2005

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Warren C. Conway
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State Universtiy, Nacogdoches, Texas 75962,
wconway@sfasu.edu

Loren M. Smith

James D. Ray

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WARREN C. CONWAY,[1] Wildlife and Fisheries Management Institute, Department of Range, Wildlife, and Fisheries Management, Mail Stop 2125, Texas Tech University, Lubbock, TX 79409, USA

LOREN M. SMITH,[2] Wildlife and Fisheries Management Institute, Department of Range, Wildlife, and Fisheries Management, Mail Stop 2125, Texas Tech University, Lubbock, TX 79409, USA

JAMES D. RAY,[3] Texas Parks and Wildlife Department, Canyon, TX 79015, USA

Abstract: Wetlands in the Playa Lakes Region (PLR) provide important habitats for wintering waterfowl, cranes, and both migrant and breeding shorebirds. Playa Lakes Region wetlands experience naturally fluctuating hydroperiods but are exposed to anthropogenic stresses, which are exacerbated during summer and may influence PLR wetland occupancy and selection by breeding shorebirds. We examined wetland-scale habitat use and nest-site selection of the 4 dominant shorebirds (American avocets [*Recurvirostra americana*], black-necked stilts [*Himantopus mexicanus*], killdeer [*Charadrius vociferus*], snowy plovers [*C. alexandrinus*]) nesting in playas, saline lakes, and in both created and riparian wetlands in the PLR of Texas, USA. All 4 species nested in saline lakes. Only avocets and killdeer nested in playas, and snowy plovers nested in riparian wetlands. No nests were found in created wetlands. Wetland habitat changed ($P < 0.001$) during the breeding season, while water habitats generally decreased. Used (i.e., shorebirds found nesting) wetlands had more ($P < 0.05$) mudflats than non-used (i.e., shorebirds not found nesting) wetlands, which had more ($P < 0.05$) dry habitats. Used and non-used wetlands had similar ($P > 0.05$) amounts of water habitats. Nests were located close to vegetation on bare dry ground and dry ground with vegetation. Because water is ephemeral in PLR wetlands, shorebirds must select—in a somewhat predictive manner upon arrival—wetlands with suitable nest-site and brood-rearing habitat. Although surface water is necessary for nesting, its presence is not adequate for delineating suitable PLR wetland habitat for breeding shorebirds. Our findings that created wetlands cannot compensate for regional wetland losses in habitat or function highlights the need for conservation of natural PLR wetlands.

Wetlands in the Playa Lakes Region (PLR) of Texas provide continentally important habitat for migrant shorebirds (Davis and Smith 1998), wintering waterfowl (Bolen et al. 1989, Haukos and Smith 1994), and sandhill cranes (*Grus canadensis*) (Iverson et al. 1985). Over 22,000 playas (Smith and Haukos 2002) and 40 saline lakes (Reeves and Temple 1986) exist in the row-crop agriculturally dominated 82,000 km^2 PLR (Bolen et al. 1989), where these wetlands serve as important reservoirs of regional biodiversity (Haukos and Smith 1994). However, PLR wetland integrity, structure, and function for migratory birds may be compromised when hydrology is impacted by interactions among naturally variable hydroperiods, high evapotranspiration rates, unpredictable precipitation patterns, and anthropogenic disturbances (i.e., groundwater pumping, wetlands used for

irrigation, plowing, etc.; Bolen et al. 1989, Haukos and Smith 1994, Luo et al. 1999). Anthropogenic alterations of wetland hydrology resulting in reduced hydroperiods (Smith 2003:162–165) may magnify impacts of periodic drought on wetland birds, especially breeding shorebirds.

Migrant shorebirds in the PLR use a variety of wetlands and habitats (i.e., shallow water, mudflats, etc.) primarily for feeding, and occupancy of these wetlands is relatively transient (Davis and Smith 1998). Breeding shorebirds, however, must find suitable habitat for multiple reproductive behaviors over extended periods within a single wetland and assess and select wetlands that provide adequate nest, brood rearing, and roosting habitats. Consequently, breeding birds may be constrained to either endure changing habitats based on decisions made upon arrival or abandon these reproductive investments (e.g., mate selection, egg laying, incubation). Confounding these decisions for breeding shorebirds are variable PLR wetland hydroperiods impacted by the aforementioned anthropogenic disturbances (Bolen et al. 1989, Luo et al. 1997).

American avocets, black-necked stilts, killdeer, and snowy plovers nest in PLR wetlands (Conway

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[1] Present address: Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Box 6109 SFA Station, Nacogdoches, TX 75962-6109, USA.

