual/2 m^2 and representing ≥3% of the total catch in more than one sampling period, and (2) estuarine transient species that met these criteria for density and relative abundance in at least one sampling period. Resident and transient species were classified according to Thompson and Forman (1987). All catch data were ln (x+1) transformed prior to analyses to correct for unequal variances (Green 1979). We tested Hypothesis 1 by regressing the mean number of animals collected in October 1991 and March 1992 with the maximum depth measured in each canal. We tested Hypothesis 2 using One-way ANOVA (Analysis of Variance) and a priori contrasts of mean catch between shallow (<1 m) and deep (≥1 m) habitats sampled May 1992 through March 1993 (Norusis 1990). To correct for the error introduced by doing multiple analyses (i.e., testing a hypothesis for several species), the significance level (0.10) for tests of individual species was adjusted using the method described by Rice (1989).

Sampling Efficacy and Efficiency

Throw trap efficacy (i.e., net avoidance) was estimated at various water depths in September 1991 using gulf killifish *Fundulus grandis* collected in minnow traps from a marsh near the LUMCON Marine Center. We stocked a large panel tank (diameter=6.1 m; height=1.8 m) with 342 killifish (S.L.: range=33-75 mm, mean=42 mm) and sampled the tank filled to various water depths over a 2-day period. The experiment was begun on day 1 by filling the tank with ambient estuarine water (salinity=11.1o/oo) to a depth of 0.6 m and adding the fish. The fish were sampled by two persons throwing the trap into the tank from 8 different positions around its perimeter. Fish were removed from the trap using the clearing net, counted, and immediately returned to the tank. After sampling was completed at one depth, ambient water was added to raise the level to the next desired depth and sampling was resumed. The following sequence of water depths was sampled: Day 1=0.6 and 0.9 m; Day 2=1.2, 1.5 and 1.8 m. ANOVA was used to test for differences in catch efficacy with water depth by comparing the means of fish collected at each depth.

To estimate the efficiency of removing organisms from the throw trap using the clearing net, we used marked gulf killifish (S.L.: range=35-60 mm, mean=50 mm) and daggerblade grass shrimp (T.L.: range=23-38 mm, mean=28 mm). Organisms were marked by clipping the anal fin of fish or uropods of shrimp. On May 11, 1992 while sampling the saline canals, ten individuals of each species were added to the throw trap immediately after it was deployed at nine sample sites having three ranges of water depth ($\geq$0.5m and <1.0 m, $\geq$1.0 m and <1.5 m, and $\geq$1.5 m). We calculated the percentage of those marked individuals retrieved with each sample. ANOVA was used to test for differences in clearing efficiency by comparing the average number of organisms retrieved at each depth.

<u>Access to Marsh Habitat</u>

A tide gauge was placed in the pipeline canal and hourly measurements of water level were taken between August 1991 and July 1992. The elevation of the marsh on the edge of the canal, the levee, and the marsh behind the levee was surveyed in relation to the tide gauge datum. A computer program, PEAKBASE (Rozas and Reed, 1993) was used to calculate the frequency and duration of flooding for these different habitats. Implicit in this exercise is the assumption that the levee does not modify the hydrology of the backmarsh by either delaying flooding during the rising tide or increasing flooding duration by impeding drainage of the marsh. Swenson and Turner (1987) found that marshes partially surrounded with dredged material levees had fewer flooding events but flooded longer than marshes unimpacted by dredging. Our assumption is valid because the levee only blocked flooding of the backmarsh from the canal. Flooding of the backmarsh could still occur from numerous natural channels entering the marsh from behind the levee. As the levee replaced *Spartina alterniflora* marsh with high marsh and upland habitats that are unavailable to aquatic organisms, estimates were also made of the resulting marsh elevations, and flooding characteristics, after levee removal for infilling.

RESULTS

Low water caused by the passage of a cold front in March 1992 precluded trawl sampling in one brackish canal and prevented the use of both the throw trap and trawl in one saline canal. Strong southerly winds occasionally raised water levels above those predicted by tide tables, and marshes were flooded during sampling periods. However, most samples were collected when nekton was restricted to subtidal areas. Most throw trap samples (98%) were collected $\geq$1.3 m from shore, but occasionally in order to sample depths <1 m, we had to sample nearer the marsh edge.

Canal characteristics measured during our study are listed in Table 3. Mean water temperatures during sampling periods ranged from 16.0 to 31.7 ^{o}C. Temperatures were highest in June and lowest in March. Average water temperatures in brackish and saline canals were similar in a given month except in March 1992. A cold front was responsible for a statistically significant difference in average water temperature between the two canal types in March 1992. Five brackish and five saline canals were sampled in the first week of March 1992, but water temperatures were substantially lower when the brackish canals were sampled on March 5 following the passage of a cold front. Mean salinities varied from 2.3 to 19.8 o/oo. Highest average salinities occurred in October and lowest salinities occurred in March. Average salinities in brackish and saline canals were similar in May, June, and March 1993. Differences in mean salinities between brackish and saline canals were most pronounced in October (Table 3). Submerged aquatics, mostly *Myriophyllum spicatum* L. and *Ruppia maritima* L., were observed only in brackish canals. In May and June, SAV occurred at all shallow (<1 m) sample sites, and although SAV biomass was much less at sites $\geq$1 m but <1.5 m deep, 50% of these sites contained at least some vegetation. Submerged vegetation was absent from sites $\geq$1.5 m deep. Peak biomass of SAV in canals occurred in June 1992. Brackish canals contained little SAV after Hurricane Andrew swept across coastal Louisiana in August 1992.

Nekton assemblages using pipeline canals in our study area included 43 species of fishes and 6 species of decapod crustaceans (Table 4). We collected a total of 25,670 organisms having a wet weight of approximately 10.94 kg. Species richness was greater in brackish than saline canals (43 vs 37 species). Although 49 species were taken in throw trap samples, only 32 of these were collected with the trawl. Most of the species absent from trawl samples were rarely collected in throw trap samples; however, the trawl was not effective in sampling some of the more common species, e.g., speckled worm eel *Myrophis punctatus* and pinfish *Lagodon rhomboides*. Species that numerically dominated the trawl samples were also very abundant in throw trap samples (Table 4).

Daggerblade grass shrimp was the most abundant estuarine resident species in both brackish and saline canals. Other numerically dominant residents occupying brackish canals were naked goby *Gobiosoma bosc*, rainwater killifish *Lucania parva*, and gulf pipefish *Syngnathus scovelli*. Two additional resident species, clown goby *Microgobius gulosus* and sailfin molly *Poecilia latipinna*, were only seasonally abundant in brackish canals. Bay anchovy *Anchoa mitchilli*, blue crab *Callinectes sapidus*, brown shrimp *Penaeus aztecus*, and gulf menhaden *Brevoortia patronus* were numerically dominant transient species in both saline and brackish canals. White shrimp *Penaeus setiferus* and Atlantic croaker *Micropogonias undulatus* were dominant transient species in saline canals only.

Variation in the abundance of numerically dominant species could not be related to maximum canal depth (Hypothesis 1; Table 5). Within the same canal, however, the distribution of some species seemed to be influenced by habitat depth (Tables 6-8). The strength of the relationship between habitat depth and animal density varied not only among species, but also by marsh type and with time of year (Table 8). The degree of habitat segregation with depth was most pronounced in brackish canals during late spring and summer (Tables 6 and 8). Densities of both total fishes and total decapod crustaceans were significantly greater in shallow water in May and June. Numerically dominant species that were significantly more abundant in shallow water at this time included naked goby, rainwater killifish, gulf pipefish, blue crab, and daggerblade grass shrimp. However, only naked goby continued to exhibit this relationship in October (Table 8). Bay anchovy was the only numerically dominant species that exhibited the opposite relationship. In June bay anchovy were concentrated in deep water. In saline canals, juvenile blue crabs selected shallow habitats in March and June, and daggerblade grass shrimp selected this habitat in March; neither species showed a preference for a specific water depth in October (Tables 7 and 8). Bay anchovy was the only fish for which a relationship between water depth and density could be shown, and the relationship was identical to that found for brackish canals, one of greater abundance in deep water in June (Table 8).

The efficacy of the throw trap was not reduced in deep water (Figure 8). In fact, highest catches were obtained when sampling at a depth of 1.5 m. The mean catch at 1.5 m exceeded the actual density of killifish (11.7 fish/m^2) in the experimental tank by 10%, whereas mean catches at other depths ranged from 59-74% of the actual density.

The efficiency of clearing the throw trap in the field was high for both species tested, although the recovery rate for daggerblade grass shrimp was less than that for killifish (Figure 9). Clearing efficiency was not influenced by water depth for either species (Figure 9).

Topographic survey of the area adjacent to one of our saline study canals (Tennesse #2) showed that the marsh on the immediate edge of the canal, between the canal and the levee, was approximately 4 cm higher in elevation than the marsh behind the levee, hereafter termed the backmarsh. This may be an artifact of the dredging but may also represent a type of natural levee development next to the canal. The crest of the levee was approximately 30 cm higher than the marsh next to the canal and 34 cm higher than the backmarsh. Extrapolations of marsh topography from the marsh next to the canal to the backmarsh, suggested that were the levee to be removed, the resulting surface elevation would be approximately 1 cm higher than the marsh next to the canal.

Figure 10a compares the duration of flooding for canal edge and backmarsh elevations for the period of tide gauge operation. There is very little difference in the frequency distributions with the backmarsh flooding for a slightly longer total time (821 vs. 629 hrs.). The canal marsh experienced more frequent but shorter flooding events, as would be expected because of its higher elevation, but there is no difference in the duration of the longest measured event. The frequency distributions of flooding depth for these two marsh sites (Figure 10b) also show similar patterns.

The flooding regimes for these natural marsh sites can be compared with those calculated for the levee with and without the presence of the dredged material (Figures11a and b).

During the entire period of tide gauge operation, the crest of the existing levee is overtopped only eight times and only for a maximum duration of 10 hours (Figure 11a). If the levee were to be removed, the duration of flooding would show a similar pattern to the natural marsh with several flooding events of over 40 hours duration. This difference is also apparent in the depth of flooding. There are only 2 events when the existing levee floods with greater than 10 cm of water, whereas without the levee, the marsh would flood with over 20 cm of water at least 13 times (Figure11b).

Dredged material was last deposited on this levee 25 years ago (see Chapter 1, Table 1 - Tennessee #2), and degradation and compaction of the levee sediments has occurred over this period. Consequently, the present elevation of this levee, approximately 30 cm above the level of the adjacent marsh, is lower than would be expected in levees where dredged material has been placed more recently.

DISCUSSION

Early life stages and small adults of fishes and decapod crustaceans residing in subtidal habitats <2 m deep were effectively sampled using the 2 m^2 throw trap. Increasing water depth to 1.8 m did not decrease sampling efficacy for small organisms, and the efficiency of removing organisms with the clearing net (83-100%) was comparable to other methods using bar seines or dip nets (Freeman et al. 1984, Zimmerman et al. 1984, Rozas and Odum 1987).

