BIOLOGICAL CONSERVATION 136 (2007) 576–586

available at www.sciencedirect.com

journal homepage: www.elsevier.com/locate/biocon

The efficacy of small-scale conservation efforts, as assessed on Australian golf courses

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ARTICLE INFO

Article history:
Received 11 May 2006
Received in revised form
29 October 2006
Accepted 6 November 2006

Keywords:
Vertebrate biodiversity
Off-reserve conservation
Multi-scale

ABSTRACT

Habitat remnants on urban green-space areas (i.e. parks, gardens and golf courses) sometimes provide refuge to urban-avoiding wildlife, leading some to suggest these areas may play a role in wildlife conservation if they are appropriately designed and managed. The high densities observed on some green-space areas may however be attributed to external influences. Localised efforts to enhance the habitat value of urban green-space areas may therefore have little more than a cosmetic effect. This study investigated environmental factors influencing bird, reptile, mammal and amphibian diversity on Australian golf courses to assess the efficacy of small-scale conservation efforts. Abundance and species richness did not simply reflect local habitat qualities but were instead, partly determined by the nature of the surrounding landscape (i.e. the area of adjacent built land, native vegetation and the number of connecting streams). Vertebrate abundance and species richness were however, also associated with on-site habitat characteristics, increasing with the area of native vegetation (all vertebrates), foliage height diversity and native grass cover (birds), tree density, native grass cover and the number of hollows (mammals), woody debris, patch width and canopy cover (reptiles), waterbody heterogeneity and aquatic vegetation complexity (frogs). Localised conservation efforts on small land types can benefit urban-avoiding wildlife. Urban green-space areas can provide refuge to urban-avoiding vertebrates provided combined efforts are made at patch (management), local (design) and landscape (planning) scales.

1. Introduction

Small habitat remnants on private land and green-space areas (i.e. parks, gardens and golf courses) can potentially provide refuge to wildlife threatened by urbanization (Franklin, 1993; Linehan et al., 1995; Freeman, 1999; Blair, 2001; Fischer and Lindenmayer, 2002). While this has led urban planners to recommend small-scale conservation on a range of land types, it is important to ensure that small-scale conservation efforts have realistic goals and target appropriate species (Ehrenfeld, 2000). Studies indicate that there are minimum size-thresholds, below which remnants will have negligible value for threatened vertebrates (Howe et al., 1981; Loney and Hobbs, 1991; Sewell and Catterall, 1998). Information is therefore required on the ecological objectives that can be realistically achieved on smaller urban land types.

Recent studies have shown that green-space areas vary dramatically in their capacity to support urban-avoiding wildlife. While many support only common urban-adapted species, some act as a valuable refuge for species threatened by

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doi:10.1016/j.biocon.2006.11.001

urbanization (Terman, 1997; Sodhi et al., 1999; Pirnat, 2000; Blair, 2001; Merola-Zwartjes and DeLong, 2005; Hodgkison et al., Accepted for publication). Some suggest this variation is largely due to local factors and that most green-space areas could have conservation value if they were designed and managed appropriately (Australian Golf Union, 1998; Hostetler and Knowles-Yanez, 2003). While many landscape ecology studies have investigated environmental factors influencing wildlife abundance and species richness, few have been conducted at small scales in urban environments. The efficacy of small-scale conservation efforts on urban green-space areas is therefore uncertain.

There is no guarantee that the high wildlife diversity observed on some green-space areas is a reflection of local environmental management. Wildlife diversity is determined by ecological influences acting at multiple spatial and temporal scales (Forman and Godron, 1986; Kotliar and Wiens, 1990; Dunning et al., 1992; Hostetler, 2001) and is rarely a simple reflection of local habitat size or quality (Kotliar and Wiens, 1990; Dunning et al., 1992). High wildlife diversity on some green-space areas may be attributed to historic or regional influences. Small-scale conservation efforts on parks and gardens may therefore only have a cosmetic effect.

Recent studies have investigated factors influencing bird diversity on golf courses in the United States. While some found that bird diversity increased with the area and complexity of on-course vegetation (Jones et al., 2005; Merola-Zwartjes and DeLong, 2005), others found regional influences explained much of the variation and that local management actions were relatively unimportant (LeClerc and Cristol, 2005; Porter et al., 2005). Most studies investigating the conservation value of small urban habitat remnants have focused on their capacity to support birds. It would be valuable to compare the influence that small-scale conservation efforts have on different wildlife groups, particularly those that are less mobile and more easily isolated.

This study investigates the cause of variations in bird, reptile, mammal and amphibian diversity on golf courses in south-east Queensland Australia, considering influences at three (patch, local and landscape) scales. While golf courses are no substitute for larger habitat reserves in south-east Queensland, their regional ubiquity and the current rate of urbanization (Catterall and Kingston, 1993; Graymore et al., 2002) is such that their conservation potential cannot be overlooked. By assessing the extent to which variations in diversity are attributed to local habitat conditions, this study will determine the potential for ecological restoration on existing golf courses and provide guidelines to maximize the conservation value of future green-space areas.

2. Methods

Bird, reptile, mammal and amphibian diversity and environmental characteristics were surveyed on 20 suburban golf courses in south-east Queensland (Brisbane and the Gold Coast), Australia between 2001 and 2004. Sites were randomly selected from golf courses in south-east Queensland that have been established for at least 20 years and occur in flat, lowland areas with eucalypt vegetation (unburnt for at least 10 years).