[2] Send reprint requests to Conway; wconway@sfasu.edu

[3] Present address: BWXT Pantex, L.L.C., P.O. Box 30020, Amarillo, TX 79120, USA.
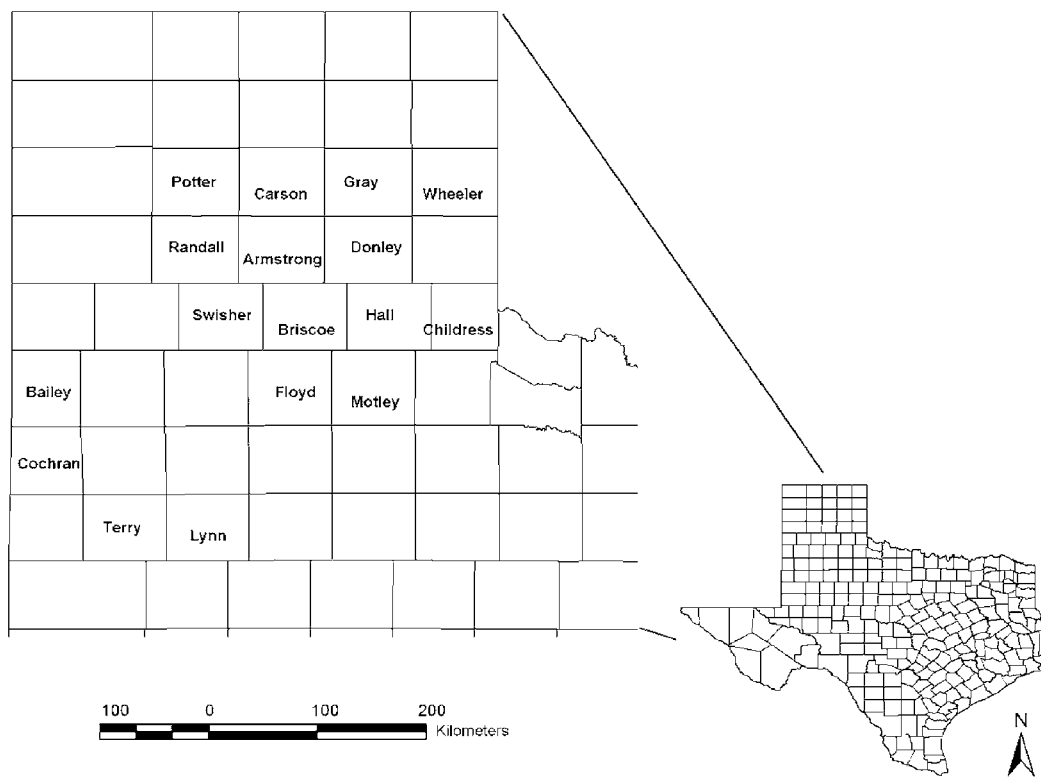
Fig. 1. Location of study area counties in the Playa Lakes Region of Texas, USA.

et al. 2005). Many species of North American shorebirds have experienced population declines, which are largely attributed to wetland habitat degradation and loss (Myers et al. 1987, Howe et al. 1989). However, use of wetland habitat and nest-site selection by breeding shorebirds in the PLR is not well understood. Understanding habitat and nest-site selection of PLR wetlands by breeding shorebirds can contribute to improved continental shorebird conservation (Brown et al. 2001, Fellows et al. 2001). To address these issues, we examined both wetland and nest-site selection by American avocets, black-necked stilts, killdeer, and snowy plovers nesting in playas, saline lakes, and riparian and created wetlands of the PLR.

STUDY AREA

The PLR of Texas encompasses more than 82,000 km² from the Panhandle south to Midland (Fig. 1; Bolen et al. 1989). It is characterized by playas, which comprise only 2% of the total Southern High Plains (SHP) landscape, yet are the dominant regional hydrologic feature in this semi-arid landscape (Haukos and Smith 1994).

Playas are shallow depressional wetlands that receive water from precipitation runoff and naturally experience 1 or more wet–dry cycles each year (Smith and Haukos 2002). Other wetlands occur on the PLR, including saline lakes and created and riparian wetlands. Approximately 40 saline lakes occur on the SHP (Reeves and Temple 1986), which generally are larger in individual area than playas, have saline water chemistry (often > 200g/L of dissolved solids), and usually are bordered by dunes on their leeward side from deflation (Osterkamp and Wood 1987). Playas are potentially important recharge wetlands; whereas, saline lakes primarily are discharge wetlands, though they also receive hydrological inputs from precipitation runoff (Smith 2003:6). Created wetlands often are associated with playas, when constructed as water storage wetlands for irrigation purposes and livestock watering. Riparian wetlands occur on the eastern edge of the PLR and historically were typical prairie river ecosystems with little or no woody vegetation and large gravel and sand bars (Magill et al. 2003). However, hydrological alterations and reduced flows have resulted in woody species expansion in

riparian wetlands (Bonner and Wilde 2000, Magill et al. 2003).

We located potential study-site wetlands by ground surveys in March, April, and May 1998 and 1999, and by aerial surveys from a fixed-wing single-engine plane (Cessna) on 10 and 17 April 1998 and 1999. We performed ground surveys by driving in counties that had recently received precipitation and relocated areas in which available wetlands were identified from aerial surveys. We defined available wetlands as those that contained surface water at the time of either aerial or ground surveys. We randomly selected study-site wetlands from the pool of available wetlands, but inclusion as study sites was ultimately dependent on landowner permission. We used all available riparian wetlands (*n* = 12) as study-site wetlands because of their limited availability.

In 1998, we randomly selected 54 playas in Floyd, Briscoe, Randall, Armstrong, Gray, and Carson counties; 10 saline lakes in Lynn, Terry, and Bailey counties; and 29 created wetlands in Floyd, Briscoe, Randall, Armstrong, Gray, and Carson counties (Fig. 1). We also surveyed 8.5 km of the Prairie Dog Fork of the Red River in Hall and Childress counties, 4 km of the North Fork of the Red River in Wheeler County, 4 km of the Salt Fork of the Red River in Donley County, 4 km of the Canadian River in Potter County, and 6.25 km of the North Fork of the Pease River in Motley County, Texas. In 1999, we randomly selected 52 playas in Floyd, Briscoe, Randall, Armstrong, Gray, Carson, and Swisher counties; 12 saline lakes in Lynn, Terry, Cochran, and Bailey counties; and 21 created wetlands in Floyd, Briscoe, Armstrong, and Carson counties. We also surveyed 2.5 km of the Prairie Dog Fork of the Red River in Hall County, 4 km of the North Fork of the Red River in Wheeler County, 4 km of the Salt Fork of the Red River in Donley County, 2 km of the Canadian River in Potter County, and 2.5 km of the North Fork of the Pease River in Motley County, Texas.

