Avian species assemblages on New Mexico golf courses: surrogate riparian habitat for birds?

by Michele Merola-Zwartjes and John P. DeLong

Abstract   The goal of our study was to determine how golf courses in the desert environment impact the indigenous bird community and, particularly, to see whether golf courses may serve as surrogate riparian habitats for southwestern birds. We compared the avian communities on 5 golf courses in the Albuquerque, New Mexico area (4 traditional and 1 "naturalistic") to those of 5 paired natural areas that served as reference sites. We surveyed birds using breeding-season point counts over 2 years and measured several habitat characteristics of each site. In agreement with most other studies of urbanization effects, we found that bird abundance was greater on 4 out of 5 golf courses. In contrast to many studies of urban birds, we found that both total species richness and species diversity was higher on the golf courses in 3 out of 5 cases, and indigenous species richness was higher on all 5 of the golf courses. Of the bird species unique to the golf-course communities, 74% were riparian associates. Although they had high numbers of indigenous species, most of the individuals on golf courses were relatively common generalist species. The naturalistic golf course that was dominated by native vegetation had greater indigenous bird species richness, diversity, and abundance when compared to its reference site and all of the other courses. We conclude that golf courses do have the potential to support riparian bird communities but that their conservation potential can be enhanced through the addition of habitat complexity and structure.

Key Words   avian diversity, avian species assemblage, avian species richness, bird community composition, bird diversity, golf course, riparian birds, riparian habitat, southwestern bird communities, urbanization

Most studies of birds in urban areas have reported a decrease in avian species richness and diversity in association with urbanization, although density typically increases (e.g., Emlen 1974, Guthrie 1974, Beissinger and Osborne 1982). However, Blair (1996) found that although bird abundance and diversity did indeed decrease in highly developed areas, total species richness, diversity, and density increased at moderate levels of

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development, such as golf courses and residential areas with detached housing. He suggested that the increased heterogeneity of the habitat, in terms of both changes in vegetation and the introduction of structures, and the abundance and diversity of resources available to birds in such areas, may account for this trend. A few other studies also have reported an increase in bird species richness or diversity in areas characterized by relatively low levels

> [A]lthough overall species richness and diversity increased on golf courses, the original native bird community nonetheless suffered negative consequences. At the 4 traditional golf courses...loss of species found in the native community ranged from 17–32%. [T]hese numbers represent the loss of a significant component of the desert bird community.

of development (Lancaster and Rees 1979, Aldrich and Coffin 1980, Jokimäki and Suhonen 1993).

In the southwestern United States, the greatest diversity of breeding birds is normally found in riparian vegetative communities; it is estimated that the bird diversity in riparian zones surpasses that of all other western landscape types combined (Johnson et al. 1977, Knopf et al. 1988, Skagen et al. 1998, Cartron et al. 1999). In a region characterized by low rainfall and often sparse vegetation, riparian zones act as an oasis for both migratory and resident birds, offering a relative abundance of the critical elements of water, food, and cover (Wauer 1977, Chaney et al. 1990). Natural riparian systems are quickly disappearing, however, in response to the demands of a growing human population on these areas for water, recreation, and development, as well as to degradation from factors such as flood control efforts and improper grazing practices (e.g., Krueper 1993, Fleischner 1994, Ohmart 1994). Estimates are that up to 95% of western riparian vegetative communities have been lost or degraded over the past century, and many of the bird species associated with these systems have been extirpated or have experienced severe declines (DeSante and George 1994, Hunter et al. 1987, Krueper 2000).

Most golf courses in the Southwest provide a combination of habitat characteristics that are reminiscent of the riparian systems used by western birds. They often have permanent water sources, used for water hazards and irrigation. They have deciduous trees that provide cover, shade, nest sites, and food. Depending upon the extent, composition, and structure of the vegetation in out-of-play areas, golf courses may potentially offer

rewarding foraging or nesting habitat for birds that utilize shrub communities as well as those that forage on the turf or in the canopy.

Given the extensive loss of riparian systems throughout the West and the potential similarity of some plant communities on golf courses to those of natural riparian areas, our objective was to determine whether golf courses might serve as surrogate riparian habitats for breeding birds in the Southwest. We hypothesized that golf courses in the Southwest would not only have greater avian species richness and abundance when compared to the surrounding natural environment, but also would support a greater number of bird species normally associated with riparian areas. The specific goals of our study were to determine: 1) how the presence of a golf course impacts the indigenous bird community through comparisons of abundance, species richness, and diversity between 5 golf courses and 5 undisturbed reference areas assumed to represent the original bird communities; 2) whether golf courses supported high numbers of typically riparian bird species; and 3) to identify those habitat features of golf courses that are most conducive to supporting high numbers of indigenous and riparian bird species.

Study areas

Our study sites were 5 golf courses and 5 paired reference sites in the high desert region of Albuquerque, New Mexico. We chose courses to represent a range of vegetation types, course features (e.g., water sources), and landscape settings. The participating golf courses were the Albuquerque Country Club, Four Hills Country Club, Paradise Hills Golf Club, PaaKo Ridge Golf Club, and University of New Mexico Championship Course.

The Albuquerque Country Club (ACC) was located in a residential area of downtown Albuquerque, directly across from the riparian forest that lines the Rio Grande River. Established in 1929, this 43-ha course was a traditional park-like course, primarily consisting of turf grass with large, isolated trees between the fairways; there was no understory, and there were no natural areas or water hazards on this course, although an irrigation ditch ran along one side. The Four Hills Country Club course (FH), 62 ha in size, was established in 1957 in eastern Albuquerque, a residential area at the edge of the Sandia Mountain foothills. There were 2 large ponds on the course, only one of which was partially surrounded

by typical riparian vegetation (e.g., cat-tails ([*Typha* sp.], willows ([*Salix* sp.]). Most of the course was park-like in structure, but there were a few large out-of-play areas that were not maintained and that retained primarily native vegetation typical of this area (e.g., blue grama [*Bouteloua gracilis*], cholla cactus [*Opuntia imbricata*], rabbitbrush [*Ericameria nauseosa*]). The Paradise Hills Golf Club (PH) was established in a residential area on Albuquerque's west mesa in 1963. This 54-ha course was primarily park-like in structure and had no remnant native vegetation or understory. It did, however, have one large pond partially surrounded by cattails and some large cottonwoods (*Populus* sp.). PaaKo Ridge (PK) was the newest of the golf courses; the initial construction was completed in 2000 in the eastern foothills of the Sandia Mountains. This 88-ha course was constructed in the midst of expansive pinyon–juniper (*Pinus edulis–Juniperus monosperma*) woodlands; the surrounding area was largely undeveloped except for the low-density housing that was under construction in association with the PaaKo development. The PaaKo course made maximum use of the natural topography and vegetation of the area; the only turf present on the course was on the fairways inserted between large areas of natural woodland. Two ponds were constructed on the PaaKo course; these were just beginning to get some emergent vegetation growth around the perimeters toward the end of our study. The UNM Championship Course (UNM) was built in 1965 in southern Albuquerque; it was situated in a low-density industrial area near the airport. This 86-ha course had several large areas of remnant native vegetation characterized by various bunchgrasses and shrubs such as yucca (*Yucca* sp.), rabbitbrush, and fourwing saltbush (*Atriplex canescens*) between the more traditional park-like fairways separated by rows of trees. The UNM course had 2 large ponds, each surrounded with riparian vegetation (cat-tails, willows, and large cottonwoods).

