OCS Study
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University Research Initiative

A Comparison of Shallow-Water and Marsh-Surface Habitats Associated with Pipeline Canals and Natural Channels in Louisiana Salt Marshes

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Minerals Management Service
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ABSTRACT

The degree to which fringing (inside-levee) marshes, which occur between pipeline canals and associated levees, function as nursery habitat was examined by comparing densities of nekton on marshes adjacent to pipeline canals and natural tidal creeks. In addition, shallow subtidal habitats in the two environments (canals and natural channels) were compared by sampling nekton along the marsh edge at low tide and measuring predator encounter rates in both habitats. Canals constructed using two different methods (flotation and push) were studied. Nekton was sampled approximately twice monthly between June 1990 and May 1991 on marshes using flume nets and within canals and natural channels with a small trawl pulled by hand. Predator encounter rates were estimated using tethering experiments. Daggerblade grass shrimp *Palaemonetes pugio* Holthuis, blue crabs *Callinectes sapidus* Rathbun, Gulf killifish *Fundulus grandis* Baird and Girard, diamond killifish *Adinia xenica* Jordan and Gilbert, brown shrimp *Penaeus aztecus* Ives, and sheepshead minnows *Cyprinodon variegatus* Lacepede dominated catches in terms of numbers and biomass on marshes as well as in canals and natural channels. Although densities of some species differed among the various sites that were sampled (e.g., dominant cyprinodonts were most abundant in creek tributaries), densities in canal and natural channel habitats were not significantly different. Predator encounter rates in canals and natural channels were similar, suggesting that the value of habitat in canals may increase over time as slumping decreases depth and steepness of bottom profiles and creates shallow subtidal refugia along the canal-marsh interface. The nursery function of canals open to tidal flushing is probably enhanced by the presence of fringing marshes, which provide expanded habitat for nekton at high tide.

The extent to which marsh habitat function is affected by canal levees was examined by comparing densities of nekton on marshes located behind levees (outside-levee marshes) with those on nearby marshes lacking levees. Nekton was sampled on marshes (three with levees, three without levees) six times between January and April 1992 using lift nets. Daggerblade grass shrimp, Gulf killifish, sheepshead minnows, bayou killifish *Fundulus pulvereus* (Evermann), diamond killifish, striped mullet, longnose killifish *Fundulus similis* (Baird and Girard), and blue crabs numerically dominated catches and accounted for over 99% of lift net samples. Three other species, freshwater goby *Gobionellus shufeldti* (Jordan & Eigenmann), sailfin molly *Poecilia latipinna* (Lesueur), and red drum *Sciaenops ocellatus* (Linnaeus) were rarely collected. Canal levees did not have a significant effect on the habitat function of outside-levee marshes in this study.

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INTRODUCTION

Canals are a ubiquitous feature of the Louisiana coastal zone. The average density of canals and associated dredge-material levees in coastal Louisiana is approximately 10% of the marsh area, about the same density as natural channels (Turner 1987). Most canals were constructed for navigation, to access oil and gas drilling sites, or as corridors for laying pipelines (Davis 1973). Although the impact of deep navigation channels on estuaries and coastal wetlands can be significant (Ward 1980), canals constructed for developing petroleum resources (access and pipeline canals) have had a greater direct impact on coastal wetlands in Louisiana because they are so much more numerous than navigation channels (Turner and Cahoon 1987).

Both access and pipeline canals are commonly flanked by dredge-material levees. Placement of this material alongside canals converts marsh to upland, an environment unavailable to aquatic organisms except during extreme tides. Dredge material can also form a hydrologic barrier causing ponding behind levees and limiting exchanges between canal waters and marshes to infrequent, high-water events (Swenson and Turner 1987). Such a disruption of marsh hydrology is thought to accelerate marsh erosion, i.e. the conversion of marsh to open water (Turner et al. 1982, Turner and Cahoon 1987) through flank subsidence and marsh submergence. Additionally, where canal density is high, marshes can become enclosed by levees and isolated from the rest of the estuary, resulting in a loss of habitat function for some species. Dredging also converts marshes and shallow subtidal areas to canals which may have very different physical properties than the former habitats. Newly dredged canals are typically straight, deep (2.4 m), and steep-sided (Wicker et al. 1989), whereas natural channels meander, and contain shallow sloping banks, which provide refuge and foraging areas for marsh nekton (McIvor and Odum 1988).

Adkins and Bowman (1976) found that the nekton assemblages in pipeline canals open to tidal exchange were similar in species composition to a nearby natural embayment. However, canals closed to tidal exchange had fewer species and individuals than open areas (Adkins and Bowman 1976). Similarly, Neill and Turner (1987b) found significantly lower densities of transients (species that spawn outside the estuary, but use estuarine nursery areas as postlarvae and juveniles) in closed canals tha
n open canals. However, even a small opening permitting regular tidal exchange allowed access by transient species, many of which are commercially and recreationally important (Gilmore et al. 1981, Neill and Turner 1987b).

When flooded at high tide, the vegetated marsh surface of Atlantic and Gulf of Mexico marshes provide habitat to many species of nekton (Talbot and Able 1984, Zimmerman and Minello 1984, Rozas and Odum 1987, McIvor and Odum 1988, Hettler 1989), and some species may be dependent on marsh-surface habitat to maintain high levels of productivity (Minello and Zimmerman 1991). Marsh-surface habitat associated with canals may be placed into two categories based on location relative to canal and levees. Inside-levee marsh occupies the intertidal area between the canal and associated levees. It occurs as fringing marsh in a discontinuous, narrow (<10m wide) band contiguous with the canal. Outside-levee marsh is separated from the canal by levees. Because it occurs behind canal levees, such marsh may be inaccessible to nekton residing in canals.

The primary objective of this study was to assess the effects of pipeline canals on the habitat function of inside-levee marshes. The degree to which inside-levee marshes function as nursery habitat for nekton residing in canals was examined by comparing densities of nekton on marshes adjacent to pipeline canals (inside-levee marshes) and natural tidal creeks. In addition, shallow subtidal habitats in the two environments (canals and natural channels) were compared by sampling nekton along the marsh edge at low tide and measuring predator encounter rates in both habitats. A secondary objective was to examine the extent to which marsh habitat function is effected by canal levees by comparing densities of nekton on outside-levee marshes with those on nearby marshes lacking levees.

STUDY AREA AND SAMPLE SITES

The study area was within the Terrebonne/Timbalier estuary and the Mississippi Deltaic Plain. Sample sites were near latitude 29° 14'N and longitude 90° 40'W, approximately 4 km southwest of the Louisiana Universities Marine Consortium (LUMCON) Marine Center (Fig. 1). Tides in the estuary are predominantly diurnal and have a mean range of approximately 0.4m (Shirzad et al. 1989, U.S. Department of Commerce 1990). Marshes within the study area are classified as saline (Chabreck and Linscombe 1978). Marsh vegetation was dominated by *Spartina alterniflora* Loisel, although *Spartina patens* (Aiton) Muhl. and small patches of *Juncus roemerianus* Scheele were also present. *Distichlis spicata* (L.) Greene was common on marshes of slightly higher elevation (e.g., on the natural levees of tidal creeks). Submerged aquatic vegetation, which is common in pipeline canals located in brackish marshes, was absent in canals within the study area.