2.1. *Fauna surveys*

Fauna surveys were conducted at 10 terrestrial and aquatic sub-sites on each golf course. Terrestrial sub-sites were randomly selected from all rough and out-of-play areas. Aquatic sub-sites were randomly selected from a list of on-site waterbodies. All sites were surveyed for birds on six occasions between 2001 and 2003, in a range of seasons. Birds were surveyed on mornings without rainfall, within 3.5 h of dawn, conducting 5-min strip transects (100 m × 30 m) at each sub-site. Each site was surveyed for reptiles on six occasions (2 times a year, in Spring and Summer) between 2001 and 2003, searching a 1 ha area in each sub-site using 25-min active searches (i.e. overturning rocks, searching vertical substrates and raking leaf litter). At each sub-site, 20-min nocturnal mammal surveys were conducted along a 100 m × 30 m transect in Summer 2002 and Spring 2003. Small ground mammals were surveyed using baited Elliott traps (33 × 10 × 9 cm) with an effort of 90 trap nights (30 traps: 3 per sub-site × 3 nights). Larger ground mammals were recorded opportunistically, as encountered during bird and reptile surveys. Each site was surveyed for frogs on three occasions between 2002 and 2003 following rainfall events. At each aquatic sub-site, 15-min spotlighting surveys were conducted along a 50 m × 20 m transect. To restrict variation due to weather, all sites were surveyed within 2 weeks in each sampling period.

2.2. *Abiotic environmental characteristics*

Terrestrial and aquatic habitat characteristics were measured at three scales: patch (individual vegetation patches), local (within the golf course boundary) and landscape (within a 5 km radius of the course boundary). In this study, 'patches' refer to discrete vegetation remnants, separated from other remnants by more than 20 m. While this distance is unlikely to be ecologically meaningful for all wildlife species, it is meaningful within the context of golf course management. None of the randomly selected patches were within 100 m of each other, thus reducing the potential for non-independence among patches. Patch scale data were measured from sites where fauna surveys were undertaken. Local and landscape data were measured from desktop analyses of rectified aerial photos in MapInfo GIS.

2.2.1. *Patch scale indices*

Patch-scale habitat complexity indices were measured at the 10 randomly selected aquatic and 10 randomly selected terrestrial patches on each golf course (coinciding with the locations where fauna surveys were conducted). An index of canopy openness, canopy gap fraction (CGF) was measured using methodology outlined in Zancola et al. (2000), from canopy photos taken at two randomly selected locations in each terrestrial and aquatic patch (i.e. 40 per golf course). Foliage height diversity (FHD) was measured at two random locations in each terrestrial patch using a 2.5 m × 0.3 m vertical profile board, divided into 50 cm height intervals. At each interval, the proportion covered by vegetation was assessed, observing the board from a distance of 10 m. The two measurements in each sub-site were pooled and used to calculate foliage height diversity using the Shannon-Weaver diversity equation.

Ground cover characteristics (i.e. the proportion of turfgrass and native grass cover, bare ground, woody debris and ground vegetation) were measured from rectified photos of a rectangular 0.9 m × 0.8 m ground cover quadrant, placed at 20 locations on each golf course (2 in each randomly located terrestrial patch). In each terrestrial patch, vegetation density measurements were recorded in a 30 m × 10 m quadrat, recording the number of trees, dead trees, logs, hollows and the circumference of trees (>5 cm) at chest-height (1.4 m). In each aquatic sub-site, the steepness of waterbody banks and bank height was measured at four points. The proportion of each waterbody occupied by floating, submerged and emergent vegetation was estimated, as was the proportion of bank fringed by reed-cover. Mean indices of habitat complexity were calculated for each golf course for use in the final analysis.

2.2.2. *Local scale indices*

The course area, area of vegetation, area of water, mean patch size, mean patch perimeter/area ratio (patch shape) and the area of vegetation connected within 20 m of each patch were calculated from polygons digitized from rectified aerial photos using MapInfo GIS software. The number of ephemeral ponds, permanent ponds and streams and the area of vegetation within 100 m of each waterbody were also recorded.

2.2.3. *Landscape scale indices*

Landscape indices were measured from rectified aerial photographs (i.e. the proportion of vegetation cover in a 200 m, 500 m, 2 km and 5 km radius of each course boundary, the proportion of built land in a 1 km radius and the area of connected vegetation within a 200 m, 500 m, 2 km and 5 km radius). Landscape scale aquatic indices were also measured (i.e. area of water in a 200 m and 500 m radius and the number of streams connected within 200 m of each course).

2.3. *Data analysis*

Multiple regressions were used to test for associations between environmental variables and the site abundance and species richness of birds, reptiles, mammals and amphibians, urban-avoiding birds, reptiles, mammals and amphibians and the abundance of specific ecological groups that are likely to respond differently to environmental characteristics. These ecological groupings were based on bird feeding and nesting behavior, frog breeding site preferences and taxonomic groups of frogs, reptiles and mammals. Urban-avoiding species were identified previously (Hodgkison et al., Accepted for publication), based on their capacity to persist in suburbia. Species membership of different ecological groups was determined from reference material: birds (Wade, 1975; Frith, 1976; Bentley and Catterall, 1997), reptiles (Cogger, 1992), frogs (Cogger, 1992; Anstis, 2002) and mammals (Strahan, 1998). A two-stage procedure was used to ensure abiotic variables were independent and thereby overcome problems of collinearity that could potentially obscure biotic–abiotic associations. Stage 1 involved performing correlations among environmental variables to identify those that would be redundant due to collinearity. Among correlated variables ($r > 0.7$), the variable considered most ecologically meaningful was retained for analysis. Variance inflation (VIF) values were then calculated. This is a statistic used to measure independence among predictor variables in multiple regression. Myers (1986) suggests problems of multicollinearity arise if Variance inflation values exceed 10. We used a conservative approach, omitting variables with Variance inflation values greater than 8. A list of potentially explanatory variables was then obtained for each vertebrate group (Table 1). Straight multiple regressions were then performed, first separately in each scale (i.e. patch, local and landscape) and then with all scales combined. This enabled an assessment of the scale at which vertebrates respond to the landscape and then to determine which characteristic is most influential, regardless of scale. Multiple regressions

