THE ECOLOGICAL IMPLICATIONS OF MARSH MANAGEMENT TO WETLAND BIRDS IN COASTAL TEXAS

A Thesis

by

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ABSTRACT

The Ecological Implications of Marsh Management to Wetland Birds in Coastal Texas

(May 2010)

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Texas coastal marshes have declined in number and quality, prompting the widespread use of levees and water control structures to create or enhance coastal marsh habitat. However, due to the controversial nature of these management practices, more research is needed to assess the effectiveness of these techniques in providing quality waterbird habitat. During 2007-08 and 2008-09, I investigated the effects of marsh management on bird, plant, and aquatic invertebrate communities by comparing managed and nonmanaged coastal marshes along the central Texas coast. Managed marshes supported more bird species, greater waterbird densities, greater plant diversity, and greater aquatic invertebrate biomass than nonmanaged sites. However, nonmanaged wetlands supported greater densities and more species of secretive marsh birds. The results suggest that management of coastal marshes can improve habitat quality for a large, diverse assemblage of wetland bird species compared to nearby nonmanaged coastal marshes.

DEDICATION

To my fellow graduate students, for all the good times.

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INTRODUCTION

The Texas Gulf Coast is extremely diverse in its wetland habitats, which provide critical resources to a wide variety of bird species. It serves as the principal wintering site for waterfowl in the Central Flyway (Stutzenbaker and Weller 1989) and is also a key area for migratory wading birds (Mikuska et al. 1998) and shorebirds (Withers and Chapman 1993). However, the Texas Gulf Coast has suffered widespread degradation and loss of wetland habitat, particularly fresh and intermediate marshes, which have declined nearly 30% in the past 40 years. Wetland loss along the central coast of Texas has mainly resulted from conversion of wetland habitat to agriculture, rural and urban development, human recreation, and other socioeconomic factors (Moulton et al. 1997). Continued pressure for future development and growth along the Texas coast, despite the documented wetland loss and degradation, illustrates the need to bolster conservation efforts in the region.

The effects of wetland loss and degradation to birds are well documented and have prompted the widespread use of marsh management techniques by private and public land managers to mitigate wetland habitat losses (Erwin et al. 1986; Tori et al. 2002; Kaminski et al. 2006). Marsh management typically uses structural modifications such as levee systems and water control structures to manipulate flood duration, frequency, and depth. Such hydrological control is often supplemented with a prescribed fire regime, livestock grazing, or mechanical manipulations to facilitate desired vegetation growth, reduce saltwater intrusion, and improve habitat for wetland birds, particularly wintering waterfowl (Cowan et al. 1988; Stutzenbaker and Weller 1989). The success of such marsh management in attracting wintering waterfowl has been

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This thesis follows the style and format of *Wetlands* documented (Weller 1990 ; Kaminski et al. 2006). However, the implications of this type of management to other wetland bird species are not as clear, especially in more mature managed wetlands. Much of the literature available compares relatively new created wetlands to nonmanaged areas to assess created wetland quality (Confer and Niering 1992; Brown 1999; Rozas and Minello 1999). Often, however, 3 to 4 years is too short a time span to gauge the effectiveness of management on created marshes, as wetland plant communities can take much longer to establish (Mitsch and Gosselink 2000).

Bird use of wetland habitat is dictated by many different variables, most of which are influenced by a wetland's hydrology. For example, changes in water depth, duration, and salinity can rapidly shape the biotic communities within wetlands, making it difficult to quantify and relate different habitat variables to bird use. Even so, many studies have indicated that managed impoundments provide quality habitat for wetland birds and, in many cases, higher quality habitat than nearby natural areas (Weber and Haig 1996; Anderson and Smith 1999; Kaminski et al. 2006). Management schemes often involve drawdowns that create areas with varying water depths, which diversifies plant and invertebrate communities and increases foraging opportunities that result in greater bird species richness and abundance. More investigation of marsh management effects on waterbird species is needed at a local level, however, to optimize future management efforts and meet desired objectives (Ma et al. 2010).

Some researchers have pointed out the potential negative effects of levee construction and marsh management. Specifically, while impounded marshes seem to attract and support a variety of target bird species, endemic salt marsh species may be negatively affected by the conversion of coastal estuarine marsh to managed impoundments, which reduces critical nesting habitat for some passerine and marsh bird species (Mitchell et al. 2006).

Another issue at the forefront of coastal wetland management is the effect of impoundments on fisheries. The general hypothesis is that marine-transient species spend critical portions of their life cycles within marsh systems, whether for refuge or nursery, before migrating to estuarine and marine systems. Thus, the construction of levee systems may hinder this movement and negatively affect these species (Herke 1995). However, Rogers et al. (1994) suggest that it is difficult to properly assess the effects of structural marsh management on fishes and crustaceans due to the wide variety of structural modifications and marsh management techniques. Similarly, Hoese and Konikoff (1995: 180) report that most studies linking restricted migration with reduced productivity ". . . suffer from various constraints, such as a lack of replication, high degree of variability in both study sites and temporally, and interference by the observer." Thus, it remains unclear as to what extent impoundments affect fishes and crustaceans.

Despite any negative associations, marsh management on the Texas Coast continues to be widely practiced. As awareness of the potential value of marsh management increases, however, more research is needed to evaluate its effectiveness, particularly in mature managed areas. Given the conspicuous nature of birds and their strong association to vegetation characteristics and prey availability, they seem ideal indicators of habitat quality (Weller 1988; Gawlik 2002).

My primary objective was to compare the quality of habitat for wetland birds between managed and nonmanaged wetlands along the Texas coast. Specifically, I investigated differences in bird community characteristics in managed and nonmanaged wetlands as well as investigated the functional roles of the wetlands for waterbirds.

STUDY AREA

This study was conducted on 2 Texas Parks and Wildlife Department (TPWD) owned and managed Wildlife Management Areas (WMA) located along the central coast of Texas: Justin Hurst WMA, and Mad Island WMA. Justin Hurst WMA, formerly named Peach Point WMA, is located in Brazoria County west of Freeport. The 4,831-ha area was acquired by TPWD during a period from 1985 to 1988. Mad Island WMA comprises 2,946 ha in Matagorda County and was acquired by TPWD from The Nature Conservancy of Texas in 1987. Both WMAs are comprised of managed, palustrine emergent wetlands, coastal prairie meadows, estuarine intertidal marshes, and unvegetated intertidal mudflats. Management schemes are similar in all the impounded areas and include spring/summer drawdowns followed by mechanical treatments, prescribed fires, and/or livestock grazing, and flooding in the fall. Natural, estuarine wetlands are also subject to periodic prescribed fires and livestock grazing. Both managed and natural areas are frequented by the public for waterfowl hunting during fall and winter.

