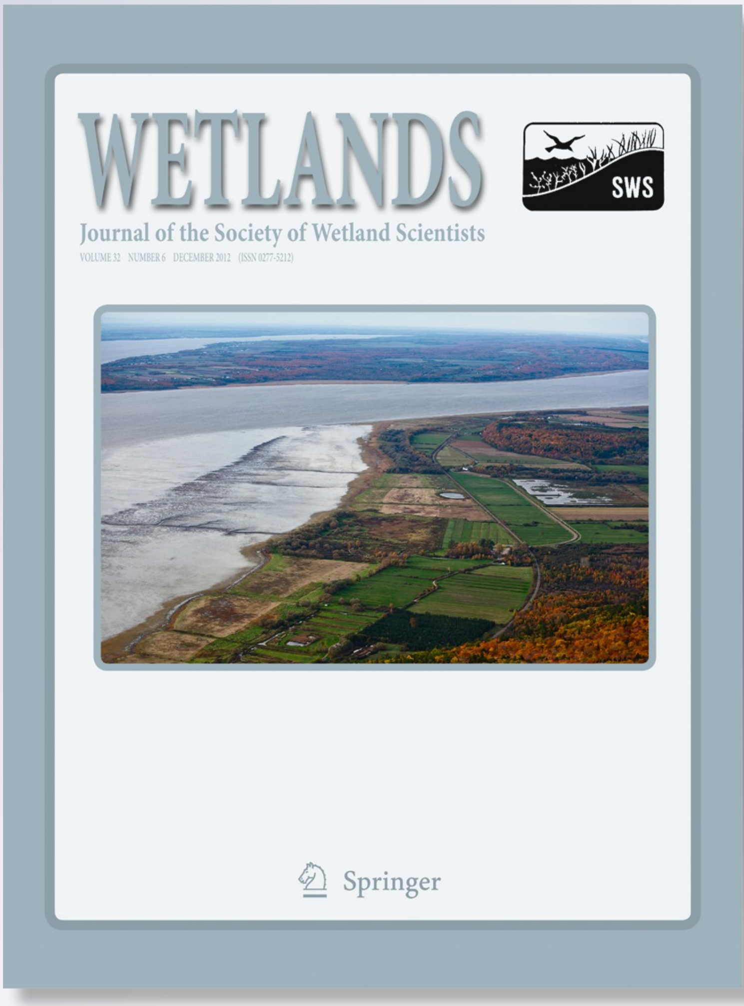
Implications of Coastal Wetland Management to Nonbreeding Waterbirds in Texas

Owen N. Fitzsimmons, Bart M. Ballard, M. Todd Merendino, Guy A. Baldassarre & Kevin M. Hartke

Wetlands
Official Scholarly Journal of the Society of Wetland Scientists

ISSN 0277-5212
Volume 32
Number 6

Wetlands (2012) 32:1057-1066
DOI 10.1007/s13157-012-0336-2



Springer

Your article is protected by copyright and all rights are held exclusively by Society of Wetland Scientists. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your work, please use the accepted author's version for posting to your own website or your institution's repository. You may further deposit the accepted author's version on a funder's repository at a funder's request, provided it is not made publicly available until 12 months after publication.

Author's personal copy

Wetlands (2012) 32:1057–1066
DOI 10.1007/s13157-012-0336-2

ARTICLE

Implications of Coastal Wetland Management to Nonbreeding Waterbirds in Texas

Owen N. Fitzsimmons · Bart M. Ballard · M. Todd Merendino · Guy A. Baldassarre · Kevin M. Hartke

Received: 12 April 2011 / Accepted: 3 September 2012 / Published online: 16 September 2012
© Society of Wetland Scientists 2012

Abstract 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. In particular, management techniques that control water to provide fresh (<0.5 ppt) and intermediate (0.5–5 ppt) marsh in a landscape dominated by brackish and saline marsh. However, research is needed to assess the effectiveness of these techniques in providing waterbird habitat. During 2007–09 along the central Texas Coast, we investigated the effects of marsh management on bird, plant, and aquatic invertebrate communities by comparing leveed areas within the coastal marsh that received water level and mechanical management, to adjacent nonmanaged marsh that received no hydrologic or mechanical manipulations. 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 (e.g., rails). Management of coastal marsh that reduces water salinities and suppresses plant succession appears to be a possible way to mitigate the effects of declines in fresh and intermediate marsh on nonbreeding waterbirds.

Keywords Aquatic invertebrates · Marsh management · Texas Coast · Waterbirds

Electronic supplementary material The online version of this article (doi:10.1007/s13157-012-0336-2) contains supplementary material, which is available to authorized users.

O. N. Fitzsimmons · B. M. Ballard (✉)
Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville,
MSC 218, 700 University Boulevard,
Kingsville, TX 78363, USA
e-mail: bart.ballard@tamuk.edu

M. T. Merendino
Ducks Unlimited, Inc.,
Texas Field Office, 915 Front Street,
Richmond, TX 77469, USA

G. A. Baldassarre
State University of New York,
207 Illick Hall, 1 Forestry Drive,
Syracuse, NY 13210, USA

K. M. Hartke
Texas Parks and Wildlife Department,
915 Front Street,
Richmond, TX 77469, USA

Present Address:
O. N. Fitzsimmons
Coastal Bend Bays and Estuaries Program,
1305 N. Shoreline Blvd., Suite 205,
Corpus Christi, TX 78401, USA

The Texas Coast is extremely diverse in its wetland habitats, which provide critical resources for a wide variety of bird species and serves as a 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). Wetlands along the Texas coast continue to experience widespread degradation and loss, particularly fresh (≤0.5 ppt) and intermediate (0.5–5 ppt) marshes, which have declined nearly 30 % in the past 40 years (Moulton et al. 1997). Wetland loss along the Texas Coast has mainly resulted from conversion of wetland to agriculture, rural and urban development, and human recreation. These continuing pressures and projected future development and growth illustrate the need to strengthen conservation efforts in the region.