METHODS

Data Collection

Wetland Habitat.—We measured wetland habitat using line-intercept techniques on variable-length transects. Length and distance between transects varied, depending on wetland area, but began and ended at wetland boundaries. We determined wetland boundaries by a noticeable change in slope/elevation and the presence of nonwetland/upland plants and soils. The following habitat variables were recorded at 1-m intervals along transects in all wetlands: (1) bare dry ground, (2) dry ground covered with vegetation, (3) dry mudflat, (4) dry mudflat with vegetation, (5) bare mudflat, (6) mudflat covered with vegetation, (7) open water, and (8) water with emergent/submergent vegetation. Dry ground categories were defined as nonsaturated soil, mudflats were saturated, and dry mudflat categories were mudflats that were no longer saturated but had cracked Randall clay soils. We measured macrohabitat early in the breeding season (Apr–May), and then after all nesting activities had ceased (Jul–Aug) in 1998 and 1999.

In each playa and created wetland, we located 4 equally spaced parallel transects in a southwesterly to northeasterly direction. Due to the larger area of saline lakes, we used 2 transects forming a "V" that began and ended at wetland boundaries, where the end of the first transect was the starting point for the second transect. In riparian wetlands, we randomly located transects perpendicular to the river channel at 0.1 km intervals (see Knopf et al. 1988). The narrowness of riparian wetlands restricted data collection from the edge of upland vegetation outward through the channel to the other side of the riparian zone until upland vegetation was again encountered. In some cases, woody vegetation bordered the upland/riparian wetland interface; in such instances, transects were halted. Cessation of transects at such points may have biased estimates of vegetative cover in riparian wetlands, but as no shorebirds occurred in woody vegetation, these habitats were not available as potential nest or foraging sites. Historically, woody vegetation was not abundant in these prairie rivers (Magill et al. 2003), so habitat availability estimates likely are conservative for riparian habitats.

Nest-site Selection.—We performed nest searches if American avocets, black-necked stilts, killdeer, snowy plovers, or other shorebirds were present. We discovered nests by searching for incubating adults with binoculars and/or a spotting scope, by watching adults flush and/or return to nests, by systematic searching, and by accidental discovery. Effort was not consistent because presence/absence of shorebirds determined the amount of time spent searching for nests. If shorebirds were not observed on a particular wetland, nest searches were discontinued. We checked nests every 1–12 days until nests hatched or failed, and we considered nests successful if ≥1 egg

Table 1. Means (%) and standard errors (SE) of habitat in saline lakes, playas, riparian, and created wetlands during the shorebird breeding season in the Playa Lakes Region of Texas, USA, 1998 and 1999 and resulting F and P values from analyses of variance.

Habitat	Saline Lake		Riparian		Playa		Created		F	P
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE		
Bare dry ground	2.35bc[a]	0.59	8.66a	1.16	0.94c	0.29	3.92b	0.53	56.27	<0.001
Dry ground with vegetation	3.96d	0.54	17.45b	1.31	10.21c	0.51	22.99a	1.20	38.80	<0.001
Dry mudflat	27.09a	2.77	22.65b	1.56	1.84c	0.26	2.32c	0.30	128.27	<0.001
Dry mudflat with vegetation	5.48c	0.75	5.89c	0.80	31.08a	1.33	11.19b	1.35	70.95	<0.001
Mudflat	36.35a	3.03	33.60b	1.55	1.87d	0.29	5.81c	0.52	242.84	<0.001
Mudflat with vegetation	5.75a	1.01	4.36ab	0.55	4.82a	0.42	3.13b	0.36	3.61	0.013
Water	16.22c	2.29	5.21d	0.46	28.13b	1.17	47.53a	1.67	91.13	<0.001
Water with vegetation	2.80b	0.65	2.18b	0.68	21.11a	1.05	3.16b	0.64	64.07	<0.001

[a] Means followed by the same letter within the same row are not different ($P > 0.05$).

hatched (Mayfield 1975). Intervals between nest checks depended on species because species that nested in more open habitat (e.g., snowy plovers) could have their nests checked more frequently from a distance (e.g., spotting scopes), while species that nested in relatively dense habitat were checked less frequently to prevent disturbance that potentially negatively influences success. Failed nests were predated, flooded, hailed, trampled, or abandoned (Conway et al. 2005).

After chicks fledged or nests failed, we measured habitat variables at each nest and 1 random point per nest, located 10 m from the nest, parallel to the wetland boundary. We recorded the following variables at each nest and random point: substrate (i.e., visual determination of bare dry ground, dry mudflat, mudflat, etc.); distance (m) to upland (defined by soil and vegetation); distances (m) to vegetative cover, surface water, and mudflat (i.e., saturated nonvegetated area); and vertical cover (cm) (measured from each of the 4 cardinal directions 4 m from a Robel pole; Robel et al. 1970).

