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Estuarine Artificial Reefs to Enhance Seagrass Planting and Provide Fish Habitat

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Small 25-m² artificial reef sets were deployed 1 m deep in Choctawhatchee Bay, FL, to determine the ability of reefs to aid in the establishment of newly planted *Ruppia maritima* (widgeon grass) while providing habitat for estuarine fishes. Seagrass survival and coverage were examined for reef configurations and compared with control plots. Visual surveys conducted from June 1996 to May 1997 indicated that the artificial reefs had no effect on the survivorship or growth of the planted *R. maritima*. The artificial reefs attracted juvenile and young adult fishes and had significantly more species, higher diversity, more individuals, and greater total biomass of fishes per area than did the nonreef controls. The 22 fish species observed at the reefs were typical estuarine residents in the area. Young gray snapper, *Lutjanus griseus* (a recreationally and commercially important species), was abundant at the reefs. Although the artificial reefs did not increase seagrass planting success, these artificial reefs may increase the number of fishes surviving to adulthood by providing protective habitat.

Seagrasses play an integral and integrative role in the overall condition of nearshore coastal and estuarine waters. For example, seagrass meadows are highly productive communities. The photosynthetically fixed energy in these meadows follows three general trophic pathways: direct herbivory of living plant material, secondary contribution to detrital food webs by way of the decaying seagrass within the seagrass meadow, and exportation of both live biomass and detritus to adjacent ecosystems (Zieman and Zieman, 1989). Seagrass meadows also provide nursery habitat and spawning areas for many estuarine species. Seagrass meadows decrease the risk of predation for these organisms and enhance their food supply by supporting benthic fauna and flora. The canopy structure formed by the blades offers a refuge from predation and is possibly the most important factor in the nursery function of seagrass meadows (Heck and Crowder, 1991; Heck et al., 1997). Last, seagrasses also help stabilize sediments. Their blades reduce the flow of water near the sediment–water interface, promoting the sedimentation of particles and inhibiting resuspension of both organic and inorganic materials (Zieman, 1982; Ward et al., 1984). Seagrass roots and rhizomes form an interlocking matrix that helps bind the sediment. The blades, together with roots and rhizomes, can also reduce shoreline erosion by dissipating wave energy in nearshore habitats (Thayer et al., 1975; Ward et al., 1984).

Recognition of the ecological and economic value of seagrass meadows combined with widespread losses of seagrass coverage (e.g., Lewis et al., 1985) have spurred concern for their preservation and restoration. Conversely, seagrass restoration has been a controversial subject, with a varied record of success. Most successful restoration sites have been limited to areas that offer protection from waves and currents. To expand potential seagrass restoration sites into higher energy areas that are otherwise unsuitable, energy-dissipating materials may be placed around the seagrass to provide the necessary physical buffer to afford the plants an opportunity to become established. For example, unsuccessful attempts at transplanting turtle grass, *Thalassia testudinum,* in Tampa Bay were primarily due to erosion by tidal currents (Kelly et al., 1971). Previous observations indicate that turtle grass is buoyant, and new transplants tend to uproot from the sediment and float to the surface when disturbed by water movement. To overcome this problem, Kelly et al. (1971) utilized concrete building blocks to deflect and reduce the force of tidal currents and waves.

Ruppia maritima, widgeon grass, is a hardy submerged aquatic plant species that is distributed worldwide in a variety of environments (Phillips, 1960; Durako et al., 1993). This species is eurythermic and can survive in water between 7 and 39 C (Phillips, 1960). Moreover, *R. maritima* is euryhaline and is found growing in fresh to hypersaline waters (McMillan, 1974). Generally, however, it is considered a brackish water species that occurs most frequently below 25 ppt (Phillips, 1960). Because *R. maritima* has the broadest physiological tolerance of many seagrasses, it may be better