MATERIALS AND METHODS

Effect of Canals on Inside-Levee Habitats. Three pipeline canals constructed using either of two methods (push or flotation) were studied to examine the effect of canals on fringing marsh habitats. The push method causes less habitat modification because it requires excavation of a relatively narrow (1.2-1.8m), shallow (2.4-3.0m) trench that is usually backfilled after pipeline installation (Tabberer et al. 1985). Because a portion of the dredge material volume is lost through compaction and organic decomposition, backfilling does not completely fill the trench, but the final depth is usually <1m (Neill and Turner 1987a, Abernethy and Gosselink 1988). The flotation method requires a canal large enough to accommodate a pipe-laying barge, 12.1-15.2m wide and 1.8-3.6m deep (Tabberer et al. 1985). Therefore, most pipeline canals constructed using the flotation method are deeper than pipeline trenches and have levees, as they are seldom backfilled.

Initially, I selected sample sites on a shallow flotation canal, a pipeline trench, a tidal creek of order 3, and three, order-2 tributaries of the tidal creek having maximum depths of approximately 1.9, 0.8, 1.8, 0.8, 0.4, and 0.8m, respectively. Each of the four channel types contained three sampling sites (Fig. 1). For general characteristics of tidal creeks related to stream order, see Odum (1984). In January 1991 I added sample sites on a deep (3.6m) flotation canal, and discontinued flume sampling of order-2 creeks; however, trawl collections were continued at these sites. All study canals were open to tidal exchange. Henceforth, the flotation canals will be referred to as shallow or deep canals, the pipeline trench as trench, the order-3 tidal creek as tidal creek, and the order-2 tidal creeks as creek tributaries.

Water temperature and salinity were monitored at each sample site (at high tide when flumes were sampled and at low tide when trawling) with a Beckman RS-5 salinometer, except June-August 1990 when a YSI Model 33 S-C-T meter was used. Nekton was sampled on marshes and in channels along the marsh edge at each site using flumes (McIvor and Odum 1986) and a small trawl, respectively. Flumes were similar to those described by Rozas and Odum (1987), except wider (2m vs. 1.5m), and walls were constructed of plastic rather than nylon netting. Flume length was 20m, except along canals where the length of each flume was equal to the marsh width (5-8m). The procedure for sampling flumes was similar to that described by Rozas and Odum (1987), except end nets were deployed from a remote location as follows. No fewer than 3 hours prior to sampling, each flume end net was positioned above the flume entrance and held in place by small wooden pegs inserted into holes drilled into end posts. A nylon cord was tied to each peg

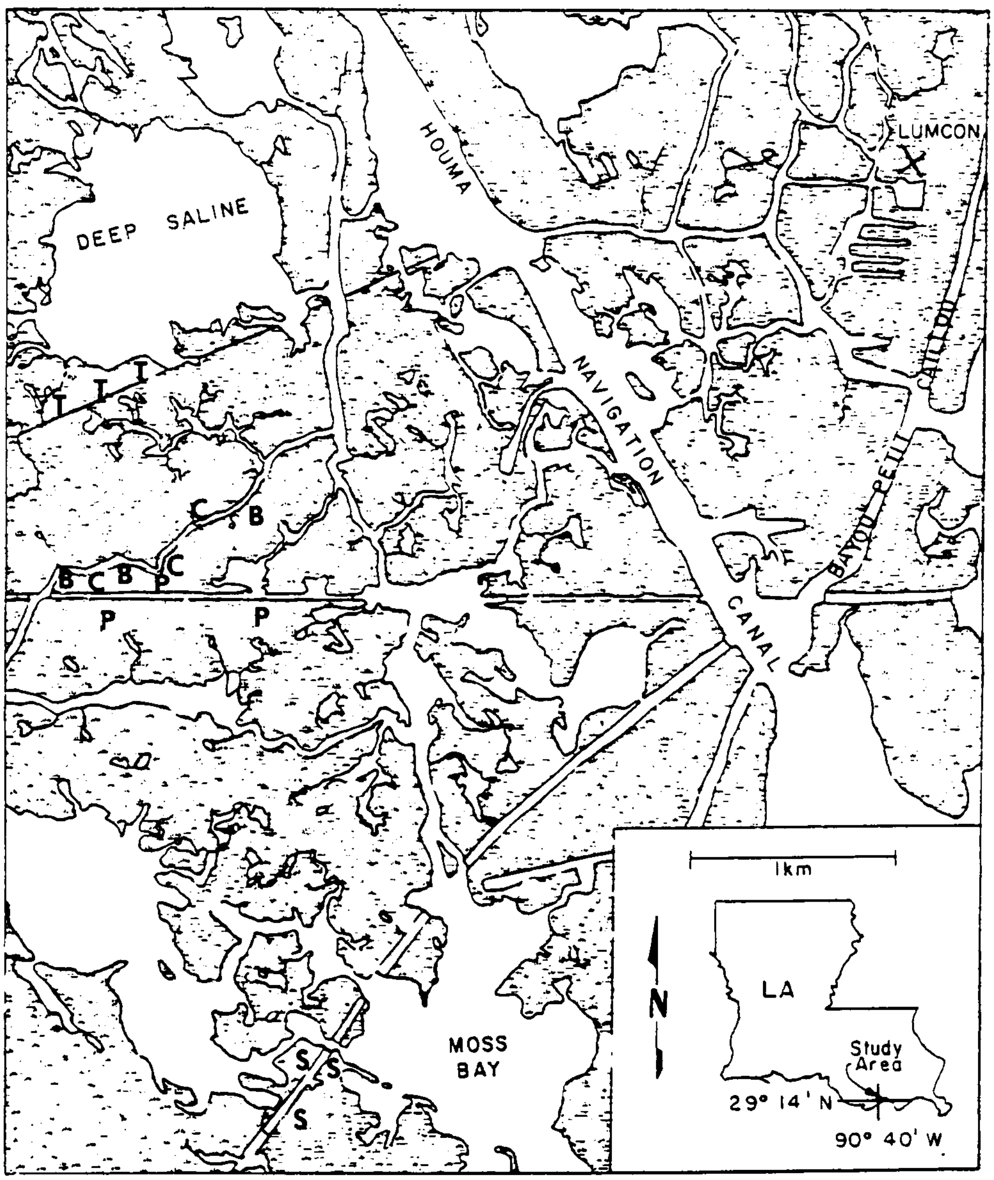

Figure 1. Locator map showing study area and sampling sites on trench (T), tidal creek (B), tributaries (C), shallow canal (P), and deep canal (S). Inset shows location of study area relative to Louisiana.

and a small wooden post 5m away. At high tide the pegs were pulled out, and the end net dropped into place, blocking the flume entrance.