We selected a paired reference site for each golf course. Reference sites were nearby natural areas that reflected as much as possible the landscape conditions that would have been present prior to the construction of the companion course. The purpose of these reference sites was to provide an avian community "baseline"; birds on the reference sites were assumed to represent the original bird community for its paired golf course. For ACC, the Rio Grande floodplain forest protected in a City of Albuquerque Open Space area directly across the road from the course served as the reference site. This forest was dominated by large cottonwoods with a dense understory. The Four Hills Open Space in the nearby foothills served as the reference site

for FH; this area was characterized by sparsely distributed pinyons and junipers among native grama grasses and shrubs and cacti such as rabbitbrush and cholla. For PH, we used the desert grasslands of the Boca Negra Open Space unit near Petroglyph National Monument. This area was characterized by desert bunchgrasses and scattered shrubs such as fourwing saltbush and sand sage (*Artemisia filifolia*) with occasional junipers. For PK, nearby pinyon–juniper woodlands in the Cibola National Forest served as the reference site. For UNM, an extensive area of undeveloped, privately owned lands directly across the freeway from the course served as the reference site; this area was primarily desert grassland with occasional small shrubs (e.g., fourwing saltbush, rabbitbrush). With the exception of PK, all reference sites were located within 1 km of their paired golf course; the PK reference site was several kilometers from the course, but the terrain and vegetative community type were largely uninterrupted between the 2 and they occupied approximately the same elevation.

Methods

Bird surveys

We conducted point counts at each site every 21–28 days during the breeding season from mid-April through July in 2001 and 2002; we thus surveyed each site 8 times over the 2-year period of the study. We conducted surveys at each golf course and its paired reference site on consecutive days whenever possible and always within the same 7-day period. We established point-count stations a minimum of 300 m apart by overlaying a grid on an aerial photo of the site. Due to the size of the golf courses, this restricted the number of stations to 5 at each site. If a water feature was present, we purposely chose a count station at the closest grid intersection since riparian birds were the focal point of the study. We began counts 15 minutes after sunrise and completed them by 1000 hours. We recorded all birds heard or seen within a 100-m radius of the observer during a 5-minute period at each station. To minimize variability due to observer differences, the same 2 observers conducted all counts throughout the study.

Habitat characteristics

We collected measures of vegetative structure and composition in August and September 2002 at each site within 6 randomly placed 500-m^2 macroplots (if on a golf course, macroplots were randomly placed in out-of-play areas, or rough). Each plot was rectangular, 62.5 m long × 8 m wide. A transect 62.5 m in length bisected

each macroplot. In addition, each macroplot contained 2 4-m^2 subplots for shrub measures, as well as 5 1-m^2 plots for measures of vertical foliage volume (described below). We recorded the following variables within each 500-m^2 macroplot: average tree height; tree species; number of woody stems in size classes 0–8 cm DBH (diameter at breast height), 9–20 cm DBH, 21–40 cm DBH, and >40 cm DBH; number of snags in size classes ≤12 cm DBH and >12 cm DBH. We determined tree heights using a clinometer. We measured 4 trees, considered by the observer to be representative of the overall average canopy height within the macroplot, to determine average tree height. We measured canopy cover and ground cover using a sighting tube constructed from a 12-cm length of PVC pipe; wires crossed at right angles across the top of the tube formed crosshairs, and a fishing weight hung from these was used to ensure proper vertical alignment of the tube. For canopy cover, the observer aimed the tube directly upward and recorded a positive "hit" if the crosshairs intersected the canopy above and a negative if not; 63 measures were made at 1-m intervals along the transect, starting at 0 m and ending at 62 m. The number of hits divided by the number of observations (63) × 100 yielded the percent of canopy cover. For ground cover, the observer aimed the tube at the ground at the same 1-m intervals along the transect and recorded type of ground cover at the crosshairs. Ground cover was classified as bare ground, dead or down wood, leaf litter, grass cover, or herb cover. Within each of the 2 4-m^2 shrub plots, placed at 19–20 m and 40–41 m along the central transect, we counted number of shrubs rooted within the plot, took two perpendicular measures across the crown of each shrub and multiplied them to estimate shrub cover, and recorded species of each shrub.

We used estimates of vertical foliage volume as a metric of understory structure within each macroplot. We constructed a stacking 1-m^2 cube from PVC pipe. We made 5 measures within each macroplot along the central transect of distances of 0–1 m, 19–20 m, 28–29 m, 40–41 m, and 60–61 m. We placed a 1-m^2 frame of PVC on the ground, and added layers vertically using corner joints and T-joints to form stacked cubes at ground level and heights of 0–0.5 m, 0.5–1 m, 1–2 m, and 2–3 m. At each level, the observer estimated percentage volume of the cube that was filled with foliage or other plant material (e.g., woody stems). The same 2 observers conducted all vegetation measures to minimize variability.

Data analysis

Estimates of bird abundance, diversity, species richness, and composition were based on the point-count surveys. We did not treat individual points as independent observations at each site but pooled all observations into a single count for each survey day. We averaged numbers of individuals observed for each of 8 surveys to derive an index of abundance (mean number of individuals observed per survey) for each site. Species richness was not a mean but the total number of species observed at each site over all 8 surveys, since equal numbers of points at each site and equal numbers of surveys at each ensured equivalent sampling effort. Community composition referred to the identity of the species observed during point-count surveys; we classified the individuals observed in our samples into 1 of 2 categories: "indigenous" or "cosmopolitan–introduced" species. We considered a cosmopolitan species to be a bird that was widespread, abundant, and that frequently increased in association with human habitation (sensu the "urban exploiters" or "suburban adaptables" of Blair 1996); non-native (introduced) was any species that originated outside of North America. Species that we classified as cosmopolitan or introduced (the latter indicated by an asterisk) included: domestic duck*, ring-necked pheasant* (*Phasianus colchicus*), mourning dove (*Zenaida macroura*), rock dove* (*Columba livia*), American crow (*Corvus brachyrhynchos*), American robin (*Turdus migratorius*), European starling* (*Sturnus vulgaris*), Brewer's blackbird (*Euphagus cyanocephalus*), common grackle (*Quiscalus quiscula*), great-tailed grackle (*Quiscalus mexicanus*), brown-headed cowbird (*Molothrus ater*), house finch (*Carpodacus mexicanus*), and house sparrow* (*Passer domesticus*). All other species were classified as indigenous. We further classified species as "riparian associates" if they were frequently associated with riparian systems during the breeding season in the Southwest (Krueper 1993, Cartron et al. 2000).