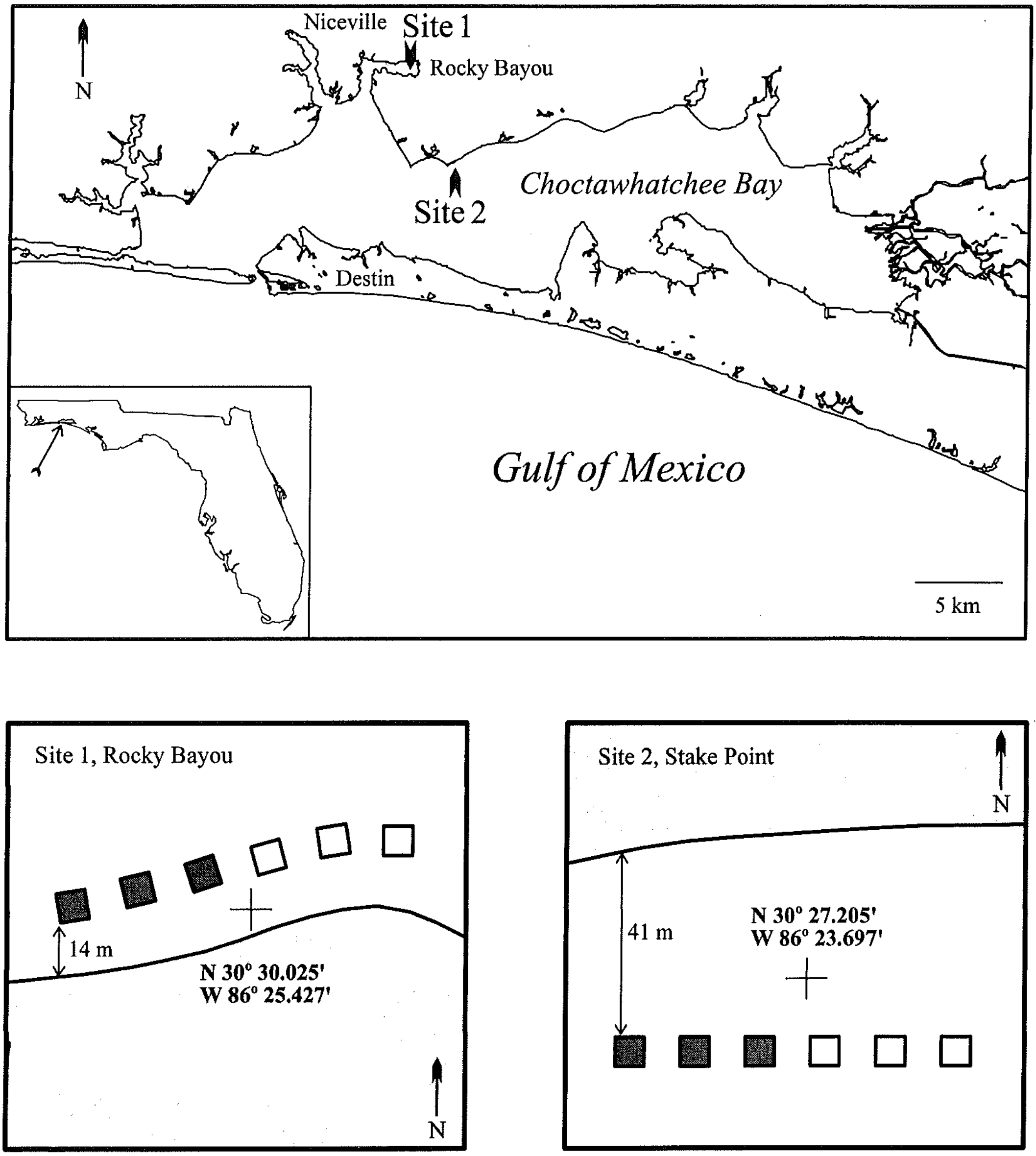


Fig. 1. Maps of Choctawhatchee Bay indicating the location of artificial reefs deployed in Rocky Bayou and at Stake Point. *Ruppia maritima* was planted in the center of the shaded reefs.

suited for initial testing of restoration site suitability than other species (Durako et al., 1993).

Ruppia maritima planting in Pensacola Bay by the Florida Department of Environmental Protection has had limited success at some locations. This has been attributed to high sedimentation rates and/or plant removal by breaking waves or tidal currents (Taylor Kirschenfeld, pers. comm.). Energy-dissipating materials were not used during these earlier restoration efforts, and water movement is assumed to have caused the loss of *R. maritima* plantings.

Artificial reefs are most commonly placed offshore in deeper water but may also be placed in shallow estuarine locations. New fish habitat in an estuary may enhance the production of fishery resources (Alevizon et al., 1985; Comp and Seaman, 1985). New habitat can also permit the settlement and colonization of offshore species not normally found in estuaries (Hastings, 1979). Artificial reefs can serve as refuge and feeding grounds for juveniles, possibly increasing their survival rate. The concentration of small fishes and invertebrates that utilize the reefs may attract larger fishes in search of prey items. The increase in species abundance around the reefs can expand the available fishery in the area.

The combined use of artificial reefs and seagrass restoration may provide additional benefits to a local area. The coupled effects of seagrass and artificial reefs may provide an enhancement of habitat quality for juvenile fishes. The fishes may feed within the seagrass, directly off the reef, or on the surrounding substrate. The control of shoreline erosion may be further increased by combined use of seagrass and reefs.

The objectives of this study were to determine if artificial reefs can be successfully utilized to enable the establishment of seagrasses in areas that are otherwise unsuitable, presumably because of tidal currents and wave energy. In addition, this study examined fish colonization of estuarine artificial reefs with seagrass, artificial reefs without seagrass, seagrass-only plots, as well as control plots with no reefs or seagrass.

Description of Study Area

Choctawhatchee Bay, in northwest Florida (Fig. 1), was the study area for our experiments. The bay is approximately 48 km from east to west and is the third largest estuarine system on the Florida Gulf coast (Burch, 1983). The bay receives water from the Choctawhatchee River and several small coastal streams and ground water (Hastings, 1979; Livingston, 1990). Bay water discharges into the Gulf of Mexico through East Pass at Destin.

Two locations in Choctawhatchee Bay were chosen for this study. Site 1 was on the south shore of Rocky Bayou, a Florida Aquatic Preserve. Site 2 was on the north shore of Choctawhatchee Bay at Stake Point. The adjacent property is a 4-H youth camp, Camp Timpoochee, operated by the University of Florida. Rocky Bayou is exposed to wave energy caused by recreational boats (Nadine Craft, pers. comm.). Stake Point is also exposed to high wave energy attributed to the long fetch of open water when winds are out of the southeast.

Methods

Six reefs were deployed on 23 and 24 May 1996 at each location with a distance of 5 m between each reef set (Fig. 1). The artificial reef modules were black truss-framed plastic crates (38 cm long, 35 cm wide, 26 cm high), each weighted with concrete tiles (30 cm long, 30 cm wide, 6 cm high). The reefs were deployed in water 1 m deep. Each reef set (sensu Grove and Sonu, 1983) was 25 m^2. The modules were placed along the perimeter (5 m along each side) in a staggered, "checkerboard" pattern to dissipate wave energy and tidal currents and to allow some water and suspended sediment to flow through the reef configuration (Fig. 2). The reefs were allowed to settle for 1 mo, after which *R. maritima* was planted. *Ruppia maritima,* laboratory cultivated by a micropropagation technique (Koch and Durako, 1991), was supplied by the Florida Department of Environmental Protection, Northwest District. Both sites were homogenous in habitat characteristics, and *R. maritima* was planted within the protected interior of three artificial reef sets. *Ruppia maritima,* along with a 6-cm-diameter peat pellet, was planted at 0.5-m centers, for a total of 36 plants per reef set. *Ruppia maritima* was also planted on three quadrats in the same manner but without the protection of the artificial reef. The plots of seagrass without a surrounding reef set were planted at each location with 5 m between plots. Three additional plots without reef or seagrass were also monitored at each location.

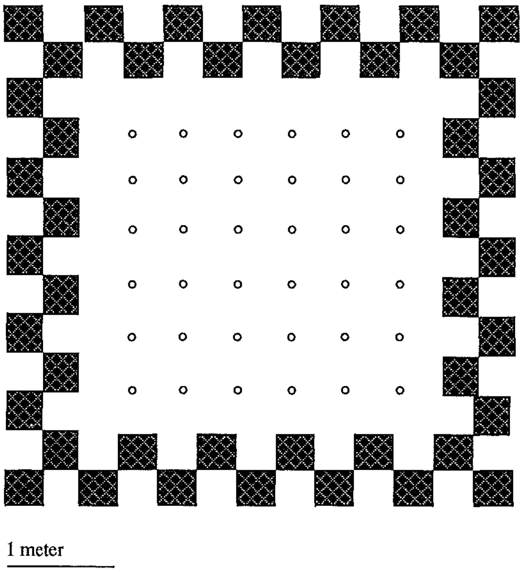
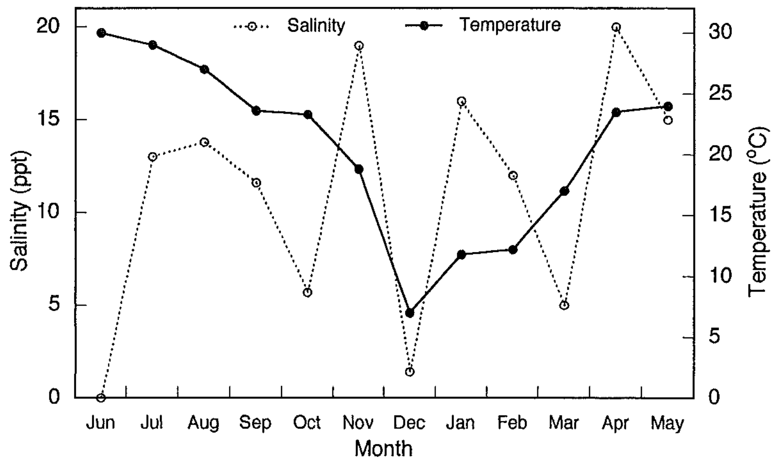