Statistical Analyses

Wetland Habitat.—We used multivariate analysis of variance (MANOVA) to examine habitat differences among wetland types (i.e., playas, saline lakes, riparian and created wetlands), years (i.e., 1998, 1999), sampling periods (i.e., early and late in the breeding season), and status (i.e., used and non-used wetlands). We defined used wetlands as those in which at least 1 shorebird nest was discovered; whereas, those in which no shorebird nests were found were defined as non-used wetlands. We used MANOVA to examine all possible interactions among multivariate linear combinations while simultaneously reducing experiment-wide type I error rates by not performing multiple sequential univariate analyses of variance (ANOVA; Zar 1996). Although not

every interaction was of specific interest, this was a more conservative approach for examining habitat differences. Wilks' λ was used as the test criterion because of its conservative power and analogy to univariate F statistics (Wichern and Johnson 2002). If differences ($P < 0.05$; i.e., Wilks' λ) were found using MANOVA, we performed follow-up analyses of variance (ANOVA) using type III sums of squares. Mean separation was performed using least squares test for equality of means (Zar 1999).

Nest-site Selection.—We also used a MANOVA to examine differences in habitat between nest sites and random sites, and between successful and failed nests among and within each of the 4 species among and within wetland type. If differences ($P < 0.05$) occurred during MANOVA, we performed further analyses using ANOVA followed by least squares tests for equality of means (Zar 1999).

Nest-site Preference.—We performed compositional analyses (Aebischer et al. 1993) to assess nest-site selection preference for each species using nest-site substrate and random substrates. For these analyses, we defined nest-site substrate as the used habitat, where available habitat was the substrate collected during random site data collection.

RESULTS

Wetland Habitat

Habitat Among Wetlands.—Habitat varied among wetlands (Wilks' λ = 0.27; 24, 3570; $P < 0.001$). Saline lakes had the most mudflats (36 %) and dry mudflats (27%); whereas, playas had the most dry mudflats with vegetation (31%) and water with vegetation (21%). Created wetlands had the most water (48%) and dry ground with vegetation (23%; Table 1).

Habitat During the Breeding Season.—Habitat also varied (Wilks' λ = 0.85; 24, 3570; $P < 0.001$) among

Table 2. Means (%) and standard errors (SE) of playas and created wetland habitats early and late in the shorebird breeding season in the Playa Lakes Region of Texas, USA, 1998 and 1999.

Habitat	Playas					Created				
	Early		Late			Early		Late		
	$\bar{x}$	SE	$\bar{x}$	SE	P^a	$\bar{x}$	SE	$\bar{x}$	SE	P
Bare dry ground	0.56	0.16	1.32	0.56	0.386	2.29	0.53	5.48	0.88	0.087
Dry ground with vegetation	7.55	0.44	12.83	0.89	<0.001	18.46	1.62	27.34	1.63	0.001
Dry mudflat	1.33	0.27	2.35	0.45	0.403	1.22	0.29	3.38	0.49	0.406
Dry mudflat with vegetation	13.30	1.22	48.61	1.94	<0.001	5.16	1.07	16.99	2.27	0.003
Mudflat	1.55	0.15	2.18	0.56	0.619	7.34	0.81	4.32	0.62	0.268
Mudflat with vegetation	5.91	0.57	3.75	0.61	0.005	2.72	0.35	3.52	0.63	0.619
Water	40.95	1.62	15.50	1.39	<0.001	58.92	1.85	36.56	2.13	<0.001
Water with vegetation	28.87	1.51	13.49	1.36	<0.001	3.88	1.03	2.46	0.75	0.679

[a] Means within the same row, within the same wetland type, followed by a nonsignificant P value ($P > 0.05$) are not different.

wetlands during the breeding season, with the largest changes occurring in playas and created wetlands. In playas, water and water with vegetation decreased by >50% while dry mudflats with vegetation almost tripled during the breeding season (Table 2). In created wetlands, water decreased by 20% while dry ground with vegetation and dry mud with vegetation increased (Table 2). In saline lakes, habitat did not change (Wilks' $\lambda = 0.91$; 8, 87; $P = 0.397$) during the breeding season, although there were nonsignificant reductions in dry mudflat ($P = 0.112$) and increases in water ($P = 0.176$). In riparian wetlands, habitat remained relatively static (Wilks' $\lambda = 0.98$; 7, 295; $P = 0.381$), but individual ANOVAs revealed that dry ground increased ($P < 0.001$) and mudflat with vegetation decreased ($P = 0.021$) during the breeding season.

Used versus Non-used Wetlands.—Habitat also varied (Wilks' $\lambda = 0.90$; 8, 1255; $P < 0.001$) between used and non-used wetlands. Used wetlands had more ($F = 8.81$; 1, 1238; $P = 0.003$) mudflats (used = 23%; non-used 11%) and more ($F = 6.41$; 1, 1238; $P = 0.012$) dry mudflats (used = 17%; non-used = 8%). Conversely, non-used wetlands had more ($F = 15.64$; 1, 1238; $P < 0.001$) dry ground with vegetation (non-used = 13%; used = 6%), and more ($F = 7.96$; 1, 1238; $P = 0.005$) dry mudflats with vegetation (non-used = 24%; used = 15%). Used and non-used wetlands had similar ($P > 0.05$) amounts of water (used = 22%; non-used = 25%), water with vegetation (used = 12%; non-used = 13%), and mudflats with vegetation (used = 4%; non-used = 5%).

Used versus Non-used Wetlands Early and Late in the Breeding Season.—As habitats changed during the breeding season, there were interactions (Wilks' $\lambda = 0.96$; 8, 1237; $P < 0.001$) between wetland status and sampling period. Subsequent ANOVAs revealed few differences, but non-used wetlands had more ($F = 39.23$; 1, 1244; $P < 0.001$) dry

ground late in the breeding season, and used wetlands had more ($F = 5.81$; 1, 1244; $P = 0.016$) water with vegetation early in the breeding season.