The negative impacts of wetland loss and degradation to bird communities have prompted the widespread use of marsh management techniques by private and public land managers (Erwin et al. 1986; Tori et al. 2002; Kaminski et

Author's personal copy

al. 2006). Marsh management along the Texas Coast generally involves controlling fresh water inflows and/or outflows behind a levee to provide freshwater marsh. Additional management techniques such as disking, burning, and seeding are also used to promote desired vegetation. An array of different wetland management techniques has been successful in supplying habitat and resources to wintering waterfowl and other wetland birds (Weller 1990; Weber and Haig 1996; de Szalay and Resh 1997; Anderson and Smith 1999; Kaminski et al. 2006). However, others have highlighted the potential negative effects of levee construction and marsh management on endemic marsh bird species such as Seaside Sparrows (*Ammodramus maritimus*), Nelson's Sharp-tailed Sparrows (*Ammodramus nelsoni*), and Clapper Rails (*Rallus longirostris*) (Gabrey et al. 2001, Mitchell et al. 2006). Changes in the vegetation community due to management inputs, for example, can reduce critical nesting habitat for some marsh bird species (Mitchell et al. 2006).

The lack of information on the effects of marsh management on waterbirds other than waterfowl has limited the attractiveness of coastal marsh management practices to the wide array of user groups involved in state and regional management in some areas. For instance, potential marsh management projects along the Texas Coast are often viewed as only benefiting waterfowl by many coastal interest groups (M. Merendino, personal communication).

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). However, few studies have addressed the effect of marsh management on all waterbirds at a given site. Further, few studies have examined the effects of management on potential food supplies to help explain differences in waterbird communities between managed and nonmanaged sites (Gawlik 2002). Consequently, more investigation of the effects of marsh management on waterbird species is needed to optimize future management efforts and meet desired objectives (Ma et al. 2010). Our primary objective was to compare bird communities between 2 types of wetlands: leveed freshwater/intermediate marsh that receives annual disturbance to increase habitat diversity, and adjacent natural, brackish/saline marsh that does not receive the hydrologic and mechanical management of the managed areas. Specifically, we examined the bird communities in each wetland type and related any differences to vegetation and invertebrate communities.

Study Area

This study was conducted on two 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, comprises 4,831 ha and is located in Brazoria County west of Freeport. Mad Island WMA comprises 2,946 ha in Matagorda County. Both WMAs were comprised of palustrine emergent wetlands, coastal prairie meadows, estuarine intertidal marshes, and unvegetated intertidal mudflats. Managed marsh projects were developed on both WMAs to increase wetland habitat diversity and in particular, to provide more open water and submerged aquatic vegetation during fall and winter. Management schemes were similar among managed areas and were typical of techniques used along the Texas coast. Within the managed areas which were behind constructed levees, the management scenario included an annual late February to mid-April drawdown immediately followed by disking and then flooding in September/October each year. Prescribed fire was implemented in lieu of mechanical treatment about every third year (Greenwing in 2000, 2003, 2007; Mottled Duck in 2002, 2007; Rattlesnake and North Savage sites in 2004 and 2007) and was implemented on the paired nonmanaged sites at the same time. Cattle were allowed to graze on the Wildlife Management Areas from 15 February to 1 September each year and they had equal opportunity in both managed and nonmanaged sites as no fences divided them. Both managed and natural areas are frequented by the public for waterfowl hunting during fall and winter, however, managed sites incurred approximately 21 % more hunter/days than the paired nonmanaged sites each year of the study (Texas Parks and Wildlife Department, unpublished data).

Two managed wetlands at each WMA were randomly chosen with 2 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. Prior to construction, each managed area was coastal marsh habitat with characteristics similar to the nonmanaged areas. At Justin Hurst WMA, the selected managed wetlands comprised the Greenwing (91 ha) and Mottled Duck (147 ha) sites, and at Mad Island WMA, the Rattlesnake (20 ha) and North Savage sites (17 ha). At Justin Hurst WMA, the Greenwing wetland was constructed in July 1998 and the Mottled Duck wetland in July 1999 (9 and 8 years old at beginning of study, respectively). Both managed wetlands at Mad Island WMA were constructed in August 2001 (6 years old at beginning of study).

Hurricane Ike had large impacts on our study sites during 2008–09. The hurricane made landfall on the Texas coast 13 September 2008 in the Galveston area approximately 60–100 miles from the study areas. The resulting Category 4 storm surge reached up to 7 m in some areas, inundating all study wetlands with sea water.

Author's personal copy

Methods

Within each managed and nonmanaged wetland, we 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 during 3, 45-day seasons during both 2007–08 and 2008–09 (fall, winter, and spring). 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 nonmigratory period during midwinter.

Avian Community

We conducted avian surveys using line transect sampling methodology (Buckland et al. 1993). 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. Group size and perpendicular distance from transect line were recorded for each bird species observed. Only visual detections were used and PVC stakes were located at know distances from the transect line at 50-m intervals to aid in distance estimation. 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 occurred between 0.5 and 3.5 h after sunrise and 3.5 and 0.5 h before sunset and were not conducted if winds were >25 km/h or during rain or fog due to likely reductions in detection rates. Up to 4 surveys were conducted per season, with no surveys conducted on days when public hunting occurred. Managed and nonmanaged wetlands had equal access for hunting.

