

# Distribution, habitat preference and conservation status of the Yellow-bellied Glider (*Petaurus australis*) in The Hills Shire, northwestern Sydney

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## ABSTRACT

Clearing of native vegetation for urban and rural development constitutes one of the major threats to conservation of forest-dependent fauna in New South Wales. The Hills Shire is an extensively forested local government area in northwestern Sydney which is experiencing rapid population growth and the associated expansion of residential and infrastructure development in both urban and rural areas. The Yellow-bellied Glider is one of many threatened species occurring in the Shire and information about this species' habitat requirements is needed for conservation planning. This study tested the hypothesis that the occurrence of Swamp Mahogany *Eucalyptus robusta* is an important factor explaining the distribution of the Yellow-bellied Glider in The Hills Shire. Spotlighting and call broadcast surveys for this and five other threatened species were undertaken on four occasions at each of 33 randomly-located sites stratified by proximity (<500 m and >1500 m) to forest containing Swamp Mahogany. The Yellow-bellied Glider was detected at 10 sites and was significantly more likely to occur at sites where Swamp Mahogany was present. Yellow-bellied Gliders were strongly associated with forests on alluvial soils occurring below 20 m elevation where Swamp Mahogany was present. Swamp Mahogany appears to be indicative of locations where a confluence of factors, including the forest types on adjacent slopes and ridges, results in favourable habitat for the gliders. The food resources provided by the winter-flowering Swamp Mahogany and other river-flat eucalypts, including Forest Red Gum *E. tereticornis*, is also thought to be important. The population of Yellow-bellied Gliders in The Hills Shire, based on all known records, was estimated to be 50 to 75 individuals occurring in at least 15 family groups most of which were distributed within seven core areas. The conservation of the Yellow-bellied Glider in the Shire requires the protection of these core areas and the existing forested corridors linking them. The Yellow-bellied Glider population in The Hills Shire is geographically isolated and warrants consideration for listing as an endangered population under the NSW Threatened Species Conservation Act 1995.

**Key words:** *Petaurus australis*, *Eucalyptus robusta*, survey, endangered population, urban development, conservation planning

## Introduction

Clearing of native vegetation has been identified as one of the major factors contributing to the decline of native fauna species in NSW (Goldney and Bowie 1990; Sivertsen 1995; Ford *et al.* 2001; Radford *et al.* 2005), culminating in the 2007 listing of this activity as a 'key threatening process' under the NSW Threatened Species Conservation Act 1995. Widespread clearing of native vegetation has occurred in parts of coastal and outer-metropolitan NSW to accommodate the residential and infrastructure development needed to support expanding human populations. Information on the distribution and habitat requirements of locally occurring fauna species is required to effectively plan for their conservation in areas where such development occurs (Kavanagh and Bamkin 1995; Kavanagh *et al.* 1995; Scotts and Drielsma 2003; Daly 2005; Wintle *et al.* 2005a).

The Hills Shire (formerly Baulkham Hills Shire), located on Sydney's northwestern fringe (Fig. 1), is an extensively (>60%) forested local government area with a human population of around 172,000 that is projected

to increase by 25% to more than 215,000 people by 2020 (Kingston *et al.* 2000; .id Consulting 2010). The Shire's population is concentrated in urban areas in its south, with approximately 10% of residents living in the rural and semi-rural parts of the Shire, which make up around 80% of the total land area. The rezoning and 'release' for urban development of land with high agricultural and conservation values on the Cumberland Plain in the Shire's south has accounted for most of the recent population growth in The Hills Shire. However, subdivision and development of rural land and bushland in other parts of the Shire has also occurred and contributed to the growing population and there is pressure for further subdivision of such land.

Unlike the neighbouring local government areas of Hornsby and Hawkesbury, both of which have a high proportion of their extant native vegetation reserved in public land tenures (62% and 86%, respectively), the majority of remnant vegetation in The Hills Shire is currently in private ownership or is unreserved public land with just

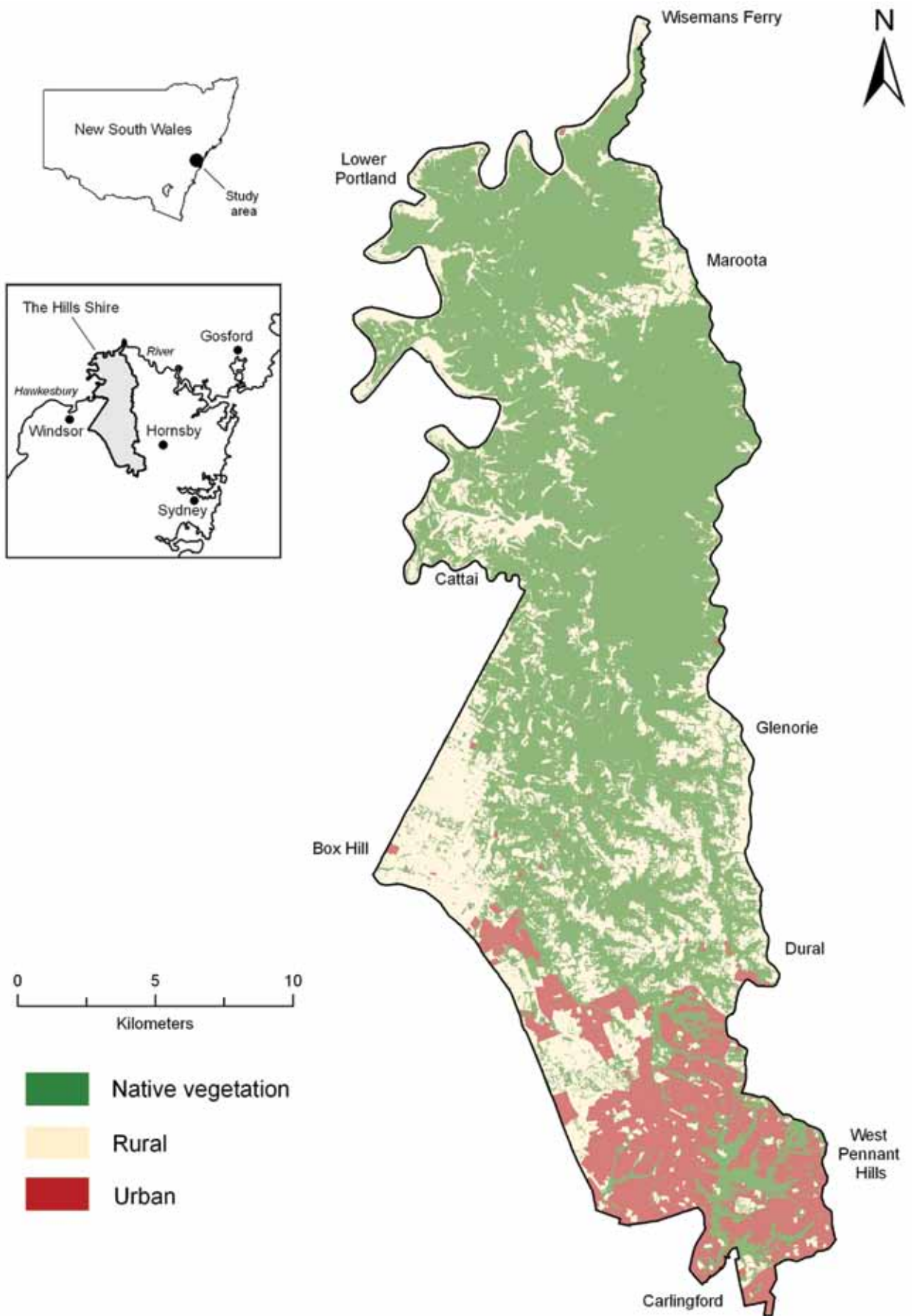


Figure 1. Location of the study area and the extent of native vegetation, rural and urban land-cover classes in The Hills Shire.