Our results were insufficient for delineating habitat differences between used and non-used wetlands. Specifically, it was still unclear what habitat characteristics shorebirds focused on during arrival in the PLR. Therefore, subsequent MANOVAs were performed between used and non-used wetlands within a wetland type, between sampling periods (i.e., early or late). As created wetlands were not used by breeding shorebirds, they were excluded from these analyses.

Playas.—Habitat varied (Wilks' $\lambda = 0.97$; 8, 696; $P = 0.007$) between used and non-used playas. Used playas had more ($F = 9.02$; 1, 703; $P = 0.003$) dry mudflat (used = 4%; non-used = 2%) and non-used playas had more ($F = 7.46$; 1, 703; $P = 0.007$) mudflat with vegetation (used = 2%; non-used = 5%). No other habitats varied between used and non-used playas. There was a sampling period × status interaction (Wilks' $\lambda = 0.69$; 16, 1392; $P < 0.001$), in which habitat changed during the breeding season. Further analyses were performed within each sampling period. Again, habitat varied between used and non-used playas early in the breeding season (Wilks' $\lambda = 0.92$; 7, 343; $P < 0.001$) but not later in the breeding season (Wilks' $\lambda = 0.98$; 8, 347; $P = 0.366$; Table 3).

Riparian Wetlands.—Habitat varied (Wilks' $\lambda = 0.80$; 7, 295; $P < 0.001$) between used and non-used riparian wetlands. Used riparian wetlands had more ($F = 21.52$; 1, 301; $P < 0.001$) dry mudflat (used = 38%; non-used = 19%), water ($F = 5.98$; 1, 301; $P = 0.015$) (used = 8%; non-used = 5%), and ($F = 14.02$; 1, 301; $P < 0.001$) mudflat (used =47 %; non-used = 31 %). Conversely, non-used wetlands had more dry ground ($F = 6.61$; 1, 301; $P = 0.011$) (non-used = 10%; used = 2%), dry

Table 3. Means (%), standard errors, *F*, and *P* values resulting from analysis of variance for shorebird habitat measured at used and non-used playas early and late in the breeding season in the Playa Lakes Region of Texas, USA, 1998 and 1999.

| | Early | | | | | | Late | | | | | |
| | Used | | Non-used | | | | Used | | Non-used | | | |
Habitat	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*[a]	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
Bare dry ground	0.39	0.40	0.59	0.17	0.18	0.673	0.31	1.44	1.50	0.61	0.58	0.448
Dry ground with vegetation	6.66	1.12	7.72	0.48	0.76	0.385	11.07	2.29	13.14	0.97	0.69	0.405
Dry mudflat	3.49	0.68	0.93	0.29	11.88	<0.001	3.90	1.15	2.07	0.49	2.12	0.146
Dry mudflat with vegetation	4.99	3.08	14.80	1.31	8.59	0.004	53.64	4.99	47.72	2.11	1.20	0.275
Mudflat	1.46	0.39	1.56	0.17	0.06	0.805	0.94	1.44	2.40	0.61	0.87	0.353
Mudflat with vegetation	3.17	1.44	6.41	0.61	4.28	0.039	1.14	1.57	4.22	0.66	3.27	0.072
Water	45.25	4.14	40.16	1.76	1.28	0.259	17.36	3.58	15.16	1.51	0.32	0.570
Water with vegetation	34.59	3.83	27.83	1.63	2.63	0.106	11.63	3.50	13.82	1.48	0.33	0.565

[a] Means within the same row, within the same sampling period, followed by a nonsignificant *P* value (*P* > 0.05) are not different.

ground with vegetation (*F* = 21.84; 1, 301; *P* < 0.001) (non-used = 20%; used = 4%), dry mudflat with vegetation (*F* = 9.30; 1, 301; *P* = 0.003) (non-used = 7%; used = < 1%), and mudflat with vegetation (*F* = 8.89; 1, 301; *P* = 0.003) (non-used = 5%; used = < 1%) than used riparian wetlands. An interaction (Wilks' λ = 0.85; 14, 590; *P* < 0.001) between status and sampling period also occurred within riparian wetlands. Habitat varied between used and non-used riparian wetlands early in the breeding season (Wilks' λ = 0.74; 7, 159; *P* < 0.001), as well as during the late sampling period (Wilks' λ = 0.74; 7, 130; *P* < 0.001; Table 4).

Saline Lakes.—Habitat varied (Wilks' λ = 0.97; 8, 696; *P* = 0.007) between used and non-used saline lakes, where used saline lakes had both more (*F* = 8.83; 1, 94; *P* = 0.005) mudflat with vegetation (used = 7%; non-used = 1%) and water with vegetation (*F* = 7.24; 1, 94; *P* = 0.008) (used = 4%; non-used = 0%), while non-used saline lakes had more (*F* = 20.17; 1, 94; *P* < 0.001) dry mudflat (non-used = 46%; used = 20%). All other habitat variables were similar (*P* > 0.05) between used and non-used saline lakes. Habitat did not vary (Wilks' λ = 0.74; 7, 40; *P* = 0.081) between used and non-used saline lakes during the early sampling period but did (Wilks' λ = 0.49; 7, 41; *P* < 0.001) during the late sampling period (Table 5).

