

# The conservation value of suburban golf courses in a rapidly urbanising region of Australia

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## Abstract

The conservation value of suburban golf courses was assessed in southeast Queensland, Australia, by investigating their capacity to support urban-threatened birds, mammals, reptiles and frogs. Terrestrial vertebrate assemblages were compared between golf courses and nearby eucalypt fragments and with suburban bird assemblages. Biotic diversity varied among golf courses. While some had conservation value (supporting high densities of regionally threatened vertebrates), most failed to realise that potential, supporting only common urban-adapted species. Golf courses were generally a better refuge for threatened birds and mammals than for threatened reptiles and amphibians. Reasons for the relative absence of threatened herpetofauna are currently unclear but could be attributed to increased sensitivity to isolation, exposure to herbicides or greater disruption of ground-level habitats. While species-specific studies are required to identify the ecological role played by habitats on golf courses and the potential for long-term viability, the results confirm that suburban golf courses can have local conservation value for threatened vertebrates. Given their ubiquity, golf courses present a significant opportunity for urban wildlife conservation. Thus while the golf industry is making genuine attempts to improve its environmental management standards, it is important to ensure those efforts target the needs of regionally threatened species. Legislation may be required to ensure ecological criteria are incorporated in new golf developments. Ongoing research is investigating the effect that golf course design and management practices have on the local diversity of threatened vertebrates.

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## 1. Introduction

Urban wildlife conservation requires a flexible approach that takes advantage of all opportunities to retain habitat, combining conservation efforts both in formal habitat reserves and in off-reserve habitats (Franklin, 1993; Freeman, 1999). In this context the ecological value of habitats retained on private land and in public ‘open-space’ areas such as urban parks, gardens and ‘greenways’ has been investigated (Adams et al., 1985; Franklin, 1993; Searns, 1995; Linehan et al., 1995; Greenway and Simpson, 1996; Sodhi et al., 1999). The ecological value of one of the most ubiquitous open-space urban land types (the suburban golf course) has however been largely ignored by ecologists (Pearce, 1993).

Golf courses have attracted strong criticism for their perceived heavy use of water, chemical herbicides and exotic ornamental vegetation, leading many ecologists to believe they have negligible value for wildlife (Pleuramom, 1992; Pearce, 1993; Warnken et al., 2001). Some urban planners have however suggested that well designed and managed golf courses could act as wildlife refuges within the context of degraded urban landscapes (Hawthorn, 1971; Wheeler, 1972; Maffei, 1978; Green and Marshall, 1987; Tatnall, 1995; Tietge, 1992). Speculation regarding the ecological value of suburban golf courses has intensified in recent decades in response to an increase in the rate of golf course construction, which has seen golf courses built at a rate of more than one per day in the USA and one per week in the UK throughout the 1980s (Chen, 1991; Pearce, 1993; Warnken et al., 2001). Golf courses account for a growing proportion of the urban land area and will therefore have a significant impact on urban biota.

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Studies have suggested golf courses have conservation value simply because they support high species diversity (Maffei, 1978; Green and Marshall, 1987; Moul and Elliott, 1994). The use of diversity indices as a measure of habitat value has however been widely criticised because it provides no information on the conservation status or ecological significance of individual species (Alatalo, 1981; Margules and Usher, 1981; Walker, 1992; Rossi and Kuitunen, 1996). The concept of 'representativeness' (i.e. the capacity to retain species that are declining at some spatial scale) is believed to reflect more adequately the motivation behind conservation efforts (Austin and Margules, 1984) and should act as a basis for assessing conservation value on urban land types (Margules and Nicholls, 1987; Huxel and Hastings, 1999).

Three US-based studies have demonstrated that golf courses have a capacity to provide habitat for regionally threatened birds (Terman, 1997; Blair, 2001; Hostetler and Knowles-Yanez, 2003). The extent to which golf courses accommodate less mobile ground-based fauna is however uncertain. The relative isolation of many golf courses may limit the capacity for ground-based fauna to colonise or persist on golf courses. An assessment of the relative ecological value of suburban golf courses that contrasts the level of utilisation by a range of vertebrates would help define the possible ecological role that could be played by small urban habitat remnants.

This study investigates the extent to which regionally threatened birds, reptiles, mammals and amphibians utilise habitats on suburban eucalypt-based golf courses in southeast Queensland, Australia. This region, (which includes the Gold Coast, Sunshine Coast and Brisbane) is characterised by rapid (approximately 1000 people/week) urban population growth (Graymore et al., 2002) and high natural species diversity, supporting 26% of Australia's vertebrate species (Australian Rainforest Conservation Society, 1999). Lowland areas of southeast Queensland have been extensively cleared and face pressure from ongoing housing development (Catterall and Kingston, 1993). All opportunities to retain lowland habitat must be considered in southeast Queensland (Catterall and Kingston, 1993). In this context, the contribution of marginal land types and open-space areas may be important. Golf courses are a prominent 'open-space' land type in southeast Queensland. The region is currently home to more than 130 18-hole golf courses and planning approval has been granted for another 39 on the Gold Coast alone (Warnken et al., 2001). Many of these retain small pockets of lowland eucalypt and melaleuca vegetation. This study investigates their value as conservation areas by comparing vertebrate wildlife assemblages on eucalypt-based golf courses with those in residential areas and in nearby eucalypt forest remnants. Specifically, this study aims to determine whether suburban golf courses can support not only high vertebrate species richness, but whether they have the capacity to act as a refuge for species that are regionally threatened by urbanisation. The study also investigates whether suburban golf courses are a better refuge for mobile threatened vertebrates (i.e. birds) than for ground-based fauna (e.g. reptiles, mammals and amphibians) that may have more restricted mobility.

## 2. Methods

### 2.1. Site and sub-site selection

Forty sites were surveyed for birds, reptiles, mammals and amphibians between August 2001 and March 2004. Sites included twenty eucalypt-based golf courses, 10 residential areas and 10 eucalypt fragments, all located on the Gold Coast and Brisbane. A stratified random sampling strategy was used to select sites, randomly selecting sites meeting certain control criteria. All sites had been established (in their current structural state) for at least 20 years and occurred in relatively flat, lowland areas with predominantly eucalypt vegetation (unburnt for at least 10 years). Wherever possible, eucalypt fragments were comparable in size to golf courses (60–100 ha), however some larger fragments (200–1000 ha) were included. Regional variations in species diversity were also controlled by selecting sites in regionally-paired groups (one golf course, suburb and eucalypt forest), all within a 3 km radius. Ten unpaired golf courses were also surveyed to increase the sample size and assess variation in terrestrial biotic diversity among golf courses (Table 1). At each site, fauna surveys were conducted at 10 terrestrial and 10 aquatic sub-sites. Forest sub-sites were randomly selected from a stratified grid overlaid onto rectified aerial images of each site. On golf courses and suburban sites, terrestrial sub-sites were selected using a stratified random sampling strategy; randomly selecting sub-sites located in rough and out-of-play areas (on golf courses) and in parks and front yards (in suburban areas). Aquatic sub-sites were randomly selected from a list of all waterbodies on each golf course and eucalypt forest site.

### 2.2. Fauna surveys

Fauna surveys conducted in this study represent those that could be readily undertaken without extensive public consultation. All faunal groups (birds, reptiles, mammals and amphibians) were surveyed in eucalypt forests and on golf courses (with the permission of golf club management). Residential areas were however surveyed for birds only, given the difficulty of readily gaining access to a sufficient number of residential properties to adequately sample reptiles, amphibians and mammals in suburbia. All sites were surveyed for birds on six occasions, in summer (2), autumn (1), winter (1) and spring (2) between 2001 and 2003. Bird surveys were conducted on mornings without rainfall, within 3.5 h of dawn. Each terrestrial and aquatic sub-site was surveyed for birds along a 100 m × 30 m strip transect, recording the number of birds seen or heard 15 m either side of the observer within a 5 min period. Birds were surveyed at close range (<15 m) to minimise the potential for among-site differences in detectability. Surveys commenced after a 5 min settling period and did not count birds in flight. Reptiles were surveyed on six occasions (in spring and summer) at each golf course and eucalypt fragment between 2001 and 2004. At each sub-site, a 1 ha (ha) area was surveyed for 25 min using active search techniques. Five minutes was spent in each of the following activities: (1) overturning rocks and logs (2) searching vertical substrates and (3) raking soil and leaf litter

Table 1  
List of sites

Golf	Eucalypt forest	Suburb
<b>Brisbane</b>		
Keperra country club (91 ha)	Brisbane Forest Park F1 (731 ha)	Keperra/Ferny Hills S2
Wynnum golf club (32 ha)	Seven Hills Conservation Park F4 (60 ha)	Wynnum: S5
Redland Bay golf club (51 ha)	Fragment: lat: -27.64, long: 153.28: F2 (892 ha)	Redland Bay S3
The Pacific golf club (57 ha)	Whites Hill Conservation Park F3 (125 ha)	Carindale: S4
California Creek golf club (22 ha)	Venman State Forest F10 (442 ha)	Cornubia/Loganholme S1
Oxley golf club (63 ha)		
Gailes golf club (54 ha)		
McLeods golf club (51 ha)		
St Lucia golf links (50 ha)		
Virginia golf club (70 ha)		
<b>Gold coast</b>		
The Grand golf club (181 ha)	Nerang State Forest west: F7 (800 ha)	Worongary: S7
Parkwood international golf club (56 ha)	Fragment: lat: -27.95, long: 153.38: F8 (65 ha)	Parkwood: S9
Gold Coast-Burleigh golf club (52 ha)	Clagiraba State Forest F5 (307 ha)	Miami/Burleigh Waters S6
Helensvale golf club (49 ha)	Coombah Conservation Park F6 (40 ha)	Helensvale: S8
Southport golf club (48 ha)	Nerang State Forest east: F9 (865 ha)	Southport: S10
Gainsborough Greens golf club (187 ha)		
Surfers Paradise golf club (44 ha)		
Robina Woods golf club (84 ha)		
Tweed Heads-Coolangatta golf club (94 ha)		
Gold Coast country club (68 ha)		

Area of golf courses and eucalypt forests shown in hectares, site codes shown for eucalypt forests (F1-10) and suburban areas (S1-10). Golf course site codes (G1-20) withheld to ensure confidentiality of results (as requested by some clubs).

