ELSEVIER

Landscape and Urban Planning 38 (1997) 183–197

LANDSCAPE
AND
URBAN PLANNING

Natural links: naturalistic golf courses as wildlife habitat

Max R. Terman *

Department of Biology, Tabor College, Hillsboro, KS 67063, USA

Abstract

Worldwide, there are over 25,000 golf courses. In the United States, there are approximately 15,000, with developers building about 350 new courses each year. Japan, Taiwan, China, and other countries are experiencing a similar golf boom. Some developers regard golf course development as one of the fastest growing types of land development in the world. Typically considered by ecologists to be an environmental problem, scientists are now reexamining golf courses to assess their potential to be wildlife habitat. Can naturalistic courses (those with substantial amounts of native wildlife habitat) actually benefit wildlife populations, especially birds, and still be attractive to golfers? My ecological research with a well-known naturalized links-style golf course in Kansas suggests that a naturalistic golf course can support significant numbers of birds, including many threatened species. When compared to a nearby natural area, the golf course equaled the natural area in total bird species richness but not in the relative abundance of specific kinds of birds. Naturalistic golf courses, while not natural areas, can complement biological reserves, military reservations, greenbelts, parks, farms, backyards and other units of the regional habitat mosaic. The large amount of habitat on naturalistic courses also reduces water runoff, irrigation, and chemical inputs. Furthermore, raising the profile of naturally landscaped golf courses can engage thousands of additional people in wildlife habitat preservation issues. Naturalistic courses are growing in popularity and the golfing community is responsive to aesthetic and environmental concerns. With the involvement of ecologists, this burgeoning interest in natural habitats on golf courses may significantly increase the amount of wildlife habitat, especially if designers build these kinds of courses in urban areas and on degraded landscapes such as landfills, quarries, and eroded lands. © 1997 Elsevier Science B.V.

Keywords: Biodiversity; Habitat; Golf; Bird conservation

1. Golf and the environment

The popularity of golf in the world is growing and the number of golf courses worldwide now exceeds 25,000. This involves a considerable amount of open space and potential habitat because the average 18-hole golf course covers about 54 ha of land. The United States now has more than 15,000 courses with more than 350 new courses being built each year (estimated from Balogh and Walker, 1992). Japan, Taiwan, China, and other Asian countries are experiencing a similar 'golf boom' (Chen, 1991).

Because of increasing concern over the growing number of golf courses and associated land development (Platt, 1994), the golfing community is now seriously addressing environmental issues associated with the game (Edmondson, 1987; Balogh and Walker, 1992, Dobereiner, 1992; Schiffman, 1994). Potential environmental problems associated with

* Corresponding author. Tel.: +1-316-947-3121; fax: +1-316-947-2607; e-mail: maxt@tcnet.tabor.edu

PII S0169-2046(97)00033-9

golf course construction and maintenance include loss of habitat (such as wetlands) and wild species; water depletion; chemical contamination of soil, surface water, ground water, and living organisms; excessive runoff and soil erosion; and urbanization around golf courses (see Balogh and Walker, 1992; Cohen, 1991; Cohen et al., 1993). Golf courses are expanding while there is growing concern about worldwide environmental degradation and loss of habitat and decline in biodiversity. The Japanese National Environmental Agency attributes the loss of more than 5000 ha of forest annually to golf-course development in that country (Platt, 1994).

In response, many golf organizations are searching for scientific information that can help make the construction and management of future and existing golf courses more environmentally compatible. The United States Golf Association (USGA), the Golf Course Superintendents Association of America (GCSAA), and the American Society of Golf Course Architects are especially active in this regard (see Balogh and Walker, 1992; Harker et al., 1993; Love, 1992; Smith, 1992; Smith et al., 1993). In Great Britain and Scotland, the Nature Conservancy Council and the Scottish Natural Heritage program promote environmentally sound approaches to golf course management and construction (see NCC, 1989). Many golf course architects are speaking out on environmental issues (see Doak, 1992; Hurdzan, 1996) and articles on what golf course superintendents can do to meet environmental expectations are appearing more frequently (Tatnall, 1991). Even environmental organizations such as Audubon International (not affiliated with the National Audubon Society) are joining in the search for ways to make golf courses more environmentally compatible (Dodson, 1990).

As part of this new focus, old and new golf courses that incorporate wildlife habitat are gaining in popularity (Klemme, 1995). Many of these naturalistic courses (those using the natural environment of a region as a development template—sometimes referred to as minimalist designs) retain the native vegetation, land form, soils, and typical habitat units of a region (for comparison, see Fig. 1). Architects intentionally use the native regional environment as a guide for development of the golf course (Smart et al., 1993). Could such naturalistic golf courses actually be wildlife reserves? This is an attractive scenario because golf courses are self-supporting economic units that come with a well-organized maintenance staff capable of caring for natural areas as well as for turf. Furthermore, as a social and cultural unit, golf clubs can make many new people aware of environmental and wildlife management issues. However, how effective can a naturalistic golf course be in providing wildlife habitat?

2. A study of Prairie Dunes Country Club and Sand Hills State Park

To examine how a naturalistic golf course compares to a natural area, I conducted a 3-year study of the birds found on Prairie Dunes Country Club and a nearby natural area, Sand Hills State Park, in Hutchinson, Kansas (Table 1). Prairie Dunes Country Club (Fig. 1) is one of the most habitat and wildlife rich golf courses in the nation (Fuller, 1996) and hosts more than 35,000 rounds of golf per year. Ranked as high as 8th in the country and 14th in the world by leading golf magazines, its honorary membership includes professional golfers Jack Nicklaus, Arnold Palmer, Sam Snead, Tom Watson, Johnny Miller, Judy Bell, and Julie Inkster.

The management program at Prairie Dunes includes environmental planning, public involvement, integrated pest management, wildlife food and cover enhancement, and water conservation and enhancement. This comprehensive approach fully certifies Prairie Dunes as a cooperative sanctuary by Audubon International (NY), which is known for its programs that encourage golf courses to adopt environmentally sustainable strategies in design, construction, and management. Approximately 74% of Prairie Dunes consists of native prairie plants growing in the roughs and out-of-play areas and in a 40-ha natural buffer zone that partially surrounds the course. This natural greenbelt separates the golf course from most of the nearby housing developments. The maintenance staff conducts prescribed burning of on-course grass areas when conditions allow.

Sand Hills State Park is a unique natural area under the control of the Kansas Department of Wildlife and Parks. Located approximately 2.5 km from Prairie Dunes, its 455 ha contain public trails

Table 1
Site descriptions of Prairie Dunes Country Club and Sand Hills State Park

	Prairie Dunes Country Club	Sand Hills State Park
Description	Constructed in 1937, 1957	Acquired 1974
	Architect Perry Maxwell	
	18-hole private country club	State park
	Formerly grazed prairie	Formerly grazed prairie
	35,000 golf rounds per year	Hikers, horseback riders
	Turf, natural roughs, buffer zone	Mowed trails, natural area
	Integrated pest management	No chemical treatment
	Spot burning on-course	Periodically burned
Size of total area (ha)	105	455
Size of survey area (ha)	64.8	56.7
Transect surveyed (km)	4.4	3.5

accessible only to walkers and permitted horseback riders. Habitats in the park include sand dunes, grasslands, wetlands, and woodlands. Park personnel burn the area to maintain a cover of native herbs and grasses. Compared to the golf course, the park is a low impact area with minimal human disturbance to wildlife.

