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Nekton utilization of restored habitat in a Louisiana marsh

Christina Samantha Bush

Louisiana State University and Agricultural and Mechanical College

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NEKTON UTILIZATION OF RESTORED HABITAT IN A LOUISIANA MARSH

A Thesis

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Louisiana State University and
Agricultural and Mechanical College
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in

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Christina S. Bush
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ABSTRACT

Marsh terracing and coconut fiber mats are two restoration techniques currently being implemented at Sabine National Wildlife Refuge. We tested two hypotheses related to these restoration techniques: (1) marsh terracing enhances nekton assemblages, so that nekton use is similar to those at natural marsh edges, and (2) coconut matted marsh edges enhance SAV recruitment, so that nekton use is similar to those found at natural marsh edges. Samples from terraces and coconut matted marsh were compared to samples from the natural marsh and open water habitats. We measured the following variables at each habitat: (1) nekton density and abundance, (2) nekton biomass, (3) nekton size, (4) nekton diversity, and (5) nekton species composition. Using a collapsible throw trap with 3 mm mesh and a 3 x 2 m straight seine, 180 nekton samples were collected at four sampling dates from winter 2001 to fall 2002. Six habitat types were sampled: (1) natural marsh edge (< 1 m from marsh – water interface), (2) coconut matted marsh edge, (3) terrace edge, and (4), (5), (6) open water (50 m from marsh – water interface for all 3 edge types). Environmental variables that may be influenced by restoration status were also monitored at each habitat. Samples from terraces and coconut matted marsh were compared to samples from the natural marsh edge and open water habitat. Results indicated that nekton variables at coconut matted edge and open water, natural edge, and terrace edge were not significantly different ($p > 0.332$). Nekton density, biomass, and diversity were lower in open water habitats associated with natural marsh and terraces than in the other four habitats (p <

0.0001). Coconut matted and natural marsh edges had significantly higher numbers of some benthic dwelling species (e.g. blue crab *Callinectes sapidus,* white shrimp *Litopaenaus setiferous,* naked goby *Gobiosoma bosc,* clown goby *Microgobius gulosus*, Gulf pipefish *Syngnathus scovelli*) than terrace marsh edges ($p < 0.0004$), potentially due to differences in substrate caused by construction of the terraces. Researchers have suggested that decreased benthic habitat quality at dredged material marshes is related to an impaired infaunal community and differences in sediment texture. At Sabine NWR, terracing and coconut matting increased nekton utilization 4.5 times above that in open water habitat by enhancing and increasing marsh edge relative to open water. The value of terrace and coconut matted marsh habitat for individual species may vary depending on their niche requirements. Future research on terrace success at providing nekton habitat should address nekton growth rates and correlate nekton composition to the infaunal community.

INTRODUCTION

Due to a combination of natural and anthropogenic causes, land is currently lost from Louisiana's coast at >33.5 mi^2/yr (Barras et al.1994). Marsh loss has been a major issue of concern in south Louisiana because of environmental impacts that include the loss of fishery habitat. Approximately 94 – 98 % of the commercial catch by weight for the southeastern U.S. and the Gulf of Mexico is made up of estuarine-dependent species (Chambers 1992). In south Louisiana, commercial fisheries were valued at $345 million in 2001 (NMFS).

Scientists and marsh managers are implementing various restoration techniques to slow marsh loss and restore fishery habitat, but few studies have quantitatively evaluated the fish assemblages associated with different restoration techniques. A summary of what has been studied with regards to fishery habitat and restoration is presented in this introduction.

Important Microhabitats for Fishery Species

When designing a restoration project for fishery habitat, managers strive to include the microhabitats that support higher diversity and densities of fishery species. Submerged aquatic vegetation (SAV) beds, the marsh surface, and the marsh edge are commonly accepted to sustain high densities of fishery species. These habitats are important because they provide: (1) increased refuge from a) predators, b) strong currents, and c) wave energy (Orth 1977, Keddy, 1982, 1983, Boesch and Turner 1984, McIvor and Rozas 1988, Fonseca 1996, Jacobsen and Berg 1998, Minello 1999) and (2) increased food availability due to the presence of a) invertebrates, b) benthic algae, c) epiphytic algae and, d) detritus (Darnell 1961, Odum and Heald 1975, Kneib and Stiven 1978, Sullivan and Moncreiff 1990, Kwak and Zedler 1997).

Submerged Aquatic Vegetation

Open water habitats attract fishery species when SAV is present (Adams 1976, Heck and Orth 1980, Irlandi and Crawford 1997). Jacobsen and Berg (1998) studied enclosures with and without SAV and with various predation pressures. They found that juvenile perch *Perca fluviatilis* use SAV microhabitat as a predation refuge during the day, and feed on plankton in the nearby non-vegetated open water at night. In Massachusetts, Heck et al. (1989) conducted trawl sampling from eelgrass and nearby non-vegetated areas. Twenty-two nekton species were found in eelgrass beds, while only 13 nekton species were found in the non-vegetated open water. Mean fish abundance was significantly greater in eelgrass beds (185 individuals) than in the non-vegetated open water (59 individuals).

Many marsh restoration projects are designed to increase SAV recruitment with varying levels of success and monitoring. To increase the abundance and diversity of fishery species in an area, restoration projects should promote favorable conditions to support SAV growth.

Marsh Surface and Edge

The marsh surface is a microhabitat that is available to nekton only when the marsh is flooded. Thus, marsh elevation and proximity to sub-tidal areas are important influences on nekton utilization of the marsh surface. Marsh edge is a general term used to describe the interface between the marsh surface and water, where emergent vegetation may be present. Marsh edge, by definition, is permanently submerged, so it is constantly accessible to nekton. The marsh edge provides increased refuge from predators and strong currents and increased food availability due to relatively high invertebrate and detritus availability when compared to open water non-vegetated habitat. In Cocodrie, Louisiana, Peterson and Turner (1994) found that abundance of most nekton species was highest within 3 m of the marsh edge. In Galveston Bay, Texas, Minello et al. (1994) found that incorporating tidal creeks into created salt marshes may increase habitat value for bay anchovy *Anchoa mitchilli* and inland silverside *Menidia beryllina*, which are food sources to commercially important species. Thus, secondary productivity is correlated to the amount of marsh surface and edge habitat (Baltz et al. 1993, Zimmerman and Minello 1984, Zimmerman et al. 1991, Zimmerman et al. 2000).

When marsh begins to deteriorate, the amount of edge habitat may temporarily increase; however, this effect will only increase secondary production for a short time (Gosselink 1984, Browder et al. 1985, Rozas and Reed 1993, Chesney et al. 2000, Zimmerman et al. 2000, Delaney et al. 2000). Many marsh restoration projects are designed with few tidal creeks and ponds, limiting the amount of marsh edge habitat that is provided (Delaney et al. 2000, Shafer and Streever 2000). To slow the loss of fish habitat, restoration projects should be designed to include an optimal amount of marsh edge (Minello et al. 1994). Restored marsh edge can be successful at sustaining fish use similar to that found by natural marsh edge. For example, Williams and Zedler (1999) studied fish assemblages at Sweetwater Marsh for eight years and found that a tidal creek channel’s physical properties (i.e.

curvature, slope grade, etc.) are more important in determining fish use than its restoration status (i.e. created or natural).

Restoration

Ecology

Ecological restoration aims to create sustainable ecosystems to replace other degraded, damaged, and destroyed ecosystems (SER 2002). Restoration success relies on how the existing compositional and structural elements of the ecosystem are incorporated into the modified ecosystem. Natural ecosystems develop over a geological time that is extremely slow compared to the rapid rate of ecosystem destruction. Ecosystem restoration is generally expected to acquire many of the functions of a natural ecosystem within a relatively short period of time (for most permitted mitigations, the time frame is 5 years). To most ecologists, it is unrealistic to assume that a restored ecosystem can support all of the functions of a natural ecosystem after such a limited time (Streever 2000, Hobbs and Harris 2001). Thus, if restoration is to be successful in a short period of time, clear goals for specific ecosystem functions must be set before project construction.

Marsh Restoration Techniques

In the field of marsh restoration, numerous techniques have been implemented to mitigate land loss and increase fish habitat (Minello and Webb 1997, Minello 1999, Mitsch and Gosselink 2000). Approaches include using dredged material to create berms along eroding canals, diverting freshwater channels over a marsh area to restore natural sediment accretion processes, creating impoundments by controlling water levels, planting marsh vegetation on dredged material, planting

SAV in the form of plugs, seedlings, sods, seeds (Fonseca 1994), and excavating upland areas that are adjacent to marsh areas (Zedler 2001).

Functionality of created marshes often depend more on environmental and physical factors than marsh age (Fonseca et al. 1983, Sacco et al. 1994, Boyer et al. 1995, Levin et al. 1996, Streever 2000). Thus, project biologists are particularly concerned with geomorphological features such as marsh elevation, area-perimeter ratios, total size of the habitat, open water fetch distances, orientation, bank slopes, habitat heterogeneity, and marsh edge (Delaney 1994, Darnell 1997, Shafer and Streever 2000). New techniques such as terracing use dredged material to construct geomorphological features that will promote a complex ecosystem with many functions, similar to a natural ecosystem.

Marsh managers are continually experimenting with new options for marsh restoration, such as marsh terracing and the use of coconut mats as substrate. These two techniques are designed to increase habitat value for fishery species in the shallow marshes of Louisiana.

Terracing

Terracing is one of many techniques that utilize dredged material planted with *Spartina alterniflora*. Early projects were conducted before wetlands were protected with no-net-loss policies and legislation such as Section 404 of the Clean Water Act. Motivation came from lowering the cost of maintaining ship channels by using vegetative plantings to stabilize dredge spoils along canal banks (Seneca et al. 1976). The first planting occurred in 1969, when Woodhouse, Seneca and Broome experimentally planted existing dredged material sites in North Carolina for the U.S. Army Corps of Engineer's Coastal Engineering Research Center (Woodhouse et al.1974, Seneca et al. 1976, Woodhouse 1979). Currently, dredged material marshes have been constructed in Florida, Georgia, Louisiana, Maryland, Mississippi, New York, North Carolina, South Carolina, Texas, and Virginia (Garbisch 1977, LaSalle et al. 1991, Landin 1997). Due to increasing concern for wetland habitat loss, the success criteria of dredged material marshes has grown from stabilizing banks to mimicking the functions of a naturally occurring salt marsh (Seneca et al. 1976, Webb and Newling 1985). Use of dredged material has continued to grow through programs such as the Coastal Wetlands Protection, Planning, and Restoration Act that aim to restore coastal marshes.