Fig. 2. Arrangement of artificial reef components and placement of *Ruppia maritima.* Textured squares represent plastic crates (i.e., modules) and circles represent plant centers.

Environmental parameters examined includ-



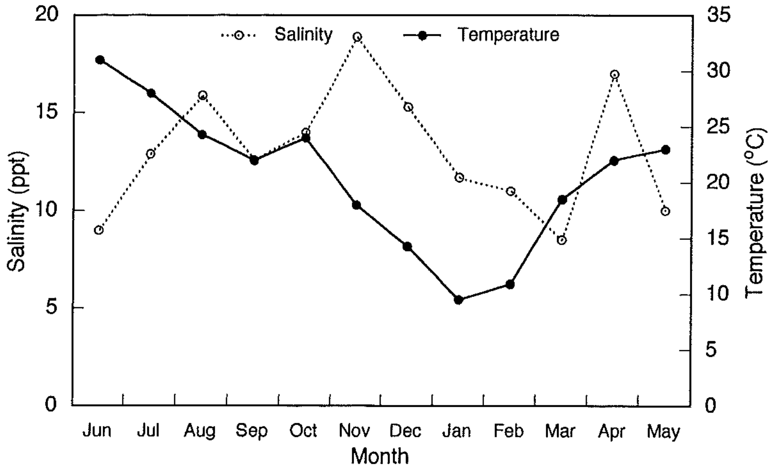
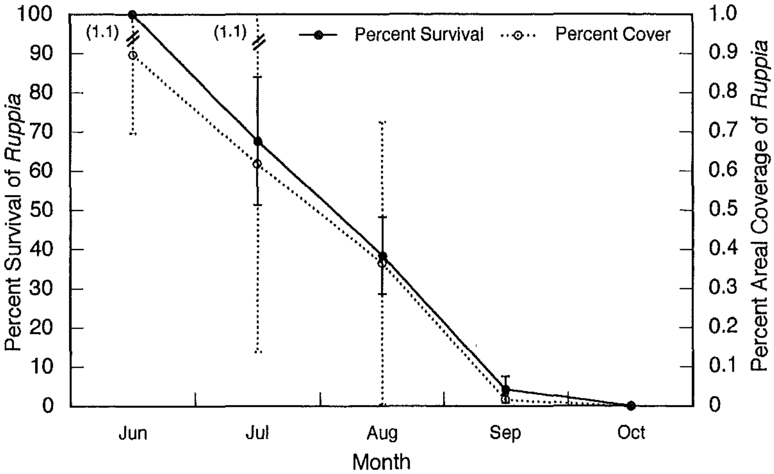


Fig. 3. Salinity and water temperature recorded during the 12-mo study period at Rocky Bayou (top) and Stake Point (bottom).

ed salinity (in ppt; refractometer), water temperature (in C), and water clarity (horizontal Secchi distance in cm). Horizontal Secchi distance was obtained by placing the disk perpendicular to the bottom and measuring the visible distance to the disk, parallel to the bottom (viewed from underwater).

Percentage of survival and percentage of areal coverage of *R. maritima* were recorded monthly. Any missing or dead plants were noted among the 36 plants within each reef or plot. The coverage area of the *R. maritima* was estimated by averaging the width of the plant (diameter, in cm) on two perpendicular axes. The diameter was determined by measuring the distance between the outermost blades. With the formula πr^2, the area for an individual plant was calculated. A random sample of 10% of the plants per reef was measured, and the mean area covered by an individual plant was determined. Each plant was assigned a number (1–36), and a table of random numbers was used to determine which plants to measure. Areal coverage was then expressed as a percentage of the total area inside the reef set (i.e., 12.25 m^2).

Fish colonization was determined in the reef sets with seagrass, reefs without seagrass, the seagrass-only plots, and in the three control plots with neither seagrass nor reefs. A visual survey that included an area that extended 1 m on the inside and outside of the modules, as well as the center of the reef set, was conducted to assess the fish assemblage. The total visual area surveyed for each reef was 49 m^2. While snorkeling along the length of each side



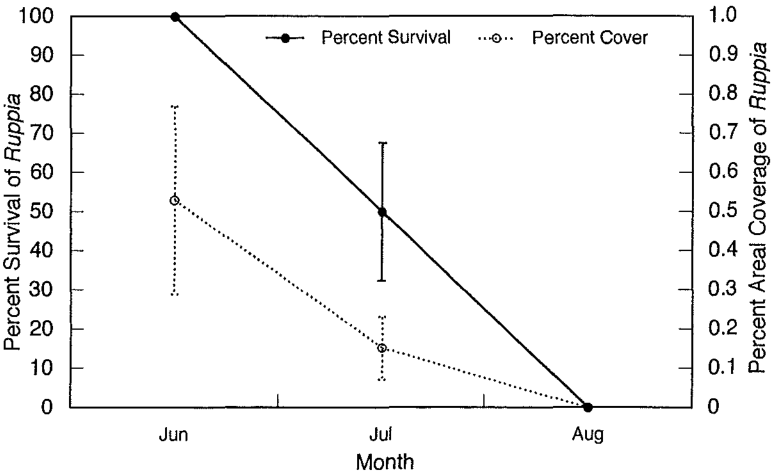


Fig. 4. Percentage of survival and percentage of areal coverage of *Ruppia maritima* planted at Rocky Bayou (top) and Stake Point (bottom). Vertical lines = standard deviation.

of the reef, an observer identified, counted, and estimated the total length (TL in cm) of fishes. Data were collected while the observer slowly swam along each 5-m side for a duration of 1 min for three sides. The fourth side was surveyed for 45 sec, and the remaining 15 sec were used to survey the center of the reef. Thus, each reef was surveyed for 4 min. If at least one member of a school of fish was seen within the survey area, then all of the individuals in the school were counted. The same school, if seen again, was not recounted. Macroinvertebrates were also noted during the surveys.