7% formally protected (HCC 2010; HSC 2010; THSC 2010). Consequently, the conservation of native fauna in this Shire is substantially dependent on appropriate land use planning at the local government level. The extensive areas of native vegetation in The Hills Shire (approximately 25,000 ha; Kingston *et al.* 2000) currently support a large number of rare and threatened fauna species (DECCW 2009). Resident species include the Giant Burrowing Frog *Heleioporus australiacus*, Sooty Owl *Tyto tenebricosa*, Glossy Black-Cockatoo *Calyptorhynchus lathami*, Cumberland Plain Land Snail *Meridolum comeovirens*, Koala *Phascolarctos cinereus* and the focus of this study, the Yellow-bellied Glider *Petaurus australis*.

The Yellow-bellied Glider is a large (500-700 g) gliding possum that inhabits mature eucalypt forest and is patchily distributed along the coast and ranges of eastern Australia from north Queensland to western Victoria (Kavanagh 2004; Goldingay 2008). It has a varied and seasonal diet consisting mainly of nectar, pollen, sap, honeydew and invertebrates (Fig. 2) (Kavanagh 1987; Goldingay 1990; Quin *et al.* 1996; Carthew *et al.* 1999) and lives in small family groups of 2-6 individuals that occupy exclusive home ranges of between 30 and 70 ha (Goldingay and Kavanagh 1990, 1993). Yellow-bellied Gliders produce frequent, loud vocalizations that are audible to humans up to 400 m away (Kavanagh and Rohan-Jones 1982; Goldingay 1994). The species is listed as “vulnerable” under the NSW Threatened Species Conservation Act 1995. Populations of Yellow-bellied Gliders are sensitive to forest removal due to their large home range area requirement and clustered distribution in the landscape (Goldingay and Kavanagh 1991). Loss of crucial forest components within home ranges and dispersal routes are serious threats to Yellow-bellied Glider populations in developing areas (Kavanagh 2004; Daly 2005).

Prior to this study, there were 19 records of the Yellow-bellied Glider in The Hills Shire, with the first record made in 1992 (DEC 2004). Field investigation of these records suggested that the Yellow-bellied Glider was associated with certain areas in the Shire, particularly those where Swamp Mahogany *Eucalyptus robusta* was present, leading to the development of the principal hypothesis in this study. Swamp Mahogany, and the sometimes co-occurring Forest Red Gum *E. tereticomis*, are well known as winter



**Figure 2.** Yellow-bellied Glider feeding on flowers (nectar and pollen) of Swamp Mahogany at O’Haras Creek, near Kenthurst. Photo by David Stowe.

flowering tree species (Law *et al.* 2000; Sharpe 2004), and previous studies have shown that winter flowering trees are an important component of habitat for the Yellow-bellied Glider because of the quality food resources they provide (Kavanagh 1987; Goldingay 1990).

This study aimed to document the distribution and habitat preference of the Yellow-bellied Glider in The Hills Shire to inform conservation planning. Specifically, the study sought to test the hypothesis that the Yellow-bellied Glider is strongly associated with forests where Swamp Mahogany is present. Recommendations for the management of this species in The Hills Shire are discussed.

## Methods

### Study Area

The Hills Shire is located in the outer metropolitan area of northwestern Sydney and encompasses approximately 40,000 ha (Kingston *et al.* 2000; Fig. 1). It is bound by the Hawkesbury River to the northwest and north, Old Northern Road to the east and by Windsor and Boundary Roads to the south and southwest. The Shire is dominated by two geo-morphological landscapes. The Cumberland Plain in the south accounts for approximately 15% of the Shire’s land area and is comprised of gently undulating slopes of fertile soils derived from shale geology. The Hornsby Plateau constitutes the majority of the Shire and occurs as a series of undulating sandstone and shale-capped ridges with steep, rocky slopes and valleys, which descend onto alluvial flats and the floodplains of the Hawkesbury and Parramatta Rivers.

The Hills Shire, in 1794, was one of the first parts of Australia to be settled by Europeans (Carr *et al.* 1997). Forest and woodland occurring on shale and alluvial soils was logged preferentially or cleared for agriculture, while vegetation on the less fertile and more rugged sandstone soils was left relatively undisturbed, apart from selective logging of the more valuable timber tree species (Charlton 1981; HDHS 1987). Today, the majority of native vegetation occurs in rugged terrain on sandstone soils and as re-growth forest on the upper alluvial flats of the Shire’s major creeks.

A wide range of land-uses exists in the Shire, including high-density urban development, rural-residential, agriculture, extractive industries and nature conservation. The average annual rainfall ranges from around 900 mm near Box Hill to 1120 mm at West Pennant Hills (BOM 2010). The Mitchell Park (114 ha) portion of Cattai National Park, while located in the adjacent Hawkesbury Shire, was included in the study area because its forests are contiguous with forest in The Hills Shire and it is otherwise surrounded by predominantly cleared land.

Swamp Mahogany is a characteristic species occurring within the endangered ecological community ‘Swamp Sclerophyll Forest on Coastal Floodplains’ (NSW Threatened Species Conservation Act 1995).

### Survey design

The distribution of Swamp Mahogany in the Shire was mapped using topographic maps, aerial photographs and detailed inspection of sites likely to support this tree species. The study area was then stratified based on

proximity to Swamp Mahogany, with survey sites located randomly near (<500 m) or distant (>1500 m) from forest containing this tree species. Each site consisted of one 200 m transect embedded in native forest which was situated at least 2 km from the next nearest site to improve sampling independence. This distance was chosen because Yellow-bellied Glider home ranges are rarely more than 1 km in diameter (Goldingay 1992; Goldingay and Kavanagh 1993; Goldingay and Quin 2004). Constraints on site selection included proximity to main roads, dwellings and cleared areas.

A total of 13 sites was located within 500 m, and 16 sites were located more than 1500 m, from forest containing Swamp Mahogany. An additional 4 sites were located between these distance categories to achieve broader geographical coverage, giving a total of 33 sites surveyed (Fig. 3). All sites were randomly located topographically, so that both “near” and “distant” sites occurred in gullies and on slopes and ridges (Near sites: gully=5, slope=5, ridge=3. Distant sites: gully=5, slope=9, ridge=4). In practice, each site effectively sampled gliders occurring on adjacent topographical positions due to the predominance of narrow valleys and low relief in the study area and the frequent, loud calling behaviour displayed by this species.