Two managed wetlands at each WMA were chosen with nonmanaged wetlands serving as control sites. Hence, there were 4 managed/nonmanaged wetland pairs. Managed and nonmanaged wetlands in each pair were directly adjacent to each other to reduce natural variation because managed areas were assumed, prior to construction, similar to the nonmanaged areas. At Justin Hurst WMA, the managed wetlands comprised the Greenwing and Mottled Duck sites, and at Mad Island WMA, the Rattlesnake and North Savage sites. At Justin Hurst WMA, the Greenwing wetland was constructed in July 1998 and the Mottled Duck wetland in July 1999. Both managed wetlands at Mad Island WMA were constructed in August 2001.

METHODS

Within each managed and nonmanaged wetland, I delineated a 400 m * 400 m (16 ha) area to keep the sampling sites similar and to match the smallest managed site. All sampling was conducted within the 16-ha area at each site. Sampling was conducted during 3, 45-day seasons during both 2007-08 and 2008-09. Fall (1 September-15 October) and spring (1 April-15 May) seasons corresponded to peak migratory periods based on historical waterbird surveys from state lands along the central coast of Texas (Brent Ortego, Texas Parks and Wildlife Dept., unpublished data). Winter sampling occurred from 1 January-15 February to include the largely non-migratory period during mid-winter.

Vegetation Community

The vegetation community at each site was surveyed once per season. Logistic constraints limited the surveying of the North Savage location in fall 2007. I placed 4 to 5 transects, totaling 1600 m, equidistant and parallel within each wetland, perpendicular to the levee that separated the managed and nonmanaged wetland pair. Such placement allowed me to thoroughly cover any variation in habitat due to changes in water depth, as managed wetlands were deepest near the levee. Along each transect I estimated percent cover for all plant species, bare ground, and open water within a 1-m^2 floating quadrat constructed of small diameter PVC pipe (Tanner and Drummond 1985). The quadrat was placed every 30 m along transects, totaling 56 sampling points in each managed and nonmanaged wetland. A 3-m modified Robel pole, constructed of 3.81-cm diameter PVC pipe and marked every 10 cm with red tape, was placed in the center of each quadrat and viewed from 4 m to the north and 1 m above ground or water surface (Robel 1970). The highest point obstructed 100% by vegetation was recorded to the nearest quarter decimeter to measure screening cover. Water depth at each quadrat was also recorded with the Robel pole to the nearest quarter decimeter.

Aquatic Invertebrates

I collected aquatic invertebrate samples once each season at 5 evenly spaced points along a 500-m transect that ran diagonally through each managed and nonmanaged wetland to account for changes in water depth and vegetation community. I collected aquatic invertebrates using a standard D-frame dip net to sample a 1-m^2 area at each point. The net was bumped along the substrate and pulled up through the water column in 1-m strips in the 3 cardinal directions least disturbed by the observer, which allowed for the collection of benthic, water-column, and water-surface dwelling invertebrates. Samples were placed in 3.79-L sealed containers and preserved in 70% ethanol solution until transported to the Texas A&M University-Kingsville laboratory. In the laboratory, I sorted the invertebrate samples, identified to taxonomic order, dried in an oven at 60^o C until constant mass was reached, and then weighed to the nearest 0.0001 g to determine biomass (Pennak 1978; Merrit and Cummins 1996). I also measured water salinity levels with an YSI Model 85 Dissolved Oxygen, Conductivity, Salinity and Temperature System at the beginning and end of each invertebrate sampling transect.

True metabolizable energy (TME) values for common waterfowl food items compiled by DiBona (2007) were used to estimate available energy based on invertebrate biomass. TME values for taxa present in our samples but not listed by DiBona (2007) were obtained by using values for similar taxa.

Avian Community

I conducted avian surveys to determine abundance and species richness in accordance to methodology outlined by Buckland et al. (1993). I deemed this technique a more effective survey method than stationary counts for detecting a wider variety of species due to the secretive nature of many waterbird species and the dense vegetation at some of the sites. In each wetland, trained observers walked the length of 2 400-m line transects located 100 m from the survey area edge and 200 m apart, thus ensuring the entire 400 m * 400 m survey area was observed. I aligned transects perpendicular to the levee that separated the managed and nonmanaged wetland pairs. Group size and distance from transect line were recorded for each bird species observed. Aerial foragers were recorded only if they were observed actively feeding or resting in the survey area. Each pair of managed and nonmanaged wetlands was surveyed concurrently to minimize temporal and weather-related variation in bird movements. Surveys took place between 0.5 - 3.5 hours after sunrise and 3.5 - 0.5 hours before sunset, with no surveys conducted in winds > 25 km/hr or during rain or fog due to likely reductions in detection rate. Up to 4 surveys were conducted per season, with no surveys conducted on days when public hunting occurred.

To compare densities in managed and nonmanaged areas, I designated bird species into 4 groups: shorebirds, waterbirds, marsh birds, and terrestrial birds. I grouped shorebirds, waterbirds, and marsh birds according to Kushlan et al. (2002), while designating all other bird species as terrestrial. I omitted waterfowl species from the waterbirds group to better elucidate effects of marsh management on nongame species, although waterfowl were included in the cumulative bird density and species richness analyses. I included passerine species in the marsh birds group that were endemic to marsh habitat, but that were not listed in Kushlan et al. (2002). These species were Marsh Wren (*Cistothorus palustris*), Sedge Wren (*Cistothorus platensis*), Seaside Sparrow (*Ammodramus maritimus*), and Swamp Sparrow (*Melospiza georgiana*).

To explore relationships between specific bird groups and physiognomic habitat characteristics, I also grouped bird species into guilds based on primary foraging habitat (Weller 1999). Foraging habitat guilds consisted of basin substrate, mudflat, water column, water surface, above water, dense emergent vegetation, and terrestrial.