(in sunny conditions in mid-morning and mid-late afternoon), (4) searching for basking reptiles (in the heat of the day) and (5) searching for nocturnal snakes (at night). Gekkonids and freshwater turtles were not surveyed. Mammals were surveyed on golf courses and eucalypt forests using a combination of nocturnal surveys (using handheld spotlights), Elliott trapping and opportunistic diurnal surveys. Twenty-minute nocturnal visual surveys were conducted along a 100 m × 30 m transect at each sub-site in summer 2002 and spring 2003. Each site was also surveyed for small ground mammals using baited Aluminium Elliott traps (33 cm × 10 cm × 9 cm) with an effort of 90 trap nights (30 traps: 3 per sub-site × 3 nights). Nocturnal visual and trapping surveys were conducted on clear nights with less than a half moon. Larger ground mammals were recorded opportunistically, as encountered while conducting bird and reptile surveys. Bats (Microchiroptera and Megachiroptera) and mid-size nocturnal ground mammals (e.g. bandicoots) were not surveyed. Amphibians were surveyed on three occasions (summer 2002, spring 2003 and summer 2003) following rainfall events at each golf course and eucalypt fragment. At each sub-site, amphibians were surveyed for 15 min along a 50 m × 20 m transect. Frogs were detected by eyeshine using a PEZL headlamp. All sites were surveyed within 2 weeks in any season to minimise environmental variation. Another three survey seasons were abandoned due to variation in rainfall among sites.

### 2.3. Data analysis

Species diversity indices (relative site abundance and species richness) were recorded at each site. In this study, the relative site

abundance values do not represent true population abundance, rather a relative index of local density. While raw counts such as these can be vulnerable to among-site differences in detectability, this potential was minimised by employing conservative search techniques, (sampling individuals at close range) and thereby reducing the potential for sampling bias due to differences in habitat complexity. This possibility was further reduced given the fact that golf courses were surveyed in rough and out-of-play areas, in areas typically covered with open woodland vegetation, similar to that found in larger eucalypt remnants. Species richness estimates were calculated using the non-parametric Bootstrap estimation method (Smith and van Belle, 1984) in the EstimateS program (Colwell, 2005). Like most non-parametric estimation techniques, the Bootstrap method predicts total species richness (including species missed) based on the rate of encountering rare individuals. The Bootstrap method was chosen a priori based on reliable performance in simulated studies (Walther and Morand, 1998). Once obtained, relative abundance and species richness estimates were compared among land types using t-tests (for reptiles, mammals and amphibians) and one-way ANOVA's with Tukey's HSD (for birds). The relative site abundances of individual species were also compared among land types, using the cumulative raw counts (for bird, reptile and mammal species) and the maximum relative abundance recorded in any one survey (for amphibians). By comparing amphibian counts under optimal conditions, the potential for variation due to environmental conditions (which can be problematic in short-term amphibian surveys) was reduced. Relative site abundances were compared using Kruskal–Wallis ANOVA (for birds) and Mann–Whitney *U*-tests (for reptiles, mammals and amphibians). Non-parametric methods were used

due to a lack of homogeneity in the variance of some species counts.

For each vertebrate group, species assemblages were compared among land types using semi-strong, hybrid multidimensional scaling ordination (Belbin, 1992) based on Bray Curtis dissimilarity measures (Bray and Curtis, 1957). These were calculated from data matrices that were range-standardised within sites to provide an index of the relative abundance of each species at each site. Rare species (found on fewer than five occasions) were omitted from the analysis. A number of common species were dominant and therefore potentially obscured among-site variation in the relative abundance of less abundant species. Data were therefore fourth root transformed to ensure all species contributed to the analysis. In each ordination, stress was managed by adjusting the cut-point between metric and non-metric multidimensional scaling. Principal axis correlation (Belbin, 1996) was used to identify species that contributed to among-site differences. These species were plotted as vectors on the ordination axes and significance levels assessed using Monte-Carlo randomisation (Belbin, 1996). Analysis of similarities (ANOSIM, Belbin, 1996) was used to test for differences in assemblage composition among land types. SIMPER analyses (Carr, 1996) were used to identify variables associated with significant differences among land types. Correlation analyses (Zar, 1996) were also used to test for associations between ordination axes and individual species abundances.

To assess the capacity for golf courses to act as a refuge for threatened wildlife, it was necessary to identify species that are dependent on a source of refuge. All species were assigned to three groups based on categories proposed by Blair (1996): i.e. suburban 'exploiting', 'tolerating' and 'avoiding' species. Birds were categorised by comparing their abundance in eucalypt forests and in residential areas, using Mann–Whitney *U*-tests. Reptiles, mammals and amphibians could not be categorised in this way (given the lack of data for residential areas) and were therefore separated into suburban exploiters, tolerators and avoiders based on a mean ranking of the subjective opinion of six local wildlife biologists (i.e. Harry Hines from the Queensland Department of Natural Resources and Damian White, Jean-Marc Hero, Luke Shoo, Naomi Doak and Simon Hodgkison from Griffith University). Survey participants assigned each species a value from 1 to 5 (where 1 = suburban exploiting, 2 = exploiting/tolerating, 3 = tolerating, 4 = tolerating/avoiding and 5 = suburban avoiding). Respondents only rated species with which they had previous field experience. The combined site abundance of likely suburban avoiding species was then calculated and compared among land types using Mann–Whitney *U*-tests.

### 3. Results

#### 3.1. Comparing biodiversity estimates

Sixteen thousand five hundred and eighty five birds from 138 species were recorded in all land types. Golf courses supported significantly higher bird species richness ( $\bar{x} = 53.2$ ) than suburban areas ( $\bar{x} = 33.4$ ,  $p < 0.0001$ ) and a significantly higher

relative abundance of birds ( $\bar{x} = 452$ ) than both residential areas ( $\bar{x} = 361$ ,  $p = 0.03$ ) and eucalypt forests ( $\bar{x} = 337$ ,  $p = 0.006$ ; Fig. 1). Bird species richness was comparable on golf courses ( $\bar{x} = 53.2$ ) and eucalypt forests ( $\bar{x} = 48.0$ ). Golf courses supported a significantly higher relative abundance and species richness of wetland birds than residential areas and eucalypt forests. There was no significant difference in terrestrial bird relative abundance among land types. Terrestrial bird species richness was however higher in eucalypt forest ( $\bar{x} = 47.9$ ) than in residential areas ( $\bar{x} = 32.0$ ,  $p = 0.003$ ) and on golf courses ( $\bar{x} = 38.5$ ,  $p = 0.049$ ). A total of 2 538 reptiles from 29 reptile species were recorded on golf courses and eucalypt forest fragments. While there was no significant difference in the relative abundance of reptiles between golf courses and eucalypt fragments (Fig. 1), species richness was significantly higher in eucalypt forests ( $\bar{x}_{\text{euc}} = 11.5$ ,  $\bar{x}_{\text{golf}} = 7.1$ ,  $p = 0.0003$ ). Eight thousand seven hundred and seventy seven individuals from 21 amphibian species were observed on golf courses and in eucalypt forest. Both the relative abundance and species richness of amphibians were significantly higher in eucalypt forest ( $\bar{x}_{\text{Abund}} = 362.5$ ,  $\bar{x}_{\text{Spprich}} = 7.6$ ) than on golf courses ( $\bar{x}_{\text{Abund}} = 257.6$ ,  $p = 0.05$ ;  $\bar{x}_{\text{Spprich}} = 4.9$ ,  $p = 0.03$ ; Fig. 1). A total of 376 mammals from 17 species were observed on golf courses and in eucalypt forests. There was no significant difference in the relative abundance and species richness of mammals between golf courses and eucalypt fragments (Fig. 1).

