Estimating the density of the Greater Glider in the Strathbogie Ranges, North East Victoria

With an assessment of coupes scheduled for timber harvesting in 2018

J.L. Nelson, M.P. Scroggie, L.K. Durkin, J.K. Cripps, D.S.L. Ramsey and L.F. Lumsden

May 2018

Arthur Rylah Institute for Environmental Research
Technical Report Series No. 293

Arthur Rylah Institute for environmental research

VICTORIA State Government | Environment, Land, Water and Planning

Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.ari.vic.gov.au

Citation: Nelson, J.L., Scroggie, M.P., Durkin, L.K., Cripps, J.K., Ramsey, D.S.L. and Lumsden, L.F. (2018). Estimating the density of the Greater Glider in the Strathbogie Ranges, North East Victoria, with an assessment of coupes scheduled for timber harvesting in 2018. Arthur Rylah Institute for Environmental Research Technical Report Series No. 293. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Front cover photo: Greater Glider (Steve Smith, Hume Region, DELWP, 2017).

Printed by Melbourne Polytechnic-Preston

ISSN 1835-3827 (print)
ISSN 1835-3835 (pdf))
ISBN 978-1-76077-130-0 (Print)
ISBN 978-1-76077-131-7 (pdf/online/MS word)

Accessibility

If you would like to receive this publication in an alternative format, please telephone the DELWP Customer Service Centre on 136 186, email customer.service@delwp.vic.gov.au or contact us via the National Relay Service on 133 677 or www.relayservice.com.au. This document is also available on the internet at www.delwp.vic.gov.au

Estimating the density of the Greater Glider in the Strathbogie Ranges, North East Victoria

With an assessment of coupes scheduled for timber harvesting in 2018

Jenny L. Nelson, Michael P. Scroggie, Louise K. Durkin, Jemma K. Cripps, David S. L. Ramsey and Lindy F. Lumsden

Arthur Rylah Institute for Environmental Research
Technical Report Series No. 293

Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
Heidelberg, Victoria

Acknowledgements

This project was funded by the Department of Environment, Land, Water and Planning (DELWP) On-ground Actions initiative – Urgent Actions fund. We thank Adrian Moorrees (Biodiversity Division, DELWP), Rod Taylor (Environment and Community Programs, DELWP) and Kim Lowe (Arthur Rylah Institute for Environmental Research (ARI), DELWP) for facilitating this funding.

Bertram Lobert (Strathbogie Sustainable Forest group) provided information about the study area and some logistic support throughout the project.

Steve Smith and Dan Pendavingh (Hume Region, DELWP), and Lucas Bluff (Gippsland Region, DELWP) provided information about their Greater Glider survey methodology and unpublished survey data. Steve Smith also provided invaluable assistance in the field during habitat assessments.

Andrew Bennett and Graeme Newell (both ARI) provided comments on earlier versions of this report.

We gratefully acknowledge the contributions of the people and organisations named above.

Contents

Tables

Figures

Summary

Context:

The Greater Gilder (*Petauroides volans*) has undergone substantial declines in abundance throughout much of its range in recent decades. There is currently insufficient information to assess abundance or density of Victorian populations for management purposes. Recent Greater Glider records from the Strathbogie Ranges suggest that this isolated population may not have declined to the same extent as populations elsewhere in the state.

Aims:

Timber harvesting is currently planned for three coupes containing Greater Glider habitat within the Strathbogie Ranges, with harvesting commencing in February 2018. We undertook surveys within these coupes prior to harvesting, and elsewhere in the Strathbogie Ranges: a) to determine how the density of Greater Gliders within the three coupes compares to densities elsewhere in the Strathbogie Ranges; b) for comparison with historical survey data from the 1980s to provide insight into whether the Strathbogie Ranges population has declined; and c) to examine the relationship between densities of Greater Gliders and key habitat attributes including availability of hollow-bearing trees and preferred food plant species.

Methods:

Surveys were undertaken between October and December 2017 within the proposed logging coupes, and at a random sample of 16 locations elsewhere in the Strathbogie Ranges. Two observers searched a 500 m, off-track spotlight transect at each location, with three transects in each coupe. We used mark-recapture distance-sampling to estimate densities while allowing for imperfect detection of Greater Gliders. Habitat attributes were also surveyed at each site. Poisson regressions were used to assess the relationships between the relative abundance of Greater Gliders and habitat attributes.

Results:

One hundred and twenty-one Greater Gliders were observed across 25 transects, with the number observed per transect ranging from 0–14. The mean detection rate was 6.3 individuals per transect (range 1–14) within coupes, and 4.1 individuals per transect (range 0–10) at randomly selected locations outside coupes. Only 21% of all Greater Gliders detected during surveys were seen by both observers, indicating a low detection probability. Using mark-recapture distance sampling, we estimated a total population of 69,000 Greater Gliders across the Strathbogie Ranges, with approximately 500 individuals inhabiting the area encompassed by the three coupes. Slightly higher density estimates were recorded within the coupes compared to elsewhere, but this difference was not statistically significant. Overall, Greater Gliders occur at mean densities of 2–4 individuals per hectare across the study area. We found significant positive relationships between the abundance of Greater Gliders and tree size, and between the basal areas of Blue Gum (*Eucalyptus globulus bicostata*) and Mountain Gum (*E. dalrympleana*). There was a significant, negative relationship with the basal area of Broad-leaved Peppermint (*E. dives*). We found no significant difference in the mean number of Greater Gliders per km from spotlight counts conducted in 1983 (mean = 3.5 individuals per km), compared with the current surveys (mean = 5.7 individuals per km).

Conclusions and implications:

Our results support the contention that a large and regionally important population of the Greater Glider occurs in the Strathbogie Ranges. Our results are also consistent with the hypothesis that the Strathbogie Ranges population has not declined to the extent that has been observed elsewhere in Victoria. Our raw counts of Greater Gliders, together with our density estimates show that many areas of the Strathbogie Ranges (including the three coupes) would exceed the high-density threshold that would invoke timber harvesting prescriptions in East Gippsland. The low detectability of individual Greater Gliders reveals that raw spotlight counts may greatly underestimate densities. We recommend the use of our mark-recapture distance sampling method for future Greater Glider surveys to allow unbiased and accurate estimation of density for survey, monitoring and management purposes. Further surveys in other areas of the species' range are recommended to determine overall patterns of variation in abundance, and to provide a solid baseline for future monitoring of Greater Glider populations for conservation risk assessment. This will also provide information to help assess the effectiveness of management interventions aimed at improving the conservation status of Greater Glider populations.

1 Introduction

The Greater Glider (*Petauroides volans*) has a broad distribution in eastern Australia, occurring along the east coast of the mainland from central Queensland to central Victoria (Woinarski et al. 2014). It is a forest-dependent species that has undergone substantial declines in recent decades throughout much of its range (TSSC 2016). Why the species has declined so rapidly remains unclear and appears to vary between regions, although a range of factors have been proposed including habitat loss and fragmentation, bushfire, planned burning, timber harvesting, hyper-predation by owls, extreme heat events and drought (Lindenmayer et al. 2011, TSSC 2016, SAC 2017). Although once considered common in the eucalypt forests of eastern Victoria and higher rainfall areas of the midlands, it is now classified as Vulnerable on the Advisory List of Threatened Fauna (DSE 2013), and was recently listed as Threatened under the Flora and Fauna Guarantee Act 1988 (SAC 2017). It is also listed as Vulnerable under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (TSSC 2016).

Greater Gliders are folivores with a diet consisting almost entirely of eucalypt leaves (Kavanagh 1984, Kavanagh and Lambert 1990, Henry 1995). They occupy small home ranges (1–4 ha), which for males are largely non-overlapping (Henry 1984, Pope et al. 2004), and require large tree hollows for shelter and breeding. Large diameter, tall trees are preferred, with each animal using multiple den trees within its home range (Kehl and Borsboom 1984, Lindenmayer et al. 2004, Smith et al. 2007). Greater Gliders have high site fidelity and dispersal appears to be limited (Suckling 1982, Taylor et al. 2007). They have a low reproductive rate, producing one young annually, and not all adult females breed each year (Tyndale-Biscoe and Smith 1969a). Together, these characteristics make Greater Glider populations particularly sensitive to disturbances including extensive bushfire, timber harvesting, planned burning, and forest fragmentation. In Victoria, much of their range is subject to forest management activities including timber harvesting and planned burning. However, the extent to which these processes are negatively impacting Greater Glider populations is likely to vary depending on the forest type, disturbance history and management regime.

Other than in East Gippsland, where prescriptions for protecting high density populations were formulated over 20 years ago (NRE 1995), there are no specific management actions currently being implemented in Victoria for the species' conservation. Collation of available survey data has revealed that for many areas of Greater Glider habitat, information that would allow a credible and robust assessment of current densities is lacking. Information on current densities is needed to identify areas where Greater Gliders are persisting, can be used to identify factors driving declines, and to identify populations at greatest risk. Accurate and reliable density estimates are also critical to guide the formulation of appropriate on-ground actions for Greater Glider conservation, and to monitor population responses to management actions.

Recent surveys have indicated that the Strathbogie Ranges, North East Victoria, are an important area for the Greater Glider (Strathbogie Forest Citizen Science Project 2017, S. Smith and D. Pendavingh Hume Region, DELWP, unpublished data). The high numbers of gliders recorded in parts of the Strathbogie State Forest during these surveys suggest that this population may not have experienced the same extent of declines witnessed elsewhere in the state (SAC 2017). Timber harvesting is planned for some areas of Greater Glider habitat within this region, with three coupes scheduled for harvest, commencing in February 2018. In the Strathbogie State Forest, the single-tree selection method of harvesting will be applied involving low-intensity removal of individual or small groups of trees (VicForests 2017a). As these coupes are within areas where recent surveys indicate high densities of Greater Gliders occur (Strathbogie Forest Citizen Science Project 2017), the planned harvesting operations may have a significant impact on the local glider population.