Species diversity was calculated using Shannon's Index ($H' = -\Sigma\, p_i \log_e p_i$), where p_i was the proportion (p) of the total community represented by each species I (Shannon and Weaver 1963, Magurran 1988). We calculated Shannon's Index for each survey and averaged over all 8 surveys for each site.

All pairs of means were compared using a standard *t*-test; if variances were unequal, we log-transformed data to meet the assumptions of the test. Where appropriate, we used the nonparametric Kruskal-Wallis for comparison of means across all 5 golf courses; if variances were unequal, we log-transformed data to meet the assumptions of ANOVA. All data are reported in their original form. Means are presented ±SD. We used chi-square contingency tables for comparisons of proportions (Zar 1996).
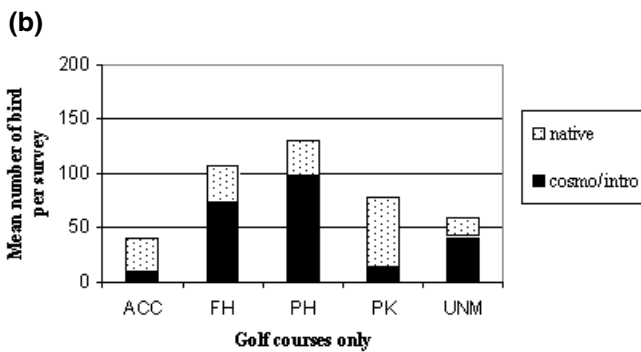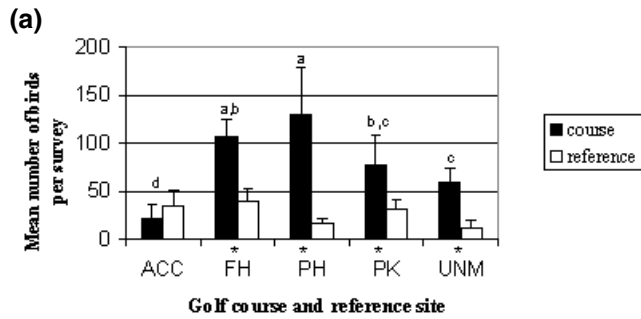
(a)

(b)

Figure 1. *a*) Index of abundance for all bird species on golf courses and reference sites in the Albuquerque, New Mexico area 2001 and 2002, in terms of mean number of individuals detected per survey (±SD, *n* = 8 for all). An asterisk (*) at the base of a pair denotes a significant difference between the abundance on a golf course and its paired reference site. Letters denote homogeneous subsets of golf courses compared by ANOVA. *b*) Numbers of individuals of indigenous (native) bird species compared to representatives of cosmopolitan–introduced species on the golf courses studied. ACC = Albuquerque Country Club; FH = Four Hills Country Club; PH = Paradise Hills Golf Club; PK = PaaKo Ridge Golf Club; UNM = UNM Championship Course.
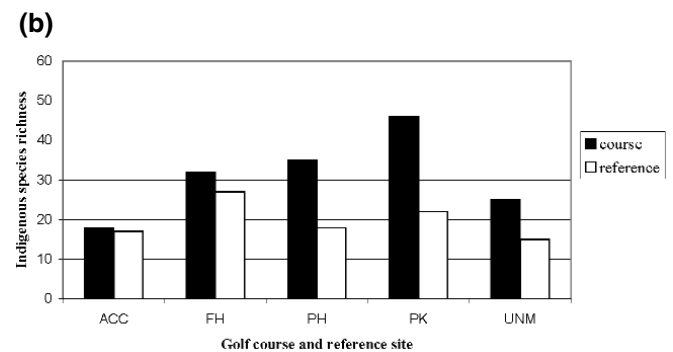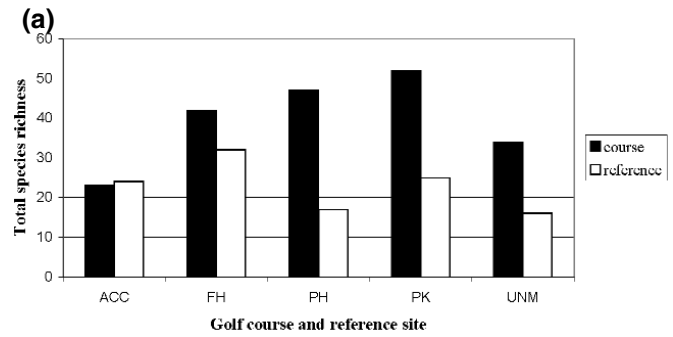
(a)

(b)

Figure 2. A) Species richness for all bird species on golf courses and reference sites in the Albuquerque, New Mexico area 2001 and 2002. As effort was equivalent between all sites (*n* = 8 surveys), the cumulative total number of species observed during the surveys was used. B) Species richness for all indigenous bird species (all birds that we did not classify as cosmopolitan–introduced) on golf courses and reference sites in the Albuquerque, New Mexico area 2001 and 2002. As survey effort was equivalent between all sites (*n* = 8), the cumulative total number of indigenous species observed was used for each site. ACC = Albuquerque Country Club; FH = Four Hills Country Club; PH = Paradise Hills Golf Club; PK = PaaKo Ridge Golf Club; UNM = UNM Championship Course.

Results

Avian abundance

Birds were more abundant on golf courses than on their respective reference sites in 4 out of 5 cases (FH: $t=$ 8.46, $P<0.001$; PH: $t=6.5$, $P<0.001$; PK: $t=3.07$, $P=$ 0.01; UNM: $t=8.6$, $P<0.001$; $n=8$ for all; Figure 1*a*). The exception was ACC, which did not differ from its reference site in index of abundance ($t=-1.4$, $P=0.18$, $n=$ 8).

Species richness

Total species richness was greater on the golf course in 4 out of 5 cases (FH, PH, PK, UNM; Figure 2*a*). Only ACC had fewer bird species than its paired reference site. Indigenous species richness (excluding cosmopolitan species) was higher at all 5 of the golf courses relative to their reference sites, although only marginally so at the

Albuquerque Country Club (Figure 2*b*).