I used conservation priority rankings of bird species to provide a different approach for assessing habitat quality, besides traditional uses of overall density or species richness. Conservation priority rankings were initially developed by Partners In Flight (PIF). PIF is an organization originally created to assess conservation needs of nongame neotropical migrants, and it has expanded its directive to include all nongame landbirds. PIF developed a system to rank bird species based on 7 parameters that use global and local threats, population status, and habitat availability to assess conservation needs. The rankings range from 1 (lowest priority) to 5 (highest priority) (Carter et al. 2000). Many avian conservation plans have comparable rankings for other bird groups. For my research needs, I have referenced the PIF conservation priority database for all landbird species, the U.S. Shorebird Conservation Plan for all shorebird species, and the North American Waterbird Conservation Plan for all other waterbirds and marsh birds (Brown et al. 2000; Kushlan et al. 2002). I compiled a list of all species detected on bird surveys that have a Threats to Nonbreeding habitat (TN) conservation priority score of 4 or 5 on the 1 to 5 scale (Carter et al. 2000). I compared densities of birds with high-priority conservation rankings between managed and nonmanaged wetlands and noted the species found in only 1 treatment type.

To assess how birds used study area wetlands, I recorded 10-minute activity budgets of randomly encountered birds. For ease of data collection and interpretation, I chose *a priori* to focus on wading bird species because of their conspicuousness and the ability to assess their foraging success. For each bird recorded, I estimated foraging rate (the number of foraging strikes/minute) and foraging success (the proportion of these strikes that were successful). Video samples were recorded up to 20 minutes per individual.

Statistical Analysis

To compare bird densities, I first had to account for different detection probabilities among wetland sites. To accomplish this, I first averaged screening cover across the 56 sampling points for each year/season/site combination. I then listed the average screening cover of each year/season/site from shortest to tallest, and I observed natural gaps in the average screening cover list that provided evidence for dividing the year/season/sites into 3 classes: short, medium, and tall. For each of the 3 classes, I then investigated histograms of all avian detection distances and delineated natural cut points based on marked drops in frequency of observations across detection distances. As a result, maximum detection distances I could assume 100% detection were: 30 m for the tall class, 60 m for the medium class, and 120 m for the short class. Encounters detected beyond these distances were not considered for density estimation within their respective screening cover class.

To test for differences in spatial heterogeneity between sites and among seasons, I estimated the coefficient of variation in the coverage of mudflat and emergent vegetation at each site during each season and year.

I used analysis of variance in PROC MIXED (SAS Institute 2002) with repeated measures to investigate any effects of wetland management (managed vs. unmanaged), season, and year on plant species richness, bird species richness, bird densities, and aquatic invertebrate biomass. I tested for interactions between the explanatory variables (wetland management, season, and year) and only report if significant (Appendix A). I also used PROC MIXED to explore the effects of vegetation species richness and aquatic invertebrate biomass on bird densities. I used the Kenward-Roger method of estimating denominator degrees of freedom to each model to make adjustments due to small sample size, and used the Tukey-Kramer adjustment to separate means (SAS Institute 2002). Because of the limited number of sampled wetlands ($n = 8$), I considered any effects significant if $P \leq 0.10$ (Tacha et al. 1982).

I calculated Shannon's (Shannon-Wiener) diversity index ($H' = \sum(p_i)(\ln p_i)$) and Jaccard's similarity index ($C_j = j/a+b-j$) to help explain relationships in vegetation and bird communities between managed and nonmanaged wetlands (Begon et al. 1990). I presented absolute values and did not test for differences for any indices I calculated.

RESULTS

Vegetation Community

Plant species richness was similar between managed and nonmanaged wetlands (P = 0.158) and among seasons (P = 0.128) (Table 1). However, plant species richness was 1.4 times greater in 2007-08 than 2008-09 ($F_{1, 16.1}$ = 7.49, P = 0.015). Plant species that dominated the nonmanaged wetlands included: Gulf cordgrass (*Spartina spartinae*), marshhay cordgrass (*Spartina patens*), and saltgrass (*Distichlis spicata*). Species that were most dominant in managed sites were maidencane (*Panicum hemitomon*), saltgrass, broad-leaf signal grass (*Brachiaria platyphylla*), and stonewart (*Nitella* spp.). In winter 2009, dead plant litter dominated sampling quadrats in both managed and nonmanaged wetlands.

Plant species diversity was 15-29% greater in managed than nonmanaged wetlands during each year*season combination, except spring 2009 when it was 7% greater in nonmanaged than managed wetlands (Table 2). Plant diversity was inversely correlated with water salinity at each site (r = -0.54, n = 46, P < 0.001).

Water salinities in managed wetlands were lower than nonmanaged wetlands during each season in 2007-08 (Table 3). Salinities remained below 2 ppt in managed wetlands and below 10 ppt in nonmanaged wetlands during fall and winter 2007-08. The managed wetland at Greenwing generally had the lowest salinities throughout the study. In 2008-09, Hurricane Ike greatly influenced both managed and nonmanaged wetlands by increasing water salinities well above those recorded the previous year (Table 3). The effects of Hurricane Ike were particularly noticeable at Mad Island WMA, as salinities were < 1 ppt in fall 2007 and 33–40 ppt in fall 2008, following Hurricane Ike. Average salinities in managed areas increased 1,280% from 2007-08 to 2008-09. Following Hurricane Ike, water salinities were greater in managed than nonmanaged wetlands on Mad Island WMA throughout 2008-09 (Table 3).

Variation in emergent vegetation coverage within wetlands was 2.3 times greater in nonmanaged than managed areas ($F_{1,\ 27.64}$=15.89, P = 0.004). Variation in mudflat coverage within wetlands was similar between managed and nonmanaged areas (P = 0.617) throughout the study.

Similarity indices for vegetation communities between managed and nonmanaged wetlands were quite variable across the study, ranging from 10% similar at North Savage in Fall 2008 to 57% similar at Mottled Duck in spring 2009 (Table 4). Similarity indices fluctuated more widely at Mad Island WMA sites than at Justin Hurst WMA sites. However, average similarity indices were greater at Mad Island both years; 1.8 times greater in 2007-08, and 2.4 times greater in 2008-09.