#### 3.2. Local species relative abundances

Thirty species had significantly higher relative abundance in eucalypt remnants than on golf courses. These included 23 species of small insectivorous birds (Appendix A), five reptiles (*Carlia vivax*, *Lampropholis amicala*, *Ctenotus robustus*, *Ctenotus taeniolatus* and *Varanus varius*), three frogs (*Litoria gracilentia*, *Crinia signifera* and *Pseudophryne raveni*) and one mammal, (*Antechinus flavipes*; Appendix B). Thirty-two species (including 20 birds, six reptiles, three amphibians and three mammals) were found in comparable relative abundance on all land types (Appendices A and B). These are likely to be ecological generalists, tolerant of urbanisation. Another four mammals (*Rattus fuscipes*, *Phascolarctos cinereus*, *Macropus rufogriseus* and *Petaurus norfolcensis*) had comparable relative abundance on golf courses and in eucalypt forest, but are not expected to widely persist in residential areas of southeast Queensland (Appendix B).

Urban-adapted species that had significantly higher relative abundance on golf courses than in eucalypt forest included one bird species (*Cacatua roseicapilla*), one reptile (*Physignathus lesueurii*), two amphibians (*Litoria fallax* and *Bufo marinus*) and one introduced mammal (*Rattus rattus*). Eight other urban-adapted birds were relatively more abundant on both golf courses and residential areas than in eucalypt forests (Appendix A). Many other species were rarely encountered and were therefore not assessed due to a lack of statistical power (Appendices A and B). Most of these species are likely to be disadvantaged by urbanisation and were found only in eucalypt forests or in well-vegetated golf courses.

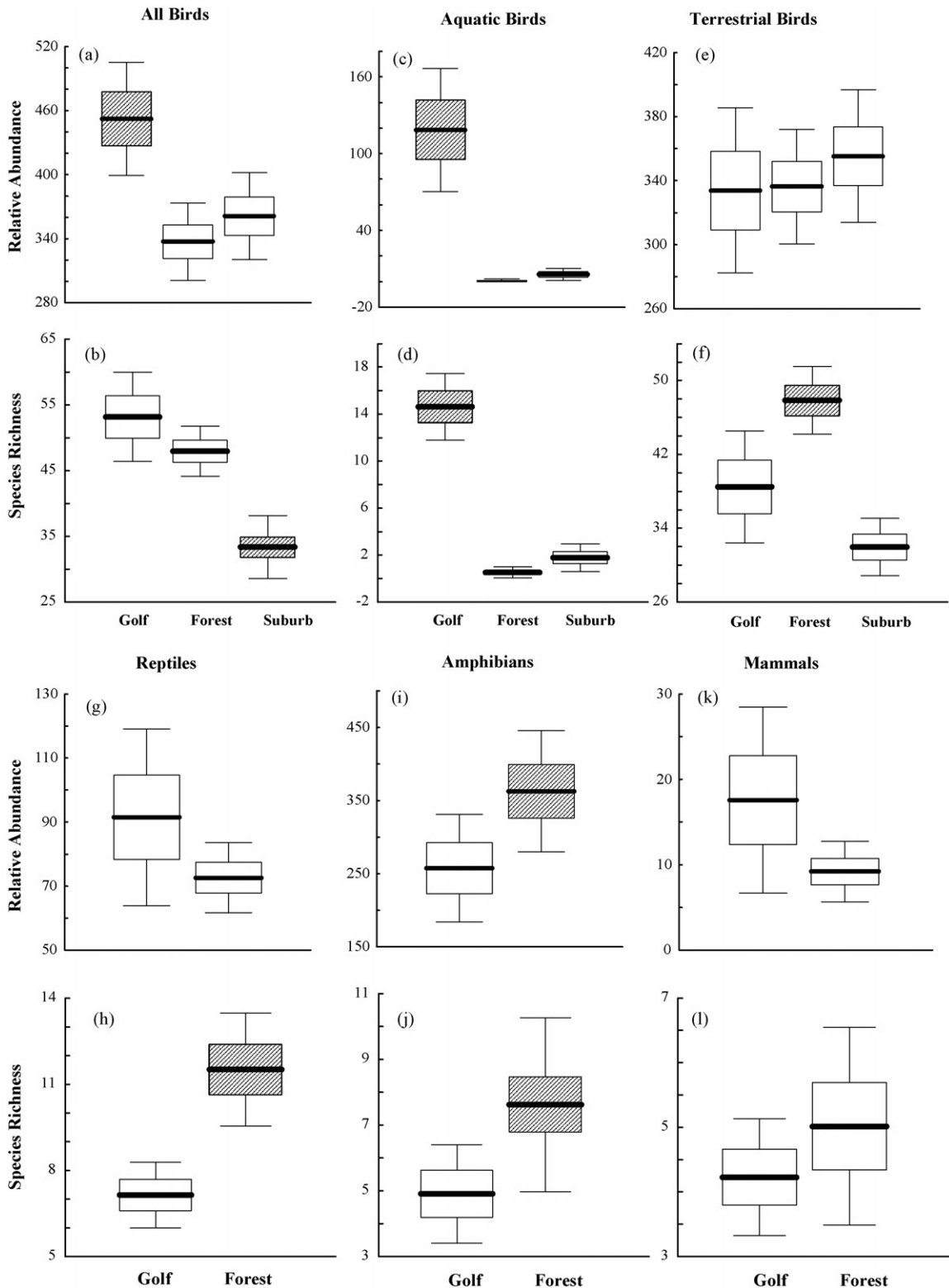


Fig. 1. Variation in abundance and species richness of all birds, aquatic birds, terrestrial birds, reptiles, amphibians and mammals among land types.  $n=20$  golf courses, 10 eucalypt fragments, 10 suburban areas; boxes = 1SE, mid-lines = means, whiskers = 95% CI, shaded boxes represent means that are significantly different. (Y-axes vary among vertebrate groups).

3.3. Species assemblages

Golf courses, suburban areas and eucalypt forests supported distinct bird species assemblages (ANOSIM, PATN

$p < 0.001$ ; PRIMER Global  $R = 0.67$ ,  $p = 0.001$ ; Fig. 2 (a)). Despite overlap in the bird assemblage on golf courses and suburban areas, the two were significantly different (ANOSIM: PRIMER,  $R = 0.42$ ,  $p = 0.001$ ). Suburban areas displayed less

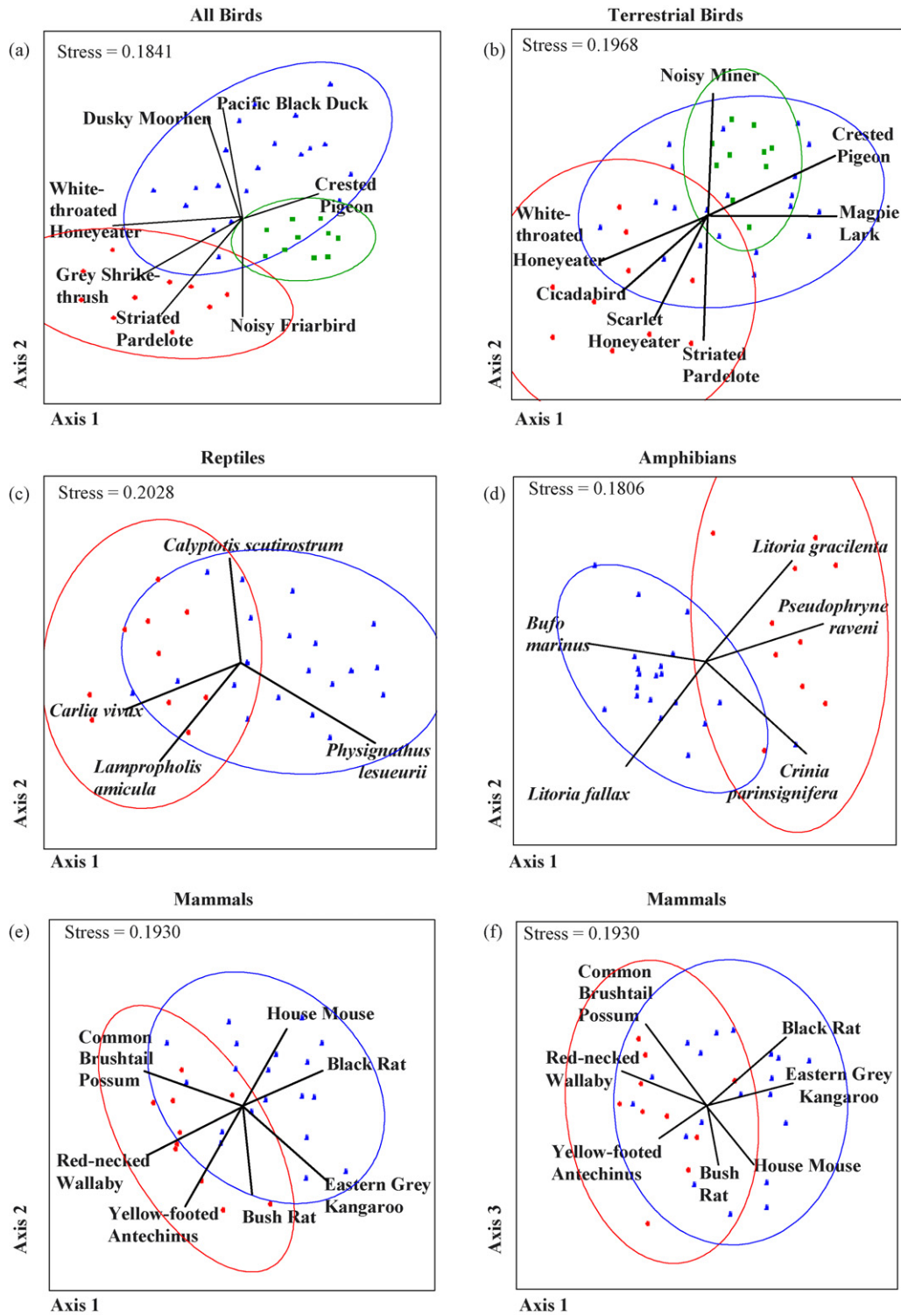


Fig. 2. Site ordinations of assemblage composition for each vertebrate group. (Golf courses = blue triangles, eucalypt forests = red circles and suburban sites = green squares; ellipses = 90% confidence intervals).