Species diversity

Three of the golf courses, PH, PK, and UNM, had greater diversity than their paired reference sites (PH: $t=$ 5.3; PK: $t=4.41$; UNM: $t=6.5$; $P<0.001$, $n=8$ for all; Figure 3). There was no difference between diversity for FH and its comparison area ($t=-1.3$, $P=0.2$, $n=8$), and the reference site for ACC had greater diversity than the course ($t=-5.02$, $P=0.001$, $n=8$). PaaKo had greater diversity than all of the other courses; ACC had the least ($F_{4,35}=20.6$, $P<0.001$).

Community composition and representation of riparian associates

At 3 out of 5 golf courses, indigenous birds were greatly outnumbered by representatives of either cosmo-
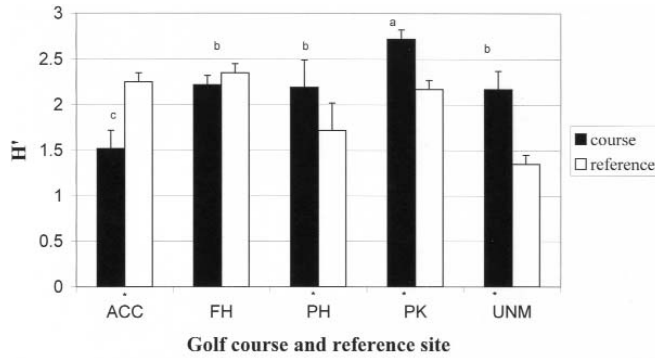
Figure 3. Shannon's Index of Diversity (H') for all golf courses and reference sites in the Albuquerque, New Mexico area 2001 and 2002, based on the mean diversity per count (± SD, $n = 8$ for all). An asterisk (*) at the base denotes a significant difference between the abundance on a golf course and its paired reference site. Letters denote homogenous subsets of the golf courses compared by ANOVA. ACC = Albuquerque Country Club; FH = Four Hills Country Club; PH = Paradise Hills Golf Club; PK = PaaKo Ridge Golf Club; UNM = UNM Championship Course.

Figure 4. The proportion of the individuals observed in each survey that were indigenous bird species (not cosmopolitan–introduced species, as identified in text) in the Albuquerque, New Mexico area 2001 and 2002. An asterisk (*) at the base denotes a significant difference between the proportion of indigenous species detected on a golf course and its paired reference site. A comparison across the 5 courses showed that the PaaKo Ridge Golf Course (PK) had a significantly greater proportion of indigenous bird species in its avian community than the other courses (all chi-square tests). ACC = Albuquerque Country Club; FH = Four Hills Country Club; PH = Paradise Hills Golf Club; PK = PaaKo Ridge Golf Club; UNM = UNM Championship Course.

politan or introduced bird species. Paradise Hills had the greatest overall index of abundance, but only 24% of the birds observed were indigenous species (Figure 4). Four Hills and UNM also had relatively low proportions of indigenous individuals (31% and 29% respectively), and at ACC 51% of the individuals observed were indigenous. The low representation of indigenous species at these 4 courses differed from that observed at PK, where indigenous individuals made up 76% of the birds observed ($\chi^2_4 = 449.5$, $P < 0.001$).

The proportion of indigenous individuals observed at reference sites exceeded that of the golf courses in all cases except that of PK, where there was no difference (ACC: $\chi^2_1 = 30.1$; FH: $\chi^2_1 = 113.6$; PH: $\chi^2_1 = 106.3$; UNM: $\chi^2_1 = 90.4$; $P < 0.001$ for all; PK: $\chi^2_1 = 0.72$, $P > 0.05$; Figure 4).

For each golf course, the majority of bird species observed were either shared by the avian community on the course and its paired reference site, or were found only on the course (Table 1). Four of 5 reference sites had some subset of the avian community that was unique,
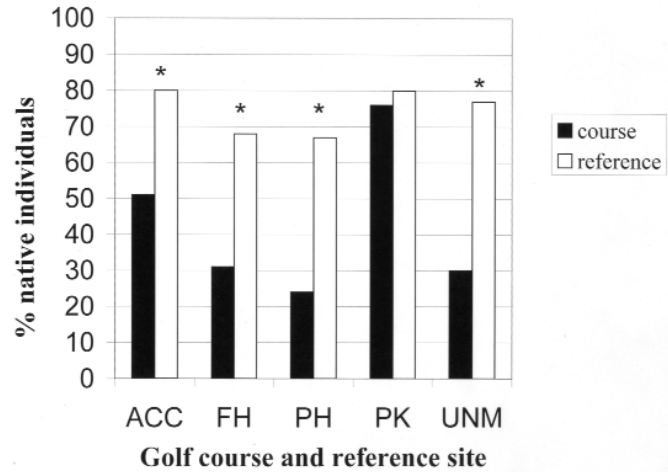
with the exception of PK. In that case, the 25 species observed on the reference site also were observed on the golf course, and an additional 27 species were observed only on the golf course; no species were unique to the reference site in this pairing.

We observed 65 species of birds on golf courses that were not detected on reference sites during our observations; these are species we assumed to have been added to the avian community of the golf course (Table 2). Most of the species that were unique to the golf course observations, 48 out of 65 species (74%), were birds that were considered riparian associates. The percentage of detected individuals that were riparian associates was 40.5% overall, ranging from 27% at PH to 64% at PK. A few species that were considered riparian associates also

Table 1. Numbers and percent of all bird species that were observed only on the golf course, found on both the course and its paired reference site, or only on the reference site for all golf course–reference site pairs, and percent of individuals on golf courses that were riparian-associate species (Table 2) based on breeding season point counts in 2001 and 2002 in the Albuquerque, New Mexico area.

	Number of bird species (%)			Percent of individuals unique to golf courses	
	Unique to golf course	Shared	Unique to reference site	All riparian associates	Riparian associates without cosmopoliton–introduced species
Albuquerque Country Club	10 (30%)	13 (38%)	11 (32%)	40%	37%
Four Hills Country Club	23 (42%)	19 (34%)	13 (24%)	38%	14%
Paradise Hills Golf Club	36 (68%)	11 (21%)	6 (11%)	27%	19%
PaaKo Ridge Golf Club	27 (52%)	25 (48%)	0 (0%)	64%	49%
UNM Championship Course	25 (61%)	9 (22%)	7 (17%)	53%	29%

Table 2. Bird species that were observed on golf courses, but not on their paired reference sites, based on sampling from breeding season point counts on five golf courses and five paired reference sites in 2001 and 2002 in the Albuquerque, New Mexico area. Species in bold are those that are often associated with riparian areas or wetlands ("riparian associates") (Krueper 1993, Cartron et al. 2000).