Samples of the entire water column along the marsh edge were taken in tidal creeks, the trench, and canals using a trawl pulled by hand (Rogers 1989). The trawl was constructed of 3-mm mesh nylon netting attached to an aluminum frame (1m wide x 0.6m high) and mounted on aluminum skids to allow sampling over soft sediments. Trawl tows of 15-m were made near each flume site during daylight when the marsh surface was not flooded. At each sample site, the trawl with a 16-m rope attached was carefully place in shallow water near the marsh edge. With one end of the rope in hand and traveling over the marsh to avoid disturbing the sample area, one person walked 15m from the trawl and quietly entered the shallow water at the edge of the channel. The trawl was then pulled along the marsh with the rope. At the end of the tow, the trawl and its contents were quickly removed from the water.

Samples were collected approximately twice monthly from June 1990 through May 1991 for a total of 25 flume- and 23 trawl-sampling events at each site. The contents of each sample were preserved in 20% formalin for at least 72h, washed in running water for 24h, 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 0.1g.

Tethering experiments were conducted to compare predator encounter rates in canals and natural channels (Heck and Thoman 1981, McIvor and Odum 1988, Rozas and Odum 1988). Gulf killifish (*Fundulus grandis* Baird and Girard, 38-90 mm, x= 56 mm S.L.) were used in these experiments because they were numerically dominant in the study area, easily captured, and tethering had little observed effect on their swimming behavior. Fish were collected in baited minnow traps and held overnight in aerated laboratory holding tanks. A tether of thin monofilament fishing line (2.7 kg test, 0.3 mm diameter, 1.0 m long) tied to a small split ring was attached to the lower jaw of each fish. I tethered fish at least 2m apart and 2m from shore by sliding the split ring over heavy monofilament line (9.1 kg test, 0.5 mm diameter) held vertically in the water column by a 111 g pyramid sinker and a fishing float attached to opposite ends. This procedure allowed fish to swim freely in any direction, constrained only by the length of the tether. However, the short tethers prevented fish from reaching emergent vegetation or hiding beneath overhanging vegetation at the marsh edge. Fish were tethered for approximately 2 hours on ebbing tides beginning shortly after the marsh surface had drained. Experiments were conducted in two study canals on two occasions in July 1991. In each experiment ten fish were tethered in each of three segments of a canal and in three nearby natural channels of similar width, for a total of 60 fish.

Because each subject (marsh or shallow water site) was sampled under all treatments and sampled repeatedly over time, I used a multivariate approach to repeated measures analysis of variance to test for differences in salinity and catches (number of individuals) among habitats (O'Brien and Kaiser 1985, Norusis 1990). Salinity data were pooled within each sampling period (Summer-Fall 1990 and Winter-Spring 1991) and analysed separately by period. I analysed catch data for the six numerically dominant species separately by period and sampling method (flume or trawl). When significant results were found among treatments, the data were analysed with a posteriori contrasts (Norusis 1990). To correct for the error introduced by making multiple statistical comparisons, the significance levels (0.10 for a posteriori contrasts and 0.05 for all other analyses) were adjusted using the method described by Rice (1989). Catch data were ln(x+1)-transformed prior to analyses in order to meet the multivariate analysis of variance (MANOVA) assumption of homogeneity of variances (Green 1979). I used a paired t-test to compare predator encounter rates (i.e., number of missing killifish) in canals and natural channels.

Effect of Levees on Outside-Levee Marsh Habitat. In December 1991, two sample sites were selected on each of three segments of the shallow canal to examine the effect of canal levees on marsh habitat. Each segment contained a continuous levee on only one side of the canal. On each canal segment one site was located behind the canal levee and the other site was placed within a portion of the segment that lacked a levee. Sample sites on the same pipeline segment were placed at an approximately equal distance from the canal (range of distances for the three segments=17-25m) and at the same marsh-surface elevation.

Nekton was sampled at each marsh site using lift nets (Rozas 1992). Briefly, lift nets (2m x 3m x 1m deep) were bottomless with walls constructed of 3-mm mesh nylon netting. Between sampling events the net walls were buried in the marsh substrate. To collect a sample at slack high tide, two persons simultaneously pulled the net walls into their upright position from remote locations, trapping organisms inside the enclosed area. As the marsh drained, organisms accumulated in a collecting pan located in one corner of each sampling area. Samples were retrieved at low tide by temporarily removing each collecting pan and placing its contents into a sample bag. Nekton was collected on m
arshes six times from January through April 1992: once in January and March, and twice in February and April. Sampling occurred on tropical tides (highest tides each month) to insure that marshes were flooded. Samples were preserved and processed as described above.

We used a sampling design in which each subject marsh was sampled repeatedly over time under both treatments (levee and no levee). Therefore, we used a multivariate approach to repeated measures analysis of variance to test for differences in catches (number of individuals) of numerically dominant species among treatments. To correct for the error introduced by making multiple statistical comparisons, the significance level (0.05) was adjusted using the method of Rice (1989). Catch data were ln (x+1)-transformed prior to analyses to meet the MANOVA assumption of homogeneity of variances.

RESULTS

Effect of Canals on Inside-Levee Habitats. Average water temperatures ranged from a high of 31.3 °C in August 1990 to a low of 13.5 °C in January 1991 (Fig. 2). Salinities generally increased from north to south across the study area, and one could usually observe a salinity gradient of 2-5 o/oo between the trench and deep canal. Mean salinities during the study ranged from 1.6 o/oo at the trench in February to 21.4 o/oo in the shallow canal in November (Fig. 2). Differences in salinities among habitats were statistically significant during both sampling periods ($p<0.0005$).

A total of 236,508 organisms having a preserved wet weight of 114.7 kg was collected during the study (300 flume and 303 trawl samples). Forty-one species (22 families) of fishes and four species (3 families) of decapod crustaceans were identified from these samples (Table 1). Daggerblade grass shrimp, blue crabs (*Callinectes sapidus* Rathbun), Gulf killifish, diamond killifish (*Adinia xenica* Jordan and Gilbert), brown shrimp (*Penaeus aztecus* Ives), and sheepshead minnows (*Cyprinodon variegatus* Lacepede) numerically dominated catches (Table 1) and accounted for over 95% of both flume and trawl samples. These species dominated catches in terms of biomass as well, representing > 92% of the total biomass. Striped mullet (*Mugil cephalus* Linnaeus) was the only other species that contributed substantially to total biomass (Table 1).