Data were analyzed with the SAS statistical program (SAS, 1985). Transformations of the data were made when appropriate. Pairwise comparisons with Tukey tests were considered significant at $\alpha = 0.05$. A two-factor analysis of variance (ANOVA) was performed for each site to identify relationships among treatments over time. Factors for the ANOVA included the presence of a reef and month of the year. Response variables for the ANOVA included number of species, species diversity (Shannon's index using the natural logarithm), number of individuals (square-root transformed), total biomass (natural logarithm transformed), and mean fish length (total length in cm, natural logarithm transformed). Biomass was determined from the fish lengths estimated during the visual surveys and calculated with length-to-weight conversion equations according to Bohnsack and Harper

TABLE 1. Mean number of individuals per reef set (standard deviation in parentheses) recorded during the 12-mo study period at Rocky Bayou.

Taxa	June		July		Aug.		Sept.		Oct.	
	Reef	Control	Reef	Control	Reef	Control	Reef	Control	Reef	Control
Atherinidae										
Menidia spp.	2.67 (2.34)		1.33 (3.27)							
Carangidae										
Caranx hippos				0.17 (0.41)						
Dasyatidae										
Dasyatis sabina					0.17 (0.41)		0.17 0.41			
Ephippidae										
Chaetodipterus faber							0.17 (0.41)			
Gerridae										
Eucinostomus argenteus										
Gobiidae										
Bathygobius soporator	0.33 (0.52)		4.17 (2.23)	0.67 (0.52)	2.17 (2.14)	0.67 (0.52)	0.33 (0.82)		0.17 (0.41)	
Microgobius gulosus										
Lutjanidae										
Lutjanus griseus	1.33 (2.80)		3.33 (2.73)		3.33 (1.75)		9.17 (4.92)		10.8 (4.17)	
Mugilidae										
Mugil cephalus			4.00 (9.80)		9.50 (12.8)		6.67 (5.43)			
Sciaenidae										
Leiostomus xanthurus	2.33 (4.41)			0.83 (2.04)	0.33 (0.52)		6.33 (6.38)			
Soleidae										
Achirus lineatus				0.17 (0.41)						
Sparidae										
Archosargus probatocephalus			0.17 (0.41)		0.17 (0.41)		1.33 (1.03)		0.17 (0.41)	
Lagodon rhomboides	16.3 (3.14)	1.67 (1.53)	16.3 (5.57)	5.00 (2.37)	17.0 (12.3)	3.00 (2.37)	26.2 (13.5)	0.67 (1.03)	17.2 (4.92)	
Juvenile fish										

[a] Surveys not conducted.

(1988) and Dawson (1965). A three-factor ANOVA was conducted for the Rocky Bayou site for the months of July, Aug., and Sep., the months during which the seagrass was surviving. Factors for this ANOVA included presence of *R. maritima*, presence of reef, and month. A two-factor ANOVA was conducted on the seagrass response variables to determine the effect of reef and month on the percentage of survival and the percentage of area covered with *R. maritima.*

Species abundance and total biomass were also used to form a similarity matrix for analysis of similarities test with the PRIMER statistical program (Plymouth Marine Laboratory, 1996). With the similarity percentages test, species abundance and total biomass were used to examine the contribution of each species to

TABLE 1. Extended.

Nov.		Dec.		Jan.		Feb.		March		April		May	
Reef	Control	Reef	Control[a]	Reef	Control[a]	Reef	Control	Reef	Control	Reef	Control	Reef	Control
7.00								2.50	4.00	5.33		5.67	
(8.37)								(4.05)	(4.00)	(7.34)		(6.47)	
								0.33					
								(0.82)					
1.50				0.17		0.83		4.17		1.00		3.50	0.33
(1.76)				(0.41)		(0.75)		(3.19)		(1.26)		(2.07	(0.58)
									0.67		1.33		0.33
									(1.15)		(1.53)		(0.58)
9.00		1.33		1.00				4.00		4.83		4.83	
(3.52)		(1.51)		(1.55)				(4.05)		(2.64)		(1.83)	
								2.83	6.67				0.33
								(4.67)	(0.58)				(0.58)
6.17								22.0	3.67	24.7		23.0	2.33
(5.15)								(3.29)	(3.21)	(4.37)		(3.03)	(3.21)
				160		87.5							
				(182)		(37.1)							

the mean Bray–Curtis dissimilarity index between the reef and no-reef treatments.

RESULTS

Environmental parameters.—The salinity in Rocky Bayou varied between a low of 0 ppt in June and a high of 20 ppt in April (Fig. 3). Water temperature varied between a low of 7 C in Dec. and a high of 30 C in June (Fig. 3). Water clarity was lowest in Dec., with a Secchi distance of 0.8 m, and greatest in Jan., with a Secchi distance of 2.3 m.

The salinity at Stake Point varied between a low of 8.5 ppt in March and a high of 18.9 ppt in Nov. (Fig. 3). Water temperature was lowest in January at 9.5 C and highest in June at 31 C (Fig. 3). Water clarity was lowest in March, with a Secchi distance of 0.63 m, and highest in February at 3.13 m.

Seagrass.—The planted *R. maritima* in Rocky Bayou survived for 3 mo. Two-factor ANOVAs were conducted to determine the effect of reef and month on the percentage of survival and the percentage of areal coverage with *R. maritima*. Percentage of survival and percentage of areal coverage of *R. maritima* within the reefs were not significantly different from the open water controls (F = 4.31, P = 0.06 and F = 4.38, P = 0.052, respectively). Monthly survival was significantly lower each successive month (F = 192.36, P = 0.0001), with 67.6% survival in July, 38.4% survival in Aug., and 4.2% survival in Sep. (Fig. 4). *Ruppia maritima* was completely absent by Oct., and no evidence of its presence was found the following spring. Percentage of area covered was significantly different between months (F = 9.13, P = 0.0009). At the time of planting, the percentage of coverage was 0.89%; it then decreased to 0.62% in July, 0.37% in Aug., and 0.02% in Sep. (Fig. 4).

The *R. maritima* planted at Stake Point survived for 2 mo. A two-factor ANOVA indicated that percentage of survival and percentage of areal coverage of *R. maritima* within the reefs were not significantly different from the open water control (F = 0.01, P = 0.94 and F = 0.03, P = 0.88, respectively). Survivorship significantly declined each month (F = 119.24, P = 0.0001), with 50% survival in July and none surviving to the Aug. survey (Fig. 4). *Ruppia maritima* did not become reestablished in the spring. Percentage of coverage was significantly lower each successive month (F = 10.07, P = 0.0131). Initial coverage was 0.53%, then declined to 0.15% in July, and none remained in Aug. (Fig. 4).