Vegetation Community

The vegetation community at each site was surveyed once at the beginning of each season. Logistic constraints did not allow us to survey the North Savage location in fall 2007. We 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 thorough coverage of any variation in habitat due to changes in water depth, as managed wetlands were deepest near the levee. Along each transect we estimated percent cover for all plant species, bare ground, and open water within a 1-m^2 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. We estimated screening cover with a 3-m modified Robel pole marked every 10 cm with red tape. We placed the Robel pole in the center of each quadrat and viewed it from 4 m to the north and 1 m above ground or water surface (Robel et al. 1970). The highest point above the water or substrate (if not standing water) obstructed 100 % by vegetation was recorded to the nearest quarter decimeter to determine screening cover. Water depth at each quadrat was also recorded with the Robel pole to the nearest quarter decimeter.

Aquatic Invertebrates

We collected aquatic invertebrate samples once during the middle of 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. We used a standard D-frame dip net to sample aquatic invertebrates from a 1-m^2 area at each point. The net was worked up and down 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 they were processed. In the laboratory, we sorted the invertebrate samples, identified them to order, dried them in an oven at 60^{o} C until constant mass was reached, and then weighed them to the nearest 0.0001 g to determine biomass (Pennak 1978; Merritt and Cummins 1996). We also measured water salinity with an YSI Model 85 salinity system at the beginning and end of each invertebrate sampling transect.

We obtained true metabolizable energy (TME) values for common waterfowl food items from the literature (Jorde and Owen 1988; Ballard et al. 2004; DiBona 2007) to estimate available energy based on sampled invertebrate biomass. TME values for taxa present in our samples but not found in the literature were obtained by using published values for similar taxa within orders.

Statistical Analysis

To compare bird densities in managed and nonmanaged areas, we classified bird species into 5 groups: shorebirds, waterbirds, waterfowl, marsh birds, and terrestrial birds. We grouped shorebirds, waterbirds, waterfowl, and marsh birds according to Kushlan et al. (2002) or Bellrose (1980), while designating all other bird species as terrestrial (Online Resource 1). We included passerine species in the marsh birds group that are commonly found in wetlands, but 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*).

Author's personal copy

We used conservation priority rankings of bird species to provide a different approach for assessing habitat quality besides traditional measures of overall density or species richness (Nuttle et al. 2003). Conservation priority rankings were initially developed to rank bird species based on parameters that use global and local threats, population status, and habitat availability to assess conservation needs. For this study, we referenced the Partners In Flight 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; Partners In Flight 2009). We 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). We compared densities of birds with high-priority conservation rankings (i.e., 4 and 5) between managed and nonmanaged wetlands.

To calculate bird densities, we first had to account for different detection probabilities among wetland sites. To accomplish this, we first averaged screening cover across the 48 sampling points for each year/season/site combination. We then sorted the average screening cover of each year/season/site from shortest to tallest, and we observed gaps in the average screening cover that provided evidence for dividing the year/season/sites into 3 classes: short, medium, and tall (Fig. 1). For each of the 3 classes, we then investigated histograms of all avian detection distances and delineated cut points based on drops in frequency of observations across detection distances. As a result, maximum detection distances that we could assume 100 % detection were 30 m for the tall class, 60 m for the medium class, and 120 m for the short class (Fig. 2). Encounters detected beyond these distances were not considered for density estimation within their respective screening cover class and resulted in a strip-transect type approach. This allowed us to make more representative comparisons among areas with different vegetation densities. Bird densities were calculated by dividing the number of birds observed within these 100 % detection distances by the area encompassed by the 100 % detection distances for each site.

We used analysis of variance in PROC MIXED (SAS Institute 2002) with repeated measures to investigate effects of wetland management (managed vs. nonmanaged), season, and year on plant species richness, bird species richness and densities (for overall birds and bird groups), and aquatic invertebrate biomass. Year and season (both fixed effects), and wetland management (treatment) were tested as well as all of their interactions (Online Resource 1). We also used PROC MIXED to explore how vegetation species richness and aquatic invertebrate biomass influenced the densities of all birds and bird groups. We used the Kenward-Roger method of estimating denominator degrees of freedom for 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 ($n=8$), we considered any effects significant if $P \leq 0.10$ (Tacha et al. 1982).

We calculated Shannon's (Shannon-Wiener) diversity index and Jaccard's similarity index to help explain relationships in vegetation and bird communities between managed and nonmanaged wetlands (Begon et al. 1990). We presented absolute values and did not test for differences in any indices we calculated.

Results

Avian Community

We detected 124 bird species overall, with 113 species that used managed wetlands and 87 species that used nonmanaged

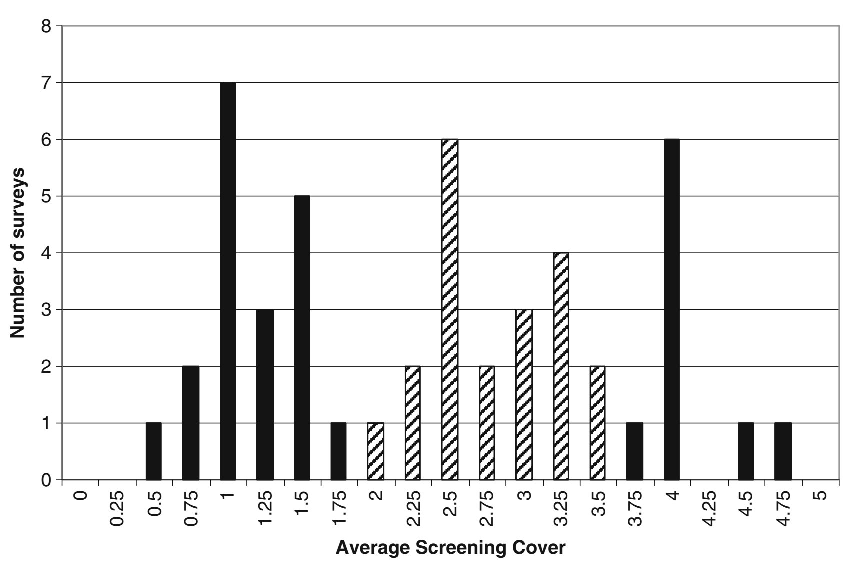


Fig. 1 Frequency of average screening cover for managed and nonmanaged coastal marsh study sites along the Texas Coast during fall (1 Sep–15 Oct), winter (1 Jan–15 Feb), and spring (1 Apr–15 May) 2007–08 and 2008–09. Managed sites (75 % 120 m, 25 % 60 m) and Nonmanaged sites (37 % 60 m, 63 % 30 m).