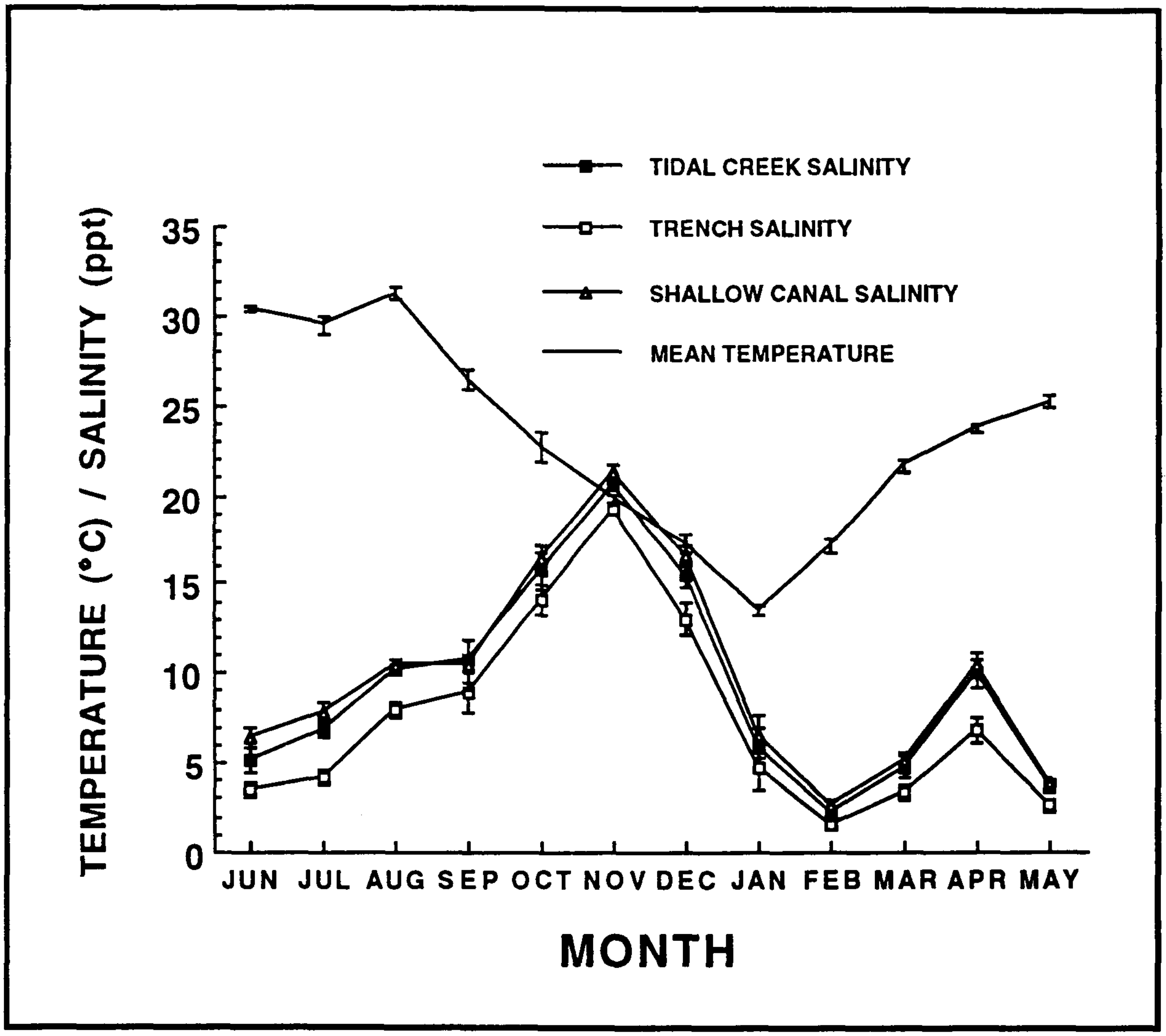

Figure 2. Average monthly temperature (all sample sites combined) and mean monthly salinity for sites on tidal creek, trench, and shallow canal from June 1990 through May 1991. Error bars equal one standard error.

Table 1. List of fishes and decapod crustaceans collected on the marsh surface and in adjacent water bodies using flumes and trawls, respectively. The total catch (number of individuals) and total biomass (g preserved wet weight) are given for each species. Relative abundance (RA=% total number) and relative biomass (RB=% total biomass) are given only when they are equal to at least 1%.

Scientific and Common Name	Flume Catch	Trawl Catch	RA	Flume Biom.	Trawl Biom.	RB
Palaemonetes pugio (Holthuis) Daggerblade grass shrimp	49,307	144,187	81.8	8,754.3	20,968.2	25.9
Callinectes sapidus (Rathbun) blue crab	4,582	3,462	3.4	33,585.4	14,918.9	42.3
Fundulus grandis (Baird and Girard) Gulf killifish	3,501	5,229	3.7	8859.2	6568.1	13.5
Adinia xenica (Jordan and Gilbert) diamond killifish	2,099	6,538	3.7	678.5	2495.7	2.8
Penaeus aztecus Ives brown shrimp	1,626	1,979	1.5	1484.3	1579.9	2.7
Cyprinodon variegatus (Lacepede) sheepshead minnow	969	2,609	1.5	1096.7	4705.6	5.1
Gobiosoma bosc (Lacepede) naked goby	381	695	--	168.6	210.8	--
Penaeus setiferus (Linnaeus) white shrimp	247	1,429	--	224.4	576.8	--
Menidia beryllina (Cope) inland silverside	244	1,097	--	162.3	820.9	--
Brevoortia patronus (Goode) Gulf menhaden	226	841	--	25.4	76.7	--
Bairdiella chrysoura (Lacepede) silver perch	197	250	--	65.9	67.7	--
Fundulus pulvereus (Evermann) bayou killifish	196	172	--	119.3	97.7	--
Poecilia latipinna (Lesueur) sailfin molly	192	325	--	168.0	236.6	--
Mugil cephalus (Linnaeus) striped mullet	184	1,108	--	3029.5	497.5	3.1
Fundulus jenkinsi (Evermann) saltmarsh topminnow	158	164	--	80.4	75.2	--
Anchoa mitchilli (Valenciennes) bay anchovy	120	1,230	--	38.6	190.5	--
Cynoscion nebulosus (Cuvier) spotted seatrout	89	80	--	290.1	58.2	--
Lagodon rhomboides (Linnaeus) pinfish	84	126	--	118.9	112.9	--
Dormitator maculatus (Bloch) fat sleeper	57	4	--	253.7	63.2	--
Fundulus similis (Baird and Girard) longnose killifish	31	36	--	87.3	66.1	--

Table 1. List of fishes and decapod crustaceans collected on the marsh surface and in adjacent water bodies using flumes and trawls, respectively (continued).