The aim of this project was to determine the densities of Greater Gliders, and key habitat elements related to the species' foraging and denning requirements, within the three coupes scheduled for harvesting in comparison to the rest of the Strathbogie Ranges. Surveys to determine local densities of Greater Gliders were undertaken within the coupes and more broadly throughout the Strathbogie Ranges using a survey protocol and analytical framework developed with the intention of ensuring a credible and robust assessment of Greater Glider density. The density estimates obtained will provide a benchmark for current densities of the Greater Glider throughout the study area. Understanding how the density of gliders within the coupes compares to densities elsewhere in the Strathbogie Ranges will place our assessment of Greater Glider abundances on these coupes in context and provide a basis for assessing their relative value to the local Greater Glider population. Historical survey data from the 1980s were also scrutinised to provide some insight into whether the Strathbogie Ranges population has undergone the marked declines that have been witnessed in other areas of the species' range.

2 Methods

2.1 Study area

The Strathbogie Ranges (36°48’ S, 145°45′ E) are comprised of undulating plateau and moderate to steep slopes within the Great Dividing Range, approximately 150 km north-east of Melbourne. The Strathbogie massif has been largely cleared, either for agriculture or for softwood (*Pinus radiata*) plantations. The higher plateau and steep escarpments remain forested but are now isolated from the more extensive forests of the Great Dividing Range to the south and east (Marshall 2007). The elevation ranges from approximately 300 m to 1033 m at Mount Strathbogie (36° 55' 37" S, 145° 55' 24" E). The average annual rainfall is 965 mm (Strathbogie weather station, Bureau of Meteorology Online Climate Statistics http://www.bom.gov.au).

The majority of remnant native vegetation in the Strathbogie Ranges occurs on public land (Strathbogie State Forest, 21,214 ha) and is mostly comprised of the Ecological Vegetation Class (EVC) Herb-rich Foothill Forest. This medium to tall (25–30 m) open forest type occurs on relatively fertile, moderately well-drained soils in areas of moderate to high rainfall. It favours sheltered easterly and southerly aspects mainly on lower slopes and gullies. Common overstorey species include Narrow-leaved Peppermint (*Eucalyptus radiata*), Broad-leaved Peppermint (*E. dives*), Blue Gum (*E. globulus bicostata*), Mountain Gum (*E. dalrympleana*), Messmate Stringybark (*E. obliqua*), and Manna Gum (*E. viminalis*). The Heathy Dry Forest and Grassy Dry Forest EVCs are also major components of the vegetation cover, generally occurring on the drier north and west facing aspects and ridge-tops on free-draining soils. These are low to medium height forests to 20 m tall. Common overstorey species include Broad-leaved Peppermint, Red Stringybark (*E. macrorhyncha*) and Long-leaved Box (*E. goniocalyx*) (Marshall 2007).

2.2 Survey design

The survey was designed with the aim of obtaining estimates of the mean density and abundance of the Greater Glider within the Strathbogie Ranges, while also obtaining separate estimates of density on the three logging coupes (Barjarg Flat - coupe number 411-501-0002, Mr Hat - coupe number 412-505-0002, and Tartan - coupe number 412-504-0002; VicForests 2017b). To this end, a stratified random sampling approach was used to allocate survey units (in this case, line transects) across the study area.

The entire area of the Strathbogie Ranges was overlaid with a grid of squares, each 2 km by 2 km (4 km^2). Only grid cells containing mapped EVCs on public land were considered for sampling. A random sample of 50 grid squares was selected to be surveyed for Greater Gliders. The probability of inclusion of grid squares in the random sample was weighted by area of native vegetation (based on mapped EVCs) to ensure that squares with a higher proportion of native forest were more likely to be selected. The grid cells containing the three logging coupes were deliberately excluded from the random site selection, as line transects were manually allocated to these areas (see below).

Within each of the randomly selected grid squares (outside the coupes), a 500 m line transect was established. Placement of the line transects was random, but constrained such that the transect was entirely located within native forest vegetation, and either crossed or touched a mapped road. The first constraint (native forest only) avoided inclusion of presumed unsuitable pine plantation and cleared land in the surveys – i.e. we assumed *a priori* that these habitats would not contain Greater Gliders (Tyndale-Biscoe and Smith 1969a, Pope et al. 2004, Lindenmayer et al. 2011). The second constraint on transect placement (proximity to a road) was used to ensure ease of access and safety for field teams carrying out the surveys. For each randomly selected grid square, four contingency transects were established. This was done to ensure a level of redundancy in the survey design. If the first selected transect in a grid square proved to be unsafe, inaccessible or otherwise unsuitable for survey, a substitute transect was selected from one of the three available contingency transects.

The northern half of the Strathbogie Ranges, north of approximately Watkins Rd (latitude 36° 49’ 20” S), contains drier forest communities, including a mix of EVCs such as Heathy Dry Forest and Grassy Dry Forest. These vegetation types are considered less suitable for Greater Gliders (Bennett et al. 1991, Henry 1995). To ensure a greater survey effort in areas more likely to be occupied by Greater Gliders, only half of the randomly selected grid squares in the north were sampled. The southern half of the ranges contains predominately Herb-rich Foothill Forest, where timber harvesting activities are focused on more productive forest stands. All grid squares were considered available for sampling in this area. Subsequent analyses treated the northern portion of the study area as a separate stratum for the purposes of estimating density and abundance.

Within each of the coupes, three 500 m transect lines were established. The three transects were placed in parallel, and evenly spaced to provide effective survey coverage of the area encompassed by each coupe.

2.3 Greater Glider survey methods

Prior to surveys, each 500 m transect was walked during daylight hours and marked with reflective flagging tape at regular intervals, so that the transect could be easily followed at night. Greater Gliders typically emerge from their dens at least 30 mins after dusk (Henry 1985, Lindenmayer et al. 1991a), so surveys commenced 60 mins after dusk to allow time for animals to leave their dens and commence foraging. Two observers, commencing 15 mins apart, walked the transect, thoroughly searching either side for gliders, using bright handheld torches (Olight M3XS-UT Javelot). Observers aimed to keep to a pace of 15 mins per 100 m. The 15 mins spacing between observers was retained throughout the full length of the transect, providing two independent searches, with the assumption that the animals remained in the same position, or at least the same tree, for this period (see below). For each animal seen, the point location on the transect (GPS coordinate), side of the transect (either left or right), distance from the observer (using a laser rangefinder, Nikon Forestry Pro) and compass bearing to the animal, were recorded. The colour morph of each animal and any distinguishing features were also recorded. If practicable the tree species and height of each animal in the tree were recorded. On completion of the survey the observers walked back along the transect line together, comparing observations on each individual seen. The two observers' data were then combined to determine which gliders had been seen only by observer one or observer two, or by both observers. In almost all cases it was straightforward to determine whether each glider had been seen by observer one, observer two, or by both observers. Where it was not obvious, duplicate observations were determined by carefully comparing the coordinates collected by each observer combined with perpendicular distances of gliders from each sighting using GIS. Individual observers alternated between being observer 1 or observer 2.

The observer glider distances (*D*), and angle between the transect line and the line from the observer to each glider (θ) were converted to a perpendicular distance (*d*) between the glider and the transect using the trigonometric formula:

$$d = D cos\theta$$

For the purposes of the distance sampling analyses (see below) it was necessary to choose only a single distance for inclusion in the analysis in cases where a glider was seen by both observers. When two distances were available for a given glider, we retained the distance estimate where θ was closest to 90° from the transect bearing, as inaccuracies in the measurement of θ will have progressively less effect on the resulting estimates of d as θ approaches 90°.

2.4 Habitat assessments

Habitat attributes likely to be related to the presence and abundance of Greater Gliders were assessed at each site. Habitat assessments aimed to quantify the abundance of the different eucalypt species present (foraging resource) and the size of trees present (Diameter at Breast Height–DBH), including hollow-bearing trees (denning resource) (Henry 1995).

At six points along the transect (0, 100, 200, 300, 400, 500 m), the basal area of each different eucalypt species present was measured using a basal area wedge prism (DECCW 2010). At the same six points along the transect, a point-centred-quarter (PCQ) survey of trees was undertaken (Causton 1988). This survey involved measuring the distance to the nearest tree in each of four 90 degree quadrants around the focal point, using a laser range finder. The DBH of the nearest tree in each quarter was measured using a diameter tape, following protocols in Standards Australia (2009); all sides of the tree were examined with binoculars for the presence of hollows; and trees were identified to species. A hollow was defined as a visible cavity entrance >6 cm in estimated minimum entrance diameter and >140 cm height above ground, as these criteria were considered to characterise cavities potentially used by Greater Gliders (S. Smith Hume Region, DELWP pers. comm.). No tree within 50 m in a quadrant was noted as a missing tree. The PCQ method allowed the density of trees present at each site to be calculated, including the density of hollow-bearing trees.