Piedbilled grebe[b]	*Podilymbus podiceps*	**Rubycrowned kinglet**	*Regulus calendula*
Blackcrowned night heron[b]	*Nycticorax nycticorax*	**BlueGray gnatcatcher**	*Polioptila caerulea*
Canada goose[b]	*Branta canadensis*	Western bluebird	*Sialia mexicana*
Mallard[a,b]	*Anas platyrhynchos*	Mountain bluebird	*Sialia currucoides*
American wigeon[a,b]	*Anas americana*	**American robin**	*Turdus migratorius*
Ruddy duck[b]	*Oxyura jamaicensis*	Curve-billed thrasher	*Toxostoma curvirostre*
Domestic duck[a,b]	*species unknown*	European starling[a,b]	*Sturnus vulgaris*
American coot[a,b]	*Fulica americana*	**Warbling vireo**	*Vireo gilvus*
Killdeer	*Charadrius vociferus*	**Yellowrumped warbler**[a]	*Dendroica coronata*
Spotted sandpiper[a,b]	*Actitis macularius*	**Yellow warbler**[b]	*Dendroica petechia*
Cooper's hawk	*Accipiter cooperii*	Cedar waxwing	*Bombycilla cedrorum*
Swainson's Hawk	*Buteo swainsoni*	**Wilson's warbler**[a]	*Wilsonia pusilla*
American kestrel	*Falco sparverius*	**Blackheaded grosbeak**	*Pheucticus melanocephalus*
Rock Dove	*Columba livia*	**Blue grosbeak**	*Passerina caerulea*
Broadtailed hummingbird	*Selasphorus platycercus*	Lark sparrow	*Chondestes grammacus*
Rufous hummingbird	*Selasphorus rufus*	**Chipping sparrow**	*Spizella passerina*
Northern flicker	*Colaptes auratus*	**Whitecrowned sparrow**	*Zonotrichia leucophrys*
Downy woodpecker[a,b]	*Picoides pubescens*	**Lincoln sparrow**[b]	*Melospiza lincolnii*
Hairy woodpecker	*Picoides villosus*	**Yellowheaded blackbird**[b]	*Xanthocephalus xanthocephalus*
Western kingbird	*Tyrannus verticalis*	**Redwinged blackbird**[a,b]	*Agelaius phoeniceus*
Ashthroated flycatcher	*Myiarchus cinerascens*	**Brewer's blackbird** [a,b]	*Euphagus cyanocephalus*
Western woodpewee[a]	*Contopus sordidulus*	**Brownheaded cowbird**	*Molothrus ater*
Black phoebe[b]	*Sayornis nigricans*	Common grackle[a,b]	*Quiscalus quiscula*
Say's phoebe	*Sayornis saya*	Greattailed grackle[a,b]	*Quiscalus mexicanus*
Dusky flycatcher[b]	*Empidonax oberholseri*	**Bullock's oriole** [a,b]	*Icterus bullockii*
Northern roughwinged swallow	*Stelgidopteryx serripennis*	**Western tanager**[a]	*Piranga ludoviciana*
Cliff swallow	*Hirundo pyrrhonota*	**Summer tanager**	*Piranga rubra*
Barn swallow	*Hirundo rustica*	House sparrow	*Passer domesticus*
Violet-green swallow	*Tachycineta thalassina*	**Pine siskin**	*Carduelis pinus*
American crow	*Corvus brachyrhynchos*	**American goldfinch**[a ,b]	*Carduelis tristis*
Mountain chickadee	*Poecile gambeli*	**Lesser goldfinch**	*Carduelis psaltria*
Bushtit	*Psaltriparus*	Evening grosbeak[b]	*Coccothraustes vespertinus*
*minimus*Whitebreasted nuthatch[a]	*Sitta carolinensis*		

[a] These species were identified in more than one golf course–reference site pair.

[b] This subset of species was observed on a golf course but not on its paired reference site nor on any of the other 4 reference sites.

fell within our classification of cosmopolitan–introduced species (mallard, domestic duck, brown-headed cowbird, Brewer's blackbird, American robin); if these species were removed from the calculations, the percentage of individuals that were riparian-associated species was 24.8% overall, ranging from 14% at FH to 49% at PK (Table 1).

Several introduced or cosmopolitan species also were unique to golf-course communities in our samples. Rock doves, American crows, European starlings, common grackles, great-tailed grackles, and house sparrows were all found on golf courses but not in the reference sites.

We observed 7 indigenous species of birds on reference sites that we did not detect on the golf courses: scaled quail (*Callipepla squamata*), burrowing owl (*Athene cunicularia*), crissal thrasher (*Toxostoma crissale*), black-throated sparrow (*Amphispiza bilineata*), Brewer's sparrow (*Spizella breweri*), western mead-owlark (*Sturnella neglecta*), and Scott's oriole (*Icterus parisorum*).

Habitat characteristics

We compared vegetation measures between each golf course and its reference site, and across all golf courses (Table 3). These measures revealed the following general patterns: the ACC and PH courses were dominated by turf and scattered trees and essentially devoid of any understory structure. Shrubs, herbs, downed wood, leaf litter, and snags were all lacking, and foliage volume went from zero to above 0.5 m. Albuquerque Country Club had less structure and complexity than its reference site in almost every category. The reference site for PH lacked any trees or saplings; thus, PH had greater canopy cover and stem densities than its reference site, which was dominated by shrubs. The reference site for UNM also lacked any trees or saplings, but here the course had

Table 3. Vegetation measures for golf course out-of-play areas and paired reference sites, presented as means (SD), collected during August and September 2002 in Albuquerque, New Mexico. Significant differences between a golf course and its paired reference site, as determined by a *t*-test ($P < 0.05$), are indicated by bold type. Significant differences between all five golf courses, as determined by an ANOVA ($P < 0.05$), are indicated by superscript letters identifying homogeneous subsets.