Nest-site Selection

Nests versus Random Habitat.—Habitat around nests was dependent on wetland type (Wilks' λ = 0.44; 10, 892; *P* < 0.001). Nests had more vegetative cover (*F* = 147.26; 2, 450; *P* < 0.001) and were closer to uplands (*F* = 8.16; 2, 450; *P* < 0.001), vegetation (*F* = 4.16; 2, 450; *P* = 0.016), mudflats (*F* = 70.08; 2, 450; *P* < 0.001), and water (*F* = 5.80; 2, 450; *P* = 0.003) in playas than nests in saline lakes or riparian wetlands. Similarly, habitat varied among American avocet, black-necked stilt, killdeer, and snowy plover nests (Wilks' λ = 0.66; 15, 1237; *P* < 0.001; Table 6). However, independent of species, nest habitat was similar (Wilks' λ = 0.99; 5, 899; *P* = 0.336) to random point habitat. Nest habitat also did not vary from random habitats (Wilks' λ = 0.99; 15, 2482; *P* = 0.878), or among wetland types (Wilks' λ = 0.97; 10, 1786; *P* = 0.966) in a species-specific manner.

Table 4. Means (%), standard errors, *F*, and *P* values resulting from analysis of variance for shorebird habitat measured at used and non-used riparian wetlands early and late in the breeding season in the Playa Lakes Region of Texas, USA, 1998 and 1999.

| | Early | | | | | | Late | | | | | |
| | Used | | Non-used | | | | Used | | Non-used | | | |
Habitat	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*[a]	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
Bare dry ground	3.31	2.06	4.56	1.00	0.30	0.583	1.56	5.85	15.99	2.41	5.21	0.024
Dry ground with vegetation	4.75	4.04	20.37	1.97	12.04	<0.001	3.18	4.80	19.99	1.98	10.48	0.002
Dry mudflat	46.26	4.63	16.15	2.25	34.17	<0.001	29.72	5.68	22.48	2.34	1.39	0.240
Dry mudflat with vegetation	0.12	2.72	9.00	1.32	8.63	0.004	0.72	2.48	4.78	1.02	2.28	0.134
Mudflat	37.57	4.86	33.73	2.37	0.50	0.479	55.66	5.61	28.64	2.31	19.81	<0.001
Mudflat with vegetation	0.81	1.89	6.70	0.92	7.81	0.006	0.41	1.71	3.31	0.71	2.45	0.120
Water	6.56	1.58	6.39	0.77	0.01	0.927	8.75	1.43	2.88	0.59	14.31	<0.001
Water with vegetation	0.62	2.33	3.09	1.13	0.91	0.341	0.00	0.00	1.92	0.93	0.61	0.436

[a] Means within the same row, within the same sampling period, followed by a nonsignificant *P* value (*P* > 0.05) are not different.

Table 5. Means (%), standard errors, *F*, and *P* values resulting from analysis of variance for shorebird habitat measured at used and non-used saline lakes early and late in the breeding season in the Playa Lakes Region of Texas, USA, 1998 and 1999.

| | Early | | | | | | Late | | | | | |
| | Used | | Non-used | | | | Used | | Non-used | | | |
Habitat	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*[a]	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
Bare dry ground	2.82	1.33	3.60	1.98	0.11	0.745	1.57	0.54	1.95	0.96	0.12	0.726
Dry ground with vegetation	3.33	0.75	1.82	1.12	1.25	0.269	4.92	0.99	5.35	1.78	0.04	0.834
Dry mudflat	24.02	5.40	42.42	8.00	3.64	0.063	16.67	2.84	49.36	5.05	31.85	<0.001
Dry mudflat with vegetation	4.63	1.46	7.84	2.17	1.52	0.224	6.33	1.02	2.19	1.82	3.95	0.052
Mudflat	42.17	5.14	29.10	7.62	2.02	0.162	35.61	4.96	31.79	8.82	0.14	0.707
Mudflat with vegetation	6.61	1.28	1.59	1.90	4.82	0.033	8.26	1.86	0.60	3.31	4.07	0.049
Water	12.78	4.15	13.62	6.15	0.01	0.911	22.59	3.41	8.76	6.07	3.95	0.053
Water with vegetation	3.65	1.02	0.00	0.00	4.00	0.051	4.05	1.08	0.00	0.00	3.35	0.073

[a] Means within the same row, within the same sampling period, followed by a nonsignificant *P* value (*P* > 0.05) are not different.

Successful versus Failed Nests.—Habitat around successful nests varied (Wilks' λ = 0.96; 5, 444; *P* = 0.001) from failed nests. Independent of species, successful nests were closer (*F* = 4.88; 1, 448; *P* = 0.028) to vegetation and had more (*F* = 13.34; 1, 448; *P* < 0.001) vegetative cover than failed nests. Conversely, distances to uplands (*F* = 0.20; 1, 448; *P* = 0.652), water (*F* = 0.04; 1, 448; *P* = 0.841), and mudflat (*F* = 0.45; 1, 448; *P* = 0.502) were similar between successful and failed nests. Although there was an interaction (Wilks' λ = 0.93; 20, 1456; *P* = 0.032) among wetland type, species, and nest fate, subsequent ANOVAs revealed few habitat differences.

Habitat was examined between successful and failed nests within each species, within each wetland type. Within playas, habitat around successful and failed killdeer nests was similar for all measures (*P* > 0.05), but it varied for avocet nests (Wilks' λ = 0.64; 5, 59; *P* < 0.001); successful nests had more (*F* = 14.45; 1, 63; *P* < 0.001) vertical cover and were closer (*F* = 6.09; 1, 63; *P* = 0.016) to water than failed avocet nests in playas. Within saline lakes, habitat did not vary (*P* > 0.05) between successful and failed killdeer nor stilt nests, but it did for snowy plover nests (Wilks' λ = 0.93; 5, 279; *P* = 0.040), where successful plover nests were closer (*F* = 4.08; 1, 283; *P* = 0.044) to vegetation but further (*F* = 4.17; 1, 283; *P* = 0.042) from mudflats than failed nests.

