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Evaluation of nekton use and habitat characteristics of restored Louisiana marsh

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Abstract

Marsh terracing and coconut fiber mats are two wetland restoration techniques implemented at Sabine National Wildlife Refuge, Louisiana, USA. Using nekton as an indicator of habitat quality, nekton community assemblages were compared between terraced, coconut-matted, unmanaged marsh (restoration goal), and open water (pre-restoration) habitats. Using a throw trap and a 3 m × 2 m straight seine, 192 nekton samples were collected over four dates in 2001 and 2002 at all habitats. Nekton abundance was similar at unmanaged marsh (restoration goal), coconut mat, and terrace edge, and significantly higher than at open water (pre-restoration) sites ($P < 0.05$). Coconut-matted habitat and unmanaged marsh edges had significantly higher numbers of benthic dependent species than terrace edges ($P < 0.05$), potentially because of differences in substrate. Terraced sites had lower organic matter and siltier substrate as compared to unmanaged marsh sites. At Sabine NWR, terracing increased nekton use as compared to pre-restoration conditions (open water samples) by providing marsh edge habitat, but failed to support a nekton community similar to unmanaged marsh (restoration goals) or coconut-matted sites. Future restoration projects may evaluate the combined use of coconut mats with terracing projects in order to enhance habitat for benthic dependent nekton.
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Keywords: Terrace; Marsh terracing; Coconut mat; Submerged aquatic vegetation; Habitat restoration; Dredged material marsh; Organic matter; Nekton; Fish; Shellfish; Macroinvertebrates

1. Introduction

Over the last 70 years, coastal Louisiana has lost 1900 square miles of land. Most of this loss results from conversion of vegetated marsh to shallow open water areas (Mac et al., 1998). Numerous techniques have been implemented over the years to reduce wetland loss, ranging from the use of levees, creation of impoundments, and use of dredged material (Turner and Streever, 2002). These approaches have met with mixed success, prompting managers and researchers to con-

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tinue searching for new and better methods. Two relatively new unproven techniques being tested in shallow open water areas are: (1) marsh terracing, thought to increase marsh edge and encourage SAV growth by reducing wave fetch and sediment suspension (Steyer, 1993), and (2) coconut mats, which are thought to promote SAV growth by providing appropriate substrate for SAV recruitment and growth (Boustany, 2003). Ultimately, both techniques have the potential to restore valuable marsh habitat, supporting fisheries use and production at levels similar to natural, unaltered marshes.

Terrace projects are proposed as a means to replace lost emergent vegetation, decrease wave energy, and decrease open water fetch in shallow open water areas (Steyer, 1993; Rozas and Minello, 2001). Terraces are ridges of discontinuous marsh constructed from dredged material on site that are vegetated with *Spartina alterniflora*. Unlike spoil banks, which are continuous and rise above normal tides, terraces are designed to be discontinuous and flood at high tide. Constructing terraces gained popularity as a restoration and mitigation technique following reports that terraces near the Calcasieu Ship Channel on Sabine National Wildlife Refuge (NWR), Louisiana, USA, reversed shoreline erosion and created almost 17 acres of saline marsh with a marsh–water interface of almost 1500 m (Steyer, 1993). The success of terraces was further supported by a more recent study finding that these same terraces supported more nekton than adjacent shallow marsh ponds (Rozas and Minello, 2001). While these findings were all based on one terrace field built in a checkerboard design, later-built terraces at Sabine NWR and elsewhere have been designed as chevron shapes or straight lines, so that the same ecological benefits could potentially be achieved at a lower cost (C. Pease, Sabine NWR Manager, personal communication, 2001). These differences in design of terraces have been governed more by economics and engineering practicalities than any biological evidence of equal or improved functioning of these terraces.

Another restoration approach being investigated involves the use of coconut fiber mats as a substrate to recruit and grow submerged aquatic vegetation (SAV). Coconut fiber is made out of coconut hulls and commonly has been used in stream bank stabilization projects (Gray and Leiser, 1982; Kondolf and Micheli, 1995). Only recently has it been considered for use as a tool to grow and recruit SAV. In degraded marsh shallow open water areas, it is often hypothesized that sediment and water quality limit SAV establishment and growth (Fonseca et al., 1983; Boustany, 2003). Coconut mats may alleviate this by providing a substrate for SAV establishment and increasing water clarity by reducing sediment suspension in the water column.

Although scientists and marsh managers are applying various restoration techniques with the goals of slowing marsh loss and restoring fishery habitat, few studies have quantitatively evaluated the effects of different restoration techniques on fish assemblages, often relying on the Field of Dreams hypothesis "if you build it, they will come" (Palmer et al., 1997). Because of the motile nature of nekton, they can rapidly colonize a habitat if conditions are suitable and they can rapidly leave an area if conditions become unsuitable. Thus, nekton can be an indicator of habitat quality. Few restoration projects have succeeded in increasing nekton productivity and abundance (Able et al., 2000; Jivoff and Able, 2003; Tupper and Able, 2000; Williams and Zedler, 1999; Rozas and Minello, 2001), and in fact, nekton productivity and abundance are often lower in constructed marshes than in natural areas (Moy and Levin, 1991; Chamberlain and Barnhart, 1993; Minello and Webb, 1997), leaving the actual success of restoration projects in question.