	ACC*	ACC REF	FH	FH REF	PH	PH REF	PK	PK REF	UNM	UNM REF
500-m² PLOTS										
Tree height (m)	18.7[a]	16.4	**7.5**[a]	**3.0**	10.2[b]	—	4.1[c]	3.7	9.2[b]	—
n = 24 trees	(4.3)	(4.9)	(2.1)	(1.0)	(3.2)		(0.7)	(0.6)	(4.7)	
Canopy cover (%)	68.3[a]	72.7	18.8[b,c]	11.3	**51.8**[a, b]	**0.0**	29.7[b,c]	47.2	**17.3**[c]	**0.0**
n = 6 transects	(10.2)	(14.2)	(20.9)	(10.1)	(20.4)	(0.0)	(25.7)	(9.0)	(18.0)	(0.0)
Grass cover (%)	**100.00**[a]	**0.0**	20.4[c]	28.0	**65.1**[b]	**2.4**	11.9[c]	4.7	5.3[c]	1.5
n = 6 transects	(0.00)	(0.0)	(15.7)	(11.3)	(35.3)	(2.2)	(8.9)	(4.0)	(6.2)	(1.4)
Herb cover (%)	**0.0**[b]	**1.8**	14.8[a]	5.8	9.8[a,b]	7.4	3.7[a,b]	3.9	9.0[a,b]	16.7
n = 6 transects	(0.0)	(3.1)	(12.8)	(2.9)	(7.2)	(2.6)	(2.6)	(1.7)	(7.9)	(11.3)
Leaf litter (%)	**0.0**[c]	**82.3**	31.2[a]	22.5	**0.0**[c]	**15.1**	39.7[a]	50.8	15.9[b]	15.1
n = 6 transects	(0.0)	(4.9)	(13.8)	(5.7)	(0.0)	(2.2)	(9.3)	(8.3)	(5.1)	(3.6)
Dead/down wood (%)	**0.0**[b]	**15.5**	2.6[a,b]	6.1	**0.0**[b]	**5.0**	7.7[a]	8.7	**4.7**[a,b]	**0.0**
n = 6 transects	(0.0)	(5.3)	(3.1)	(11.9)	(0.0)	(4.1)	(6.1)	(4.5)	(4.1)	(0.0)
Bare ground (%)	**0.0**[b]	**9.0**	30.1[a]	38.9	24.8[a,b]	64.0	30.7[a]	23.3	41.0[a]	59.8
n = 6 transects	(0.0)	(20.6)	(20.9)	(6.8)	(30.5)	(8.6)	(9.9)	(6.9)	(7.5)	(6.5)
# of stems 0 - 8 cm	**0.0**[b]	**178.83**	189.0[a,b]	94.2	**30.8**[b]	**0.0**	268.3[a]	295.0	**11.8**[b]	**0.0**
n = 6 plots	(0.0)	(78.3)	(228.6)	(71.2)	(52.4)	(0.0)	(105.9)	(56.5)	(17.7)	(0.0)
# of stems 9-20 cm	0.33[b]	23.50	21.83[b]	20.83	**4.83**[b]	**0.0**	59.17[a]	57.17	**3.0**[b]	**0.0**
n = 6 plots	(0.8)	(10.3)	(33.6)	(18.3)	(7.4)	(0.0)	(21.8)	(18.5)	(3.2)	(0.0)
# of stems 21 - 40 cm	**0.0**[b]	**7.7**	1.2[a,b]	0.0	**4.8**[a,b]	**0.0**	2.3[a,b]	3.2	**3.2**[a,b]	**0.0**
n = 6 plots	(0.0)	(4.9)	(1.8)	(0.0)	(3.8)	(0.0)	(0.8)	(1.2)	(4.5)	(0.0)
# of stems > 40 cm	**6.0**[a]	**2.7**	0[c]	0	**1.8**[b]	**0.0**	0.0[c]	9.0	**0.7**[b,c]	**0.0**
n = 6 plots	(1.9)	(2.1)	(0.0)	(0.0)	(1.2)	(0.0)	(0.0)	(0.0)	(0.5)	(0.0)
Tree species richness	**1.7**	**6.2**	3.3	2.8	3.3	—	**4.0**	**2.3**	1.3	—
n = 6 plots	(0.8)	(1.5)	(2.6)	(1.2)	(1.5)		(1.3)	(0.5)	(1.1)	
Snags - # < 12 cm	**0**[b]	**111.3**	45.5[b]	12.2	0[b]	0.0	92.5[a]	83.7	0.0[b]	0.0
n = 6 plots	(0.0)	(137.3)	(45.8)	(12.9)	(0.0)	(0.0)	(39.5)	(29.2)	(0.0)	(0.0)
Snags - # > 12 cm	**0**	**9.3**	1.7	0.2	0	0.0	**2.5**	**10.0**	0.0	0.0
n = 6 plots	(0.0)	(8.8)	(2.8)	(0.4)	(0.0)	(0.0)	(2.1)	(6.1)	(0.0)	(0.0)
4-m² SHRUB PLOTS										
Number of shrubs	0[c]	0.4	4.3[a,b]	1.9	**0**[c]	**5.3**	0.8[b]	4.1	9.6[a]	1.7
n = 12 subplots	(0.0)	(1.4)	(5.6)	(2.6)	(0.0)	(4.0)	(1.7)	(3.4)	(9.6)	(2.6)
Shrub cover (cm²)	—	428,491	129,421[b]	54,521	—	132,939	85,396[b]	136,183	**670,206**[a]	**63,136**
n = 12 subplots		(148,433)	(247,770)	(140,298)		(120,021)	(199,041)	(158,290)	(765,724)	(127,727)
Shrub species richness	—	3.0	1.8	1.3	—	1.6	2.3	1.7	**2.6**	**1.6**
n = 12 subplots		(0.0)	(1.3)	(0.5)		(0.8)	(1.9)	(1.1)	(1.4)	(0.5)
FOLIAGE VOLUME										
Ground level (%)	**95.0**[a]	**11.9**	34.7[b]	31.8	**71.4**[a]	**14.4**	29.3[b]	26.9	15.7[b]	25.3
n = 30	(0.0)	(24.4)	(30.0)	(21.9)	(39.1)	(9.1)	(21.7)	(17.9)	(18.5)	(14.9)
Height 0 - 0.5 m (%)	**5.0**[d]	**19.1**	22.4[a,b]	21.5	**8.6**[b,c,d]	**11.0**	15.8[a,b,c]	22.6	**17.8**[a,b,c,d]	**10.9**
n = 30	(0.0)	(27.4)	(22.8)	(22.0)	(2.8)	(4.1)	(11.9)	(14.1)	(17.8)	(12.2)
Height 0.5 - 1m (%)	**0**[b]	**26.4**	15.6[a]	9.0	**0**[b]	**1.3**	7.4[a,b]	**15.3**	12.5[a]	2.6
n = 30	(0.0)	(34.6)	(21.2)	(18.0)	(0.0)	(3.9)	(8.0)	(14.4)	(21.0)	(7.2)
Height 1 - 2 m (%)	**0**[b]	**20.7**	5.8[a,b]	3.0	0[b]	0	11.4[a]	19.5	**5.6**[a,b]	**0.4**
n = 30	(0.0)	(25.3)	(11.7)	(6.6)	(0.0)	(0.0)	(16.6)	(18.6)	(11.4)	(1.4)
Height 2 - 3m (%)	**0**[b]	**20.7**	4.8[a,b]	0.6	0[b]	0	10.0[a]	12.4	1.6[b]	0
n = 30	(0.0)	(25.4)	(14.5)	(3.2)	(0.0)	(0.0)	(16.5)	(15.7)	(5.4)	(0.00)
WATER SOURCE										
Pond(s) present?	No	No	Yes - 2	No	Yes - 1	No	Yes - 2	No	Yes - 2	No

 * ACC = Albuquerque Country Club; FH = Four Hills Country Club; PH = Paradise Hills Golf Club; PK = PaaKo Ridge Golf Club; UNM = UNM Championship Course; REF = the paired reference site for each golf course.

greater canopy cover, stem densities, foliage volumes, and more diverse ground cover as well as greater shrub cover. Out-of-play areas at both FH and PK differed little from their reference sites in most of the variables measured. Ponds were present on all courses except ACC.

