Effects of marsh pond terracing on coastal wintering waterbirds before and after Hurricane Rita

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Abstract From February to March 2005–2006, we surveyed wintering waterbirds to test effects of terracing on coastal pond use before and after Hurricane Rita. Marsh terracing is intended to slow coastal marsh loss in the Chenier Plain by slowing marsh erosion and encouraging vegetation expansion. Terraces also increase marsh edge in ponds, possibly benefiting waterbirds. We monitored paired terraced and unterraced ponds in three sites within southwestern Louisiana's Chenier Plain. Waterbirds were 75% more numerous in terraced than unterraced ponds. Waterbird richness was similar among ponds when corrected for number of individuals, suggesting terracing increased bird density but did not provide habitat unique from unterraced ponds. Birds were 93% more numerous following Hurricane Rita, mostly due to an influx of migrating waterfowl. Year round residents were similar in number before and after Hurricane Rita. Resident richness did not differ among years after correcting for number of observed individuals. Wading and dabbling foragers were more abundant in terraced ponds and these two guilds represented 74% of birds observed. We detected no difference among ponds for other guilds, i.e., probing, aerial, and diving foragers. Increasing proportion of mash edge increased bird density disproportionately: On average ponds with 10% edge had 6 birds observed and ponds with 30% edge had 16 birds observed. Terraces increased habitat interspersion and were an effective tool for increasing numbers of wintering waterfowl and wading birds. The extent to which terraces were sustainable following hurricane forces is unknown.

Keywords: edge effects; habitat interspersion; waterfowl; wading birds; wetland restoration

Introduction

Louisiana contains 30% of remaining coastal wetlands in the conterminous United States (Field and others *1991*) but these wetlands are disappearing rapidly, averaging 16.3 km^2 $year^{-1}$ in the Chenier Plain during 1978–2000 (Barras and others *2003*). Louisiana marshes provide important habitat for waterbirds (Keller and others *1984*; Myers and others *1987*; Martin and Lester *1990*; Michot *1996*), including wintering and stopover sites for migrants. Continued marsh degradation could therefore affect waterbird population declines locally and regionally. Pond terracing is a novel technique used ubiquitously in Louisiana's coastal Chenier Plain to slow marsh loss (O'Connell and Nyman *2010*). As such, terracing may improve waterbird habitat in the Chenier Plain, with possible benefits for all Central Flyway migrants, but an evaluation of terraced marsh for wintering waterbirds is lacking.

One outcome of marsh loss in the Chenier Plain is interior marsh breakup (Byrnes and others *1995*), which may reduce waterbird densities in coastal marsh ponds. Causes of interior marsh breakup in the Chenier Plain are likely varied, but often initiated by human activities. For example, salt-water intrusion along navigation channels causes vegetation die-off in previously fresh or brackish areas, converting emergent marsh into shallow open-water ponds (Turner *1997*). Once initiated, wave energy accelerates erosion along pond edges as they deepen, increasing open-water areas through time (Nyman and others *1994*). Lateral marsh erosion possibly is accelerated by global sea level rise and sediment starvation resulting from the channelization of the Mississippi and other rivers (Boesch and others *1994*; Turner *1997*).

Hurricanes also can cause extensive marsh loss, as occurred when Hurricane Rita, a category 5 storm, struck the Chenier Plain in September 2005, resulting in 217 km^2 of marsh loss (Barras *2006*). Hurricanes cause marsh loss by generating strong wind and waves, churning up marsh areas and over-washing seawater which may kill fresh to brackish vegetation (Chabreck and Palmisano *1973*). Hurricanes and other strong storms interact with the Gulf Coast regularly (Gray *1990*; Neumann and others *1993*). There also is clear evidence of a global increase in tropical storm intensity and duration (Trenberth and others *2007*; Elsner and others *2008*; Emanuel and others *2008*). Such increases may accelerate marsh loss, further impacting Gulf Coast waterbird populations. However, hurricanes and strong storms have complex effects on marshes. While they can cause direct mortality of both vegetation and wildlife, they also are dispersal agents for seeds, vegetative root stock, and nutrient rich off-shore sediments. Therefore, sometimes hurricanes stimulate productivity (Conner and others *1989*) and elevation in surviving wetlands (Nyman and others *1995*; Turner and others *2006*). Some coastal vegetation may be well adapted to storms. For example, Battaglia and Sharitz (*2005*) suggested storms structured coastal bottomland forest composition and regenerated forests. Waterbirds also may benefit from storm inputs of sediment and nutrients into coastal systems. For example, Convertino and others (*2011*) demonstrated Snowy Plovers (Charadrius alexandrines) prefer nesting grounds struck the previous season by strong storms, probably because over-washed sediments and storm wrack provided ideal habitat. However, the full effects of hurricanes on waterbirds are not completely known and difficult to test. Consequently, we should evaluate effects of common restoration techniques, such as pond terracing, on waterbird populations in the context of potential marsh instability caused by hurricanes and human-mediated factors.