Our results are consistent with previous studies that document selection of shallow subtidal habitats by some estuarine species (Baltz et al. 1993, Ruiz et al. 1993). daggerblade grass shrimp and blue crabs selected shallow water (<1 m) in saline canals. Likewise, Ruiz et al. (1993) reported significantly higher densities of several small species including daggerblade grass shrimp in water depths <70 cm. Although they found large blue crabs preferred water >70 cm deep, the proportion of small juvenile blue crabs decreased with water depth in their study. Small fishes and crustaceans vulnerable to predation may concentrate in shallow water to avoid large aquatic predators (Schlosser 1987, McIvor and Odum 1988, Baltz et al. 1993). Ruiz et al. (1993) reported that aquatic predators of small fishes and crustaceans were often more abundant in deep water, and the mortality of tethered daggerblade grass shrimp and small blue crabs increased significantly with depth. Had our shallow sample sites been adjacent to the marsh edge, we may have observed greater selection for shallow subtidal habitats. Baltz et al. (1993) found greatest densities of early life stages of fishes in shallow water near the marsh-edge interface. The proximity of the marsh vegetation was an important influence on habitat selection in their study.

In brackish canals, where (prior to the hurricane) the shallow subtidal always contained submerged vegetation, three additional species (gulf pipefish, rainwater killifish and naked goby) showed a preference for shallow water. Predator encounter rates can be very high in unvegetated areas of pipeline canals, even in water < 1 m deep (Rozas 1992), and submerged vegetation may enhance such areas by providing protection from predators as well as a food-rich environment (Rozas and Odum 1988, Lubbers et al. 1990, Fredette et al. 1990). A comparison of the patterns of habitat selection in brackish canals before and after the passage of Hurricane Andrew provides additional support for an enhancing effect of SAV in subtidal areas. In brackish canals prior to hurricane passage in August 1992, the average densities of total fishes, total decapods, and most dominant species were significantly greater in shallow water (<1 m) where SAV was abundant. However, after most SAV was removed by the hurricane, only one species (naked goby) showed a preference for the shallow habitat. In a study of hurricane effects on marsh vegetation, Chabreck and Palmisano (1973) also observed a drastic decline in the relative abundance of SAV in ponds and lakes of coastal Louisiana. Our study documents the dramatic change such an event may have on the nekton assemblage of habitats containing SAV.

Species dominating the assemblages in pipeline canals are common in estuaries of the northern Gulf of Mexico (Adkins and Bowman 1976, Neill and Turner 1987b, Rozas 1992). Because our study was confined to open-water habitats, pelagic species (e.g., bay anchovy and gulf menhaden) were more prominent and some demersal species were less so than in studies of vegetated marsh habitats. For example, cyprinodonts which dominate marsh-surface habitats (Hettler 1989, Kneib 1991, Rozas 1992, Peterson and Turner 1994), were uncommon in our study with the exception of rainwater killifish. Interestingly, green goby *Microgobius thalassinus* was common in pipeline canals, but it is considered rare along the northern Gulf coast (Hoese and Moore 1977), .

Brackish and saline canals differed both in terms of average salinity and the presence of SAV. Both factors could affect the distribution of some species, and may explain differences in species' densities between brackish and saline canals. High salinities undoubtedly excluded some freshwater species from saline canals. For example, bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, and yellow bullhead *Ameiurus natalis* were collected only in brackish canals. Redear sunfish *Lepomis microlophus*, although present in saline canals, were much more abundant in brackish canals.

Although salinity has a major influence on the distribution of freshwater species in estuaries, the presence of SAV may also affect their abundance. Other studies of low salinity estuarine habitats have documented high densities of early life stages of centrarchids and ictalurids in SAV (Weaver and Holloway 1974, Rozas and Odum 1987). The apparent preference for brackish canals by gulf pipefish and rainwater killifish was likely due to the presence of SAV there and not to differences in salinity. Both species are euryhaline, and the salinities encountered in saline canals are well within their range of tolerance. In a study of brackish marsh ponds with similar salinities, Weaver and Holloway (1974) found much higher densities of gulf pipefish and rainwater killifish in vegetated than unvegetated ponds. Further evidence for their strong association with submerged vegetation was their dramatic decline in brackish canals when SAV disappeared following passage of Hurricane Andrew in August 1992.

Backfilling the canals in our study area would decrease deep subtidal area and increase shallow habitat. The resulting mean depths of most canals would be less than 1 m (Reed and Rozas, Chapter 1). Similar results were reported in other studies of canals in coastal Louisiana. Backfilling a 56-km long pipeline canal resulted in mean depths of 67 and 60 cm in brackish and saline sections, respectively (Abernethy and Gosselink 1988). In a study of oil and gas access canals, Neill and Turner (1987a) found that after backfilling most (81%) had an average depth ≤1 m. Our results suggest that increasing shallow subtidal habitat in canals at the expense of deep areas would enhance the value of nursery habitat for some species, especially in brackish canals where backfilling would expand the subtidal area capable of supporting SAV. Abernethy and Gosselink (1988) reported that four years after backfilling, SAV covered 23% of the bottom in the brackish section of a pipeline canal, but it was rarely observed in the saline section. Increasing the abundance of SAV in backfilled canals would also enhance habitat quality for waterfowl, which use submerged vegetation as food (Chabreck 1971, Neill and Turner 1987a). The only species that might be negatively affected by a reduction in deep habitats is the bay anchovy which preferred deep water during some times of the year.

Backfilling would also benefit organisms that exploit marsh-surface habitats. Species dominating the assemblages in our study canals and known to use the adjacent marsh surface when it is flooded include daggerblade grass shrimp, naked goby, blue crab, brown shrimp, and white shrimp (Zimmerman and Minello 1984; Rozas 1992; Peterson and Turner 1994). Backfilling would benefit these species by restoring marsh-surface habitat which is presently buried beneath dredged material. Both the frequency and duration of flooding, and therefore habitat availability, would be dramatically increased in the area presently covered by the levee. Because dredged material levees are often located immediately adjacent to canals, they cover up potentially valuable habitat along canal shorelines. Restoring this marsh would be especially beneficial because it would increase marsh edge used extensively by many fishery species (Neill and Turner 1987a, Peterson and Turner 1994). In marsh partially impounded by intersecting canals, removing levees would also restore the hydrology of backmarsh areas (Swenson and Turner 1987), and remove a potential barrier for nekton migration from the canal to adjacent marshes.

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Table 1. Summary of results from field survey of selected pipeline segments.

Pipeline	Canal Age (yrs)	Orig. Depth (m)	BP Index	BP Width (m)	BP Depth (m)	BUP Index	BUP Width (m)	BUP Depth (m)	SP Index	SP Width (m)	SP Depth (m)	SUP Index	SUP Width (m)	SUP Depth (m)
Tennessee #2	25	1.8	-	-	-	0.830	34.5	2.0-2.5	0.683	24.2	<0.5	0.795	27.6	1.5-2.0
Tennessee #3[1]	16	1.8	-	-	-	-	-	-	0.813	36.3	3.0-3.5	0.780	48.8	2.5-3.0
Tennessee #5	34	1.8	-	-	-	0.854	31.9	0.5-1.0	3.136	3.13	<0.5	-	-	-
Trunkline #8	13	4.0	0.871	36.9	2.0-2.5	-	-	-	0.832	37.0	3.0-3.5	0.821	44.8	1.5-2.0
Columbia Gulf #9	28	2.7	0.398	31.7	2.0-2.5	0.712	35.0	1.5-2.0	-	-	-	0.824	35.4	2.0-2.5
Shell #1	25	-[2]	-	-	-	-	-	-	-	-	-	0.683	22.9	0.5-1.0
United Gas #17	40	1.2	0.524	25.4	2.0-2.5	0.757	27.8	1.0-1.5	1.497	25.2	<0.5	0.800	25.0	2.0-2.5
Dow #18	24	1.2	0.922	29.4	3.0-3.5	0.553	36.7	2.5-3.0	-	-	-	0.872	31.3	1.5-2.0
MEAN			**0.679**	**30.85**	**2.75**	**0.741**	**33.2**	**2.0**	**1.392**	**25.2**	**1.7**	**0.796**	**33.7**	**2.2**

BP - Brackish, Plugged
BUP - Brackish, Unplugged
SP - Saline, Plugged
SUP - Saline, Unplugged

1 Pipeline does not cross brackish marsh areas
2 No depth information available from pipeline company
\- Survey not possible on this segment type

Table 2. Estimated canal depth after infilling for all surveyed canal segments.

Pipeline	Canal Age (yrs)	Orig. Depth (m)	BP Depth After Infilling (m)	BUP Depth After Infilling (m)	SP Depth After Infilling (m)	SUP Depth After Infilling (m)
Tennessee #2	25	1.8	-	0.98	0.17	1.27
Tennessee #3[1]	16	1.8	-	-	2.23	1.84
Tennessee #5	34	1.8	-	0.26	*	-
Trunkline	13	4.0	3.19	-	2.32	1.19
Columbia Gulf	28	2.7	0.72	0.59	-	0.64
Shell	25	-[1]	-	-	-	0.16
United Gas	40	1.2	0.07	-	*	0.62
Dow	24	1.2	0.94	1.01	-	0.36
MEAN			**1.23**	**0.62**	**1.57**	**0.87**

BP - Brackish, Plugged
BUP - Brackish, Unplugged
SP - Saline, Plugged
SUP - Saline, Unplugged

[1] No depth information available from company
\- Survey not possible on this segment type
* Mean Infilling Index >1 for this segment

Table 3. A comparison of salinity, water temperature, and submerged aquatic vegetation (SAV) biomass measured in pipeline canals within brackish (B) and saline (S) marshes. n=number of canals sampled. Means (± one standard error of the mean) were calculated by first averaging data from 3 or 4 samples collected within each canal and then averaging canal means.

Sample Date	Marsh Type	n	Salinity (o/oo)	Water Temperature (^{o}C)	SAV Biomass (g dry weight)
October 1991	B	7	9.6±1.1	25.2±0.6	24.6±16.0
	S	7	19.8±0.9	24.2±0.5	0.0±0.0
March 1992	B	7	2.3±0.6	16.0±1.8	23.3±7.1
	S	6	6.7±1.3	21.6±0.9	0.0±0.0
May 1992	B	3	10.6±0.5	24.9±0.4	66.1±24.9
	S	3	10.7±2.3	25.0±1.3	0.0±0.0
June 1992	B	3	11.2±0.7	31.7±0.9	77.6±31.0
	S	3	14.3±3.1	30.3±0.6	0.0±0.0
October 1992	B	3	7.9±0.5	24.1±0.7	0.1±0.0
	S	3	14.7±0.8	23.1±0.9	0.0±0.0
March 1993	B	3	5.6±0.6	20.7±0.8	7.5±7.4
	S	3	6.5±1.4	20.3±1.0	0.0±0.0

Table 4. List of fishes and decapod crustaceans collected with throw trap and trawl in subtidal habitats of pipeline canals within brackish (B) and saline (S) marshes. Total numbers and (biomass, g wet weight) are given for each sp. collected during each sampling period. n=number of canals sampled during each period. For March 1992 n equals 7 and 6 for Brackish and Saline canals, respectively.