2.5 Statistical analyses

The standard methodology for analysis of distance-detection data collected on line transects for estimating population density and abundance is conventional distance sampling (CDS, Buckland et al. 2005). This approach involves fitting a mathematical function to the observed distribution of perpendicular distances from the transect line to each animal out to some maximum detection distance (the strip width). If animals are randomly distributed in space in relation to the transect line, the fitted function can be used to infer the number of individuals that missed sampling at increasing distances from the transect line. The corrected number of individuals is then used to estimate animal abundance and density within the area defined by the transect length and twice the strip width. If a set of line transects is located randomly in a geographic area of interest, then statistical sampling theory can be used to extrapolate the statistical inferences regarding density and abundance to the entire area of interest, and to calculate associated measures of statistical uncertainty (coefficients of variation and confidence intervals).

Conventional line-transect distance sampling methods assume that all animals located on the transect line will be detected with certainty by the observer. The high level of variability in the number of Greater Gliders recorded during repeat spotlight counts along line transects in East Gippsland (L. Bluff, Gippsland Region, DELWP pers. comm.) and northeast Victoria (S. Smith and D. Pendavingh, Hume Region, DELWP pers. comm.), together with published accounts of Greater Glider surveys (Lindenmayer et al. 2001, Wintle et al. 2005) suggest that this assumption may not be valid for Greater Gliders. Individual gliders may not be visible in the tree canopy even when close to the observer if they are hidden in thick foliage. Also, as detection of Greater Gliders during spotlight surveys often depends on detection of eye-shine, many individuals may go undetected if their orientation at the time the observer passes does not permit reflection of eye-shine.

Accordingly, use of a conventional distance sampling model that assumes perfect detection of animals located on the transect line was not appropriate. Instead, to properly estimate density and abundance from our distance sampling data we used mark recapture distance sampling (MRDS) (Borchers et al. 1998, Burt et al. 2014). MRDS models combine a conventional distance sampling component fitted to the observed distribution of distances of animals with a mark-recapture component. The mark-recapture component of the model uses the capture histories of each observed animal (seen by observer 1, seen by observer 2, seen by both observers) to infer the likely rate at which animals on the transect line go undetected by both observers. The recent review by Burt et al. (2014) provides a thorough discussion of the methods, including discussion of the use of several alternative variants of MRDS with differing assumptions and data requirements.

Following the decision tree provided by Burt et al. (2014, Figure 8), we elected to use the point-independence MRDS model originally described by Borchers et al. (2006). This variant of MRDS is most appropriate in situations where:

1. Two observers undertake independent searches of the transect with the second observer not receiving any information about the first observer's observations during their survey.
2. Duplicate observations (i.e. animals seen by both observers) can be unambiguously identified.
3. Animals do not move in relation to the transect line during the interval between the two observers' surveys.
4. There is likely to be non-ignorable variability in the detectability of different individual animals at the same distance (capture heterogeneity, Borchers et al. 2006).

These assumptions were either inherent in the design of the survey (assumptions 1–2), explicitly tested during the survey (assumption 3, see below), or judged as likely to be true due to knowledge of the detection process (assumption 4). In the case of assumption 4 (capture heterogeneity), we considered it likely that some Greater Gliders would be inherently more detectable than others during a given survey, due to random, but unmodeled factors such as their locations in tree canopy, or their orientation with respect to the observers and transect line.

The MRDS models also require that probabilities of detection decline with increasing distance. We checked this assumption by constructing histograms of detection distances, and left-truncated the distances where necessary. Outlying extreme distances were also truncated from the dataset to avoid the excessive influence that a few extreme values can have on the fit of the distance function. The truncated distances were then binned into 20 m increments to smooth peaks and troughs that were apparent in the raw distance data.

The point-independence MRDS model was fitted to the repeat detection data using the *R* package *mrds* (Laake et al. 2017). Models with alternative distance-detection key functions (half-normal, hazard-rate) and with and without cosine adjustment terms were fitted, and compared using Akaike's Information Criterion (AIC, Burnham and Anderson 2002).

Goodness of fit of the selected model was assessed by comparing expected and observed numbers of detections in binned distances from each observer, and for both observers combined using a series of χ^2 tests conducted with the *dht.gof* function provided in the package *mrds*. To ensure adequate goodness of fit, detection data were binned into progressively wider distance classes to smooth out the distribution of distances such that they better conformed to the fitted distance function model.

2.5.1 Testing of non-movement assumption

The MRDS model assumes that the distances of individual animals from the line transect do not change between the times of survey by the two observers. We conducted limited testing of this assumption by observing a subset of gliders during surveys, with the aid of a thermal imaging camera (FLIR model E60, FLIR Systems Australia Pty Ltd., Mulgrave, Victoria).

During these tests a third observer accompanied observer 1. When observer 1 detected a Greater Glider, the third observer remained close by, but out of view of observer 2. While observer 1 continued along the transect and until observer 2 arrived, the third observer quietly observed the Greater Glider in darkness, using the thermal imaging camera, noting and estimating the distances of any movements within and between trees.

2.5.2 Associations with habitat variables

A selection of habitat variables (see section 2.4) assessed on the transects were examined to determine the relationships between these variables and transect-level abundances of Greater Gliders. Variables assessed included: mean tree DBH, proportion of trees >50 cm DBH, >75 cm DBH, and >100 cm DBH, density of hollow-bearing trees, and the proportion of Narrow-leaved Peppermint, Broad-leaved Peppermint, Mountain Gum, Messmate and Blue Gum. We used single-variable Poisson regressions to test the influence of each of the variables on the number of Greater Gliders detected, with the number of gliders counted on each 500 m transect as the dependent variable.

2.5.3 Comparison with historical data

To gain insights into potential changes in Greater Glider abundance in the Strathbogie Ranges population over time, records of the species obtained during surveys in the area in the 1980s were scrutinised. These records are publicly available on the Victorian Biodiversity Atlas (VBA). To determine density, or the relative abundance of animals seen during these surveys requires that the survey effort (i.e. the length of the spotlight transect and duration of the survey) was recorded. However, this information could not be extracted from the VBA. Instead, we obtained historical spotlight transect data from original datasheets for surveys undertaken by the Arthur Rylah Institute for the Land Conservation Council (LCC) in 1983 (LCC 1984) held by a member of the original LCC survey team (L. Lumsden). These historical data did not include distance from transect information, and were largely obtained from spotlight surveys conducted along roads and tracks. Therefore, it was not possible to analyse the historical data using distance sampling, and issues of detection had to be ignored. Instead, we conducted a simple comparison between the numbers of gliders seen per spotlight km in the historical data set, and the numbers of gliders seen per spotlight km during the current surveys.

3 Results

3.1 Survey results

Surveys for Greater Gliders were undertaken on a total of 25 transects between 9 October and 13 December 2017. Nine transects were surveyed in the three coupes (three transects per coupe) scheduled for harvesting (Barjarg Flat, Mr Hat and Tartan), and 16 randomly selected transects outside the coupes in the remainder of the Strathbogie Ranges (Figure 1).

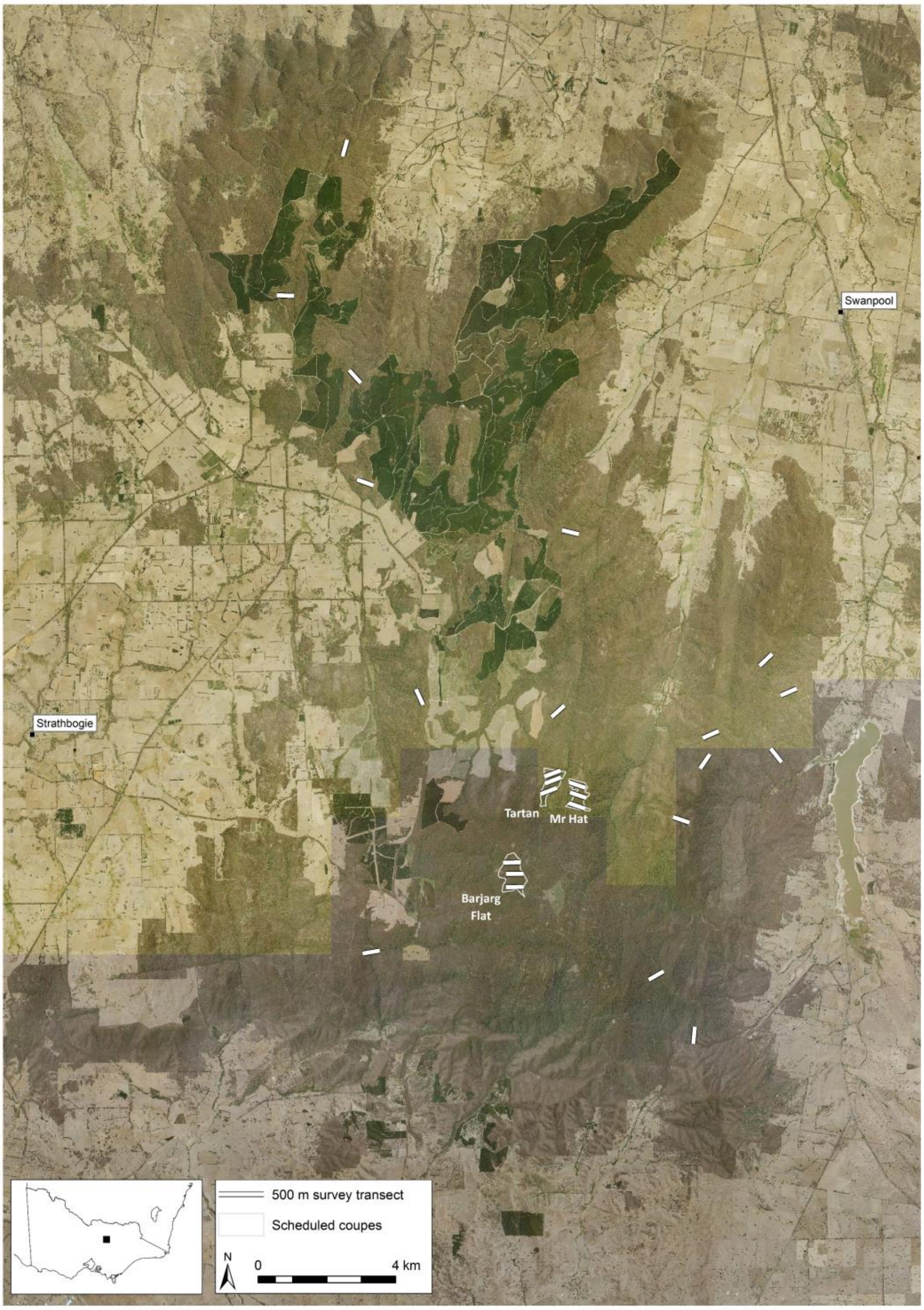

Figure 1. The locations of 25 line transects surveyed for Greater Gliders, including nine transects within three coupes (Barjarg Flat, Tartan and Mr Hat), Strathbogie Ranges, October–December 2017.