Table 1 – List of potentially explanatory variables included in final multiple regressions to assess environmental factors associated with the abundance and species richness of vertebrates on golf courses in south-east Queensland, Australia

Scale	Birds	Mammals	Reptiles	Frogs
Patch	% Native grass cover Foliage height diversity Canopy gap fraction Number of dead trees Number of hollows	% Native grass cover % Turfgrass cover Woody debris Number of dead trees Number of trees Number of hollows	Woody debris Canopy gap fraction % Turfgrass cover	% Floating vegetation % Turfgrass cover % Reed cover Mean bank angle
Local (golf course)	Area of vegetation Area of core vegetation Course connectivity Area of water	Area of vegetation Mean patch size Course connectivity	Area of vegetation Mean patch shape	Area of vegetation Number of ephemeral ponds Number of permanent ponds Area of vegetation in 100 m Area of water
Landscape	% Built land in 1 km Connectivity at 200 m % Vegetation in 200 m % Vegetation in 5 km	% Built land in 1 km Connectivity at 2 km Connectivity at 200 m % Vegetation in 200 m % Vegetation in 500 m	% Built land in 1 km Connectivity at 2 km Connectivity at 200 m % Vegetation in 200 m % Vegetation in 500 m	% Built land in 1 km Number of creeks connected % of Vegetation in 500 m % of Vegetation in 200 m

investigating factors influencing the abundance of different ecological groups were not conducted in each separate scale, given the large number of groups and the peripheral nature of these analyses.

3. Results

3.1. *Birds*

On average, golf courses supported 452 (SE = 25) birds from 114.9 species (SE = 8.4), including 54.9 individuals (SE = 15) from 29.1 (SE = 6.2) urban-avoiding species (Hodgkison et al., Accepted for publication). Bird abundance and species richness were associated with environmental variables measured at all three scales (Table 2). At the patch scale, bird species richness increased with increases in native grass cover and mean foliage height diversity (species richness). Bird abundance increased with native grass cover and the number of hollows. The relative abundance and species richness of birds increased with the area of vegetation. The abundance of urban-avoiding birds was positively associated with on-course vegetation connectivity. Bird abundance and species richness declined with increases in the proportion of adjacent built land (in 1 km) and increased with the area of vegetation connected within a 2 km radius. When all scales were combined, bird abundance increased with the area of vegetation and mean canopy gap fraction (Table 2). Bird species richness was negatively associated with the area of built land in a 1 km radius and positively associated with the area of on-course vegetation and mean foliage height diversity. The relative abundance of urban-avoiding birds increased with the area of vegetation on the course and decreased with the proportion of built land in a 1 km radius. Similarly, the species richness of urban-avoiding birds was positively associated with the area of vegetation and mean foliage height diversity and negatively associated with the proportion of built land within 1 km (Table 2).

The abundance of all bird groups increased with the area of native vegetation. Different bird groups did however respond to different environmental factors (Table 3). Hawk gleaners were also negatively associated with patch shape, the proportion of adjacent built land and the proportion of vegetation within a 200 m radius. High gleaners were negatively associated with the proportion of vegetation in 200 m. Pounce gleaners were positively associated with canopy gap fraction, the area of water on the course, on-course connectivity and negatively associated with the proportion of vegetation in 2 km. The abundance of understorey nesters and canopy nesters increased with foliage height diversity. The abundance of cleared land birds increased with the proportion of adjacent built land, the area of water and native grass cover (Table 3).

3.2. *Mammals*

On average, golf courses supported 13.5 (SE = 4.9) mammals from 5.4 species (SE = 0.7), including 8.7 individuals (SE = 4.9) from 2 (SE = 0.6) urban-avoiding species. While mammal abundance and species richness were low due to insufficient trapping effort, significant associations were nevertheless recorded at all three scales (Table 2). Mammal abundance and species richness responded to patch-scale environmental variables, increasing with increases in the number of hollows, native grass cover, mean canopy gap fraction and mean tree density and decreasing with increasing turfgrass cover. Mammal abundance and species richness increased with increasing mean patch size, on-course connectivity and the area of water on the course. Landscape-scale factors had little influence on total mammal abundance, but were closely associated with species richness and the relative abundance and species richness of urban-avoiding mammals. These variables decreased with increases in the proportion of built land in 1 km and increased with increases in the area of vegetation in 2 km. When all scales were combined, mammal abundance was positively associated with native grass cover, the number of hollows and mean tree density. Mammal species richness increased with increasing tree density, the number of hollows and the area of vegetation connected within a 2 km radius. The abundance of urban-avoiding mammals increased with increasing tree density and mean patch size and decreased with increasing turfgrass cover. Urban-avoiding mammal species richness increased with increasing tree density and patch size (Table 2).

Different mammal groups responded to different environmental characteristics (Table 3). The abundance of urban-exploiting arboreal mammals increased with the number of hollows and the proportion of adjacent built land and decreased with on-course connectivity, the area of water and the proportion of vegetation within 5 km. Golf courses that supported high macropod densities generally had large patches, high tree density, areas of open canopy and high vegetation cover within 2 km (Table 3). While the abundance of urban-avoiding and urban-exploiting small ground mammals were both positively associated with native grass cover and negatively associated with turfgrass cover, other factors distinguished between the abundance of the two groups. Urban-avoiding small mammals were generally more abundant on golf courses with high levels of canopy cover and vegetation cover within the adjacent 200 m. In contrast, urban-exploiting rodents were more abundant on golf courses with small patch sizes and a high level of adjacent built land.