Terracing and coconut mats may be valuable restoration tools for nekton because both techniques have the goal of creating habitat for fishery species; shallow water habitat with submerged aquatic vegetation is associated with higher densities of nekton as compared to non-vegetated shallow open-water areas (Orth, 1977; Rozas and Odum, 1988; Fonseca, 1996; Jacobsen and Berg, 1998; Minello, 1999). Furthermore, terrace projects immediately increase marsh edge, another habitat characteristic important in supporting fishery species (Zimmerman and Minello, 1984; Zimmerman et al., 1991; Baltz et al., 1993; Peterson and Turner, 1994; Zimmerman et al., 2000).

At Sabine National Wildlife Refuge (NWR), LA, USA the effects of saltwater intrusion and marsh subsidence on wetland areas are being counteracted by restoration projects such as terracing. Sabine NWR is also interested in restoration techniques to increase SAV recruitment and growth, leading to an interest in testing the effects of coconut mats. Using nekton as an indicator of habitat quality, the goal of this project was to evaluate nekton use of terraced and coconut-matted areas within one terrace field constructed in straight lines at Sabine NWR. Specifically, we compared nekton community assemblages (density, biomass, composition) between terraced, coconut-matted substrate, unmanaged marsh and open water (pre-restoration) habitats.

2. Methods

2.1. Study area

The study area is a terrace field located in southwest Louisiana within Unit 7 of Sabine National Wildlife Refuge (NWR), between Calcasieu and Sabine Lakes (Cameron Parish, Louisiana) (Fig. 1). The terrace field studied is located in a 3 km^2 brackish open water area that replaced emergent vegetation between 1956 and 1978. This shallow embayment consists of an open pond area fringed by unmanaged marsh with small natural marsh islands throughout, and recently constructed, randomly placed straight line terraces. Terraces were designed to be perpendicular to predominant winds with the goals of decreasing wave energy and erosion in the embayment, and ultimately encouraging SAV growth and providing valuable habitat (Pease, personal communication, 2001). Tides in the area are diurnal with a range of 0.30–0.45 m. The brackish marsh is vegetated with 100% cover. Vegetative cover consists of *Spartina patens*, *Paspalum vaginatum*, *Scirpus olneyi*, and *Phragmites australis* (Linscombe et al., 2001). Most of the shallow open-water areas within the embayment do not support SAV, although *Ruppia maritima*, *Myriophyllum spicatum* L., *Ceratophyllum demersum* L., *Najas guadalupensis*, *Nitella* spp. and *Chara* spp. occur in nearby ponds and canals. Over the last few decades, this area has experienced increasing salinity and decreasing marsh acreage, possibly as a result of changes caused by ship channel construction and maintenance and extensive oil and gas exploration ongoing in the area.

2.2. Restoration methods

Terraces in this embayment were constructed in 1996, 1997, 1998, 1999, and 2001. We restricted our observations to terraces constructed in 1999 and within the same terrace field to reduce variability that may result from terrace age, construction technique, and environmental setting. We did not study the older terraces because they were constructed adjacent to a canal and functioned more as spoil banks. Terraces studied are 10 m wide with a crown approximately 0.75 m above mean water level and range in length from 244 m to 468 m.

Coconut fiber mats (2.2 m × 5.4 m; BioD-Mesh™ 60, Rolanka International) were installed in November 2001 at each of three coconut mat transects randomly located along natural marsh edges within the study area. Mats were composed of loosely woven thick fiber threads. Each coconut mat was pinned to the bottom with bent rebar that was inserted through the mat into the sediment at each corner of the mat.

2.3. Sampling design

The study was conducted using a stratified random sampling design. Three transects were selected at coconut mats, unmanaged marsh and terrace sites. Each transect was sampled at two stations: (1) the "edge" habitat (within one meter of the marsh–water interface) and (2) open-water habitat (50 m from the marsh edge), for a total of 18 samples per collection period (three habitats × three transects × two stations). This design provided a pre-restoration control (50 m open-water unmanaged marsh sites) and a comparable restoration "goal" (marsh edge). The 50 m sites were assumed to be free of edge effect or any impacts from terrace construction. These assumptions are based on (1) current evidence that the value of edge habitat for nekton does not extend beyond 10 m from the marsh–water interface (Raposa and Oviatt, 2000) and (2) hypothesized benefits of terraces which are based almost entirely on the assumed physical effects of terraces reducing wave disturbance and increasing light availability which are unlikely to extend to 50 m. Each of the nine transects was sampled four times (12/2001, 2/2002, 5/2002, 9/2002) for a total of 72 samples (18 samples per collection by four time periods).

Additionally, in the spring (5/2002) and fall (9/2002) samples, extra samples were collected as this is when most transient species are known to be present in the marsh (Czapla et al., 1991). We focused this intensive