Paler green areas are native vegetation, dark green areas are softwood plantations.
Source: DELWP aerial imagery, December 2015.

One hundred and twenty-one individual Greater Gliders were observed on the 25 transects. The number of Greater Gliders detected varied from 0–14 per transect. No Greater Gliders were seen on four transects (16%), while more than five gliders were detected on nine transects (36%). The double-observer method of surveying revealed that on average, only 21% of the total number of gliders detected on the transects were seen by both observers. The remaining 79% of gliders were only seen by a single observer.

Other mammal species detected included: Koala (*Phascolarctos cinereus*, 23 transects, 92% of sites), Common Ringtail Possum (*Pseudocheirus peregrinus*, 12 transects, 48%), Mountain Brushtail Possum (*Trichosurus cunninghami*, 10 transects, 40%), Common Brushtail Possum (*T. vulpecula*, 3 transects, 12%), Sugar Glider (*Petaurus breviceps*, 4 transects, 16%), and Feathertail Glider (*Acrobates spp*., 1 transect, 4%). Overall, there were 207 individual arboreal mammals detected across all transects. Greater Gliders made up 59% of detections, followed by Koala (14.5%), Common Ringtail Possum (13%), Mountain Brushtail Possum (8%), Sugar Glider (3%), Common Brushtail Possum (2%) and Feathertail Glider (0.5%).

The mean number of Greater Gliders seen on the coupe transects was 6.3 individuals per 500 m transect, equivalent to a sighting rate of 12.6 individuals per km (Table 1). This was a somewhat higher detection rate than was observed on the randomly selected transects elsewhere in the Strathbogie Ranges, which had a mean detection rate of 4.1 individuals per 500 m transect, equivalent to 8.3 individuals per km (Table 2).

Table 1. The number of Greater Gliders detected on three transects (T1–T3) in each of the three coupes (Barjarg Flat, Mr Hat, Tartan) surveyed in the Strathbogie Ranges, October–December 2017.

Transect name	No. of individual Greater Gliders seen per 500 m transect	Equivalent numbers per km*
Barjarg Flat_T1	7	
Barjarg Flat_T2	14	
Barjarg Flat_T3	1	
Barjarg Flat total	**22**	**14.7**
Mr Hat_T1	10	
Mr Hat_T2	6	
Mr Hat_T3	5	
Mr Hat total	**21**	**14.0**
Tartan_T1	2	
Tartan_T2	7	
Tartan_T3	5	
Tartan total	**14**	**9.3**
Mean:	**6.3**	**12.6**

* Assuming that twice the number of Greater Gliders would be detected if the transect length was doubled to 1 km.

Table 2. The number of Greater Gliders detected on 16 transects at randomly selected sites in the Strathbogie Ranges, October–December 2017.

Transect name	No. of individual Greater Gliders seen per 500 m transect
36	0
65	0
111	0
176	0
177	1
159	2
157	4
191	4
81	5
161	5
162	5
236	5
114	8
147	8
220	9
201	10
Mean	**4.1**
Equivalent to individuals per km	**8.3**

3.2 Habitat assessments

3.2.1 Eucalypt species

The number of species of eucalypts recorded at each site varied from three to seven, with most sites having either three (28% of sites) or four (56% of sites) different species. Mountain Gum and Manna Gum were not readily distinguishable in the field, so were combined in a single category. However, the majority of these trees were most likely Mountain Gums owing to the elevation and topographical position of the sites (D. Frood pers. comm.) and are hereafter referred to as Mountain Gum, without discounting the possibility that some Manna Gum were present on the sites. Narrow-leaved Peppermint was present at every site and had the highest total basal area of all species, with a mean of 13.8 m^2 per hectare across all transects (range 6–30 m^2 per ha). Blue Gum was also commonly recorded, being present at 21 transects (84%). Blue Gum had a mean basal area of 5.2 m^2 per hectare (range 0–18 m^2 per ha). Other commonly recorded species were Broad-leaved Peppermint (mean basal area = 4.8, range 0–20 m^2 per ha), Mountain Gum (mean basal area = 2.4, range 0–8 m^2 per ha), each being recorded on 52% of the transects (13 transects) and Messmate (mean basal area = 2.9, range 0–14 m^2 per ha).

3.2.2 Tree characteristics

A total of 600 trees (i.e. 24 per site) were measured and visually assessed for hollows. The mean DBH of all recorded trees was 56.0 cm (range 20–236 cm). All sites contained at least some trees with a DBH >50 cm (mean number per transect = 11.7, range 5–20). Ninety-six percent of sites contained trees with a DBH >75 cm (mean number per transect = 4.8, range 1–11), while 76% of sites contained trees with a DBH >100 cm (mean number per transect = 2.4, range 1–7). Only eight of the 600 trees measured (1.3%) had a DBH >150 cm, and none were >250 cm.

Of the 600 trees assessed, 73 were visually confirmed as containing a hollow potentially suitable for a Greater Glider. Dead trees represented 33% of all trees with hollows. The average number of hollow-bearing trees per transect was 2.9 (range 0–9) and only one transect had no hollow-bearing trees detected at any of the six sampling points (i.e. hollow-bearing tree density from the PCQ calculations at this location was less than 4%). Eleven transects (44%) had three or more hollow-bearing trees in the sample. The mean DBH of hollow-bearing trees was 98.9 cm (range 28–236 cm), with 72% of sites containing hollow-bearing trees greater than 100 cm DBH and only 28% of sites with at least one hollow-bearing tree greater than 150 cm DBH. Generally, for all species of eucalypts, hollow-bearing trees were larger than those without hollows (Table 3). Using the PCQ method, the mean density of hollow-bearing trees was 26.7 trees per hectare (range 0–77.4). In comparison, the mean density of all trees was calculated as 229 trees per hectare (range 97–522).

Twenty-five hollow-bearing trees were measured across the nine transects within the three coupes (mean number per transect = 2.7, range 2–6), and 48 hollow-bearing trees were measured on the 16 transects outside of coupes (mean number per transect = 3, range 0–9). Generally, hollow-bearing trees were larger on coupes, with a mean DBH of 117.5 cm (range 28–236) compared with 89.2 cm (range 32.5–180) on the transects outside coupes. The mean density of hollow-bearing trees on coupes (from the PCQ calculations) was 21.9 trees per hectare (range 8.1–37.5) while it was 29.4 trees per hectare (range 0–77.4) in areas outside of the coupes.

Table 3. Mean diameter at breast height (DBH) of dead trees and five common eucalypt species in the Strathbogie Ranges.

Trees are divided into hollow-bearing (n = 73) or non-hollow-bearing (n = 527). Total is the mean DBH of all hollow-bearing and non-hollow-bearing eucalypt species measured.

	Mean DBH of hollow-bearing trees (cm)	Mean DBH of non-hollow-bearing trees (cm)
Broad-leaved Peppermint	None in sample	36.8
Dead tree	78.9	45.9
Narrow-leaved Peppermint	96.0	49.9
Mountain Gum	114.1	61.9
Blue Gum	135.4	56.5
Messmate Stringybark	183.5	65.5
Total	**98.9**	**50.03**

3.3 Estimating densities using distance sampling

A histogram of raw detection distances is given in Figure 2. Examination of the histogram revealed a peak in the distribution of distances displaced somewhat to the right of zero. This suggests that animals close to the transect line are more difficult to see than animals further away, likely due to the angle of the animal relative to the observer (e.g. eyeshine less likely to be seen if animals are directly overhead). Use of this data in a MRDS analysis would violate the assumption that detection probability is maximised at zero distance from the transect. Therefore, gliders observed at distances less than 15 m from the transect line were removed from the dataset for the density estimates. This resulted in the removal of a total of 35 gliders from the analysis. Very few gliders (five) were detected at distances greater than 75 m. These very few detections at extreme distances beyond 75 m were also removed from the analysis. In all, it was necessary to remove these 40 individuals from the total set of 121 gliders detected to ensure that the data were consistent with the distributional assumptions of the analysis and to minimise the influence of extreme distance values on the model fitting process. MRDS models require that the relationships between distance and probability of detection are monotonic-decreasing. As the observed distribution of distances was hump-shaped (Figure 2), deletion of observations on the left-side of the hump was necessary. After removal of the gliders on either side of the truncation distances (15 m and 75 m), 15 m was subtracted from the remaining data to place the minimum detection distance at zero for the purposes of analysis. The remaining distance data were then binned into 20 m distance intervals to smooth out the distribution of distances prior to analysis.