Prairie Dunes and Sand Hills present an ideal situation for a comparative ecological study. With the exception of tees, fairways, greens, and construction, Prairie Dunes is very similar to Sand Hills State Park in topography and vegetation. Both have native prairie plants and rolling dunes typical of the sandhills biotic region of Kansas, a relatively narrow band of ancient river-borne Rocky Mountain sediments deposited in the south central part of the state of Kansas.

The public trail used for the bird transect in the park is approximately the same shape and distance (3.5 km) as a loop transect through both nine-hole layouts of the golf course (4.4 km). Birds on both sites were censused in good weather between 0700 and 1100 and we alternated the sites as to which was censused first. Another trained observer and I counted and recorded by species all birds seen along the park trail and near the tees, fairways, roughs, and greens of the golf course. To sample the birds using the two areas in different seasons, we performed 12 censuses over three years, with five censuses occurring during the autumn, one during winter, two during spring, and four during summer. The off-course natural areas at Prairie Dunes were not censused and all the bird observations on Prairie Dunes pertain to the golf course proper. Future studies will census the natural areas at Prairie Dunes.

I converted the data for all census periods to birds per kilometer and relative abundance (the number of birds in a species divided by the total number of birds for all species) (Table 2). Chi-square contin-

Fig. 1. Photographs of a traditional, completely mowed golf course (left) and a naturalistic golf course, Prairie Dunes Country Club (right).

Table 2
Numbers (birds/km) and relative abundance (% of total) for birds on Prairie Dunes (PD) and Sand Hills State Park arranged in descending order of Prairie Dunes bird numbers

Species	Birds/km		Relative abundance	
	PD	SH	PD	SH
American robin, *Turdus migratorius*	91.6	26.0	20.0%	9.1%
European starling, *Sturnus vulgaris*	70.5	2.6	15.3%	0.9%
American tree sparrow, *Spizella arborea*	51.1	8.0	11.1%	2.8%
House sparrow, *Passer domesticus*	23.9	0.0	5.2%	0.0%
Harris sparrow, *Zonotrichia querula*	21.8	10.6	4.8%	3.7%
Barn swallow, *Hirundo rustica*	17.0	0.9	3.7%	0.3%
Eastern kingbird, *Tyrannus tyrannus*	16.8	12.0	3.7%	4.2%
Common grackle, *Quiscalus quiscula*	15.5	4.6	3.4%	1.6%
Mourning dove, *Zenaida macoura*	12.7	8.3	2.8%	2.9%
Northern cardinal, *Cardinalis cardinalis*	12.7	12.6	2.8%	4.4%
Blue jay, *Cyanocitta cristata*	12.5	8.9	2.7%	3.1%
Black-capped chickadee, *Parus atricapillus*	9.3	20.3	2.0%	7.1%
Dark-eyed junco, *Junco hyemalis*	8.0	8.9	1.7%	3.1%
House wren, *Troglodytes aedon*	7.7	10.3	1.7%	3.6%
American goldfinch, *Carduelis tristis*	7.0	15.1	1.5%	5.3%
Northern oriole, *Icterus galbula*	7.0	5.4	1.5%	1.9%
Bell's vireo, *Vireo bellii*	6.8	4.3	1.5%	1.5%
Field sparrow, *Spizella pusilla*	6.1	4.0	1.3%	1.4%
Western kingbird, *Tyrannus verticalis*	6.1	1.1	1.3%	0.4%
Northern flicker, *Colaptes auratus*	5.2	16.6	1.1%	5.8%
Brown-headed cowbird, *Molothrus ater*	4.1	2.6	0.9%	0.9%
Cattle egret, *Bubulcus ibis*	3.4	0.3	0.7%	0.1%
Northern bobwhite, *Colinus virginianus*	3.4	9.4	0.7%	3.3%
Eastern meadowlark, *Sturnella magna*	3.2	4.3	0.7%	1.5%
Red-winged blackbird, *Agelaius phoeniceus*	3.0	11.7	0.6%	4.1%
Canada goose, *Branta canadensis*	2.7	1.4	0.6%	0.5%
Killdeer, *Charadrius vociferus*	2.5	0.3	0.5%	0.1%
Chimney swift, *Chaetura pelagica*	2.3	0.3	0.5%	0.1%
Gray catbird, *Dumetella carolinensis*	2.3	5.7	0.5%	2.0%
Brown thrasher, *Toxostoma rufum*	2.0	3.7	0.4%	1.3%
Song sparrow, *Melospiza melodia*	2.0	0.6	0.4%	0.2%
American crow, *Corus brachyrhynchos*	1.8	13.4	0.4%	4.7%
Franklin's gull, *Larus pipixcan*	1.8	0.0	0.4%	0.0%
Red-headed woodpecker, *Melanerpes erythrocephalus*	1.6	2.9	0.3%	1.0%
Wild turkey, *Meleagris gallopavo*	1.4	0.0	0.3%	0.0%
Common yellowthroat, *Geothlypis trichas*	1.1	6.0	0.2%	2.1%

Eastern bluebird, *Sialia sialis*	1.1	1.7	0.2%	0.6%
Grasshopper sparrow, *Ammodramus savannarum*	0.9	5.1	0.2%	1.8%
Orchard oriole, *Icterus spurius*	0.9	0.3	0.2%	0.1%
Red-tailed hawk, *Buteo jamaicensis*	0.9	4.3	0.2%	1.5%
Yellow-rumped warbler, *Dendroica coronata*	0.9	0.6	0.2%	0.2%
Downy woodpecker, *Picoides pubescens*	0.7	1.7	0.1%	0.6%
Great blue heron, *Ardea herodias*	0.7	0.6	0.1%	0.2%
Upland sandpiper, *Bartramia longicauda*	0.7	0.0	0.1%	0.0%
American kestrel, *Falco sparverius*	0.5	0.0	0.1%	0.0%
Belted kingfisher, *Ceryle alcyon*	0.5	0.0	0.1%	0.0%
Mississippi kite, *Ictinia mississippiensis*	0.5	0.9	0.1%	0.3%
Ring-necked pheasant, *Phasianus colchicus*	0.5	0.0	0.1%	0.0%
Yellow-billed cuckoo, *Coccyzus americanus*	0.5	0.6	0.1%	0.2%
Chipping sparrow, *Spizella passerina*	0.2	0.0	0.0%	0.0%
Dickcissel, *Spiza americana*	0.2	9.4	0.0%	3.3%
Great crested flycatcher, *Myiarchus crinitus*	0.2	1.1	0.0%	0.4%
House finch, *Carpodacus mexicanus*	0.2	0.0	0.0%	0.0%
Northern harrier, *Circus cyaneus*	0.2	0.6	0.0%	0.2%
Northern mockingbird, *Mimus polyglottos*	0.2	0.3	0.0%	0.1%
Red-bellied woodpecker, *Melanerpes carolinus*	0.2	2.3	0.0%	0.8%
Turkey vulture, *Cathartes aura*	0.2	2.0	0.0%	0.7%
Bewick's wren, *Thryomanes bewickii*	0.0	0.3	0.0%	0.1%
Blue grosbeak, *Guiraca caerulea*	0.0	0.3	0.0%	0.1%
Carolina wren, *Thryothorus ludovicuabys*	0.0	0.6	0.0%	0.2%
Rufous-sided towhee, *Pipilo erythrophthalmus*	0.0	3.1	0.0%	1.1%
Eastern wood-peewee, *Contopus virens*	0.0	0.6	0.0%	0.2%
Hairy woodpecker, *Picoides villosus*	0.0	0.6	0.0%	0.2%
Indigo bunting, *Passerina cyanea*	0.0	0.3	0.0%	0.1%
Lark sparrow, *Chondestes grammacus*	0.0	0.3	0.0%	0.1%
Least flycatcher, *Empidonax minimus*	0.0	0.6	0.0%	0.2%
Red-breasted grosbeak, *Pheucticus ludovicianus*	0.0	0.6	0.0%	0.2%
N. rough-winged swallow, *Stelgidopteryx serripennis*	0.0	0.3	0.0%	0.1%
Vesper sparrow, *Pooecetes gramineus*	0.0	0.9	0.0%	0.3%
White-breasted nuthatch, *Sitta carolinensis*	0.0	0.3	0.0%	0.1%
White-throated sparrow, *Zonotrichia albicollis*	0.0	0.3	2.3	0.8%
Yellow-breasted chat, *Icteria virens*	0.0	0.6	0.0%	0.2%
Total	459.1	285.7	100.0%	100.0%