Terracing is increasing in occurrence and is used to replace submerged marsh, decrease wave energy, and decrease open water fetch in shallow embayments often surrounded by a natural marsh fringe (Steyer 1993, Rozas and Minello 2001). Terraces are ridges of discontinuous marsh constructed from dredged material on site that are vegetated with *S. alterniflora* (Steyer 1993).

Many dredged material salt marshes have a low marsh edge: area ratio, when compared to natural marshes (Minello et al. 1994). Consequently, terraces are designed as linear structures with gradually sloping sides to maximize the amount of marsh edge habitat (Steyer 1993, Rozas and Minello 2001). Terraces, if built close together, can create a ponding effect, which has been known to be lacking in other dredged material marshes (Shafer and Streever 2000). Another benefit of terracing is that restoration can occur with a continuous connection to tidal marsh habitats, which allows for the presence of marine transient species (Kneib

1997). This proximity may also lead to a shorter recruitment period for native vegetation, fish, and invertebrates (Minello and Webb 1997).

Rozas and Minello (2001) studied the first terraces built in the U.S. in 1990 at Unit 1 of Sabine NWR, and concluded that maximizing marsh edge increases fish habitat in restored marshes. Since the 1990 terraces were built, numerous terraces have been constructed in various patterns. The 1990 terraces were designed in a checkerboard pattern, but the later-built Unit 7 terraces at Sabine NWR were designed as chevron shapes, so that the same ecological benefits could potentially be achieved at a lower cost (Pease, personal communication, Sept 2001). The implications of this design change on fishery habitat value have yet to be determined, and are the subject of this study.

Coconut Matting

Many projects designed to increase SAV growth have failed because seedlings are destroyed by waves and currents before they can be established (Fonseca 1996). A new restoration technique is the use of coconut fiber mats as a substrate to recruit the growth of SAV. Coconut fiber is made out of coconut hulls and is commonly used in stream bank stabilization projects. In Cameron Prairie NWR, Louisiana, Boustany (2000) used pre-vegetated fibrous biodegradable mats (similar to coconut mats) to establish *Vallisneria americana*. Establishment was successful at only one of three sites, potentially due to factors such as the timing of the initial planting, salinity, turbidity, and mat placement. Although no studies have addressed SAV colonization on coconut mats, SAV restoration techniques do include installing coconut mats imbedded with SAV seeds or seedlings in

Chesapeake Bay. Coconut mats are also used as a substrate for some laboratory experiments. While studying micropropogation of *Ruppia maritima,* Woodhead and Bird (1998) successfully rooted *R. maritima* to coconut mats in outdoor aquariums.

Monitoring Nekton Utilization of Restored Habitat

Restoration projects are often designed to create proper hydrology and physical characteristics, where plants and animals are expected to re-establish (Palmer et al. 1997, Williams and Zedler 1999, Williams and Desmond 2001). Due to 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. Based on the speed at which nekton can colonize an area and the economic importance of fishery species, a success criteria of some marsh restoration projects is to provide habitat for nekton (Mitsch and Gosselink 1986, Kneib 1997, Minello 2000).

By monitoring the effectiveness of restoration projects, managers can assess which technique will work most effectively for a project. To gain insight to the functioning of the restoration project, researchers compare data collected from the project area to data collected at the same site before construction or to data collected from nearby natural marsh areas that are similar to the pre- or post-construction conditions. Pre-construction monitoring of the project area is not completed for many restoration projects due to financial limitations.

Approaches

In all approaches, researchers concentrate on comparing a constructed and natural site that have similar hydrologic regimes, location, and topography

(Cammen 1976a, 1976b, Lindau and Hossner 1981, Webb and Newling 1985, Sacco et al. 1994, Craft et al. 1999, West et al. 2000, Williams and Desmond 2001). When comparing one restored marsh to a natural marsh, no conclusions can be drawn about restoration success in general; the researcher can only infer conclusions about the sampled location, else the error of pseudoreplication has been committed (Hurlbert 1984).

Researchers have attempted to make generalizations about habitat success by including many marshes restored with similar techniques in their analysis (Craft et al. 1988, Minello and Zimmerman 1992, Minello and Webb 1997, Melvin and Webb 1998, Shafer and Streever 2000). Some restoration projects have succeeded in increasing nekton productivity and abundance (Williams and Zedler 1999, Rozas and Minello 2001). However, 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).

Approaches to monitoring fish communities at restoration projects have included: (1) experiments comparing fish growth rates at restored sites and nearby natural sites (West et al. 2000), (2) diversity comparisons between restored and natural marsh (Williams and Zedler 1999), (3) abundance (i.e. catch) comparisons between restored and natural marsh (Williams and Zedler 1999), (4) density comparisons between restored and natural marsh (Minello and Webb 1997, Rozas and Minello 2001), (5) biomass (i.e. secondary productivity) comparisons between restored and natural marsh (Rozas and Minello 2001), and (6) size comparisons of abundant species between restored and natural marsh (Rozas and Minello 2001).

Studies often include more than one of these approaches, because each comparison may not provide an adequate measure of habitat function. For instance, Minello and Webb (1997) found that total density comparisons can be affected by an overwhelming abundance of schooling species or opportunistic species that have a high tolerance to degraded systems. Williams and Zedler (1999) suggest including information on the presence or relative abundance of individual species with narrower habitat requirements.

At the East Mud Lake Marsh Management Project in Louisiana, managers monitored fish use by comparing fish communities at the restored habitat to natural reference marshes both before and after construction (LDNR 1998). The project goal was to decrease the rapid movement of high-salinity water from the Calcasieu Ship Channel into the project area by building water control structures that allow for fish movement into and out of the project area. Researchers found that the project area sustained densities of resident nekton species similar to densities found in the reference marsh. However, densities of transient marine species were lower in the project area than the reference area. Researchers concluded that the water control structures were impeding fish movement into and out of the project area. By comparing densities between reference areas and restored areas, researchers determined that part of the restoration goal was not met. This outcome has been incorporated into future projects to develop more suitable water control structures.

At Sabine NWR, Rozas and Minello (2001) monitored the 1990 terraces by collecting 1-m^2 drop trap samples in spring and fall, when most transient marine species enter the marsh. The success of the restoration project was measured by comparing the project area to nearby reference marsh areas that resembled the project area prior to construction. The data that was compared between the project and reference natural area included nekton length, biomass, size, and composition, so that patterns can be traced through more than one attribute of nekton communities. Researchers concluded that habitat utilization at terrace ponds was higher than at pre-existing open water conditions, but terraces were not functionally equivalent to natural marsh because of differences in species composition.

Research Objectives

At Sabine NWR, the effects of saltwater intrusion and marsh subsidence on wetland areas are being counteracted by restoration projects such as terracing. The refuge is also interested in restoration techniques to increase SAV recruitment and growth, leading to an interest in testing the effects of coconut mats.

Terracing and coconut fiber mat projects are new restoration techniques that should be monitored to determine their effectiveness. We tested two hypotheses related to these restoration techniques: (1) marsh terracing enhances nekton assemblages, so that nekton use is similar to those at natural marsh edges, and (2) coconut matted marsh edges enhance SAV recruitment, so that nekton use is similar to those found at natural marsh edges. Samples from terraces and coconut matted marsh were compared to samples from the natural marsh and open water habitats. We measured the following variables at each habitat: (1) nekton density and abundance, (2) nekton biomass, (3) nekton size, (4) nekton diversity, and (5) nekton species composition. Environmental variables that may be influenced by restoration status were also monitored at each habitat.

METHODS

Study Site

Data were collected in tidal brackish marshes at Sabine NWR between Calcasieu and Sabine Lakes (Cameron Parish, Louisiana) (Figure 1), where the emergent vegetative community is composed of *Spartina patens*, *Paspalum vaginatum*, *Scirpus olneyi*, and *Phragmites australis* (Linscombe et al. 2001). In 1949, the area was mostly intermediate marsh with dominant vegetation consisting of *Cladium jamaicense*. This change in the vegetative community may reflect increasing salinities in the area as a result of disturbances caused by ship channel construction and maintenance and gas exploration. The marsh acreage on the refuge is also decreasing due to these human disturbances. Currently, the refuge is composed of 16,124 hectares of open water and 34,264 hectares of grassland/herbaceous/marsh land.

Restoration Techniques and Construction

Terraces

The Unit 7 terrace field is located in a 3-km^2 open water embayment that has developed over the past 50 years (Figure 2). This shallow embayment is surrounded by natural marsh fringe with some small natural marsh islands (water depth = 60 – 80 cm). Terraces were constructed in 1996, 1997, 1998, 1999, and 2001. Terraces in this unit were designed to be perpendicular to predominant winds to decrease wave energy and erosion in the embayment, and to encourage SAV growth (Pease, personal communication). Tides in the area are diurnal and the range can be as high as 0.30 – 0.45 m.