3.3.1 Fitting the distance model

Models with half-normal and hazard rate key functions, and with and without cosine adjustment terms (Buckland et al. 2005) were fitted to the data. Model selection was conducted using Akaike's Information Criterion (AIC, Table 4). The model with a half-normal key function and no cosine adjustment was found to be the most parsimonious amongst those models fitted, and was therefore selected for inferring density and abundance of Greater Gliders.

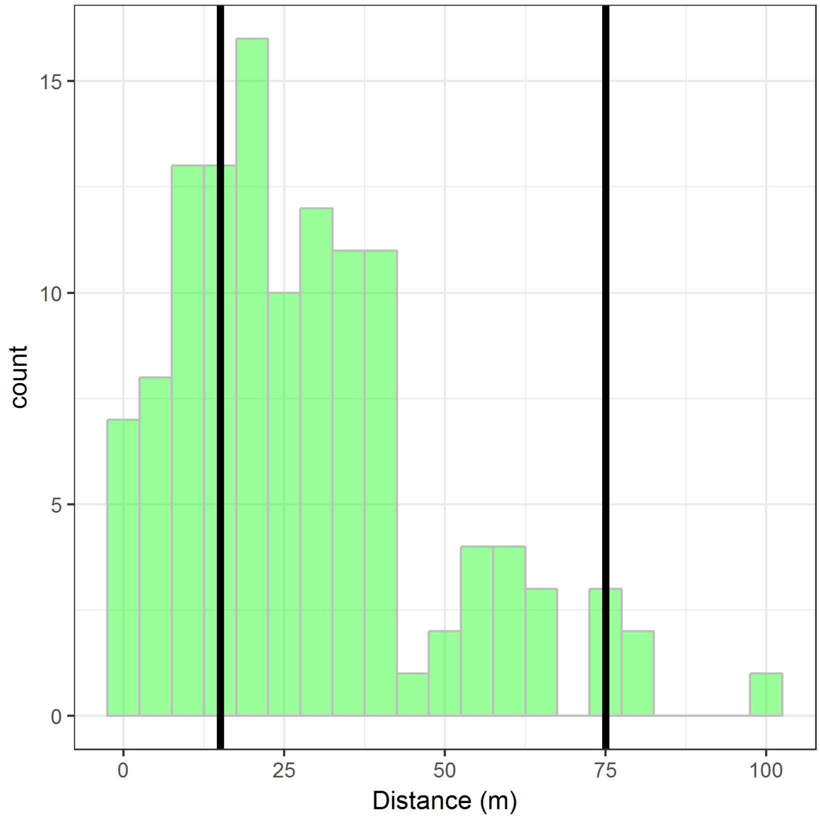

Figure 2. A histogram of raw detection distances of Greater Gliders, binned into 5 m increments.

Note the apparent deficit of detections at distances <15 m, and the very small number of detections at distances >75 m.

Table 4. Model selection results. AIC for each MRDS model is presented. The most parsimonious model is in boldface.

Key	Adjustment	AIC
Half-normal	-	**320.928**
Half-normal	Cos_2	322.8439
Hazard rate	-	327.9294
Hazard rate	Cos_2	322.9788

The fitted detection curves for observer 1, observer 2 and both observers pooled are given in Figure 3. The estimated probability of detection for Greater Gliders at the modelled zero distance from the transect (i.e. at 15 m from the transect once the observations within 0–15 m of the transect line were excluded – see Methods) was substantially less than 1 and was similar for both observers. This indicates that the use of a MRDS approach, which does not assume detection with certainty along the transect line, was justified (Figure 3).

To test if the distribution of the observed distance and detection data were consistent with the fitted statistical model, goodness of fit checks were undertaken. Separate χ^2 tests for the mark-recapture and distance-sampling components of the model were used to compare the observed and expected data, along with a global (omnibus) χ^2 test of overall fit. These tests showed no significant lack of fit of the model to the data

(Table 5). As the χ^2 tests were non-significant ($p>0.05$, Table 5), it was considered appropriate to use the fitted model to derive estimates of density and abundance from the survey data.

Table 5. χ^2 tests for goodness of fit of the half-normal MRDS model to the data.

Separate tests were undertaken to test the fit of the distance-sampling and mark-recapture components of the model, along with an omnibus test of total fit. Non-significant p-values show adequate goodness of fit of the observed data to the statistical model.

Component	χ^2	Degrees of freedom	p
Distance sampling	0.945	1	0.331
Mark recapture	1.236	4	0.872
Total	2.182	5	0.823

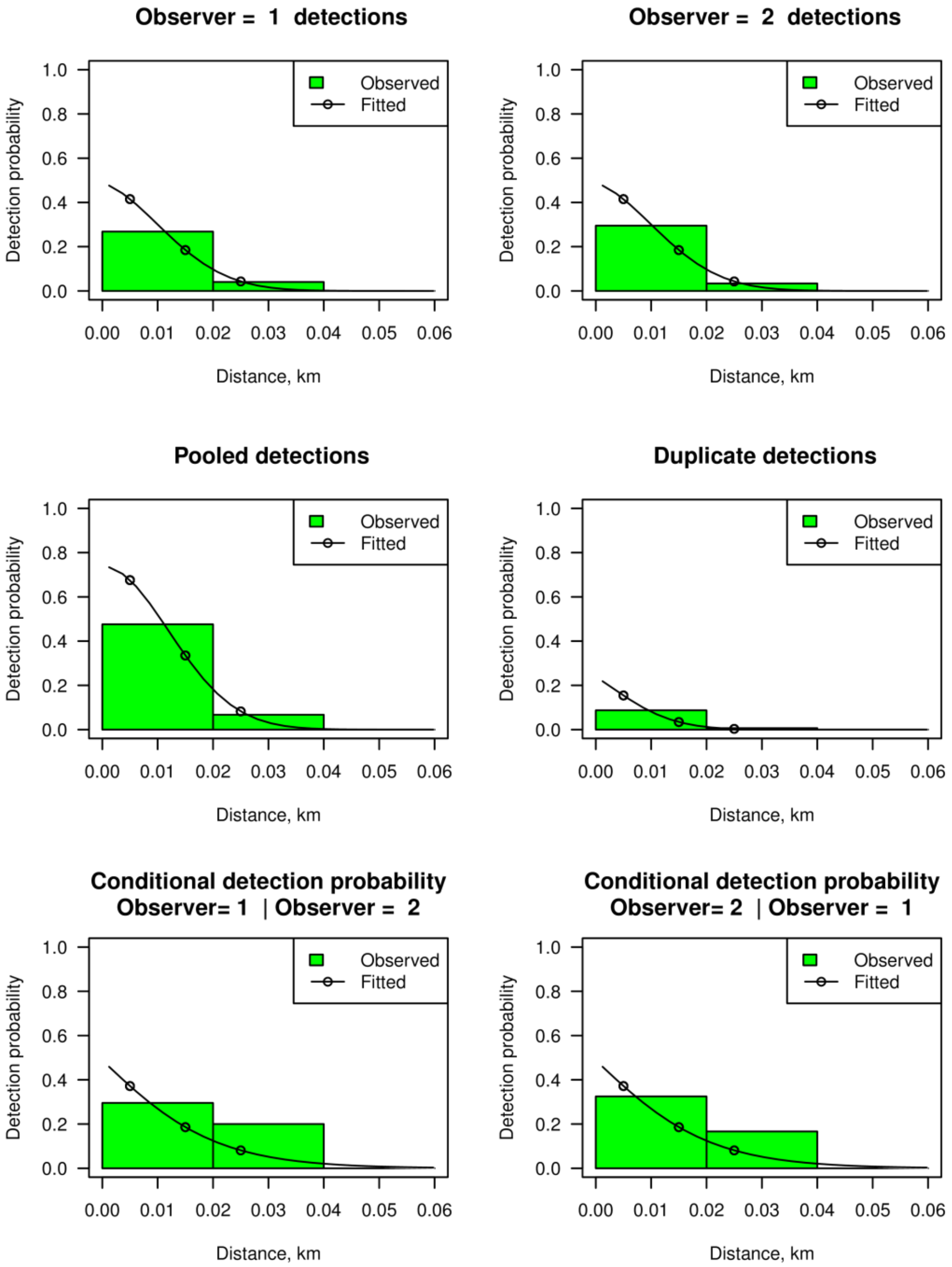

Figure 3. Fitted distance-detection functions for the MRDS model showing the relationship between detection probability and distance from the transect, allowing comparison of observed (filled bars) and expected (black lines) distance distributions.

Left-to-right, top-to-bottom these are: Fitted model for all detections by observer 1, fitted model for all detections by observer 2, fitted model for all detections ("Pooled detections"), fitted model for Greater Gliders seen by both observers ("Duplicate detections"), conditional detection by observer 1, given seen by observer 2, and conditional detection by observer 2, given seen by observer 1. Note that the distances represent 0–60 m from the transect line as used in the model (i.e. once observation from the first 15 m had been removed and therefore they represent the actual distances from the transect of 15–75 m).

3.3.2 Density and abundance estimation

Estimates of abundance were computed from the MRDS model for each stratum in the study area (the coupes, and the northern and southern parts of the Strathbogie Ranges). Two alternative stratification schemes were considered, with the three logging coupes either treated as three separate strata, or treated as a single, combined stratum. Estimates of abundance under the first stratification scheme had very broad confidence intervals for the individual coupes, particularly the Barjarg Flat coupe (Table 6). Under the second stratification scheme, much narrower confidence intervals could be computed for the abundance of gliders in the habitat encompassed by the coupes (Table 7).