gency table analysis was used to test for significant differences between the golf course and natural area in species richness and relative abundance. Indices of community similarity and species diversity were also calculated and used in the comparison (using Brower et al., 1990).

Both the golf course and the natural area supported complex bird communities, sharing many species (Table 2). The golf course had a higher density of birds than the natural area (459 to 286 birds per km). In terms of the number of species (species richness), the golf course (57 species) compared favorably to the natural area (63 species) and a statistical comparison indicated no significant differences ($\chi^2 = 13.2$, $df = 11$, $p > 0.10$). However, there were significant differences in relative abundance (the specific kinds, numbers, and proportions of the total in each kind) ($\chi^2 = 195.7$, $df = 27$, $p < 0.001$). Measures of community similarity and species diversity also indicated noticeable differences. Standard community similarity indices (Canberra–Metric, Bray–Curtis, Morisita's, Standers, Horn, Sorensen, and Jaccard) ranged from 0.372 to 0.809, respectively, on a scale of 0 to 1, indicating that Sand Hills and Prairie Dunes had only moderately similar bird communities. Species diversity indices (Simpson and Shannon indices) and dominance (Simpson) and evenness (Sheldon) measures also revealed noticeable differences with the natural area being much more even in its spread of species than the golf course. Sheldon evenness for the natural area was 0.541 and for the golf course 0.343. The number of equally abundant species on Sand Hills was 34.1 while Prairie Dunes had only 19.6. The Simpson dominance on the natural area was 3.56 while the golf course had 8.77.

Sand Hills had more species of birds than Prairie Dunes but fewer individuals. Sand Hills had 15 bird species that did not occur on Prairie Dunes and nine species occurred on the golf course but not on the park (Table 2). For the most part, habitat-sensitive birds requiring areas away from human disturbance (e.g., least flycatcher) occurred more frequently on the natural area while those with less restrictive habitat needs and higher tolerances for disturbance frequented the golf course (e.g., American robin). According to Blair (1996), birds can be categorized as urban avoiders, urban exploiters, and suburban adaptable species. While Prairie Dunes shared many species with Sand Hills, the golf course had more urban exploiter and suburban adaptable birds and less urban avoiders than Sand Hills.

Is it worthwhile to include areas of natural habitat areas on golf courses? If providing a home for a significant number of threatened birds is important, the answer is yes. Fifty-seven species of birds used Prairie Dunes in my survey and knowledgeable observers have added 15 to 20 more species to the list. Some birds using Prairie Dunes such as the great crested flycatcher, and yellow-billed cuckoo are listed in Ehrlich et al. (1988) as birds considered at risk. Furthermore, naturalistic golf courses may be able to help the many birds that require open grassland-type environments. Grassland birds such as the grasshopper sparrow and eastern meadowlark make up a large percentage of the threatened and endangered species (DeGraaf and Rappole, 1995). With grasslands, pastures, and weedy areas disappearing rapidly in the spread of urbanization, golf courses could provide additional critical habitat for grassland birds (Watts, 1995).

My students and I have studied other golf courses (unpublished data) without wildlife habitat and rarely does the count exceed 27 species. Furthermore, the bird community on Prairie Dunes differs significantly from these courses in much the same way that Sand Hills differs from Prairie Dunes. The occurrence of sensitive species and the distribution of individuals among the species appears to be much more stable on naturalized golf courses than on the more simple landscapes of conventional courses (see Moul and Elliot, 1992).

Can naturalistic golf courses offer the same habitat conditions as natural areas for birds? The answer here is no because many birds require the larger, less fragmented habitats found in undisturbed areas away from human activities. The human activity and high amount of patchiness and edge habitat on golf courses are problematic for many of these birds. For this reason, natural areas may lose many birds if a golf course is constructed on the site (Blair, 1996). It is unknown whether golf courses with large areas of undisturbed habitat (such as the approximately 41 ha of natural area on Prairie Dunes) will lose fewer

species. Our future studies of these undisturbed areas on Prairie Dunes should provide more information in this regard.

3. Golf course ecology

Naturalistic golf courses offer much more promise in the larger struggle to preserve plant, animal, and ecosystem diversity than conventional golf courses (Balogh and Walker, 1992; Moul and Elliot, 1992). My own research indicates that providing habitat around tees, in rough areas along fairways, and in out-of-play areas (see Fig. 1) does attract an exceptional number of birds to a golf course. Furthermore, these areas may be especially important to migratory birds needing a place to stop and refuel (for example, the yellow-rumped warbler) or to spend the winter (Harris sparrow).

If managed correctly, naturalistic courses may fit well into an emerging philosophy of ecosystem management that recognizes the considerable potential of private lands for preserving nature (Shafer, 1995). While naturalistic golf courses are not natural areas, courses with wildlife habitat may complement parks and wildlife reserves in the effort to increase the survival chances of many plants and animals. Especially attractive in this regard are the naturalized golf courses built on already disturbed land such as old mines, landfills, and highly eroded or otherwise negatively impacted wildlife-poor landscapes (Klemme, 1995).

There are already many courses around the country that can be classified as naturalistic to varying degrees. Love (1992) describes over 20 such courses and Audubon International has over 1800 courses participating in it's Cooperative Sanctuary Program (Dodson, 1990). The U.S. Fish and Wildlife Safe Harbor Program is also enrolling golf courses (such as Pine Needles in North Carolina) which provide habitat to threatened and endangered species such as the red-cockaded woodpecker. This species requires mature living pine trees in a protected area (Parkes, 1996) and it appears the golf-course environment is suitable to its needs.