3.3. *Reptiles*

On average, golf courses supported 87.8 (SE = 12.8) reptiles from 16.8 species (SE = 1.3), including 6.6 individuals (SE = 1) from 5 (SE = 0.8) urban-avoiding species (Hodgkison et al., Accepted for publication). Reptile abundance and species richness were more strongly associated with patch-scale variables than with local or landscape factors (Table 2). The relative abundance of all reptiles increased with the abundance of coarse woody debris and decreased with increasing mean canopy gap fraction. The abundance and species richness of urban-avoiding reptiles increased with the abundance of woody debris and decreased with increasing turfgrass cover. Local (golf course-scale) factors that were positively associated with the relative abundance and species richness of urban-avoiding reptiles were the area of vegetation and water on the course and mean patch perimeter/area ratio (i.e. patch shape). Landscape factors were weakly associated with reptile abundance and species richness. Abundance and species

Table 2 – Environmental factors associated with the abundance and species richness of vertebrates (all species and regionally urban-avoiding species) on golf courses in south-east Queensland

	All species		Urban-avoiding species	
	Abundance	Species richness	Abundance	Species richness
Birds				
Patch	Hollows (0.46) Native grass cover (0.68) $R^2 = 0.54$, $p = 0.001$	Native grass cover (0.38) FHD (0.63) $R^2 = 0.70$, $p < 0.0001$	Native grass cover (0.74) $R^2 = 0.55$, $p = 0.0002$	Native grass cover (0.44) FHD (0.47) $R^2 = 0.62$, $p = 0.0003$
Local (golf course)	Area of vegetation (0.80) $R^2 = 0.64$, $p < 0.0001$	Area of vegetation (0.71) $R^2 = 0.51$, $p = 0.0004$ $R^2 = 0.77$, $p < 0.0001$	Area of vegetation (0.75) Connectivity (0.36)	Area of vegetation (0.77) $R^2 = 0.60$, $p < 0.0001$
Landscape	Built land/1 km (–0.73) % Vegetation/2 km (–0.56) Con. Vegetation/2 km (0.34) $R^2 = 0.55$, $p = 0.005$	Built land/1 km (–0.72) % Vegetation/2 km (–0.51) Con. vegetation/2 km (0.55) $R^2 = 0.63$, $p = 0.001$	Built land/1 km (–0.71) % Vegetation/2 km (–0.40) Con. vegetation/2 km (0.40) $R^2 = 0.62$, $p = 0.001$	Built land/1 km (–0.69) $R^2 = 0.48$, $p = 0.001$
Combined	Area of vegetation (0.79) CGF (–0.48) $R^2 = 0.72$, $p < 0.0001$ $R^2 = 0.82$, $p < 0.0001$	Area of vegetation (0.53) Built land/1 km (–0.37) FHD (0.72)	Area of vegetation (0.79) Built land/1 km (–0.57) $R^2 = 0.82$, $p < 0.0001$ $R^2 = 0.90$, $p < 0.0001$	Area of vegetation (0.62) Built land/1 km (–0.38) FHD (0.58)
Mammals				
Patch	Tree density (0.46) Native grass cover (0.52) Hollows (0.52) $R^2 = 0.59$, $p = 0.002$	Tree density (0.36) Turfgrass cover (–0.70) CGF (0.54) $R^2 = 0.74$, $p < 0.0001$	Tree density (0.53) Native grass cover (0.42) $R^2 = 0.51$, $p = 0.002$	Hollows (0.25) Native grass cover (0.60) $R^2 = 0.40$, $p = 0.01$
Local (golf course)	Connectivity (0.56) Patch size (0.28) Area of water (–0.44) $R^2 = 0.58$, $p = 0.003$	Connectivity (0.67) $R^2 = 0.45$, $p = 0.001$	Connectivity (0.64) Patch size (0.55) Area of water (–0.38) $R^2 = 0.76$, $p < 0.0001$	Connectivity (0.41) Patch size (0.63) $R^2 = 0.72$, $p < 0.0001$
Landscape	Built land/1 km (–0.43) Con. vegetation/2 km (0.26) $R^2 = 0.34$, $p = 0.03$	Built land/1 km (–0.54) Con. vegetation/2 km (0.54) $R^2 = 0.57$, $p = 0.001$	Built land/1 km (–0.74) $R^2 = 0.54$, $p = 0.0002$	Built land/1 km (–0.71) Con. vegetation/2 km (0.32) $R^2 = 0.62$, $p < 0.0001$
Combined	Tree density (0.46) Hollows (0.52) Native grass cover (0.52) $R^2 = 0.59$, $p = 0.002$	Tree density (0.71) Hollows (0.37) Con. vegetation/2 km (0.60) $R^2 = 0.714$, $p = 0.0001$	Tree density (0.79) Patch size (0.85) Turfgrass cover (–0.57) $R^2 = 0.85$, $p < 0.0001$	Tree density (0.45) Patch size (0.80) $R^2 = 0.73$, $p < 0.0001$
Reptiles				
Patch	CGF (–0.72) Woody Debris (0.75) $R^2 = 0.66$, $p = 0.0001$	Turfgrass cover (–0.56) $R^2 = 0.32$, $p = 0.01$	Turfgrass cover (–0.63) Woody Debris (0.52) $R^2 = 0.49$, $p = 0.003$	Turfgrass cover (–0.65) Woody Debris (0.43) $R^2 = 0.49$, $p = 0.003$
Local (golf course)	Patch size (0.42) Connectivity (–0.44) $R^2 = 0.21$, $p = 0.1$	Area of water (–0.22) Area of vegetation (0.20) Patch size (0.18) $R^2 = 0.28$, $p = 0.1$	Area of water (–0.36) Area of vegetation (0.52) Patch shape (–0.50) $R^2 = 0.46$, $p = 0.02$	Area of water (–0.21) Area of vegetation (0.56) $R^2 = 0.34$, $p = 0.04$
Landscape	% Vegetation/200 m (0.06) $R^2 = 0.003$, $p = 0.8$ $R^2 = 0.33$, $p = 0.03$	Built land/1 km (–0.25) % Vegetation/200 m (0.32) $R^2 = 0.39$, $p = 0.02$	Built land/1 km (–0.42) Con. vegetation/200 m (0.25) $R^2 = 0.35$, $p = 0.03$	Built land/1 km (–0.27) % Vegetation/200 m (0.32)
Combined	Woody debris (0.75) CGF (–0.72) $R^2 = 0.66$, $p = 0.0001$	Woody debris (0.35) % Vegetation/200 m (0.59) $R^2 = 0.37$, $p = 0.02$ $R^2 = 0.80$, $p < 0.0001$	Woody debris (0.80) % Vegetation/200 m (0.78) Patch shape (–0.78) $R^2 = 0.77$, $p < 0.0001$	Woody debris (0.75) % Vegetation/200 m (0.79) CGF (–0.76)
Amphibians				
Patch	Bank angle (–0.49) Turfgrass cover (–0.61) % Floating vegetation (0.69) $R^2 = 0.71$, $p = 0.0002$	Bank angle (–0.73) Turfgrass cover (–0.75) $R^2 = 0.73$, $p < 0.0001$	Bank angle (–0.51) Turfgrass cover (–0.60) $R^2 = 0.53$, $p = 0.002$	Bank angle (–0.73) Turfgrass cover (–0.75) $R^2 = 0.73$, $p < 0.0001$
Local (golf course)	Area of vegetation (0.74) Area Vegetation/100 m (–0.39) $R^2 = 0.56$, $p = 0.001$	Area of vegetation (0.61) Ephemeral ponds (0.57) $R^2 = 0.64$, $p < 0.0001$	Area of vegetation (0.74) Ephemeral ponds (0.62) $R^2 = 0.75$, $p < 0.0001$	Area of vegetation (0.61) Ephemeral ponds (0.57) $R^2 = 0.69$, $p < 0.0001$