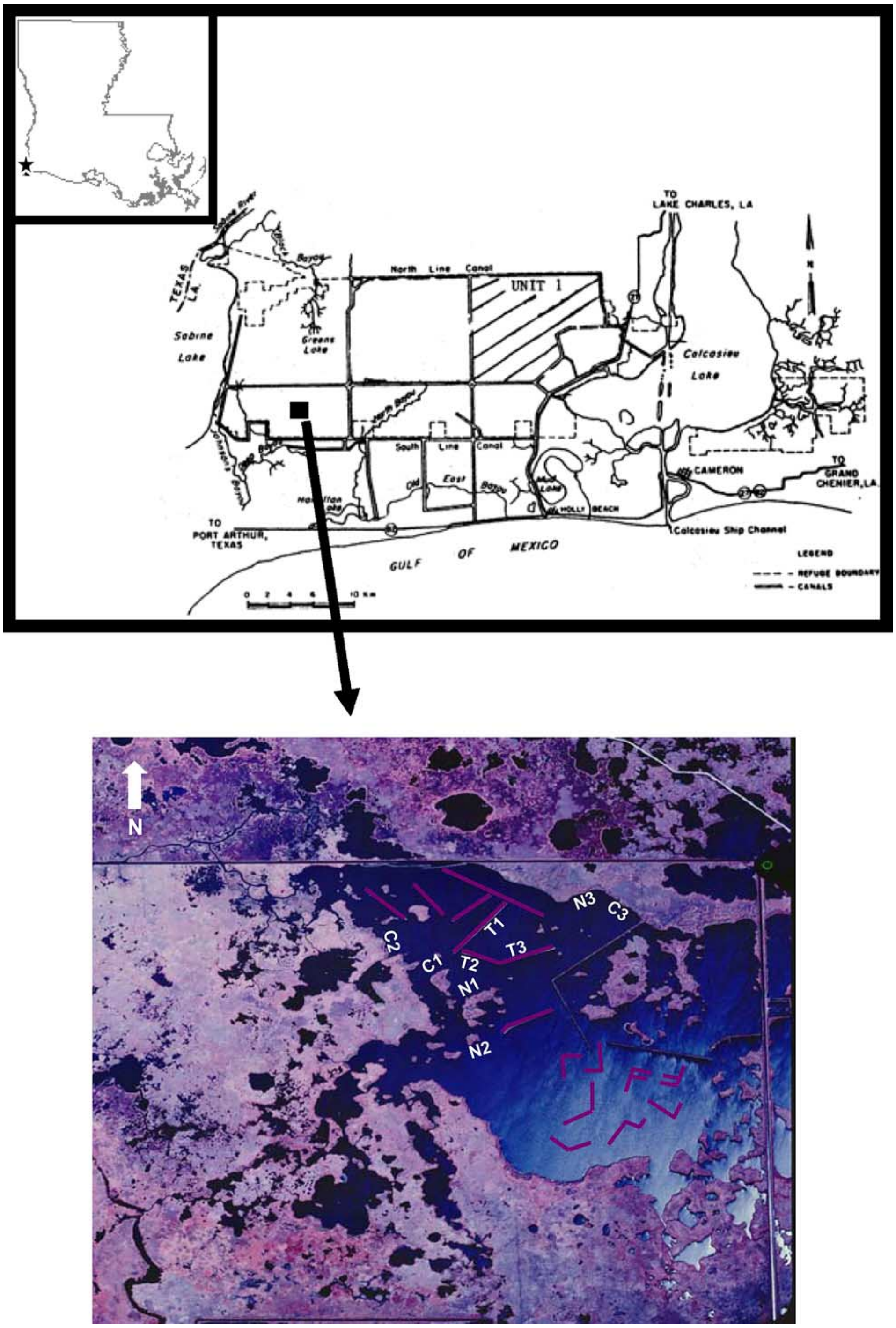

Fig. 1. Location of the study area and specific sample transects. The study area is a terrace field created in 1999 in Unit 7 at Sabine NWR in a brackish marsh. The sample transects are identified by habitat type as unmanaged (natural) marsh (N1–N3), terrace transects (T1–T3), and coconut-matted transects (C1–C3). Lines visible in the open water area are terraces.

sampling on unmanaged marsh and terrace transects only. This sampling consisted of an additional 10 unmanaged marsh transects (two sites/transect) and 20 terrace transects (two sites/transect) for a total of 120 samples (60 samples per collection by two time periods). Twice as many samples were collected at terraces as unmanaged marsh sites due to the lower catches in the initial sampling (12/2001 and 2/2002). In total, 192 samples were collected.

2.4. Sampling methods

To compare nekton community assemblages and nekton use of terraces, unmanaged marsh, and coconut-matted substrate, two techniques were used: collapsible throw traps and seine nets. Throw traps are considered the best option for sampling shallow-water habitats to compare nekton use (Chick et al., 1992). The throw-trap consisted of a 1 m^2 Wegener ring with mesh sides (mesh size = 1.6 mm). A heavy metal ring was attached to the bottom of the throw trap for rapid sinking and a floating ring attached to the top. The metal ring on the bottom of the throw trap was pushed into the substrate to prevent nekton escape during clearing. A dip net (mesh size = 3.2 mm; 36 cm × 30 cm) was used to clear nekton from the trap. The trap was considered free of nekton after ten consecutive sweeps without organisms were completed.

Seine net trawls were conducted with a 3 m × 2 m straight seine (mesh size = 5 mm) using methods found in Peterson and Turner (1994). Seine nets were pulled parallel to the marsh edge. Each seine sample covered 30 m of marsh edge. Seine net trawls were only conducted in the spring and fall samples at the same randomly selected transects for unmanaged marsh and terrace sites used for the throw trap during the quarterly sampling. Of the 192 samples taken, only 24 were taken with a seine (12 terrace, 12 unmanaged marsh). These were analyzed separately from the throw trap data, and used to corroborate the findings and effectiveness of the throw traps.

2.5. Sample handling

All nekton samples collected were immediately placed in an ice slurry, transported to the laboratory and placed in a freezer until processed. Nekton was identified to species or the lowest feasible taxon. All nekton were individually weighed to the nearest 0.001 g wet-weight to determine biomass. Throw trap data are reported as density (nekton/m^2) and biomass (g/m^2); seine net data are reported as catch per unit effort (CPUE; # nekton/trawl) and biomass (g/trawl).