Regardless of the stratification scheme, the overall abundance of Greater Gliders in the Strathbogie Ranges was estimated at approximately 69,000, with a 95% confidence interval (hereafter, CI) from approximately 39,000 to 121,000. The abundance of gliders on the three coupes combined (Table 7), was estimated at 503 (95% CI 271–933). These analyses therefore indicate that the proportion of the total Strathbogie Ranges population of Greater Gliders resident on the three logging coupes at the time of survey is unlikely to be more than 1% of the total population.

Estimates of density and abundance for the Northern stratum were very imprecise (Tables 6 and 7, Figure 4). The estimates for this stratum were based on surveys of a very small number of transects (four).

The point estimate of the density of gliders on the coupe stratum (3.8 individuals per hectare, 95% CI 2.0–6.9) was slightly higher than elsewhere in the Strathbogie Ranges (2.8 individuals per hectare, 95% CI 1.6–4.7), although the confidence intervals overlapped substantially (Figure 4). All point estimates of density for Greater Gliders were between two and four individuals per hectare, regardless of the stratification scheme adopted (Figure 4).

Table 6. Estimated abundances of Greater Gliders within three coupes (Barjarg Flat, Mr Hat, Tartan), areas outside the coupes (North and South) and throughout the Strathbogie Ranges (Total).

SE – standard error, CV – coefficient of variation, 95% CI – 95 % confidence interval. Separate abundance estimates are given for each of the three logging coupes.

Stratum	Estimated number of Greater Gliders	*SE*	*CV*	*95% CI*
Barjarg Flat	258	140	0.54	47 – 1,423
Mr Hat	142	72	0.51	29 – 689
Tartan	115	33	0.29	60 – 219
South	61,081	16,919	0.28	35,321 – 105,628
North	7,618	7,878	1.03	251 – 230,724
Total	69,214	19,762	0.29	39,307 – 121,876

Table 7. Estimated abundances of Greater Gliders across the three coupes (Barjarg Flat, Mr Hat, Tartan) combined and areas outside coupes (North and South) within the Strathbogie Ranges.

SE – standard error, CV – coefficient of variation, 95% CI – 95 % confidence interval.

Stratum	Estimated number of Greater Gliders	*SE*	*CV*	*95% CI*
Coupe	503	154	0.31	271 – 933
South	61,081	16,920	0.28	35,321 – 105,628
North	7,618	7,878	1.03	252 – 230,724
Total	69,045	19,661	0.29	39,407 – 120,971

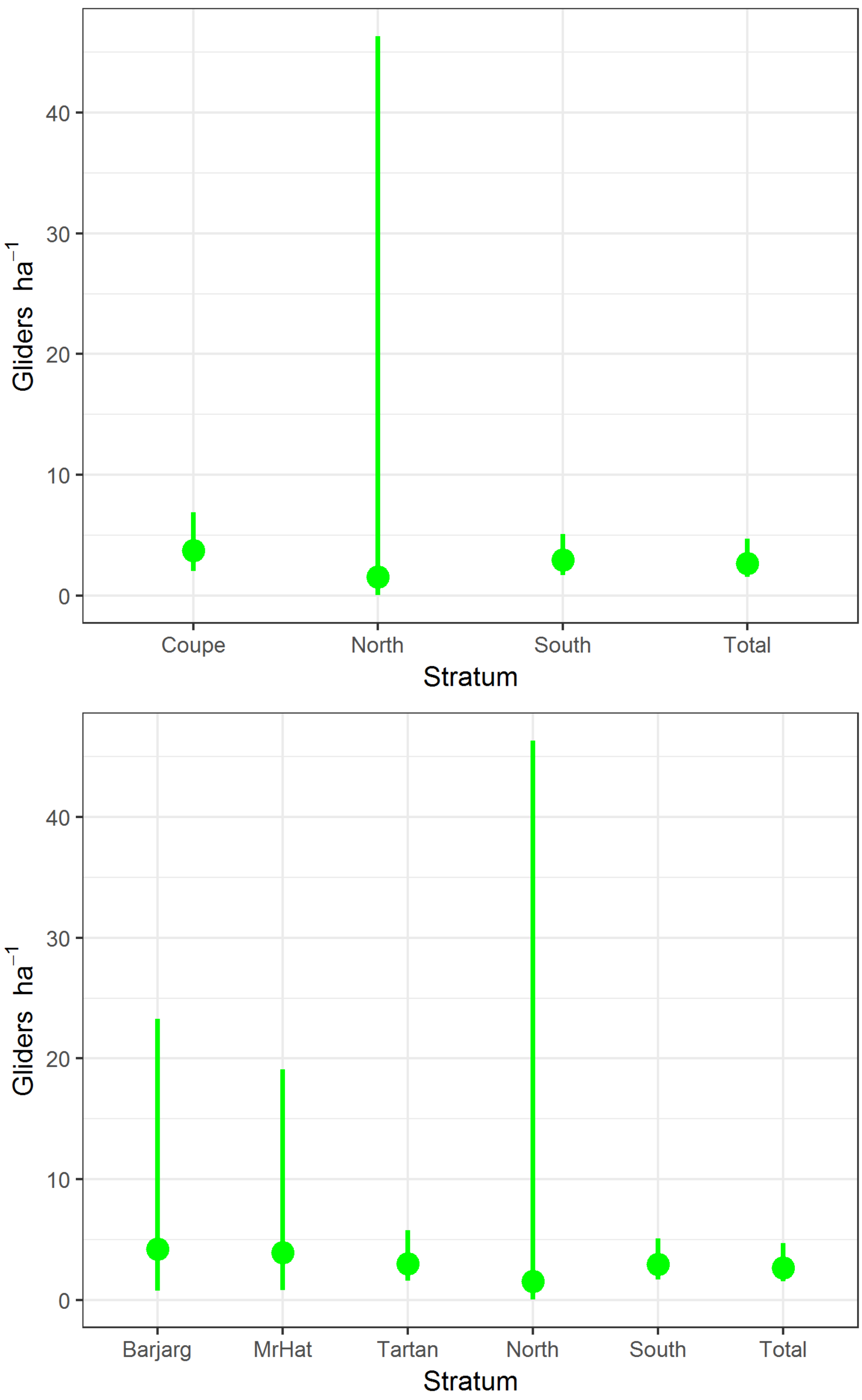

Figure 4. Estimated densities of Greater Gliders within three coupes (Barjarg Flat, Mr Hat, Tartan), two areas outside the coupes (North and South) and throughout the Strathbogie Ranges (Total).

Two alternative stratification methods are used for the two sets of estimates, either treating each of the three logging coupes separately (bottom panel), or combining the three coupes into a single aggregated stratum (top panel). Error bars are 95% confidence intervals on the means. The average density estimate for the Coupe stratum was 3.8 individuals per hectare, 95% CI 2.0–6.9, and the overall estimated mean density across the entire Strathbogie ranges was 2.8 individuals per hectare, 95% CI 1.6–4.7).

3.3.3 Testing of non-movement assumption

Four Greater Gliders were observed as a preliminary test of the non-movement assumption. The gliders were observed with a thermal camera during the time interval between the passage of the first and second observers along the transect (approximately 15 minutes). Of these four Greater Gliders, one remained stationary for the entire observation period. The other three individuals undertook limited movement, but remained within the same tree, and no individual was observed to move more than approximately 4 m during the observation period.

3.3.4 Associations with habitat variables

The results of a series of simple univariate Poisson regressions, relating the raw detection data (total number of Greater Gliders detected) to selected habitat variables are given in Figures 5, 6 and 7. The analyses detected weak, and marginally significant associations between the abundance of Greater Gliders, and several measures of availability of large, old trees (Figure 5). Of the four large-tree availability measures considered, the strongest relationships were with mean tree DBH ($p = 0.05$), and with the proportion of sampled trees with DBH >100 cm ($p = 0.063$, Figure 5).

The relationship between the density of hollow-bearing trees (as defined in the Methods) and abundance of Greater Gliders was non-significant ($p = 0.71$, Figure 6).

The analyses confirmed the presence of some strong positive and negative associations between Greater Glider abundance and the basal area of several eucalypt species (Figure 7). There was a strongly positive relationship between the abundance of Greater Gliders and the basal area of both Mountain Gum ($p = 0.02$) and Blue Gum ($p = 0.034$). In contrast, the relationship between the abundance of Greater Gliders and Broad-leaved Peppermint was strongly negative ($p = 0.0014$). There was no significant relationship with Narrow-leaved Peppermint ($p = 0.72$) or Messmate ($p=0.62$, Figure 7).