Aquatic Invertebrates

Aquatic invertebrate biomass between managed and nonmanaged wetlands was affected by year ($F_{1,\ 11.7}$ = 4.77, P = 0.050). Managed areas ($\bar{x}$ = 3.15, SE = 0.53) supported 8.5 times (P = 0.007) greater aquatic invertebrate biomass than nonmanaged areas in 2007-08 ($\bar{x}$ = 0.37, SE = 0.66), while managed and nonmanaged areas in 2008-09 were similar (P = 0.558) (Table 5). Aquatic invertebrate biomass was similar among seasons throughout the study (P = 0.597). Coleoptera, Diptera, and Hemiptera occurred most frequently across samples in both managed and nonmanaged wetlands. In 2007-08, Gastropods comprised the greatest proportion of invertebrate biomass in the samples collected during each season in managed and nonmanaged wetlands (range: 29%–90%).

In 2008-09, Gastropods again comprised the largest component of the invertebrate community in nonmanaged wetlands. In contrast, Hemiptera and Ostracoda dominated the invertebrate biomass in managed wetlands in 2008-09. Collectively, Gastropoda, Coleoptera, Hemiptera, Diptera, Ostracoda, Decapoda, and Odonata consistently comprised > 80% of the invertebrate biomass, except for spring 2009 when Trichoptera contributed 31% of the total biomass in managed wetlands.

Estimated TME values (kcal/total sample biomass) for invertebrates were consistently greater in samples collected from managed wetlands compared to those from nonmanaged wetlands (Table 5). Differences ranged from 1.4 times greater in fall 2008 to 296 times greater in fall 2007. Total energy was directly related to biomass as average kcal/g was similar between managed and nonmanaged wetlands. Amphipoda, Ostracoda, Brachyura, Cladocera, and Decapoda had the highest TME values.

Avian Community

I detected a total of 115 bird species that used managed wetlands and 91 that used nonmanaged wetlands over the entire study, with 79 species common to both (Table 7). Managed wetlands supported 1.6 times more bird species than nonmanaged wetlands across the study ($F_{1,\,59.4} = 30.83$, $P < 0.0001$) (Table 6). Seasonal differences in bird species richness were affected by year ($F_{2,\,80.8} = 4.27$, $P = 0.017$). Following hurricane Ike, bird species richness in 2008-09 was lower in fall ($\bar{x} = 8.93$, $SE = 1.19$) than winter ($\bar{x} = 16.07$, $SE = 1.33$) and spring ($\bar{x} = 13.92$, $SE = 1.19$) seasons, though not in 2007-08. Managed wetlands supported more species from each foraging habitat guild except for above water and transition zone foragers (Tables 8 and 9).

Bird diversity tended to be greater in managed than nonmanaged wetlands with the exception of the Mottled Duck site, which had higher bird diversity in the nonmanaged wetland during 4 of 6 sampling periods (Table 6). Bird communities were relatively dissimilar throughout the study, with Jaccard's Index values ranging from 10%–57% (Table 6). Managed and nonmanaged wetlands differed the most in fall of 2008-09, as Jaccard's Similarity Indices were collectively the lowest (ranging from 10% –32%). In spring 2009, similarity in bird communities between 3 of the 4 managed/nonmanaged pairs approached or exceeded 50% and collectively was the greatest in any season.

I detected no wetland management effect on overall bird densities. However, overall bird densities differed among seasons ($F_{2, 25.4} = 5.24$, $P = 0.013$) with winter ($\overline{x}$ = 15.6 birds/ha, $SE = 1.89$) supporting greater densities than fall ($\overline{x}$ = 9.6 birds/ha, SE = 1.89, $P = 0.043$) and spring ($\overline{x}$ = 8.9 birds/ha, $SE = 1.89$, $P = 0.020$). Overall bird densities also differed between years, with year 2007-08 supporting 1.8 times more birds/ha than year 2008-09 ($F_{1, 18.1} = 6.67$, $P = 0.019$). Managed areas supported 2.2 times more waterbirds/ha than nonmanaged areas ($F_{1, 6.13} = 4.49$, $P = 0.077$) throughout the study. Shorebird densities did not differ between managed and nonmanaged wetlands ($P = 0.380$) or among seasons ($P = 0.127$), however, 2008-09 supported 2.8 times more shorebirds/ha than 2007-08 ($F_{1, 30} = 4.77$, $P = 0.037$). Marshbird densities were 4.4 times greater in nonmanaged areas than managed areas ($F_{1, 10.8} = 13.42$, $P = 0.004$) but did not differ among seasons ($P = 0.373$) or between years ($P = 0.546$). Terrestrial bird densities were similar in managed and nonmanaged areas ($P = 0.308$). However, I detected a season*year interaction ($F_{2, 27.6} = 2.96$, $P = 0.069$) as terrestrial bird densities were greater in winter ($\bar{x} = 16.29$, $SE = 2.01$) than spring ($\bar{x} = 5.20$, $SE = 2.01$) in 2007-08.

Overall bird densities throughout the study were influenced by invertebrate biomass within wetlands ($F_{1, 2.99} = 5.79$, $P = 0.096$) as well as plant species richness ($F_{1, 2.98} = 34.21$, $P = 0.010$). Of the 4 bird groups, all but marsh bird densities ($P = 0.918$) were influenced by plant species richness (shorebirds: $F_{1, 15.3} = 4.79$, $P = 0.045$; waterbirds: $F_{1, 27.3} = 7.28$, $P = 0.012$; terrestrial birds: $F_{1, 2.96} = 6.78$, $P = 0.081$).

Managed and nonmanaged wetlands supported similar densities of birds with high conservation priority scores ($P = 0.418$). Of the 23 bird species detected with conservation priority scores of 4 or 5, 19 were detected in managed areas and 17 were detected in nonmanaged areas. Twelve of the 23 species were detected in both managed and nonmanaged wetlands. More mudflat and water-column feeding species with high conservation priority rankings were detected in managed than nonmanaged areas, including Stilt Sandpiper (*Calidris mauri*), Wilson's Plover (*Charadrius wilsonia*), Least Grebe (*Tachybaptus dominicus*), and Least Tern (*Sterna antillarum*). However, nearly all Rallidae species were detected only in nonmanaged areas, with Sora (*Porzana carolina*) being the exception. Two passerine species with high conservation priority rankings were detected only in managed areas: Nelson's Sharp-tailed Sparrow (*Ammodramus nelsoni*) and Olive-sided Flycatcher (*Contopus cooperi*) (Table 11).