Author's personal copy

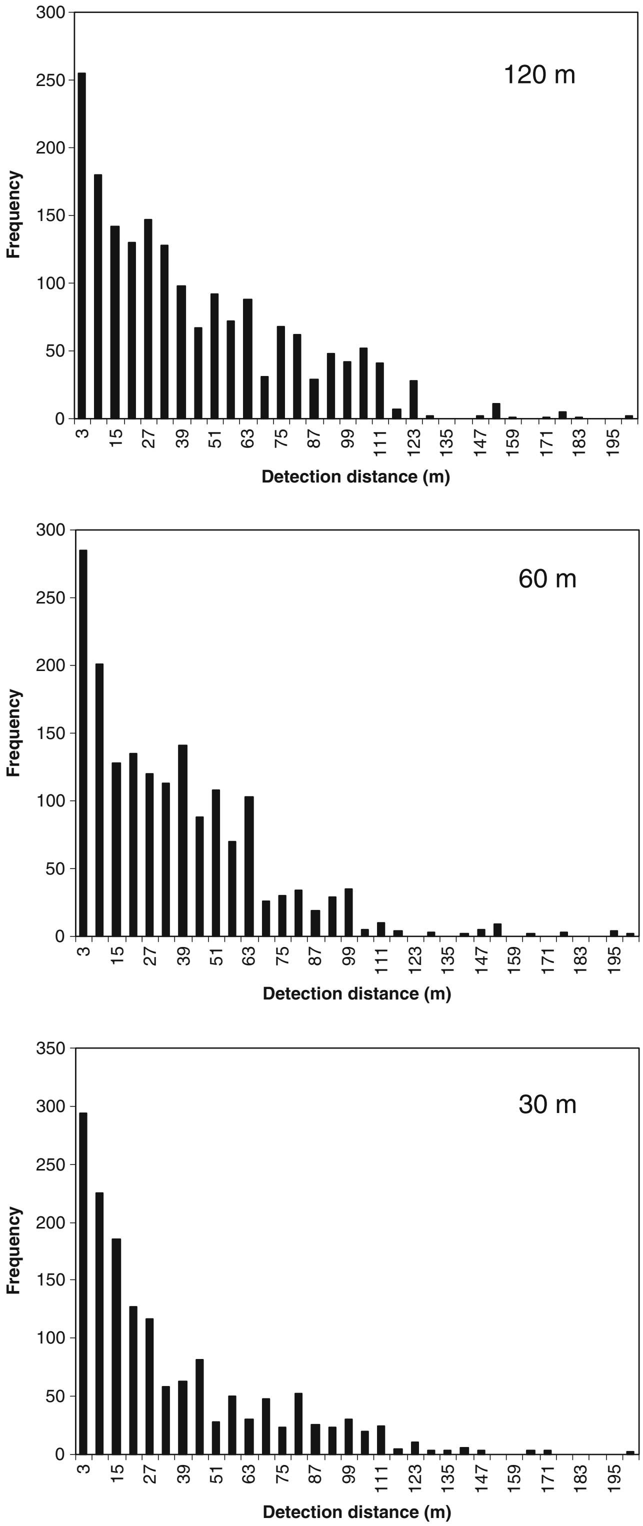


Fig. 2 Frequency of bird observations across detection distances for each of 3 cover classes in managed and nonmanaged coastal marsh along the Texas Coast during fall (1 Sep–15 Oct), winter (1 Jan–15 Feb), and spring (1 Apr–15 May) 2007–08 and 2008–09

wetlands over the entire study (Online Resource 2). Seventy-six species (61 %) were observed in both managed and nonmanaged wetlands. Managed wetlands ($\bar{x}$=18.3) supported 1.6 times more bird species than nonmanaged wetlands ($\bar{x}$=11.9) across the study ($F_{1,\ 21.7}$=20.65, n=48, P<0.001). We also detected a strong year effect ($F_{1,\ 30.4}$=9.29, n=48, P=0.004) and a season x year interaction ($F_{2,\ 72.4}$=2.96, n=48, P=0.058) for bird species richness.

Bird diversity also tended to be greater in managed than nonmanaged wetlands, with the exception of winter 2008 when diversity was the same, and in fall 2009 when bird diversity was higher in nonmanaged sites (Table 1). Bird communities were relatively dissimilar throughout the study, with Jaccard's Index values ranging from 0.10–0.57 (Table 2).

We detected no significant wetland management effect on overall bird densities (P=0.171) (Table 1). Although overall, waterbird densities were 2.2 times greater in managed areas ($\bar{x}$=2.07, SE=0.37) than nonmanaged areas ($\bar{x}$=0.96, SE=0.37; $F_{1,\ 6.13}$=4.49, n=48, P=0.077), but nonmanaged areas ($\bar{x}$=1.47, SE=0.22) supported 4.4 times greater marsh bird densities than managed areas ($\bar{x}$=0.33, SE=0.22; $F_{1,\ 10.8}$=13.42, n=48, P=0.004) (Table 3). We also tested for differences in waterbird and marsh bird densities between managed and nonmanaged areas within cover classes to see if there was any potential bias associated with different proportions of treatment areas within cover classes. We found similar results (F≥4.96, P≤0.096) for all cover classes except for the 30 m cover class for waterbirds where we found no difference ($F_{1,3}$=3.95, P=0.141). Waterfowl, shorebird, and terrestrial bird densities were similar between managed and nonmanaged wetlands (P≥0.621) (Table 3).