		Throw Trap						Trawl	
Species		Oct 1991 n=7	Mar 1992 n=7/6	May 1992 n=3	Jun 1992 n=3	Oct 1992 n=3	Mar 1993 n=3	Oct 1991 n=7	Mar 1992 n=6
Palaemonetes pugio	B	285 (25.9)	1,069 (162.4)	125 (32.0)	158 (33.6)	25(3.0)	529(113.9)	529(66.3)	8 (1.3)
Daggerblade Grass Shrimp	S	28 (3.5)	828 (161.1)	1 (0.4)	2 (0.3)	55 (5.7)	1,006 (219.7)	2 (0.3)	3,145 (607.5)
Brevoortia patronus	B	0 (0.0)	1,048 (182.2)	6 (0.9)	0 (0.0)	2 (26.3)	10 (0.6)	0 (0.0)	131 (13.3)
Gulf Menhaden	S	0 (0.0)	662 (138.7)	1 (7.8)	0 (0.0)	0 (0.0)	486 (53.3)	0 (0.0)	984 (231.7)
Anchoa mitchilli	B	110 (20.3)	163 (18.9)	29 (4.5)	72 (12.6)	399 (42.6)	66 (17.0)	1,416 (469.3)	904 (212.7)
Bay Anchovy	S	71 (12.3)	55 (19.9)	190 (45.1)	298 (27.7)	151 (26.3)	41 (4.5)	683 (243.2)	1,508 (398.7)
Callinectes sapidus	B	388 (27.8)	454 (418.5)	82 (52.0)	35 (316.1)	122 (15.1)	86 (26.1)	135 (9.4)	78 (8.2)
Blue Crab	S	93 (35.2)	207 (266.7)	9 (3.3)	13 (1.1)	41 (1.9)	90 (33.7)	37 (92.2)	324 (498.5)
Lucania parva	B	240 (30.4)	250 (82.9)	90 (18.9)	440 (58.3)	6 (1.5)	2 (0.5)	736 (157.9)	1 (0.2)
Rainwater Killifish	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	4 (1.0)	0 (0.0)
Gobiosoma bosc	B	44 (3.8)	256 (75.4)	29 (11.1)	137 (13.8)	74 (8.7)	75 (20.0)	84 (7.4)	16 (3.3)
Naked Goby	S	7 (1.1)	23 (10.3)	0 (0.0)	5 (0.5)	6 (0.3)	14 (3.6)	0 (0.0)	6 (1.2)
Microgobius gulosus	B	176 (21.5)	44 (33.8)	10 (6.7)	62 (14.9)	7 (2.4)	0 (0.0)	126 (22.9)	5 (3.0)
Clown Goby	S	6 (0.2)	1 (0.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7 (3.2)
Poecilia latipinna	B	1 (0.2)	16 (7.7)	0 (0.0)	200 (42.4)	0 (0.0)	0 (0.0)	9 (4.0)	0 (0.0)
Sailfin Molly	S	1 (2.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.5)	0 (0.0)
Penaeus aztecus	B	25 (19.6)	14 (4.2)	52 (54.2)	21 (69.8)	5 (24.9)	4 (0.5)	53 (90.7)	4 (3.3)
Brown Shrimp	S	11 (11.6)	23 (5.1)	37 (37.2)	6 (3.3)	9 (5.0)	9 (2.7)	17 (40.0)	157 (14.5)
Syngnathus scovelli	B	2 (0.6)	63 (18.1)	60 (10.6)	58 (13.0)	5 (0.5)	4 (1.9)	5 (0.5)	12 (2.5)
Gulf Pipefish	S	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

Table 4. List of fishes and decapod crustaceans collected in subtidal habitats of canals in brackish (B) and saline (S) marshes (ctd.).

Species		Throw Trap						Trawl	
		Oct 1991 n=7	Mar 1992 n=7/6	May 1992 n=3	Jun 1992 n=3	Oct 1992 n=3	Mar 1993 n=3	Oct 1991 n=7	Mar 1992 n=6
Micropogonias undulatus	B	1 (0.0)	29 (43.5)	4 (7.8)	0 (0.0)	0 (0.0)	21 (24.2)	28 (1.0)	122 (148.1)
Atlantic Croaker	S	0 (0.0)	95 (122.4)	0 (0.0)	0 (0.0)	0 (0.0)	27 (49.2)	27 (1.0)	556 (517.7)
Penaeus setiferus	B	6 (3.6)	0 (0.0)	0 (0.0)	0 (0.0)	5 (10.7)	0 (0.0)	48 (75.1)	0 (0.0)
White Shrimp	S	60 (46.9)	0 (0.0)	0 (0.0)	0 (0.0)	52 (73.6)	0 (0.0)	210 (274.3)	0 (0.0)
Menidia beryllina	B	15 (5.0)	3 (2.4)	23 (2.9)	10 (5.0)	6 (3.7)	0 (0.0)	25 (10.7)	1 (0.5)
Inland Silverside	S	6 (8.7)	12 (21.9)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Lepomis microlophus	B	50 (68.7)	10 (24.7)	0 (0.0)	3 (3.6)	0 (0.0)	0 (0.0)	52 (358.0)	0 (0.0)
Redear Sunfish	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (1.8)	0 (0.0)
Leiostomus xanthurus	B	0 (0.0)	6 (6.3)	0 (0.0)	0 (0.0)	2 (238.0)	0 (0.0)	0 (0.0)	22 (62.4)
Spot	S	0 (0.0)	25 (37.8)	9 (69.3)	0 (0.0)	0 (0.0)	8 (11.6)	0 (0.0)	153 (129.3)
Gobionellus boleosoma	B	3 (0.2)	6 (6.2)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.5)	0 (0.0)	0 (0.0)
Darter Goby	S	16 (3.3)	9 (4.0)	0 (0.0)	0 (0.0)	2 (0.2)	12 (6.2)	25 (2.9)	4 (2.3)
Microgobius thalassinus	B	17 (1.3)	1 (0.5)	1 (0.4)	1 (0.5)	3 (0.9)	4 (1.9)	21 (1.2)	0 (0.0)
Green Goby	S	7 (1.1)	1 (0.4)	0 (0.0)	0 (0.0)	3 (0.4)	1 (0.6)	9 (1.1)	4 (1.2)
Lagodon rhomboides	B	0 (0.0)	3 (2.1)	0 (0.0)	1 (12.4)	0 (0.0)	3 (0.3)	0 (0.0)	0 (0.0)
Pinfish	S	0 (0.0)	6 (2.3)	2 (8.1)	1 (6.1)	0 (0.0)	24 (4.7)	0 (0.0)	0 (0.0)
Lepomis macrochirus	B	22 (25.4)	7 (104.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	66 (280.9)	0 (0.0)
Bluegill	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Myrophis punctatus	B	8 (4.5)	7 (6.6)	1 (1.0)	0 (0.0)	1 (0.8)	1 (0.9)	0 (0.0)	0 (0.0)
Speckled Worm Eel	S	1 (0.1)	3 (2.4)	1 (0.1)	0 (0.0)	0 (0.0)	1 (1.3)	0 (0.0)	0 (0.0)

Table 4. List of fishes and decapod crustaceans collected in subtidal habitats of canals in brackish (B) and saline (S) marshes (ctd.).

Species		Throw Trap Oct 1991 n=7	Throw Trap Mar 1992 n=7/6	Throw Trap May 1992 n=3	Throw Trap Jun 1992 n=3	Throw Trap Oct 1992 n=3	Throw Trap Mar 1993 n=3	Trawl Oct 1991 n=7	Trawl Mar 1992 n=6
Gobionellus shufeldti	B	0 (0.0)	5 (10.9)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.3)
Freshwater Goby	S	0 (0.0)	15 (5.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.5)
Symphurus plagiusa	B	0 (0.0)	1 (0.3)	0 (0.0)	1 (0.0)	1 (0.6)	2 (0.7)	3 (0.1)	3 (0.2)
Blackcheek Tonguefish	S	8 (7.6)	1 (0.1)	0 (0.0)	1 (0.2)	4 (4.6)	0 (0.0)	12 (8.6)	10 (12.4)
Paralichthys lethostigma	B	0 (0.0)	1 (7.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.6)
Southern Flounder	S	0 (0.0)	8 (4.2)	5 (6.4)	0 (0.0)	0 (0.0)	3 (3.0)	3 (50.8)	19 (9.5)
Sphoeroides parvus	B	0 (0.0)	0 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Least Puffer	S	2 (10.8)	0 (0.0)	2 (0.7)	5 (7.7)	1 (2.7)	0 (0.0)	2 (1.9)	0 (0.0)
Palaemonetes vulgaris	B	0 (0.0)	5 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.7)	3 (0.5)	0 (0.0)
Marsh Grass Shrimp	S	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	3 (0.3)	0 (0.0)	0 (0.0)	1 (0.1)
Cynoscion nebulosus	B	1 (4.1)	0 (0.0)	0 (0.0)	1 (7.8)	1 (5.3)	0 (0.0)	4 (35.7)	0 (0.0)
Spotted Seatrout	S	2 (11.3)	1 (25.1)	0 (0.0)	0 (0.0)	3 (3.6)	0 (0.0)	1 (8.0)	0 (0.0)
Fundulus jenkinsi	B	0 (0.0)	8 (7.9)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Saltmarsh Topminnow	S	0 (0.0)	1 (0.6)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Eucinostomus argenteus	B	4 (2.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Spotfin Mojarra	S	4 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Gobionellus oceanicus	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	6 (5.2)	0 (0.0)	0 (0.0)
Highfin Goby	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Fundulus grandis	B	0 (0.0)	1 (3.9)	0 (0.0)	0 (0.0)	0 (0.0)	1 (7.7)	0 (0.0)	2 (15.6)
Gulf Killifish	S	0 (0.0)	2 (5.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (3.8)

Table 4. List of fishes and decapod crustaceans collected in subtidal habitats of canals in brackish (B) and saline (S) marshes (ctd.).

Species		Throw Trap						Trawl	
		Oct 1991 n=7	Mar 1992 n=7/6	May 1992 n=3	Jun 1992 n=3	Oct 1992 n=3	Mar 1993 n=3	Oct 1991 n=7	Mar 1992 n=6
Cyprinodon variegatus	B	0 (0.0)	4 (7.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Sheepshead Minnow	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Micropterus salmoides	B	0 (0.0)	1 (105.9)	2 (3.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Largemouth Bass	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Fundulus pulvereus	B	1 (0.0)	2 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.7)	0 (0.0)
Bayou Killifish	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Trinectes maculatus	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.1)	2 (0.2)	0 (0.0)	0 (0.0)
Hogchoker	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Porichthys plectrodon	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Atlantic Midshipman	S	0 (0.0)	0 (0.0)	3 (0.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Adinia xenica	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Diamond Killifish	S	1 (0.3)	1 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Bairdiella chrysoura	B	0 (0.0)	0 (0.0)	0 (0.0)	2 (4.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Silver Perch	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.6)	0 (0.0)	1 (1.2)	0 (0.0)
Achirus lineatus	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)
Lined Sole	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Arius felis	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Hardhead Catfish	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (12.9)	0 (0.0)	0 (0.0)	0 (0.0)
Menticirrhus americanus	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.6)	0 (0.0)	0 (0.0)	0 (0.0)
Southern Kingfish	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

Table 4. List of fishes and decapod crustaceans collected in subtidal habitats of canals in brackish (B) and saline (S) marshes (ctd.).