### Survey methods

A spotlighting and call broadcast survey was undertaken at each site using the following protocol. Transects were spotlighted, using a 50-watt spotlight, during a walking traverse for 20 minutes. At the transect midpoint, after 10 minutes of spotlighting, calls of three species were broadcast and then spotlighting was resumed with calls of another three species broadcast at the end of the transect. The six species were the Powerful Owl (*Ninox strenua*), Barking Owl (*N. connivens*), Sooty Owl (*Tyto tenebricosa*), Masked Owl (*T. novaehollandiae*), Koala (*Phascolarctos cinereus*) and the Yellow-bellied Glider. Calls were broadcast in random order, except for the Yellow-bellied Glider which was always broadcast last. The survey method is effective for the Yellow-bellied Glider because this species frequently utters unelicited calls and it is also known to respond strongly to broadcasts of its own calls and to calls by large forest owls (Kavanagh and Rohan-Jones 1982; Goldingay 1994; Kavanagh and Bamkin 1995). For each species, the call playback sequence consisted of 2 minutes of call broadcast, followed by 1 minute of listening for responses, then 2 additional minutes of call broadcast and 2 minutes of listening for responses. Calls (Stewart 2000) were broadcast from a compact disc using a 12-volt amplifier and speaker.

Each site was surveyed on four occasions, twice during the period of flowering by Swamp Mahogany (May-August 2005, May-September 2006) and twice at other times of the year (October 2005-March 2006, November 2006-April 2007). The order in which sites were surveyed was rotated according to time of night. Call broadcasts for a species were discontinued after the first detection of that species at a site. Observations were also made of sap-feeding trees used by Yellow-bellied Gliders.

A population estimate for the Yellow-bellied Glider in The Hills Shire was derived from the maximum number of gliders recorded in known groups and an estimate of the additional number of groups likely to occur in under-

surveyed areas of suitable habitat. These groups were assumed to comprise three or four individuals (Goldingay and Kavanagh 1990, 1993).

### Habitat variables

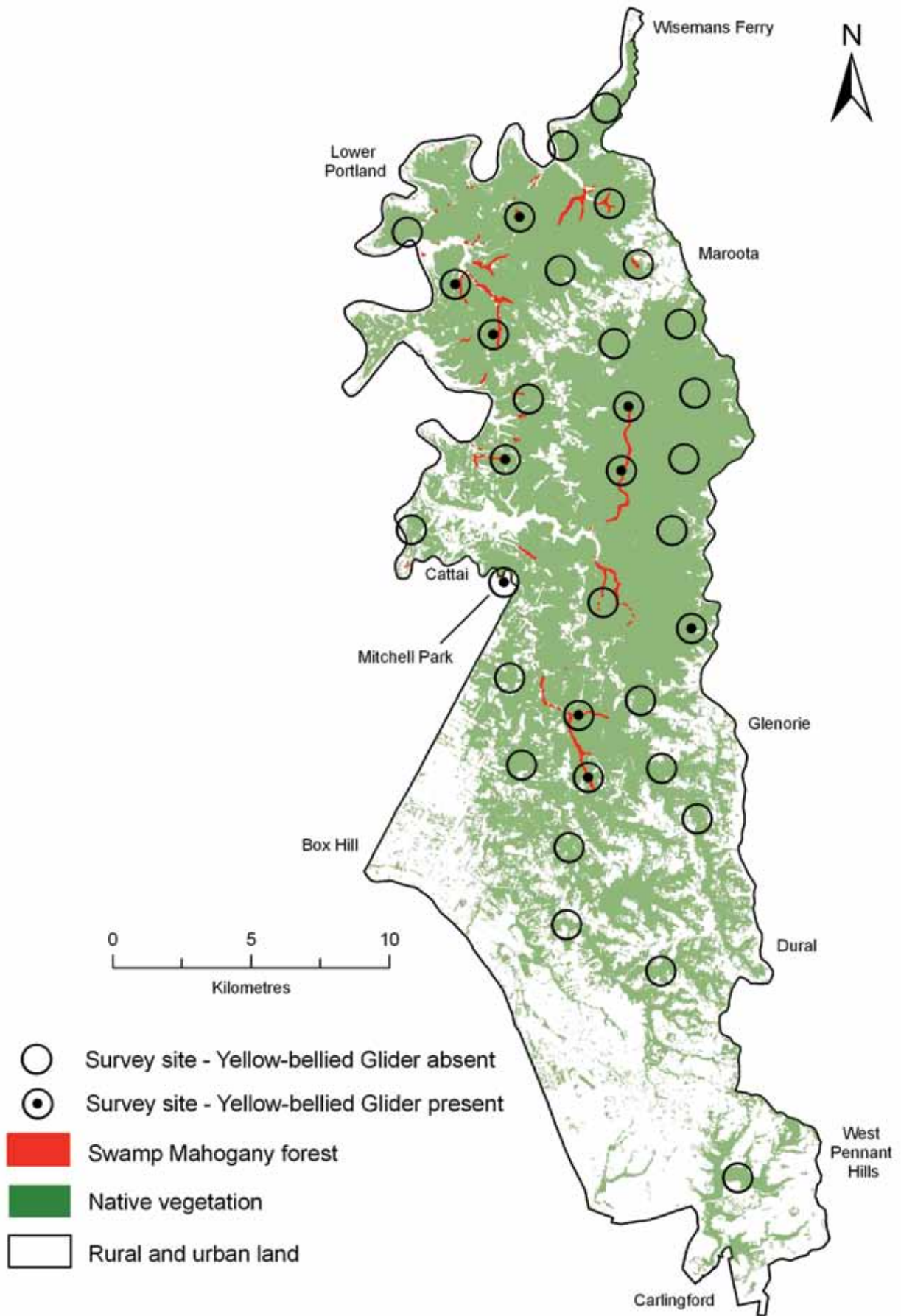
The distribution of Yellow-bellied Gliders in the Shire was expected to be determined by a combination of floristic and topographic features, and disturbance history (Kavanagh 2004). Data for vegetation type and cover, topography and post-1980 fire history of the Shire were obtained from The Hills Shire Council, Hornsby Shire Council, Hawkesbury City Council and the NSW Rural Fire Service.

The following variables were calculated within buffers of 500 m and 2000 m surrounding each site: area of native forest, area of Swamp Mahogany forest, area of forest occurring below 20 m elevation, area of combined forest types classified as “wet” forest (mainly those occurring in gullies and slopes on more sheltered aspects), area of combined forest types classified as “dry” forest (mainly those occurring on ridges and slopes on more exposed aspects), minimum elevation, maximum elevation, elevation range, area of forest burnt recently by wildfire (2002-2006), area of forest burnt by wildfire between 1980-1997, and total area of forest burnt by wildfire from 1980-2006. All of the above, except for the three fire variables and the two amalgamated forest types, were also calculated within 1000 m buffers surrounding each site. These three buffer sizes were chosen to investigate the influence of landscape context and the degree of forest loss on the habitat used by the gliders.