within variation than golf courses and eucalypt forests, indicating a higher level of homogenisation. Suburban bird assemblages shared 71% compositional similarity, compared to 63% within eucalypt forests and 57% within golf courses (SIMPER). The separation of sites was driven by species including

the dusky moorhen *Gallinula tenebrosa* ( $r=0.80$ ) and Pacific black duck (*Anas superciliosa*) ( $r=0.87$ ), which were relatively abundant on golf courses, and the white-throated honeyeater (*Meliphreptus albogularis*) ( $r=0.88$ ), grey shrike-thrush (*Coluricincla harmonica*) ( $r=0.89$ ), striated pardalote (*Pardalo-*

*tus striatus*) ( $r=0.79$ ), scarlet honeyeater (*Myzomela sanguinolenta*) ( $r=0.85$ ) and noisy friarbird (*Philemon corniculatus*) ( $r=0.75$ ), which were more abundant on eucalypt fragments (Fig. 2 (a)).

When aquatic species were removed from the ordination, there was greater overlap among land types (Fig. 2 (b)). Despite this, there were still significant differences in the terrestrial bird assemblage found in each land type (ANOSIM, PATN:  $p<0.0001$ , PRIMER Global  $R=0.53$ ,  $p=0.001$ ). Assemblages in eucalypt forests were well separated from those in suburbia ( $R=0.96$ ,  $p=0.001$ ) and golf courses ( $R=0.76$ ,  $p=0.001$ ). Assemblages on golf courses and residential areas were however, barely separable ( $R=0.14$ ,  $p=0.05$ ). Within variation was greatest for eucalypt fragments, intermediate for golf courses and most restricted for suburban areas, indicating increasing

homogenisation as land types become more urbanised. This was reflected in the SIMPER results. Suburban bird assemblages shared 72% compositional similarity, compared with 59% within golf courses and eucalypt forests. The separation of sites was driven by species including the white-throated honeyeater ( $r=0.89$ ), cicadabird (*Coracina tenuirostris*) ( $r=0.83$ ) and scarlet honeyeater ( $r=0.87$ ) which were more abundant in forests, the noisy miner (*Manorina melanocephala*) ( $r=0.87$ ) which was more abundant in suburbia and the crested pigeon (*Ocyphaps lophotes*) ( $r=0.79$ ) and magpie-lark (*Grallina cyanoleuca*) ( $r=0.83$ ) which were abundant on golf courses.

Reptile assemblages on golf courses and eucalypt fragments displayed considerable variation and overlap (Fig. 2 (c)). Reptile assemblages on golf courses were nevertheless, significantly different from those found in eucalypt forests (ANOSIM,

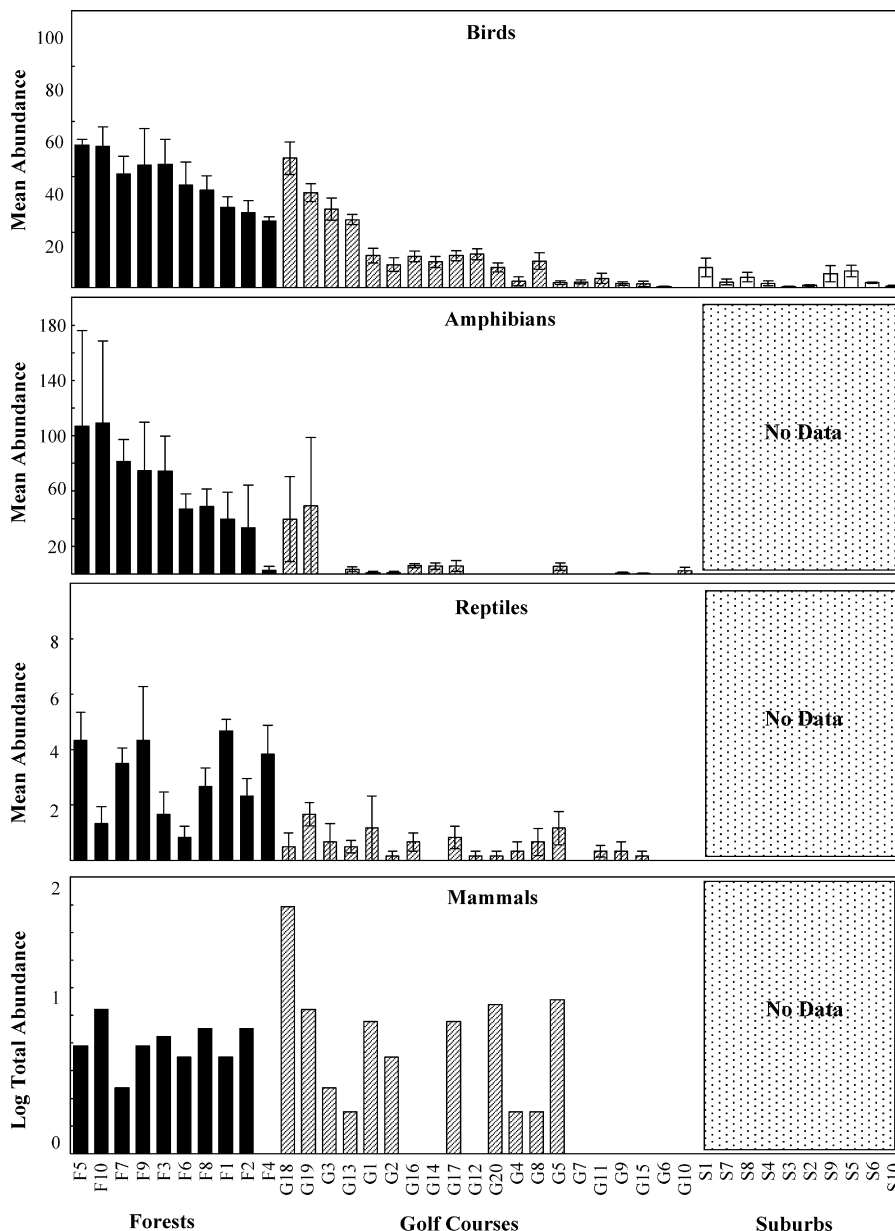


Fig. 3. Mean site abundance of regionally-threatened species. Black bars = forest fragments, shaded bars = golf courses, white bars = suburban areas. Whiskers = 1SE. Mammal data represents total cumulative abundance (from two spotlighting surveys and 90 Elliott trap nights per site).

PATN  $p < 0.0001$ ; PRIMER Global  $R = 0.46$ ,  $p = 0.001$ ). Variation within land types was comparable for both eucalypt fragments (SIMPER similarity = 65%) and golf courses (SIMPER similarity = 62%). Reptile species driving the separation of sites included the eastern water dragon, (*P. lesueurii*), (Principal axis correlation  $r = 0.94$ ) which was more abundant on golf courses and skinks including *C. vivax*, (Principal axis correlation  $r = 0.86$ ); *L. amacula*, (Principal axis correlation  $r = 0.76$ ) and *Calypotis scutirostrum* (Principal axis correlation  $r = 0.80$ ; Fig. 2 (c)) which were more abundant in eucalypt remnants. Reptiles correlated with ordination Axis 1 included the lace monitor (*V. varius*), ( $r = -0.68$ ,  $p < 0.0001$ ), *C. vivax*, ( $r = -0.83$ ,  $p < 0.0001$ ) and *P. lesueurii*, ( $r = 0.90$ ,  $p < 0.0001$ ). *C. scutirostrum*, ( $r = 0.79$ ,  $p < 0.0001$ ) was significantly correlated with ordination Axis 2.