Table 2 – continued

	All species		Urban-avoiding species	
	Abundance	Species richness	Abundance	Species richness
Landscape	Built land/1 km (−0.41) Creek connectivity (0.48) $R^2 = 0.51$, $p = 0.002$	Built land/1 km (−0.52) Creek connectivity (0.54) $R^2 = 0.62$, $p = 0.0002$	Built land/1 km (−0.65) $R^2 = 0.43$, $p = 0.002$	Built land/1 km (−0.52) Creek connectivity (0.54) $R^2 = 0.62$, $p = 0.0002$
Combined	Bank angle (−0.49) Turfgrass cover (−0.61) % Floating vegetation (0.69) $R^2 = 0.71$, $p = 0.0002$	Area of vegetation (0.44) Ephemeral ponds (0.57) Creek connectivity (0.51) $R^2 = 0.75$, $p < 0.0001$	Area of vegetation (0.74) Ephemeral ponds (0.62) $R^2 = 0.75$, $p < 0.0001$	Area of vegetation (0.44) Ephemeral ponds (0.57) Creek connectivity (0.51) $R^2 = 0.75$, $p < 0.0001$

Numbers in parentheses represent partial *r* values.
Con. vegetation/2 km = the area of vegetation connected to vegetation within a 2 km radius of the course boundary, CGF = Canopy gap fraction, FHD = foliage height diversity, % Vegetation/2 km = the proportion of vegetation cover within a 2 km radius.
CGF = canopy gap fraction, % vegetation/200 m = proportion of vegetation cover in a 200 m radius of course boundary, con. vegetation/200 m = area of vegetation connected to vegetation in a 200 m radius of course boundary, for amphibians: area vegetation/100 m = mean area of vegetation within 100 m of waterbodies, % floating vegetation = mean proportion of waterbodies covered by floating vegetation.

richness decreased with the proportion of built land in 1 km and increased with the proportion of vegetation in 200 m. When all scales were combined, reptile abundance was positively associated with the mean canopy gap fraction and the abundance of coarse woody debris. Reptile species richness increased with increases in the number of logs and the proportion of vegetation cover in 200 m. The abundance of urban-avoiding reptiles increased with increases in mean patch shape, the abundance of woody debris and the proportion of vegetation cover in 200 m. Urban-avoiding reptile spe-

Table 3 – Environmental variables associated with the relative site abundance of different wildlife groups on golf courses in south-east Queensland

Wildlife groups	R^2	Environmental variables associated with abundance
Birds		
Hawk gleaners	0.74	Built land (−0.75), area of veg (0.63), patch shape (0.60), % veg 200 m (−0.57)
High gleaners	0.48	Area of veg (0.68), % veg 200 m (−0.36)
Pounce gleaners	0.77	Area of veg (0.67), % veg 2 km (−0.56), CGF (0.52), area of water (0.35), Connectivity (0.29)
Undergrowth nesters	0.77	Area of veg (0.78), FHD (0.52)
Closed mid-storey nesters	0.74	Area of veg (0.86)
Canopy nesters	0.69	Area of veg (0.75), FHD (0.32)
Open mid-storey birds	0.45	CGF (−0.64), Turfgrass cover (0.42), area of veg (0.36), FHD (0.18)
Cleared land birds	0.5	Built land (0.68), area of water (0.56), native grass (0.47)
Reptiles		
Fossorial skinks	0.47	CGF (−0.60), Conn. Veg 200 m (0.49), area of veg (−0.44)
Urban-avoiding skinks	0.68	% Veg 200 m (0.70), woody debris (0.68), patch shape (−0.64)
Urban-exploiting skinks	0.67	woody debris (0.76), CGF (−0.54), patch shape (−0.37)
Snakes	0.74	Area of veg (0.69), built land (0.58), % veg 2 km (0.46), native grass (0.33)
Urban-exploiting Agamids	0.52	Built land (0.71), tree density (0.47), area of water (0.42), native grass (−0.34)
Varanids	0.8	% Veg 500 m (0.89), number of dead trees (0.48), area of water (−0.42), CGF (−0.41)
Mammals		
Urban-exploiting rodents	0.57	Native grass (0.57), CGF (0.52), turfgrass (−0.41), patch size (−0.40), built Land (0.35)
Urban-avoiding rodents	0.67	% Veg 200 m (0.62), CGF (0.49), turfgrass (−0.32), native grass (0.28)
Urban-exploiting arboreal	0.65	Hollows (0.77), connectivity (−0.64), water area (−0.63), Built land (0.59), % veg 5 km (−0.53)
Macropods	0.82	Patch size (0.83), CGF (0.65), Tree density (0.60), % Veg 5 km (−0.55), % veg 2 km (0.54)
Amphibians		
Ephemeral pond breeders	0.62	Number of ephemeral ponds (0.61), number of connected streams (0.57)
Urban-avoiding active foragers	0.54	Bank steepness (−0.66), floating vegetation (0.60), permanent ponds (−0.57), Ephemeral ponds (−0.36)
Threatened tree frogs	0.68	Turfgrass (−0.73), number of permanent ponds (0.52), CGF (0.45), bank steepness (−0.37)
Urban-exploiting tree frogs	0.62	Floating vegetation (0.57), Turfgrass (−0.55), area vegetation in 50 m (−0.46)
Cane toads	0.66	Built land (0.78), bank steepness (−0.69), reed cover (0.55), floating vegetation (0.50)