Overall bird densities throughout the study were positively related to invertebrate biomass within wetlands ($F_{1,\ 2.99}$=5.79, n=48, P=0.096). However, our largest differences in invertebrate biomass between managed and nonmanaged sites did not necessarily equate to the largest differences in bird densities, suggesting that our test was not overly robust. We also found overall bird densities to be positively related to plant species richness ($F_{1,\ 2.98}$=34.21, n=48, P=0.010). Of the 4 bird groups, all but marsh bird densities (P=0.918) were positively related to plant species richness (shorebirds: $F_{1,\ 15.3}$=4.79, n=48, P=0.045; waterbirds: $F_{1,\ 27.3}$=7.28, n=48, P=0.012; terrestrial birds: $F_{1,\ 2.96}$=6.78, n=48, P=0.081).

Managed and nonmanaged wetlands supported similar densities of birds with high conservation priority scores (P=0.418). Also, richness of species with high conservation priority scores was similar between managed and nonmanaged sites. 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 (Online Resource 2). Twelve of the 23 species were detected in both managed and nonmanaged wetlands. Managed wetlands

Author's personal copy

Table 1 Mean values (SE) for 6 biological parameters in managed and nonmanaged coastal marsh along the Texas Coast during fall (1 Sep–15 Oct), winter (1 Jan–15 Feb), and spring (1 Apr–15 May) 2007–08 and 2008–09

Season	Biological Parameter[a]	2007–08		2008–09	
		Managed	Nonmanaged	Managed	Nonmanaged
Fall	Bird species richness	23.3 (4.4)	15.5 (11.8)	24.3 (3.0)	15.3 (2.9)
	Bird diversity[b]	2.2 (0.16)	2.0 (0.18)	1.9 (0.15)	2.3 (0.27)
	Bird density[e]	9.7 (2.1)	8.1 (3.0)	7.7 (2.6)	1.8 (0.7)
	Plant species richness	19.3 (2.9)	16.7 (8.1)	15.3 (10.2)	12.0 (2.8)
	Plant diversity[b]	1.8 (0.04)	1.5 (0.2)	1.4 (0.4)	1.3 (0.2)
	Invertebrate biomass[c]	4.0 (0.6)	tr[d]	1.4 (0.3)	0.9 (0.7)
Winter	Bird species richness	28.0 (4.4)	25.3 (2.5)	31.3 (3.2)	23.8 (4.3)
	Bird diversity	2.1 (0.43)	2.1 (0.24)	2.5 (0.12)	2.0 (0.24)
	Bird density	10.8 (2.6)	10.6 (4.4)	15.7 (3.6)	6.6 (2.8)
	Plant species richness	20.5 (3.8)	16.3 (3.4)	12.0 (3.7)	8.3 (0.9)
	Plant diversity	1.6 (0.1)	1.4 (0.1)	1.2 (0.2)	1.2 (0.2)
	Invertebrate biomass	2.4 (1.5)	0.5 (0.3)	0.2 (0.3)	tr
Spring	Bird species richness	26.8 (5.0)	19.8 (5.1)	27.8 (1.8)	21.0 (4.0)
	Bird diversity	2.6 (0.4)	1.7 (0.4)	2.7 (0.2)	2.4 (0.1)
	Bird density	10.4 (2.9)	7.3 (1.8)	5.6 (1.5)	10.4 (3.4)
	Plant species richness	19.5 (0.9)	17.5 (4.2)	17.3 (5.5)	15.0 (3.6)
	Plant diversity	1.9 (0.3)	1.5 (0.1)	1.6 (0.4)	1.4 (0.1)
	Invertebrate biomass	3.2 (2.2)	1.0 (0.5)	0.9 (0.5)	0.4 (0.2)

[a] averaged across 4 wetland sites

[b] Shannon's diversity index was used

[c] g/m^2

[d] tr=<0.001

[e] number of birds/ha

supported more shorebirds and waterbirds with high conservation priority, including Stilt Sandpiper (*Calidris mauri*), Wilsons' Plover (*Charadrius wilsonis*), Least Grebe (*Tachybaptus dominicus*), and Least Tern (*Sterna antillarum*). However, nearly all rail 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 2 Jaccard's similarity index comparing bird communities 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	0.30	0.39	0.23	0.31
Mottled Duck	0.30	0.26	0.24	0.27
North Savage	0.52	0.37	0.18	0.36
Rattlesnake	0.24	0.15	0.25	0.21
Average	0.34	0.29	0.23	
2008–09				
Greenwing	0.32	0.27	0.25	0.28
Mottled Duck	0.29	0.35	0.57	0.40
North Savage	0.10	0.44	0.46	0.33
Rattlesnake	0.19	0.39	0.48	0.35
Average	0.23	0.36	0.44	
Total Average	0.29	0.33	0.33	

Vegetation Community

Similarity indices for vegetation communities between managed and nonmanaged wetlands were variable across the study, ranging from 9 % similar at Mottled Duck in winter 2007–08 to 50 % similar at North Savage in winter 2008–09 (Table 4). We identified 96 species of plants across the study; 84 species of emergent plants, 7 species of submergent plants, and 5 species of floating-leaf/free-floating plants. 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, broadleaf signal grass (*Brachiaria platyphylla*), and stonewort (*Nitella* spp.). Although the vegetation communities differed markedly between managed and nonmanaged sites, 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, n=46, P=0.015).

Plant species diversity was relatively greater in managed than nonmanaged wetlands during each year×season combination, except winter 2009 when it was the same (Table 1). 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.