Golf courses supported amphibian assemblages that were significantly different to those found in eucalypt fragments (ANOSIM—PATN  $p < 0.001$ , PRIMER Global  $R = 0.76$ ,  $p = 0.001$ ; Fig. 2 (d)). These differences were largely defined by ordination Axis 1, which separated sites (i.e. golf courses) with a relative abundance of *B. marinus* ( $r = -0.68$ ,  $p < 0.0001$ ) and *L. fallax* ( $r = -0.52$ ,  $p = 0.003$ ), from sites (i.e. eucalypt fragments) that had greater proportions of *P. raveni* ( $r = 0.87$ ,  $p < 0.0001$ ), *C. signifera* ( $r = 0.61$ ,  $p = 0.0003$ ), *L. gracilentia* ( $r = 0.53$ ,  $p = 0.002$ ) and *Crinia parinsignifera* ( $r = 0.52$ ,  $p = 0.003$ ; Fig. 2 (d)). In contrast, ordination Axis 2 largely defined within-land-type variation. Species significantly correlated with ordination Axis 2 included: (*L. gracilentia*,  $r = 0.51$ ,  $p = 0.004$ ; *L. fallax*,  $r = -0.78$ ,  $p < 0.0001$ ; *Crinia tinnula*,  $r = -0.41$ ,  $p = 0.02$  and *Litoria peronii*,  $r = -0.38$ ,  $p = 0.04$ ). Amphibian assemblages on golf courses were more predictable than those in eucalypt forests. Three species (*B. marinus*, *L. fallax* and *Limnodynastes peronii*) contributed 96.9% of the similarity in amphibian assemblage on golf courses. In contrast, six species including (*P. raveni*, *B. marinus*, *L. peronii*, *L. gracilentia*, *L. fallax* and *Crinia parinsignifera*) explained 90.7% of the similarity in amphibian species assemblages in eucalypt forests. There was very little overlap in the amphibian assemblage on golf courses and eucalypt forests. Only two of the twenty golf courses supported an amphibian assemblage comparable to those found in eucalypt forests.

Mammal assemblages varied substantially among sites. Three dimensions were therefore required to represent that variation spatially while maintaining acceptable stress levels. There was substantial overlap in mammal assemblage composition between golf courses and eucalypt fragments (Fig. 2 (e and f)). Mammal assemblages on golf courses and eucalypt fragments were nevertheless, significantly different (ANOSIM—PRIMER, Global  $R = 0.24$ ,  $p = 0.002$ ). Differences between the two land types were evident in the Axis 1–Axis 2 observation plane. Golf courses were distinguished from eucalypt forests by a relatively high abundance of the introduced rat, (*R. rattus*) (Principal axis correlation,  $r = 0.87$ ) and house mouse, (*Mus musculus*) (Principal axis correlation,  $r = 0.80$ ). Other species correlated with the ordination matrix (Principal axis correlation) included the common brushtail possum, (*Trichosurus vulpecula*) ( $r = 0.87$ ); eastern grey kangaroo, (*Macro-*

*pus giganteus*) ( $r = 0.72$ ); yellow-footed antechinus, (*A. flavipes*) ( $r = 0.62$ ) and bush rat, (*R. fuscipes*) ( $r = 0.61$ ).

### 3.4. Refuge value

As expected, eucalypt forests were a better source of refuge for regionally threatened birds than golf courses and suburban areas. Golf courses varied substantially in the extent to which they provide habitat for regionally threatened wildlife. Golf courses were generally a better refuge for birds and mammals than for reptiles and amphibians (Fig. 3). Threatened mammals were found in densities comparable to those in eucalypt forest on seven golf courses (G1,2,5,17,18,19,20). Four golf courses (G3,13,18,19) were a substantial refuge for regionally threatened birds, supporting a species richness of threatened birds comparable to that recorded in eucalypt forests. Only two courses (G18,19) were a refuge for threatened amphibians and three to four courses (G1,5,17,19) supported threatened reptiles in densities comparable to those found in low quality eucalypt remnants. Most golf courses had negligible refuge value, supporting primarily common urban-adapted species.

## 4. Discussion

Urban planners require information on the ecological value of all urban land types in order to provide an ecological basis for urban zoning decisions and development application assessments (Marzluff and Ewing, 2001). The results of this study indicate that urban planners would currently have little ability to predict the ecological value of golf courses, based simply on their land-use. As was found in an urban bird study in Phoenix, Arizona (Hostetler and Knowles-Yanez, 2003), species richness varied substantially among golf courses. Importantly, the results indicate that suburban golf courses can provide habitat for a range of regionally threatened vertebrates and therefore do have conservation potential. However, while some golf courses evidently have the capacity to act as a refuge for a range of threatened wildlife, most only support common urban-adapted species and therefore fail to realise that potential.

Wildlife assemblages on many golf courses and in residential areas were generally more homogenised than those in eucalypt fragments. Community-level homogenisation is typically observed in degraded landscapes and is caused when a limited number of persistent species (able to tolerate the modified conditions), occur in high local densities (Blair, 1996, 2001; McKinney and Lockwood, 1999). Bird assemblages on golf courses were generally less homogenised than those in suburbia and while reptile, mammal and amphibian assemblages were not directly compared between golf courses and eucalypt forests, the utilisation of golf courses by species rarely observed in suburban areas of southeast Queensland (e.g. koalas, macropods, gliders, lace monitors, forest-dwelling skinks and ephemeral pond-breeding amphibians), suggests golf courses can be a superior source of habitat to suburbia.

Like urban waste-water settling ponds (Greenway and Simpson, 1996) and storm-water mitigation areas (Adams et al., 1985; McGuckin and Brown, 1995), pond networks on sub-

urban golf courses appear to act as an urban refuge for wetland birds. The conservation value of these habitats could however, not be determined by comparison with eucalypt forests, since these are not a typical source of waterbird habitat. Wetland bird assemblages on golf courses were dominated by a suite of relatively urban-adapted species (e.g. the Eurasian coot (*Fulica atra*), dusky moorhen (*G. tenebrosa*), Pacific black duck (*A. superciliosa*), Australian wood duck (*Chenonetta jubata*) and purple swamphen (*Porphyrio porphyrio*)) and may therefore be more homogenised than assemblages in natural wetlands. Nevertheless, regionally uncommon species (e.g. the comb-crested jacana (*Jacana gallinacea*), black swan (*Cygnus atratus*), wandering whistling duck (*Dendrocygna arcuata*) and buff-banded rail (*Rallus philippensis*)) occurred (and some nested) on a number of golf courses, suggesting golf courses do have some conservation value for aquatic birds.

#### 4.1. Implications for new golf course construction

The results support previous studies that have stressed the need to use appropriate selection criteria when assessing ecological value (Margules and Usher, 1981; Margules and Nicholls, 1987) and consider the consequences of landscape change at more than one scale (Savard et al., 2000; Hazell et al., 2001). Some golf courses supported higher bird species richness than eucalypt forests. The replacement of eucalypt forest with a newly constructed golf course could therefore in some circumstances, lead to a local increase in bird species richness. However since most birds occurring on golf courses are regionally common and the majority found in eucalypt fragments are regionally rare or declining, it cannot be suggested that golf courses have higher conservation value than eucalypt fragments, or that the replacement of forest by golf courses would result in a positive ecological outcome. While the construction of a new golf course may result in increased species richness at a local level, it would inevitably contribute to reduced species richness on a regional scale. Urban land-use decisions must therefore look beyond local and immediate changes in species richness and consider the consequences at other spatial and temporal scales. Ultimately, the ecological consequences of any golf course construction will depend on the type of land that is lost to development. Any development that results in substantial loss of eucalypt forest will lead to the local decline of many regionally threatened species.

#### 4.2. Refuge-value of golf courses

Golf courses were however, not without ecological value. A small number of golf courses retained threatened suburban-avoiding wildlife. Threatened species found on golf courses included a range of small forest-dependent birds, three macropod species, three species of native rats, the koala, squirrel glider, yellow-footed antechinus and 14 forest-dependent reptile and amphibian species. The results confirm suggestions (Maffei, 1978; Tatnall, 1995; Tietge, 1992; Pearce, 1993; Terman, 1997; Dawson, 2000) that golf courses have the potential to act as a refuge for threatened wildlife. Golf courses that were a refuge for one vertebrate group were however not necessarily of value

to others. This was not unexpected, since animals are known to respond to different landscape elements, depending on their morphology, home range and behaviour (Wiens, 1989; Kotliar and Wiens, 1990).

Interestingly, golf courses were a better refuge for threatened birds and mammals than for threatened reptiles and amphibians. The relative failure of golf courses to support threatened herpetofauna could be attributed to a number of factors. Many amphibians and reptiles have limited mobility (Harris, 1975; Beshkov and Jameson, 1980; Sinsch, 1990; Ficetola and DeBernardi, 2004), and can therefore be particularly susceptible to the isolating effects of habitat fragmentation (Laan and Verboom, 1990; Wake, 1991; Sjögren, 1991; Blaustein et al., 1994; Marsh and Pearman, 1997). Many golf courses in southeast Queensland are isolated by suburbia. This may inhibit the capacity for some amphibians and reptiles to colonise, re-colonise or persist on isolated suburban golf courses. While large, ground-based mammals would also be susceptible to entrapment on isolated golf courses, they may have a greater capacity for short-term persistence, given their relative longevity (and thus reduced rate of population turnover). Alternatively, the relative absence of threatened herpetofauna from golf courses could be attributed to a difference in the extent to which their habitats have been compromised or to increased exposure to local threats (e.g. herbicides, predators). Further research assessing differences in vertebrate habitat quality and wildlife threats could explain the relative absence of threatened herpetofauna from golf courses in southeast Queensland.