Scientific and Common Name	Flume Catch	Trawl Catch	RA	Flume Biom.	Trawl Biom.	RB
Lucania parva (Baird) rainwater killifish	28	16	--	11.4	7.4	--
Gobionellus shufeldti (Jordan & Eigenmann) freshwater goby	22	26	--	10.4	4.4	--
Paralichthys lethostigma Jordan and Gilbert southern flounder	10	5	--	230.6	33.3	--
Leiostomus xanthurus Lacepede spot	7	97	--	32.8	194.2	--
Sciaenops ocellatus (Linnaeus) red drum	7	66	--	233.6	18.9	--
Archosargus probatocephalus (Walbaum) sheepshead	7	4	--	3.2	1.4	--
Myrophis punctatus Lutken speckled worm eel	7	1	--	49.4	5.3	--
Symphurus plagiusa (Linnaeus) blackcheek tonguefish	6	12	--	36.5	10.5	--
Citharichthys spilopterus Gunther bay whiff	6	10	--	18.7	14.4	--
Achirus lineatus (Linnaeus) lined sole	4	34	--	6.3	28.4	--
Evorthodus lyricus (Girard) lyre goby	4	0	--	16.8	0.0	--
Syngnathus scovelli (Evermann & Kendall) Gulf pipefish	2	11	--	0.9	6.4	--
Micropogonias undulatus (Linnaeus) Atlantic croaker	2	1	--	0.8	0.3	--
Pogonias cromis (Linnaeus) black drum	2	0	--	0.1	0.0	--
Syngnathus louisianae Gunther chain pipefish	1	3	--	0.9	1.6	--
Elops saurus Linnaeus ladyfish	1	2	--	0.1	0.3	--
Opsanus beta (Goode and Bean) Gulf toadfish	1	0	--	<0.1	0.0	--
Eleotris pisonis (Gmelin) spinycheek sleeper	1	0	--	7.7	0.0	--
Cynoscion arenarius Ginsburg sand seatrout	0	2	--	0.0	2.1	--
Pomatomus saltatrix (Linnaeus) bluefish	0	2	--	0.0	0.5	--
Sphoeroides parvus Shipp and Yerger least puffer	0	2	--	0.0	2.1	--

Table 1. List of fishes and decapod crustaceans collected on the marsh surface and in adjacent water bodies using flumes and trawls, respectively (continued).

Scientific and Common Name	Flume Catch	Trawl Catch	RA	Flume Biom.	Trawl Biom.	RB
Strongylura marina (Walbaum) Atlantic needlefish	0	2	--	0.0	1.8	--
Eucinostomus argenteus Baird spotfin mojarra	0	1	--	0.0	0.1	--
Gambusia affinis (Baird and Girard) mosquitofish	0	1	--	0.0	<0.1	--
Synodus foetens (Linnaeus) inshore lizardfish	0	1	--	0.0	0.2	--
Totals	64,608	171,860	95.6	59,951.0	54,720.7	95.4

Average catches of several abundant species differed with respect to habitat, sampling method, and study period (Tables 2 and 3). The mean number of Gulf killifish and brown shrimp collected was significantly different among habitats sampled during Summer-fall 1990 (Table 4). Greatest catches of Gulf killifish were taken in tributary creeks, and fewer brown shrimp were collected on marshes adjacent to tributaries than in other marsh habitats (Tables 2, 4, and 5). Although not statistically significant, catches of diamond killifish and sheepshead minnows also exhibited a strong trend toward greatest numbers in tributary creeks.
In the winter-spring period catches of daggerblade grass shrimp, Gulf killifish, diamond killifish, and sheepshead minnows were significantly different among habitats sampled (Tables 3, 5, and 6). Sheepshead minnows were collected in greatest numbers on marshes adjacent to the trench. Gulf and diamond killifishes were most abundant in trawl samples from tributary creeks. The average catch of sheepshead minnows was significantly less in the large canal than in the tidal creek, its tributaries, or the trench, but was not statistically different than that from the small canal. Grass shrimp were most abundant in trawl samples from the large canal.

Although average water depth along the marsh edge was greater in canals than in nearby natural channels (deep canal=69 cm, shallow canal=54 cm, natural channels=38 cm), predator encounter rates in the two habitats were similar ($T=0.20$, $p \leq 0.425$). Percentages of fish missing at the end of experiments were 0-50%, 60-100%, and 20-100% in shallow canal, deep cana
l, and natural channels, respectively.

Effect of Levees on Outside-Levee Marsh Habitat. Daggerblade grass shrimp, Gulf killifish, sheepshead minnows, bayou killifish *Fundulus pulvereus* (Evermann), diamond killifish, striped mullet, longnose killifish *Fundulus similis* (Baird and Girard), and blue crabs numerically dominated catches and accounted for over 99% of lift net samples. Three other species, freshwater goby *Gobionellus shufeldti* (Jordan & Eigenmann), sailfin molly *Poecilia latipinna* (Lesueur), and red drum *Sciaenops ocellatus* (Linnaeus) were rarely collected. Average catches of numerically dominant species collected on outside-levee marshes were not significantly different from those taken on marshes lacking levees (Table 7).

DISCUSSION

Nekton assemblages and densities of dominant species in channel-edge and adjacent marsh habitats of canals and natural channels were remarkably similar. Although there were differences in densities of some species among the various sites sampled, no clear differences emerged between natural habitats and those associated with canals. Nekton occupied narrow strips of marsh along canals at high tide in densities similar to those found on natural marshes.

Although narrow fringing marshes along canals open to tidal flow represent a very small portion of the total canal area, they are undoubtedly important habitat for nekton at high tide. These inside-levee marshes may be particularly important where canal levees block access to most surrounding marshes (outside-levee marshes). In such canals where fringing marshes have been eroded back to levees by boat traffic or where marsh-surface habitat is otherwise unavailable to nekton, habitat function is likely diminished for some species even when the canals are open to tidal exchange and use by transient species. For example, brown shrimp, a commercially important transient species, require marsh-surface habitat to maintain rapid growth (Minello and Zimmerman 1991). Other species collected on marshes in the present study may be similarly dependent on marsh-surface habitat.

Because pipeline canals are designed with steep banks (Wicker et al. 1989), I expected higher predation rates there than in natural channels (McIvor and Odum 1988). However, predator

Table 2. Comparisons of average catches (number of individuals) of numerically dominant species among different habitats in Summer-Fall (June-December 1990). Means ± standard errors are listed for both flume and trawl collections. TC=tidal creek, CT=creek tributaries, T=pipeline trench, SC=shallow pipeline canal. n.d.=no data, --- = value <0.05. Number of samples=45 (flume) and 42 (trawl): n=42.