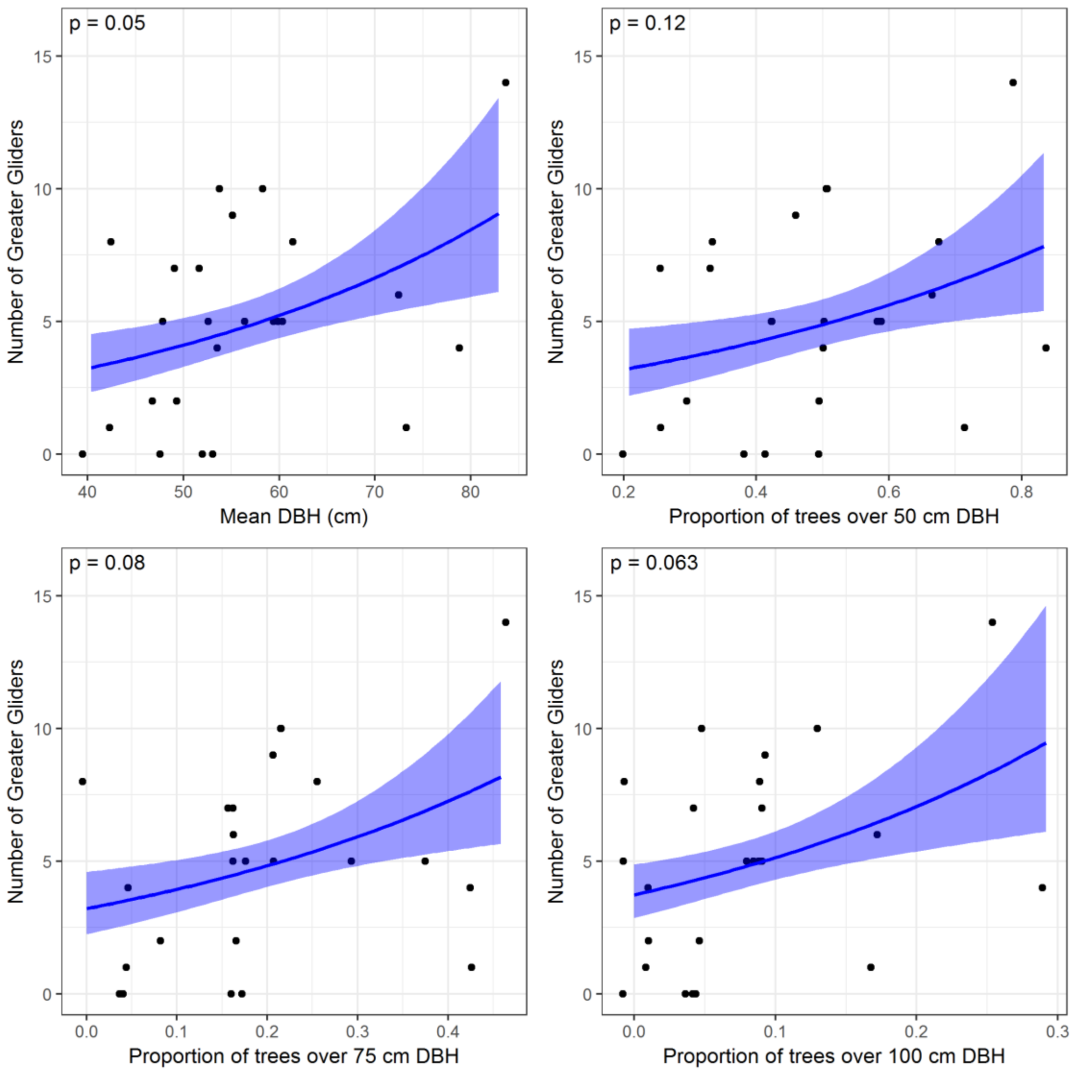

Figure 5. Association between abundance of Greater Gliders and the proportion of trees in four categories (mean DBH, DBH >50 cm, >75 cm, >100 cm), in the Strathbogie Ranges.

The p-values are for the slopes of the Poisson regressions fitted to the data. The shaded area on the fitted model encompasses one standard error around the fitted model.

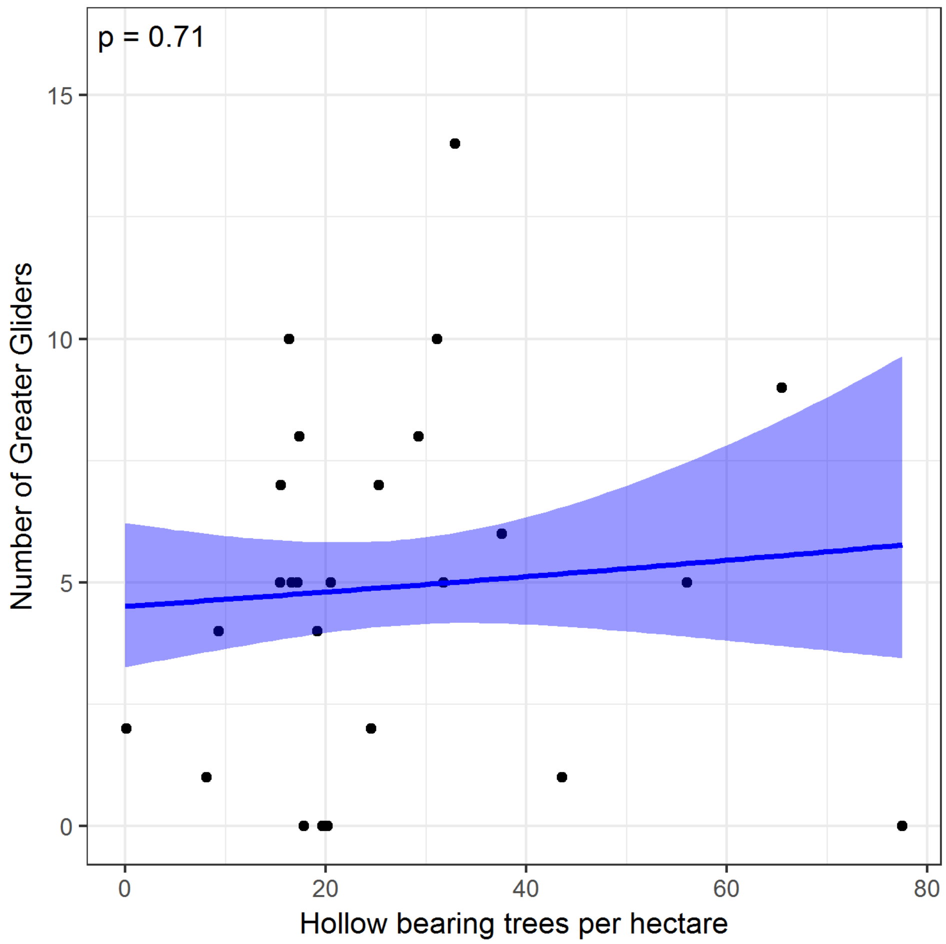

Figure 6. Association between the abundance of Greater Gliders and the density of hollow-bearing trees on survey transects, Strathbogie Ranges.

The density of hollow-bearing trees was calculated using the point-centred-quarter method. The p-values are for the slopes of the Poisson regressions fitted to the data. The shaded area on the fitted model encompasses one standard error around the fitted model. Only trees with hollows as defined in the methods are included in these estimates.

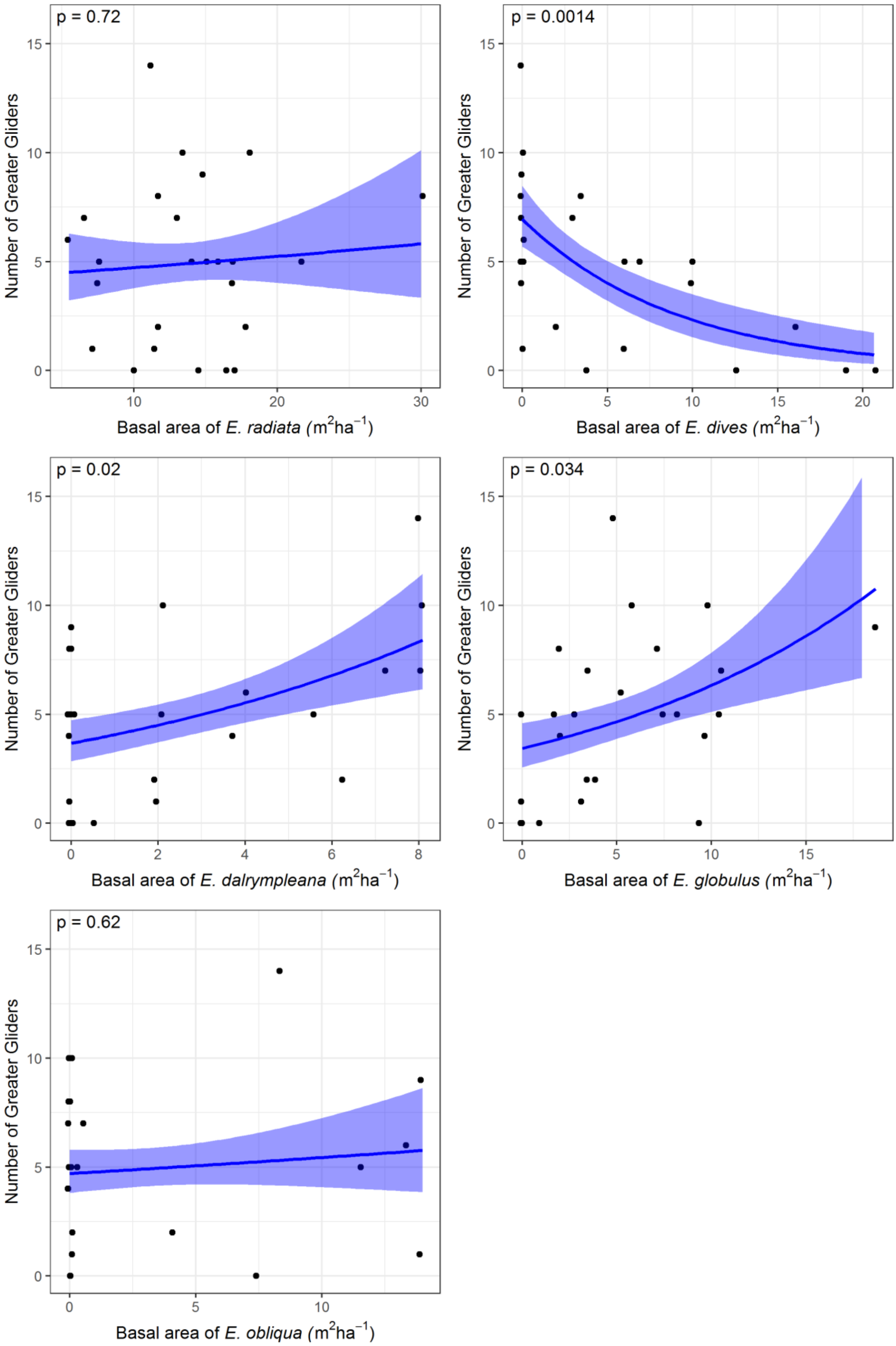

Figure 7. Association between abundance of Greater Gliders and the basal area of Narrow-leaved Peppermint (*Eucalyptus radiata*), Broad-leaved Peppermint (*E. dives*), Mountain Gum (*E. dalrympleana*), Blue Gum (*E. globulus bicostata*) and Messmate Stringybark (*E. obliqua*) present on survey transects in the Strathbogie Ranges.