Pond terracing, ubiquitous in the Chenier Plain, is intended to slow conversion of marsh into open-water ponds by providing a barrier to water movement (Underwood and others *1991*; Steyer *1993*; Rozas and Minello *2001*). Terraces are discontinuous, narrow strips of created marsh formed of dredge material from pond bottoms and stabilized with emergent plants such as Spartina alterniflora (Underwood and others *1991*; Steyer *1993*; Rozas and Minello *2001*). Though never evaluated, terraces are thought to reduce wave action in ponds, potentially slowing erosion of pond edges, decreasing water turbidity, encouraging submerged vegetation production, and decreasing pond depths. Terraced ponds perhaps provide a more hospitable environment for emergent vegetation expansion and increase aerial marsh extent.

Terracing also may support waterbird populations by increasing waterbird forage items, such as nekton, invertebrates, and submerged aquatic vegetation (Rozas and Minello *2001*; Whaley and

Minello *2002*; Barras and others *2003*; Bush Thom and others *2004*; Cannaday *2006*; La Peyre and others *2007*; O'Connell and Nyman *2010*). These increases likely occur because terracing increases the proportion of marsh edge (boundary between emergent vegetated marsh and open-water) in ponds (O'Connell and Nyman *2010*). Marsh edge is a shallow, protected environment which serves as a nursery and refugia for aquatic organisms. Waterbird habitat also may be improved because increasing marsh edge maximizes interspersion of water and vegetated marsh in ponds, i.e. pond cover of open-water and emergent vegetation each approach 50%, as in the hemi-marsh model (Weller and Spatcher *1965*). Thus, terracing ponds may improve habitat quality for wintering waterbirds.

We are unaware of previous studies investigating the relationship between wintering waterbirds and habitat interspersion, though this relationship has been demonstrated for breeding waterbirds (Mack and Flake *1980*; Kaminski and Prince *1981*; Fairbairn and Dinsmore *2001*). Additionally, terrace effects on wintering waterbirds have never been evaluated, though during the summer breeding season, we demonstrated that terraces increased waterbird density (O'Connell and Nyman *2010*). We originally intended for that previous study to include wintering birds, but the passage of a category 5 storm (Hurricane Rita, 24 September 2005), forced a sampling hiatus and a drastic methodology change. Terrace effects on wintering birds should be evaluated because many Louisiana waterbirds are migrants that only use marsh ponds during winter. These migrants include economically important waterfowl as well as shorebirds. Finally, Hurricane Rita may have caused direct mortality of waterbirds. We have data on wintering waterbird density from 2005, prior to the passage of Hurricane Rita, and from winter 2006, directly following Hurricane Rita. Therefore, we uniquely are able to examine migrating and resident waterbird marsh use in terraced ponds before and after a strong hurricane.

Methodology

Study Area. Our study sites were in coastal southwestern Louisiana's Chenier Plain. This region of the Gulf Coast extends from west of Vermilion Bay, Louisiana, to High Island, Texas. The Chenier Plain consists of shore-parallel, linear transgressive beach ridges or "cheniers", separated by broad areas of low-elevation marsh (Penland and Suter *1989*). Hurricane Rita struck in September 2005, separating the two wintering periods (February–March 2005 and 2006) we evaluated. Hurricane Rita was an unpredictable event, forcing a change in sampling methods. We minimized these differences by sub-setting our data in both years to equal sampling sites and survey periods. However, some sampling differences remain: 2005 contained one survey in a site not sampled in 2006, plot sizes differed between years (though survey area was approximately equivalent), and time spent in each survey differed. We discuss biases associated with methodological differences and account for them as much as possible.

Site Selection

We monitored pond pairs at each site, one terraced (treatment), and one nearby unterraced pond (control). We selected study ponds by identifying terraced ponds where adjacent marsh was dominated by Spartina patens, an indicator of intermediate to brackish conditions. From these, we excluded sites receiving major mineral sediment sources because, unlike Louisiana deltaic wetlands, most Chenier Plain marshes do not receive substantial sediments from rivers, streams or bayous. Unterraced ponds were open-water ponds similar in condition to terraced ponds before terraces were added, i.e. near to the terraced pond and hydrologically connected to it. Study sites were each in different watersheds and hydrologically independent from other sites.

Site Descriptions

Sites differed somewhat in 2005 (before Hurricane Rita) and 2006 (after Hurricane Rita). We monitored waterbirds at two sites each survey period. Ponds averaged 213 ha (range 70–1190 ha). Terraced ponds had more edge habitat (18.3%, SE = 3.1%) than did unterraced ponds (6.4%, SE = 0.3%), when terraced edge and natural edge were combined into one edge category (Table 1). Sites used were in Sabine National Wildlife Refuge (NWR) (terraced pond coordinates: 0434212 East and 3304478 North, Unit 5 and unterraced pond coordinates: 0434609 East and 3311970 North, Unit 6, hydraulically connected to Unit 5). Sweet Lake (coordinates: 480933 East and 3312269 North, owned by Sweet Lake Gas and Oil Co. and Miami Corporation), and an impounded unit in Rockefeller State Wildlife Refuge (SWR) (coordinates: 523597 East and 3284941 North, Unit 4, owned by Louisiana Department of Wildlife and Fisheries). Coordinates are UTM NAD 1984, Zone 15 N. Terraces were constructed in Sweet Lake in 2001, in Rockefeller SWR in 2002, and in Sabine in 2001. Waterfowl hunting occurred in Sweet Lake during January months in terraced and unterraced ponds equally. Hunting was not allowed in Rockefeller SWR or Sabine NWR. The unterraced pond at Sabine NWR was terraced after our first survey in 2005. We discontinued sampling this site and replaced it with the Sweet Lake site. We retained Sabine NWR in our study so that two sites are sampled in all surveys in both years.