Video monitoring to estimate foraging effort and success proved to be difficult due to heavy cover (particularly in nonmanaged wetlands) and the discreet nature of the individual birds. Thus, our sample size was small ($n = 15$). However, average strikes/minute was 35% greater for wading birds foraging in managed areas compared to those foraging in nonmanaged areas. Average success rate of foraging strikes was similar for wading birds in both managed and nonmanaged wetlands, averaging about 76% success.

DISCUSSION

My findings suggest that managed marshes can provide high quality habitat for wetland birds compared to nonmanaged areas. Kaminski et al. (2006) reached a similar conclusion in their study, which compared managed and nonmanaged Wetland Reserve Program wetlands in central New York. They reported greater richness and relative abundance in managed areas and recommended further management to promote wetland bird use. However, they did not estimate food availability or any other habitat components in an attempt to explain bird use.

I found overall bird densities were positively influenced by invertebrate biomass, indicating that managed wetlands may have a greater foraging capacity than nonmanaged sites (Anderson and Smith 1999). Marsh management practices can increase aquatic invertebrate biomass and taxa richness relative to nonmanaged sites, mostly due to abundance of aquatic vegetation that provides food, cover, and wider niche diversity (De Szalay and Resh 1997; Anderson and Smith 2000; Davis and Bidwell 2008). Managed wetlands did support considerably greater aquatic invertebrate biomass in 2007-08 in addition to consistently providing more available energy throughout the study. Greater available energy in aquatic invertebrates most likely attracted more bird species in managed areas, as aquatic invertebrates comprise a considerable portion of the diet of many wetland bird species and are particularly important to support nutrients and energy for certain annual cycle events (Krapu and Reinecke 1992; Skagen and Oman 1996).

Marsh management techniques are conducive to creating diverse waterbird habitat by varying water depths and providing foraging opportunities for a wide breadth of morphologically specialized wetland birds (Kushlan 1986). The varied foraging opportunities most likely contributed to the greater number of bird species, higher diversity, and greater densities of waterbirds found in managed areas. Other studies have come to similar conclusions, suggesting that greater resource availability, such as foraging habitat and prey density and availability, may contribute to greater numbers of waterbirds in managed wetland areas (Epstein and Joyner 1988; Kaminski et al. 2006). Managed wetlands also supported more species from different foraging habitat guilds than did nonmanaged wetlands. The flexibility in foraging tactics of many wetland bird species probably allowed them to exploit a variety of ephemeral resources, regardless of major changes in plant communities and aquatic invertebrate biomass in managed areas (Kushlan 1986).

Differences in plant species richness, invertebrate biomass, and overall bird density between 2007-08 and 2008-09 were most likely due to extreme changes in water salinity between years. Hurricane Ike hit the Texas coast 13 September 2008 in the Galveston area, approximately 60-100 miles from the study areas and the resulting Category 4 storm surge reached up to 7 m in some areas, inundating the study wetlands with sea water. Although marsh management techniques allow managers to control drawdown speed and timing, they can also reduce water circulation, resulting in water quality issues such as extreme salinities (Birkitt 1984; McGovern and Wenner 1990). This seemed to be the case following Hurricane Ike. After storm surge effects increased salinities in the managed areas, managers delayed drawdown into early spring to allow freshwater inflows to reduce salinity levels inside the impoundments. However, limited rainfall and high evapotranspiration rates threatened to further increase soil salinity, prompting managers to quickly draw down the remaining, highly saline water from the managed areas. The extreme increase in salinities in the managed areas decreased plant species richness and appeared to have altered plant communities in managed wetlands to more closely match the salt-tolerant communities that dominated the nonmanaged sites, including creating large mats of dead vegetation litter that dominated both managed and nonmanaged sites in winter 2008-09.

Despite the negative effects of major salinity changes on plant communities, aquatic invertebrates, and overall bird densities, shorebird densities were much greater after Hurricane Ike. Shorebird densities have been shown to correlate with the amount of exposed substrate (Darnell and Smith 2004). However, I found no management or temporal effects on the amount of variation of mudflat coverage within wetlands. Changes in mudflat coverage may have been masked by effects from Hurricane Ike, as extreme changes in water salinities caused considerable plant die-off in managed wetlands, creating sparsely vegetated mudflats that were seasonally atypical of managed marshes in my study. The sparse vegetation, coupled with decreased mobility of prey items due to changes in water quality, may have increased shorebird accessibility to prey items, which may be more important in attracting foraging birds than the type or amount of invertebrates supported in coastal marshes (Epstein and Joyner 1988; Bolduc and Afton 2004).

Little research is available on nonbreeding marsh bird habitat associations, however, research suggests that many species that do not benefit from managed wetlands usually require more dense vegetation, or grassland-like conditions (Mitchell et al. 2006). My findings support this, as greater densities of marsh birds in nonmanaged wetlands, coupled with the disparity in the presence of secretive rail species between wetland types, were most likely associated with the greater variation in emergent vegetation cover I found within nonmanaged wetlands.

I detected similar numbers of species of conservation concern in nonmanaged and managed wetlands, elucidating the value of both wetland types. Though results did not indicate a difference in mudflat coverage or marsh bird densities, more high-ranking species related to open water and mudflat habitat were detected in the managed wetlands whereas more secretive marsh species were detected in nonmanaged wetlands, illustrating the unique value of each habitat type for specific bird groups. The close proximity of the managed and nonmanaged areas seemed to attract species that were not exclusive to one habitat type, as over half of the species of conservation concern I detected were found in both. This was consistent with my findings of overall bird species richness, where 63% of the species detected were found in managed and nonmanaged wetlands. Given the dynamic nature of wetland resources, the location of managed areas near natural marsh is probably a driving factor influencing the diversity and abundance of bird species detected. Several studies have shown the value of wetland complexes in supporting greater species richness, and this should be taken into account when developing management plans for specific bird species or groups (Brown and Dinsmore 1986; Craig and Beal 1992; Fairbairn and Dinsmore 2001). At the very least, managed wetlands increased habitat diversity and supported resource needs for high-priority bird species.