All habitats, large and small, play a role in wildlife conservation (Shafer, 1995). Conservation biology, restoration ecology, and landscape ecology are growing and active fields in the ecological sciences that are just now beginning to address questions of how habitats of different sizes interact. Increasingly, scientists are realizing that a more holistic view that includes all types of habitat addresses biodiversity issues more effectively than one that just values large reserves (Noss and Cooperider, 1994). Populations of wildlife in an area dynamically interact with each other and rarely are plants and animals found only in natural areas (Oconnell and Noss, 1992). "Every population persists only because it is part of a larger 'metapopulation' and because it is regularly rescued from extinction by immigration from other independently varying populations" (Stacey and Taper, 1992). Designing and restoring golf courses in natural ways may facilitate the survival of wildlife metapopulations and the ecosystems on which they depend.

This emerging philosophy of ecosystem management strives to develop a regional habitat mosaic—a constellation of connected habitats in an area that allows metapopulations of plants and animals to exchange genes and periodically revitalize. Satellites, global positioning systems, aerial photos, and computer imaging are increasingly being used to construct layered maps of landscapes (Geographic Information Systems, GIS) for evaluating the importance of large and small habitats to wildlife populations (see Morrison et al., 1992). In the future, golf courses may be planned this way—as units of a total habitat landscape rather than as isolated parcels. Obviously, courses with maximal amounts of natural vegetation will be most valuable in this regard.

4. Naturalistic golf courses as wildlife habitat

Large natural preserves provide the best habitat for most wildlife and are an essential component of a successful biodiversity strategy (Shafer, 1995). However, small connected habitat parcels are also valuable when managed to promote native organisms and ecological processes such as succession, competition, territoriality, predation, and decomposition (Simberloff and Abele, 1982; Soule, 1991). However, our knowledge for managing a diversity of small habitats in a region is incomplete (see Hobbs, 1993 for a

discussion of issues surrounding corridors) and much research is needed in this area.

Only recently have ecologists focused their attention on the conservation potential of human-dominated and managed landscapes such as golf courses. Jodice and Humphrey (1992, 1993) describe a golf course that has a larger population of endangered Big Cypress fox squirrels (*Sciurus niger avicennia*) than the surrounding natural areas. A more dependable supply of food and water, less competition, and more amenable microclimates may be involved. Indeed, golf course type habitats may be particularly well suited for many species, like squirrels and perhaps loggerhead shrikes (*Lanius ludovicianus*) (Smith and Kruse, 1992). The open landscapes and prey-base (birds, rodents) of golf courses also appeal to birds of prey. The links-style management schemes of European golf courses have long been considered prime bird habitat (Fordham and Iles, 1987; Harthoorn, 1971).

Golf courses are probably best considered habitat for the conservation of small organisms (such as birds and small mammals) because of their relatively small size (on the average 54 ha). However, there are a number of questions that apply particularly to golf courses. Do golf courses support viable ecological communities or are they just sinks for 'weed species'? Can a reproducing bird community be supported on a golf course or are the individuals found there just excess 'floaters' unable to secure territories and consequently cannot reproduce? Furthermore, are small habitat areas 'ecological traps' (Noss, 1983), places that look appealing but which can not support the individuals who try to live there? Worse yet, do golf courses lure in birds only to expose them to chemicals used in turf management?

More research is needed but what little data that are available (Balogh and Walker, 1992; Rainwater et al., 1995; Terman, 1996) suggests that birds do reproduce on golf courses and that bioaccumulation of chemicals is negligible. As more courses become naturalistic and decrease the amount of intensively managed turf (see Conard, 1992) the exposure to toxics should become less. Furthermore, I suspect that most native birds on naturalistic golf courses will concentrate their feeding activities in non-turf natural areas thus reducing their exposure to chemicals even more. However, this supposition needs to be researched.

How about the impact of humans (golfers, carts, crowds of people, mowing machines and so forth) on birds? Some evidence suggests that many birds can coexist with recreational-type human activity (Bosakowski et al., 1993; Datta and Pal, 1993; Fernandez and Azkona, 1993; Hanowski et al., 1993; Squires et al., 1993; Knight and Gutzwiller, 1995; Riffell et al., 1996; Steidl and Anthony, 1996) if enough habitat is provided and if the human activity is scheduled around nesting and other sensitive times. If true, golf courses could contribute significantly to the conservation value of human dominated landscapes, especially in tropical areas where migrant birds have difficulty finding appropriate overwintering habitat (Estrada et al., 1993).

While most wildlife is welcomed on golf courses, some organisms may present some special problems. Some birds may attack people during nesting seasons (e.g., Mississippi kites, *Ictinia mississippiensis*, see Engle, 1980; Gennaro, 1988; Parker, 1988). Burrowing and gnawing rodents (e.g., beaver, *Castor canadensis*) can damage ponds and trees, larger herbivores can leave tracks on greens and in bunkers. Canada geese (*Branta canadensis*) may litter greens and fairways with droppings (Kemper, 1995). Surprisingly, the habitats on naturalized courses may have advantages over conventional designs with these kinds of animals. If they are of sufficient size and contain adequate resources, the natural habitats on the golf course will attract most of the wildlife which will normally confine their activities to the native vegetation. While some animals such as Canada geese inhabit mowed areas, tall vegetation along the fairways and bodies of water may discourage them since they can not see potential predators. I have rarely seen Canada geese on the fairways or greens at Prairie Dunes even though they are frequent visitors at other courses in the area.

5. Golf course architecture and naturalistic courses

The beauty of natural features often graces the great holes of golf (Doak, 1992) (Fig. 1). A great golf hole is playable by the average golfer but still

challenges the skills of the professional (Hurdzan, 1996). It rewards good shots, punishes bad ones, and is aesthetically pleasing. While natural beauty has always been foremost in the golf architect's mind, naturalistic courses demand golf holes that are integrated with the surrounding habitat–ecological integrity must accompany beauty. Many old and new courses offer good examples of this balancing act between golf and nature (Love, 1992; Klemme, 1995) and ecologists should study these courses to determine if they indeed have ecological integrity and support wildlife.

From an ecological point of view, golf holes should be designed to preserve the maximum amount of natural habitat. There are many ways to do this and the skills of both architect and ecologist are needed in the task. Elevating tee areas so golfers can hit shots over areas of natural habitat (wetlands, prairies, marshes and so forth) and onto landing areas or target zones of managed turfgrass is a technique popular with both golfer and architect. Alternate tee areas near the landing zone accommodate persons unable to hit long shots. Raised walkways and cart paths through wetlands, marshes, and other sensitive habitat allow traffic to move from tee to landing area without disturbing the habitat (Smart et al., 1993). Non-target zones in the fairway and in the primary and secondary roughs consist of mowed native or drought-resistant grasses requiring little water, fertilizer, or pesticides. The managed turfgrass is confined to the fairway landing area and the section around the small green. The goal is to reduce the 'manicured high chemical and water input areas' to the right places–tees, landing areas for good shots, and greens (Conard, 1992). Banked areas drain away water from sensitive habitats and allow for slightly off-target golf shots to funnel to the fairway.