Table 1. Area (ha) of water classified as open-water (OW), water near a natural edge (NE), terraced edge (TE), total water near any edge (Total E), the ratio of TE:NE, and the percent of water that is edge habitat

Site	Pond Type	OW	TE	NE	Total E	TE:NE Ratio	% Edge
Sabine	Terraced	427.8	35.5	9.8	45.3	1.99	9.6
	Unterraced	1099.7	-	91.1	91.1	-	7.6
Sweet Lake	Terraced	155.5	50.5	10.3	60.8	4.9	28.1
	Unterraced	95.5	-	5.4	5.4	-	5.4
Rockefeller	Terraced	59.3	7.3	5.1	12.3	1.4	17.2
	Unterraced	72.3	-	4.8	4.8	-	6.2

Survey Methods 2005 (Pre-Hurricane). Surveys were conducted every two-weeks from 11 February 2005 through 20 March 2005. Each pond contained multiple survey plots. One plot/pond was sampled each survey session; different plots were sampled in subsequent sessions. Ultimately, sampling effort was even among plots. Survey methods are as described in O'Connell and Nyman (*2010*), but briefly, plots were delineated by marking plot corners with PVC pipe. Plots ranged from 9–12 ha (average 11 ha) due to geographical constraints. Observers were dropped off at plots by boat. One observer counted plots while hidden in emergent vegetation. Terraced and unterraced ponds were surveyed simultaneously by separate observers. Surveys began at dawn. To minimize double-counting, observers counted birds by scanning plots from end to end, disregarding birds that entered or left plots after an area had been counted. Observers counted birds after a 15 min settling period. Observers counted plots multiple times, but for comparison with 2006 survey methods, only the first plot count was used in analyses.

Survey Methods 2006 (Post-Hurricane). Field housing was unavailable in the Chenier Plain following Hurricane Rita. We therefore designed surveys to maximize ponds visited during a single day and surveyed all plots/pond each survey session. To minimize bias associated with time of day, surveys began at different ponds and plots each survey session, such that sampling effort was even among ponds. Hurricane wreckage prevented access to the Chenier Plain from September to early November 2005. During December, we tested survey methods. We inferred from these trials that boat noise disturbance to birds was reduced when plots were approached at low speeds and oblique angles, boats stopped at a distance from birds, and small discrete plots were counted rather than large plots or long, narrow transects. Flushing of birds was minimal using these methods, though some did occur. However, our view was unobstructed because ponds are large and open, and we successfully determined bird locations prior to boat disturbance. Thus, we ensured we counted birds using plots and ignored birds flushed from adjacent marsh.

Plots were delineated with PVC as in 2005. Plot locations overlapped 2005 plots, but plot size was reduced from 10 ha average, allowing quick, complete bird counts. Plots ranged from 3–5 ha (average 4.3 ha) due to geographical constraints. We surveyed 2–3 plots in ponds during each survey rather than one plot as was done in 2005. Total survey area in ponds was approximately equivalent to plot size surveyed in 2005.

Two observers and one boat driver conducted surveys. Plots were counted upon arrival via boat, rather than after a 15 min settling period as was done in 2005. We interpret this bias in our discussion. Each observer independently recorded observations and the same observers counted both terraced and unterraced ponds. We used the average number for each species counted by both observers as our species abundance estimate. We sampled sites once every two weeks from 7 February 2006 to 29 March 2006, generating equal survey periods between years.

<u>Statistical Methods</u>**.** We grouped bird species into foraging guilds to compare numbers of individuals between pond types. We used foraging classifications of De Graaf and others (*1985*), except that we classified Common Moorhen as dabblers based on our behavior observations. Guilds were as follows: diving foragers, dabbling foragers, wading foragers, probing foragers, and aerial foragers (Table 2). We also grouped year round residents to compare whether species present during Hurricane Rita's passage differed in number among years (Table 3).