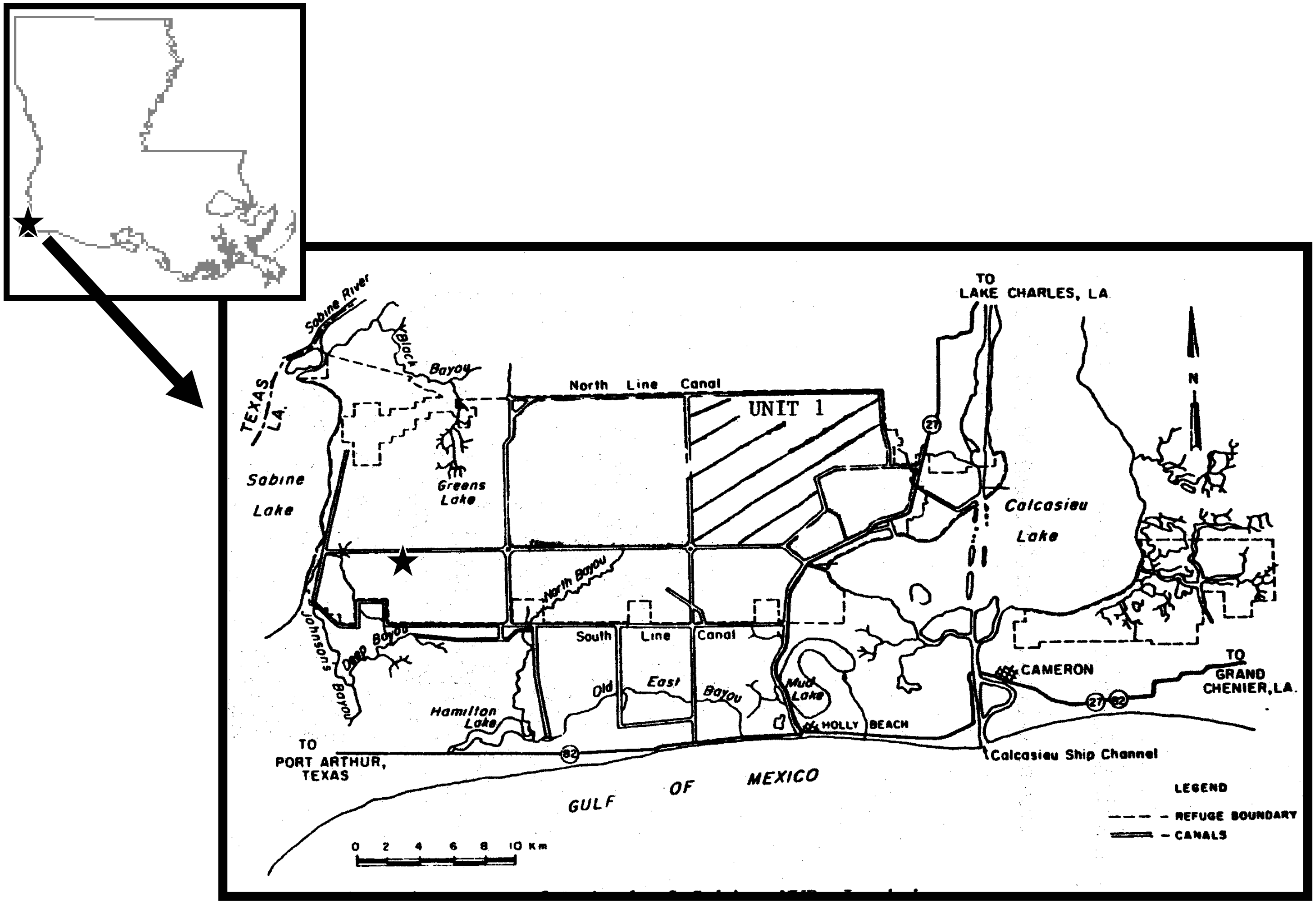

Figure 1. Location of the Unit 7 terrace embayment in Unit 7 at Sabine NWR.

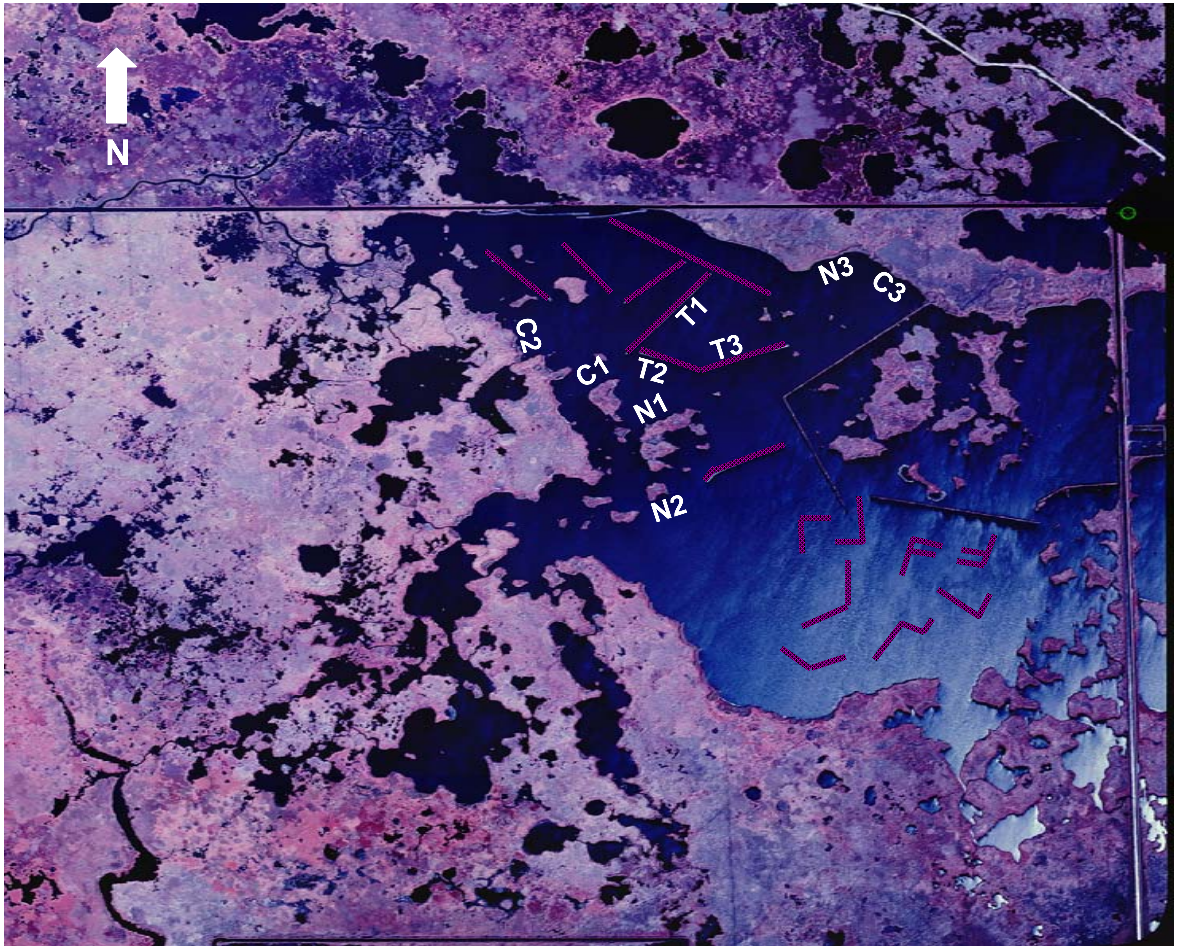

Figure 2. Location of the sample sites within the Unit 7 terrace embayment at Sabine NWR. N1 – N3 represent natural marsh sites. T1 – T3 represent terrace sites built in 1999. C1 – C3 represent coconut matted sites. All lines represent terraces. Scale: 1 inch = 653 m.

We sampled terraces built in 1999 that were approximately 10 m wide and ranged in length from 244 m to 468 m (Figure 3). Terraces were built as mitigation for oil/gas exploration for $33/m (Pease, personal communication). Terraces were constructed using a backhoe that collected sediment approximately 10 m away from the terrace. Sediment was loaded to form the terrace with gently sloping sides to promote emergent vegetation growth (width = 10 m) and a crown that was approximately 0.75 m above the water level. Sediment was collected from both sides of the terrace in a random pattern to prevent a continuous trench from forming beside the terrace (Pease, personal communication). The holes formed by sediment dredging were expected to fill in over time due to natural sediment deposition. However, at the time of sampling (3 yrs after construction), holes were still approximately 2 m deep. Shortly after construction, terraces were planted with *Spartina alterniflora*. Currently, terraces have vegetation emerging from the water < 0.75 m from the marsh – water interface. Natural marsh edges in the area had a vertical edge with some vegetation overhanging the bank, but no vegetation emerging from the water.

Figure 3. Unit 7 terraces built in 1999.

Coconut Mat Installation

Coconut fiber mats (2.2 x 5.4 m) were purchased for $10/m, and installed at each of 3 randomly selected natural marsh edges in November 2001. Mats were composed of loosely woven thick fiber threads (Figure 3). 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. At each natural marsh edge, two coconut mats were installed: (1) < 1 m from the marsh edge and (2) 50 m from the marsh edge.

Figure 4. From top left, clockwise: (1) coconut mat texture before installation, (2) rebar and a coconut mat before installation, (3) coconut mat during installation, (4) white PVC poles mark the edges of the installed coconut mats.

Design

Two sample designs were used: the first was used to document year round nekton assemblages and the second was used to increase the number of nekton sampled in spring and fall when most marine transient species are present.

Year Round Design

Sampling occurred quarterly over the course of one year (12/14 – 12/15/01, 2/21 – 2/22/02, 5/20 – 5/22/02, & 9/9 – 9/10/02) at each of 9 sites (Figure 2). Nekton samples were collected from 18 sites, along transects located in 3 habitat types: (1) terraces built in 1999, (2) coconut matted natural marsh, and (3) natural marsh. For each habitat, triplicate sites were randomly selected. In each site, a randomly located point was selected and samples were taken at 2 points along a transect, perpendicular to the marsh edge: (1) < 1 m from the marsh – water interface beyond emergent vegetation (edge) and (2) 50 m away from the marsh edge (open water). It was assumed that each habitat (terrace edge, marsh edge) did not affect the 50 m sample. The 50 m samples were used as a control for conditions that would exist if the restoration was not completed. The natural marsh edge samples represented restoration goals. By sampling the marsh edge and the open water at the same time, variations due to changing environmental conditions are removed. Environmental variables were collected for every sample.

Seasonal Design

Intensive sampling occurred at the spring (5/2002) and fall (9/2002) samplings, when most marine transient species are known to be present in the marsh (Czapla et al. 1991). In addition to year round samples, samples at these dates also consisted of: 1) 14 throw trap samples taken < 1 m and 50 m from 7 randomly selected natural marsh sites, 2) 34 throw trap samples taken < 1 m and 50 m from 17 randomly selected sites on terraces built in 1999, 3) 12 seine net trawls at each site sampled for the year round sampling design. Environmental variables were collected for all seine net samples.

Sampling Techniques

Throw Trap

A modified Wegener ring (Weinstein and Brooks 1983) that encloses the entire water column was used to sample the nekton community. For sampling shallow-water habitats to compare fish use, throw traps are considered the best option (Rozas and Minello 1997). The Wegener ring consists of a 1-m^2 throw trap that is collapsible and circular with mesh sides (mesh size = 1.6 mm). A heavy metal ring attaches to the bottom of the throw trap and a floating ring attaches to the top. The throw trap is commonly used to sample small adult fish, juveniles of larger fish species, and decapod crustaceans (Chick et al. 1992, Raposa and Roman 2001). The trap was tossed ~1 m from the bow of a boat into the sunlight to prevent nekton movement due to shadows. 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 x 30 cm) was used to clear nekton from the trap. The dip net was swept in a circular motion, creating a funnel that forces organisms toward the middle of the trap. The dip net was then dragged up the middle of the trap. Duffy (1997) suggested that hand netting grass shrimp *Palaemonetes pugio* from the throw trap removed 97 % of the organisms, when six consecutive sweeps were made of the entire basal area of the throw trap. For this study, ten consecutive sweeps without organisms were completed before the trap was considered free of nekton. Nekton samples were stored on ice before returning to the laboratory.

Seine Net

Seine net trawls were conducted with a 3 m x 2 m straight seine (mesh size = 5 mm) using methods found in Peterson and Turner (1994) (Figure 2). Seine nets were dragged by two people perpendicular to the marsh edge. Each seine sample covered 30 m of marsh edge.

Nekton Processing

Nekton samples were frozen for storage. Nekton were identified to species or the lowest feasible taxon. Total lengths were measured to the nearest millimeter for fish and shrimp. Carapace width was measured to the nearest millimeter for crabs. All nekton were weighed to the nearest 0.001 g wet-weight to determine biomass (g/m^2).