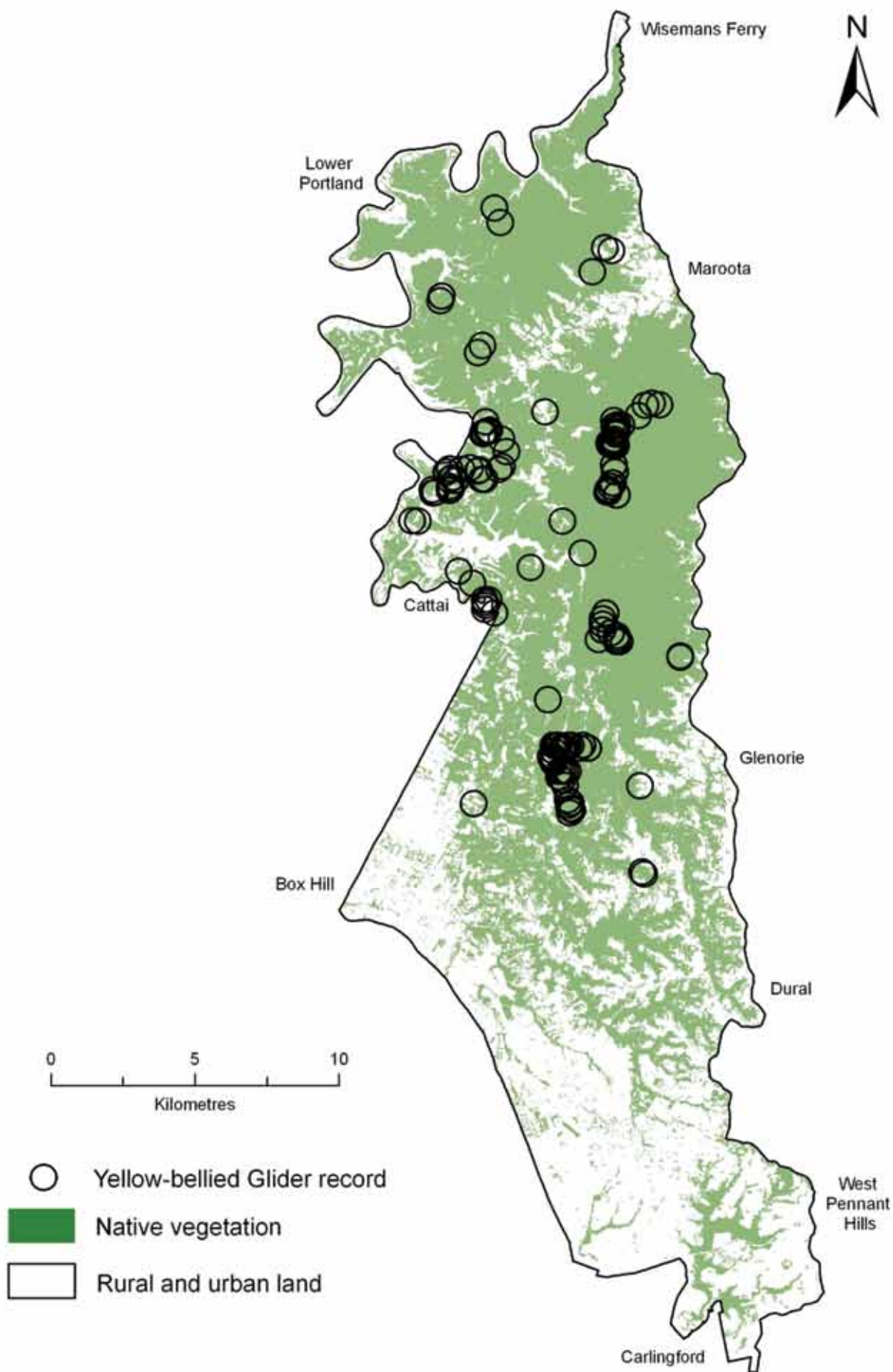
### Statistical analysis

Three response (dependent) variables were available for analysis: the presence at a site of the Yellow-bellied Glider following four visits, the maximum count of gliders at a site after any one visit, and the total number of visits to a site during which the species was recorded. The data for independent (habitat) variables were inspected using boxplots according to treatment (“near”, “distant”, “intermediate” from Swamp Mahogany) and scatterplots. Correlations among the variables (habitat and other species) were examined using the Spearman rank correlation test. Fishers Exact Test was used to test the degree of association between sites where the Yellow-bellied Glider was recorded and the presence of Swamp Mahogany. “Intermediate” sites were excluded from the test to ensure that expected values for each cell were greater than, or close to, 5 (Zar 1984).

Classification and regression trees (Breiman *et al.* 1984), implemented using “rpart” in R, were used to explore and model relationships between the dependent and independent variables. For each response variable, all habitat variables in each buffer size were entered into the models. A minimum of five sites per terminal node was specified and this ensured that a maximum of five habitat variables (n=33 sites) could be used in the models. In practice, the models were built using fewer (1-2) variables. Generalised linear models (e.g. logistic regression) were not attempted because the number of sites where Yellow-bellied Gliders were recorded prohibited the use of more than one habitat variable in the models (Burnham and Anderson 2002; p. 245, Wintle *et al.* 2005a; p. 726). All statistical procedures were done in R, version 2.8.0 (2008).



**Figure 3.** Location of the study sites in relation to the distribution of Swamp Mahogany in The Hills Shire. Sites where the Yellow-bellied Glider was recorded during the study are indicated.



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Figure 4. Distribution of all known records of the Yellow-bellied Glider in The Hills Shire.

## Results

The Yellow-bellied Glider was detected at 10 of the 33 sites surveyed in this study: nine sites near Swamp Mahogany, one site distant from Swamp Mahogany and no sites between 500 m and 1500 m from Swamp Mahogany (Table 1). The Gliders showed a significant association with proximity (<500 m) to Swamp Mahogany ( $\chi^2=12.59$ , 1df,  $P<0.01$ ). There are now more than 150 records (including observations made during repeat visits) of the Yellow-bellied Glider in The Hills Shire (Fig. 4), a significant increase since the first record in 1992 (DEC 2004).

A total of 14 species of nocturnal birds and arboreal mammals were recorded during the study (Table 1), including the threatened Powerful Owl, Sooty Owl and Masked Owl. Despite being targeted, the Koala and Barking Owl were not detected during the study. Records of the Yellow-bellied Glider were correlated with sites where the Sooty Owl and Common Brushtail Possum were also recorded (Spearman rank correlation coefficients:  $r=0.620$ ,  $P<0.01$  and  $r=0.361$ ,  $P<0.05$ , respectively).

## Habitat models

The most important explanatory variable accounting for the distribution of survey records of the Yellow-bellied Glider was the area of Swamp Mahogany forest. This was consistent across all nine habitat models, representing the three methods of recording responses by the gliders at the three different scales assessed for landscape context. In eight of these models, the area of Swamp Mahogany forest was the only explanatory variable. The total area of forest cover was included as a secondary variable in one of the models. However, when the area of Swamp Mahogany forest was deleted from a sub-set of the models using glider presence-absence as the response variable, and the decision tree