A fair amount of information and many examples exist on how architects can preserve nature and build exciting golf holes (Doak, 1992; Hurdzan, 1996). However, promoting the growth and establishment of native grasses on the non-target zones of the fairway requires more knowledge and research. On courses where it is already established, mowed native grass provides an acceptable ball striking surface once it has matured and tillered (Green and Marshall, 1987) and it makes a good transition zone to the natural areas in the roughs and out-of-play areas.

Natural areas on golf courses should be as large as possible and circular to oblong in shape to reduce the amount of edge (Harker et al., 1993). A loop pattern for hole layouts and a surrounding natural buffer zone such as at Prairie Dunes Country Club are one way to accomplish this (Fig. 1). However, every golf course is different and many factors determine the hole layout. Some urban courses (such as the St. Charles Country Club in Illinois) have a relatively large and independent natural area beside a conventional golf course. Others may have the holes encircling a core natural area at the center of the course. Others have the golf course encircle housing and parking areas. The goal is to produce exciting golf courses with ecological integrity but every site is different and creative golf course design must be balanced with the needs of living organisms. This illustrates the need for cooperation between golf course architects and ecologists familiar not only with ecosystems but with the game of golf.

6. Wildlife management on naturalistic golf courses

Most golf clubs value the native birds, butterflies, and wildflowers that inhabit their courses (Milliard, 1992). But how much habitat is needed and how should it be maintained? Much is unknown about how to determine minimum habitat sizes for many organisms and this is an area of increasing research activity (Haila et al., 1993; Mccollin, 1993). Some researchers find little correlation with bird numbers and the area of habitat (Hamel et al., 1993; Nour et al., 1993; Roth and Johnson, 1993; Rudnicky and Hunter, 1993a; Yahner, 1993) while others find that bird numbers significantly increase with increasing area (Johns, 1993; Wenny et al., 1993). These findings illustrate the complexity of the ecological realities in wildlife management.

The study of ecosystem management is in its early stages and managers must acknowledge the tentative nature of any recommendation. At this stage in our study of ecosystem management, guidelines are like hypotheses, subject to modification as we monitor the success of our actions (Christensen et al., 1996). Nevertheless, following are some general guidelines for incorporating optimal habitat for birds

on golf courses (after Willson, 1974; Smith and Schaefer, 1992, Croonquist and Brooks, 1993, Harker et al., 1993, and Westworth and Telfer, 1993).

High quality habitat generally consists of native vegetation representative of the pre-development state of a region. Remnant patches of historic pre-development ecosystems such as native prairie, woodlands, and marshes should be preserved to the maximum extent possible. Streambank or riparian ecosystems are especially valuable. Leave snags, fallen logs, and other forms of habitat complexity in place if possible. Natural features and microhabitats such as slopes, springs, water falls, ravines, and other complex environmental features should be preserved also. Minimize roads or paths through these habitat patches.

Direct run-off from managed turf areas away from habitat areas unless it goes through a buffer zone or filter strip of adequate size to purify the water (minimum of 15 m on level terrain, more on slopes).

Minimize human disturbance to natural habitat. This can be done by fencing off environmentally sensitive areas, keeping trails and buildings on the outside of habitat areas, using raised walkways or cart paths, and providing buffer zones around habitat areas (for example, moderately mowed rough areas between the fairway and a marsh).

Habitat patches on the golf course (such as wetlands, marshes, streambanks, pond edges, grasslands, wooded areas) should be as large as possible but smaller parcels are valuable if they can be connected to other natural areas with corridors of native vegetation (here termed a 'connected habitat matrix').

Buffer zones of natural habitat surrounding the golf course or core areas within the golf course should interdigitate with on-course natural areas.

Manage the habitat to match the requirements of native species (see Ehrlich et al., 1988 for birds). For birds, this includes providing such features as song posts, nest sites (Steele, 1993; Kelly, 1993), and native plants of varying heights and widths. Scientifically locate nest sites (boxes, snags, platforms, and so forth) to provide maximum protection from predators and from nest parasites (Martin, 1993).

Where appropriate for the species concerned, habitats should be varied and complex with a mix of vegetative layers and good ground cover (litter, dead standing grass, and dead logs). Willson (1974) found that ground cover added one to two species of birds to an area; a shrub layer added one to four species; and a tree layer added 12 to 15 species.

Management by controlled burns may be needed, especially for some grassland and other fire-dependent plants and animals.

Since native species are disappearing with the spread of urbanization, golf course developers should use the natural (pre-development) environment of a region as a template for the development of a golf course on reclaimed areas such as landfills, old mines, eroded areas, and other degraded sites (see Harker et al., 1993).

How important could the managed patches of natural habitat on 15,000 golf courses be to birds in the United States? Leach and Recher (1993) found that habitat islands and remnant habitat areas were vital to maintaining bird diversity in Australia. Not many studies of golf courses by ecologists have been done so their potential as wildlife reserves remains uncertain. At this time, the least that can be said is that naturalistic golf courses do much more than conventional golf course landscaping to improve the lot of many birds and other wildlife (Lancaster and Rees, 1979; Maffei, 1978; Balogh and Walker, 1992; Terman, 1996).

In theory, the ecological role of smaller habitat parcels such as golf courses may be to serve as 'population sinks' for natural areas which function as 'population sources'. Larger natural areas (such as Sand Hills State Park in my study) provide a wide variety of niches where native species with many different requirements can establish themselves. Dominant individuals of these species secure territories on the natural area and reproduce. As the area fills up with dispersing offspring, individuals spread out across the country side from these reproductive 'fountains'. Golf courses (like Prairie Dunes) receive these dispersing individuals and provide them a home if they can adapt to the smaller habitat patches and human activity. Not all species can adapt but a good number apparently succeeds. How to increase this number is the critical question. Whether this scenario plays itself out in reality is unknown. Answers await more research. However, the stakes are high as the fate of many birds hangs in the balance.

That neotropical migrant species are suffering dramatic declines has been demonstrated for some but not all regions of the United States (Bibby, 1992;

Ehrlich et al., 1988; Welsh et al., 1993). Some threatened species are actually increasing in some regions while dramatically decreasing in others. This illustrates the complex nature of wildlife conservation. However, this should not deter saving as much potential habitat as possible, regardless of where it occurs.

What about the large amount of habitat fragmentation and edge habitat on golf courses? Doesn't this expose golf course birds to higher rates of predation from raptors, cats, snakes, raccoons, and other predators as well as to cowbirds (Hoover and Brittingham, 1993; Robinson, 1992)? (Cowbirds are nest parasites that lay their eggs in the nests of other birds who then feed the cowbirds at the expense of their own young). While this is certainly a concern, I did not find cowbirds to be numerous on Prairie Dunes (Table 2). Likewise, Rudnicky and Hunter (1993b) found little nest predation on birds near edges in agricultural habitat. Again more research is needed on golf courses. If predation and nest parasitism are problems, golf courses, under the guidance of local wildlife officials, could adopt management schemes to control the effects of cowbirds on native birds. Removing cowbird eggs from monitored nests and trapping adult cowbirds may work well in the golf course environment.