Conclusion

My findings suggest that proper management of impounded wetlands along the central coast of Texas can provide productive, diverse, high-quality habitat for many wetland bird species. Despite disturbances from hurricane storm surge, managed wetlands supported greater bird species richness, waterbird densities, and higher diversity than adjacent, nonmanaged wetlands. Factors that probably contributed to enhanced habitat quality for wetland birds in managed areas include greater invertebrate biomass and available energy, seasonal variation in hydrology, and proximity to other marsh types. The value of nonmanaged marsh was evident, also, as nonmanaged areas supported the majority of secretive marsh bird species detected as well as greater marsh bird densities throughout the study.

Many factors influence bird species richness, density, and diversity, and it is impossible to account for them all. I attempted to quantify some major components of wetland biotic communities, habitat and prey, to explain differences in seasonal bird use between the managed and nonmanaged wetlands. I did not consider broad spatial effects such as site isolation or regional habitat availability (Brown and Dinsmore 1986). Nor did I consider breeding habitat, though that would have included important periods in the annual cycle and might have provided more information to fully assess the effects of management efforts on wetland bird communities.

Future comparative studies should examine extended monitoring efforts to account for broader temporal changes in plant and bird communities, and to better assess any patterns across years. Also, investigating differences in foraging values of managed and nonmanaged marshes to different groups of waterbirds would help explain differences in their use, as aquatic invertebrates are but a portion of the foods available to waterbirds in wetlands. Too, major events such as hurricanes can provide interesting preand post event research opportunities, and future monitoring in these areas might provide clearer understanding of the post-event changes.

Dependent on specific objectives, managed, impounded wetlands on the Texas coast can provide high quality habitat during crucial non-breeding periods to a large, diverse assemblage of birds, some of which are of high priority for conservation. Marsh management techniques present managers with a valuable, effective way to alleviate negative effects of recent loss and degradation of freshwater marsh on the Texas coast. The benefits of such management are justification for the establishment and continued management of impounded, freshwater marshes on the Texas coast, in conjunction with natural areas, to not only improve small-scale habitat but improve landscape-scale diversity as well.

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Table 1. Plant species richness in 4 managed and 4 adjacent, nonmanaged coastal marsh sites along the central Texas Coast during fall, winter, and spring 2007-08 and 2008-09.

			Species Richness	
		Site	Managed	Nonmanaged
Year 1	Fall	Greenwing	21	26
		Mottled Duck	21	13
		North Savage	-	-
		Rattlesnake	16	11
	Winter	Greenwing	27	26
		Mottled Duck	13	12
		North Savage	27	16
		Rattlesnake	15	11
	Spring	Greenwing	22	30
		Mottled Duck	18	12
		North Savage	19	14
		Rattlesnake	19	14
		Average	19.82	16.82
Year 2	Fall	Greenwing	28	14
		Mottled Duck	19	8
		North Savage	7	14
		Rattlesnake	7	12
	Winter	Greenwing	21	6
		Mottled Duck	15	8
		North Savage	5	10
		Rattlesnake	7	9
	Spring	Greenwing	31	25
		Mottled Duck	21	9
		North Savage	10	15
		Rattlesnake	7	11
		Average	14.83	11.75
		Total Average	**17.22**	**14.17**

Table 2. Plant species diversity (*H’*) in 4 managed and 4 adjacent, nonmanaged coastal marsh sites along the central Texas coast during fall, winter, and spring 2007-08 and 2008-09.

Year	Season	Managed	Nonmanaged
1	Fall	2.41	2.10
	Winter	2.62	2.03
	Spring	2.44	1.97
2	Fall	2.31	1.93
	Winter	2.32	1.98
	Spring	1.54	1.65

Table 3. Average water salinities (ppt) in 4 managed and 4 adjacent nonmanaged coastal marsh sites along the central Texas Coast during fall, winter, and spring 2007-08 and 2008-09.

		Managed			Nonmanaged		
Year	Site	Fall	Winter	Spring	Fall	Winter	Spring
2007-08							
	GW	0.35	0.30	1.60	3.50	0.60	14.0
	MD	0.40	0.80	0.70	9.65	2.65	22.60
	NS	0.95	1.55	4.15	4.10	4.70	10.50
	RS	0.80	1.90	12.25	2.95	2.70	18.45
2008-09							
	GW	11.30	13.45	4.95	28.10	39.30	11.70
	MD	11.85	12.20	9.00	32.20	[a]	35.95
	NS	33.65	28.70	25.05	14.15	23.50	15.40
	RS	40.40	33.10	[a]	30.10	[a]	22.80

[a] salinity measurements not possible due to lack of measurable standing water.

Table 4. Jaccard's similarity index comparing vegetation community similarity between managed and nonmanaged wetland pairs during fall, winter, and spring 2007-08 and 2008-09 along the central Texas coast.

	Area	Fall	Winter	Spring	Average
2007-08					
	Greenwing	0.18	0.26	0.27	0.24
	Mottled Duck	0.26	0.09	0.15	0.17
	North Savage	-	0.30	0.44	0.37
	Rattlesnake	0.29	0.37	0.44	0.37
	Average	0.24	0.26	0.33	
2008-09					
	Greenwing	0.20	0.17	0.24	0.20
	Mottled Duck	0.13	0.21	0.15	0.16
	North Savage	0.31	0.50	0.47	0.43
	Rattlesnake	0.46	0.46	0.39	0.44
	Average	0.28	0.34	0.31	
	Total Average	**0.26**	**0.30**	**0.32**	

Table 5. Total invertebrate biomass (g dry mass) and estimated true metabolizable energy (TME; kcal) values from invertebrates in managed and nonmanaged coastal marsh sites along the central Texas Coast during fall, winter, and spring 2007-08 and 2008-09. TME values obtained from published sources and multiplied by total biomass of invertebrate samples.

		Managed		Nonmanaged	
Year	Season	Biomass	TME	Biomass	TME
1	Fall	7.79	2.96	0.03	0.01
	Winter	9.59	3.65	2.16	0.82
	Spring	8.15	3.10	4.02	1.53
2	Fall	4.87	1.85	3.53	1.34
	Winter	0.57	0.22	0.01	< 0.01
	Spring	3.17	1.20	1.36	0.52

Table 6. Bird species richness, Shannon's (Shannon-Wiener) diversity index, and Jaccard's similarity index for bird communities in managed and nonmanaged coastal marsh sites along the central Texas coast during fall, winter, and spring 2007-08 and 2008-09.