Environmental Variables

Water Quality

At each site, water temperature (^{o} 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 for every sample.

Submerged Aquatic Vegetation

All SAV present in throw trap samples was removed and returned to the laboratory. The SAV was placed in a drying oven at 60 ^{o} C to a constant weight.

Emergent Vegetation

During the September 2002 sampling, emergent vegetation was sampled at each of the terrace and natural marsh edge sites, but not at the coconut matted sites (6 sites). Three 0.25 m^2 quadrats were randomly placed at each site and all standing vegetation was collected. In the laboratory, stems were identified, counted and dried to a constant weight (g) at 60 ^{o}C.

Sediment Organic Matter and Texture

Organic matter content of terrace and natural marsh sediment was examined in September 2002. Samples were collected at random locations in 4 habitat types: (1) 0 m from natural marsh (N = 4), (2) 0 m from terrace (N = 4), (3) 50 m from natural marsh (N = 2), and (4) 50 m from terrace (N = 2). Five 10-cm diam cores were collected from the top 5 cm of sediment at each location. Organic matter content was determined using methods similar to those in Moy and Levin (1991). Samples were homogenized, dried at 60 ^{o}C to a constant weight, weighed (initial weight), fired at 500 ^{o}C in a muffle furnace for 4 hours (to combust away all organic matter), and weighed again (final weight). Organic matter was calculated as: 1.00 – [(final dry weight)/(initial dry weight)].

Sediment texture was qualitatively evaluated on site.

Marsh – Water Edge Ratios

Following data collection, marsh – water edge ratios were calculated for each site following the description given by Delaney et al. (2000). Ratios were calculated using digital ortho-quarter 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.

Calculations and Analyses

Nekton Density

Density (nekton/m^2) was determined for each sample by summing the number of nekton collected in the throw trap.

Nekton Abundance

Abundance (nekton/trawl) was determined for each sample by summing the number of nekton collected in the seine net trawl.

Nekton Biomass

Biomass was determined for each sample by summing the weight of nekton found in each throw trap (g/m^2) or each seine net trawl (g/trawl).

Nekton Size

Size of individual species was quantified as the weight of each individual collected.

Nekton Diversity

Diversity was determined for each sample using the Shannon-wiener index of diversity (H'), Margalef's D index of diversity (Dmg), and Pielou's J index of evenness (J) (Magurran 1988). These indices were selected to measure the number of species present (diversity) and the relative proportions of species present (evenness).

Nekton Species Composition—Functional Groups

Species were divided into one of three functional groups based on life history strategies: (1) crustaceans, (2) benthic dependent fish, and (3) pelagic fish. Species composition was defined as the total catch of each functional groups at all sample dates. Seasonal throw trap samples were not included, so that comparisons between habitats could be made with equal sample sizes.

Statistical Analyses

The Statistical Analyses System (SAS Institute, Inc. 1981) was used for calculation of standard descriptive statistics. Due to the potential differences that may exist between two sampling techniques, statistics were run separately for throw trap and seine net samples.

Environmental variables, nekton density, biomass, size, and diversity were analyzed separately using a three-way mixed analysis of variance with factors including habitat type (coconut matted, natural, or terrace), sampling date (Dec 2001, Feb 2002, May 2002, or Sept 2002), and location (< 1 m or 50 m from marsh edge) (Tables 1 and 2). Variation due to sample site 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 ($p < 0.05$). Data were log transformed where necessary to achieve normality and homogeneity of variance.

Table 1. Factors entered into the model for the mixed ANOVA analyses for samples taken with a throw trap.

Factor	N	df	levels
habitat	3	2	coconut mat, natural, terrace marsh
distance from edge	2	1	< 1 m and 50 m
h*d		2	
month sampled	4	3	12/01, 2/02, 5/02, 9/02
h*m		6	
d*m		3	
h*d*m		6	
main effects total	24	23	
site(habitat)	33	32	
d*s(h)		32	
m*s(h)		96	
random effects total	33	160	

Table 2. Factors entered into the model for the mixed ANOVA analyses for samples collected with a seine net.

Factor	**N**	**df**	**levels**
habitat	2	1	natural, terrace marsh
distance from edge	2	1	< 1 m and 50 m
h*d		1	
month sampled	2	1	5/02, 9/02
h*m		1	
d*m		1	
h*d*m		1	
main effects total	8	7	
site(habitat)	6	5	
d*s(h)		5	
m*s(h)		5	
random effects total	6	125	

Differences in nekton species composition among habitats (coconut matted, natural, or terrace) and location (< 1 m or 50 m from edge) were compared using a Chi-square test. Chi-square was tested for the 13 most abundant species caught with a throw trap and the 5 most abundant species caught with a seine net. Only throw trap samples from sites sampled at every sampling date were used for Chi-square analysis (N = 12), and all seine samples were used for Chi-Square analysis. Significance was determined at $p < 0.05$.

To test for differences in nekton utilization of habitats by functional group, a Chi-square test was used (3 habitats x 2 distances x 3 functional groups). Using data from year round sampling with throw traps, the proportion of each functional group was compared among habitats and distances from edge. Species were categorized as one of three functional groups: (1) crustaceans, (2) benthic dependent fish, and (3) pelagic fish. Conditional independence was tested using a Cochran-Mantel-Hanzel test.

RESULTS

Environmental Variables

Water Quality

Temperature varied with season, and ranged between 12.54 and 29.39 °C. Salinity ranged between 1.11 and 2.21 g/L for all sample dates, except 2/2001, when salinities ranged between 4.30 and 4.65 g/L. Dissolved oxygen ranged between 2.99 and 10.24 mg/L. The pH ranged between 6.69 and 7.78. Secchi depths ranged between 3 and 50 cm. Water depths ranged between 30.0 and 84.5 cm.

Water depth was significantly higher at the terraces (edge = 61.83 ± 7.42 cm and open water = 69.92 ± 10.20 cm) than the coconut matted (edge = 44.57 ± 11.76 cm and open water = 56.17± 11.63 cm) or natural sites (edge = 50.14 ± 15.86 cm and open water = 57.04 ± 14.51 cm) (Table 3). Water depth was also significantly higher at open water associated with terraces than at terrace edges ($p < 0.023$) (Table 3). No significant differences were found among habitats for the following variables (Table 3): (1) water temperature, (2) salinity, (3) dissolved oxygen, (4) pH, (5) secchi depth.

Submerged Aquatic Vegetation

Biomass of SAV was not significantly different among the coconut matted, natural, and terrace sites (Table 3). Biomass of SAV was almost significantly greater at coconut matted open water than at coconut matted edge ($p = 0.055$) (Table 3).

Table 3. Environmental variables (mean ± SD) at each habitat type. P-values are from an ANOVA model that tested the relationship of each environmental parameter to independent variables and their interactions: habitat, distance from the marsh edge (< 1 m = edge, 50 m = open water), and date sampled. 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 do not have a mean listed.

ENVIRONMENTAL VARIABLES	COCONUT MAT		NATURAL		TERRACE		p > F	
	< 1 m	50 m	< 1 m	50 m	< 1 m	50 m	habitat	distance
TEMPERATURE (^{o}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
% ORGANIC MATTER IN SUBSTRATE	.	.	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	.	1.22 ± 0.12	.	**1.00 ± 0.00**	.	0.027	.
EMERGENT VEGETATION (kg/m^2)	.	.	7.88 ± 2.08	.	3.25 ± 1.33	.	0.117	.

Emergent Vegetation

Spartina alterniflora and *Paspalum vaginatum* dominated the emergent vegetation on the terraces. The natural marsh vegetation was dominated by *Spartina patens* and *P. vaginatum* at all locations with *Phragmites australis* forming an additional shrub layer at one (of 3) coconut matted and one (of 3) natural sites.

Emergent vegetation biomass ranged between 1.26 and 12.60 kg/m^2. Emergent vegetation biomass was not significantly different between natural marsh (7.88 ± 2.08 kg/m^2) and terraces (3.25 ± 1.33 kg/m^2) ($p = 0.117$) (Table 3).

Organic Matter

Organic matter in the substrate ranged between 2.58 and 41.70%. Organic matter content was not significantly different between natural and terrace sites (Table 3).

A t-test comparing natural edge and terrace edge suggested that organic matter content was significantly less at the terrace edge ($p = 0.003$) (Table 3).

Sediment Texture

Woody debris and plant detritus covered the coconut mats at the edge and open water samples. Silt combined with woody debris and plant detritus comprised the texture of the natural edges. Clay silt comprised the texture of the natural open water samples. Clay comprised the texture of the terrace edge and open water samples.

Marsh – Water Edge Ratio

Marsh – water edge ratios ranged between 1.00 and 1.54. The marsh water - edge ratio was significantly less at the terrace edge (1.00 ± 0.00) than coconut matted edge (1.23 ± 0.28) and natural edge (1.22 ± 0.12) ($p = 0.027$) (Table 3).

Nekton Assemblages

Throw Trap

A total of 644 animals (46% crustaceans) were collected with a throw trap. Total biomass was 198.4 g wet weight (57% crustaceans).

Seine Net

A total of 1665 animals (40% crustaceans) were collected with a seine net. Total biomass was 1332.9 g wet weight (39% crustaceans).

Catch Abundance

Frequently collected species (> 50 individuals) were often collected seasonally. Frequently collected crustaceans included blue crab *Callinectes sapidus*, brown shrimp *Farfantepenaeus azteca*, white shrimp *Litopenaeus setiferus*, grass shrimp *Palaemonetes* spp. (Table 4). Frequently collected fish included bay anchovy *Anchoa mitchilli*, juvenile gulf menhaden *Brevoortia patronus*, naked goby *Gobiosoma bosc*, inland silverside *Menidia beryllina*, and clown goby *Microgobius gulosus*.

Infrequently collected species (< 50 individuals) were mostly fish, except for the mud crab (Fam. Xanthidae) (Table 4). Fish included western mosquitofish *Gambusia affinis*, juvenile pinfish *Lagodon rhomboides*, juvenile Atlantic Croaker

Micropogonias undulatus, juvenile striped mullet *Mugil cephalus*, juvenile white mullet *Mugil curema,* and gulf pipefish *Syngnathus scovelli*.

Rarely collected species (< 10 individuals) were all fish (Table 4). They included juvenile silver perch *Bairdiella chrysoura*, ragged goby *Bollmannia communis*, juvenile bay whiff *Citharichthys spilopterus*, juvenile sand sea trout *Cynoscion arenarius*, bayou killifish *Fundulus pulvereus*, juvenile spot *Leiostomus xanthurus*, rainwater killifish *Lucania parva*, and juvenile speckled worm eel *Myrophis punctatus*.