7. Golf course management and construction issues

If wildlife is encouraged to inhabit a golf course, it follows that exposure to harmful chemicals should be reduced as much as possible. Naturalistic courses accomplish this end by reducing the areas of managed turf. Applewood Golf Course in Golden Colorado has only 11 ha of 'pampered' turf that has drastically reduced the use of water and chemicals. The wildlife value of the course has increased and these reductions in irrigation and chemical inputs have lowered the risk of groundwater contamination (Conard, 1992). Pesticide movement is thought to be low in properly managed turfgrass (Harrison et al., 1993) and in a naturalistic course it should be even lower because the vegetative cover also reduces water runoff and soil erosion. Furthermore, natural areas enhance stream flow because of increased absorption of water. For this reason alone, some experts recommend that at least 70% of an area should be in natural cover (Lowe, 1991).

Reduced pesticide use and increased natural predators accompany increased natural cover and reduced turf. Predators of turf grass pests increase (Terry et al., 1993) as do rodent predators such as hawks (Newton and Wyllie, 1992) when pesticide usage is reduced. Birds seem to return comparatively quickly after reduced use of pesticides (see Hockin et al., 1992; Mackinnon and Freedman, 1993). While some chemicals may always be needed even on a naturalistic course, the strategies of integrated pest management (see Balogh and Walker, 1992) will certainly be easier to implement.

Many golf courses are using reclaimed water (sewage effluent) as a source of irrigation water (Meisner et al., 1993; Miles et al., 1992; Mujeriego and Sala, 1991). While this technique has its benefits and risks (Sullivan, 1991; Asano et al., 1992), naturalistic courses should facilitate the positive aspects because the borders and buffer zones of native vegetation around the tees, fairways, and greens hold the effluent on the golf course (see Osborne and Kovacic, 1993). If modern systems of irrigation are used that closely control application rates (Ruskin, 1993), these benefits can even be more pronounced.

Choosing a site for a golf course is one of the most important ecological decisions that must be made (Pedrick, 1992; Pope, 1994). Degraded lands such as landfills and old mining sites seem ideal for golf courses and naturalistic designs could improve the environmental conditions considerably (see Pope, 1994). The Links at Spanish Bay in California (Love, 1992) is such a course built on an old sand mine area. Klemme (1995) illustrates many others around the country. Unique natural ecosystems should be preserved, however, and may not be the most suitable places to build golf courses. Organizations such as The Nature Conservancy should be consulted and if a site is not able to be preserved, perhaps an ecologically designed naturalistic golf course may offer a valid option for protecting some of the ecological characteristics of the area. The most sensitive wildlife species may be lost but other more tolerant species may be saved (Blair, 1996).

Real estate developers often include golf courses in housing developments as a means of providing

open space (Pedrick, 1992). Again, well-designed naturalistic golf courses can save 70% or more of the natural habitat on a site. Natural landscaping around the houses can further ameliorate the negative effects of buildings on wildlife and water quality. Using earth sheltered construction (see Terman, 1985) for buildings enhances the wild nature of the development even more. With earth sheltered construction, the tee for hole 1 and the green for hole 18 could be on the clubhouse! In such a scheme, no buildings could be seen–only green 'roofs', rolling fairways, natural roughs, and the profiles of nature. A more exciting and sustainable future for golf may just depend on this kind of creative architecture and landscaping.

Modern golf courses are costly to construct and maintain which puts golf out of the reach of many potential players. Naturalistic courses mean less irrigation, fertilizing, pesticide use and maintenance thus lowering the costs for those willing to take up golf's challenges. In most cases, naturalistic designs also alleviate much of the cost of construction by reducing the need for extensive earth moving. Only tees, landing zones, and greens need to be extensively landscaped and manicured. Natural habitat such as wetlands remains in place (or can be constructed) providing character to the course and challenge to the golfer.

Even public courses can have naturalistic designs with wider fairways of mowed native grass rather than turf. While not as good as a carpet of turfgrass, the ball striking characteristics are adequate for less than good shots. The Scottish flavor of golf's history thus comes alive on these courses. Even professional golfers are saying that such courses will better hone the skills of the American golfer (Faxon, 1994).

What do golfers think of naturalized courses? Prairie Dunes is one of the most highly regarded courses in the world. Extensive surveys by Gentry (1988) revealed that all of the naturalized courses in Kansas are held in high regard by golfers. Many of the naturalistic courses featured in Klemme (1995) and Love (1992) host major tournaments.

The heart of the game of golf consists of challenge and risk and it is only natural to play golf over an infinite variety of terrains. Naturalistic courses not only help solve golf's environmental problems but may help return the game to its roots. The needs of both the golfing and ecological publics can be met by combining creative golf course architecture and ecosystem management. Niche, corridor, buffer zone, ecotone, foraging area, and nesting site join bogey, par, birdie, and eagle–on a naturalistic golf course all take on more meaning and significance.

Acknowledgements

I would like to thank Tabor College and the United States Golf Association (USGA) for supporting the preparation of this report which is part of a larger cooperative project with Audubon International and Ann Arbor Press of Chelsea, Michigan to produce a book on Golf Course Ecology. My thanks also go to P. Stan George, superintendent of Prairie Dunes Country Club; Paul Jantzen, friend and naturalist; Brent Konen, wildlife technician, Kansas Department of Wildlife and Parks and an anonymous reviewer who supplied some hard to find references.

References

Asano, T., Rigby, L., Sakaji, M., 1992. Evaluation of the California waste-water reclamation criteria using enteric virus monitoring data. Water Sci. Technol. 26, 1513–1524.

Balogh, J., Walker, W., 1992. Golf Course Management and Construction: Environmental Issues. Lewis Publishers, Boca Raton, 951 pp.

Bibby, C., 1992. Conservation of migrants on their breeding grounds. Ibis 134, 29–34.

Blair, R.B., 1996. Land use and avian species diversity along an urban gradient. Ecol. Appl. 6, 506–519.

Bosakowski, T., Speiser, R., Smith, D., Niles, L., 1993. Loss of Coopers hawk nesting habitat to suburban development: inadequate protection for a state-endangered species. J. Raptor Res. 27, 26–30.

Brower, J.E., Zar, J.H., von Ende, C.N., 1990. Field and Laboratory Methods for General Ecology. Wm.C. Brown Publishers, Dubuque, IA.

Chen, D., 1991. Different strokes. Free China Rev. 41, 36–41.

Christensen, N.C. et al., 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecol. Appl. 6, 665–691.

Cohen, S., 1991. Ground water contamination by golf courses: fact and fiction. Abstr. Pap. Am. Chem. Soc. 201, 38.

Cohen, S., Durborow, T., Barnes, N., 1993. Groundwater and surface-water risk assessments for proposed golf courses. ACS Symp. Ser. 522, 214–227.