Numbers in parentheses represent partial *r* values.
FHD = foliage height diversity, cgf = canopy gap fraction, Area of veg = area of vegetation, % Veg 200 m = proportion of vegetation cover in a 200 m radius of course boundary, conn. veg 200 m = area of vegetation connected to vegetation in a 200 m radius of the course, floating vegetation = proportion of floating vegetation cover.

cies richness was positively associated with patch-scale and landscape factors (i.e. woody debris, mean canopy gap fraction and the proportion of vegetation cover in a 200 m radius; Table 2).

Different reptile groups responded to different environmental characteristics (Table 3). The abundance of fossorial reptiles decreased with canopy gap fraction and the area of native vegetation on the course and increased with the area of vegetation connected within 200 m. Urban-avoiding skinks were significantly more abundant on golf courses with a high proportion of vegetation cover within 200 m, a large amount of woody debris and rounded patches. The site abundance of urban-exploiting skinks also increased with woody debris, patch roundness and canopy gap fraction. Urban-exploiting Agamids increased in abundance with the proportion of adjacent built land, tree density and the area of water and decreased with native grass cover. Varanids were more abundant on golf courses with a high proportion of vegetation cover within 500 m, high tree density and a small area of water and high canopy cover (Table 3).

3.4. *Amphibians*

On average, golf courses supported 257.6 (SE = 28.4) amphibians from 4.9 species (SE = 0.6), including 16.7 individuals (SE = 8.5) from 1.4 (SE = 0.5) urban-avoiding species (Hodgkison et al., Accepted for publication). Amphibian abundance and species richness were associated with environmental variables measured at all three scales (Table 2). At the patch scale, amphibian abundance and species richness decreased with increasing waterbody bank steepness and turfgrass cover on banks. Amphibian abundance and species richness increased with the number of ephemeral ponds, the area of terrestrial vegetation and the area of native vegetation within 100 m of each waterbody. At the landscape scale, amphibian abundance and species richness increased with the number of connecting creeks and decreased with the proportion of built land in a 1 km radius. When all scales were combined amphibian abundance was negatively associated with mean bank steepness and the proportion of turfgrass cover on waterbody banks and positively associated with floating vegetation cover. Amphibian species richness decreased with bank steepness and turfgrass cover on waterbody banks. The abundance of urban-avoiding amphibians increased with the area of terrestrial vegetation and the number of ephemeral ponds. Urban-avoiding amphibian species richness increased with the area of native vegetation, the number of ephemeral ponds and the number of creeks connected to each golf course (Table 2).

Different amphibian groups responded to different environmental characteristics (Table 3). The abundance of ephemeral pond breeders increased with the number of ephemeral waterbodies and connecting streams. Urban-avoiding active foragers were more abundant on golf courses with a high proportion of floating vegetation, shallow banks and few permanent ponds. The site abundance of urban-avoiding tree frogs increased with canopy cover, the number of permanent ponds and decreased with turfgrass cover and waterbody bank steepness. The exotic cane toad (*Bufo marinus*) was most abundant on golf courses that have a high proportion of adjacent built land, reed cover, floating vegetation and shallow waterbody banks.

4. Discussion

Many landscape ecology studies have shown that wildlife abundance and species richness increases with the size, connectivity and structural complexity of habitat remnants (Forman and Godron, 1986; Collinge, 1996), thereby providing a framework for the design and management of conservation reserves. Importantly, this study has shown that many of the principles previously identified on relatively large landscape scales are also relevant to the ecological management of small urban land types. Small-scale landscape design and management actions that increase the size and structural complexity of vegetation on urban parks, gardens and golf courses can significantly enhance their capacity to provide refugial habitat for urban-avoiding birds, reptiles, mammals and amphibians. The results, therefore, support recent North American studies that have shown that local land management actions can increase bird diversity on golf courses (Jones et al., 2005; LeClerc and Cristol, 2005; Merola-Zwartjes and DeLong, 2005) and demonstrate that this also applies to other less mobile vertebrate groups (reptiles, mammals and amphibians) that have received less research attention. If designed and managed appropriately, golf courses (and presumably other urban green-space areas) could perform a positive wildlife conservation role in degraded urban landscapes. Ecological criteria should therefore be considered in the design and management of urban golf courses, parks and gardens.