Table 2. General linear models of the relationship among bird density (birds ha^{-1} ± SE), pond type (factor), survey week (continuous), and year (factor), with Poisson error structure and log-link between the model and response

Model	Intercept	Pond Type (Unterraced)	Year (2006)	Survey Week
Total bird density	-1.18 ± 0.82*	-1.17 ± 0.46***	2.95 ± 0.82***	0.45 ± 0.05***
Dabbler density	-4.78 ± 1.57**	-1.8 ± 0.84*	4.33 ± 1.47**	0.95 ± 0.09***
Wader density	-1.61 ± 0.72*	-1.39 ± 0.65*	1.89 ± 0.76*	NS
Prober density	NS	NS	NS	NS
Aerial density	NS	NS	NS	NS
Diver density	NS	NS	NS	NS
Density of residents	1.12 ± 0.61˜	-1.15 ± 0.57*	NS	NS

*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$; and ˜ $P < 0.1$

We compared number of total birds, divers, dabblers, waders, probers, aerialists, and year round residents with general linear mixed models using Poisson error (lmer program using R) and random intercepts by site and plot size to account for correlated repeated measurements within sites and variation due to plot size (Zuur and others *2009*). We reduced independent variables in models if explanatory variables were not significant ($P > 0.1$). We used EstimateS (Colwell *2005*) to generate species accumulation curves, accounting for rarefaction in species richness among treatments (Pielou *1975*; Palmer and others *2008*). We used 500 randomizations and plot moment-based estimation (Mao Tau estimator in EstimateS) of species richness versus number of individuals as recommended by Colwell and others (*2004*).

Additionally, we used a general linear mixed model with Poisson error and random site and plot size to compare number of all birds observed with proportion of pond within 10 m of marsh edge (e.g., habitat interspersion). We used ArcGIS 9.1 (ESRI Corp, Redlands, CA) to compute the proportion of open-water and water near marsh edge in each pond type by analyzing 2004 DOQQ aerial photographs of sites (See O'Connell and Nyman *2010* for methods).

Table 3. Common and scientific names and mean number of individuals (± SE) for observed species and foraging guilds.