Conard, R., 1992. Applewood golf course: reintroducing the short-

grass prairie and links-style golf. USGA Green Section Record November/December, 11–12.
Croonquist, M., Brooks, R., 1993. Effects of habitat disturbance on bird communities in riparian corridors. J. Soil Water Conservation 48, 65–70.
DeGraaf, R.M., Rappole, J.H., 1995. Neotropical Migratory Birds: Natural History, Distribution, and Population Change. Comstock Publishing Associates, Ithaca, NY, 676 pp.
Datta, T., Pal, B., 1993. The Effect of human interference on the nesting of the openbill stork (*Anastomus oscitans*) at the Raiganj Wildlife Sanctuary India. Biol. Conservation 64, 149–154.
Doak, T., 1992. The Anatomy of a Golf Course. Lyons and Burford, New York.
Dobereiner, P., 1992. How to resolve environmental enmity. Golf Digest 43, 28.
Dodson, R., 1990. Audubon cooperative sanctuaries for golf course management. Green Section Record United States Golf Association, 28, pp. 14-16
Edmondson, J., 1987. Hazards of the game. Audubon 89 (11), 25–37.
Ehrlich, P., Dobkin, D., Wheye, D., 1988. The Birder's Handbook. Simon and Schuster, New York 785 pp.
Engle, M.C.F., 1980. Mississippi kite strikes human being. Bull. Oklahoma Ornithol. Soc. 13, 21–22.
Estrada, A., Coatesestrada, R., Meritt, D., Montiel, S., Curiel, D., 1993. Patterns of frugivore species richness and abundance in forest islands and in agricultural habitats at Los-Tuxtlas Mexico. Vegetatio 108, 245–257.
Faxon, B., 1994. Our watered-down game. Golf World 48, 48.
Fernandez, C., Azkona, P., 1993. Human disturbance affects parental care of marsh harriers and nutritional status of nestlings. J. Wildlife Manage. 57, 602–608.
Fordham, M., Iles, J., 1987. Encouraging Wildlife on Golf Courses. London Wildlife Trust, London, 12 pp.
Fuller, G., 1996. Best of golf awards: golf and the environment. Links 9 (5), 20–30.
Gennaro, A.L., 1988. Extent and control of aggressive behavior toward humans by Mississippi kites. In: Glinski, R.L. et al. (Eds.), Proceedings Southwestern Raptor Management Symposium and Workshop, Natl. Wildlife Fed. Sci. Technol., Ser. No. 11, 249–252.
Gentry, S., 1988. Attitudes of golfers toward the characteristics of naturalistic golf courses. Master's Thesis. Kansas State University, 86 pp.
Green, B., Marshall, I., 1987. An assessment of the role of golf courses in Kent England in protecting wildlife and landscapes. Landscape Urban Planning 14, 143–154.
Haila, Y., Hanski, I., Raivio, S., 1993. Turnover of breeding birds in small forest fragments: the sampling colonization hypothesis corroborated. Ecology 74, 714–725.
Hamel, P., Smithand, W., Wahl, J., 1993. Wintering bird populations of fragmented forest habitat in the central basin Tennessee. Biol. Conservation 66, 107–115.
Hanowski, J., Blake, J., Niemi, G., Collins, P., 1993. Effects of extremely low-frequency electromagnetic fields on breeding and migrating birds. Am. Midland Naturalist 129, 96–115.
Harker, D.S., Evans, M., Harker, K., 1993. Landscape Restoration Handbook. Lewis Publishers, Boca Raton, 542 pp.
Harrison, S.A., Watschke, T.L., Mumma, R.O., Jarrett, A.R., Hamilton, G.W., 1993. Nutrient and pesticide concentrations in water from chemically treated turfgrass. ACS Symp. Ser. 522, 191–207.
Harthoorn, P.C., 1971. Golf courses as nature reserves. Sussex Trust for Nature Conservation Newsletter, 37 pp.
Hobbs, R.J., 1993. The role of corridors in conservation: solution or bandwagon. Trends Ecol. Evolution 7, 389–392.
Hockin, D., Ounsted, M., Gorman, M., Hill, D., Keller, V., Barker, M.A., 1992. Examination of the effects of disturbance on birds with reference to its importance in ecological assessments. J. Environ. Manage. 36, 253–286.
Hoover, J.P., Brittingham, M.C., 1993. Regional variation in cowbird parasitism of wood thrushes. Wilson Bull. 105, 228–238.
Hurdzan, M., 1996. Golf Course Architecture. Sleeping Bear Press, Chelsea, MI, 406 pp.
Jodice, P.G.R., Humphrey, S.R., 1992. Activity and diet of an urban population of big cypress fox squirrels. J. Wildlife Manage. 56, 685–692.
Jodice, P.G.R., Humphrey, S.R., 1993. Activity and diet of an urban population of big cypress fox squirrels: a reply. J. Wildlife Manage. 57, 930–933.
Johns, B.W., 1993. The influence of grove size on bird species richness in aspen parklands. Wilson Bull. 105, 256–264.
Kelly, J.P., 1993. The effect of nest predation on habitat selection by dusky flycatchers in limber pine-juniper woodland. Condor 95, 83–93.
Kemper, S., 1995. What's good for the goose may not be good for you. Smithsonian 25 (10), 70–78.
Klemme, M. 1995. A View From the Rough. Sleeping Bear Press, Chelsea, MI, 136 pp.
Knight, R.L., Gutzwiller, G.J., 1995. Wildlife and Recreationists: Coexistence Through Management and Research. Island Press, Washington, DC.
Lancaster, R.K., Rees, W.E., 1979. Bird communities and the structure of urban habitats. Can. J. Zool. 57, 2358–2368.
Leach, G.J., Recher, H.F., 1993. Use of roadside remnants of softwood scrub vegetation by birds in southeastern Queensland. Wildlife Res. 20, 233–249.
Love, W.R., 1992. An Environmental Approach to Golf Course Development. American Society of Golf Course Architects, Chicago. 43 pp.
Lowe, M.D., 1991. Shaping Cities: The Environmental and Human Dimensions. Worldwatch Institute, Washington, DC, 69 pp.
Mackinnon, D.S., Freedman, B., 1993. Effects of silvicultural use of the herbicide glyphosate on breeding birds of regenerating clearcuts in Nova Scotia Canada. J. Appl. Ecol. 30, 395–406.
Martin, T.E., 1993. Nest predation and nest sites. BioScience 43 (8), 523–532.
Maffei, E.J., 1978. Golf courses as wildlife habitat. Transactions Northeast Section Wildlife Soc. 35, 120–129.
Mccollin, D., 1993. Avian distribution patterns in a fragmented wooded landscape (North-Humberside UK): the role of be-