#### 4.3. The ecological role of habitat on golf courses

While this study has demonstrated that suburban golf courses can provide refugial habitat for regionally threatened vertebrates, it could not provide information on the ecological role performed by these habitats. Habitats on golf courses will inevitably perform different ecological roles for different animals. A species-specific approach would therefore be required to define their precise ecological function. It is also important to recognise that the high densities observed on some golf courses are not necessarily an indication of local reproductive success (Van Horne, 1983; Vickery et al., 1992). Wildlife movements can redistribute animals throughout the landscape, thereby elevating species richness in sub-optimal habitats (Pulliam, 1988; Pulliam and Danielson, 1991; Dunning et al., 1992). High levels of species richness observed on some golf courses may therefore be to some extent, an artefact of historical or contextual influences. Population ecology studies, assessing local productivity and survivorship would help determine the long-term viability of wildlife populations on relatively isolated golf courses and determine whether golf courses should be actively connected to formal reserve networks, given the potential risks and benefits associated with connecting potentially sub-optimal (i.e. sinks) and optimal habitat (i.e. sources; Lidicker, 1975; Van Horne, 1983; Pulliam, 1988; Pulliam and Danielson, 1991; Delibes et al., 2001).

Although many questions remain, this paper has shown that golf courses are not too small to retain habitat that has conserva-

tion value for a range of regionally threatened vertebrates. Thus, while the golf industry is making genuine attempts to enhance the value of on-course habitats, it is important to ensure those efforts target the needs of threatened species, rather than simply supporting charismatic but otherwise common species (e.g. brushtail possums and rainbow lorikeets). The potential conservation value of suburban golf courses is made more significant by their current ubiquity and the paucity of urban conservation opportunities. It is therefore important to ensure that the conservation opportunities presented by golf courses are realised wherever possible. This will ultimately depend on the social and political processes governing urban land-use decisions and the design and management of new golf courses.

The current low conservation value of most existing golf courses reflects a traditional failure to recognise and thus protect the ecological contribution that can be made by smaller urban habitat remnants. Few golf courses in southeast Queensland (<1%) have been subjected to Environmental Impact Assessment (Warnken et al., 2001). Legislation may therefore be required to ensure ecological criteria are incorporated in new golf developments. Ongoing research is investigating reasons for the current high level of variation in threatened

species diversity among golf courses. This will establish the extent to which ecological enhancements can be made through improvements to golf course design and management.

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### Appendix A

A.1. Total abundance of terrestrial bird species (letters beside significance values indicate land type of highest abundance: G = golf, F = forest, S = suburb)

Land type		Suburb n = 10		Golf n = 20		Forest n = 10		p-Value	Response group
Species	Common Name	Total	Sites	Total	Sites	Total	Sites		
Terrestrial birds									
<i>Manorina melanocephala</i>	Noisy miner	524	10	1236	20	57	8	0.00006 GS	Suburban exploiting
<i>Streptopelia chinensis</i>	Spotted turtle-dove	393	10	123	17	23	5	0.00003 GS	Suburban exploiting
<i>Gymnorhina tibicen</i>	Australian magpie	183	10	228	20	103	10	0.028 S	Suburban exploiting
<i>Ocyphaps lophotes</i>	Crested pigeon	180	10	214	20	3	2	0.00002 GS	Suburban exploiting
<i>Grallina cyanoleuca</i>	Magpie-lark	180	10	185	20	23	7	0.00004 GS	Suburban exploiting
<i>Acridotheres tristis</i>	Common myna	105	10	112	16	4	1	0.00009 GS	Suburban exploiting
<i>Sphecotheres viridis</i>	Figbird	93	9	213	18	6	4	0.005 GS	Suburban exploiting
<i>Passer domesticus</i>	House sparrow	76	10	2	1	0	0	0.000001 S	Suburban exploiting
<i>Rhipidura leucophrys</i>	Willy wagtail	47	10	162	19	2	2	0.00006 GS	Suburban exploiting
<i>Entomyzon cyanotis</i>	Blue-faced honeyeater	32	8	4	3	0	0	0.0004 S	Suburban exploiting
<i>Sturnus vulgaris</i>	Common starling	31	3	0	0	0	0	0.04 S	Suburban exploiting
<i>Columba livia</i>	Feral pigeon	28	3	2	1	0	0	0.04 S	Suburban exploiting
<i>Hirundo neoxena</i>	Welcome swallow	8	5	60	12	0	0	0.002 GS	Suburban exploiting
<i>Trichoglossus haematodus</i>	Rainbow lorikeet	757	10	1383	20	522	10	NS	Suburban tolerating
<i>Trichoglossus chlorolepidotus</i>	Scaly-breasted lorikeet	109	8	359	15	118	8	NS	Suburban tolerating
<i>Corvus orru</i>	Torresian crow	183	10	342	19	217	9	NS	Suburban tolerating
<i>Cracticus nigrogularis</i>	Pied butcherbird	119	10	283	19	100	10	NS	Suburban tolerating
<i>Cracticus torquatus</i>	Grey butcherbird	79	10	204	18	76	9	NS	Suburban tolerating
<i>Lichmera indistincta</i>	Brown honeyeater	62	7	167	12	39	6	NS	Suburban tolerating
<i>Cacatua roseicapilla</i>	Galah	28	6	116	15	6	3	0.03 G	Suburban tolerating
<i>Cacatua sanguinea</i>	Little corella	9	5	106	10	3	1	NS	Suburban tolerating
<i>Zosterops lateralis</i>	Silveryeye	20	7	87	8	75	8	NS	Suburban tolerating
<i>Platyercus adscitus</i>	Pale-headed rosella	27	6	56	16	43	8	NS	Suburban tolerating
<i>Philemon corniculatus</i>	Noisy friarbird	53	10	50	10	76	10	0.003 S F	Suburban tolerating
<i>Cacatua galerita</i>	Sulphur crested cockatoo	7	5	48	10	10	3	NS	Suburban tolerating
<i>Caracina novaehollandiae</i>	Black-faced cuckoo-shrike	32	10	46	15	59	10	NS	Suburban tolerating
<i>Strepera graculina</i>	Pied currawong	42	6	37	9	54	8	NS	Suburban tolerating
<i>Geopelia humeralis</i>	Bar-shouldered dove	2	2	26	9	24	4	NS	Suburban tolerating
<i>Eudynamis scolopacea</i>	Common koel	5	4	24	12	3	2	NS	Suburban tolerating
<i>Anthochaera lunulata</i>	Little wattlebird	8	3	9	3	3	3	NS	Suburban tolerating
<i>Milvus sphenurus</i>	Whistling kite	2	1	9	4	5	5	NS	Suburban tolerating
<i>Malurus assimilis</i>	Variegated wren	3	1	53	9	45	5	NS	Suburban tolerating