Table 4. Total catch of each species collected in the Unit 7 terrace embayment, categorized by the frequency of collection.

FREQUENTLY COLLECTED (> 50 individuals)	**TOTAL**	**INFREQUENTLY COLLECTED (< 50 individuals)**	**TOTAL**	**RARELY COLLECTED (< 10 individuals)**	**TOTAL**
Anchoa mitchilli	410	*Lagodon rhomboides*	15	*Bairdiella chrysoura*	2
Brevoortia patronus	461	*Micropogonias undulatus*	38	*Bollmannia communis*	1
Calinectes sapidus	77	*Mugil cephalus*	14	*Citharichthys spilopterus*	2
Farfantepenaeus azteca	195	*Mugil curema*	12	*Cynoscion arenarius*	4
Gobiosoma bosc	78	*Syngnathus scovelli*	28	*Fundulus grandis*	1
Litopenaeus setiferous	917	Fam. Xanthidae	37	*Fundulus pulvereus*	1
Menidia beryllina	141			*Gambusia affinis*	8
Microgobius gulosus	58			*Leiostomus xanthurus*	1
Palaemonetes spp.	249			*Lucania parva*	6
				Myrophis punctatus	3

Crustacean Density and Abundance

Throw Trap

Total crustacean density was significantly lower at the open water habitats associated with natural marsh (0.88 ± 0.73 crustaceans/m^2) and terraces (0.13 ± 0.06 crustaceans/m^2) than at the natural edge (2.38 ± 0.58 crustaceans/m^2) and terrace edge (2.46 ± 0.43 crustaceans/m^2) and coconut matted sites (edge = 3.83 ± 0.21 crustaceans/m^2 and open water = 4.08 ± 1.32 crustaceans/m^2) (p = 0.0001) (Figure 5).

Seine Net

Total crustacean abundance was significantly higher at the terrace edge (40.62 ± 15.83 crustaceans/trawl) than at the open water associated with the terraces (7.20 ± 3.39 crustaceans/trawl), but not significantly different from the natural sites (edge = 44.19 ± 18.33 crustaceans/trawl and open water = 5.72 ± 2.48 crustaceans/trawl) ($p = 0.0001$) (Figure 6).

Fish Density and Abundance

Throw Trap

Total fish density was significantly lower at the open water samples associated with natural marsh (1.38 ± 0.65 fish/m^2) and terraces (0.26 ± 0.14 fish/m^2) than at the natural edge (3.19 ± 0.21 fish/m^2) and terrace edge (2.02 ± 0.56 fish/m^2) and coconut matted sites (edge = 5.67 ± 1.74 fish/m^2 and open water = 4.41 ± 1.38 fish/m^2) ($p = 0.0001$) (Figure 5).

Seine Net

Total fish abundance was significantly lower at the open water samples associated with the natural marsh (10.83 ± 2.46 fish/m^2) and terraces (20.33 ± 12.04 fish/m^2) than at the natural edge (67.5 ± 50.29 fish/m^2) and terrace edge (56.50 ± 33.21 fish/m^2) ($p = 0.0069$) (Figure 6).

Crustacean Biomass

Throw Trap

Crustacean biomass was significantly lower at open water associated with terraces (0.07 ± 0.06 g/m^2) than at the natural edge (0.78 ± 0.20 g/m^2) and terrace edge (1.17 ± 0.20 g/m^2) and coconut matted sites (edge = 1.17 ± 0.32

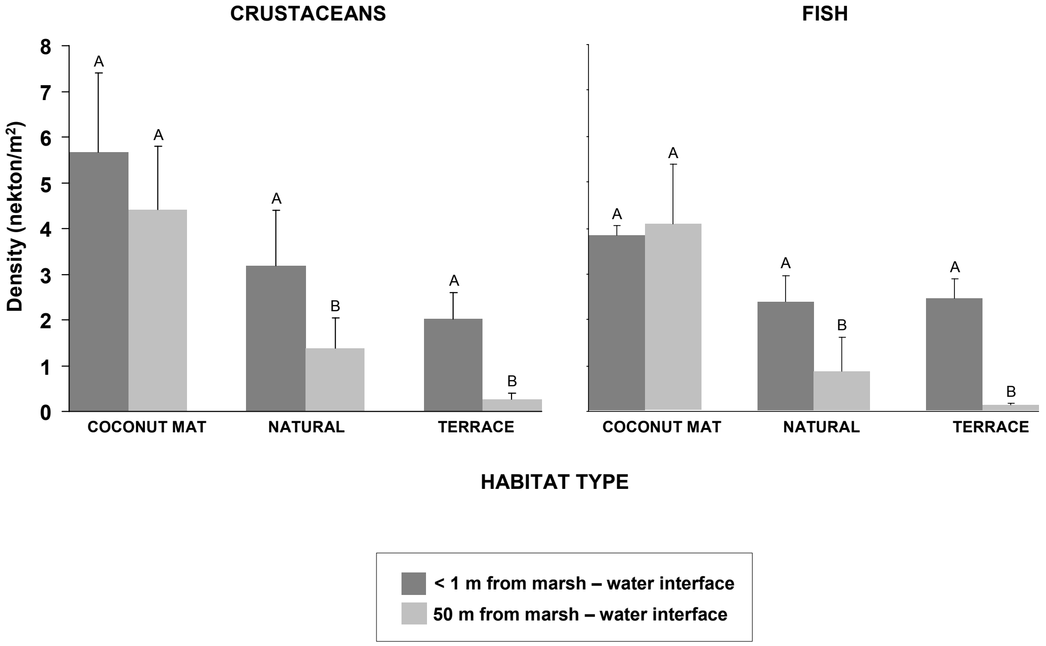

Figure 5. Mean density of decapod crustaceans and fish collected quarterly with a throw trap. Samples were collected at coconut matted marsh, natural marsh, and terraces. Within each individual graph, bars with different letters were significantly different ($p < 0.05$). Error bars represent standard errors. (Coconut mat: N = 12, Natural: N = 19, Terraces: N = 29).

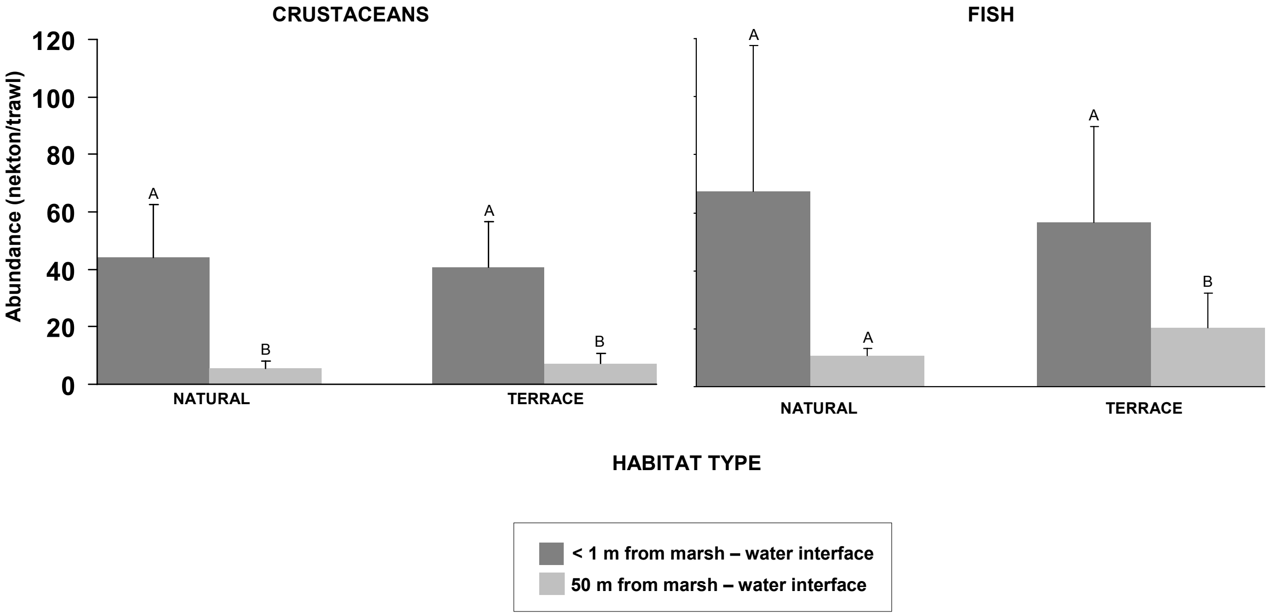

Figure 6. Mean abundance of decapod crustaceans and fish collected in spring and fall with a seine net. Samples were collected at natural marsh and terraces. Within each individual graph, bars with different letters were significantly different ($p < 0.05$). Error bars represent standard errors. (Natural: N = 6, Terraces: N = 6).

g/m^2 and open water = 0.89 ± 0.27 g/m^2), but not significantly different from the open water associated with the natural marsh (0.45 ± 0.40 g/m^2) ($p = 0.0259$) (Figure 7).

Seine Net

Crustacean biomass was significantly lower at the open water samples associated with the natural marsh (5.72 ± 2.48 g/trawl) and terraces (7.20 ± 3.40 g/trawl) than at the natural edge (44.19 ± 18.33 g/trawl) and terrace edge (40.61 ± 15.83 g/trawl) ($p > 0.0001$) (Figure 8).

Fish Biomass

Throw Trap

Fish biomass was significantly lower at the open water associated with terraces (0.10 ± 0.06 g/m^2) than at the natural edge (0.83 ± 0.21 g/m^2) and terrace edge (0.57 ± 0.16 g/m^2) and coconut matted sites (edge = 1.67 ± 0.73 g/m^2 and open water = 0.56 ± 0.20 g/m^2), but not significantly different from the open water associated with natural marsh (0.21 ± 0.10 g/m^2) ($p = 0.0280$) (Figure 7).

Seine Net

Fish biomass was significantly lower at the open water samples associated with natural marsh (7.32 ± 1.98 g) and terraces (16.97 ± 11.58 g) than at the natural edge (34.76 ± 17.75 g) and terrace edge (75.06 ± 25.79 g) ($p > 0.0001$) (Figure 8).