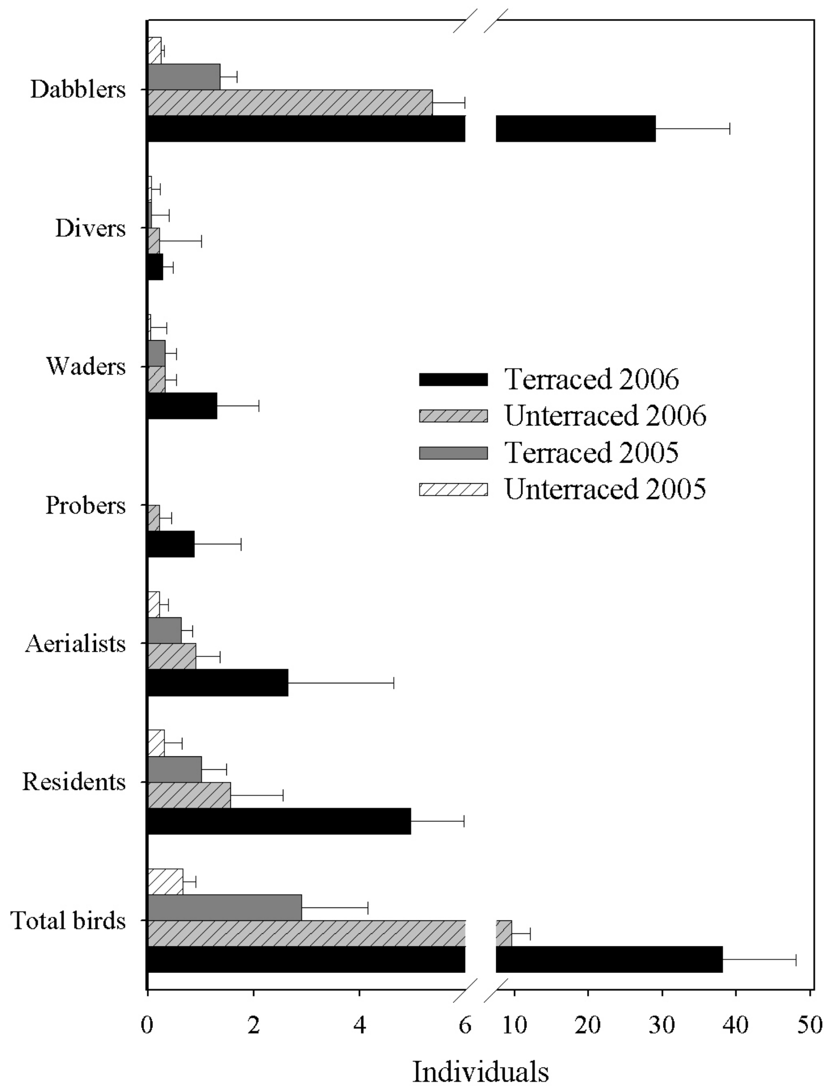
	2005		2006	
Species	Terraced	Unterraced	Terraced	Unterraced
Diving foragers	**0.1 ± 0.33**	**0.1 ± 0.17**	**0.3 ± 0.21**	**0.2 ± 0.79**
^Pied-billed Grebe *(Podilymbus podiceps)*	0.1 ± 0.13	0.3 ± 0.25	0.3 ± 0.25	0.3 ± 0.16
Common Loon *(Gavia immer)*	0 ± 0	0 ± 0	0 ± 0	0.3 ± 0.16
^Double-crested Cormorant *(Phalacrocorax auritus)*	0.9 ± 0.58	0 ± 0	0.4 ± 0.38	3.0 ± 3.00
Wading foragers	**0.3 ± 0.21**	**0.1 ± 0.3**	**1.3 ± 0.8**	**0.3 ± 0.21**
^Great Blue Heron *(Ardea herodias)*	0.1 ± 0.13	0 ± 0	0.4 ± 0.26	0 ± 0
^Tricolored Heron *(Egretta tricolor)*	0 ± 0	0 ± 0	0.1 ± 0.13	0 ± 0
^Great Egret *(Ardea alba)*	0.1 ± 0.13	0 ± 0	0.8 ± 0.31	0.3 ± 0.16
^Snowy Egret *(Egretta thula)*	0.1 ± 0.13	0 ± 0	0 ± 0	0 ± 0
^White Ibis *(Eudocimus albus)*	0 ± 0	0 ± 0	0.1 ± 0.13	0 ± 0
Dabbling foragers	**1.4 ± 0.31**	**0.3 ± 0.05**	**29.1 ± 9.46**	**5.4 ± 1.92**
Blue-winged Teal *(Anas discors)*	0 ± 0	0 ± 0	5.9 ± 2.80	2.4 ± 2.38
Gadwall *(Anas strepera)*	1.3 ± 0.73	0.3 ± 0.25	5.1 ± 4.29	1 ± 0.42
Green-winged Teal *(Anas crecca)*	0 ± 0	0 ± 0	26.0 ± 12.97	0.9 ± 0.88
Mallard *(Anas platyrhynchos)*	0 ± 0	0 ± 0	0.1 ± 0.13	0 ± 0
^Mottled Duck *(Anas fulvigula)*	0 ± 0	0.3 ± 0.25	0.3 ± 0.25	0.6 ± 0.42
Northern Pintail *(Anas acuta)*	0 ± 0	0 ± 0	0.5 ± 0.5	0 ± 0
Northern Shoveler *(Anas clypeata)*	0 ± 0	0 ± 0	5.1 ± 2.29	2.5 ± 2.50
^Common Moorhen *(Gallinula chloropus)*	0 ± 0	0.1 ± 0.13	0 ± 0	0 ± 0
Probing foragers	**0 ± 0**	**0 ± 0**	**0 ± 0**	**0.3 ± 0.33**
^Black-necked Stilt *(Himantopus mexicanus)*	0 ± 0	0 ± 0	0.1 ± 0.13	0 ± 0
Greater Yellowlegs *(Tringa melanoleuca)*	0 ± 0	0 ± 0	0.5 ± 0.5	0.6 ± 0.63
Lesser Yellowlegs *(Tringa flavipes)*	0 ± 0	0 ± 0	0 ± 0	0.4 ± 0.38
^Willet *(Catoptrophorus semipalmatus)*	0 ± 0	0 ± 0	1.5 ± 1.5	0 ± 0
Aerial foragers	**0.7 ± 0.21**	**0.2 ± 0.17**	**0.7 ± 0.21**	**1.0 ± 0.45**
^Laughing Gull *(Larus atricilla)*	0 ± 0	0.1 ± 0.13	0.6 ± 0.63	0 ± 0
Ring-billed Gull *(Larus delawarensis)*	0 ± 0	0 ± 0	0.6 ± 0.38	0.3 ± 0.16
^Caspian Tern *(Sterna caspia)*	0.3 ± 0.16	0 ± 0	0.6 ± 0.38	0 ± 0
^Forster's Tern *(Sterna forsteri)*	0.4 ± 0.38	0.4 ± 0.38	2.4 ± 1.46	1.3 ± 1.25
^Royal Tern *(Sterna maxima)*	0 ± 0	0 ± 0	0.8 ± 0.62	0 ± 0
Year round residents	**1.0 ± 0.48**	**0.3 ± 0.33**	**5.0 ± 2.58**	**1.6 ± 1**
Total birds	**2.9 ± 1.25**	**0.7 ± 0.25**	**38.1 ± 9.97**	**9.6 ± 2.11**

^ Year round residents

Results

Interaction terms between pond type, survey week and year were not significant for any response variable. Birds were 75% more numerous in terraced ponds than unterraced (Fig. 1).

Fig. 1 Number of waterbird foraging guilds and resident species in terraced and unterraced ponds (mean ± SE), in winter of 2005 and 2006, Chenier Plain, Louisiana. Hurricane Rita struck between years.



When species richness was corrected for number of individuals (rarefaction), richness was similar among pond types, i.e. confidence intervals for species accumulation curves overlap though the number of individuals was not equal (Fig. 2a, b). Birds were 93% more numerous following Hurricane Rita, mostly due to influx of migrating dabbling ducks (Fig. 1).

Numbers of resident birds was roughly equivalent between years (Table 3). Resident species richness also was similar among years when numbers of individuals were accounted for (Fig. 2c).