Comparing between the courses, ACC and PH had greater grass cover and foliage volume at ground level, reflecting the nearly continuous turf cover at these courses. Four Hills, PK, and UNM all had greater amounts of down wood, herbs, leaf litter, and vertical foliage volume above 0.5 m. PaaKo had more small snags and had the greatest foliage volumes into the upper levels measured (between 1 and 3 m) of any course. Four Hills, PK, and UNM all maintained some vertical foliage volume above 0.5 m, while ACC and PH had none above this level ($F_{4, 146}=5.53$, $P<0.01$).

Discussion

Golf courses supported a greater number of birds than surrounding natural areas, a response that is common throughout studies of avian responses to urbanization (Emlen 1974, Hohtola 1978, Beissinger and Osborne 1982, Green 1984). In contrast to many such studies, we also found greater avian species richness on most of the golf courses, as well as higher diversity (Figures 2, 3).

The increase in avian abundance on golf courses was largely at the expense of more specialized indigenous bird species, as has been witnessed in numerous other studies of urbanization effects (e.g., Emlen 1974, Lancaster and Rees 1979, Beissinger and Osborne 1982, Bezzel 1985). We found that a relatively few widespread and abundant species made up the majority of individuals detected (including, but not limited to, house sparrows, house finches, common grackles, and European starlings; see Figure 1*b*), comprising 69–76% of the individuals detected on 3 out of the 5 courses. Although they had fewer species, the reference sites were composed primarily of indigenous bird species. The PaaKo Ridge golf course was exceptional in several aspects, as it demonstrated greater species richness and diversity when compared to its natural area reference site, and was the only course that did not have a significantly lower proportion of indigenous individuals (Figure 4).

Species richness of indigenous birds was greater on golf courses, in contrast to the results of many other studies of birds in urban environments (Emlen 1974, Beissinger and Osborne 1982, Tweit and Tweit 1986, Savard et al. 2000). This result held across all 5 of the courses we studied (Figure 2*b*). Golf courses supported numerous indigenous bird species that were not components of the avian community in the surrounding natural areas. Of birds that were exclusive to our golf-course observations, 54 (83%) were indigenous species that we did not consider to be cosmopolitan or introduced (Table 2). Furthermore, we found strong support for our hypothesis that golf courses would provide habitat for riparian birds; over 70% of the species observed exclusively on golf courses were riparian associates (Tables 1, 2). The numbers of individuals in this group were relatively low, particularly once we excluded those that were also considered cosmopolitan species (e.g., American robin). Still, 25% of the birds observed on golf courses were riparian-associate species that were not represented in our samples of the surrounding natural-area bird communities.

Our results add support to the hypothesis that avian species richness or diversity does not respond to urbanization in a linear fashion (Cam et al. 2000), but instead peaks at a level of intermediate disturbance or development (Jokimäki and Suhonen 1993, Blair 1996). At the higher levels of urbanization, most of the land area is dominated by buildings or paved areas, and any vegetation is primarily ornamental (Beissinger and Osborne 1982, Blair 1996, Germaine et al. 1998). Golf courses, however, represent an intermediate level of development in which most of the land area is still vegetated, some areas of native vegetation may remain, and trees and ponds are common. Landscape diversity may actually increase under such a scenario, as structural diversity is added through changes in vegetation as well as the introduction of buildings and other structures that may serve as nest sites or perch sites, openings are created for edge species, and lawn or turf is capable of supporting high numbers of ground-foraging birds (Emlen 1974, Falk 1976, Lancaster and Rees 1979, Blair 1996).

This potential increase in landscape diversity at low-to-moderate levels of development is particularly noticeable in the desert landscape. In general, there is a strong positive correlation between bird species diversity and habitat diversity (MacArthur and MacArthur 1961, Cavareski 1976, Tilghman 1987), such that any increase in habitat diversity, particularly in a relatively simple landscape such as a desert, is likely to result in increased species richness (Emlen 1974). The features added to the landscape by a golf course often stand in sharp contrast to those of the desert environment; courses may provide numerous shade trees, water sources, turf, structures, and vegetation types that are not available in the surrounding natural areas. Photographs contrasting one of the available habitats on the UNM Championship Course with that of its reference site illustrate some of these differences (Figure 5). Riparian-like vegetative communities surrounding ponds on the course offer tall broad-leaved trees, multiple understory vegetation layers, and abundant water with emergent vegetation—all features that are absent from the desert landscape in the immediate area. In conjunction with numerous out-of-play areas dominated by remnant native shrublands and expansive open

Figure 5. Top) This pond at the UNM Championship Course demonstrates how golf courses may provide habitats that are similar in structure and composition to natural riparian habitats. Cottonwoods, willows, and cattails surround the water, providing habitat for a variety of bird species including red-winged blackbirds, black-crowned night herons, warbling vireos, yellow warblers, and western tanagers. Thirty-four species of birds were detected on this course, and 21 of these were riparian-associate species that were not found on the paired reference site in the Albuquerque, New Mexico area 2001 and 2002. Bottom) The relatively simple vegetative structure of the reference site for the UNM Championship Course can be deduced from this photograph. This undeveloped natural area, located directly across from the golf course, offers less for many bird species in terms of habitat diversity, complexity, and resources, which is reflected in lower overall species richness (16 species). However, this site did support some of the desert specialist species that were not detected on any of the golf courses in our study in the Albuquerque, New Mexico area 2001 and 2002, including scaled quail and burrowing owls.

areas of turf, this golf course collectively provided a range of habitats that supported a wide variety of birds, including such diverse species as yellow warblers, spotted sandpipers, greater roadrunners (*Geococcyx californianus*), ash-throated flycatchers, northern rough-winged swallows, and American robins. Given this landscape diversity, it was hardly surprising that the UNM course had a greater number of species, including greater numbers of indigenous species, than its comparison reference site. In general, we found that the golf courses that offered remnant areas of native shrubby vegetation, vari-

able types of ground cover (e.g., leaf litter, herbaceous plants), greater stem densities and vertical foliage structure, ponds, and riparian vegetation in addition to the standard areas of turf and scattered large trees supported greater numbers of indigenous bird species than the surrounding desert landscape (FH, PH, PK, UNM; see Table 3).