Author's personal copy

Table 3 Mean density (bird/ha [SE]) for 5 bird groups in managed and nonmanaged coastal marsh along the Texas Coast during fall (1 Sep–15 Oct), winter (1 Jan–15 Feb), and spring (1 Apr–15 May) 2007–08 and 2008–09

Season		2007–08		2008–09	
		Managed	Nonmanaged	Managed	Nonmanaged
Fall	Waterbirds	2.88 (0.67)	1.77 (1.01)	0.97 (0.58)	0.30 (0.11)
	Marsh birds	0.82 (0.28)	1.80 (0.81)	0.53 (0.25)	0.66 (0.19)
	Shorebirds	0.51 (0.35)	0.10 (0.10)	2.50 (1.32)	0.26 (0.13)
	Waterfowl	3.40 (1.73)	1.25 (0.72)	1.39 (0.53)	0.09 (0.06)
	Terrestrial birds	2.11 (0.93)	3.15 (1.07)	2.35 (1.10)	0.45 (0.15)
Winter	Waterbirds	2.52 (1.20)	1.05 (0.72)	2.40 (0.95)	0.82 (0.31)
	Marsh birds	0.33 (0.16)	0.89 (0.28)	0.23 (0.14)	0.89 (0.52)
	Shorebirds	0.17 (0.09)	1.67 (1.34)	5.69 (3.15)	3.55 (1.72)
	Waterfowl	5.35 (2.07)	2.81 (2.69)	5.11 (1.79)	0.13 (0.08)
	Terrestrial birds	2.46 (1.03)	4.15 (3.73)	2.22 (0.72)	1.20 (0.70)
Spring	Waterbirds	2.26 (0.58)	0.42(0.11)	1.72 (0.82)	1.79 (0.96)
	Marsh birds	0.13 (0.05)	2.97 (0.76)	0.12 (0.07)	2.37 (0.57)
	Shorebirds	4.38 (2.19)	0.26 (0.15)	2.74 (0.88)	3.48 (1.21)
	Waterfowl	1.93 (0.65)	0.19 (0.19)	0.25 (0.06)	0.69 (0.28)
	Terrestrial birds	1.65 (0.40)	3.42 (0.92)	0.81 (0.30)	2.04 (0.34)

Salinities remained below 2 ppt in managed wetlands and below 10 ppt in nonmanaged wetlands during fall and winter 2007–08. In 2008–09, the high storm surge from Hurricane Ike greatly influenced both managed and nonmanaged wetlands by increasing water salinities well above those recorded the previous year. The effects of Hurricane Ike were particularly evident at Mad Island WMA, where salinities increased from <1 ppt in fall 2007 to 33–40 ppt in fall 2008. Water salinities remained higher in managed than nonmanaged wetlands at Mad Island WMA throughout 2008–09. Overall, average salinities in managed areas increased 1,566 % from 2007–08 ($\bar{x}$=1.22 ppt, SE=1.11) to 2008–09 ($\bar{x}$=20.33 ppt, SE=12.11).

Mean water levels in managed areas varied from 18.9 (0.5) cm in fall, to 3.1 (0.3) cm in winter, and 2.1 (0.3) cm in spring. There was less seasonal variability in water levels in nonmanaged areas, as mean water levels varied from 5.0 (0.3) cm in fall, to 2.1 (0.4) cm in both winter and spring.

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

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	

Aquatic Invertebrates

Differences in aquatic invertebrate biomass between managed and nonmanaged wetlands varied by year ($F_{1,\ 11.7}$= 4.77, P=0.050). Managed areas ($\bar{x}$ = 3.15 g/m^2, SE=0.53) supported 8.5 times (P=0.007) greater aquatic invertebrate biomass than nonmanaged ($\bar{x}$= 0.37 g/m^2, SE=0.66) areas in 2007–08, while managed and nonmanaged areas in 2008–09 were similar (P=0.558) (Table 1). Aquatic invertebrate biomass was similar among seasons throughout the study (P=0.597). Energy from invertebrates was directly related to biomass as average kcal/g was similar between managed and nonmanaged wetlands.

Coleoptera, Diptera, and Hemiptera occurred most frequently (i.e., occurred in most samples) in both managed and nonmanaged wetlands. In 2007–08, Gastropods comprised the greatest biomass of any invertebrate during each season in managed and nonmanaged wetlands (range: 29 %–90 % of all invertebrate biomass). In 2008–09, Gastropods again comprised the greatest biomass of invertebrates in nonmanaged wetlands. In contrast, Hemiptera and Ostracoda comprised the greatest invertebrate biomass in managed wetlands in 2008–09. Collectively, Gastropoda,

Author's personal copy

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.

Discussion

We found species richness and densities of waterbirds to be greater in managed than nonmanaged coastal wetlands. 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 of wetland birds 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.

We found that overall bird densities were positively related to invertebrate biomass, suggesting that managed wetlands may have provided more foraging opportunity than nonmanaged sites. 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). Overall, managed wetlands supported considerably greater aquatic invertebrate biomass in 2007–08 in addition to consistently providing more available energy from invertebrates 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 nutrient and energy requirements 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). Other studies have come to similar conclusions, suggesting that greater resource availability, such as foraging habitat and prey density and availability, contribute to greater numbers of waterbirds in managed wetlands (Epstein and Joyner 1988; Kaminski et al. 2006). 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). Management goals on our study sites were based on providing more open water and submerged aquatic vegetation during fall and winter. This also provides managers the ability to easily provide mudflat habitat for shorebirds in spring. These managed wetlands increase habitat diversity in a landscape of predominately brackish to saline emergent marsh.