Species		Throw Trap						Trawl	
		Oct 1991 n=7	Mar 1992 n=7/6	May 1992 n=3	Jun 1992 n=3	Oct 1992 n=3	Mar 1993 n=3	Oct 1991 n=7	Mar 1992 n=6
Ameiurus natalis	B	1 (66.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Yellow Bullhead	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Mugil cephalus	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	4 (47.0)
Striped Mullet	S	0 (0.0)	1 (21.6)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (13.5)	0 (0.0)
Fundulus similis	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.9)	0 (0.0)	0 (0.0)	0 (0.0)
Longnose Killifish	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Sciaenops ocellatus	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (725.0)
Red Drum	S	0 (0.0)	0 (0.0)	1 (8.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Syngnathus louisianae	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)
Chain Pipefish	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Elops saurus	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	32 (4.4)
Ladyfish	S	0 (0.0)	0 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Cynoscion arenarius	B	1 (1.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	7 (8.9)	0 (0.0)
Sand Seatrout	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	10 (19.6)	0 (0.0)
Palaemonetes intermedius	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Brackish Grass Shrimp	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)
Lutjanus griseus	B	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.9)	0 (0.0)
Gray Snapper	S	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Totals	B	**1,401**	**3,477**	**515**	**1,202**	**671**	**819**	**3,354**	**1,348**
		(332.6)	**(1,347.8)**	**(206.5)**	**(608.2)**	**(387.6)**	**(222.8)**	**(1,603.7)**	**(1,253.9)**
	S	**325**	**1,980**	**262**	**332**	**334**	**1,722**	**1,047**	**6,881**
		(156.5)	**(856.0)**	**(187.1)**	**(47.1)**	**(139.2)**	**(394.1)**	**(761.9)**	**(2,432.1)**

Table 5. Results of regression analyses in which abundance of each dominant species was regressed with maximum canal depth. Spring and fall data were analysed separately. n=6 for Saline Canal in March 1992 and n=7 for all others. None of the results were significant at an adjusted *p*<0.10. Dash=no data.

Species	October 1991 R^2	October 1991 *p*	March 1992 R^2	March 1992 *p*
Brackish Canals				
Bay anchovy	0.000	0.99	0.567	0.05
Daggerblade grass shrimp	0.009	0.84	0.099	0.49
Blue crab	0.055	0.61	0.014	0.80
Rainwater killifish	0.103	0.48	0.233	0.27
Gulf menhaden	-	-	0.014	0.80
Saline Canals				
Bay anchovy	0.507	0.11		
Daggerblade grass shrimp	0.056	0.65	0.016	0.81
Blue crab	0.000	0.99	0.000	0.97
White shrimp	0.041	0.70	-	-
Gulf menhaden	-	-	0.475	0.13
Atlantic croaker	-	-	0.199	0.38

Table 6. Numerically dominant species of nekton collected in subtidal habitats of pipeline canals within brackish marshes. Means (± one standard error of the mean) are given for each species, total fishes, and total decapods for each depth range sampled in each sampling period. Sample size was 2 m^2 and means were calculated from 3 observations. Data are not given for months when species were not numerically dominant.

Taxon	<0.5m	<1.0m	<1.5m	≥1.5m	<0.5m	<1.0m	<1.5m	≥1.5m
	May 1992				**June 1992**			
Bay anchovy	0.0±0.0	2.3±2.3	1.0±1.0	6.3±4.9	0.3±0.3	0.7±0.7	12.0±6.7	11.0±10.0
Daggerblade grass shrimp	38.3±13.9	3.0±1.0	0.0±0.0	0.3±0.3	46.0±21.6	3.7±3.2	3.0±1.7	0.0±0.0
Naked goby	5.3±3.4	3.7±0.3	0.7±0.7	0.0±0.0	9.7±4.1	17.3±4.5	18.3±17.8	0.3±0.3
Blue crab	11.0±4.4	14.0±3.6	1.7±1.2	0.7±0.7				
Rainwater killifish	17.0±9.6	12.0±7.6	1.0±1.0	0.0±0.0	66.7±28.8	59.7±30.4	19.7±19.2	0.7±0.7
Gulf pipefish	10.7±7.2	8.0±7.5	1.3±1.3	0.0±0.0	7.7±2.6	11.0±4.7	0.7±0.7	0.0±0.0
Brown shrimp	8.0±0.6	6.3±4.9	2.3±1.3	0.7±0.3				
Total fish	34.0±16.3	36.7±20.8	7.3±5.0	7.3±5.0	155.3±76.7	98.7±37.2	62.7±55.3	12.7±10.7
Total decapods	57.3±18.5	23.3±4.8	4.0±2.5	1.7±0.3	55.7±23.2	7.3±3.4	7.7±4.3	0.7±0.3
	October 1992				**March 1993**			
Bay anchovy	24.7±11.5	19.7±16.7	21.3±20.3	67.3±54.4	3.7±3.7	2.3±0.9	12.3±7.0	3.7±2.0
Daggerblade grass shrimp	8.3±8.3	0.0±0.0	0.0±0.0	0.0±0.0	175.0±173.5	0.3±0.3	0.3±0.3	0.7±0.3
Naked goby	12.3±2.8	9.7±0.9	1.0±1.0	1.7±1.2	16.7±9.7	4.3±0.9	1.7±1.7	2.3±2.3
Blue crab	11.0±4.4	14.0±3.6	1.7±1.2	0.7±0.7	15.0±11.1	4.7±1.8	5.7±2.6	3.3±0.9
Total fish	44.3±13.2	32.0±15.0	23.7±20.2	71.3±52.5	25.7±9.3	11.3±2.4	19.7±5.2	9.7±5.0
Total decapods	31.7±11.4	9.7±5.0	5.7±3.0	8.0±5.0	190.0±184.5	5.0±2.1	7.0±3.2	4.7±1.5

Table 7. Numerically dominant species of nekton collected in subtidal habitats of pipeline canals within saline marshes. Means (± one standard error of the mean.) are given for each species, total fishes, and total decapods for each depth range sampled in each sampling period. Sample size was 2 m^2 and means were calculated from 3 observations. Data are not given for months when species were not numerically dominant.

Taxon	<0.5m	<1.0m	<1.5m	≥1.5m	<0.5m	<1.0m	<1.5m	≥1.5m
		May 1992				**June 1992**		
Bay anchovy	0.0±0.0	25.7±7.3	14.3±4.7	23.3±11.6	0.3±0.3	0.0±0.0	13.3±10.9	85.7±45.3
Blue crab					1.3±0.7	2.0±0.0	0.0±0.0	1.0±1.0
Brown shrimp	2.0±1.2	1.7±1.2	3.7±1.8	5.0±2.6				
Total fish	0.3±0.3	30.0±8.5	16.0±5.9	25.3±12.0	2.6±1.2	1.0±0.6	14.0±10.6	86.0±45.0
Total decapods	4.3±1.2	2.3±0.9	3.7±1.8	5.3±2.6	3.0±2.1	2.3±0.3	0.3±0.3	1.3±1.3
		October 1992				**March 1993**		
Bay anchovy	4.7±2.4	11.3±7.5	4.0±2.0	30.3±12.7				
Blue crab	3.0±1.5	4.3±3.0	3.0±2.0	3.3±4.9	18.3±6.5	6.7±5.2	1.3±0.3	3.7±0.3
Daggerblade grass shrimp	2.0±1.2	0.0±0.0	0.0±0.0	16.3±16.3	256.0±117.8	66.0±53.3	7.7±2.8	5.7±2.8
Gulf menhaden					4.1±0.8	2.3±1.2	1.6±0.9	1.5±1.5
White shrimp	11.7±11.2	1.7±1.7	1.0±0.6	3.0±2.1				
Total fish	6.7±3.3	12.7±6.9	5.3±1.7	33.0±11.5	112.0±63.5	43.3±22.2	16.3±4.9	34.0±24.6
Total decapods	18.3±10.0	7.0±2.1	4.7±2.0	25.0±21.5	5.3±0.6	3.5±1.0	2.2±0.4	2.2±0.3

Table 8. One-way ANOVA comparisons in mean number of individuals between shallow (<1m) and deep (≥1m) subtidal habitats of pipeline canals within brackish and saline marshes. The t- and p-values are given for each variable tested and for each sampling period. Degrees of freedom=8. Underscored values=significant difference (adjusted p<0.10). T-values with negative signs indicate that mean in shallow water is greater than mean in deep water. Dash = no data.

Variable	May 1992 t	May 1992 *p*	June 1992 t	June 1992 *p*	October 1992 t	October 1992 *p*	March 1993 t	March 1993 *p*
Brackish Canals								
Total fish	-2.430	0.041	-2.591	0.032	-0.757	0.470	-0.811	0.441
Total decapods	-7.482	0.000	-3.622	0.007	-1.819	0.106	-0.919	0.385
Bay anchovy	1.007	0.343	2.489	0.038	0.117	0.910	1.074	0.314
Daggerblade grass shrimp	-9.545	0.000	-3.524	0.008	-1.000	0.347	-1.210	0.261
Naked goby	-4.105	0.003	-2.400	0.043	-5.321	0.001	-2.764	0.025
Blue crab	-5.121	0.001	-	-	-2.254	0.054	-0.774	0.461
Rainwater killifish	-3.872	0.005	-2.756	0.025	-	-	-	-
Gulf pipefish	-2.268	0.053	-6.124	0.000	-	-	-	-
Brown shrimp	-2.240	0.055	-	-	-	-	-	-
Saline Canals								
Total fish	2.162	0.063	3.748	0.006	1.036	0.330	-1.665	0.134
Total decapods	0.362	0.726	-1.763	0.116	-0.583	0.576	-3.473	0.008
Bay anchovy	2.295	0.051	4.445	0.002	0.733	0.484	-	-
Blue crab	-	-	-2.322	0.049	-0.091	0.930	-2.444	0.040
Daggerblade grass shrimp	-	-	-	-	0.289	0.780	-2.953	0.018
Gulf menhaden	-	-	-	-	-	-	-1.437	0.189
Brown shrimp	1.395	0.200	-	-	-	-	-	-
White shrimp	-	-	-	-	-0.252	0.807	-	-

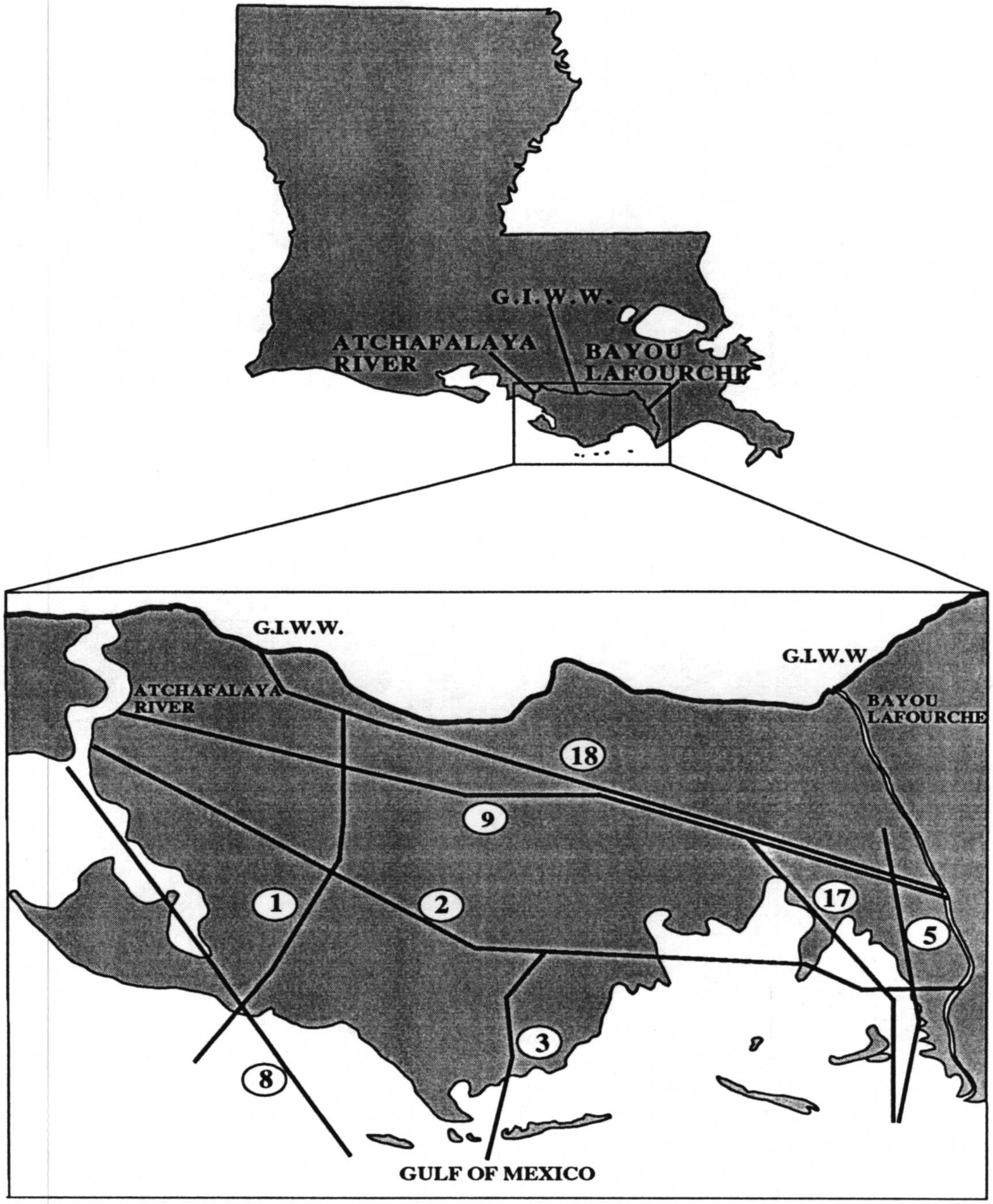

Figure 1. Location of the canals selected for field survey. The numbers denote their position in the database and are used in Table 1 with additional information on the canals.