4.1. *Local scale effects – the influence of golf course design*

Golf course architects have an important role to play in determining the habitat value of urban golf courses. The local abundance and species richness of birds, reptiles, mammals and frogs were significantly influenced by the size and spatial arrangement of terrestrial and aquatic habitats on golf courses. The principal factor associated with increased abundance and species richness of birds, mammals, amphibians and to a lesser extent, reptiles was the area of native terrestrial vegetation retained within the golf course boundary. Similar results were found in recent studies investigating the cause of variation in bird abundance and species richness among golf courses in the United States (Jones et al., 2005; LeClerc and Cristol, 2005; Merola-Zwartjes and DeLong, 2005). Golf courses that retain a large area of terrestrial vegetation are likely to have a greater diversity of microhabitats and incorporate areas of essential core habitat that are protected to some extent from edge effects. Both factors will tend to increase species richness. The association between amphibian species richness and terrestrial vegetation area was important, highlighting amphibian dependence on habitats beyond the breeding site. While amphibian conservation efforts often focus on the quality of aquatic habitats (Semlitsch, 2000), many adult frogs also utilize terrestrial feeding and sheltering sites (Dole and Durant, 1974; Harris, 1975) and therefore respond to terrestrial habitat characteristics including woodlot area (Marsh and Pearman, 1997; Knutson et al., 1999; Hazell et al., 2001), proximity to woodland (Laan and Verboom, 1990; Marsh and Pearman, 1997) and terrestrial habitat complexity (Dupuis et al., 1995; Maisonneuve and Rioux, 2001). Efforts to enhance amphibian diversity should not ignore the role played by terrestrial habitats.

The study also investigated whether the shape and spatial arrangement of habitats is relevant, or if high wildlife diversity can be achieved simply by retaining a sufficient area of habitat. Habitat configuration and connectivity are often critical determinants of biodiversity in fragmented landscapes (Verboom and Van Apeldoorn, 1990). These factors determine the intensity of edge-effects and the extent to which wildlife can continue normal foraging and dispersal movements, thereby allowing opportunities for periodic recolonization, gene exchange and ‘rescue-effects’ (Brown and Kodric-Brown, 1977; Fahrig and Merriam, 1994). Small-scale variations in habitat shape and connectivity (such as those induced by variations in golf course design) may however have negligible influence on wildlife diversity, particularly if wildlife can move freely across fairways. The results however, indicate that habitat shape and configuration do have some influence in determining wildlife abundance and species richness on golf courses. Reptiles in particular, responded to patch shape, with narrow linear remnants supporting significantly lower abundance and species richness than rounded remnants. The decline is likely to be due to the impact of edge-effects, which have been known to adversely affect reptile diversity (Gambold and Woinarski, 1993; Demaynadier and Hunter, 1998). On golf courses, edge-effects may be exacerbated, since the understorey of narrow patches is often cleared to allow play from the rough. This would reduce resource availability and increase exposure to predation and adverse environmental conditions. Habitat connectivity also had an impact, improving the association between landscape conditions and the abundance and species richness of urban-avoiding birds and mammals. Maximizing habitat connectivity on urban green-space areas will therefore increase their refuge value for urban-avoiding wildlife. Maximizing biodiversity on golf courses is therefore not simply a matter of maximizing the area of terrestrial vegetation. Innovative design strategies are required to maximize habitat connectivity and ensure vegetation patches are as wide and round as possible.

Wildlife abundance and species richness were also dependent on the diversity of habitat types available. In particular, the abundance and species richness of amphibians was influenced by the diversity of waterbody types. This association has been commonly observed in amphibian studies (Snodgrass et al., 2000; Hazell et al., 2003; Weyrauch and Grubb, 2004; Rubbo and Kiesecker, 2005) and is the result of species-specific breeding site preferences. Many amphibians are adapted to breed in certain waterbody types, having evolved specific strategies to overcome the inherent threats (i.e. predation and environmental stress) that are unique to those waterbodies (Wiggins et al., 1980; Wellborn et al., 1996; Weyrauch and Grubb, 2004). Amphibians are therefore vulnerable to landscape changes that alter local hydrology. Typically, urban and agricultural landscape changes result in a homogenization of waterbody types, as ephemeral and semi-permanent waterbodies are replaced by permanent ponds and dams (Hazell et al., 2003; Rubbo and Kiesecker, 2005). Similarly on golf courses, a tendency to construct only permanent ornamental ponds has meant that ephemeral and semi-permanent pond breeding amphibians are generally not accommodated. Golf courses that retain a mix of waterbody types tend to support higher amphibian species richness.

4.2. *Patch scale effects – the influence of golf course management*

The role that habitat structure plays in maintaining vertebrate abundance and species richness was of central importance to this study. While many golf courses have a limited capacity to increase the size of on-course habitats, most have greater freedom to alter management actions that affect habitat structural complexity. Many golf clubs have considered allowing rough and out-of-play areas to revert to a more natural state, given the economic benefits associated with reducing maintenance costs (Australian Golf Union, 1998; Smith, 1998). It was important to assess the ecological benefits that could be obtained by these actions. The results indicate that such efforts can significantly increase the local abundance and species richness of urban-avoiding vertebrates. Species richness and abundance were closely associated with habitat complexity, with different vertebrates responding to different structural features.

Bird abundance and species richness increased with foliage height diversity and the proportion of native grass cover. Similar findings have been observed in other bird studies (MacArthur and MacArthur, 1961; Willson, 1974; Lancaster and Rees, 1979). Bird species typically forage and nest at specific vegetation strata. Habitat remnants that have greater structural complexity can therefore support a greater diversity of bird species. On golf courses, as in other urban areas, there is a tendency to clear (or tidy) ground-level and understorey vegetation. This reduces the diversity of foraging and nesting habitats and increases exposure to predation, noise, disturbance and significantly, to competition with aggressive noisy miners (*Manorina melanocephala*). This species has been attributed to the local decline of many small insectivores from edge-affected Australian forests (Grey et al., 1997; French et al., 2005).