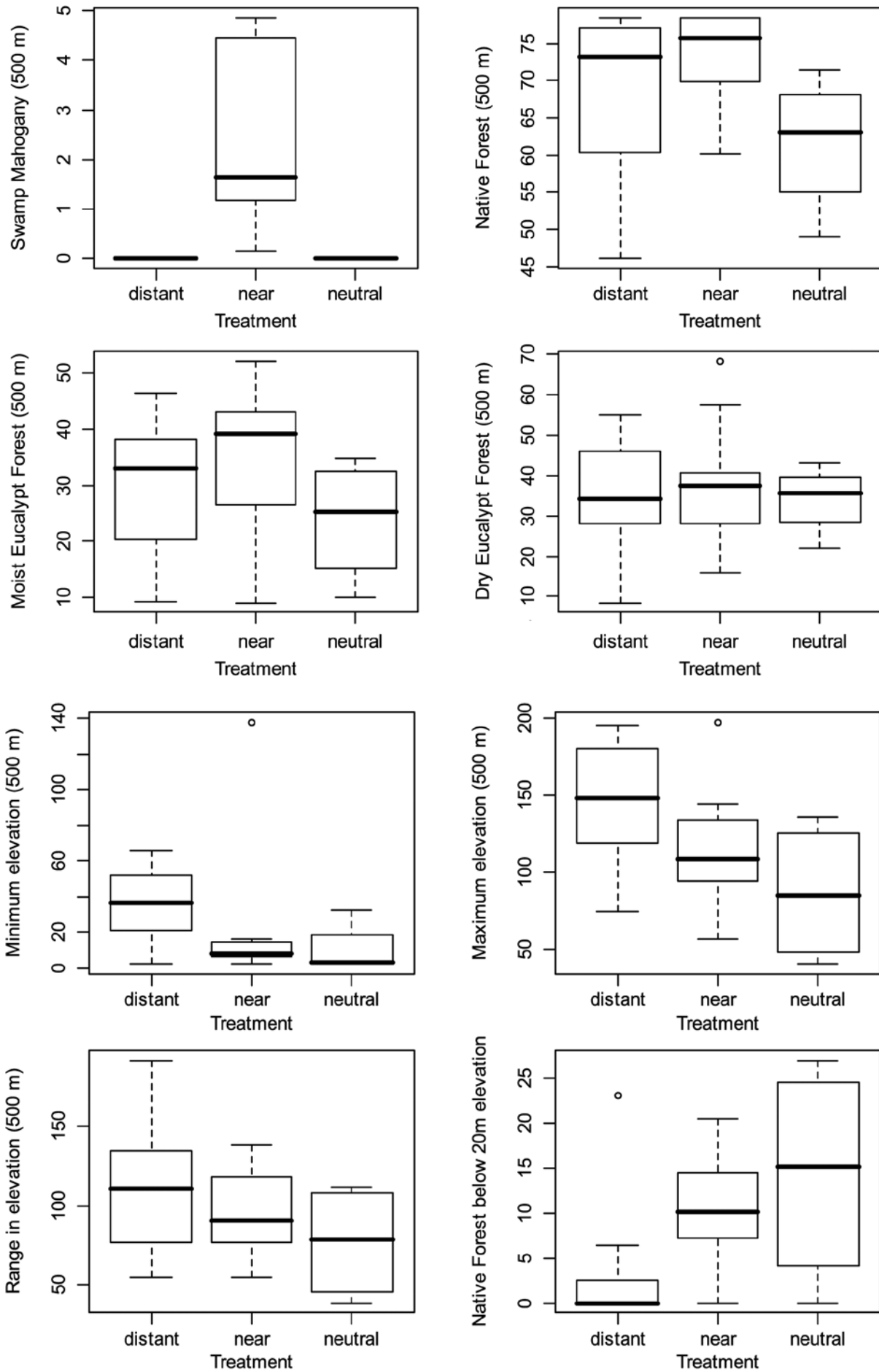
models re-run, the most important explanatory variables became the area of forest occurring below 20 m elevation (which included Swamp Mahogany) and the total area of forest cover at the 500 m and 1000 m buffer scales, respectively. The area of Swamp Mahogany forest (within the 500 m buffer) was strongly correlated with the area of forest occurring below 20 m elevation (Spearman rank correlation coefficient  $r=0.494$ ,  $P<0.01$ ); the correlation was weaker for the total area of native forest cover within 500 m ( $r=0.309$ ,  $P<0.1$ ). Other variables assessed in this study appeared to have little influence on the distribution of the Yellow-bellied Glider. Fire history variables had little influence due, in part, to the large proportion of forest in The Hills Shire that had been burnt recently (2002-2006) by wildfire (Fig. 5).

The Yellow-bellied Glider was most likely to be recorded at sites having at least 0.07 ha of Swamp Mahogany forest within the 500 m buffer (i.e. at the 78.5 ha landscape scale). Five of 33 sites were mis-classified at this level. That is, the Gliders were not recorded at four sites that had at least 0.07 ha of Swamp Mahogany forest, and one Glider was recorded at a site that had apparently no Swamp Mahogany present. Swamp Mahogany forest was always restricted to small areas wherever it occurred, such that the maximum area recorded at any site (within the 500 m buffers) was 4.88 ha. Similarly, for the larger buffers, the Yellow-bellied Glider was most likely to be present where there was more than 0.11 ha and 5.04 ha of Swamp Mahogany forest present within the 1000 m (314 ha) and 2000 m (1256 ha) buffers, respectively. For these larger buffers, the maximum recorded areas of Swamp Mahogany forest were 9.78 ha and 22.69 ha, respectively.

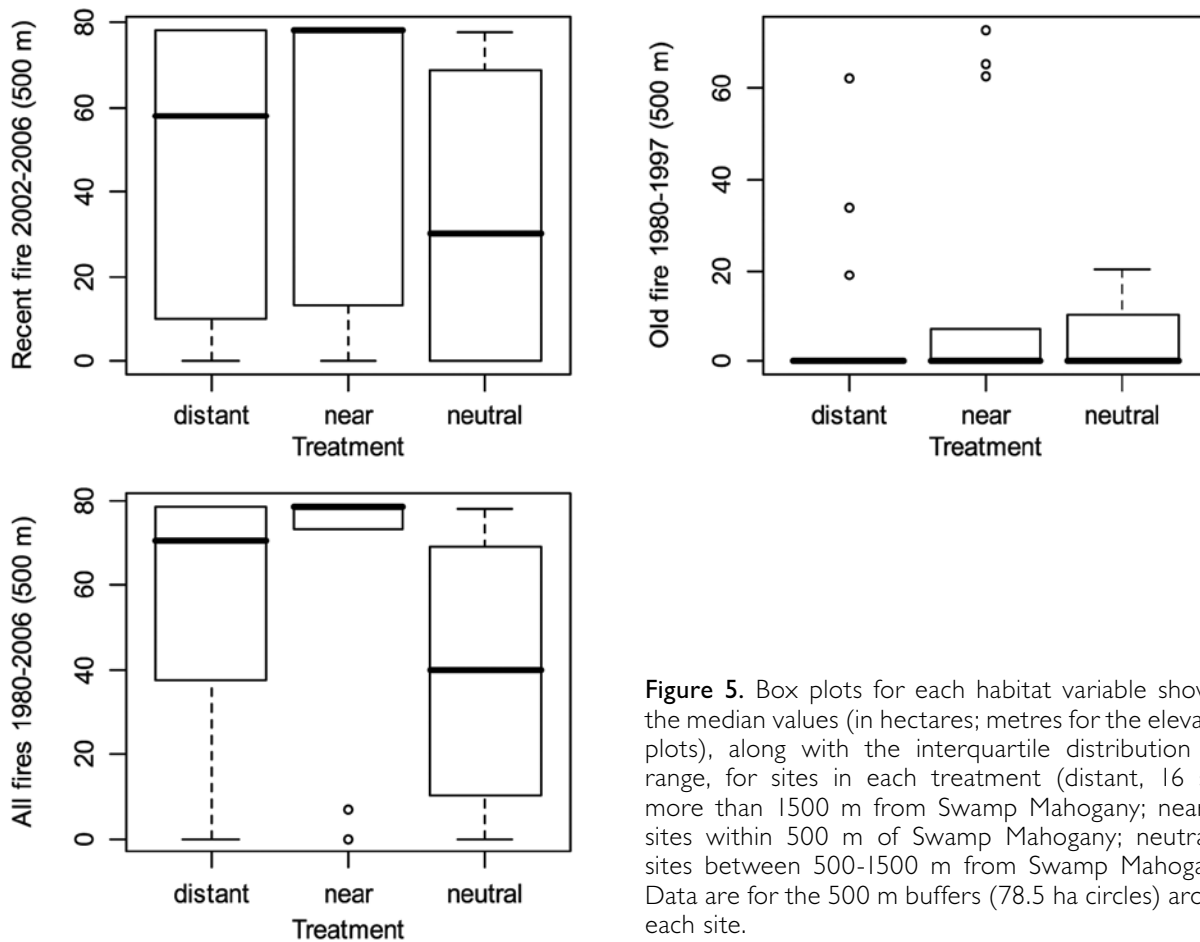
The other, less significant, variables contributing to an explanation of the presence of the Yellow-bellied Glider at a site were the area of forest occurring below 20 m elevation and the total area of native forest in

**Table 1.** Nocturnal birds and arboreal mammals recorded during the study. Data represent number of sites at which the species was detected after four visits.