2.6. Environmental characteristics

At each site, water temperature (°C), salinity (g/L), dissolved oxygen (mg/L), conductivity (μS/cm), and pH were measured with a YSI Model 556. Water turbidity was measured with a secchi disc (cm). These measurements along with water depth (cm) were taken with every nekton sample. All SAV present in throw trap samples was removed and returned to the laboratory. The SAV was placed in a drying oven at 60 °C and dried to a constant weight.

Cores were collected in September 2002 to determine organic matter content of terrace and unmanaged marsh sediment. Fourteen samples were collected from edge and open water stations near unmanaged marsh (seven samples) and terrace transects (seven samples). For each sample, five 10 cm diameter cores were collected from the top 5 cm of sediment for a total of 35 cores per sample station (140 cores total). Samples were homogenized, dried at 60 °C to a constant weight, weighed (initial weight), fired at 500 °C in a muffle furnace for 4 h, and weighed again (final weight). Organic matter was calculated as: 1.00 − [(final dry weight)/(initial dry weight)] (Moy and Levin 1991). Sediment texture was qualitatively evaluated on site as silt, clay, or sand.

Marsh–water edge ratios were calculated for each site following the description given by Delaney et al. (2000). Ratios were calculated using digital orthoquarter quadrangle (DOQQ) images. The marsh–water edge ratio was derived by dividing the length of the marsh–water edge (at a scale of 1:100) by the length of a straight line on the same marsh edge.

2.7. Statistical analyses

Data from throw trap and seine net samples were analyzed separately using Statistical Analyses System (SAS, 1989). Environmental variables, fish and

Table 1
Total catch of each species collected in the study area, categorized by the frequency of collection

Frequently collected (>50 individuals)	Total #	Infrequently collected (<50 individuals)	Total #	Rarely collected (<10 individuals)	Total #
Crustaceans	1438	Crustaceans	37	Crustaceans	0
C. sapidus	77	Fam. Xanthidae	37	Fish	29
F. azteca	195	Fish	107	*Bairdiella chrysoura*	2
L. setiferous	917	*L. rhomboides*	15	*Bollmannia communis*	1
Palaemonetes spp.	249	*Micropogonia undulatus*	38	*C. spilopterus*	2
Fish	1148	*Mugil cephalus*	14	*C. arenarius*	4
A. mitchilli	410	*Mugil curema*	12	*Fundulus grandis*	1
B. patronus	461	*Syngnathus scovelli*	28	*Fundulus pulverus*	1
G. bosc	78			*Gambusia affinis*	8
M. beryllina	141			*L. xanthurus*	1
M. gulosus	58			*L. parva*	6
				M. punctatus	3

crustacean density, catch per unit effort (CPUE), and biomass (throw trap and seine) were analyzed using a three-way analysis of variance with habitat type (coconut mat, unmanaged marsh, or terrace), sampling date (December 2001, February 2002, May 2002, or September 2002), and location (<1 m or 50 m from marsh edge). Variation due to transect was accounted for in the random statement of the mixed ANOVA. Analysis of variance was followed by Tukey's post-ANOVA test when significant differences were found ($P < 0.05$). Environmental variables were log transformed to improve normality and homogeneity of variance.

To test for differences in nekton use of habitats by functional group, a chi-square test was performed (three habitats × two distances × three functional groups). Species were divided into three functional groups: crustaceans (*Callinectes sapidus*, *Farfantepenaeus azteca*, *Litopenaeus setiferous*, *Palaemonetes* spp., Fam Xanthidae), benthic or demersal dwelling fish (*Citharichthys spilopterus*, *Gobiosoma bosc*, *Leiostomus xanthurus*, *Microgobius gulosus*, *Micropogonias undulates*, *Myrophis punctatus*, *Syngathus scovelli*) and pelagic dwelling fish (*Anchoa mitchilli*, *Brevoortia patronus*, *Cynoscion arenarius*, *Lagodon rhomboides*, *Lucania parva*, *Menidia beryllina*). The proportion of each functional group was compared among habitats and distances from edge using data from year round sampling with throw traps. Conditional independence was tested using a Cochran–Mantel–Hanzel test.

3. Results

3.1. Nekton assemblages

A total of 644 nekton (46% crustaceans) was collected from the throw traps with a total biomass of 198.4 g wet weight (57% crustaceans). A total of 1665 nekton (40% crustaceans) was collected from the seine trawls with a total biomass of 1332.9 g wet weight (39% crustaceans). For frequently collected species ($N > 50$) (Table 1), no significant differences in individual species weight were found among habitat types. The overall mean individual mass was: brown shrimp *F. azteca* (462 ± 52 mg), white shrimp *Litopenaeus setiferus* (499 ± 43 mg), grass shrimp *Palaemonetes* spp. (166 ± 14 mg), bay anchovy *A. mitchilli* (445 ± 60 mg), juvenile gulf menhaden *B. patronus* (203 ± 20 mg), naked goby *G. bosc* (159 ± 15 mg), clown goby *M. gulosus* (126 ± 20 mg), blue crab *C. sapidus* (240 ± 36 mg) and inland silverside *M. beryllina* (250 ± 22 mg).