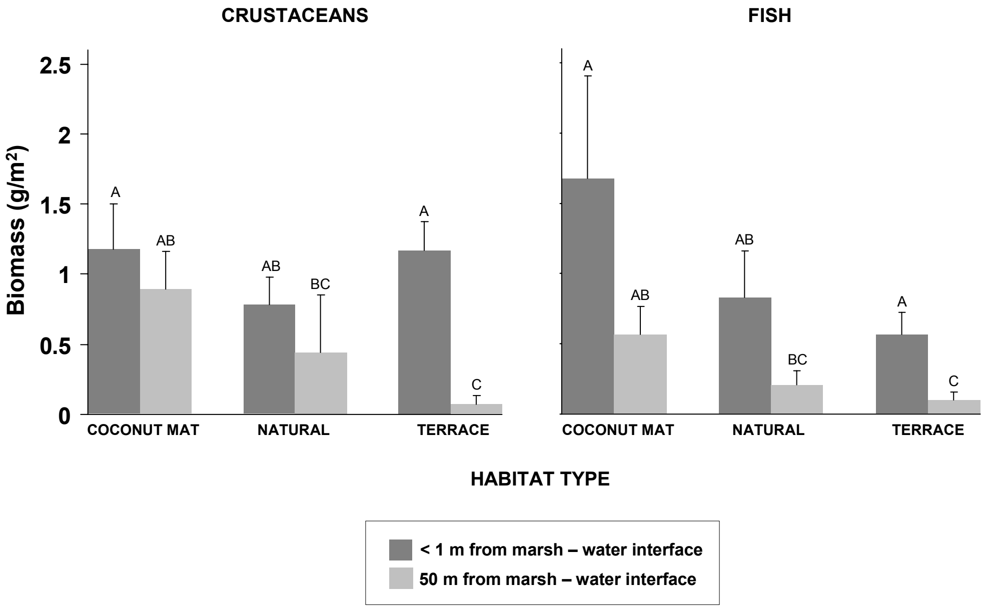

Figure 7. Mean biomass of decapod crustaceans, and fish collected quarterly with a throw trap. Samples were collected at coconut matted marsh, natural marsh, and terraces. Within each individual graph, bars with different letters were significantly different ($p < 0.05$). Error bars represent standard errors. (Coconut mat: N = 12, Natural: N = 19, Terraces: N = 29).

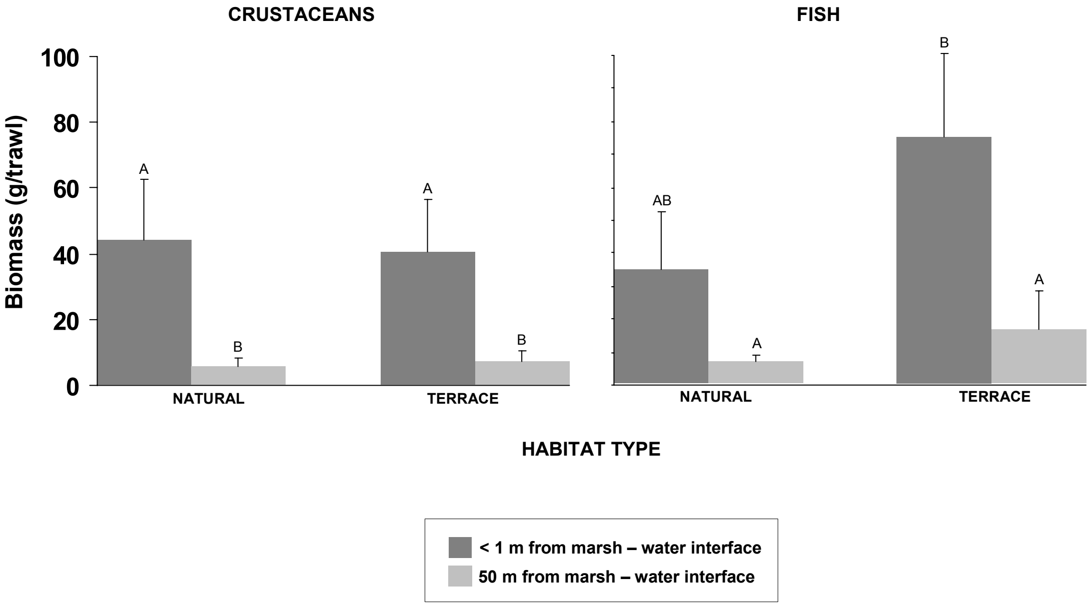

Figure 8. Mean biomass of total nekton, decapod crustaceans, and fish collected in spring and fall with a seine net. Samples were collected at natural marsh and terraces. Within each individual graph, bars with different letters were significantly different ($p < 0.05$). Error bars represent standard errors. (Natural: N = 6, Terraces: N = 6).

Size of Individuals

Throw Trap

Size analysis was conducted for species for which we collected 50 or more individuals. No significant differences were found among coconut matted sites, natural sites, or terrace sites for any species.

The overall mean size of individuals collected was: brown shrimp *Farfantepenaeus azteca* (462.12 ± 52.15 mg), white shrimp *Litopenaeus setiferus* (499.57 ± 43.33 mg), grass shrimp *Palaemonetes* spp. (166.20 ± 14.02 mg), bay anchovy *Anchoa mitchilli* (445.20 ± 60 mg), juvenile gulf menhaden *Brevoortia patronus* (203.19 ± 20.86 mg), naked goby *Gobiosoma bosc* (158.77 ± 14.85 mg), and clown goby *Microgobius gulosus* (125.97 ± 19.87 mg).

Nekton Diversity

The Shannon-wiener index (H') was the only diversity or evenness index used due to the high correlation of H' with Pielou's J (evenness) and Margalef's D (diversity) (R-sq = 0.92).

Throw Trap

Total nekton diversity (H') was significantly lower at the open water samples associated with natural marsh (0.09 ± 0.07) and terraces (0.03 ± 0.02) than at the natural edge (0.46 ± 0.09) and terrace edge (0.55 ± 0.07) and coconut matted sites (edge = 0.79 ± 0.14 and open water = 0.92 ± 0.15) ($p < 0.0001$) (Figure 9).

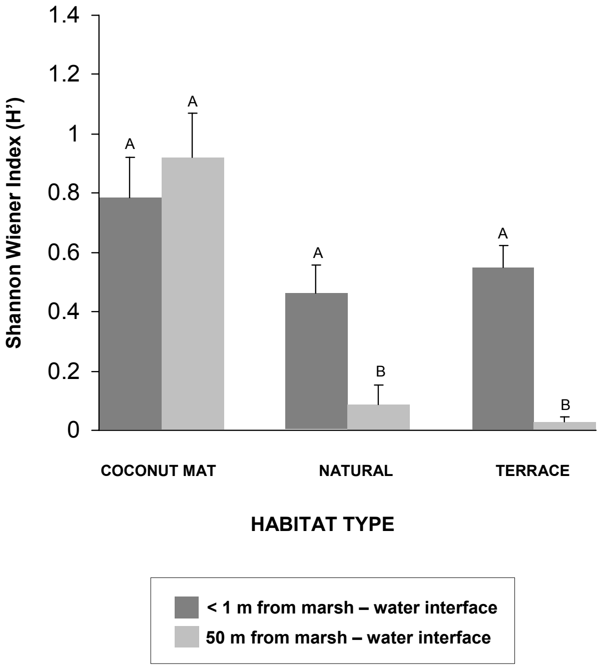

Figure 9. Mean diversity (H') of total nekton collected quarterly with a throw trap. Samples were collected at coconut matted marsh, natural marsh, and terraces. Bars with different letters were significantly different ($p < 0.05$). Error bars represent standard errors. (Coconut mat: N = 12, Natural: N = 19, Terraces: N = 29).

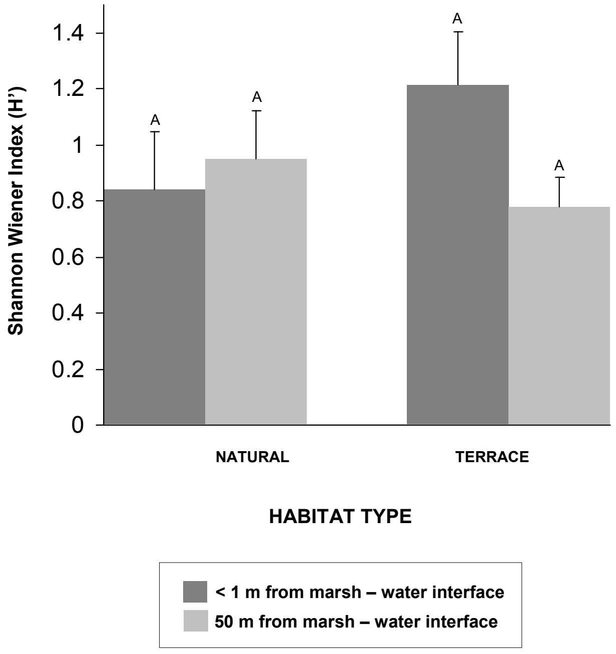

Figure 10. Mean diversity (H') of total nekton collected in spring and fall with a seine net. Samples were collected at natural marsh and terraces. Bars with different letters were significantly different ($p < 0.05$). Error bars represent standard errors. (Natural: N = 6, Terraces: N = 6).

Seine Net

Total nekton diversity (H') was not significantly different among the natural sites (edge = 0.84 ± 0.20 and open water = 0.95 ± 0.17) and terrace sites (edge = 1.22 ± 0.19 and open water = 0.78 ± 0.11) (Figure 10).

Crustacean Species Composition

Throw Trap

Total crustacean catch was significantly different at each habitat type (Chi-sq: p = 0.0004) (Table 5). Crustacean catch was highest at the coconut matted sites (edge = 48 individuals and open water = 50 indiv.), moderately high at the natural sites (edge = 17 indiv. and open water = 19 indiv.) and the terrace edge (15 indiv.), and lowest at the open water associated with terraces (1 indiv.).

No significant differences were found among habitats for the catch of brown shrimp *Farfantepenaeus azteca* (coconut matted: edge = 9 indiv. and open water = 3 indiv., natural: edge = 9 indiv. and open water = 0 indiv., terraces: edge = 6 indiv. and open water = 0 indiv.) (Table 5). No significant differences were found among habitats for the catch of grass shrimp *Palaemonetes* spp. (coconut matted: edge = 27 indiv. and open water = 7 indiv., natural: edge = 11 indiv. and open water = 6 indiv., terraces: edge = 2 indiv. and open water = 0 indiv.). No significant differences were found among habitats for the catch of mud crabs (Fam. Xanthidae) (coconut matted: edge = 5 indiv. and open water = 3 indiv., natural: edge = 2 indiv. and open water = 0 indiv., terraces: edge = 5 indiv. and open water = 1 indiv.). Catch of white shrimp *Litopenaeus setiferous* was highest at the coconut matted open water (22 indiv.)

Table 5. Total nekton individuals by habitat type and distance from edge, collected during quarterly sampling with a throw trap. Chi-square values reported tested differences of individual species abundances across habitats and distances. Chi-square was only tested for the most abundant species. Extra samples taken at terraces and natural marsh habitats in May and September 2002 were not included so that chi-square analysis could be performed on even sample sizes. P-values are bold when species abundance was significantly different among habitats ($p < 0.05$).