			Species Richness		Shannon's		Jaccard's
		Site	Managed	Nonmanaged	Managed	Nonmanaged	
2007-08	Fall	GW	23	8	2.37	1.74	0.35
		MD	17	32	2.02	2.12	0.30
		NS	16	16	1.78	2.43	0.52
		RS	25	6	2.46	1.67	0.24
	Winter	GW	25	25	2.40	1.95	0.39
		MD	17	32	0.89	2.58	0.26
		NS	35	24	2.45	1.49	0.37
		RS	35	20	2.85	2.30	0.15
	Spring	GW	13	9	1.65	0.62	0.23
		MD	28	13	2.50	1.55	0.24
		NS	29	29	3.23	2.12	0.18
		RS	37	28	3.19	2.36	0.25
		Mean	25.0	20.17	2.32	1.91	0.29
2008-09	Fall	GW	25	16	2.01	2.21	0.32
		MD	28	17	2.18	2.78	0.29
		NS	23	11	1.73	1.52	0.10
		RS	21	17	1.48	2.50	0.19
	Winter	GW	34	27	2.72	1.98	0.27
		MD	26	13	2.49	2.28	0.35
		NS	26	33	2.70	2.32	0.44
		RS	39	22	2.21	1.29	0.39
	Spring	GW	23	12	2.24	1.99	0.25
		MD	27	17	2.47	2.58	0.57
		NS	31	26	3.17	2.58	0.46
		RS	30	29	2.88	2.48	0.48
		Mean	27.75	20.0	2.26	2.21	0.34
	Total Average		26.38	20.08	2.34	2.06	0.32

Table 7. Bird species found only in managed or only in nonmanaged coastal marsh sites along the central Texas coast during fall, winter, and spring 2007-08 and 2008-09.

Managed (n = 33)	Nonmanaged (n = 11)
Baird's Sandpiper (*Calidris bairdii*)	Black Rail (*Laterallus jamaicensis*)
Black-bellied Plover (*Pluvialis squatarola*)	Black Skimmer (*Rynchops niger*)
Black-bellied whistling duck (*Dendrocygna autumnalis*)	Brewer's Blackbird (*Euphagus cyanocephalus*)
Blue-gray Gnatcatcher (*Polioptila caerulea*)	Brown Pelican (*Pelecanus occidentalis*)
Bonaparte's Gull (*Larus philadelphia*)	Clapper Rail (*Rallus longirostris*)
Cinnamon Teal (*Anas cyanoptera*)	Eastern Kingbird (*Tyrannus tyrannus*)
Common Moorhen (*Gallinula chloropus*)	King Rail (*Rallus elegans*)
Common Nighthawk (*Chordeiles minor*)	Lincoln's Sparrow (*Melospiza lincolnii*)
Fulvous Whistling Duck (*Dendrocygna bicolor*)	Orchard Oriole (*Icterus spurious*)
Greater White-fronted Goose (*Anser albifrons*)	Purple Martin (*Progne subis*)
Hooded Merganser (*Lophodytes cucullatus*)	Sandwich Tern (*Sterna sandvicensis*)
Le Conte's Sparrow (*Ammodramus leconteii*)	
Least Grebe (*Tachybaptus dominicus*)	
Lesser Scaup (*Aythya affinis*)	
Mallard (*Anas platyrhynchos*)	
Neotropic Cormorant (*Phalacrocorax brasilianus*)	
Northern Mockingbird (*Mimus polyglottos*)	
Northern Rough-winged Swallow (*Stelgidopteryx serripennis*)	
Nelson's Sharp-tailed Sparrow (*Ammodramus nelsoni*)	
Olive-sided Flycatcher (*Contopus cooperi*)	
Pectoral Sandpiper (*Calidris melanotos*)	
Redhead (*Aythya Americana*)	
Ring-necked Duck (*Aythya collaris*)	
Semipalmated Plover (*Charadrius semipalmatus*)	
Snow Goose (*Chen caerulescens*)	
Snowy Plover (*Charadrius alexandrinus*)	
Solitary Sandpiper (*Tringa solitaria*)	
Song Sparrow (*Melospiza melodia*)	
Sprague's Pipit (*Anthus spragueii*)	
Stilt Sandpiper (*Calidris himantopus*)	
Wilson's Plover (*Charadrius wilsonia*)	
Yellow-crowned Night Heron (*Nyctanassa violacea*)	
Yellow-rumped Warbler (*Dendroica coronata*)	

Table 8. Total number of bird species by foraging habitat guild that were observed in managed and nonmanaged coastal marsh sites along the central Texas Coast during fall, winter, and spring in 2007-08 and 2008-09.

Guild	Managed	Nonmanaged
Benthic	11	6
Mudflat	23	16
Water column	25	22
Water surface	14	9
Above water	6	6
Dense emergent	6	9
Terrestrial	30	23

Table 9. Number of bird species by foraging habitat guild and season that were observed in managed and nonmanaged coastal marsh sites along the central Texas Coast during the fall, winter, and spring in 2007-08 and 2008-09.

Season	Guild	Managed	Nonmanaged
Fall	Benthic	6	3
	Mudflat	12	3
	Water column	16	15
	Water surface	9	5
	Above water	6	6
	Dense emergent	4	4
	Terrestrial	12	8
Winter	Benthic	10	5
	Mudflat	10	12
	Water column	17	15
	Water surface	9	8
	Above water	7	6
	Dense emergent	5	5
	Terrestrial	18	14
Spring	Benthic	7	4
	Mudflat	18	10
	Water column	16	15
	Water surface	7	6
	Above water	5	6
	Dense emergent	5	5
	Terrestrial	16	13

Table 10. Average densities of birds observed on managed and nonmanaged coastal marsh sites along the central Texas Coast during fall, winter, and spring in 2007-08 and 2008-09.

		Managed	Nonmanaged
2007-08			
	Fall	15.86	12.32
	Winter	20.10	18.34
	Spring	14.03	8.61
2008-09			
	Fall	8.21	2.18
	Winter	5.71	9.18
	Spring	16.55	6.77

Table 11. Bird species of high conservation priority (priority ranking of 4 or 5) detected in managed (M) and nonmanaged (N) coastal marsh sites along the central Texas Coast during fall, winter, and spring 2007-08 and 2008-09.