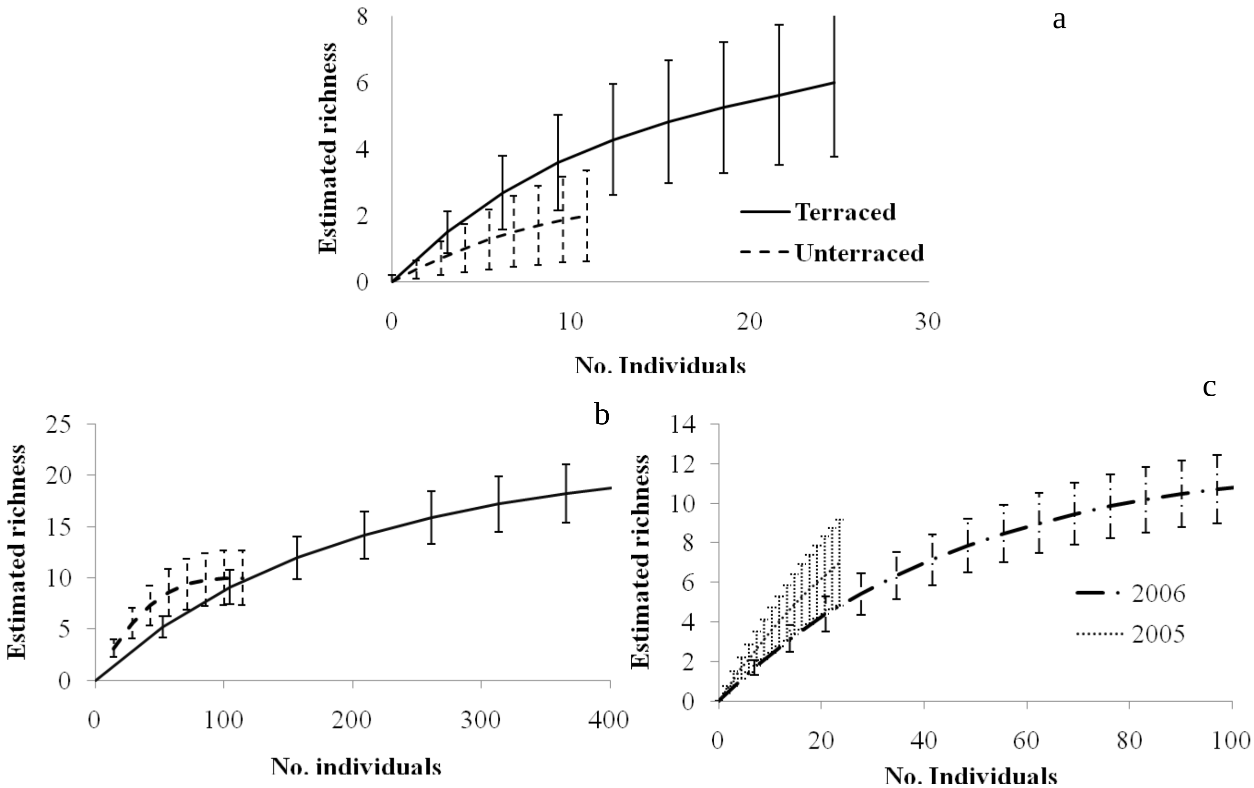


Fig. 2 Species accumulation curves of all species among pond types in 2005 (a), 2006 (b), and resident species among years (c), depicting moment-based estimation of observed species richness versus number of individual birds in ponds

After combining pond types and years guilds were, in order of lowest average density to highest: divers (0.2, SE = 0.4), probers (0.3, SE = 0.3), waders (0.5, SE = 0.04), aerialists (1.1, SE = 0.7), and dabblers (9.0, SE = 2.7).

Dabbling birds and wading birds were 82 and 77% more numerous in terraced ponds than in unterraced ponds (Table 3; Fig. 1) and together comprised 74% of all birds observed. Dabblers and waders were 95 and 77% more numerous in 2006 than 2005, respectively. Aerialists were somewhat abundant (Fig. 1), but we did not detect a difference in numbers among pond types or years. Probing and diving foragers were not abundant, and we also did not detect differences among pond types or years. Resident species were 80% more numerous in terraced ponds than unterraced, but we detected no difference in numbers between years (Table 3; Fig. 1). Finally, there were greater number of birds in ponds with greater proportion of marsh edge (Model: total number of birds = 1.3 + 4.9 × (proportion edge), Poisson error structure and log link between response and model; Fig. 3).