	COCONUT MAT		**NATURAL**		**TERRACE**		
DISTANCE FROM MARSH EDGE	**< 1 m**	**50 m**	**< 1 m**	**50 m**	**< 1 m**	**50 m**	**p > Chi-sq**
N	12	12	12	12	12	12	
CRUSTACEANS							
Callinectes sapidus	4	16	6	2	2	1	**0.0151**
Farfantepenaeus azteca	9	3	9	0	6	0	0.1213
Litopenaeus setiferous	3	22	4	13	8	0	**<0.0001**
Palaemonetes spp.	27	7	11	6	2	0	0.2901
Fam. Xanthidae	5	3	2	0	5	1	0.4594
TOTAL	35	32	17	19	15	1	**0.0004**
FISH							
Anchoa mitchilli	3	2	1	0	25	0	**0.0039**
Bairdiella chrysoura	0	0	0	0	0	0	.
Bollmannia communis	0	0	0	0	0	0	.
Brevoortia patronus	20	2	13	16	13	0	**< 0.0001**
Citharichthys spilopterus	1	0	0	0	0	0	.
Cynoscion arenarius	0	0	0	0	1	0	.
Fundulus grandis	0	0	0	0	0	0	.
Fundulus pulvereus	0	0	0	0	0	0	
Gambusia affinis	0	0	0	0	0	0	.
Gobiosoma bosc	21	24	14	0	1	0	**0.0013**
Lagodon rhomboides	0	0	1	0	0	0	.
Leiostomus xanthurus	0	0	0	0	1	0	.
Lucania parva	1	0	1	4	0	0	.
Menidia beryllina	8	0	8	0	5	0	.
Microgobius gulosus	1	18	9	6	3	1	**0.0007**
Micropogonias undulatus	6	2	2	1	6	0	0.3515
Mugil cephalus	0	0	0	0	0	0	.
Mugil curema	0	0	0	0	0	0	.
Myrophis punctatus	0	0	1	0	1	0	.
Syngnathus scovelli	9	6	0	4	2	0	**0.0421**
TOTAL	67	52	49	31	33	1	**<0.0001**

and the open water associated with the natural marsh (13 indiv.), moderately high at the terrace edge (8 indiv.), and lower at the coconut matted edge (3 indiv.) and natural edge (4 indiv.) and the open water associated with terraces (0 indiv.) (Chi-sq: $p < 0.0001$). Catch of blue crab *Callinectes sapidus* was highest at the coconut matted open water (16 indiv.), and lower at the coconut matted edge (4 indiv.), natural sites (edge = 6 indiv. and open water = 2 indiv.), and terrace sites (edge = 2 indiv. and open water = 1 indiv.) (Chi-sq: $p = 0.0151$).

Seine Net

No significant differences were found among habitats for the catch of crustaceans (natural: edge = 542 indiv. and open water = 33 indiv., terrace: edge = 415 indiv. and open water = 22 indiv.) (Table 6).

No significant differences were found among habitats for the catch of brown shrimp *Farfantepenaeus azteca* (natural: edge = 77 indiv. and open water = 20 indiv., terrace: edge = 28 indiv. and open water = 7 indiv.) (Table 8), blue crab *Callinectes sapidus* (natural: edge = 15 indiv. and open water = 2 indiv., terrace: edge = 12 indiv. and open water = 1 indiv.), white shrimp *Litopenaeus setiferous* (natural: edge = 396 indiv. and open water = 29 indiv., terrace: edge = 369 indiv. and open water = 22 indiv.), grass shrimp *Palaemonetes* spp. natural: edge = 146 indiv. and open water = 4 indiv., terrace: edge = 46 indiv. and open water = 0 indiv.), and mud crab (Fam. Xanthidae) (natural: edge = 0 indiv. and open water = 0 indiv., terrace: edge = 0 indiv. and open water = 0 indiv.).

Fish Species Composition

Throw Trap

Total fish catch was significantly different at each habitat type (Chi-sq: $p < 0.0001$) (Table 5). Fish catch was highest at the coconut matted sites (edge = 67 indiv. and open water = 52 indiv.), marginally high at the natural sites (edge = 49

Table 6. Total nekton individuals by habitat type and distance from edge, collected with a seine net during spring and fall samplings. Chi-square values reported tested differences of individual species abundances across habitats and distances. Chi-square was only tested for the 13 most abundant species. P-values are not included because no significant differences were observed ($p < 0.05$).

	SEINE NET			
	NATURAL		**TERRACE**	
DISTANCE FROM MARSH EDGE	**< 1 m**	**50 m**	**< 1 m**	**50 m**
N	6	6	6	6
CRUSTACEANS				
Callinectes sapidus	15	2	12	1
Farfantepenaeus azteca	77	20	28	7
Litopenaeus setiferous	396	29	369	22
Palaemonetes spp.	146	4	46	0
Fam. Xanthidae	0	0	0	0
TOTAL	542	33	415	22
FISH				
Anchoa mitchilli	48	31	171	111
Bairdiella chrysoura	1	0	1	0
Bollmannia communis	1	0	0	0
Brevoortia patronus	303	24	56	8
Citharichthys spilopterus	0	0	0	1
Cynoscion arenarius	2	0	0	0
Fundulus grandis	1	0	0	0
Fundulus pulvereus	1	0	0	0
Gambusia affinis	7	0	1	0
Gobiosoma bosc	1	0	0	0
Lagodon rhomboides	6	1	6	0
Leiostomus xanthurus	0	0	0	0
Lucania parva	0	0	0	0
Menidia beryllina	20	2	76	1
Microgobius gulosus	1	0	0	0
Micropogonias undulatus	13	7	0	0
Mugil cephalus	0	0	14	0
Mugil curema	0	0	12	0
Myrophis punctatus	0	0	0	0
Syngnathus scovelli	2	0	2	1
TOTAL	357	34	167	11

indiv. and open water = 31 indiv.) and the terrace edge (33 indiv.), and lowest at the open water associated with the terraces (1 indiv.).

No significant differences were found among habitats for the catch of Atlantic croaker *Micropogonias undulatus* (Table 5). Catch of gulf menhaden

Brevoortia patronus was lowest at the coconut matted open water (2 indiv.) and higher at the coconut matted edge (20 indiv.), natural sites (edge = 13 indiv. and open water = 16 indiv.), and terrace sites (edge = 13 indiv. and open water = 0 indiv.) (Chi-sq: $p < 0.0001$). Catch of bay anchovy *Anchoa mitchilli* was highest at the terrace edge (25 indiv.) and lower at the coconut matted sites (edge = 3 indiv. and open water = 2 indiv.), natural sites (edge = 1 indiv. and open water = 0 indiv.), and the open water associated with terraces (0 indiv.) (Chi-sq: $p = 0.0039$). Catch of gulf pipefish *Syngnathus scovelli* was highest at the coconut matted sites (edge = 9 indiv. and open water = 6 indiv.), and lower at natural sites (edge = 0 indiv. and open water = 4 indiv.) and terrace sites (edge = 2 indiv. and open water = 0 indiv.) (Chi-sq: $p = 0.0421$). Catch of naked goby *Gobiosoma bosc* was highest at the coconut matted sites (edge = 21 indiv. and open water = 24 indiv.), moderately high at the natural sites (edge = 14 indiv. and open water = 0 indiv.) and terrace sites (edge = 1 indiv. and open water = 0 indiv.) (Chi-sq: $p = 0.0013$). Catch of clown gobies was highest at the coconut matted open water (18 indiv.), moderately high at the natural sites (edge = 9 indiv. and open water = 6 indiv.), and lower at the coconut matted edge (1 indiv.) and terrace sites (edge = 3 indiv. and open water = 1 indiv.) (Chi-sq: $p = 0.0007$).

Seine Net

White mullet *Mugil curema* and striped mullet *Mugil cephalus* were only collected from the terrace edge (26 individuals). No significant differences were found among habitats for the catch of bay anchovy *Anchoa mitchilli* (Table 6), inland silverside *Menidia beryllina*, gulf pipefish *Syngnathus scovelli*, and gulf menhaden *Brevoortia patronus*.

Nekton Species Composition—Functional Groups

Total catch of crustaceans at the coconut matted edge (27% of total catch) was greater than catch at both the natural edge (18%) and terrace edge (13%) (Chi-sq: $p = 0.0004$) (Figure 11). Total catch of crustaceans at the coconut matted open water (29%) was greater than catch at both open water samples associated with natural marsh (12 %) and terraces (1%).

Total catch of benthic dependent fish at the coconut matted edge (27 % of total catch) was greater than catch at both the natural edge (19 %) and terrace

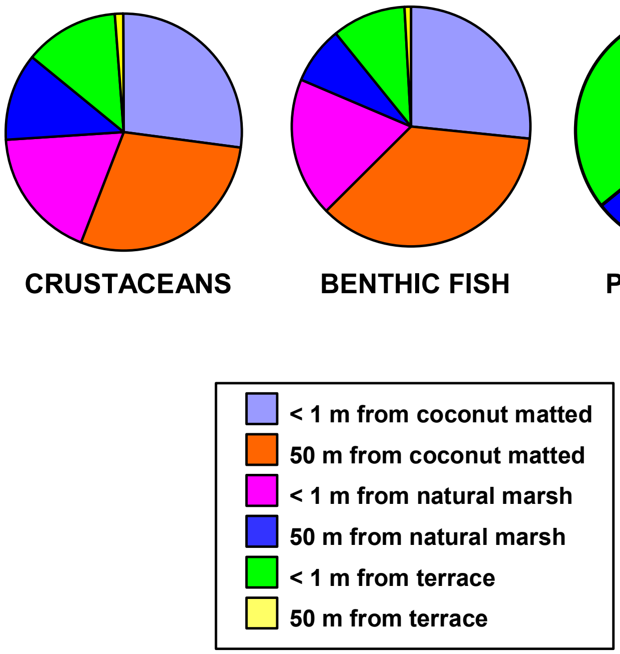

Figure 11. Total catch at each habitat type for (1) crustaceans (*C. sapidus, F. azteca, L. setiferous, Palaemonetes* spp., Fam Xanthidae) (Chi-sq: $p = 0.0004$, $N = 177$), (2) benthic or demersal dwelling fish (*C. spilopterus, G. bosc, L. xanthurus, M. gulosus, M. undulatus, M. punctatus, S. scovelli*) (Chi-sq: $p = 0.0001$, $N = 139$) and (3) pelagic dwelling fish (*A. mitchilli, B. patronus, C. arenarius, L. rhomboides, L. parva, M. beryllina*) (Chi-sq: $p < 0.0001$, $N = 123$). Catch data is based on year round throw trap sampling.

edge (10 %) (Chi-sq: $p = 0.0001$) (Figure 11). Total catch of benthic dependent fish at the coconut matted open water (36 %) was greater than catch at both the open water samples associated with the natural marsh (1%) and the terraces (1%), and was also greater than catch at the coconut matted edge.