Differences in plant species richness, invertebrate biomass, and overall bird density between 2007 and 08 and 2008 and 09 were most likely due to extreme changes in water salinity between years as a result of Hurricane Ike. Although levees and water control structures 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 and invertebrate communities in managed wetlands to more closely match the salt-tolerant communities that dominated the nonmanaged sites (see Table 4). This was particularly apparent at Mad Island WMA during fall and winter, as vegetation community similarity indices were much greater following Hurricane Ike.

Despite the effects of major salinity changes on plant communities, aquatic invertebrates, and overall bird densities, we found that shorebird densities were much greater in both managed and nonmanaged sites after Hurricane Ike. Shorebird densities have been shown to correlate with the amount of exposed substrate (Darnell and Smith 2004). The increase in water salinities following Hurricane Ike caused considerable plant die-off in managed wetlands and created sparsely vegetated mudflats that were seasonally atypical of managed marshes in our 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 the habitat associations of nonbreeding marsh birds; however, available information suggests that managed wetlands may lack the dense vegetation or grass-like conditions required by certain bird species (Mitchell et al. 2006). Our findings support this, as greater densities of marsh birds (e.g., rails, least bittern) in nonmanaged wetlands were likely associated with the greater emergent vegetation cover within these sites. The higher water levels in managed sites during fall and winter resulted

Author's personal copy

in less emergent cover in deeper areas. Also, characteristically small tidal amplitudes along the Texas coast produce little variation in water levels in natural marsh area (Smith 1977).

We 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 we detected were found in both. This finding was consistent with our overall bird species richness, where 61 % 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).

Conclusion

Our findings suggest that proper management of wetlands along the Texas coast can provide productive and diverse habitat for many wetland bird species. Greater invertebrate biomass and available energy, as well as greater seasonal variation in hydrology may have contributed to the higher bird species richness, bird diversity, and waterbird densities that we observed in managed wetlands. Marsh management techniques that reduce water salinities and suppress plant succession appear to create habitat for a suite of species that are not present in adjacent saltwater marshes. However, the value of nonmanaged marsh also was evident, as nonmanaged areas supported the majority of secretive marsh bird species (e.g., rails, bittern, sparrows) detected and greater marsh bird densities throughout the study.

Future comparative studies should use extended monitoring efforts to account for broader temporal changes in plant and bird communities, and to better assess 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 represent only a portion of the foods available to waterbirds in wetlands. Evaluating stopover duration, vital rates, or mass change of birds using managed and unmanaged marsh would allow a stronger assessment as to the quality of these habitats to migratory and wintering birds. Finally, major events such as hurricanes can provide valuable pre- and post event research opportunities, and future monitoring in these areas might provide clearer understanding of natural disturbances.

Depending on specific objectives, managed wetlands on the Texas Coast can provide important habitat during crucial non-breeding periods to a large and diverse assemblage of birds, some of which are of high priority for conservation. Marsh management techniques present managers with an effective way to alleviate the negative effects of recent loss and degradation of freshwater and intermediate marsh on the Texas Coast (Moulton et al. 1997). The benefits of such practices are justification for the establishment of managed marshes in conjunction with the conservation of natural areas to improve habitat diversity for wetland birds at the local and landscape level on the Texas Coast.

Acknowledgements We thank M. Nelson, D. Butler, and L. Alford from Texas Parks and Wildlife Department for their assistance with logistics regarding our study sites. We also thank A. Tjelmeland for assistance with avian surveys. Funding was provided by the Jess Y. Womack, II Fellowship in Wetlands and Wetland Bird Research, and the Texas Parks and Wildlife Department. We thank A. Fedynich and D. Hewitt and 2 anonymous reviewers for comments that improved this manuscript. This is manuscript #11-119 of the Caesar Kleberg Wildlife Research Institute.

References

Anderson JT, Smith LM (1999) Carrying capacity and diel use of managed playa wetlands by nonbreeding waterbirds. Wildlife Society Bulletin 27:281–291

Anderson JT, Smith LM (2000) Invertebrate response to moist-soil management of playa wetlands. Ecological Applications 10:550–558

Ballard BM, Thompson JE, Petrie MJ, Checkett M, Hewitt DG (2004) Diet and nutrition of northern pintails wintering along the southern coast of Texas. Journal of Wildlife Management 68:371–382

Begon M, Harper JL, Townsend CR (1990) Ecology: individuals, populations, and communities, 2nd edn. Blackwell Scientific Publications, London

Bellrose FC (1980) Ducks, geese, and swans of North America. Stackpole Books, Harrisburg

Birkitt BF (1984) Considerations for the functional restoration of impounded wetlands. In: Webb FJ Jr (ed) Proceedings of the 10th Annual Conference of Wetlands Restoration and Creation. Hillsborough Community College, Tampa

Bolduc F, Afton AD (2004) Relationships between wintering waterbirds and invertebrates, sediments and hydrology of coastal marsh ponds. Waterbirds 27:333–341

Brown M, Dinsmore JJ (1986) Implications of marsh size and isolation for marsh bird management. Journal of Wildlife Management 50:392–397

Brown S, Hickey C, Gill B, Gorman L, Gratto-Trevor C, Haig S, Harrington B, Hunter C, Morrison G, Page G, Sanzenbacher P, Skagen S, Warnock N (2000) National shorebird conservation

Author's personal copy

assessment: shorebird conservation status, conservation units, population estimates, population targets, and species prioritization. Manomet Center for Conservation Sciences http://www.Manomet.org/USSCP/files.htm

Buckland ST, Anderson DR, Burnham KP, Laake JL (1993) Distance sampling: estimating abundance of biological populations. Chapman and Hall, London, New York

Carter MF, Hunter WC, Pashley DN, Rosenberg KV (2000) Setting conservation priorities for landbirds in the United States: the Partners In Flight approach. The Auk 117:541–548

Craig RJ, Beal KG (1992) The influence of habitat variables on marsh bird communities of the Connecticut River estuary. Wilson Bulletin 104:295–311