Significant differences were found among habitats for density ($P < 0.0001$, Fig. 2), CPUE ($P < 0.0001$, Fig. 3), biomass by throw trap ($P = 0.03$, Fig. 4), and biomass by seine ($P < 0.0001$, Fig. 5) for both crustacean and fish (only highest P-value listed). Patterns of both crustacean and fish use were similar for all of the variables, and hereafter are collectively reported as "nekton". Coconut mat and terrace edges supported nekton use similar to unmanaged marsh edge (restoration goal), and higher nekton use than that found in

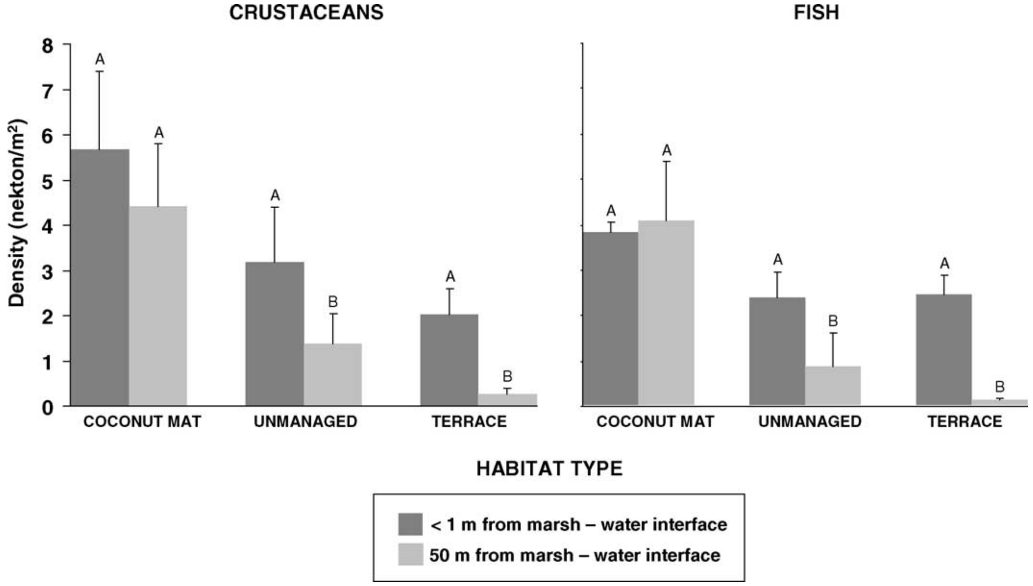

Fig. 2. Mean density (nekton/m^2) of decapod crustaceans and fish collected quarterly (12/2001, 2/2002, 5/2002, 9/2002) with a 1 m^2 throw trap. Throw trap samples were collected at coconut mat, unmanaged (natural) marsh, and terrace transects. Within each individual graph, bars with different letters were significantly different ($P < 0.05$). Error bars represent standard errors.

pre-restoration (open water) conditions. At the same time, coconut mats increased nekton use of open water sites, as compared to unmanaged open water sites.

At edge sites, nekton density at all three habitat types had an overall mean of 3.3 ± 0.6 nekton/m^2, and a mean CPUE at terrace and unmanaged edge sites of 52.2 ± 21.2 nekton/trawl. Unmanaged open water sites (pre-restoration conditions) had a mean density of 1.3 ± 0.7 nekton/m^2 and a mean CPUE of 8.3 ± 2.5 nekton/trawl. Biomass patterns were identical with edge sites for all three habitat types having an overall mean of 1.1 ± 0.02 g/m^2 (or 59.7 ± 19.4 g/trawl)

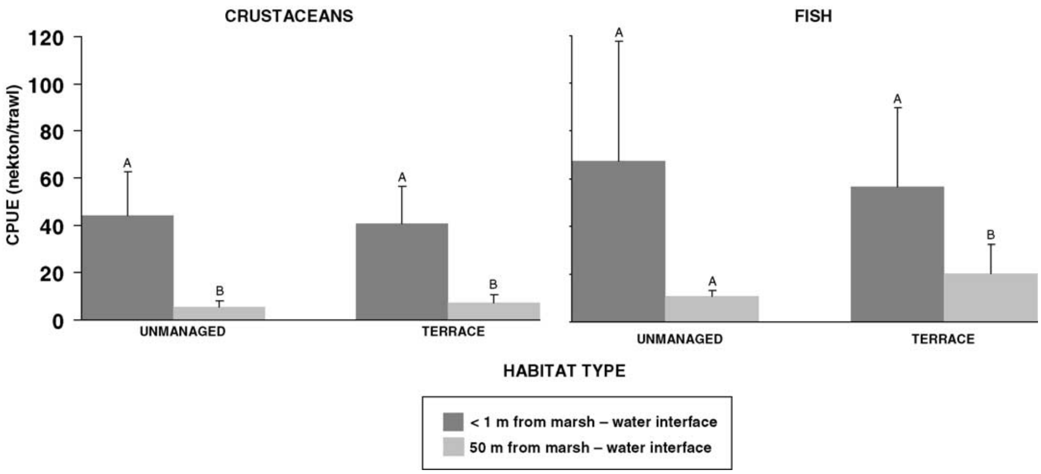

Fig. 3. Mean catch per unit effort (CPUE) of decapod crustaceans and fish collected in spring (5/2002) and fall (9/2002) with seine trawls. Samples were collected at unmanaged (natural) marsh and terrace transects only. Within each individual graph, bars with different letters were significantly different ($P < 0.05$). Error bars represent standard errors.