Reptile species richness increased with increases in the abundance of coarse woody debris and the level of canopy cover. Many studies have identified positive associations between reptile diversity and ground habitat complexity (Kitchener et al., 1980; Hadden and Westbrooke, 1996; MacNally and Brown, 2001). Many reptile species forage and shelter among logs and rotting wood (MacNally et al., 2001) and would therefore be disadvantaged by the clearance of understorey areas that occurs on some golf courses. The association between reptile species richness and canopy cover conflicts with the findings of forestry studies that have typically recorded high reptile diversity in clearings (Mushinsky, 1985; Greenberg, 2001). The high reptile counts observed in forestry clearings may however represent a localized response within closed forest. On golf courses and other urban green-space areas (where habitats are more intensively cleared), urban-avoiding reptiles are dependent on areas of closed forest.

Mammal abundance and species richness also responded to variations in habitat complexity, increasing with mean tree density, the proportion of turfgrass cover and the abundance of hollows. Other studies have found that mammal diversity increases with vegetation complexity (Lindenmayer et al., 1994; Catling and Burt, 1995; Maisonneuve and Rioux, 2001), and suggest this reflects an association between foliage volume and food availability (Rowston et al., 2002). In particular, the association between mammal abundance and turfgrass cover reflects the fact that irrigated grass represents a valuable food resource for macropods (the most abundant mammal group recorded in this study). The abundance of arboreal marsupials increased with the number of hollow-bearing trees. Hollows are a limiting factor for many arboreal mammals (Smith and Lindenmayer, 1988; Traill and Lill, 1997; Smith and Murray, 2003). Hollow-bearing trees should therefore be retained on green-space areas wherever safety issues permit.

Amphibians also responded to the structure of local waterbodies and aquatic habitat complexity. Golf courses in south-east Queensland predominantly contain ornamental ponds with steep concrete sides and banks vegetated with manicured turfgrass. These accommodate fewer frog species than natural waterbodies with shallow banks and adjacent reed cover. Waterbodies with steep banks are likely to be inaccessible to many species and those surrounded by turfgrass would have fewer predator refuges and calling sites. Other studies have produced similar results with amphibian diversity typically increasing with aquatic vegetation complexity (Vos and Chardon, 1998; Vallan, 2000; Hazell et al., 2001) and declining where terrestrial vegetation has been removed from areas surrounding waterbodies (Verrell, 1987; Raymond and Hardy, 1990).

4.3. *Landscape scale effects – the influence of urban planning*

While this study has shown that small-scale design and land management actions can increase the conservation value of habitats on urban golf courses, it also confirmed that these are not the only factors influencing local wildlife diversity. The local abundance and species richness of all vertebrates was affected by regional environmental factors including the area of adjacent native vegetation, built land and the number of connecting streams. In general, animals responded to the landscape at scales that were proportional to their dispersal abilities. Bird and mammal species richness increased with the proportion of vegetation cover in a 2 km radius and decreased with the proportion of built land in a 1 km radius. In contrast, reptile species richness was only weakly associated with the proportion of vegetation cover in a 200 m radius. Amphibian species richness increased with the number of connecting streams. Regional factors also influenced colonization by urban-adapted species. Urban-exploiting rodents, possums, reptiles and frogs were more abundant on golf courses that were surrounded by built land than those that were adjacent to native vegetation.

Many studies have found that local wildlife species richness is partly determined by remote environmental factors (Arnold and Weeldenburg, 1990; Gascon et al., 1999; Hostetler and Holling, 2000; Savard et al., 2000; Debinski et al., 2001; Donnelly and Marzluff, 2004). These factors determine rates of immigration and recolonization and the nature and intensity of external suppressive pressures. These in turn, affect local productivity and survivorship (Savard et al., 2000; Debinski et al., 2001). The associations with remote environmental factors observed in this study are therefore not unusual. They are nevertheless important, highlighting the fact that local wildlife diversity is determined by factors acting at multiple scales, and that maximizing biodiversity on urban parks, gardens and golf courses is not simply a matter of enhancing the size and complexity of local habitats. The regional location of any park, garden or golf course, relative to built land and existing habitat reserves will play an important role in determining its capacity to support regionally threatened vertebrates. In south-east Queensland, the distribution of golf courses is currently determined on an ad hoc basis, in response to individual development applications (Warnken et al., 2001). The results of this study suggest a strategic urban planning approach is required to coordinate regional off-reserve conservation opportunities on urban green-space areas.

Before this can be recommended, information is required on the reproductive value and local threats (i.e. predation, herbicide exposure) inherent on urban green-space areas. While recent studies have shown that some bird species can maintain high or only marginally reduced reproductive output on golf courses (LeClerc et al., 2005; Stanback and Seifert, 2005), reproductive success will vary among taxa. More research is required to assess productivity, threats and the long-term viability of populations on urban green-space areas. This will determine the potential risks and benefits associated with connecting potentially sub-optimal habitats on parks, gardens and golf courses to more productive habitats. Regardless, this study demonstrates that golf courses and other green-space areas can provide refuge to species that are disappearing from urban areas and that their local densities can be enhanced through small-scale conservation actions that increase the size and structural complexity of native habitat remnants.

Acknowledgements

We thank all golf clubs that participated in this study. Thanks also to M. Arthur and C. Wild for statistical advice and M. Van Sluys, G. Castley, D. Saunders, M. Hostetler and an anonymous reviewer for providing comments on drafts. This research was conducted on Queensland Parks and Wildlife Services Scientific Purposes Permit no. WISP01260903 and Griffith University Ethics permit number EAS/04/03/aec and was funded by a Griffith University Postgraduate Research Scholarship.

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