Species	Proximity of sites to Swamp Mahogany			Total
	Near (<500 m) (n=13)	Distant (>1500 m) (n=16)	Intermediate (500-1500 m) (n=4)	
Yellow-bellied Glider <i>Petaurus australis</i>	9	1	0	10
Sugar Glider <i>P. breviceps</i>	12	13	3	28
Feathertail Glider <i>Acrobates pygmaeus</i>	3	4	0	7
Common Ringtail Possum <i>Pseudocheirus peregrinus</i>	10	10	4	24
Common Brushtail Possum <i>Trichosurus vulpecula</i>	7	4	1	12
Grey-headed Flying-fox <i>Pteropus poliocephalus</i>	7	7	0	14
Powerful Owl <i>Ninox strenua</i>	8	10	2	20
Southern Boobook <i>N. novaeseelandiae</i>	9	10	3	22
Sooty Owl <i>Tyto tenebricosa</i>	5	2	0	7
Masked Owl <i>T. novaehollandiae</i>	2	3	0	5
Eastern Barn Owl <i>T. javanica</i>	1	2	1	4
Australian Owlet Nightjar <i>Aegotheles cristatus</i>	13	15	4	32
White-throated Nightjar <i>Eurostopodus mystacalis</i>	1	0	0	1
Tawny Frogmouth <i>Podargus strigoides</i>	1	0	1	2







**Figure 5.** Box plots for each habitat variable showing the median values (in hectares; metres for the elevation plots), along with the interquartile distribution and range, for sites in each treatment (distant, 16 sites more than 1500 m from Swamp Mahogany; near, 13 sites within 500 m of Swamp Mahogany; neutral, 4 sites between 500-1500 m from Swamp Mahogany). Data are for the 500 m buffers (78.5 ha circles) around each site.

the surrounding landscape. Gliders were more likely to be recorded where there was at least 8.69 ha of forest below 20 m elevation present within the 500 m buffers (mis-classification rate 7/33), and at least 257.3 ha (82%) of forest cover present within the 1000 m buffers (mis-classification rate 9/33; i.e. nine sites had more than 257.3 ha of forest cover but no Gliders were recorded at them). At the landscape scale of 500 m surrounding the survey locations, there was an extensive coverage of native forest (median 73.0 ha within the 78.5 ha 500 m buffers). However, the area of native forest became more fragmented when larger landscape scales were considered (1000 m buffers, median 264.8 ha; 2000 m buffers, median 961.3 ha) but the study area was still extensively forested (Fig. 5). At the largest scale, the Yellow-bellied Glider was only recorded when the area of native forest cover was at least 873.2 ha (70%) within the 2000 m buffers.

**Population estimate**

The population of Yellow-bellied Gliders in The Hills Shire, based on all known records, was estimated to be 50 to 75 individuals. This estimate included animals from at least 15 family groups, most of which were distributed in seven core areas. These were: Scalybark Creek / O’Haras Creek (≥ five groups), Little Cattai Creek (≥ two groups), lower South Maroota (≥ two groups), Doyles Swamp catchment (≥ two groups), Kellys Creek (≥ one group), Mitchell Park (≥ one group) and Leets Creek (≥ one group). Outside of these core areas, additional records were made during the

study in tributaries of Scalybark Creek (Guppy Creek, one group), Kellys Creek (Brushtail Creek, one individual) and at Maraylya (Birds Lane, one individual). Previous records of the Yellow-bellied Glider occur elsewhere within the catchments of O’Haras Creek, Little Cattai Creek and Jacksons Swamp, however, these locations require confirmation of continued occupancy by the gliders.

**Discussion**

**Distribution and habitat preferences**

It is important for conservation planning that land managers understand the distribution and habitat requirements of species, particularly those that are sensitive to land-use practices. We found that Yellow-bellied Gliders in The Hills Shire were strongly associated with forests growing on alluvial soils occurring below 20 m elevation where Swamp Mahogany was present. These low-elevation vegetation types are thought to be crucial, and limiting, for the gliders because of the food resources provided by the winter-flowering Swamp Mahogany and other river-flat eucalypts such as Forest Red Gum *E. tereticornis*, Sydney Blue Gum *E. saligna* and Round-leaved Blue Gum *E. deanei* (Kavanagh 1987; Law *et al.* 2000). However, the gliders also foraged in adjacent forest types occurring on the flats, slopes and nearby ridges within their large home-ranges. These adjacent forests are also known to provide important sap, nectar, pollen and insect food resources for the Yellow-bellied Glider.

The association between Swamp Mahogany and the presence of the Yellow-bellied Glider was remarkable in that only small patches of this tree species (sometimes less than 1.0 ha) were sufficient to account for the presence of the glider. Swamp Mahogany in this study was a reliable winter flowering species (*contra* Sharpe (2004) in north-eastern NSW), with flowering by this species recorded at each site from 2003-2006 and during ad hoc visits from 2007-2009. However, it is important to recognise that such small areas of Swamp Mahogany are unlikely to satisfy the energy requirements of the Yellow-bellied Glider (Goldingay and Kavanagh 1993; Goldingay and Quin 2004). Rather, the presence of Swamp Mahogany in this study appeared to be indicative of sites having a range of habitat characteristics that, together, comprise the habitat needed by the gliders (e.g. Kavanagh 1987). This hypothesis-driven study was not designed to measure every habitat variable that could have accounted for the distribution of the Yellow-bellied Glider in The Hills Shire and the proximity of other tree species which provide important food resources for the gliders at other times of the year is certain to be a factor.

Important food trees for the Yellow-bellied Glider in NSW, and which also occur in The Hills Shire, include Grey Gum *E. punctata*, Red Bloodwood *Corymbia gummifera* and Sydney Blue Gum (Mackowski 1988; Goldingay 1990). Of these, the Grey Gum was the most frequently observed sap-feeding tree in The Hills Shire and this widespread species may be an important habitat component for the gliders. Other tree species used for sap-feeding in the Shire include the Scribbly Gum *E. racemosa* and Sydney Blue Gum. Nectar sources (and presumably pollen) used by the gliders in this study were provided by Swamp Mahogany, Forest Red Gum, Red Mahogany *E. resinifera*, Blackbutt *E. pilularis*, Red Bloodwood, Yellow Bloodwood *C. eximia* (J. Guidice personal communication) and Smooth-barked Apple *Angophora costata*. Additional species with large flowers, such as the Grey Gum, are also likely to be used. Yellow-bellied Gliders in the study area were also observed foraging for invertebrates and exudates in bark-shedding tree species, including Forest Red Gum, Sydney Blue Gum, and Round-leaved Blue Gum.