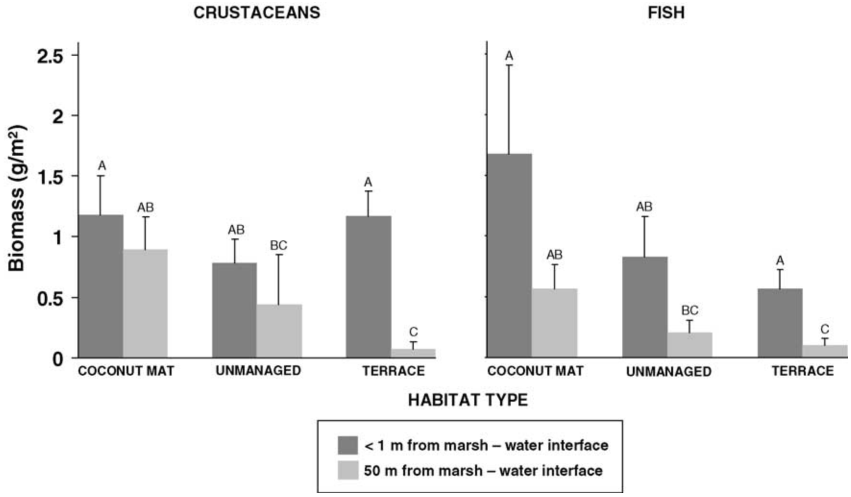

Fig. 4. Mean biomass of decapod crustaceans and fish collected quarterly with a 1 m^2 throw trap (12/2001, 2/2002, 5/2002, 9/2002). Samples were collected at coconut mat, unmanaged (natural) marsh, and terrace transects. Within each individual graph, bars with different letters were significantly different ($P < 0.05$). Error bars represent standard errors.

and the unmanaged open water sites (pre-restoration conditions) having an overall mean biomass of $0.4 \pm 0.3\,g/m^2$ (or 6.5 ± 2.2 g/trawl).

3.2. Nekton functional groups

Nekton composition analyzed by functional group differed significantly by habitat type (chi-square: $P < 0.001$; Fig. 6). Terrace edges supported a disproportionately higher percentage of pelagic fish (54% of total catch) as compared to unmanaged marsh (28%) or coconut-matted edges (27%). In contrast, terrace edges supported a disproportionately lower percentage of benthic fish (17%) and crustaceans (28%) as compared to unmanaged marsh (benthic fish: 32%; crustaceans: 40%). Coconut-matted edge sites supported

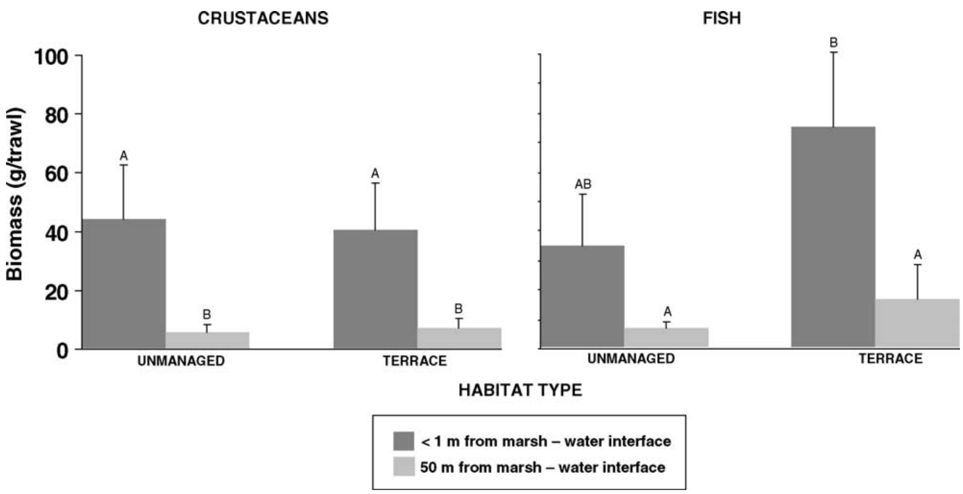

Fig. 5. Mean biomass of decapod crustaceans, and fish collected in spring (5/2002) and fall (9/2002) with seine trawls. Samples were collected at unmanaged (natural) and terrace transects only. Within each individual graph, bars with different letters were significantly different ($P < 0.0001$). Error bars represent standard errors.

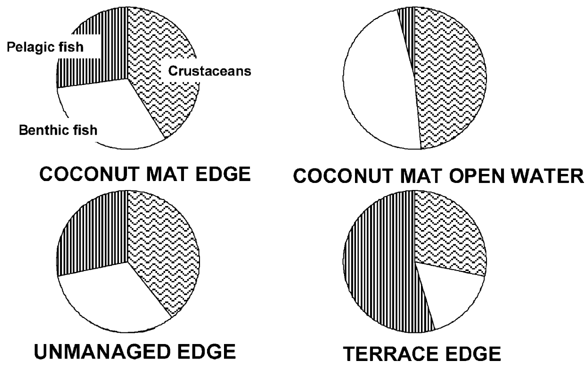

Fig. 6. Total percentage catch composition at terrace edge, unmanaged (natural) marsh edge, coconut mat edge and coconut mat open water sites. All four habitat types had higher nekton density, biomass and CPUE than unmanaged marsh open water (pre-restoration) sites. Prercent of each functional group was significantly different by habitat for (1) crustaceans (*C. sapidus*,*F. aztecа*,*L. setiferous*,*Palaemonetes* spp., Fam Xanthidae) (chi-square: $P = 0.0004$), (2) benthic or demersal dwelling fish (*C. spilopterus*,*G. bosc*,*L. xanthurus*,*M. gulosus*, *M. undulatus*,*M. punctatus*,*S. scovelli*) (chi-square: $P = 0.0001$) and (3) pelagic dwelling fish (*A. mitchilli*,*B. patronus*,*C. arenarius*, *L. rhomboides*,*L. parva*,*M. beryllina*) (chi-square: $P < 0.0001$). Catch data are based on quarterly throw trap sampling.

similar benthic fish (32%) and crustaceans (41%) as unmanaged marsh edge.