tween patch and within-patch structure. Global Ecol. Biogeography Lett. 3, 48–62.
Meisner, J.D., Quinn, B., O Brien, J., 1993. Golf: sport of the effluent. Am. City County 108, 24–38.
Miles, C.J., Leong, G., Dollar, S., 1992. Pesticides in marine sediments associated with golf course runoff. Bull. Environ. Contamination Toxicol. 49, 179–185.
Milliard, C., 1992. Golf courses for the birds. Golf Digest 43, 110–111.
Morrison, M.L., Marcot, B.G., Mannan, R.W., 1992. Wildlife–Habitat Relationships: Concepts and Applications. University of Wisconsin Press, Madison, 343 pp.
Moul, I.E., Elliott, J.E., 1992. A survey of pesticide use and bird activity on selected golf courses in British Columbia. Technical Report Series No. 163. Canadian Wildlife Service, Pacific and Yukon region, British Columbia.
Mujeriego, R., Sala, L., 1991. Golf course irrigation with reclaimed waste-water. Water Sci. Technol. 24, 161–171.
NCC, 1989. On Course Conservation: Managing Golf's Natural Heritage. Dept. OCC Nature Conservancy Council Northminster House Peterborough PE1 U1A, 46 pp.
Newton, I., Wyllie, I., 1992. Recovery of a sparrowhawk population in relation to declining pesticide contamination. J. Appl. Ecol. 29, 476–484.
Noss, R.F., 1983. A regional landscape approach to maintain diversity. BioScience 33, 706.
Noss, R.F., Cooperider, A.Y., 1994. Saving nature's legacy. Island Press, Washington, DC, 416 pp.
Nour, N., Matthysen, E., Dhondt, A.A., 1993. Artificial nest predation and habitat fragmentation: different trends in bird and mammal predators. Ecography 16, 111–116.
Oconnell, M.A., Noss, R.F., 1992. Private land management for biodiversity conservation. Environ. Manage. 16, 435–450.
Osborne, L.L., Kovacic, D.A., 1993. Riparian vegetated buffer strips in water quality restoration and stream management. Freshwater Biol. 29, 243–258.
Parker, 1988.
Parkes, M., 1996. A happy partnership. Golf J. XLIX 5, 47.
Pedrick, C., 1992. Golf blight: green deserts for 'select few' menace developing countries' environments. Ceres 24, 3–4.
Platt, A.E., 1994. Toxic Green: The Trouble With Golf. Washington, DC, Worldwatch Institute.
Pope, C., 1994. Not green enough. Hemispheres, July 1994
Rainwater, T.R., Leopold, V.A., Hooper, M.J., Kendall, R.J., 1995. Avian exposure to organophosphorus and carbamate pesticides on a coastal South Carolina golf course. Environ. Toxicol. Chem. 14 (12), 2155–2161.
Riffell, S.K., Gutzwiller, E.J., Anderson, S.H., 1996. Does repeated human intrusion cause cumulative declines in avian richness and abundance? Ecol. Appl. 6 (2), 492–505.
Robinson, S., 1992. Population dynamics of breeding neotropical migrants in a fragmented Illinois landscape. In: Hagan, J.M., Johnston, D.W. (Eds.), Ecology and Conservation of Neotropical Migrant Landbirds. Smithsonian Institution Press, Washington, DC, pp. 408–418.
Roth, R.R., Johnson, R.K., 1993. Long-term dynamics of a wood thrush population breeding in a forest fragment. Auk 110, 37–48.
Rudnicky, T.C., Hunter, M.L., 1993a. Reversing the fragmentation perspective: effects of clear-cut size on bird species richness in Maine. Ecol. Appl. 3, 357–366.
Rudnicky, T.C., Hunter, M.L., 1993b. Avian nest predation in clearcuts, forests, and edges in a forest-dominated landscape. J. Wildlife Manage. 57, 358–364.
Ruskin, R., 1993. Underground irrigation. Agric. Eng. 74, 9–11.
Schiffman, R., 1994. A sustainable future. Golf Digest, September, 8–10.
Shafer, C.L., 1995. Values and short-comings of small reserves. BioScience 45 (2), 80–88.
Simberloff, D.S., Abele, L.G., 1982. Refuge design and island biogeographic theory: effects of fragmentation. Am. Naturalist 120, 41–50.
Smart, M.M., Spencer, J.D., Calvo, R.N., Peacock, C.H., 1993. Working with nature for better golf developments. Urban Land 52 (3), 17–20.
Smith, A.E., 1992. Potential leaching of herbicides applied to golf course greens. Abstr. Pap. Am. Chem. Soc. 203, 130.
Smith, A.E., Weldon, O., Slaughter, W., Peeler, H., Mantripragada, N., 1993. A greenhouse system for determining pesticide movement from golf course greens. J. Environ. Quality 22, 864–867.
Smith, E.L., Kruse, K.C., 1992. The relationship between land-use and the distribution and abundance of loggerhead shrikes in south-central Illinois. J. Field Ornithol. 63, 420–427.
Smith, R.J., Schaefer, J.M., 1992. Avian characteristics of an urban riparian strip corridor. Wilson Bull. 104, 732–738.
Soule, M., 1991. Land use planning and wildlife maintenance: guidelines for conserving wildlife in an urban landscape. J. Am. Planning Assoc. 57, 313–323.
Squires, J.R., Anderson, S.H., Oakleaf, R., 1993. Home range size and habitat-use patterns of nesting prairie falcons near oil developments in northeastern Wyoming. J. Field Ornithol. 64, 1–10.
Stacey, P.B., Taper, M., 1992. Environmental variation and the persistence of small populations. Ecol. Appl. 2, 18–29.
Steele, B.B., 1993. Selection of foraging and nesting sites by black-throated blue warblers: their relative influence on habitat choice. Condor 95, 568–579.
Steidl, R.J., Anthony, R.G., 1996. Responses of bald eagles to human activity during the summer in interior Alaska. Ecol. Appl. 6 (2), 482–491.
Sullivan, R., 1991. Should Barton Springs be out-of-bounds? Sports Illustrated 75, 8–9.
Tatnall, T., 1991. How 'green' is your golf course? Parks and Recreation 26, 30–32.
Terman, M.R., 1985. Earth Sheltered Housing: Principles in Practice. Chapman & Hall, New York, 209 pp.
Terman, M.R., 1996. The bird communities of Prairie Dunes Country Club and Sand Hills State Park. Green Section Record (in press).
Terry, L.A., Potter, D.A., Spicer, P.G., 1993. Insecticides affect predatory arthropods and predation on Japanese-beetle (Cole-

optera:Scarabaeidae) eggs and fall armyworm (Lepidoptera:Noctuidae) pupae in turfgrass. J. Econ. Entomol. 86, 871–878.

Watts, B., 1995. Research news. Center for Conservation Biology, College of William and Mary Cornerstone Newslett. 1 (1), 9.

Welsh, C., Healy, J.E., William, M., 1993. Effect of even-aged timber management on bird species diversity and composition in northern hardwoods of New Hampshire. Wildlife Soc. Bull. 21, 143–154.

Wenny, D.G., Clawson, R.L., Faaborg, J., Sheriff, S.L., 1993. Population density habitat selection and minimum area requirements of 3 forest-interior warblers in central Missouri. Condor 95, 968–979.

Westworth, D.A., Telfer, E.S., 1993. Summer and winter bird populations associated with 5 age classes of aspen forest in Alberta. Can. J. Forest Res. 23, 1830–1836.

Willson, M.F., 1974. Avian community organization and habitat structure. Ecology 55, 1017–1029.

Yahner, R.H., 1993. Effects of long-term forest clear-cutting on wintering and breeding birds. Wilson Bull. 105, 239–255.