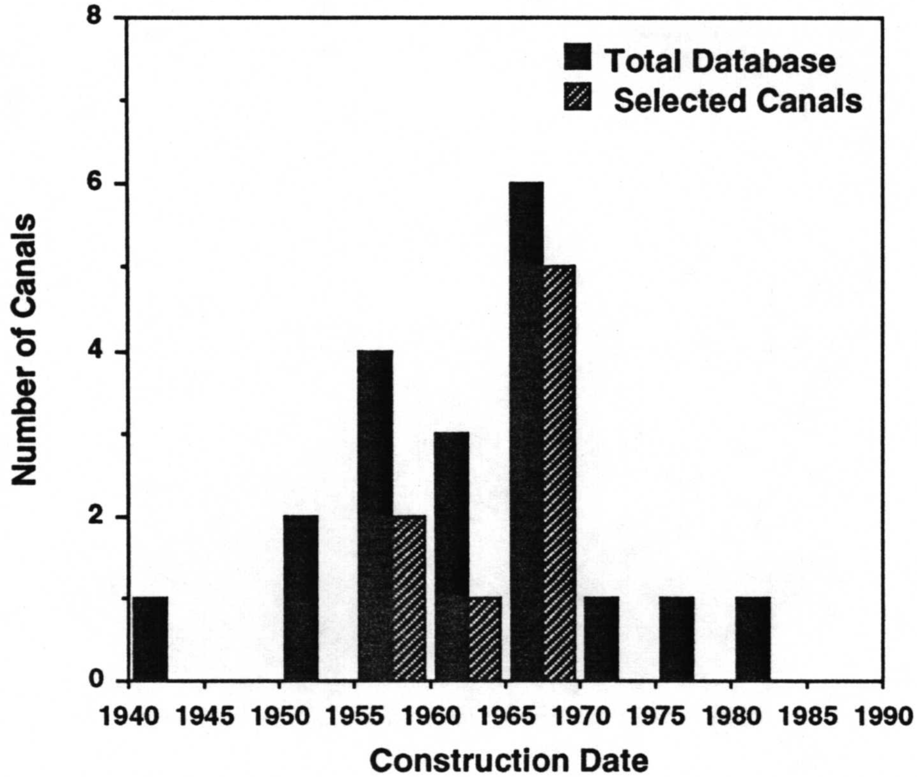

Figure 2. Comparison of frequency distributions for canal construction date between all canals in database and those selected for study.

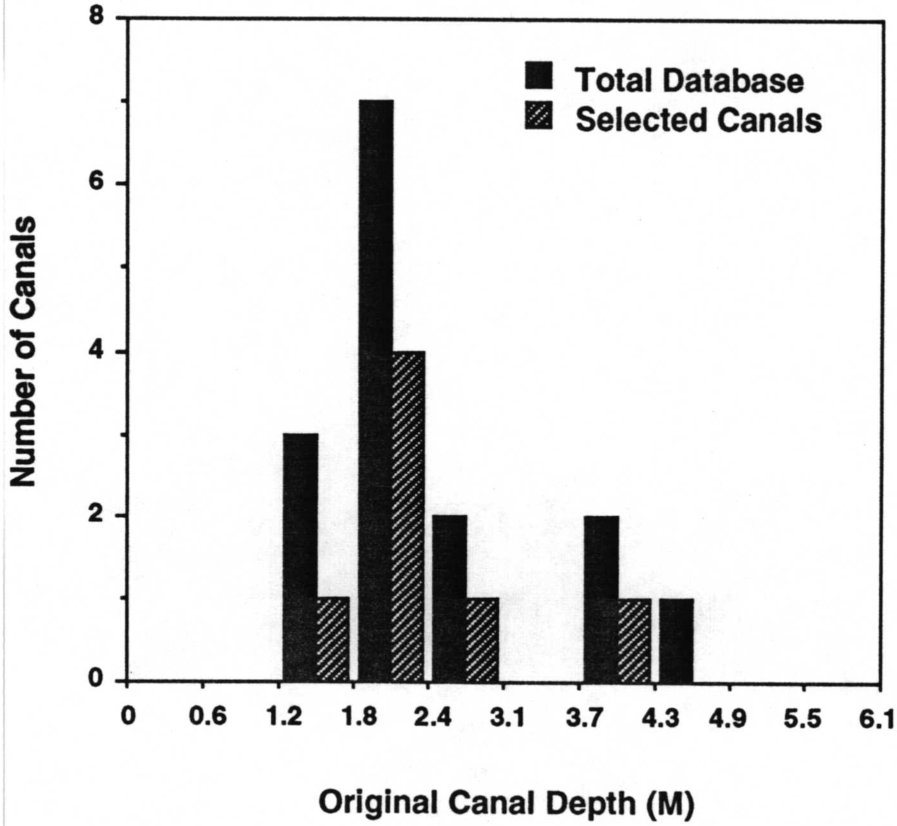

Figure 3. Comparison of frequency distributions for original depth between all canals in database and those selected for study.

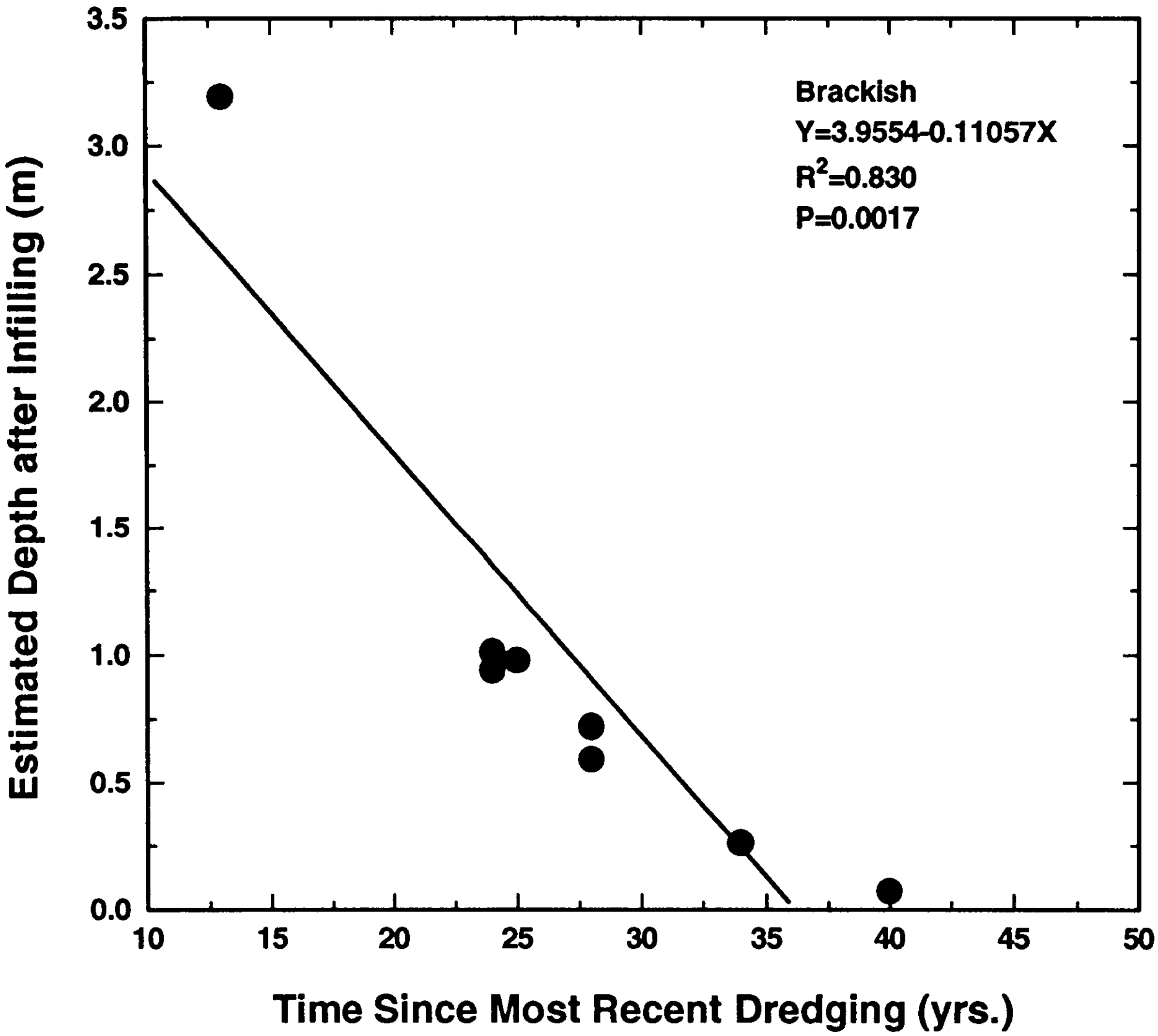

Figure 4. Relationship between canal age and the estimated depth after infilling for brackish canal segments.