Nest Site Preferences

Compositional analyses revealed differences between nest and random site selection for each species. Avocets (Wilks' λ = 0.41; 6, 86; *P* < 0.001) preferred nest sites on dry ground with vegetation and avoided dry mudflats with vegetation, mudflats, and mudflats with vegetation. Stilts (Wilks' λ = 0.26; 6, 20; *P* < 0.001) preferred nest sites on dry ground with vegetation and bare dry ground and avoided placing nests on dry mudflats and mudflats with vegetation. Killdeer (Wilks' λ = 0.68; 5, 38; *P* = 0.008) preferred nest sites on bare dry ground and dry ground with vegetation and avoided mudflats with vegetation and dry mudflats with vegetation. Snowy plovers (Wilks' λ = 0.79; 5, 289; *P* < 0.001) preferred bare dry ground but avoided placing nests on dry mudflats, dry mudflats with vegetation, and mudflats with vegetation (Table 7).

DISCUSSION

The importance of PLR playas for wetland-dependent migrating birds is known, and the region has become a focus of large-scale regional

Table 6. Means (%) and standard errors (SE) of American avocet, black-necked stilt, killdeer, and snowy plover nests in wetlands in the Playa Lakes Region of Texas, USA, 1998 and 1999 and resulting *F* and *P* values from analyses of variance.

| | American avocet | | Black-necked stilt | | Killdeer | | Snowy plover | | | |
Habitat	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	*F*	*P*
Distance to upland (m)	147.0[a][1]	13.8	119.3[a]	26.1	44.7[b]	10.6	143.2[a]	9.4	5.94	<0.001
Distance to vegetation (m)	12.4[a]	5.2	31.2[a]	17.1	3.1[b]	1.3	24.9[a]	3.6	2.75	0.042
Distance to mudflat (m)	7.3[b]	0.8	7.2[b]	2.1	25.9[ab]	5.3	33.9[a]	2.8	11.96	<0.001
Distance to water (m)	63.0[b]	15.1	22.5[b]	7.7	98.7[ab]	29.8	158.6[a]	14.7	6.66	0.002
Vegetative cover	2.70[a]	0.24	1.84[b]	0.28	1.40b	0.21	1.01[c]	0.01	49.54	<0.001

[1] Means followed by the same letter within a row are not different (*P* > 0.05).

Table 7. Nest-site preferences from compositional analyses (Aebischer et al. 1993) for American avocets, black-necked stilts, killdeer, and snowy plovers nesting[a] in the Playa Lakes Region of Texas, USA, 1998 and 1999.

Habitat	American avocet (n = 111)		Black-necked stilt (n = 126)		Killdeer (n = 43)		Snowy plover (n = 298)	
	Rank[c]	*t*-test[d]	Rank	*t*-test	Rank	*t*-test	Rank	t-test
Dry ground with vegetation	1	A	1	A	2	AB	2	B
Bare dry ground	2	B	2	A	1	A	1	A
Dry mudflat	4	C	5	C	4	C	5	D
Dry mudflat with vegetation	3	D	2	AB	5	CD	4	D
Mudflat	6	E	3	B	3	BC	3	C
Mudflat with vegetation	5	F	4	D	5	D	5	D
Water[b]	7	G	6	D	6	D	6	D

[a] Analyses performed within each species, pooling wetland type, nest fate, and year. Nest-site substrates were defined as "used" and random site substrates were defined as "available" (Aebischer et al. 1993).

[b] Water habitat type is combined among 2 water variables; open water and water with emergent vegetation. These categories were pooled into 1 category because no nests were found using this habitat type; although they were "available," they were not "used." This category was left in for the compositional analyses where the water category was used as a common denominator (Aebischer et al. 1993).

[c] Each habitat type receives a rank, where the highest-ranked habitat type is most preferred (Aebischer et al. 1993).

[d] Habitat variables followed by the same letter within a column are not different ($P > 0.05$).

wetland conservation planning (Fellows et al. 2001). Our study additionally demonstrated the importance of saline lakes and playas for nesting shorebirds in the PLR (see Conway et al. 2005). Because of the semi-arid climate and anthropogenic influences on wetland hydroperiods, PLR wetland surface water presence is ephemeral and dependent upon precipitation (Haukos and Smith 1994). With adequate habitat during the breeding season, playas and saline lakes may support several thousand breeding pairs of avocets, killdeer, and snowy plovers (Conway 2001). The complete lack of nesting in created wetlands indicates that created wetlands cannot compensate for natural wetland destruction. Furthermore, created wetlands lacked nesting shorebirds even when surface water in other wetlands was limited or absent and when created wetlands had water coverage in excess of 30%. These open water habitats were likely too deep and provided little foraging habitat for adults or broods. Consequently, water presence alone cannot be used exclusively to identify suitable wetland habitats for breeding shorebirds. Rather, wetlands providing a diversity of habitats for nesting, foraging, and brood rearing are more important than the simple presence of water.