Fish colonization.—Rocky Bayou: Thirteen fish species representing 11 families were observed during the 12-mo survey period at Rocky Bayou (Table 1). Gray snapper, *Lutjanus griseus*, and frillfin goby, *Bathygobius soporator*, occurred most often and were present 11 out of 12 mo. Pinfish, *Lagodon rhomboides*, were present during 9 mo. Spot, *Leiostomus xanthurus*, and silversides, *Menidia* spp., were observed during 6 mo. Striped mullet, *Mugil cephalus*, and sheepshead, *Archosargus probatocephalus*, were present during 3 and 4 mo, respectively. Jack crevalle, *Caranx hippos*; Atlantic spadefish, *Chaetodipterus faber*; Atlantic stingray, *Dasyatis sabina*; lined sole, *Achirus lineatus*; and spotfin mojarra, *Eucinostomus argenteus*, occurred once or twice as single individuals. Juvenile fishes, comprised mostly of *L. rhomboides* and sciaenids, occurred in Jan. and Feb. and were numerous.

In two-way ANOVAs, significant differences were found by month and treatment for the dependent variables: number of species, species diversity (H'), and number of individuals. The mean number of species observed per survey was significantly higher for reef (2.7, SD = 1.3) versus no-reef (1.1, SD = 1.1) treatments (F = 122.67, P = 0.0001). The mean number of species within reef treatments increased from 2.7 (SD = 0.82) in June to a high of 4.8 (SD = 1.2) in Sep., then declined to a low of 0.5 (SD = 0.55) in Dec. (Fig. 5). The number of species then increased to 3.8 (SD = 0.98) in March.

Species diversity (H') was significantly higher for reef (0.65, SD = 0.42) versus no-reef (0.46, SD = 0.41) treatments (F = 22.24, P = 0.0001). Initial diversity within reef treatments was 0.65 (SD = 0.24), which increased to a high of 1.2 (SD = 2.2) in Sep., then decreased to a low of 0 (SD = 0) in Dec. (Fig. 5).

The mean number of individuals observed per survey was significantly higher for reef (47.1, SD = 68.2) versus no-reef (4.3, SD = 5.7) treatments (F = 47.65, P = 0.0001). The mean number of individuals within reef treatments steadily increased from 23 (SD = 7.2) in June to 50.3 (SD = 23) in Sep., then declined to a low of 1.3 (SD = 1.5) in Dec. (Fig. 6). January, with a mean of 161.2 (SD = 181.2) individuals, was significantly higher than all other months except Sep. and Feb. Results from the analysis of similarities test also indicated a significantly higher number of individuals at the reef treatments than at the no-reef treatments (P = 0.0001).

In two-way ANOVAs, significant interaction effects were found between month and treatment for the dependent variables total biomass (F = 7.33, P = 0.0001) and mean length (F = 4.59, P = 0.0028). Results from the analysis of similarity test indicated a significantly higher total biomass at the reef treatments than at the no-reef treatments (P = 0.0001). A significantly greater total biomass of fishes was at the reef treatments for the months Aug.–Nov., April, and May. The total biomass within reef treatments was 4.5 g/m^2 (SD = 4.8) in June and increased to a high of 56.5 g/m^2 (SD = 39.3) in Sep. (Fig. 6). Total biomass declined to a low of 0.45 g/m^2 (SD = 0.6) in Dec., which was significantly lower than for all other months.

Mean total length of fishes within reef treatments increased from 7.1 cm (SD = 1.2) in

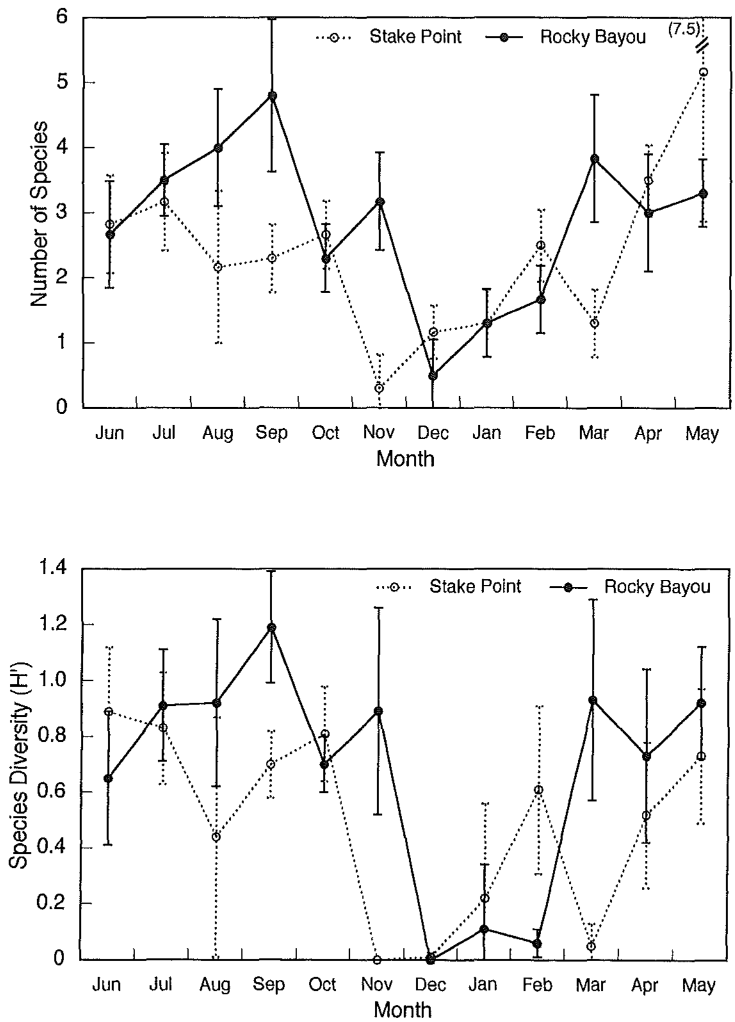
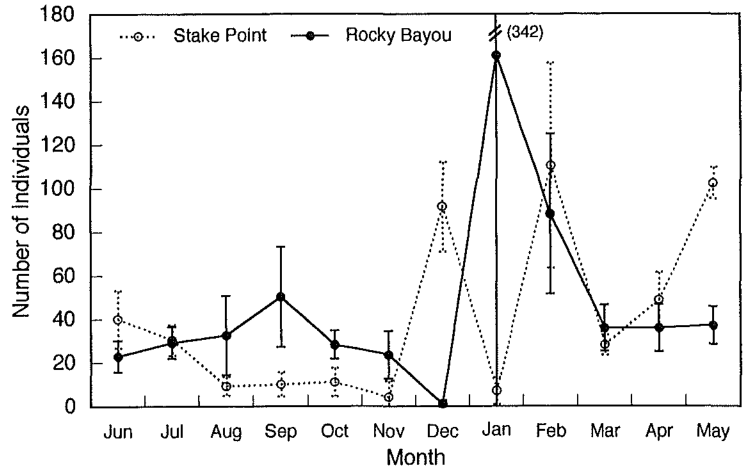