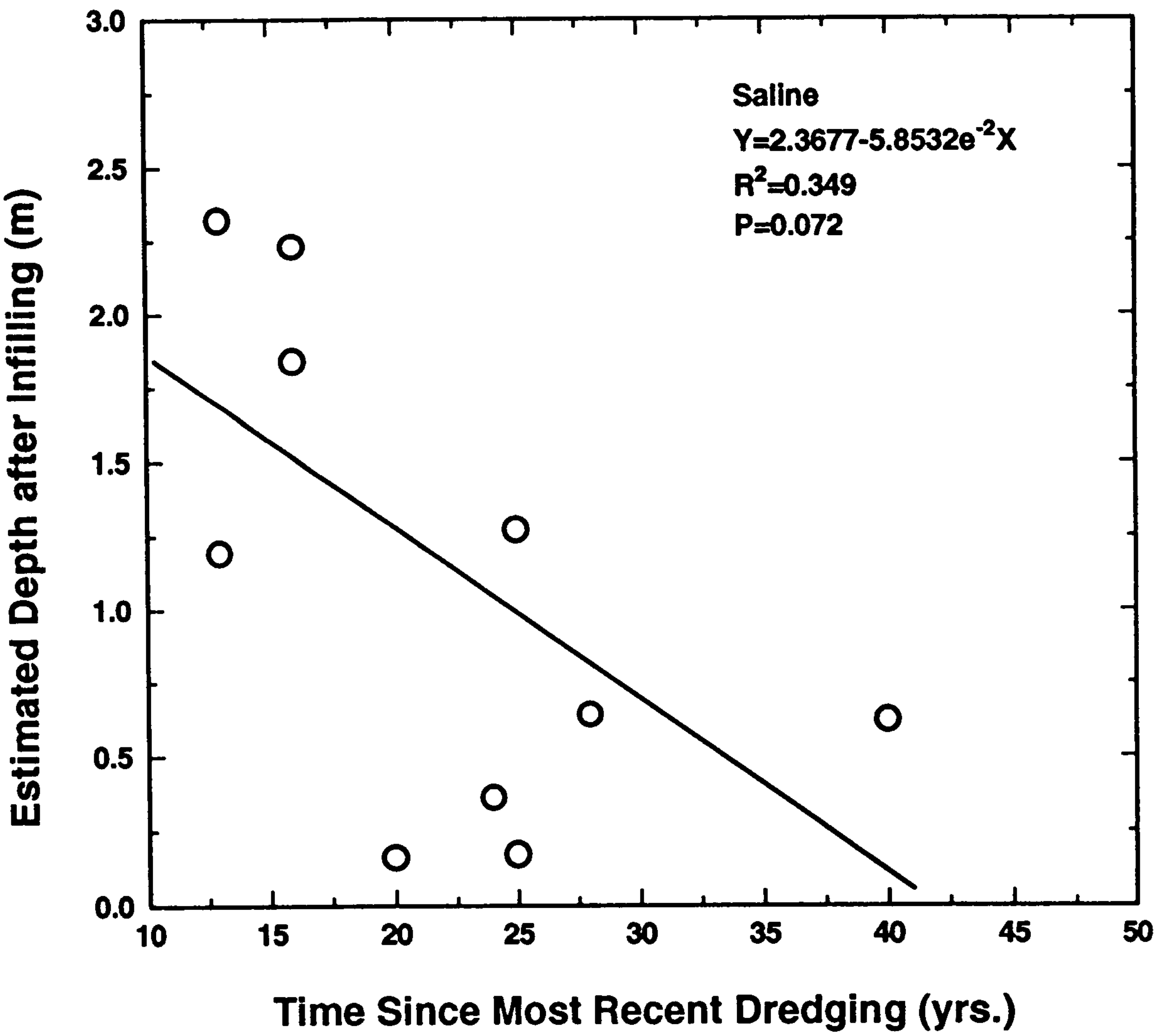

Figure 5. Relationship between canal age and the estimated depth after infilling for saline canal segments.

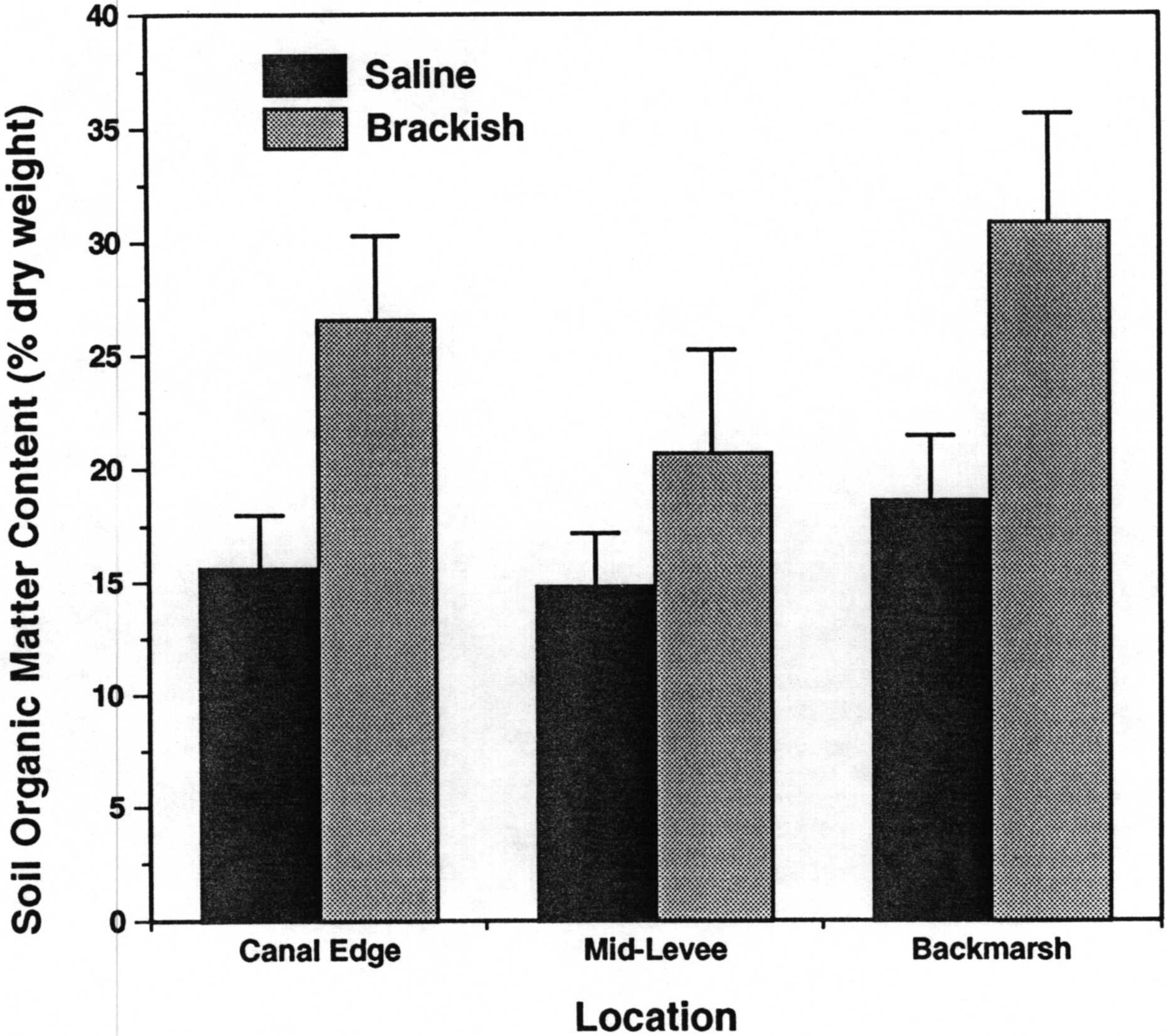

Figure 6. Organic matter content of soil samples from marsh and levee environments.

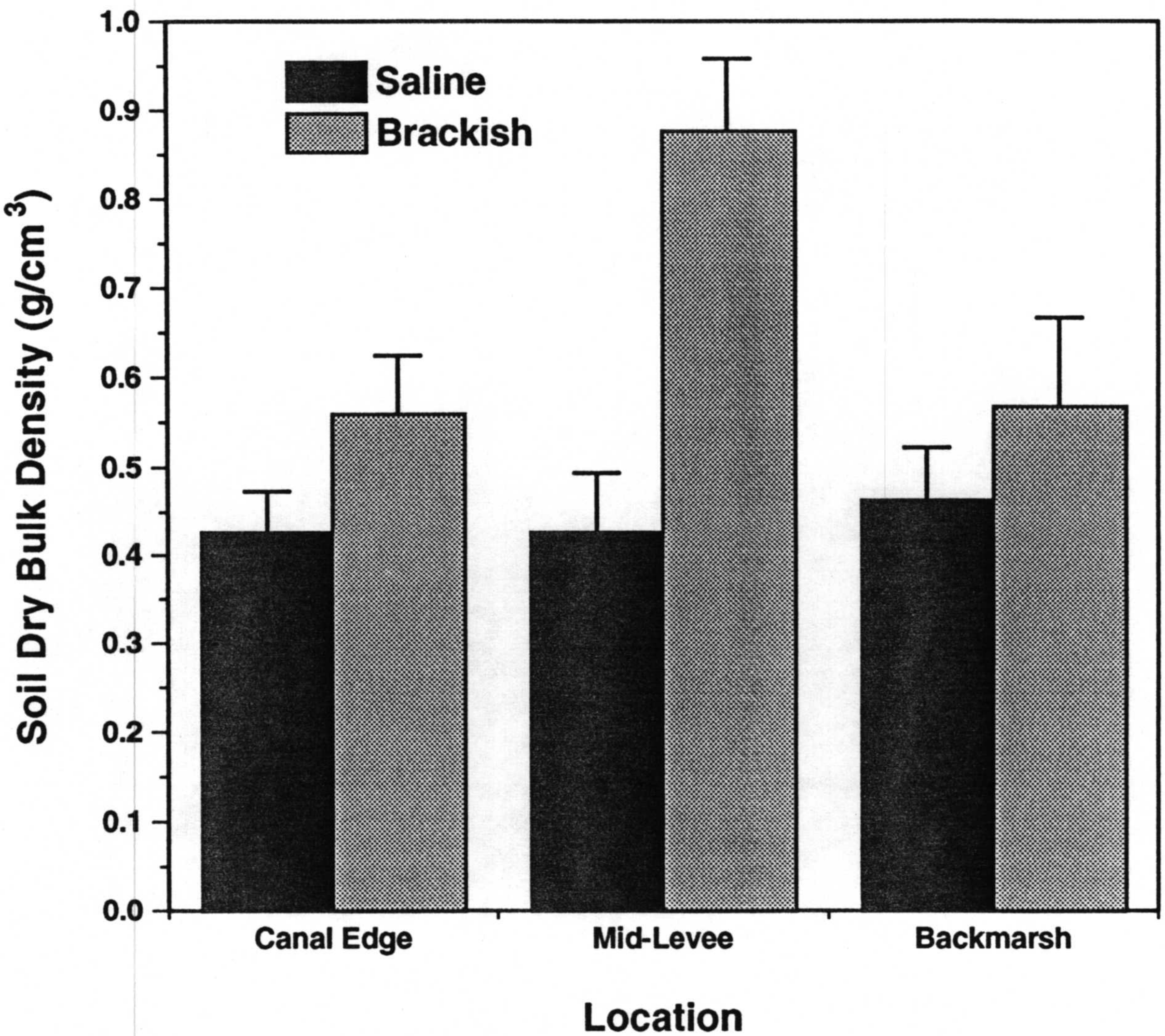

Figure 7. Dry bulk density of soil samples from marsh and levee environments.