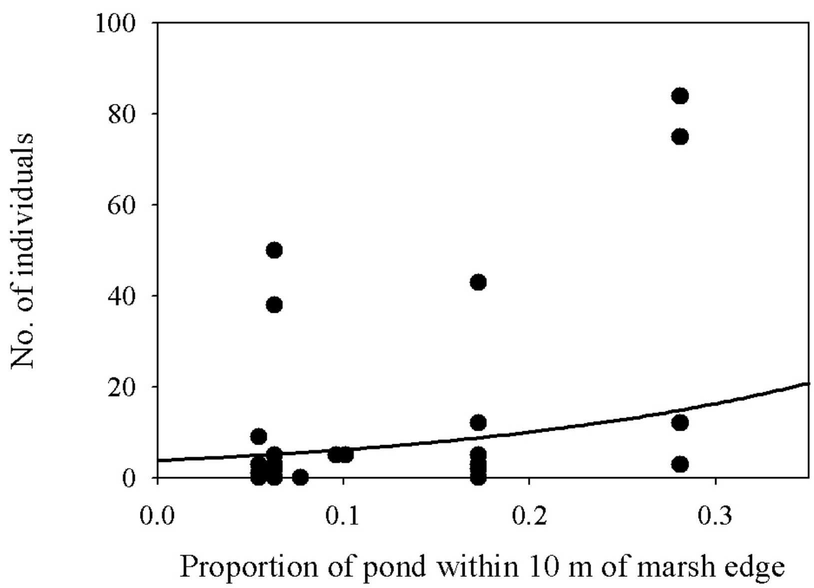


Fig. 3 Number of birds explained by proportion of marsh edge in ponds in winter 2005 and 2006 Chenier Plain, LA

Discussion

<u>Terrace Effects</u>. Waterbirds were more numerous in terraced ponds, probably because terracing increased the proportion of marsh edge (O'Connell and Nyman *2010*) and enhanced habitat complexity (Feagin and Wu *2006*). Birds likely were also more numerous in ponds with greater marsh edge because this increases habitat interspersion of cover and open-water. Ours is the first demonstration of a habitat interspersion effect on wintering waterbirds. However, we demonstrated similar effects in these sites for spring and summer waterbirds during 2005 (O'Connell and Nyman *2010*). Others have shown the importance of habitat interspersion for breeding waterbirds in northern marshes (Weller and Spatcher *1965*; Mack and Flake *1980*;

Kaminski and Prince *1981*; Fairbairn and Dinsmore *2001*). Additionally habitat interspersion has other ecological influences. For example, habitat interspersion has increased macroinvertebrate densities, improved water quality, reduced mosquito populations, and increased mosquito predator populations (Thullen and others *2002*, *2005*). Therefore, maximizing habitat interspersion in marshes may improve multiple ecological services, potentially benefiting waterbirds.

Foraging guilds varied in their response to pond terracing. Waders and dabblers were more numerous in terraced ponds. Waterbirds that forage either for SAV or for items dependent on SAV for food, habitat, or refuge likely benefited from terracing because of increased SAV (Cannaday *2006*; O'Connell and Nyman *2010*), invertebrates (Whaley and Minello *2002*), and nekton (Minello and Rozas *2002*; La Peyre and others *2007*; O'Connell and Nyman *2010*) adjacent to terraced edges. Terracing should have therefore improved densities of SAV-foraging dabblers and piscivorous waders.

We did not detect differences among pond types for aerialists, divers and probers. During spring and summer, aerial foragers in these sites used terraced ponds more often (O'Connell and Nyman *2010*). Aerialists may behave differently during winter than during the breeding season, when proximity to nest sites and provisioning of young are important. For example, Ring-billed Gulls have been frequently observed foraging along terrestrial edges during summer (Baird *1976*; Welham *1987*), but often observed plunge diving for fish in shallow open-water during winter (Chapman and Parker *1985*). Diving foragers were not abundant and did not differ in their use of ponds in either winter (this study) or summer (O'Connell and Nyman *2010*). Diving foragers likely do not rely on shallow ponds as important habitat (ponds studied were less than 1 m deep). They also may feed on forage items from pond bottoms, rather than those close to pond edges. Probing foragers also were not abundant and did not differ among pond types over winter. Probers such as shorebirds may not have been numerous because winter water depths were too deep. Water depths possibly were deeper because of undrained storm surge following Hurricane Rita (see discussion below). However, few shorebirds winter in Louisiana and generally are more abundant during spring and fall migration. Terraced ponds could be improved as shorebird habitat if terraces had broader widths and gentler slopes, increasing accessible shallow areas.

It is possible unterraced ponds provide habitat characteristics not present in terraced ponds. However, there is little evidence to support this. For example, species richness was similar among pond types when numbers of individuals were accounted for. Conclusive evidence for habitat heterogeneity among ponds would be provided only if species richness were independent of density (Fridley and others *2006*).

Hurricane Effects. Hurricane Rita hit the Chenier Plain in September 2005, causing extensive destruction of coastal development and substantial upheaval in adjacent marshes. Numerous "marsh balls" of uprooted S. patens were deposited in previously open-water areas of our study ponds. Undrained storm surge remained in ponds, likely elevating salinities. Fish kills were observed on adjacent uplands, perhaps reducing food sources. However, the hurricane also may have brought in additional nutrients and food sources from offshore areas. We observed no alteration of terrace widths or of surrounding natural marsh edge morphology. The sides of terrace edges also did not appear undercut directly following the hurricane. However, we revisited our study sites in Rockefeller SWR in late spring 2006 following the completion of this study. Terraces at this impounded site were vastly degraded, perhaps because sustained high salinity killed vegetation. Effects of hurricanes on terraced marsh are undetermined. If constant repair of eroding terraces is necessary, many marsh functions may never return to pre-disturbance conditions. Long-term monitoring is necessary to determine if terraces are sustainable.