3.3. Environmental characteristics

Water depth, substrate organic content, and marsh–water edge ratio differed significantly between terrace transects and both unmanaged marsh and coconut mat transects ($P < 0.05$, Table 2). Terrace transects were significantly deeper than other habitat types, and the terrace open water stations was deeper than the terrace edge stations. Terrace edges had significantly lower organic matter as compared to unmanaged marsh edges. Substrate texture also differed depending on habitat type and location. Woody debris and plant detritus covered the coconut mats. Silt combined with woody debris and plant detritus comprised the texture of the unmanaged marsh edges. Clay silt comprised the texture of the unmanaged, open water stations. Silt clay comprised the texture of the terrace edge and open water stations. The marsh–water edge ratio was significantly less at the terrace than unmanaged marsh edge. Samples did not differ by water temperature, salinity, dissolved oxygen, pH, secchi depth, or SAV biomass.

4. Discussion

Restoration projects are often designed to create hydrological and physical conditions that are conducive to re-establishing self-sustaining populations of plants and animals (Palmer et al., 1997; Williams and Zedler, 1999; Williams and Desmond, 2001). When designing a restoration project in estuarine waters where fishery habitat is important, the marsh surface, the marsh edge and submerged aquatic vegetation (SAV) are commonly accepted to sustain high densities of fishery

Table 2
Environmental variables (mean ± S.D.) at each habitat type

Environmental variables	Coconut mat		Unmanaged marsh		Terrace		$P > F$	
	<1 m	50 m	<1 m	50 m	<1 m	50 m	Habitat	Distance
Temperature (°C)	21.68 ± 5.27	21.90 ± 5.06	23.46 ± 5.03	22.83 ± 5.27	23.05 ± 5.11	23.06 ± 4.87	0.966	0.905
Salinity (g/L)	2.44 ± 1.15	2.47 ± 1.25	2.20 ± 1.09	2.24 ± 1.13	2.15 ± 1.07	2.15 ± 1.07	0.606	0.936
Dissolved oxygen (mg/L)	5.48 ± 1.92	5.40 ± 1.63	6.38 ± 1.88	6.51 ± 1.89	6.90 ± 2.07	6.54 ± 2.06	0.062	0.84
pH	7.28 ± 0.30	7.32 ± 0.30	7.39 ± 0.27	7.49 ± 0.22	7.47 ± 0.29	7.46 ± 0.29	0.353	0.386
Secchi depth (cm)	16.71 ± 11.77	17.79 ± 9.43	19.78 ± 11.72	20.38 ± 13.56	25.19 ± 8.08	25.67 ± 11.46	0.055	0.864
Water depth (cm)	44.57 ± 11.76	56.17 ± 11.63	50.14 ± 15.86	57.04 ± 14.51	**61.83 ± 7.42**	**69.92 ± 10.20**	0.023	0.011
SAV (g)	0.19 ± 0.42	3.98 ± 10.59	0.004 ± 0.01	1.31 ± 3.49	0.001 ± 0.002	0.03 ± 0.06	0.161	0.055
Percentage organic matter in substrate	ND	ND	19.52 ± 14.98	14.14 ± 0.38	5.10 ± 3.14	7.52 ± 0.67	0.121	0.493
Marsh–water edge ratio	1.23 ± 0.28	ND	1.22 ± 0.12	ND	**1.00 ± 0.00**	ND	0.027	ND

Results of ANOVA examining differences in environmental variables by habitat and distance from the marsh edge (<1 m = edge, 50 m = open water). Means that are significantly different ($P < 0.05$) from other habitat types, as determined with Tukey's post-ANOVA test, are bold. SAV cover was sampled as biomass (g) for throw trap samples. Habitats that were not sampled are indicated by ND (no data).

species by providing microhabitats. Terraces and coconut mats both provided some aspect of physical structure often associated with higher nekton densities.

Both terrace edges and coconut mat sites increased habitat structure, and supported nekton use at a level similar to unmanaged edge sites. These results are consistent with other studies concluding that nekton or fish use (abundance) did not differ significantly between dredged material marsh and unmanaged marshes (La Salle et al., 1991; Minello and Zimmerman, 1992; Minello and Webb, 1997; Kurz et al., 1998; Williams and Zedler, 1999; Streever, 2000). No previous studies have documented the effects of coconut mats on fish habitat.

While nekton use of coconut mat sites, terrace, and unmanaged marsh edge was similar, terraced marsh edge was not functionally equivalent to unmanaged marsh edge; significant differences were found in the species composition from these habitats. Most pelagic species (i.e., bay anchovy, gulf menhaden, inland silverside) can be categorized as being generalists that are not strongly affected by environmental changes. Compared to the unmanaged marsh edge, there was an absence of specialized, less tolerant species at the terrace edge, while at the coconut mats, there was an abundance of specialized species. This pattern was similar to past studies (Minello and Zimmerman, 1992; Minello and Webb, 1997; Streever, 2000; Rozas and Minello, 2001), where species dependent on benthic refuge and benthic food sources were more abundant at unmanaged edge sites as compared to terrace edge sites. Furthermore, coconut mat edges, which provided increased benthic microhabitat, also had higher abundances of benthic dependent species as compared to unmanaged edges.