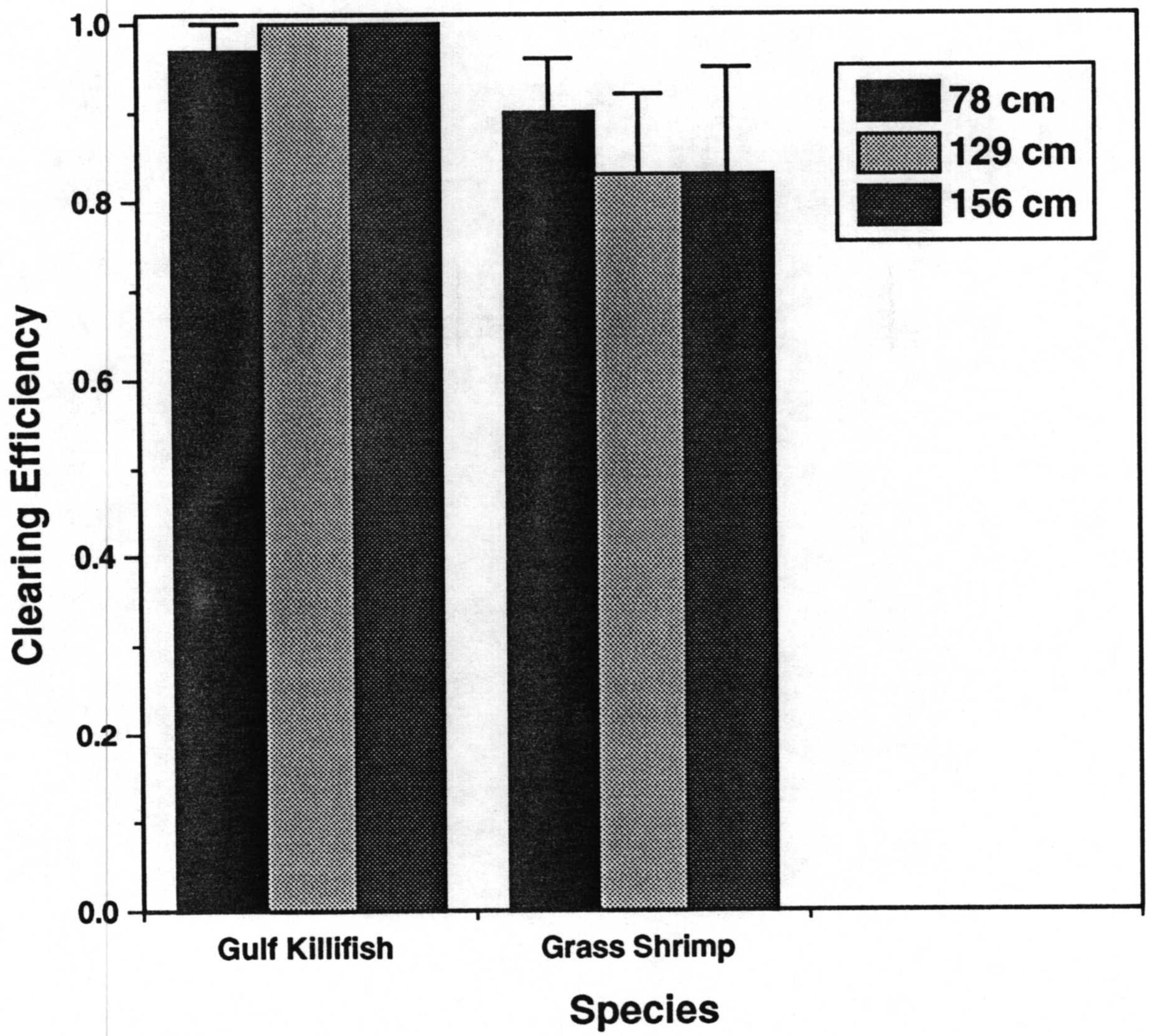

Figure 8. Results of the estimation of 2 m^2 throw trap efficiency showing the average number of animals captured with the throw trap at a range of water depths. Samples were taken eight times at each depth. The stocking density was 23.4 animals/$2m^2$. Error bars equal one standard error (1 SE).

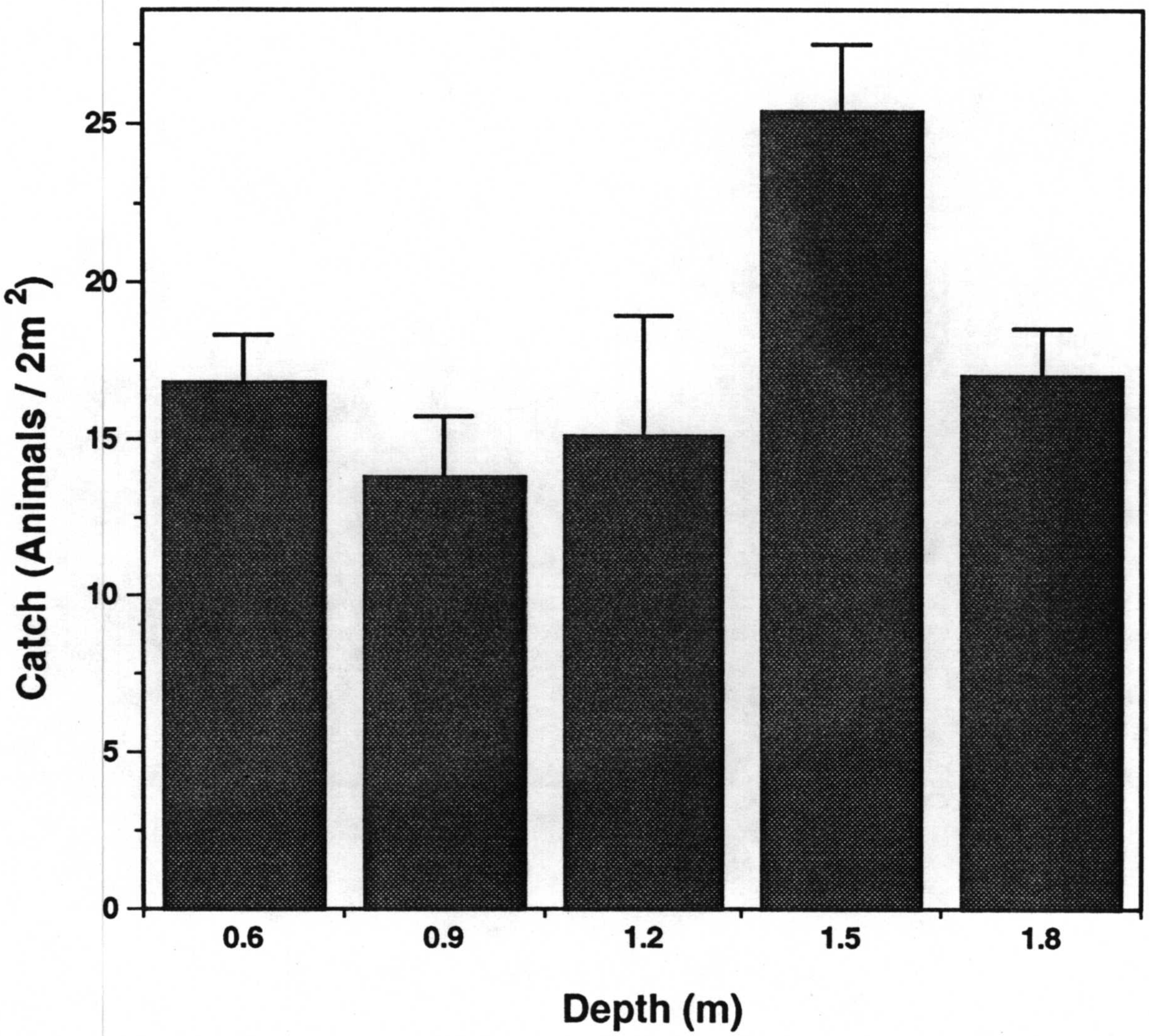

Figure 9. Estimation of the efficiency of removing animals from the throw trap with a clearing net. The proportions of gulf killifish and grass shrimp retrieved from the trap are plotted for three different average water depths in which experiments were conducted. Experiments were replicated three times at each depth for each species. Error bars equal 1 SE.

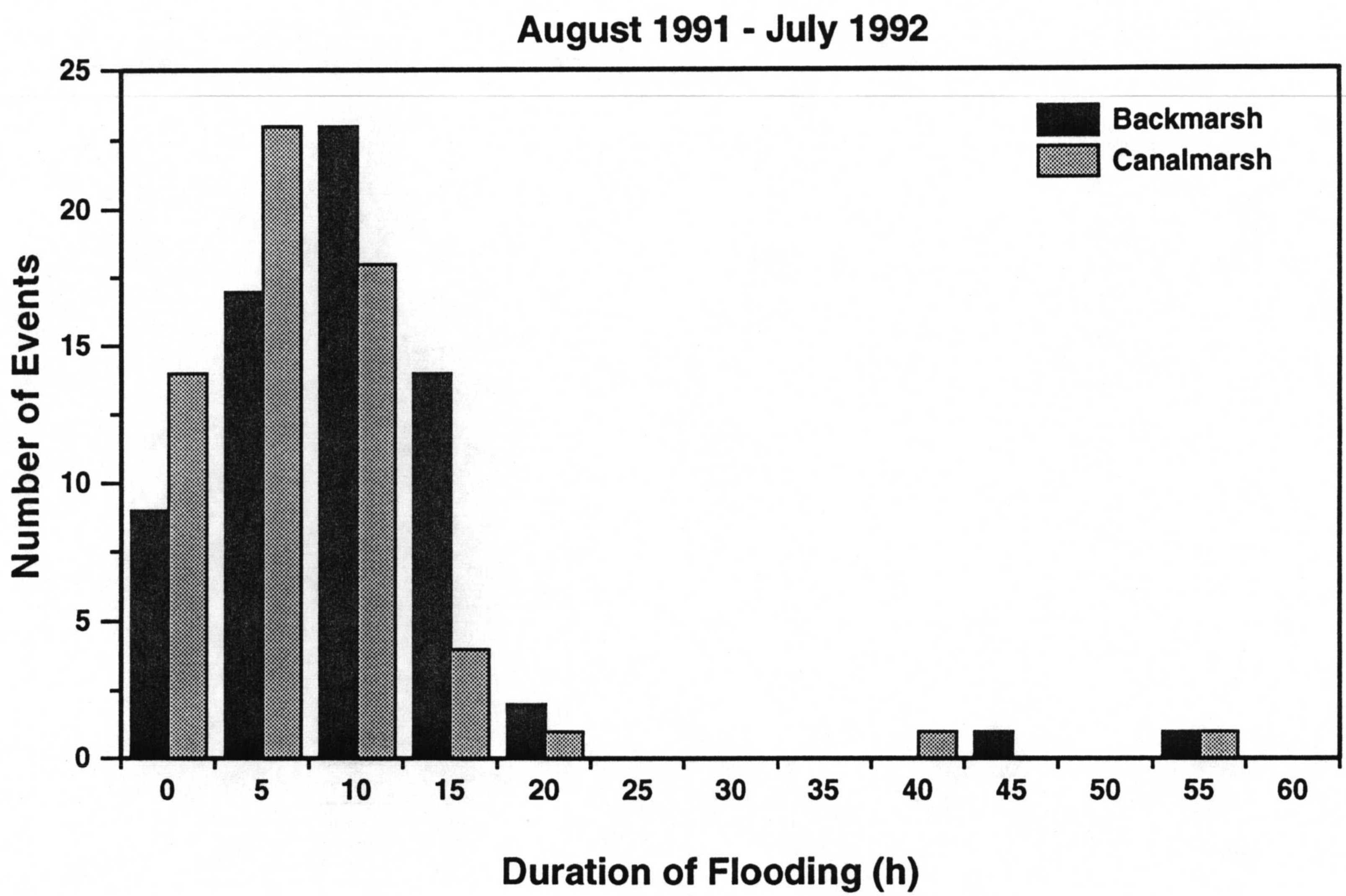

Figure 10a. Frequency distribution of flooding duration for marsh habitats.