Hurricane Rita did not appear to reduce bird numbers during this study. Species observed were typical for winter in coastal Louisiana. Many dabbling ducks and shorebirds were migrants not present during the hurricane's passage. Total waterbird numbers observed in plots were greater following the hurricane then during the previous winter, or than observed during summer at these same sites (O'Connell and Nyman *2010*). Higher numbers particularly were observed for migrating dabbling ducks following Hurricane Rita. There is little reason to presume the hurricane directly influenced migrant density. One explanation for higher numbers could be plot size differences among years. Smaller plots, such as those sampled following the hurricane, are known to inflate density estimates over estimates from larger plots because of larger plot edge to plot area ratios (White and others *1982*). We minimized this bias by modeling individuals rather than density and including plot area as a covariate in analyses. However, this well known sampling artifact may still account for part of observed between year differences. Further, locally, weather was warmer and drier in 2006 than 2005 (Table 4).

Table 4. Temperature and rainfall in southwestern Louisiana during February and March of 2005 and 2006.

year	month	average temperature	departure from normal	total rainfall	departure from normal
2005	January	55	4	3.17	-3.17
2005	February	56	1	7.55	3.59
2005	March	59	-2	2.69	-1.74
2006	January	57	6	2.7	-3.34
2006	February	53	-2	4.54	0.58
2006	March	64	3	1.22	-3.21

Data from the Louisiana Office of State Climatology (http://www.losc.lsu.edu/).

However, continent-wide weather patterns or region-wide hunting pressure were likely as influential as local conditions. Sampling during 2005 was amidst El Nino conditions, while 2006 sampling was at the end of La Nina conditions (NOAA *2011*). La Nina sometimes has been linked with severe droughts in North American northern prairies (Trenberth and Guillemot *1996*), where most waterfowl migrants breed. Corroborating this, a record drought persisted during summer 2005 across American mid-west prairies (Palecki and Hilberg *2006*), perhaps limiting grain foods and encouraging waterfowl migration southwards. Year round residents did not differ among years, implying either that there was not substantial direct hurricane mortality or that immigration offset mortality. Only two species were observed in 2005 and not 2006: Common Moorhen and Snowy Egret. Other resident species were either roughly equivalent between years or were more numerous following Hurricane Rita. Leberg and others (*2007*) found in their comparison of nesting colonial waterbirds that nesting pairs for most species increased following Hurricanes Rita and Katrina in southern Louisiana. They also documented substantial movement of birds between colony sites. One further study has documented hurricane effects on waterbird communities, in this case following Hurricane Hugo in South Carolina (Shepherd and others *1991*). They documented increases for some species in study sites following the hurricane while others vastly declined, but could not definitively attribute declines to mortality or emigration. Studies of non-waterbird species also have documented bird declines in some habitats and increases in others and generally have ascribed this to populations tracking dispersed food and resources following hurricanes (Wunderle and others *1992* and references therein). Generally, resident waterbirds fair better if hurricanes strike outside the breeding season. Brackish species also are more resilient than beach and fresh marsh species because of high wave and salt-water impacts (Michener and others *1997*). Taken altogether, we suggest Hurricane Rita caused a redistribution of resources rather than substantial waterbird mortality in these sites; however, evidence is not conclusive.

Sampling differences between seasons could have influenced our results, but likely did not. During winter 2005 we counted larger plots. Following the hurricane, we counted smaller plots, which has often been associated with finding fewer individuals and species (Rosenzweig *1995*) and especially fewer rare species (Tjørve and others *2008*), though it also inflates density estimates (White and others *1982*), as discussed above. We minimized area bias by adding multiple small plots together to achieve roughly equivalent survey areas between years and modeling plot size bias in our analyses. Additionally, following the hurricane, surveys were conducted via boat rather than while hidden in emergent vegetation and settling periods prior to counting differed. We therefore may have counted fewer secretive birds in 2006. Despite this bias toward detecting fewer species following the hurricane, species richness was equivalent between years, further implying that direct hurricane mortality was minimal.

Summary and Conclusions

Overall, terraces increased the proportion of edge in ponds and numbers of wintering birds by 93%, a dramatic increase. Terraces benefited waterbirds by increasing habitat interspersion in ponds, generating ideal waterbird conditions. Further improvements in waterbird habitat may be achieved by building terraces with shallower slopes, which could increase water depth variation in ponds and promote use by shorebirds. We do not know whether Hurricane Rita caused significant bird mortality, but for remaining birds, terracing increased their use of coastal marsh ponds. Further monitoring is necessary to determine if use of pond terracing is sustainable both within and outside the Chenier Plain. However, habitat interspersion benefits waterbirds in both winter and summer.

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