In saline lakes, the presence of water provided shallow water and mudflat foraging and brood-rearing habitat. Early in the breeding season, when shorebirds were arriving at PLR wetlands, mudflat and shallow water habitats accounted for almost 65% of the habitat in used saline lakes; whereas, these same habitats accounted for

approximately 40% of non-used saline lakes. This trend was consistent throughout the breeding season. Conversely, saline lakes dominated by dry mudflats (>40%) were not used for nesting by any species. These trends demonstrate the importance of a diversity of habitat types for breeding shorebirds. Saline lakes were the only wetland type in which all 4 species nested; they contained >95% of all snowy plover nests discovered during this study.

Although habitat did not vary between used and non-used playas, habitat changed during the breeding season, highlighting the ephemeral nature of playa hydroperiods (Bolen et al. 1989). Water habitats accounted for nearly 70% of the available habitat during the early breeding season but were reduced to <30% late in the breeding season. This loss of surface water during a relatively short period may decrease shorebird nesting success in playas. For example, in 1998, the loss of surface water by the middle of June resulted in abandonment of nests (particularly avocets, Conway et al. 2005) and the discontinuation of nesting by shorebirds in playas. Similarly, as surface water disappeared, playa habitats changed, as the amount of dry mudflat with vegetation increased, effectively reducing potential brood rearing grounds.

Nest-site Selection and Preferences

In other studies, distinct habitat use patterns have emerged when using a nest versus random site type analysis (Neu et al. 1974), but this pattern was not evident in our study. Nest-site selection is likely not random, but our measures may not have been precise enough to discern differ-

ences between nests and random sites. Other studies have suggested nest-site selection patterns in these species on relatively small spatial scales using nest placement to explain selection patterns (Page et al. 1983, Hill 1985, Warriner et al. 1986, Sordahl 1996, Robinson et al. 1997, Powell and Collier 2000, Winton et al. 2000).

Although we detected no differences in nest and random site habitats, we found nest-site differences among species. American avocets, regardless of nest fate, more often than the other 3 species tended to place nests in areas that had some vertical cover more often than the other 3 species. In Oklahoma, Winton et al. (2000) found that avocets nested in relatively more open areas. Successful nests for all 4 species tended to be closer to vegetation than nonsuccessful nests, a pattern that was particularly strong for snowy plovers. Surprisingly, there were no consistent patterns of nest success or nest placement in relation to proximity to water.

Suitable nest-site substrate availability also was an important determinant of shorebird nest-site selection. All 4 species preferred nesting on dry ground with vegetation or bare dry ground. These nest placement patterns are similar to studies in which nest placement also was on encrusted mudflats (plovers and avocets), close (<5 cm) to vegetation (avocets), on bare mudflats or on dry ground with vegetation (avocets and stilts; Page et al. 1983, 1995; Sordahl 1996; Winton and Leslie 1997).

For shorebirds to nest in wetlands in the PLR of Texas, 3 conditions must be met. First, there must be surface water present during arrival, which preferably would last through incubation and the brood rearing periods. However, presence is not the sole determinant of use. Suitable shallow water and mudflat habitats need to be present for adult foraging while pairing, egg laying, and incubating and as brood-rearing habitat (Page et al. 1995, Robinson et al. 1997). Second, if water is present, there must be areas within the wetland consisting of bare dry ground and dry ground with vegetation for shorebirds to nest, providing suitable nest substrates. Finally, there must be some vegetative cover. Vegetative cover is an important determinant of nest-site selection for all species studied, but particularly for avocets. Such vegetation likely provides cover for precocial chicks after hatching but prior to fledging.

MANAGEMENT IMPLICATIONS

Maintaining saline lake hydrological integrity of saline lakes and natural spring flow (Brune 1981) should result in successful long-term use by nesting shorebirds, particularly snowy plovers. As we demonstrated in this study, saline lakes are used extensively by nesting shorebirds when conditions (i.e., shallow water and mudflat habitats) are suitable. However, when aquifer pumping for agricultural irrigation is combined with high evapotranspiration rates during summer, saline lake springs cease to flow. As these springs may be the only source of surface water and are responsible for creating mudflats and shallow water habitats, spring integrity is critical for maintaining habitat suitability for nesting shorebirds. Cooperation among private landowners and natural resources agencies is essential for successful conservation of these wetlands.

Water-covered habitats in playas change dramatically during the breeding season, which will influence long-term shorebird productivity. As habitat suitability declined with water loss during the breeding season, nesting shorebirds abandoned nests or failed to successfully reproduce. Therefore, playa hydroperiod protection should be emphasized for breeding shorebird conservation and management. Most playas have cropland watersheds and have lost their natural plant communities (Smith and Haukos 2002) and hydric-soil defined volume as a result of erosion and sedimentation (Luo et al. 1997, 1999). Therefore, watershed prairie restoration or protection will decrease sedimentation rates and result in more stable playa hydrological cycles (Smith and Haukos 2002), which in turn should maintain suitable habitat conditions for nesting shorebirds throughout the breeding season. Maintaining the ability of playas to hold water during precipitation events, combined with the reduction or cessation of playa irrigation pumping during the breeding season should increase use by nesting avocets and killdeer and attract other less common playa nesting species such as black-necked stilts.

Although snowy plovers were the only shorebird nesting in riparian wetlands, these rivers provide nesting habitat for colonies of endangered interior least terns (*Sterna antillarum athalassos*; Hill 1985, Thompson et al. 1997, Conway et al. 2003) and should also receive attention. Management and conservation plans should incorporate brush-removal programs in these habitats, while simultaneously reestablishing natural water flows.

ACKNOWLEDGMENTS

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Associate Editor: Flaspohler.