Four locations predicted to support the Yellow-bellied Glider (i.e. where Swamp Mahogany was present) were apparently unoccupied by the gliders at the time of the surveys. Two of these sites contained disused glider sap-feeding trees, and previous records of the gliders existed in the vicinity of all four sites. Four visits to each site should have been adequate to detect this glider if it was present (Wintle *et al.* 2005b). Other factors, such as predation, wildfire (see below) or unknown historical events, may have been responsible for these absences.

The Yellow-bellied Glider was also recorded (once only) at one site where Swamp Mahogany was not present. In every other case, gliders were recorded at sites where forest on alluvial soils below 20 m elevation, including Swamp Mahogany, was present. At one site containing just several Swamp Mahogany trees, an abundance of Forest Red Gum, a tree absent from most other Yellow-bellied Glider sites in the Shire, may substitute for the

small area of Swamp Mahogany (see also Goldingay and Quin 2004). Forest Red Gum also flowers during winter (Law *et al.* 2000) and is known to be important for the gliders in other areas (Mackowski 1988; Quin *et al.* 1996). Forest Red Gum does not occur independently of Swamp Mahogany on alluvial soils in the Shire except in small, highly disturbed stands. Forests dominated by other river-flat eucalypts, such as Sydney Blue Gum and Round-leaved Blue Gum, did not support the Yellow-bellied Glider in the absence of Swamp Mahogany.

Landscape context (i.e. the area of forest within the buffer) had remarkably little effect on the results, based on the similarity of the models using data from the three buffer sizes. This was probably due to most sites being located within substantially forested areas. Indeed, only three sites had less than 50% forest cover remaining within the largest (2000 m) buffer zones. The percentage of "unmodified forest" occurring within a 2 km radius was found to be an important variable explaining the distribution of the Yellow-bellied Glider on the Central Coast of NSW (Wintle *et al.* 2005a).

Insufficient data were available to assess the influence of surrounding land-use and disturbance history. Most of the gullies surveyed in this study showed evidence of previous logging. While the availability of large tree hollows for shelter and breeding by the gliders may have been limited at many gully sites, there appeared to be little shortage of suitable hollows in adjacent forests on the slopes. The large home-ranges of these gliders would enable them to access both feeding areas on the creek flats and den hollows in adjacent forests (Goldingay and Kavanagh 1993). A range of other tree-hollow dependent fauna species was also recorded at the sites, suggesting that hollow availability is not yet a limiting factor in these areas.

A large proportion of the forest within the Shire, and on the survey sites, had been burnt by wildfire during 2002-2006. It is remarkable that Yellow-bellied Gliders were still present at a number of sites following recent wildfire, given the sensitivity of populations of this species to severe wildfire (Lunney 1987; Goldingay and Kavanagh 1991). However, it is possible that recent wildfire may account for the absence of the species at several sites.

### Limitations of the study

The number of sites was limited by the size of the study area, the restricted distribution of Swamp Mahogany, and by the need to separate sites by at least 2 km to provide some confidence that the sites were independent. It is important to recognise that the range in values for important habitat variables, and their particular relationships to site occupancy by the gliders, is specific to the study area and should not be extrapolated beyond The Hills Shire. Also, while the presence of Swamp Mahogany trees was shown to be an important factor explaining the distribution of the Yellow-bellied Glider in this study, it is clear that other tree species are also required to provide suitable habitat for the gliders. Site-specific variables such as forest structural characteristics, including the abundance of hollow-bearing and sap-feeding trees, as well as site history, including predation

and wildfire intensity, were not measured but these could also be important explanatory factors. The strengths of the study include the detailed (ground-based) mapping of the distribution of Swamp Mahogany in The Hills Shire and the employment of four survey visits to each site over a two-year period. Work by Wintle *et al.* (2005b) showed that a survey effort of four visits is likely to provide confidence that the Yellow-bellied Glider will be detected at more than 90% of the sites at which it occurs.

### Conservation status in The Hills Shire

The Hills Shire population of the Yellow-bellied Glider is separated from adjacent populations to the north (Gosford Local Government Area) and west (Hawkesbury Local Government Area) by extensive land clearing and the Hawkesbury River, which forms a natural barrier to movement. To the east, there are no records of the Gliders in the adjacent Hornsby Shire (NSW Wildlife Atlas; accessed 20 August 2010), despite surveys having been undertaken. The population of Yellow-bellied Gliders in The Hills Shire, based on all known records, was estimated to be 50 to 75 individuals occurring in at least 15 family groups that were distributed within seven core areas. The conservation of the Yellow-bellied Glider in the Shire requires the protection of these core areas and the existing forested corridors linking them. Any further reduction in the numbers of animals should be considered as a significant threat to the local occurrence of the species (Goldingay and Possingham 1995). The Yellow-bellied Glider population in The Hills Shire is

geographically isolated and warrants consideration for listing as an endangered population under the NSW Threatened Species Conservation Act 1995.

The occurrences of the Yellow-bellied Glider were associated with other threatened species, in particular the Sooty Owl, such that protection afforded to the habitat of the wide-ranging Yellow-bellied Glider is likely to benefit many other species. Protecting the habitat of the Yellow-bellied Glider will also benefit conservation of the Swamp Sclerophyll Forest Endangered Ecological Community.

### Management recommendations

The presence of Swamp Mahogany in The Hills Shire appears to be indicative of locations where a confluence of factors results in favourable habitat for a range of forest-dependent animals, including the Yellow-bellied Glider. All areas of Swamp Mahogany and adjacent forests on river flats, slopes and ridges in The Hills Shire should be marked on planning maps and zoned for conservation management to protect the habitat of the Yellow-bellied Glider and a range of other fauna species. The seven core areas identified in the Shire need to be protected from further habitat loss and existing forested connections between them need to be maintained. Areas known to have previously supported Yellow-bellied Gliders, and other areas of suitable habitat, should be investigated. Consideration should be given to listing this population as an endangered population under the NSW Threatened Species Conservation Act 1995.

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### References

- Bureau of Meteorology. 2010. Climate data online. <http://www.bom.gov.au/climate/data/index.shtml>. Website accessed 3 June 2010.
- Burnham, K.P. and Anderson, D.R. 2002. Model selection and multimodel inference: A practical information-theoretic approach. (Second Edition). Springer, New York.
- Breiman, L., Friedman, J.H., Olshen, R. and Stone, C. J. 1984. Classification and Regression Trees. Wadsworth International Group, Belmont, California.
- Carr, H., Wilson, P., Pullen, N. and McCluskey, L. 1997. Settlement of Baulkham Hills and Castle Hill Townships 1791 – 1997. The Hills District Historical Society, Castle Hill.
- Carthew, S.M., Goldingay, R.L. and Funnell, D.L. 1999. Feeding behaviour of the yellow-bellied glider (*Petaurus australis*) at the western edge of its range. *Wildlife Research* 26: 199-208.
- Charlton, C. 1981. A History of Kenthurst and Annangrove. Kangaroo Press, Annangrove.
- Daly, G. 2005. Mapping glider songlines: development of a landscape management policy for the Yellow-bellied Glider *Petaurus australis* (Shaw 1791) in the Eurobodalla Shire on the south coast of New South Wales. *Australian Zoologist* 33 (2): 180-187.
- DEC. 2004. Atlas of NSW Wildlife, NSW Department of Environment and Conservation, Hurstville, Sydney.
- DECCW. 2009. Atlas of NSW Wildlife, NSW Department of Environment, Climate Change and Water, Hurstville, Sydney.
- Ford, H.A., Barrett, G.W., Saunders, D.A., and Recher, H.F. 2001. Why have birds in the woodlands of southern Australia declined? *Biological Conservation* 97: 71-88.
- Goldingay, R.L. 1990. The foraging behaviour of a nectar-feeding marsupial, *Petaurus australis*. *Oecologia* 85: 191-199.