Darnell TM, Smith EH (2004) Avian use of natural and created salt marsh in Texas, USA. Waterbirds 27:355–361

Davis CA, Bidwell JR (2008) Response of aquatic invertebrates to vegetation management and agriculture. Wetlands 28:793–805

de Szalay FA, Resh VH (1997) Responses of wetland invertebrates and plants important in waterfowl diets to burning and mowing of emergent vegetation. Wetlands 17:149–156

DiBona MT (2007) Seasonal food availability for wintering and migrating dabbling ducks and its implications for management at the Hackensack Meadowlands of New Jersey. Thesis, University of Delaware, Newark, Delaware, USA

Epstein MB, Joyner RL (1988) Waterbird use of brackish wetlands managed for waterfowl. Proceedings of the Annual Conference of Southeast Association Fish and Wildlife Agencies 42:476–490

Erwin ME, Coulter M, Cogswell H (1986) The use of natural vs. man-modified wetlands by shorebirds and waterbirds. Colonial Waterbirds 9:137–138

Fairbairn SE, Dinsmore JJ (2001) Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. Wetlands 21:41–47

Gabrey, SW, Afton AD, Wilson BC (2001) Effects of structural marsh management and winter burning on plant and bird communities during summer in the Gulf Coast Chenier Plain. Wildlife Society Bulletin 29:218–231

Gawlik DE (2002) The effects of prey availability on the numerical response of wading birds. Ecological Monographs 72:329–346

Jorde DG, Owen RB Jr (1988) Efficiency of nutrient use by American black ducks wintering in Maine. Journal of Wildlife Management 52:209–214

Kaminski MR, Baldassarre GA, Pearse AT (2006) Waterbird responses to hydrological management of wetlands reserve program habitats in New York. Wildlife Society Bulletin 34:921–926

Krapu GL, Reinecke KJ (1992) Foraging ecology and nutrition. In: Batt BDJ, Afton AD, Anderson MG et al (eds) Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis

Kushlan JA (1986) The management of wetlands for aquatic birds. Colonial Waterbirds 9:246–248

Kushlan JA, Steinkamp MJ, Parsons KC, Capp J, Cruz MA, Coulter M, Davidson I, Dickson L, Edelson N, Elliot R, Erwin RM, Hatch S, Kress S, Milko R, Miller S, Mills K, Paul R, Phillips R, Saliva JE, Sydeman B, Trapp J, Wheeler J, Wohl K (2002) Waterbird conservation for the Americas: The North American waterbird conservation plan, Version 1. Waterbird Conservation for the Americas, Washington, DC, 78 pp

Ma ZJ, Cai Y, Li B, Chen JK (2010) Managing wetland habitats for waterbirds: an international perspective. Wetlands 30:15–17

McGovern JC, Wenner CA (1990) Seasonal recruitment of larval and juvenile fishes into impounded and non-impounded marshes. Wetlands 10:203–221

Merritt RW, Cummins KW (1996) Aquatic insects of North America, 3rd edn. Kendall/Hunt Publishing Company, Iowa

Mikuska T, Kushlan JA, Hartley S (1998) Key areas for wintering North American herons. Colonial Waterbirds 21:125–134

Mitchell LR, Gabrey S, Marra PP, Erwin RM (2006) Impacts of marsh management on coastal-marsh bird habitats. Studies in Avian Biology 32:155–175

Moulton DW, Dahl TE, Dall DM (1997) Texas coastal wetlands; status and trends, mid-1950's to early 1990's. U. S. Department of the Interior, Fish and Wildlife Service, Albuquerque

Nuttle T, Leidolf A, Burger AW Jr (2003) Assessing conservation value of bird communities with Partners in Flight-based ranks. Auk 120:541–549

Partners In Flight—http://www.rmbo.org/pif/downloads/downloads.html accessed 1 November 2009.

Pennak RW (1978) Fresh-water invertebrates of the United States, 2nd edn. Wiley, New York

Robel RJ, Briggs JN, Dayton AD, Hulbert LC (1970) Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295–297

SAS Institute, Inc (2002) SAS/STAT User's Guide, version 9.1. SAS Institute, Cary

Skagen SK, Oman HD (1996) Dietary flexibility of shorebirds in the western hemisphere. Canadian Field Naturalist 110:419–444

Smith NP (1977) Meteorological and tidal exchanges between Corpus Christi Bay, Texas, and the northwestern Gulf of Mexico. Estuarine and Coastal Marine Science 5:511–520

Stutzenbaker CD, Weller MW (1989) The Texas Coast. In: Smith LM, Pederson RL, Kaminski RM (eds) Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock, pp 385–405

Tacha TC, Ward WD, Burnham KP (1982) Use and interpretation of statistics in wildlife journals. Wildlife Society Bulletin 10:355–362

Tanner GW, Drummond ME (1985) A floating quadrat. Journal of Range Management 38:287

Tori GM, McLeod S, McKnight K, Moorman T, Reid FA (2002) Wetland conservation and Ducks Unlimited: real world approaches to multispecies management. Waterbirds 25(Special Publication 2):115–121

Weber LM, Haig SM (1996) Shorebird use of South Carolina managed and natural coastal wetlands. Journal of Wildlife Management 60:73–82

Weller MW (1988) Issues and approaches in assessing cumulative impacts on waterbird habitat in wetlands. Environmental Management 12:695–701

Weller MW (1990) Waterfowl management techniques for wetland enhancement, restoration and creation useful in mitigation procedures. In: Kusler JA, Kantula ME (eds) Wetland creation and restoration: the status of science (1990). Island Press, Washington, D.C, pp 517–528

Withers K, Chapman BR (1993) Seasonal abundance and habitat use of shorebirds on an Oso Bay mudflat, Corpus Christi, Texas. Journal of Field Ornithology 64:382–392