## Appendix A (Continued)

Land type		Suburb <i>n</i> = 10		Golf <i>n</i> = 20		Forest <i>n</i> = 10		<i>p</i> -Value	Response group
Species	Common Name	Total	Sites	Total	Sites	Total	Sites		
<i>Psophodes olivaceus</i>	Eastern whipbird	3	2	50	9	43	5	NS	Suburban tolerating
<i>Myzomela sanguinolenta</i>	Scarlet honeyeater	7	4	47	6	210	9	0.0003 F	Suburban avoiding
<i>Colluricincla harmonica</i>	Grey shrike-thrush	7	3	62	10	138	10	0.00004 F	Suburban avoiding
<i>Pardalotus striatus</i>	Striated pardalote	48	9	88	15	138	10	0.0008 F	Suburban avoiding
<i>Rhipidura fuliginosa</i>	Grey fantail	4	2	39	3	110	9	0.00003 F	Suburban avoiding
<i>Melithreptus albigularis</i>	White-throated honeyeater	4	2	23	9	87	10	0.00002 F	Suburban avoiding
<i>Gerygone olivacea</i>	White-throated Gerygone	3	2	26	6	64	8	0.001 F	Suburban avoiding
<i>Cormobates leucophaea</i>	White-throated treecreeper	1	1	10	6	61	10	0.00002 F	Suburban avoiding
<i>Merops ornatus</i>	Rainbow bee-eater	2	2	18	4	58	8	0.001 F	Suburban avoiding
<i>Oriolus sagittatus</i>	Olive-backed oriole	16	6	67	15	57	10	0.008 F	Suburban avoiding
<i>Pachycephala rufiventris</i>	Rufous whistler	0	0	37	6	57	8	0.0005 F	Suburban avoiding
<i>Acanthiza reguloides</i>	Buff-rumped thornbill	0	0	0	0	46	3	0.04 F	Suburban avoiding
<i>Malurus melanocephalus</i>	Red-backed wren	0	0	18	4	45	7	0.001 F	Suburban avoiding
<i>Todiramphus sancta</i>	Sacred kingfisher	4	3	57	14	44	7	0.05 F	Suburban avoiding
<i>Malurus cyaneus</i>	Superb blue wren	0	0	110	11	44	5	0.03 F	Suburban avoiding
<i>Lichenostomus chrysops</i>	Yellow-faced honeyeater	2	1	17	4	42	5	0.03 F	Suburban avoiding
<i>Dacelo noveguineae</i>	Laughing kookaburra	10	4	62	14	39	10	0.03 F	Suburban avoiding
<i>Pachycephala pectoralis</i>	Golden whistler	0	0	14	3	38	7	0.0002 F	Suburban avoiding
<i>Poephila bichenovii</i>	Double-barred finch	0	0	14	4	37	4	0.05 F	Suburban avoiding
<i>Acanthiza pusilla</i>	Brown thornbill	0	0	32	7	34	8	0.002 F	Suburban avoiding
<i>Dicrurus bracteatus</i>	Spangled drongo	4	2	19	7	31	8	0.006 F	Suburban avoiding
<i>Coracina tenuirostris</i>	Cicadabird	0	0	10	5	25	7	0.001 F	Suburban avoiding
<i>Rhipidura rufifrons</i>	Rufous fantail	0	0	6	3	22	4	0.01 F	Suburban avoiding
<i>Eurystomus orientalis</i>	Dollarbird	0	0	50	13	16	7	0.003 F	Suburban avoiding
<i>Geopelia striata</i>	Peaceful dove	0	0	5	3	16	5	0.03 F	Suburban avoiding
<i>Sericornis frontalis</i>	White-browed scrubwren	0	0	7	3	15	5	0.01 F	Suburban avoiding
<i>Cuculus flabelliformis</i>	Fan-tailed cuckoo	0	0	3	2	12	5	0.003 F	Suburban avoiding
<i>Myiagra rubecula</i>	Leaden flycatcher	0	0	3	1	12	4	0.01 F	Suburban avoiding
<i>Cinclosoma punctatum</i>	Spotted quail-thrush	0	0	0	0	11	3	0.04 F	Suburban avoiding
<i>Smicromis brevirostris</i>	Weebill	0	0	5	1	11	3	0.04 F	Suburban avoiding
<i>Myiagra inquieta</i>	Restless flycatcher	0	0	5	3	8	4	0.04 F	Suburban avoiding
<i>Eopsaltria australis</i>	Eastern Yellow robin	0	0	3	1	5	3	0.04 F	Suburban avoiding
<i>Meliphaga lewinii</i>	Lewin's honeyeater	0	0	45	6	20	4	NS	No power
<i>Todiramphus macleayii</i>	Forest kingfisher	0	0	11	5	7	4	NS	No power

## A.2. Total abundance of terrestrial and aquatic bird species

Land type		Suburb ( <i>n</i> = 10)		Golf ( <i>n</i> = 20)		Forest ( <i>n</i> = 10)		<i>p</i> -Value
Species	Common name	Total	Sites	Total	Sites	Total	Sites	
Terrestrial birds								
<i>Neochmia temporalis</i>	Red-browed firetail	2	1	32	1	5	2	No power
<i>Alectura lathami</i>	Australian brush-turkey	0	0	22	3	0	0	No power
<i>Lonchura castaneothorax</i>	Chestnut-breasted manikin	0	0	20	2	0	0	No power
<i>Centropus phasianinus</i>	Pheasant coucal	0	0	15	7	3	3	No power
<i>Philemon citreogularis</i>	Little friarbird	6	3	14	4	0	0	No power
<i>Scythrops novaehollandiae</i>	Channel-billed cuckoo	0	0	13	6	6	4	No power
<i>Pomatostomus temporalis</i>	Grey crowned babbler	0	0	12	1	0	0	No power
<i>Myiagra cyanoleuca</i>	Satin flycatcher	0	0	10	2	2	2	No power
<i>Alisterus scapularis</i>	Australian king parrot	1	1	9	1	5	3	No power
<i>Todiramphus chloris</i>	Collared kingfisher	0	0	9	4	0	0	No power
<i>Falco cenchroides</i>	Nankeen kestrel	0	0	9	7	1	1	No power
<i>Sericornis magnirostris</i>	Large-billed scrubwren	0	0	8	3	4	2	No power
<i>Gerygone laevigaster</i>	Mangrove gerygone	0	0	7	2	3	2	No power
<i>Chrysoccyx basalis</i>	Horsfield's bronze cuckoo	0	0	6	4	6	2	No power
<i>Platycercus eximius</i>	Eastern Rosella	0	0	4	3	0	0	No power
<i>Podargus strigoides</i>	Tawny frogmouth	0	0	4	4	1	1	No power
<i>Ceyx azurea</i>	Azure kingfisher	0	0	3	2	0	0	No power
<i>Cuculus variolosus</i>	Brush cuckoo	0	0	3	1	3	2	No power
<i>Accipiter cirrhocephalus</i>	Collared sparrowhawk	0	0	3	1	1	1	No power

## Appendix A.2 (Continued)

Land type		Suburb (n = 10)		Golf (n = 20)		Forest (n = 10)		p-Value
Species	Common name	Total	Sites	Total	Sites	Total	Sites	
<i>Cisticola exilis</i>	Golden-headed cisticola	0	0	3	1	2	1	No power
<i>Dicaeum hirundinaceum</i>	Mistletoebird	0	0	3	2	1	1	No power
<i>Pardalotus punctatus</i>	Spotted pardalote	0	0	3	2	0	0	No power
<i>Hirundo nigricans</i>	Tree martin	0	0	3	1	0	0	No power
<i>Macropygia amboinensis</i>	Brown cuckoo-dove	0	0	2	1	2	2	No power
<i>Climacteris picumnus</i>	Brown treecreeper	0	0	2	1	3	2	No power
<i>Ninox novaeseelandiae</i>	Southern boobook	0	0	2	1	0	0	No power
<i>Lalage leucomela</i>	Varied triller	0	0	2	1	0	0	No power
<i>Falco berigora</i>	Brown falcon	0	0	1	1	0	0	No power
<i>Aviceda subcristata</i>	Pacific baza	0	0	1	1	0	0	No power
<i>Manorina melanophrys</i>	Bell miner	2	1	0	0	3	1	No power
<i>Calyptorhynchus lathami</i>	Glossy black cockatoo	0	0	0	0	3	1	No power
<i>Turnix varia</i>	Painted button quail	0	0	0	0	4	2	No power
<i>Falco peregrinus</i>	Peregrine falcon	0	0	0	0	1	1	No power
<i>Ninox strenua</i>	Powerful owl	0	0	0	0	1	1	No power
<i>Plectorhyncha lanceolata</i>	Striped honeyeater	0	0	0	0	2	1	No power
Aquatic birds								
<i>Gallinula tenebrosa</i>	Dusky moorhen	0	0	407	14	0	0	0.0002 G
<i>Chenonetta jubata</i>	Australian wood duck	0	0	371	18	1	1	0.0001 G
<i>Fulica atra</i>	Eurasian coot	0	0	286	8	0	0	0.003 G
<i>Porphyrio porphyrio</i>	Purple swamphen	0	0	215	11	3	1	0.01 G
<i>Anas superciliosa</i>	Pacific black duck	2	3	204	17	1	1	0.0002 G
<i>Threskiornis aethiopica</i>	Sacred ibis	45	0	202	10	1	1	0.01 G
<i>Aythya australis</i>	Hardhead	0	0	160	14	0	0	0.0008 G
<i>Threskiornis spinicollis</i>	Straw-necked ibis	0	0	145	10	0	0	0.01 G
<i>Vallenus miles</i>	Masked lapwing	6	2	123	15	0	0	0.0003 G
<i>Phalacrocorax sulcirostris</i>	Little black cormorant	0	0	88	11	0	0	0.003 G
<i>Anas castanea</i>	Chestnut teal	0	0	47	6	0	0	0.04 G
<i>Tachybaptus novaehollandiae</i>	Australasian grebe	0	0	45	13	0	0	0.0008 G
<i>Ardea novaehollandiae</i>	White-faced heron	1	1	24	13	0	0	0.0001 G
<i>Anas platyrhynchos</i>	Mallard	0	0	22	6	0	0	0.04 G
<i>Platalea regia</i>	Royal spoonbill	0	0	20	9	0	0	0.01 G
<i>Phalacrocorax melanoleucos</i>	Little pied cormorant	0	0	19	8	0	0	0.003 G
<i>Anhinga melanogaster</i>	Australian darter	0	0	10	4	0	0	No power
<i>Anas gracilis</i>	Australian grey teal	0	0	9	3	0	0	No power
<i>Gallinago hardwickii</i>	Japanese snipe	0	0	9	2	0	0	No power
<i>Nycticorax caledonicus</i>	Nankeen night heron	0	0	9	7	0	0	No power
<i>Cygnus atratus</i>	Black swan	0	0	8	3	0	0	No power
<i>Ardea intermedia</i>	Intermediate egret	0	0	8	5	0	0	No power
<i>Ardea garzetta</i>	Little egret	0	0	8	5	0	0	No power
<i>Ardea alba</i>	Great egret	1	2	7	6	0	0	No power
<i>Himantopus himantopus</i>	Black-winged stilt	0	0	4	1	0	0	No power
<i>Jacana gallinacea</i>	Comb-crested jacana	0	0	4	3	0	0	No power
<i>Dendrocygna eytoni</i>	Plumed whistling duck	0	0	4	1	0	0	No power
<i>Ardea ibis</i>	Cattle egret	0	0	3	2	0	0	No power
<i>Rallus philippensis</i>	Buff-banded rail	0	0	2	1	0	0	No power
<i>Burhinus grallarius</i>	Bush thick-knee	0	0	2	2	0	0	No power
<i>Ardeola striatus</i>	Mangrove bittern	0	0	2	1	0	0	No power
<i>Charadrius melanops</i>	Back-fronted dotterel	0	0	1	1	0	0	No power
<i>Plegadis falcinellus</i>	Glossy ibis	0	0	1	1	0	0	No power
<i>Dendrocygna arcuata</i>	Wandering whistling duck	0	0	1	1	0	0	No power
<i>Pelecanus conspicillatus</i>	Australian pelican	1	1	0	0	0	0	No power
<i>Ardea pacifica</i>	Pacific heron	0	0	0	0	1	1	No power