The impact of a golf course on avian community composition in the desert environment appears to be very different from development in a forested area. In their comparison of an urban area with a reference site intended to represent the original bird community, Beissinger and Osborne (1982) worked with a reference community in a climax beech–maple forest in Ohio, and Blair (1996) compared a variety of development types with a natural oak woodland in California. Increased development in these communities led to a loss of canopy-foraging or bark-gleaning birds, since canopy trees were lost from the habitat. This was consistent with Batten's (1972) observation that the loss of bird diversity was likely when development occurred in an area that had initially high landscape diversity. By contrast, the addition of a golf course actually added this component of structural diversity (high-canopy trees) at 3 out of 5 of our study sites (FH, PH, and UNM; see Table 3), thereby attracting canopy species or bark-gleaners that would not otherwise be present in the avian community. Several of the species that decreased in response to urbanization in these other studies (Beissinger and Osborne 1982, Blair 1996) were species that we detected exclusively on the golf courses in our study, including northern flickers, white-breasted nuthatches, downy woodpeckers, cliff swallows, and western wood-pewees. The only course we studied that had less complexity and structural diversity than its reference site, the Albuquerque Country Club, was also the only course that had lower bird abundance, species richness, and diversity. Our study suggested that in the structurally simple desert landscape, the additional resources and landscape complexity provided by golf courses resulted in greater avian abundance and species richness, including indigenous species richness.

High numbers of birds do not necessarily reflect high-quality habitat, however, nor can we assume that they represent self-sustaining populations (Van Horne 1983). Many anthropogenic habitats have been found to function as ecological "sinks," even though they are utilized by large numbers of birds (Pulliam 1988, Vierling 2000), and golf courses in particular have been the subject of concern regarding their possible environmental impacts (e.g., Stuller 1997). Measures of physiological condition or productivity would offer greater insight into the viability of riparian bird populations on golf courses.

It should be noted that, although overall species richness and diversity increased on golf courses, the original native bird community nonetheless suffered negative consequences. At the 4 traditional golf courses—Albuquerque Country Club, Four Hills, Paradise Hills, and UNM—loss of species found in the native community ranged from 17–32%. This was somewhat lower than the 40% loss reported by Blair (1996), but nonetheless these numbers represent the loss of a significant component of the desert bird community. Furthermore, 7 species of desert specialists were excluded from golf courses altogether, including 2 species of management concern, the burrowing owl and black-throated sparrow (United States Fish and Wildlife Service [USFWS] 1995), and a species that is experiencing population declines throughout its range, the western meadowlark (Sauer et al. 2003).

Certain characteristics of the PaaKo Ridge golf course deserve attention, as this course was exceptional in both the abundance and diversity of indigenous bird species. PaaKo was what Terman (1997:184) called a "naturalistic" golf course, one that retains "the native vegetation, land form, soils, and typical habitat units of a region." The course at PaaKo was based upon the natural topography of the Sandia foothills, turf was minimized, and the out-of-play areas were nearly indistinguishable from the surrounding pinyon–juniper woodlands (Figure 6). PaaKo was the only course that had greater abundance, species richness, and diversity of indigenous species rel-

Figure 6. Unlike more traditional golf courses, the design of the course at PaaKo makes maximum use of the natural topography and native vegetation of the area. The area in turf is minimized, and fairways and ponds are surrounded by extensive stands of undisturbed woodlands, resulting in a course that provides a variety of habitats for high numbers of indigenous bird species. PaaKo was the only golf course in our study in the Albuquerque, New Mexico area 2001 and 2002 that had greater species richness and abundance of more specialized native birds than cosmopolitan or introduced species.

ative to its reference site; 76% of the individuals observed at this course were indigenous species. No indigenous species observed at the reference site were excluded from the PaaKo course, and 27 species were added to the community (a few of these, however, were invasive species such as brown-headed cowbirds or Brewer's blackbirds).

In addition to increased habitat diversity through the addition of ponds and turf, the greater indigenous species richness at PaaKo and the continued dominance of its avian community by native species was likely attributable to the extensive areas of undisturbed native vegetation on the course. Greater numbers of native bird species and the ability to exclude invasive avian species are associated with the amount of native vegetation present (Green 1984, Mills et al. 1989). However, a potentially confounding factor was the undeveloped matrix that surrounded the PaaKo course. The Four Hills course provided an interesting contrast, since, like PaaKo, the vegetative characteristics of the out-of-play areas differed little from the reference site, yet this course surrounded by houses did not maintain the numbers or species richness of indigenous birds observed at PaaKo, despite its proximity to a large open-space area. Some low-density housing had recently been constructed in association with the golf course at PaaKo, but other than this, the landscape surrounding the course was largely undisturbed. The presence of houses adjacent to the course makes the avian community vulnerable to future incursions by increased numbers of "urban exploiter" species (Friesen et al. 1995, Rodewald 2003). The PaaKo course may provide a valuable natural experiment in whether such a naturalistic course can maintain its ecological integrity over the long term, as several thousand new homes are planned for future development not far from the course.

Management implications

Golf courses in the high desert area of Albuquerque have the potential to support large numbers of native bird species, at least for foraging, if not for breeding. The resources and habitat diversity provided on these courses may mitigate to some extent the loss of riparian systems in the Southwest. These golf courses do not function as true riparian habitats, however, in terms of excluding invasive bird species (Germaine et al. 1998). As presently constructed, most of the traditional courses support large numbers of birds that are relatively widespread and abundant species, and that may even be considered pests or nuisance species (e.g., common grackles, European starlings). Our study and others suggest that the conser-

vation value of golf courses in this desert region could be improved to support greater numbers of native birds and exclude more invasive exotics or pest species by increasing landscape complexity and vertical structure in the out-of-play areas on the courses, and by increasing the extent and usage of native plants (Green 1984, Mills et al. 1989, Germaine et al. 1998, Savard et al. 2000). Such improvements, even on a very small, localized scale, have the potential to affect changes in bird species composition (Germaine et al. 1998, Clergeau et al. 2001), and golf courses that are dominated by native vegetation may support significant numbers of native bird species (Terman 1997).

Whether golf courses in the desert have the potential to support viable populations of native and riparian species of birds remains to be tested. It is possible that even if improved, the habitat fragments on these courses may be too small and isolated to support some indigenous species (Savard et al. 2000). At the very least, our data showing increased species richness of indigenous birds, and particularly high numbers of riparian species on these courses, demonstrate that these golf courses may be capable of providing valuable stopover habitat for the numerous species of migratory birds that utilize riparian corridors in the Southwest. The potential for desert golf courses to serve as surrogate riparian areas for these species has important conservation implications, as many migratory birds in the western United States are currently experiencing population declines associated with the loss of riparian habitats (Hunter et al. 1987, DeSante and George 1994, Krueper 2000).

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