Species	Sampling Device	TC	CT	T	SC
Daggerblade grass shrimp	Flume	81.8 ±13.4	53.0 ± 10.0	113.1 ±19.0	193.4 ±24.9
	Trawl	336.4 ±65.6	1,021.5 ±295.6	225.1 ±93.9	565.2 ±121.7
Blue crab	Flume	15.6 ±1.4	8.2 ±1.0	12.5 ±1.3	18.4 ±1.4
	Trawl	17.6 ±2.8	15.4 ±2.0	14.9 ±2.2	14.4 ±2.5
Gulf killifish	Flume	12.3 ±1.8	16.3 ±1.6	23.6 ±2.3	11.9 ±2.3
	Trawl	22.9 ±7.0	62.9 ±16.2	15.1 ±3.4	4.0 ±2.1
Diamond killifish	Flume	2.5 ±0.9	7.7 ±2.5	5.4 ±1.5	26.1 ±10.6
	Trawl	3.0 ±1.0	39.9 ±18.7	1.8 ±0.7	12.6 ±9.8
Brown shrimp	Flume	1.1 ±0.2	0.4 ±0.2	1.9 ±0.6	2.7 ±0.5
	Trawl	10.5 ±2.0	2.4 ±0.6	5.1 ±1.0	7.4 ±0.7
Sheepshead minnow	Flume	0.6 ±0.2	8.5 ±2.4	5.4 ±1.5	1.6 ±1.3
	Trawl	1.0 ±0.4	28.3 ±6.9	9.4 ±3.1	1.1 ±0.7
Naked goby	Flume	1.2 ±0.4	—	—	1.7 ±0.3
	Trawl	3.0 ±0.9	0.1 ±0.1	—	3.3 ±1.0
White shrimp	Flume	0.8 ±0.3	0.6 ±0.3	1.2 ±0.6	2.8 ±0.8
	Trawl	4.0 ±0.8	8.0 ±2.9	15.3 ±3.7	6.7 ±1.6
Inland silverside	Flume	0.5 ±0.3	0.8 ±0.3	2.4 ±0.6	0.3 ±0.3
	Trawl	5.5 ±2.8	9.6 ±4.3	5.9 ±1.4	2.7 ±1.0
Gulf menhaden	Flume	0.0	0.0	0.0	0.0
	Trawl	—	0.0	0.5 ±0.2	1.4 ±1.0
Silver perch	Flume	0.2 ±0.2	0.0	0.0	0.9 ±0.6
	Trawl	0.5 ±0.2	0.1 ±0.1	—	1.0 ±0.5
Bayou killifish	Flume	0.2 ±0.1	0.5 ±0.2	0.6 ±0.2	2.8 ±1.2
	Trawl	0.1 ±0.1	0.6 ±0.3	0.1 ± —	—
Sailfin molly	Flume	0.1 ±0.1	0.7 ±0.3	0.3 ±0.1	0.9 ±0.3
	Trawl	0.2 ±0.1	1.7 ±0.6	—	1.7 ±1.1
Striped mullet	Flume	—	0.6 ±0.2	1.0 ±0.4	0.2 ±0.1
	Trawl	0.1 ±0.1	0.3 ±0.2	—	0.0

Table 3. Comparisons of average catches (number of individuals) of numerically dominant species among different habitats in Winter-Spring (January-May 1991). Means ± standard errors are listed for both flume and trawl collections. TC=tidal creek, CT=creek tributaries, T=pipeline trench, SC=shallow pipeline canal, DC=deep pipeline canal. n.d.=no data, --- = value <0.05. Number of samples=30 (flume) and 27 (trawl).

Species	Sampling Device	TC	CT	T	SC	DC
Daggerblade grass shrimp	Flume	167.0 ±28.6	n.d.	142.5 ±16.3	207.1 ±35.3	465.0 ±70.1
	Trawl	134.7 ±26.5	205.0 ±76.9	166.3 ±42.8	353.1 ±70.2	1,156.4 ±166.3
Blue crab	Flume	19.8 ±2.3	n.d.	15.3 ±3.1	17.0 ±1.7	18.2 ±2.3
	Trawl	6.2 ±1.5	3.9 ± 0.9	4.6 ±1.0	4.9 ±0.9	11.6 ±3.5
Gulf killifish	Flume	4.2 ±0.8	n.d.	7.4 ±1.1	7.3 ±2.6	2.9 ±0.8
	Trawl	3.6 ±0.9	19.7 ±6.1	2.6 ±0.7	4.0 ±0.9	2.8 ±0.8
Diamond killifish	Flume	0.8 ±0.2	n.d.	1.3 ±0.3	3.6 ±1.3	1.7 ±0.7
	Trawl	7.5 ±1.8	107.5 ±41.5	11.1 ±3.3	19.5 ±11.3	8.3 ±3.2
Brown shrimp	Flume	12.4 ±4.6	n.d.	11.0 ±4.0	9.5 ±2.6	12.2 ±3.8
	Trawl	8.7 ±3.2	3.5 ±1.7	8.1 ±2.9	5.2 ±2.0	7.8 ±3.1
Sheepshead minnow	Flume	1.2 ±0.3	n.d.	5.9 ±1.0	0.6 ±0.2	0.2 ±0.1
	Trawl	3.9 ±1.7	20.7 ±7.1	9.5 ±2.2	1.6 ±0.6	0.1 ±0.1
Naked goby	Flume	1.2 ±0.5	n.d.	0.4 ±0.3	0.8 ±0.3	5.9 ±1.3
	Trawl	1.2 ±0.6	—	—	1.5 ±0.8	12.7 ±4.0
White shrimp	Flume	0.0	n.d.	0.0	0.0	0.0
	Trawl	0.0	0.0	0.0	0.0	—
Inland silverside	Flume	0.4 ±0.3	n.d.	1.2 ±0.5	0.2 ±0.1	0.2 ±0.2
	Trawl	0.8 ±0.4	1.7 ±1.0	0.7 ±0.2	0.2 ±0.1	0.6 ±0.2
Gulf menhaden	Flume	0.1 ±0.1	n.d.	5.4 ±4.0	0.0	2.0 ±1.9
	Trawl	1.5 ±0.8	3.4 ±1.9	8.1 ±3.0	2.6 ±0.6	12.6 ±7.2
Silver perch	Flume	0.3 ±0.1	n.d.	0.8 ±0.3	1.9 ±0.8	2.0 ±0.8
	Trawl	2.1 ±1.8	2.1 ±1.9	0.2 ±0.1	0.9 ±0.5	1.6 ±1.0
Bayou killifish	Flume	0.1 ±0.1	n.d.	—	0.3 ±0.1	—
	Trawl	0.2 ±0.1	1.1 ±0.5	0.0	3.8 ±3.6	—
Sailfin molly	Flume	0.1 ± ---	n.d.	0.0	0.2 ±0.1	3.1 ±1.2
	Trawl	0.1 ±0.1	0.6 ±0.3	—	1.0 ±0.6	4.8 ±1.7
Striped mullet	Flume	0.1 ±0.1	n.d.	3.0 ±1.0	0.3 ±0.1	0.1 ±0.1

Table 4. Results of the MANOVA tests of differences in catch among habitats for the Summer-Fall 1990 sampling period. *=significant result (adjusted $p<0.05$). d.f. = degrees of freedom, F = F value or F ratio, p = Significance of F.

Species	Sampling Device	d.f.	F	p
Daggerblade Grass shrimp	Flume	3,6	3.14	0.108
	Trawl	3,6	6.50	0.026
Blue crab	Flume	3,6	6.33	0.027
	Trawl	3,6	0.21	0.885
Gulf killifish	Flume	3,6	5.30	0.040
	Trawl	3,6	11.32	0.007 *
Diamond killifish	Flume	3,6	3.73	0.080
	Trawl	3,6	9.25	0.011
Brown shrimp	Flume	3,6	14.82	0.004 *
	Trawl	3,6	2.75	0.135
Sheepshead minnow	Flume	3,6	2.55	0.152
	Trawl	3,6	7.67	0.018

Table 5. Results of the MANOVA a posteriori contrasts of mean catches among specific habitats. *=significant result (adjusted $p<0.10$). d.f. = degrees of freedom, F = F value or F ratio, p = Significance of F. TC=tidal creek, CT=creek tributaries, T=pipeline trench, SC=shallow pipeline canal.