Substrate organic matter content and texture (microhabitat heterogeneity) have been suggested as potentially driving differences in nekton use of habitats. Substrate characteristics of the terrace, unmanaged marsh, and coconut mat habitats differed in organic matter content and texture, which could lead to potential differences in the abundance of benthic prey items that support benthic predators (Moy and Levin, 1991; Shreffler et al., 1992; Levin et al., 1996; Minello and Webb, 1997). The decrease in benthic species near terraces could result from substrate disturbances associated with project construction. The increase in benthic nekton at coconut mats may be due to increased organic matter and structure provided by the coconut mat fibers and detritus trapping in the mat.

Inadequate organic matter content is a common problem observed in dredged material marshes (Cammen, 1976; Craft et al., 1988; Moy and Levin, 1991; Sacco et al., 1994; Streever, 2000), but inadequate organic matter has been implicated in limiting denitrification and plant production rather than nekton use. Organic matter was lower at terrace edges as compared to unmanaged marsh. Minello and Zimmerman (1992) found that densities of decapod crustaceans were positively correlated with densities of benthic prey (or infaunal communities) in sediment cores, and that densities of prey were associated with higher organic matter in sediment cores. Thus, decreased abundance of benthic species may be due to decreased food availability near terraces as compared to unmanaged marsh edge.

4.1. Terrace design

While there were significant differences in terrace age, location and restoration design between the terraces in this study and the earlier studied terraces (Rozas and Minello, 2001), overall patterns of nekton use, and a finding of different species compositions in terrace and reference sites were similar. The most striking difference between the two studies is that nekton densities in this study were as much as 10 times lower than those reported by Rozas and Minello (2001). While terrace age could be a factor (9 years versus 3 years), past studies have suggested that nekton can establish stable densities in restored habitat in as little as 1 year (Streever, 2000). Microhabitat provided by SAV is not likely to be a factor influencing nekton density differences, because there was very little to no SAV at both the Unit 7 and Unit 1 terraces at the time of sampling. Site location could be another factor affecting nekton densities. Decreased habitat connectivity to other areas, although not measured, could limit nekton access to the terraces in this study. The older terraces studied by Rozas and Minello (2001) were located in saline marsh adjacent to Calcasieu Lake and less than 0.5 km from the artificially deep Calcasieu Ship Channel, whereas the terraces in this study were in brackish marsh more than 6 km from any large lake. Differences in connectivity between the terraces and marine environments might explain the lower abundance of marine transients that we observed relative to Rozas and Minello (2001) but does not explain the lower abundance in resident nekton that we observed.

The restoration design may be a large contributing factor to differences between our observations and those of Rozas and Minello (2001), because the older terraces were built in a checkerboard pattern with significantly greater marsh area and marsh edge as compared to the terraces in this study. The checkerboard design resulted in all remaining terrace pond areas being within 10 m of emergent vegetation, while terraces in this study were often over 100 m apart. As the value of marsh edge to nekton may extend as far as 10 m from the marsh edge (Raposa and Oviatt, 2000; Kanouse, 2003), the checkerboard design used may be providing more valuable nekton habitat as compared to the sparse straight line design. In fact, based on their study, Rozas and Minello (2001) suggest that future restoration projects should include design changes which increase the proportion of marsh in a terrace field. Impacts to the substrate from this more intensive terrace construction would need, however, to be examined more closely.

4.2. Management implications

Overall, coconut mats supported nekton densities that were at least four times greater than densities found in pre-restoration (open-water) sites. Terrace edges supported nekton densities that were at least two times greater than densities found in pre-restoration (open-water) sites. Although coconut matting appeared to increase nekton use more than terracing, terracing is a much more commonly practiced restoration technique due to cost-effectiveness and the hypothesized added benefits of simultaneously achieving other restoration goals, such as decreased open water fetch, turbidity, and wave energy. A relatively small area was coconut matted for this study at a cost that was 1.6 times higher than the cost of terrace construction (coconut mat = US$ 5.23/m^2, terrace = US$ 3.30/m^2). In addition, the life span of a coconut mat is expected to be about 3–4 years, while theoretically, a terrace can remain for many decades.

Based on results of this study, terraces are successful at increasing nekton habitat. While many dredged material marshes, including terraces, appear to be successful at providing habitat for nekton use, the restored habitat appears to differ from unmanaged marsh (restoration goal) to such an extent that the restored and unrestored habitat support different nekton community composition. At terrace sites, substrate disturbance due to construction of the terraces may be a major factor in determining the differences in nekton composition. Until detritus can build up in the substrate around the terraces, a benthic community that resembles a natural site may not be achieved. This process may take decades.

Although not tested in this study, it may be feasible to enhance the benthic community by installing coconut matting in selected locations near terraces. Further studies should evaluate the cost effectiveness and benefits of installing coconut matting in restoration projects to recruit SAV and an infaunal community. Future research on terrace success at providing nekton habitat should address nekton growth rates and correlate nekton composition to the infaunal community. In addition to investigating the potential influences that organic matter may have on nekton compositions, another consideration that was not addressed by this study is how much secondary production the terraces and coconut-matted marshes are providing. Investigating nekton growth and mortality within restored and unmanaged habitats could suggest whether restored sites are increasing secondary production in an area or merely providing a habitat where nekton congregates (West et al., 2000; Minello and Webb, 1997).

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