Fig. 5. Number of species (top) and species diversity, H′ (bottom), recorded at artificial reefs during the 12-mo study period at Stake Point and Rocky Bayou. Vertical lines = standard deviation.

June to the longest mean length of 11.6 cm (SD = 1.4) in Sep. (Fig. 7). Mean length was least in Feb. (3.1 cm, SD = 0.07).

Species abundance and total biomass were examined to determine the contribution of each species to the mean Bray–Curtis dissimilarity between the reef and no-reef treatments. At Rocky Bayou, 91% of the differences in species abundance between the reef and no-reef treatments was attributed to five fishes (in decreasing order of abundance): *L. rhomboides,* juvenile fishes, *L. griseus, Menidia* spp., and *L. xanthurus.* When total biomass was analyzed, 88% of the differences could be attributed to *L. rhomboides, L. griseus,* juvenile fishes, *B. soporator,* and *M. cephalus.*

To determine the effect that R. maritima had on the dependent variables, a three-factor ANOVA was conducted with *R. maritima* presence, reef presence, and month as factors. *Ruppia maritima* was present in July, Aug., and Sep. The *R. maritima* treatments had a significantly higher number of individuals than the no-*R. maritima* treatments for July and Sep. Conversely, in Aug., the no-*R. maritima* treatments had significantly higher number of individuals than the *R. maritima* treatments. The presence of *R. maritima* had no detectable effect on the number of species (F = 0.2, P = 0.66), diversity (F = 1.01, P = 0.33), total biomass (F = 0.01, P = 0.93), and mean length (F = 0.02, P = 0.89). The number of individuals and total biomass from the similarity test indicated that the reefs with *R. maritima* were not statistically different



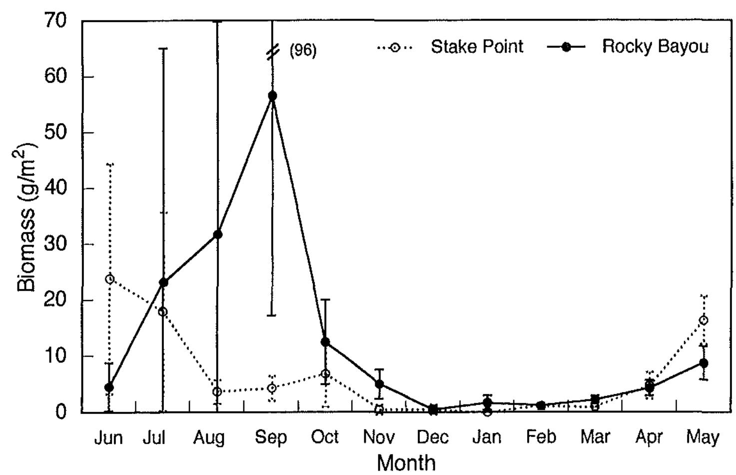


Fig. 6. Number of individuals (top) and biomass (bottom) recorded at artificial reefs during the 12-mo study period at Stake Point and Rocky Bayou. Vertical lines = standard deviation.

from the reefs without *R. maritima* ($P = 0.37$ and $P = 0.38$, respectively).

Stake Point: Seventeen fish species representing 15 families were observed during the survey period at Stake Point (Table 2). *Lagodon rhomboides* occurred most often and was observed during 10 out of 12 surveys. *Lutjanus griseus* occurred during seven surveys; *L. xanthurus* and *Menidia* spp. were observed during five surveys. *Caranx hippos, C. faber, Chilomycterus schoepfi* (striped burrfish), *D. sabina, Sphoeroides* spp. (puffers), and *Synodus foetens* (inshore lizardfish) occurred one or two times as single individuals. *Gobiesox strumosus* (skilletfish), *Orthopristis chrysoptera* (pigfish), *Oligoplites saurus* (leatherjacket), *M. cephalus,* and *Trachinotus carolinus* (Florida pompano) also occurred only once or twice but were more numerous. Juvenile fishes were present in great numbers in Dec. and Feb. and consisted mostly of sciaenids and *L. rhomboides,* but gobiid juveniles were also present.

Two-factor ANOVAs were conducted with the factors month and reef presence to compare the response variables. Interaction between the two factors was significant for each response variable.

The mean number of species was significantly higher in July, April, and May at the reef treatments than at the no-reef treatments. The mean number of species was highest in May (5.2, SD = 2.3) and was significantly higher for all months except April and July (Fig. 5).

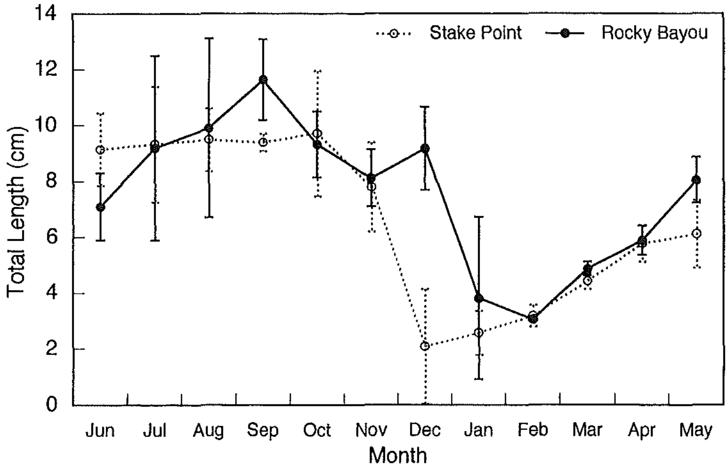


Fig. 7. Total length (in cm) recorded at artificial reefs during the 12-mo study period at Stake Point and Rocky Bayou. Vertical lines = standard deviation.