Species	Sampling Device	Contrast	d.f.	F	p
Summer-Fall 1990					
Gulf killifish	Trawl	CT vs SC	2,1	56.08	0.017 *
		CT vs TC	2,1	39.06	0.025 *
		CT vs T	2,1	10.89	0.081 *
Brown shrimp	Flume	CT vs TC	2,1	99.39	0.010 *
		CT vs SC	2,1	35.92	0.027 *
		CT vs T	2,1	17.98	0.051 *
Winter-Spring 1991					
Daggerblade Grass shrimp	Trawl	DC vs T	2,1	100.19	0.010 *
		DC vs CT	2,1	45.00	0.022 *
		DC vs TC	2,1	20.45	0.046 *
		DC vs SC	2,1	10.38	0.084 *
Gulf killifish	Trawl	CT vs TC	2,1	5967.94	0.000 *
		CT vs DC	2,1	34.29	0.028 *
		CT vs T	2,1	7.69	0.109
		CT vs SC	2,1	6.68	0.123
Diamond killifish	Trawl	CT vs TC	2,1	135.13	0.007 *
		CT vs DC	2,1	13.54	0.067
		CT vs SC	2,1	8.38	0.102
		CT vs T	2,1	5.86	0.136
Sheepshead minnow	Flume	T vs DC	2,1	219.53	0.005 *
		T vs TC	2,1	165.21	0.006 *
		T vs SC	2,1	105.71	0.009 *
	Trawl	T vs DC	2,1	220.48	0.005 *
		TC vs DC	2,1	192.99	0.005 *
		CT vs DC	2,1	30.16	0.032 *
		SC vs DC	2,1	5.05	0.154

Table 6. Results of the MANOVA tests of differences in catch among habitats for the Winter-Spring 1991 sampling period. *=significant result (adjusted $p<0.05$). d.f. = degrees of freedom, F = F value or F ratio, p = Significance of F.

Species	Sampling Device	d.f.	F	p
Daggerblade grass shrimp	Flume	3,6	8.50	0.014
	Trawl	4,8	14.63	0.001 *
Blue crab	Flume	3,6	4.03	0.069
	Trawl	4,8	0.21	0.885
Gulf killifish	Flume	3,6	3.73	0.080
	Trawl	4,8	6.50	0.012 *
Diamond killifish	Flume	3,6	1.18	0.392
	Trawl	4,8	6.50	0.012 *
Brown shrimp	Flume	3,6	0.63	0.625
	Trawl	4,8	1.59	0.268
Sheepshead minnow	Flume	3,6	60.28	0.000 *
	Trawl	4,8	15.42	0.001 *

Table 7. List of numerically abundant fishes and decapod crustaceans collected on the marsh surface at sites along shallow canal. The average number (±1 S.E.) of individuals collected at each treatment (levee present, levee absent) and the results of the MANOVA tests of differences between treatments are given for each species. d.f. = degrees of freedom, F = F value or F ratio, p = Significance of F.

Species	Levee Present	Levee Absent	d.f.	F	p
Daggerblade grass shrimp	8.6±3.9	7.2±4.0	1,2	0.39	0.598
Gulf killifish	8.4±10.2	0.8±0.3	1,2	5.36	0.147
Sheepshead minnow	4.1±2.4	0.1±0.1	1,2	5.40	0.146
Bayou killifish	2.2±0.7	0.8±0.7	1,2	5.35	0.147
Diamond killifish	1.5±0.9	0.8±0.5	1,2	0.55	0.536
Striped mullet	1.7±1.4	0.4±0.7	1,2	14.56	0.062
Longnose killifish	1.0±1.6	0.0±0.0	1,2	1.88	0.304
Blue crab	0.4±0.3	0.5±0.4	1,2	0.04	0.862

encounter rates in canals were similar to those in nearby natural channels. This result may be due to changes that took place after canal construction; the shallow and deep canals were last dredged in 1958 and 1976, respectively. Where canals are dredged in marshes with soft substrates, canal banks usually slump after construction, reducing bank steepness and depth (Adkins and Bowman 1976). Although bottom profiles of both study canals were steeper than those of the tidal creek (slopes: shallow canal=0.12, deep canal=0.25, tidal creek=0.09) (Fig. 3), bottom profiles of canals had slopes much less than one, the slope called for in design specifications for flotation canals (Wicker et al. 1989). The slumping process apparently led to bottom profiles approaching that of a natural channel and may have improved nekton habitat by creating shallow refugia along the canal-marsh interface (McIvor and Odum 1988).

Variation in nekton abundance among habitats were probably not related to the differences in salinity. Although salinities increased from north to south across the study area, most species collected are euryhaline, and salinities were well within the tolerance of these species. The most striking difference among habitats was that of significantly higher densities of numerically dominant cyprinodonts (Gulf killifish and diamond killifish) found in creek tributaries. This relationship of increasing densities of nekton with decreasing stream-order has been observed elsewhere (Weinstein 1979). Rozas et al. (1988) also found high densities of nekton in small tributaries (rivulets) in a tidal freshwater marsh. However, high densities of these species in tributaries at low tide did not translate into significantly higher densities on the adjacent marsh surface at high tide as observed in other studies (Rozas and Odum 1987, Hettler 1989), and in 1990 brown shrimp were collected in significantly lower numbers on marshes adjacent to tributaries than other habitats (Table 4). This result may have been influenced by the location of tributary flumes. Nekton swim up tributaries as the tide rises, and most organisms probably enter marshes near the heads of tributaries where marsh flooding occurs first. My flumes were within 15-20m of tributary mouths and therefore, may have been bypassed by most organisms.

Densities of several organisms collected on marshes also varied seasonally. For example, Gulf killifish and diamond killifish were most abundant in Summer-Fall 1990; grass shrimp and brown shrimp were most numerous on marshes in Winter-Spring 1991 (Tables 2 and 3). Seasonal variability in the use of marshes by these species is probably related to their reproductive cycles. Greatest densities on marshes were observed during periods of highest reproduction or peak recruitment to the estuary. For example, brown shrimp were an order of magnitude more abundant in flumes during Winter-Spring 1991 than in Summer-Fall 1990, although average trawl catches during the two periods were similar (Tables 2 and 3). This apparent increase in the use of the marsh surface during 1991 coincided with the brown shrimp's (February-April) period of peak recruitment into Louisiana estuaries (Gaidry and White 1973). Brown shrimp collected in my flumes averaged 54 mm in Summer-Fall 1990 and 40 mm in Winter-Spring 1991. Zimmerman and Minello (1984) also found that small, newly recruited brown shrimp showed an affinity for marsh vegetation, and that their use of the marsh surface decreased as they increased in size; brown shrimp exited Galveston Bay marshes when they reached a total length of 50-60 mm.

Although canal residents were precluded from using outside-levee marshes, their absence was more than compensated for by organisms that reached these marshes from other waterbodies. For most species, the average number of individuals collected on outside-levee marshes was higher than on marshes lacking levees (Table 7). Perhaps by blocking the movement of organisms, canal levees effectively concentrated nekton near levees on outside-levee marshes.