- Goldingay, R.L.** 1992. Socioecology of the Yellow-bellied Glider (*Petaurus australis*) in a coastal forest. *Australian Journal of Zoology* **40**: 267-278.
- Goldingay, R.L.** 1994. Loud calls of the Yellow-bellied Glider, *Petaurus australis*: Territorial behaviour by an arboreal marsupial? *Australian Journal of Zoology* **42**:279-293.
- Goldingay, R.L.** 2008. Yellow-bellied Glider *Petaurus australis*. Pp. 228-230 in The Mammals of Australia, edited by S. Van Dyck and R. Strahan. Reed New Holland, Sydney.
- Goldingay, R.L. and Kavanagh, R.P.** 1990. Socioecology of the Yellow-bellied Glider, *Petaurus australis*, at Waratah Creek, NSW. *Australian Journal of Zoology* **38**: 327-341.
- Goldingay, R.L. and Kavanagh, R.P.** 1991. The Yellow-bellied Glider: a review of its ecology, and management considerations. Pp. 365-375 in Conservation of Australia's Forest Fauna, edited by D. Lunney. Royal Zoological Society of New South Wales, Mosman.
- Goldingay, R.L. and Kavanagh, R.P.** 1993. Home-range estimates and habitat of the Yellow-Bellied Glider (*Petaurus australis*) at Waratah Creek, New South Wales. *Wildlife Research* **20**: 387-404.
- Goldingay, R. and Possingham, H.** 1995. Area requirements for viable populations of the Australian gliding marsupial *Petaurus australis*. *Biological Conservation* **73**:161-167.
- Goldingay, R.L. and Quin, D.** 2004. Components of habitat of the yellow-bellied glider in north Queensland. Pp. 369-375 in The Biology of Australian Possums and Gliders, edited by R.L. Goldingay and S.M. Jackson. Surrey Beatty and Sons, Sydney.
- Goldney, D.C. and Bowie, I.J.S.** 1990. Some management implications for the conservation of vegetation remnants and associated fauna in the central western region of New South Wales. *Proceedings of the Ecological Society of Australia* **16**: 427-440.
- HCC.** 2010. Land information, GIS data shape files. Hawkesbury City Council.
- HSC.** 2010. Land information, GIS data shape files. Hornsby Shire Council.
- HDHS.** 1987. The beginnings of the Hills District. The Hills District Historical Society, Castle Hill.
- .id Consulting.** 2010. The Hills Shire Council Community Profile and Population Forecasts. <http://profile.id.com.au/Default.aspx?id=261> and <http://forecast.id.com.au/Default.aspx?id=261&gid=10&pg=30011>. Website accessed 13 January 2010.
- Kavanagh, R.P.** 1987. Forest phenology and its effect on foraging behaviour and selection of habitat by the Yellow-bellied Glider, *Petaurus australis* Shaw. *Australian Wildlife Research* **14**: 371-84.
- Kavanagh, R.P.** 2004. Distribution and conservation status of possums and gliders in New South Wales. Pp. 130-148 in The Biology of Australian Possums and Gliders, edited by R.L. Goldingay and S.M. Jackson. Surrey Beatty and Sons, Sydney.
- Kavanagh, R.P. and Bamkin, K.L.** 1995. Distribution of nocturnal forest birds and mammals in relation to the logging mosaic in south-eastern New South Wales, Australia. *Biological Conservation* **71**: 41-53.
- Kavanagh, R.P., Debus, S., Tweedie, T. and Webster, R.** 1995. Distribution of nocturnal forest birds and mammals in north-eastern New South Wales: relationships with environmental variables and management history. *Wildlife Research* **22**: 359-377.
- Kavanagh, R.P. and Rohan-Jones, W.G.** 1982. Calling behaviour of the Yellow-bellied Glider, *Petaurus australis* Shaw (Marsupialia: Petauridae). *Australian Mammalogy* **5**: 95-111.
- Kingston, M.B., Hall, P.W. and Turnbull, J.W.** 2000. 1999 remnant bushland and landcover mapping. Report to Baulkham Hills Shire Council. Ecograph, Limpinwood, NSW.
- Law, B., Mackowski, C., Schoer, L. and Tweedie, T.** 2000. The flowering phenology of myrtaceous trees and their relation to climatic, environmental and disturbance variables in northern New South Wales. *Austral Ecology* **25**: 160-178.
- Lunney, D.** 1987. Effects of logging, fire and drought on possums and gliders in the coastal forests near Bega, N.S.W. *Australian Wildlife Research* **14**: 263-274.
- Mackowski, C.M.** 1988. Characteristics of eucalypts incised for sap by the Yellow-bellied Glider, *Petaurus australis* Shaw (Marsupialia: Petauridae), in north-eastern New South Wales. *Australian Mammalogy* **11**: 5-13.
- Quin, D., Goldingay, R., Churchill, S. and Engel, D.** 1996. Feeding behaviour and food availability of the Yellow-bellied Glider in North Queensland. *Wildlife Research* **23**: 637-646.
- R, version 2.8.0.** 2008. The R Foundation for Statistical Computing.
- Radford, J.Q., Bennett, A.F. and Cheers, G.J.** 2005. Landscape-level thresholds of habitat cover for woodland-dependent birds. *Biological Conservation* **124**: 317-337.
- Scotts, D. and Drielsma, M.** 2003. Developing landscape frameworks for regional conservation planning: and approach integrating faunal spatial distributions an ecological principles. *Pacific Conservation Biology* **8**: 235-254.
- Sharpe, D.J.** 2004. Effect of flowering patterns on a population of squirrel gliders *Petaurus norfolcensis* in north-east New South Wales. Pp. 339-349 in The Biology of Australian Possums and Gliders, edited by R.L. Goldingay and S.M. Jackson. Surrey Beatty and Sons, Sydney.
- Sivertsen, D.P.** 1995. Habitat loss: its nature and effects (including case studies from New South Wales). Pp. 28-42 in Conserving biodiversity: threats and solutions, edited by R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunney and D.P. Sivertsen. Surrey-Beatty and Sons, Sydney.
- Stewart, D.** 1998. Nocturnal bird and mammal calls of north-east New South Wales. Nature Sound, Mullumbimby.
- THSC.** 2010. Land information, GIS data shape files. The Hills Shire Council.
- Wintle, B.A., Elith, J. and Potts, J.M.** 2005a. Fauna habitat modeling and mapping: A review and case study in the Lower Hunter Central Coast region of NSW. *Austral Ecology* **30**: 719-738.
- Wintle, B.A., Kavanagh, R.P., McCarthy, M.A. and Burgman, M.A.** 2005b. Estimating and dealing with detectability in occupancy surveys for forest owls and arboreal marsupials. *Journal of Wildlife Management* **69**: 905-917.
- Zar, J.H.** 1984. Biostatistical Analysis. Prentice-Hall, New Jersey.