Total catch of pelagic dwelling fish at < 1 m from the terrace (36 % of total catch) was greater than catch at both < 1 m from the coconut matted marsh (27 %) and natural marsh (19 %) (Chi-sq: $p < 0.0001$) (Figure 11). Total catch of pelagic dwelling fish at 50 m from the natural marsh (16 %) was greater than catch at both 50 m from the coconut matted marsh (3 %) and terrace (0 %).

DISCUSSION

Comparisons to Natural Marsh Edge

Results supported the hypothesis that nekton used terrace edges and natural marsh edge similarly. Increased SAV habitat was not provided by the coconut mats, and results indicated that coconut mats increased nekton use of open water sites, but not of edge sites. Coconut matted edge and open water, natural edge, and terrace edge had similar nekton density, abundance, biomass, and diversity. Open water sites that were not coconut matted had decreased nekton density, abundance, biomass, and diversity than the natural marsh edge. Patterns were generally the same for nekton density, abundance, biomass, and diversity, and this consistency adds strength to conclusions about nekton habitat utilization (Streever 2000).

Results from other studies that compared nekton or fish between dredged material marsh and natural marsh edges were consistent with our results, and found no significant differences between dredged material and natural marshes (LaSalle et al. 1991, Minello and Zimmerman 1992, Minello et al. 1994, Minello and Webb 1997, Kurz et al. 1998, Williams and Zedler 1999, Streever 2000, Rozas and Minello 2001). No previous studies have documented the effect of coconut mats on fish habitat.

In contrast, nekton composition was significantly different between the coconut matted sites, natural edge, and terrace edge. Species dependent on benthic habitat and benthic food sources (crustaceans, gobies, Atlantic croaker) were less abundant at the terrace edge and more abundant at the coconut matted marsh edge than the natural marsh edge. Most pelagic species (bay anchovy, gulf menhaden, inland silverside) were equally or more abundant at the terrace edge than the coconut matted marsh and natural marsh edge. These species tend to be opportunistic and tolerant of degraded habitats (Minello and Webb 1997, Williams and Zedler 1999). A study of 5 natural and 10 created salt marshes in Texas suggested that fish (mainly gobies and pinfish) abundance was significantly lower in dredged material marshes than in natural marshes (Minello and Webb 1997). Past studies often found significantly higher densities of crustaceans at natural marshes when compared to dredged material marshes (Minello and Zimmerman 1992, Minello and Webb 1997, Streever 2000, Rozas and Minello 2001).

Compared to the natural marsh edge, there was an absence of specialized, less tolerant species at the terrace edge. In contrast, there was an abundance of specialized species at the coconut matted marsh edge. The potential mechanisms driving these differences in habitat value could be related to differences in substrate characteristics such as: (1) organic matter content or (2) texture (microhabitat heterogeneity).

Organic Matter

Substrate characteristics of the coconut matted marsh, natural marsh, and terrace edge were different 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, Minello and Webb 1997). The increase in habitat value associated with coconut mats may be due to a likely increase in organic matter availability as a result of the coconut mat fibers, detritus trapping in the mat, and increased algal cover. The decrease in benthic species near terraces could relate to substrate disturbances associated with project construction.

Lower organic matter content is a common problem observed in dredged material marshes (Sacco 1989, Cammen 1976, Moy and Levin 1991, Streever 2000). Organic matter was lower at terrace edges as compared to natural 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 compared to natural marsh edge.

Texture (Microhabitat Heterogeneity)

Another potential cause of the differences in nekton utilization is that the coconut mats increase microhabitat heterogeneity, providing refuge for benthic species. The interstitial spaces created by the loosely woven texture of the coconut mats may have contributed to increased refuge for benthic fish and crustaceans. Natural marsh provided some refuge because the substrate was unconsolidated with large pieces of detritus, but perhaps this refuge was not as extensive as that provided by the coconut mat. The terrace substrate was a fine-grained clay, providing little microhabitat heterogeneity.

The fish that were caught more frequently at the terrace were not benthic dwelling or benthic feeders. The structure provided by the emergent vegetation may have provided a suitable habitat for their niche requirements. This structure may have been limited at the natural marsh edge because the natural marsh edge had a vertical undercut shore. Emergent vegetation biomass at the terrace and natural marsh were similar, supporting the idea that terraces provide adequate above-ground structure.

Comparisons to Open Water

Because SAV was almost always absent from our samples, results indicate that natural and terrace marsh edge habitat increase nekton habitat value when compared to a non-vegetated open water habitat. Natural marsh and terrace edges both supported higher nekton density, abundance, biomass, and diversity than open water habitats. The open water samples were assumed to represent conditions that would have existed before terrace construction or without edge habitat. Terraces appear to increase nekton habitat value from pre-existing open water conditions by providing edge habitat. This edge habitat increased structure and decreased water depth, thereby providing refuge and food sources for nekton species, as previously discussed (Darnell 1961, Odum and Heald 1975, Orth 1977, Kneib and Stiven 1978, Keddy, 1982, 1983, Boesch and Turner 1984, McIvor and Rozas 1988, Sullivan and Moncreiff 1990, Fonseca 1996, Kwak and Zedler 1997, Jacobsen and Berg 1998, Minello 1999).

In contrast, patterns found at the coconut matted open water were different than the patterns observed at the natural marsh and terrace. Coconut matted open water habitat had similar nekton density, biomass, size, and diversity to marsh edge habitats. In some cases, benthic species catch was highest at the coconut matted open water. Thus, installing coconut matting may increase nekton utilization of open water habitat. When the experiment was designed, coconut matting was thought to increase habitat value by increasing SAV recruitment. The coconut mats did not increase SAV recruitment, and there was no observable evidence that seedlings present would establish mature SAV beds. Increased nekton utilization could be driven by the increased organic matter that was discussed above, or it could be driven by the increased microhabitat heterogeneity provided by the loosely woven mat.

Open water samples at all habitat types may still be influenced by the nearest marsh edge type, even when it is 50 m away. Organic matter content, unconsolidated texture, and total catch of some benthic species were higher at the open water samples near the natural marsh when compared to open water samples near the terrace marsh. Based on differences observed between the open water samples from the terrace and natural marsh edge, conditions may still have been influenced by the marsh habitat.

Design Implications

Terracing

At the Sabine NWR Unit 7 terraces, nekton densities were relatively low compared to densities found by other studies in the Gulf of Mexico (Welsh 1975, Minello and Zimmerman 1992, Minello and Webb 1997). Rozas and Minello (2001) found mean nekton densities as high as 101.5 individuals/m^2 in Unit 1 at

Sabine NWR, while we found mean nekton densities in Unit 7 as high as 9.8 individuals/m^2.

A potential cause for this discrepancy could be differences in restoration design. For example, the Unit 1 terraces studied by Rozas and Minello (2001) at Sabine NWR were built in a checkerboard pattern so that all remaining pond area was within 10 m of emergent vegetation, while Unit 7 terraces were often over 100 m apart from each other. The presence of these small, enclosed areas may be critical for nekton use for a number of reasons including refuge and detrital sequestration due to decreased current velocity (Delaney et al. 2000). The Unit 1 terraces were also 10 years old when they were sampled, as compared to the Unit 7 terraces (3 yrs old). However, a review of past studies suggested that nekton can establish stable densities at a restored habitat in as soon as 1 year (Streever 2000). Decreased habitat connectivity to other areas, although not measured, could lead to decreases in nekton density.

Increased marsh – water edge ratios may provide greater habitat complexity for nekton. The Unit 7 terraces are built with straight non-undulating edges. The natural marsh tends to have undulating edges with variable degrees of concavity, providing greater microhabitat structure for nekton. This increased microhabitat may lead to increased refuge from currents and predators and increased food availability.

Submerged Aquatic Vegetation Recruitment

One of the goals of the terrace project was to decrease turbidity and wave energy, thereby increasing SAV recruitment. However, SAV coverage and secchi depth were not significantly greater at the terrace samples. Turbidity at the terrace was close to having significantly lower turbidity than other sites (p = 0.055), suggesting that differences may be found if the sample size was increased or if more exact measurements were taken with a turbidometer rather than a secchi disk.

Terracing and coconut matting did not increase SAV cover. Some seedlings observed only on coconut mats remained small and did not grow into mature SAV beds any time during during the 12-month study. Thus, it is unclear whether installing coconut mats will increase SAV habitat.

Conclusions: Restoration Implications of Terracing and Coconut Matting

Because only one area was sampled, it is important to note that conclusions of this study apply only to the Unit 7 terrace field. Data from other terraces are needed to determine if observations are typical or unique to this study.

Terraces support nekton densities that are approximately 4.5 times greater than the densities that would be supported in the same location if the project was not constructed. Based on results of this study, terraces are successful at increasing nekton habitat value. Nekton density, abundance, biomass, size, and diversity were similar between the terrace and natural marsh edge; however, species composition at the terrace was different than at the natural marsh edge. While many dredged material marshes, including terraces, appear to be successful at providing marsh edge habitat to increase nekton habitat utilization, the restored habitat may not have the environmental characteristics to support the same composition as the natural marsh.

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 longer than expected. However, the close proximity of the natural marsh fringe to the restoration area will speed infaunal colonization. If feasible, coconut mat installation may also speed infaunal colonization and increase habitat value for benthic dwelling nekton species. However, this speculation must be investigated in future studies.

Future Directions

Future research on terrace success at providing nekton habitat should address nekton growth rates and correlate nekton composition to the infaunal community. Further studies should evaluate the cost effectiveness and benefits of installing coconut matting in restoration projects to recruit SAV and an 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 natural habitats could suggest whether restored sites are increasing secondary production in an area or merely providing a habitat where nekton congregate (West et al. 2000, Minello and Webb 1997).

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VITA

Christina Samantha Bush graduated from Marist High School in Atlanta, Georgia, in 1996. Chrissy attended Kenyon College in Gambier, Ohio, where she earned a Bachelor of Science degree with highest honors and distinction in biology and a concentration in environmental studies. While at Kenyon, Chrissy researched an honors thesis entitled, “Effects of Plant Diversity on Wetland Ecosystem Processes.” Following graduation, Chrissy returned to Atlanta to accept a position as an environmental scientist with PBS&J, an engineering and planning consulting firm. In August 2001, Chrissy began graduate studies at Louisiana State University with Dr. Megan K. G. La Peyre, and is now a candidate for the degree of Master of Science in fisheries from the School of Renewable Natural Resources. Following graduation, Chrissy will be married to Charles G. Thom, III in Atlanta, Georgia, where she will continue her career.