Species diversity was similar for all months between reef and no-reef treatments except for Oct., in which the reef treatment had a higher diversity. The species diversity within reef treatments ranged from 0 (SD = 0) to 0.89 (SD = 0.23) (Fig. 5).

The mean number of individuals was significantly higher in Dec., Feb., and May at the reefs than at the no-reef treatments. Results of the analysis of similarities test indicated that the reef treatments had a significantly higher number of individuals than the no-reef treatments ($P = 0.0001$). The mean number of individuals within reef treatments was 40.2 (SD = 13.2) in June, then decreased significantly from Aug. through Nov. (Fig. 6). The number of individuals varied widely for the remainder of the study period. The mean number of individuals was significantly higher at the reef treatments in Dec. (91.8, SD = 20.5), Feb. (110.7, SD = 47.1), and May (102.7, SD = 18) than in all other months.

The mean monthly biomass of fishes was significantly higher in July–Sep., March, and April at the reef treatments than at the no-reef treatments. Results of the analysis of similarities test indicate that the reef treatments had significantly higher biomass than the no-reef treatments ($P = 0.013$). Total biomass within reef treatments was least in Jan., with 0.03 g/m^2 (SD = 0.02), and greatest in June, with 23.8 g/m^2 (SD = 20.6) (Fig. 6).

Total length of fishes was similar for all months between reef and no-reef treatments except during May, in which fish from the no-reef treatment were larger. The smallest mean total length of 2.1 cm (SD = 0.26) occurred in Dec., and the largest mean total length of 9.7 cm (SD = 2.2) occurred in Oct. (Fig. 7).

Species abundance and total biomass were examined to determine the contribution of each species to the mean Bray–Curtis dissimilarity between the reef and no-reef treatments. At Stake Point, 93% of the differences in species abundance between reef and no-reef treatments can be attributed to five fishes (in decreasing order of abundance): *L. rhomboides,* juvenile fishes, *Menidia* spp., *L. griseus,* and *L. xanthurus.* With total biomass, 82% of the variation can be attributed to *L. rhomboides, Menidia* spp., *M. cephalus, L. griseus,* and juvenile fishes.

Rocky Bayou and Stake Point comparison: A three-factor ANOVA with the factors site, presence of reef, and month was used to compare the dependent variables from Rocky Bayou and Stake Point. A significant interaction was found between site and month for each response variable. Total length of fish was not statistically different for each month except Dec., where Rocky Bayou had larger fish. For the remaining variables, no pattern was detected in the differences between the two sites. The parameters had an overall tendency to decrease during the winter months, followed by an increase in the spring.

Macroinvertebrate colonization.—The artificial reefs at Rocky Bayou were colonized by six macroinvertebrate species that were initially observed in August and remained for the duration of the study period. Blue crabs, *Callinectes sapidus,* were abundant, with individuals often

TABLE 2. Mean number of individuals per reef set (standard deviation in parentheses) recorded during the 12-mo study period at Stake Point.

	June		July		Aug.		Sep.		Oct.	
Taxa	Reef	Control	Reef	Control	Reef	Control	Reef	Control	Reef	Control
Atherinidae										
Menidia spp.	0.50 (1.22)	1.33 (2.31)							2.00 (4.90)	
Blenniidae										
Chasmodes saburrae										
Carangidae										
Caranx hippos			0.17 (0.41)							
Oligoplites saurus					0.33 (0.82)	0.33 (0.82)				
Trachinotus carolinus					0.50 (1.22)					
Dasyatidae										
Dasyatis sabina										
Diodontidae										
Chilomycterus schoepfi			0.17 (0.41)						0.17 (0.41)	
Ephippidae										
Chaetodipterus faber							0.17 (0.41)			
Gobiesocidae										
Gobiesox strumosus										
Gobiidae										
Bathygobius soporator										
Haemulidae										
Orthopristis chrysoptera									0.83 (1.33)	
Lutjanidae										
Lutjanus griseus			0.33 (0.52)		0.33 (0.82)		6.83 (4.62)	0.33 (0.58)	4.50 (2.81)	
Mugilidae										
Mugil cephalus	7.33 (9.00)		3.67 (5.89)							
Sciaenidae										
Leiostomus xanthurus	11.2 (4.88)	0.67 (1.15)	8.50 (4.14)	0.33 (0.82)	0.67 (0.82)					
Sparidae										
Lagodon rhomboides	21.2 (3.43)		17.8 (3.76)	0.83 (1.33)	7.50 (2.88)	0.50 (0.84)	3.17 (1.17)	0.33 (0.58)	3.67 (2.94)	0.33 (0.58)
Synodontidae										
Synodus foetens					0.17 (0.41)					0.33 (0.58)
Tetraodontidae										
Sphoeroides spp.							0.17 (0.41)		0.17 (0.41)	
Juvenile fish										

[a] Surveys not conducted.

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TABLE 2. Extended.

Nov.		Dec.		Jan.		Feb.		March		April		May	
Reef	Control	Reef	Control	Reef	Control[a]	Reef	Control[a]	Reef	Control	Reef	Control	Reef	Control
2.83 (6.94)	7.67 (13.3)					2.50 (4.18)						5.50 (7.84)	5.00 (4.00)
								0.17 (0.41)		3.33 (1.63)		2.17 (2.04)	
		0.17 (0.41)										0.17 (0.41)	
										1.83 (1.72)		1.17 (1.33)	
								0.17 (0.41)		1.00 (1.10)		1.33 (2.16)	
												5.67 (2.73)	
1.67 (4.08)										0.33 (0.82)		0.67 (1.63)	
						1.67 (4.08)						5.33 (5.50)	
				3.33 (2.25)		21.5 (12.1)		27.8 (4.58)		42.3 (13.5)	0.33 (0.58)	80.7 (9.03)	4.00 (6.08)
		91.7 (20.4)		4.00 (4.94)		85.0 (53.1)							

found between and also burrowed under crates. Oysters, *Crassostrea virginica*; bent mussels, *Brachidontes recurvus*; and barnacles, *Balanus* spp., colonized the plastic crates (i.e., modules) but were more abundant on top of the concrete tiles. Olive nerites, *Neritina reclivata*, and green striped hermit crabs, *Clibanarius vittatus*, were also present.

The artificial reefs at Stake Point were colonized by seven species of macroinvertebrates that were first observed in Aug. and remained for the duration of the study period. *Callinectes sapidus* were abundant, with individuals often found between crates and also burrowed beneath the edge of the crates. *Crassostrea virginica*, *B. recurvus*, and *Balanus* spp. colonized the plastic crates but were more abundant on top of the concrete tiles. *Clibanarius vittatus* were also present. Penaeid shrimp and grass shrimp were observed only Dec.–March.