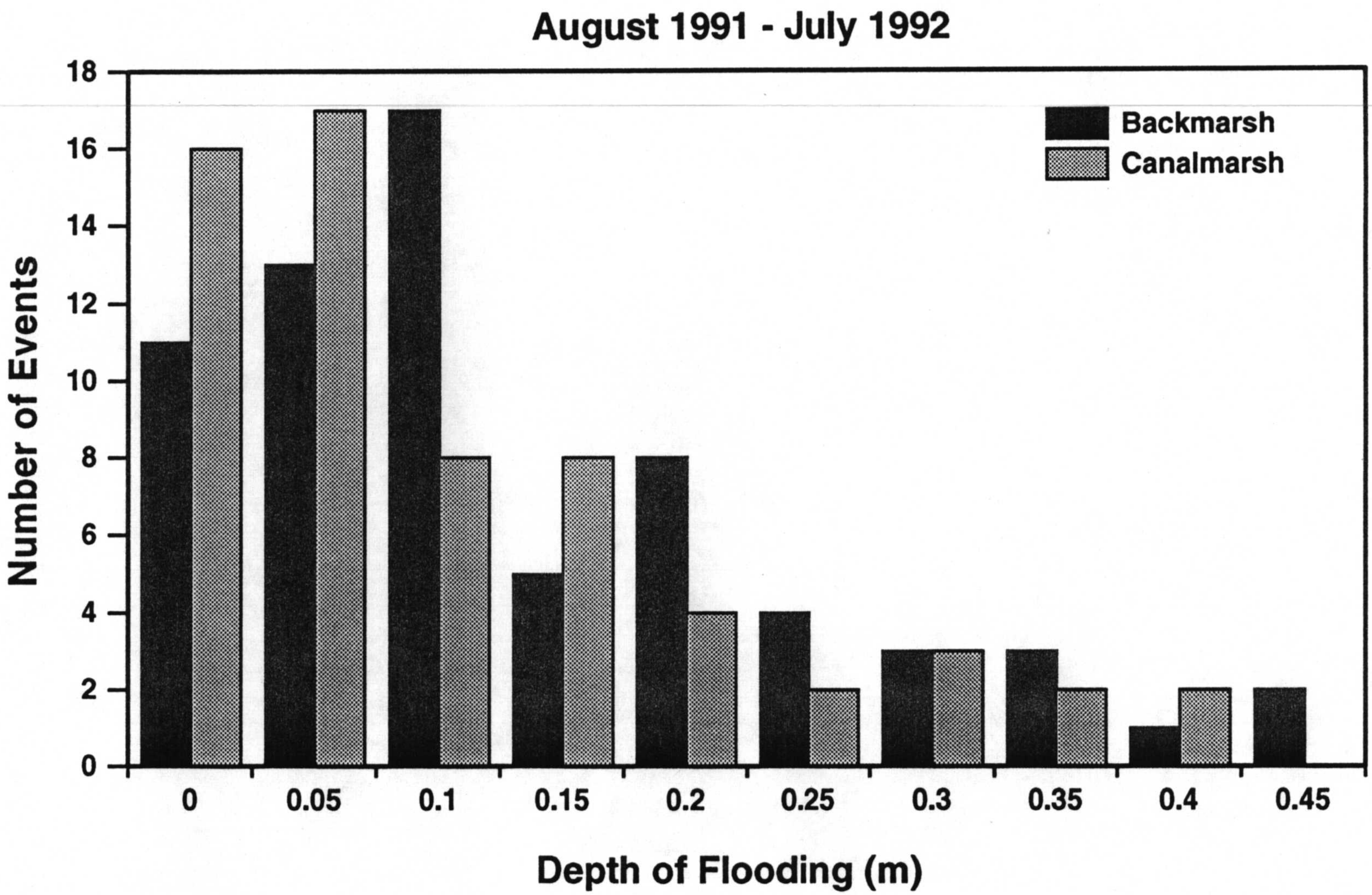

Figure 10b. Frequency distribution of flooding depth for marsh habitats.

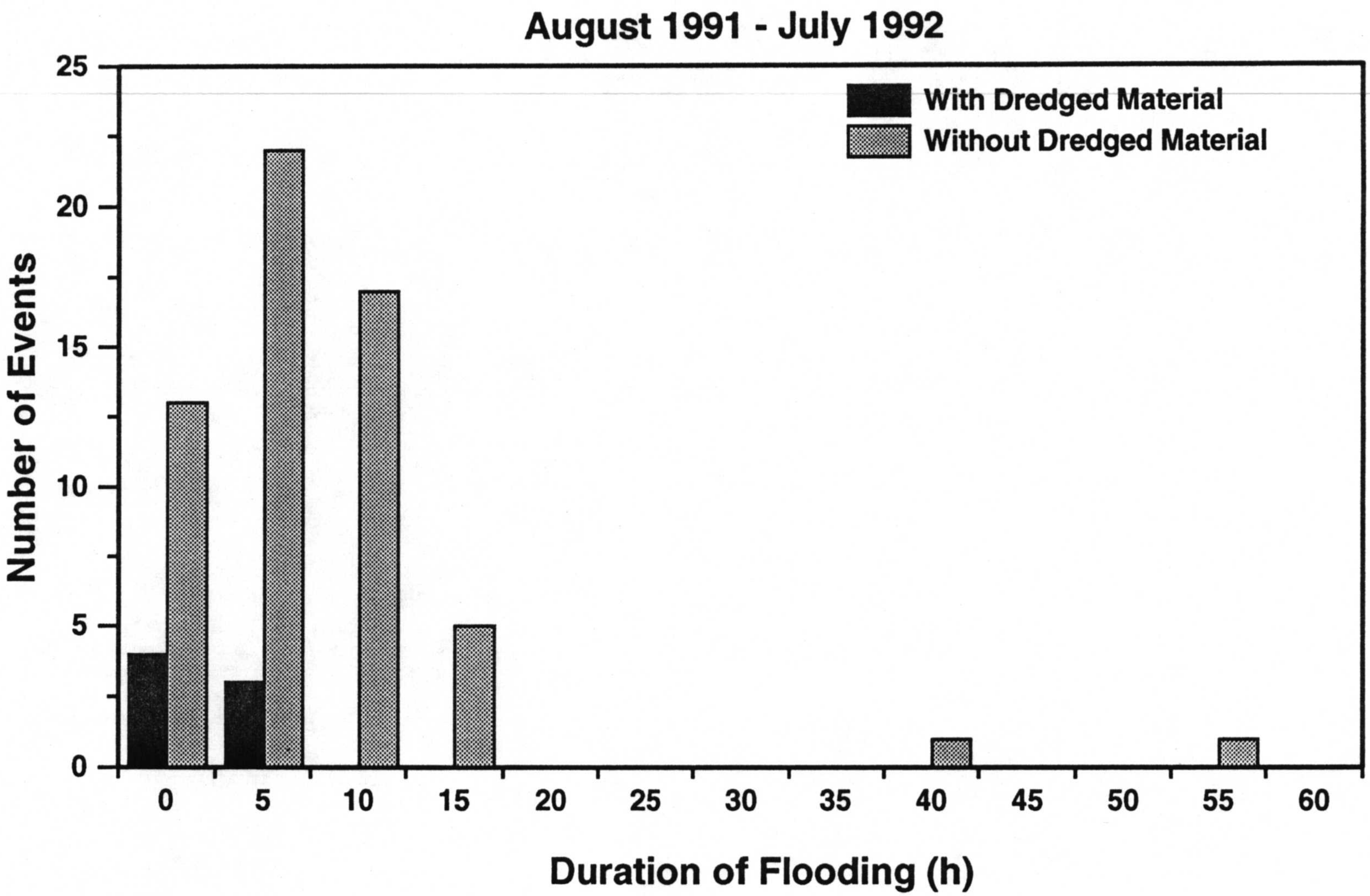

Figure 11a. Frequency distribution of flooding duration with and without levee.

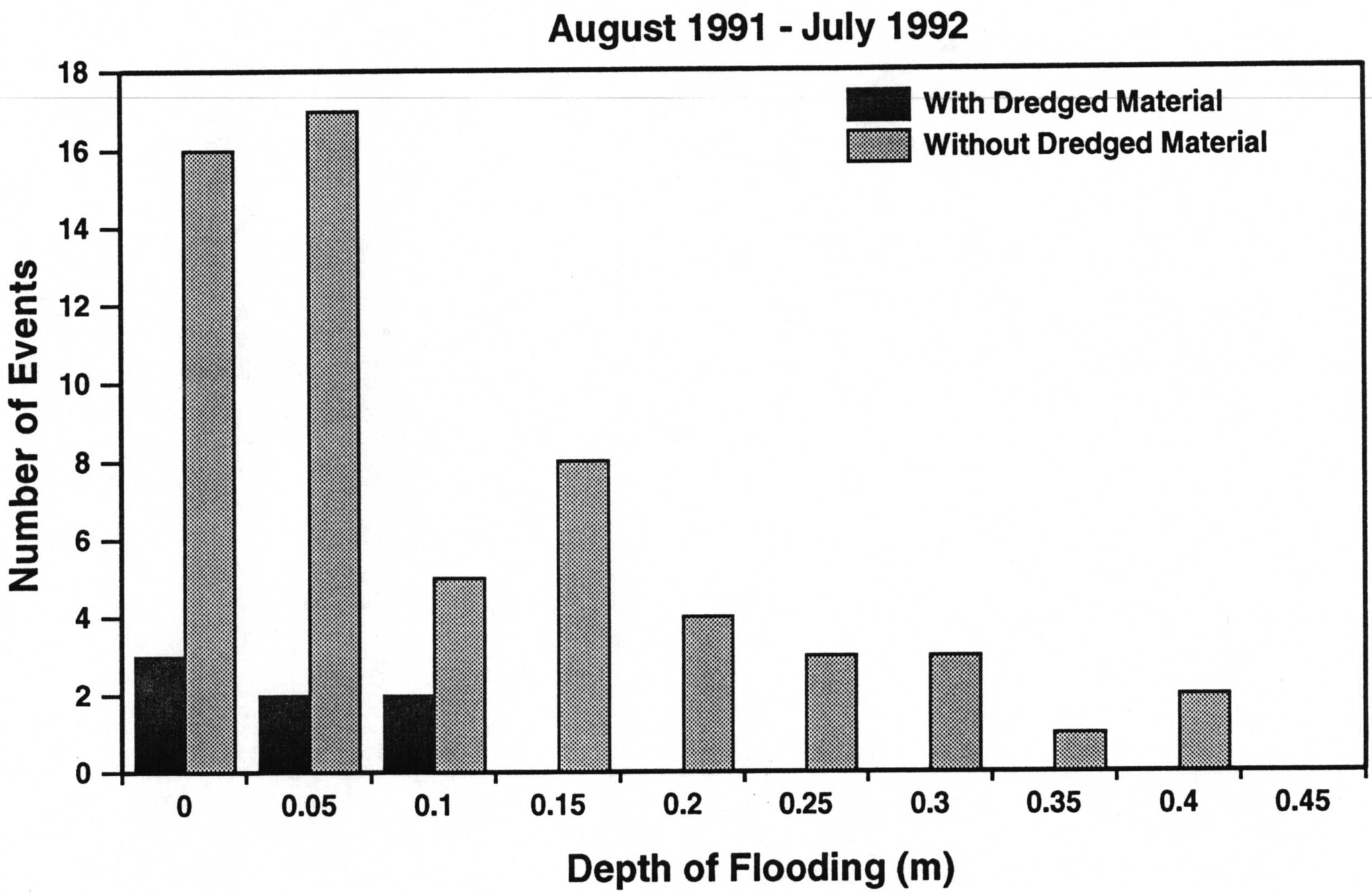

Figure 11b. Frequency distribution of flooding depth with and without levee.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.