**Appendix B. Total abundance of reptile, amphibian and mammal species (letters beside significance values indicate land type of highest abundance: G = golf, F = forest, S = suburb)**

Land type		Golf <i>n</i> = 20		Forest <i>n</i> = 10		<i>p</i> -Value	Response group
Species	Common Name	Total	Sites	Total	Sites		
<b>Reptiles</b>							
<i>Cryptoblepharus virgatus</i>	Wall skink	345	20	153	10	NS	Suburban exploiting
<i>Lampropholis delicata</i>	Grass skink	898	20	347	10	NS	Suburban exploiting
<i>Physignathus lesueurii</i>	Eastern water dragon	413	16	11	3	0.001 G	Suburban tolerating
<i>Ctenotus robustus</i>	Robust skink	1	1	4	4	0.03 F	Suburban tolerating
<i>Anomalopus verreauxii</i>	Verreaux's skink	1	1	4	4	NS	Suburban tolerating
<i>Eulamprus quoyii</i>	Eastern water skink	21	4	0	0	NS	Suburban tolerating
<i>Pogona barbata</i>	Bearded dragon	42	13	13	5	NS	Suburban tolerating
<i>Calypotis scutirostrum</i>	Scaly-snouted skink	32	10	15	6	NS	Suburban tolerating
<i>Tiliqua scincoides</i>	Blue-tongued skink	1	1	2	2	No power	Suburban tolerating
<i>Carlia vivax</i>	Lively skink	8	4	72	10	0.00001 F	Suburban avoiding
<i>Lampropholis amacula</i>	Secretive skink	13	6	23	7	0.006 F	Suburban avoiding
<i>Varanus varius</i>	Lace monitor	8	4	29	8	0.007 F	Suburban avoiding
<i>Ctenotus taeniolatus</i>	Copper tailed skink	6	4	10	5	0.04 F	Suburban avoiding
<i>Carlia schmeltzii</i>	Robust rainbow skink	3	1	3	2	NS	Suburban avoiding
<i>Eulamprus martini</i>	Martin's skink	4	4	11	5	NS	Suburban avoiding
<i>Ramphotyphlops nigrescens</i>	Blind snake	0	0	7	2	NS	Suburban avoiding
<i>Lialis burtonis</i>	Burton's legless lizard	2	2	5	3	NS	Suburban avoiding
<i>Dendrelaphis punctulata</i>	Common tree snake	9	6	3	3	NS	Suburban avoiding
<i>Rhinoplocephalus nigrescens</i>	Eastern Small-eyed snake	0	0	2	2	No power	Suburban avoiding
<i>Morelia spilota</i>	Carpet python	3	3	0	0	No power	Suburban avoiding
<i>Amphibolurus muricatus</i>	Jacky lizard	0	0	2	1	No power	Suburban avoiding
<i>Coeranoscincus reticulatus</i>	Three-toed snake-tooth skink	0	0	1	1	No power	Suburban avoiding
<i>Ctenotus arcanus</i>	No common name	0	0	3	1	No power	Suburban avoiding
<i>Demansia psammophis</i>	Yellow-faced whip snake	0	0	1	1	No power	Suburban avoiding
<i>Diporiphora australis</i>	Eastern two-lined dragon	0	0	1	1	No power	Suburban avoiding
<i>Eulamprus tenuis</i>	Bar-sided skink	0	0	3	1	No power	Suburban avoiding
<i>Pseudechis porphyriacus</i>	Red-bellied black snake	0	0	1	1	No power	Suburban avoiding
<i>Ophioscincus truncatus</i>	Short-limbed snake skink	1	1	0	0	No power	Suburban avoiding
<i>Tropidonophis mairii</i>	Keelback snake	1	1	0	0	No power	Suburban avoiding
<b>Amphibians</b>							
<i>Bufo marinus</i>	Cane toad	1747	20	445	10	0.001 G	Suburban exploiting
<i>Limnodynastes peronii</i>	Striped marsh frog	489	18	672	7	NS	Suburban exploiting
<i>Litoria fallax</i>	Eastern sedge frog	2348	18	126	6	0.01 G	Suburban tolerating
<i>Litoria gracilentata</i>	Dainty green tree frog	167	3	386	6	0.01 F	Suburban tolerating
<i>Crinia parinsignifera</i>	Beeping froglet	40	3	143	5	NS	Suburban tolerating
<i>Litoria caerulea</i>	Green tree frog	4	2	0	0	No power	Suburban tolerating
<i>Pseudophryne raveni</i>	Copper-backed brood frog	1	1	1515	9	0.00001 F	Suburban avoiding
<i>Litoria nasuta</i>	Rocket frog	225	3	28	5	NS	Suburban avoiding
<i>Litoria latopalmeta</i>	Broad palmed frog	26	2	7	2	NS	Suburban avoiding
<i>Adelotus brevis</i>	Tusked frog	27	5	12	2	NS	Suburban avoiding
<i>Crinia signifera</i>	Common eastern froglet	3	1	96	5	NS	Suburban avoiding
<i>Litoria peronii</i>	Peron's tree frog	45	6	3	1	NS	Suburban avoiding
<i>Pseudophryne major</i>	Great brown brood frog	0	0	118	2	No power	Suburban avoiding
<i>Crinia tinnula</i>	Wallum froglet	11	1	57	1	No power	Suburban avoiding
<i>Mixophyes fasciolatus</i>	Great barred frog	0	0	10	3	No power	Suburban avoiding
<i>Limnodynastes dumerilii</i>	Eastern banjo frog	2	1	3	1	No power	Suburban avoiding
<i>Limnodynastes salmini</i>	Salmon-striped frog	0	0	2	1	No power	Suburban avoiding
<i>Uperoleia fusca</i>	Dusky toadlet	1	1	2	1	No power	Suburban avoiding
<i>Limnodynastes ornatus</i>	Ornate burrowing frog	5	1	0	0	No power	Suburban avoiding
<i>Litoria dentata</i>	Bleating tree frog	10	2	0	0	No power	Suburban avoiding
<i>Litoria tyleri</i>	Tyler's tree frog	1	1	0	0	No power	Suburban avoiding
<b>Mammals</b>							
<i>Rattus rattus</i>	Black rat	31	11	0	0	0.02 G	Suburban exploiting
<i>Mus musculus</i>	House mouse	20	10	2	1	NS	Suburban exploiting
<i>Trichosurus vulpecula</i>	Common brushtail possum	44	13	32	8	NS	Suburban tolerating
<i>Pseudocheirus peregrinus</i>	Common ringtail possum	18	6	3	2	NS	Suburban tolerating
<i>Macropus rufogriseus</i>	Red-necked wallaby	12	4	14	5	NS	Suburban avoiding

## Appendix B (Continued)

Land type		Golf <i>n</i> = 20		Forest <i>n</i> = 10		<i>p</i> -Value	Response group
Species	Common Name	Total	Sites	Total	Sites		
<i>Rattus fuscipes</i>	Bush rat	8	4	5	3	NS	Suburban avoiding
<i>Petaurus norfolcensis</i>	Squirrel glider	2	2	4	4	NS	Suburban avoiding
<i>Antechinus flavipes</i>	Yellow-footed antechinus	3	2	10	6	0.03 F	Suburban avoiding
<i>Macropus giganteus</i>	Eastern grey kangaroo	116	3	4	1	No power	Suburban avoiding
<i>Phascolarctos cinereus</i>	Koala	7	2	8	4	No power	Suburban avoiding
<i>Rattus tunneyi</i>	Pale field rat	1	1	2	1	No power	Suburban avoiding
<i>Petauroides volans</i>	Greater glider	0	0	4	2	No power	Suburban avoiding
<i>Rattus lutreolus</i>	Swamp rat	4	3	1	1	No power	Suburban avoiding
<i>Wallabia bicolor</i>	Swamp wallaby	2	2	0	0	No power	Suburban avoiding
<i>Lepus capensis</i>	Brown hare	3	3	0	0	No power	Suburban avoiding
<i>Canis lupis familiaris</i>	Wild dog	0	0	1	1	No power	Suburban avoiding
<i>Vulpes vulpes</i>	European fox	2	2	2	2	No power	Suburban avoiding

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