Assemblages on inside-levee and outside-levee marshes differed. Resident marsh species (mostly cyprinodonts) composed a much larger portion of the assemblage of outside-levee marshes than inside-levee marshes. Only two estuarine transients (blue crabs and striped mullet) used

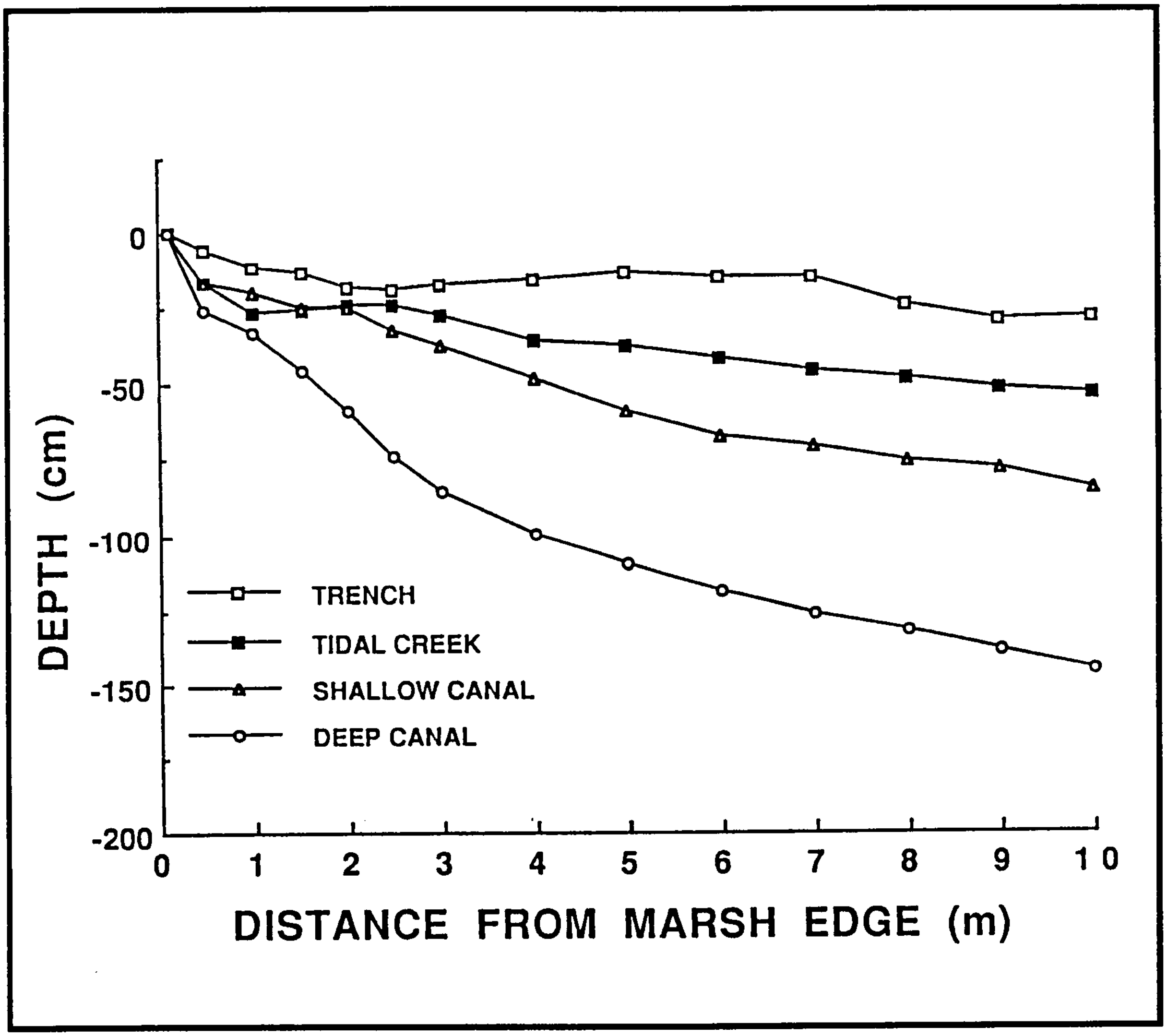

Figure 3. Average depth of subtidal area (subtidal profiles) in front of flumes out to a distance of 10m from the marsh-channel interface.

outside-levee marshes to any extent from January through April. Brown shrimp a transient species that was abundant on inside-levee marshes, was absent from outside-levee marshes. A possible Figure 3. Average depth of subtidal area (subtidal profiles) in front of flumes out to a distance of 10m from the marsh-channel interface explanation for these results may be that most transient species do not travel very far across the marsh surface from a subtidal refuge. Transient species may favor marsh habitat near the marsh-water interface (Minello and Zimmerman 1989). The density of marsh residents collected in lift nets was generally low, and may have also been affected by the distance of sample sites from the marsh edge.

Potentially, the most important negative effect of canal levees on fisheries production may be in situations where they enhance marsh waterlogging and increase the rate of marsh habitat loss through erosion (Turner et al. 1982, Turner and Cahoon 1987). In wetlands where canal levees would enhance marsh waterlogging and the push method cannot be used, gaps should be placed in levees, canals should be backfilled, or innovative dredging techniques that do not create levees (e.g., high-pressure spray dredging) should be encouraged (Cahoon and Cowan 1988). Where ponding is a problem along levees of existing canals, breaching levees at various locations (especially at sites where natural channels were blocked by levee construction) would reduce ponding behind levees and reopen areas of marsh for use by nekton. Openings in levees would also allow tidal exchange in canals that are impounded by plugs and levees and would permit their use by transient organisms (Neill and Turner 1987b). However, hydrologic conditions should be carefully studied prior to breaching levees to avoid inducing marsh erosion at levees openings.

CONCLUSIONS

Shallow subtidal areas within pipeline canals and adjacent inside-levee marshes support nekton in numbers comparable to similar habitats associated with natural channels. Inside-levee marshes probably enhance the habitat function of pipeline canals by providing nekton with an expanded area for foraging and finding refuge at high tide.

However, canals with continuous levees are not equivalent to natural channels in terms of the amount of marsh-surface habitat they provide. Using aerial photography I estimated the length of marsh-water interface (edge) along five natural channels and their tributaries in my study area. Estimates of tributary lengths were conservative, because small creeks are not always visible on photographs. Nonetheless, the average length of edge along natural channels was about half that found bordering their tributaries. Because marshes fringing canals are not continuous, the amount of edge associated with canals is even less than that along natural channels of equal length. Therefore, natural channel systems contained more than three times as much marsh edge habitat as canals of equal length. Backfilled pipeline trenches, on the other hand, do not have levees that block access to small tributaries and adjacent marshes; small waterbodies that are intersected only add to the edge associated with these features. Therefore, installing pipeline canals with the push method and backfilling provides more marsh edge habitat for fishery species than using the flotation method.

Canal levees did not have a significant effect on outside-marsh habitat function in this study. However, in areas where canal levees intersect and marshes are semi-impounded or completely isolated, habitat function may be diminished or lost completely.

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