Guild	Species	M	N
Benthic	Roseate Spoonbill (*Ajaia ajaja*)	X	X
Mudflat	American Avocet (*Recurvirostra americana*)	X	X
	Long-billed Curlew (*Numenius americanus*)	X	X
	Short-billed Dowitcher (*Limnodromus griseus*)	X	X
	Stilt Sandpiper (*Calidris himantopus*)	X	
	Western Sandpiper (*Calidris mauri*)	X	X
	Wilson's Plover (*Charadrius wilsonia*)	X	
Water Column	American Bittern (*Botaurus lentiginosus*)	X	X
	Brown Pelican (*Pelecanus occidentalis*)		X
	Little Blue Heron (*Egretta caerulea*)	X	X
	Least Bittern (*Ixobrychus exilis*)	X	X
	Least Grebe (*Tachybaptus dominicus*)	X	
	Least Tern (*Sterna antillarum*)	X	
	Pied-billed Grebe (*Podilymbus podiceps*)	X	X
	Reddish Egret (*Egretta rufescens*)	X	X
Water Surface	Wilson's Phalarope (*Phalaropus tricolor*)	X	X
Above Water	Nelson's Sharp-tailed Sparrow (*Ammodramus nelsoni*)	X	
Transition zone	Black Rail (*Laterallus jamaicensis*)		X
	Clapper Rail (*Rallus longirostris*)		X
	King Rail (*Rallus elegans*)		X
	Sora (*Porzana carolina*)	X	X
Terrestrial	Dickcissel (*Spiza americana*)	X	X
	Olive-sided Flycatcher (*Contopus cooperi*)	X	
	Total	19	17

APPENDIX A

Results from analyses of treatment (management), season, and year effects, including 2-way and 3-way interactions, on bird species richness, overall bird density, waterbird density, shorebird density, marshbird density, terrestrial bird density, high conservation priority bird species density, plant species richness, aquatic invertebrate biomass, coefficient of variation (CV) of emergent vegetation coverage within wetlands, and CV of mudflat coverage within wetlands

Variable	Effect	Num df	Den df	F value	Pr > F
Bird Species Richness	Treatment	1	59.4	30.8	< 0.0001
	Season	2	87.1	3.72	0.028
	Year	1	65.6	13.2	0.001
	Season*Treatment	2	86.9	0.01	0.988
	Yr*Treatment	1	65.5	0.38	0.538
	Yr*Season*Treatment	2	80.9	1.42	0.247
Overall Bird Density	Treatment	1	8.57	2.23	0.171
	Season	2	25.4	5.24	0.013
	Year	1	18.1	6.67	0.019
	Season*Treatment	2	25.4	0.50	0.619
	Yr*Treatment	1	18.1	0.00	0.945
	Yr*Season*Treatment	2	27.1	1.59	0.223
Waterbird Density	Treatment	1	6.13	4.49	0.077
	Season	2	23.2	0.03	0.969
	Year	1	15.2	0.63	0.439
	Season*Treatment	2	23.2	0.51	0.607
	Yr*Treatment	1	15.2	0.32	0.578
	Yr*Season*Treatment	2	25.5	0.23	0.795
Shorebird Density	Treatment	1	3.00	1.05	0.380
	Season	2	30.0	2.22	0.127
	Year	1	30.0	4.77	0.037
	Season*Treatment	2	30.0	0.26	0.772
	Yr*Treatment	1	30.0	0.11	0.742
	Yr*Season*Treatment	2	30.0	1.91	0.166
Marshbird Density	Treatment	1	10.8	13.4	0.004
	Season	2	11.6	1.07	0.373
	Year	1	12.2	0.39	0.546
	Season*Treatment	2	11.6	2.04	0.175
	Yr*Treatment	1	12.2	0.04	0.846
	Yr*Season*Treatment	2	10.1	0.55	0.593

Appendix A (Continued)

Variable	Effect	Num DF	Den DF	F value	Pr > F
Terrestrial Bird Density	Treatment	1	7.33	1.20	0.308
	Season	2	25.5	9.77	0.001
	Year	1	18.0	12.8	0.002
	Season*Treatment	2	25.5	0.80	0.461
	Yr*Treatment	1	18.0	0.00	0.974
	Yr*Season*Treatment	2	27.6	0.74	0.488
High Conservation Priority Bird Species Density	Treatment	1	27.0	1.49	0.233
	Season	2	27.0	2.25	0.125
	Year	1	33.0	0.76	0.390
	Season*Treatment	2	27.0	0.90	0.418
	Yr*Treatment	1	33.0	0.07	0.789
	Yr*Season*Treatment	2	13.8	0.21	0.810
Plant Species Richness	Treatment	1	5.78	2.63	0.158
	Season	2	23.6	2.24	0.128
	Year	1	16.1	7.49	0.015
	Season*Treatment	2	23.6	0.23	0.800
	Yr*Treatment	1	16.0	0.00	0.948
	Yr*Season*Treatment	2	25.6	0.01	0.986
Aquatic Invertebrate Biomass	Treatment	1	7.10	9.88	0.016
	Season	2	18.4	0.53	0.597
	Year	1	12.3	4.21	0.062
	Season*Treatment	2	18.4	0.32	0.732
	Yr*Treatment	1	11.7	4.77	0.050
	Yr*Season*Treatment	2	15.3	0.26	0.774
CV-Emergent Vegetation Coverage Within Wetlands	Treatment	1	7.64	15.9	0.004
	Season	2	25.7	0.61	0.549
	Year	1	19.3	0.19	0.669
	Season*Treatment	2	25.7	0.04	0.963
	Yr*Treatment	1	19.2	0.01	0.933
	Yr*Season*Treatment	2	27.3	0.74	0.487
CV-Mudflat Coverage Within Wetlands	Treatment	1	8.86	0.02	0.893
	Season	2	18.6	0.54	0.590
	Year	1	12.6	0.41	0.536
	Season*Treatment	2	18.8	1.23	0.314
	Yr*Treatment	1	12.2	3.37	0.091
	Yr*Season*Treatment	2	18.0	0.92	0.418

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