Discussion

Seagrass.—The deployment of the artificial reefs had no effect on the growth or survival of the planted *R. maritima*. The rapid death of the *R. maritima* at Stake Point may be attributed to sediment fluctuation at this site. The plantings were probably not removed by wave action, but rather the *R. maritima* may have been unable to survive the duration in which they were covered by sand. A similar problem was reported for seagrass transplanting in Panama City, FL, by Fonseca et al. (1986) when they attributed seagrass loss to a moderate sediment fluctuation rate at the planting site. At Stake Point, sparse patches of *Halodule wrightii* were found growing approximately 150 m offshore from the reefs. The water there was shallow (1.5 m), but the area was presumed to have less sediment movement because of its increased distance from the eroding shoreline.

The *R. maritima* planted in Rocky Bayou lived for a longer period than that at Stake Point but not longer than the control. The plants remained in place here also, despite waves created by boats. Plant death may have been because of light attenuation. Water clarity was low, with a mean Secchi distance of 1.85 m (SD = 0.64). Small areas of growing *R. maritima* were observed in similar habitats within Rocky Bayou and directly shoreward of the reefs, but in water depths between 0.2 m and 0.6 m. During March and April, a dense epiphytic film was observed on the nearby *R. maritima* and on the reefs. Another reason for the poor survival may have been bioperturbation. *Lagodon rhomboides* were observed picking at the *R. maritima*, and blue crabs were seen burrowed near the plants.

The survivorship of *R. maritima* at Rocky Bayou might be increased by planting the seagrass in shallower water. Planting at a decreased depth would allow more light to reach the seagrass; however, there would be a concomitant increase in wave action. Assuming the artificial reefs decreased water movement, several rows of the crates used in this study would be sufficient to diffuse the waves caused by recreational boat use in the bayou. The shallow nature of the breakwater would be a less effective artificial habitat for fish, but this may facilitate oyster reef formation.

A different species of seagrass (e.g., *Halodule wrightii*) may be a more successful candidate for replanting at Stake Point. At this site, seagrass planting should occur much farther from the shoreline and adjacent to the remnant *H. wrightii* meadow. The higher salinities at this site may also favor the growth of *H. wrightii* over *R. maritima*.

The presence of *R. maritima* at Rocky Bayou had little effect on the dependent variables. Although the ANOVA indicated differences in the number of individuals, similarity analysis did not. The seagrass at its highest level of coverage was only 0.89% of the area within the reef. This amount of seagrass may have been insignificant to attract fish, which is suggested by the few fish observed near the seagrass during the surveys. The attraction of fish was apparently to the structure provided by the reefs and not the small amount of seagrass.

Fish colonization.—The shallow artificial reefs attracted fishes and had more species, higher diversity, more individuals, and greater total biomass of fishes per area than the surrounding substrate. The 22 fish species observed for the combined sites are typical estuarine residents and are often associated with nearshore artificial reefs. Twenty of these species were previously reported by Hastings (1979) at the rock Jetties at East Pass. *Chasmodes saburrae* (Florida blenny) and *Microgobius gulosus* (clown goby) were not observed during Hastings' study.

In another artificial reef study in Choctawhatchee Bay, Bortone et al. (1994) found that the reefs in the bay were primarily colonized by offshore species. In the current study, fishes that colonized the reefs were from within the bay. The number of species, species diversity, number of individuals, and biomass were often less than was found by Bortone et al. (1994). They observed 31 species during the 13-mo survey; planehead filefish, *Monacanthus hispi-*

dus, and gag, *Mycteroperca microlepis,* were found nearly every month. The differences between the two artificial reef studies in Choctawhatchee Bay are likely due to the greater depth (6.5 m) at which Bortone et al. (1994) placed their reefs and their closer proximity to the Gulf of Mexico.

A study investigating the colonization of artificial reefs in the Halifax River lagoon system on the Atlantic coast of Florida also placed artificial reefs in 1 m of water (Borntrager and Farrell, 1992). The reefs in this location were colonized by only six fish species. Oyster toadfish, *Opsanus tau,* was the most abundant. The greater size and habitat complexity of the reefs in the current study may explain the higher diversity and number of individuals.

Small fish predominated at these artificial reefs, and individuals larger than 15 cm were rarely observed. *Lutjanus griseus,* a recreationally and commercially important fish, was abundant at Rocky Bayou throughout the study and was also present at Stake Point Sep.–Nov. The young as well as the adults of this species are commonly found within bays and estuaries in the fall (Hastings, 1979). *Lagodon rhomboides* was the most numerous fish found at both sites, but they rarely exceeded 10 cm TL. Small cryptic fishes such as *B. soporator, C. saburrae,* and *G. strumosus* were present, but their numbers were not substantial. Considerable numbers of juvenile fishes were observed during Dec., Jan., and Feb. Many adult estuarine fish undertake spawning migrations offshore in the winter. Soon after spawning, the young arrive in the estuary. The artificial reefs may increase the survivorship of the juvenile fishes, as well as young adult fishes, by providing refuge in the otherwise uniform substrates found at Stake Point and Rocky Bayou. A study of the interaction between artificial reefs and ichthyoplankton in coastal waters of the Japan Sea found a higher diversity as well as nine times greater number of larval fishes near artificial reefs than at control areas (Tchizhov, 1994). Tchizhov (1994) attributed this difference to weaker currents and wave action at the reefs, as well as an abundance of food and shelter. Gorham and Alevizon (1989) observed similar results on the effects of habitat complexity on the abundance of juvenile fishes. They found that the number of juvenile fishes was significantly higher at reefs with unraveled lengths of rope than at identical reefs without rope.

Conclusions.—Environmental conditions such as the sediment fluctuation at Stake Point and low water clarity at Rocky Bayou may have superseded any benefit of using artificial reefs to protect the *R. maritima.* Whether or not artificial reefs can be successfully used to enhance seagrass planting is unclear. Protecting newly planted seagrass from tidal currents and wave energy to aid in seagrass restoration remains a potentially important area of investigation.

Increased settlement habitat may benefit commercially and recreationally important fishes that recruit to estuaries as juveniles because of the concomitant reduction in predation and possible increased food availability. Because of declining habitat (i.e., seagrass meadows and marshes) within Choctawhatchee Bay, the enhancement of habitat structure, such as with artificial reefs, may increase the number of fishes surviving to adulthood. Future research should be directed to determine how estuarine artificial reefs can be used to better meet the survival needs of seagrass plantings as well as juvenile and young adult fishes.

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