The p-values are for the slopes of the Poisson regressions fitted to the data. The shaded area around the fitted regression lines encompasses one standard error.

3.3.5 Comparison with historical data

A comparison of the numbers of Greater Gliders per kilometre from spotlight counts conducted in 1983 and the present study is given in Figure 8. Twenty-three spotlight transects were conducted by foot along tracks in 1983, which resulted in the detection of an average of 3.46 Greater Gliders per spotlight kilometre. During the current surveys, the mean number of gliders detected was 5.69 per spotlight kilometre. The difference between the means was non-significant ($t_{45} = 1.7381$, $p = 0.089$). As two observers, each fully searching the area individually, were used during the 2017 surveys, while in 1983 a pair of observers worked together each surveying one side of the track (occasionally with just a single observer present), only the sighting data collected by the first observer during the double-observer counts in 2017 was used in this analysis.

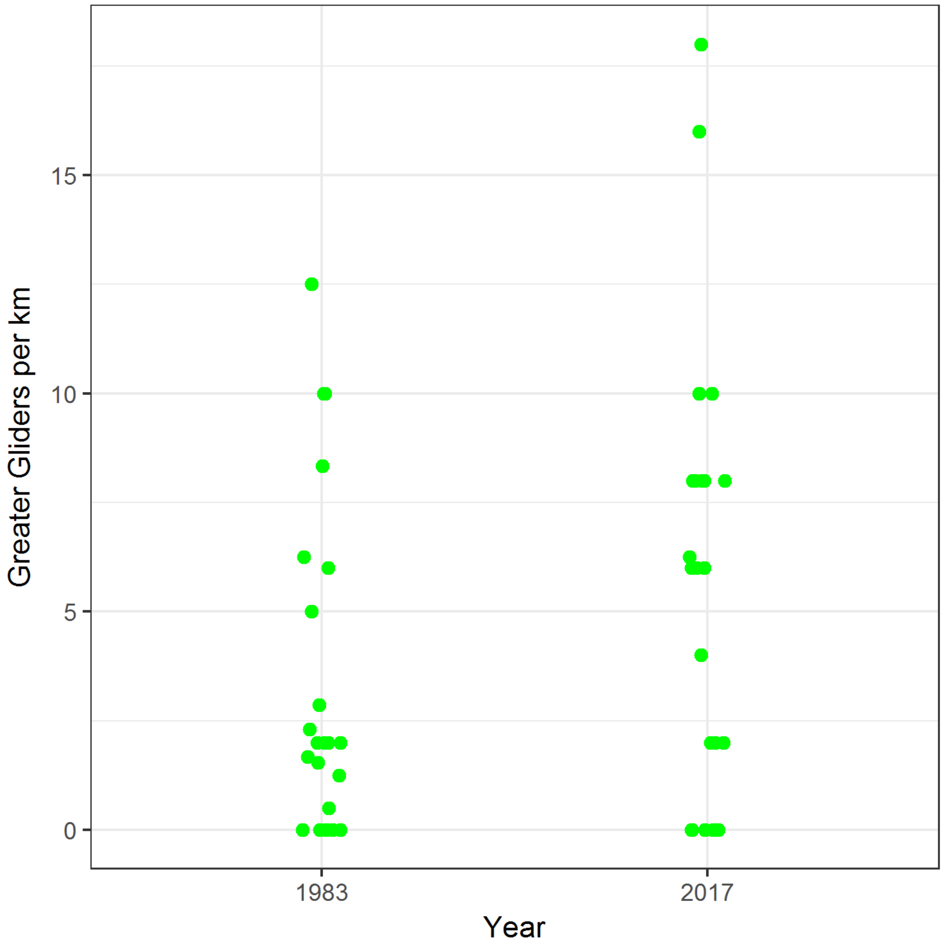

Figure 8. Comparison of historical (1983) and recent (2017) spotlight indices for Greater Gliders in the Strathbogie Ranges.

The index for 2017 is calculated using only gliders detected by the first observer on each transect line. 1983 – mean = 3.46 Greater Gliders per km, 2017 – mean = 5.69 Greater Gliders per km.

4 Discussion

4.1 Greater Glider abundance and density

Our study has used a rigorous survey protocol and analytical technique (MRDS) to estimate the abundance of Greater Gliders in the Strathbogie Ranges, and in three coupes scheduled for timber harvesting in early 2018. We estimated the Strathbogie Ranges population was in the order of 69,000 individuals but with relatively broad confidence intervals (95% CI 39,000–121,000 individuals). This relatively large uncertainty is attributable to the survey transects covering a relatively small proportion of the total area over which our estimates were extrapolated, as well as the uncertainty associated with detecting animals in the areas covered by the transects (i.e. low detection probability). The relatively small amount of sampling effort applied to the Northern stratum resulted in density and abundance estimates with very low precision. Further survey effort in the north of the Strathbogie Ranges would be necessary to address this deficiency.

At the time of the surveys, a substantial number of Greater Gliders were estimated to occur in the three coupes scheduled for timber harvesting (~500 individuals). This represents 0.73% of the estimated total Strathbogie Ranges population. This is proportionately higher than the total area of native forest in the Strathbogie Ranges that is encompassed by these three coupes (i.e. 0.52%). In the future, if additional coupes are harvested, the proportion of gliders impacted may increase.

We estimate that throughout the Strathbogie Ranges, Greater Gliders occur at a density of approximately 2–4 individuals per hectare (i.e. average = 2.8 individuals per hectare, 95% CI 1.6–4.7, Figure 4). Our density estimates for each of the three coupes had poor precision, as the estimate for each coupe was based on a relatively small amount of survey effort (Figure 4). Combining the data from the three coupes into a single stratum resulted in a more precise density estimate of approximately 3.8 individuals per hectare (95% CI 2.0–6.9, Figure 4). Although this was somewhat higher than the density of animals elsewhere in the Strathbogie Ranges, the substantial overlap in the 95% CIs on these density estimates indicate this difference is not statistically significant. Earlier density estimates for some Victorian Greater Glider populations vary from 0.2–2.8 individuals per hectare (Henry 1984, Downes et al. 1997, van der Ree et al. 2004). In East Gippsland, areas with a high relative abundance of Greater Gliders are defined as those where >10 individuals are detected per kilometre of spotlight transect (assuming transects are 50 m wide), or densities of >2 per hectare, or >15 individuals per hour of spotlighting (DSE 2011a). In setting these guidelines, no allowance was made for animals that may be present but not seen. Our raw counts of Greater Gliders in the Strathbogie Ranges, together with our density estimates, reveal that many areas of the Strathbogie Ranges, including the three coupes scheduled for harvesting, would exceed the specified high-density thresholds that apply in East Gippsland. Similarly, raw counts of Greater Gliders on nearly 30% of transects surveyed during the Strathbogie Forest Citizen Science Project (2017) exceeded 10 individuals per kilometre. Our findings further support the suggestion that the Strathbogie Ranges supports a significant population of Greater Gliders in Victoria. It should be noted however, that comparable contemporary data for many other parts of the species' range in Victoria are almost entirely lacking so it is difficult to place the results obtained from our survey of the Strathbogie Ranges into a clear state-wide context.

4.1.1 Greater Glider detectability

Due to their large size, tendency to remain stationary for long periods and bright eyeshine, Greater Gliders are relatively easy to detect by spotlighting (Henry 1995, Lindenmayer et al. 2001, Wintle et al. 2005). However, only 21% of all the gliders detected during this study were seen by both observers. Our results show that the detection probability of gliders on occupied sites (i.e. the proportion of gliders present in the vicinity of a transect at the time of the survey that are actually detected) is relatively low. As a result, reliance on raw spotlight counts will result in potentially severe underestimation of the density and abundance of gliders present at a site. This is consistent with the low detection rates (26%) of radio-collared Greater Gliders, known with certainty to be in the vicinity of a transect, during spotlight surveys reported by Lindenmayer et al. (2001), as well as the high variability in the number of gliders detected during four repeated spotlight counts along transects in East Gippsland (L. Bluff, Gippsland Region, DELWP, unpublished data) and north-east Victoria (S. Smith and D. Pendavingh, Hume Region, DELWP, unpublished data). To produce accurate and reliable estimates of abundance for Greater Gliders, therefore, requires the use of survey methods and analytical techniques that explicitly account for non-detection of a non-negligible proportion of individuals during surveys. We have successfully used MRDS methods to achieve this aim. Our analysis provides strong confirmation that spotlight counts fail to detect a large proportion of Greater Gliders, and that uncorrected spotlight counts can at best be interpreted as a crude index of relative abundance.

4.2 Greater Glider habitat quality

Several species of eucalypts were recorded on all the transects surveyed, including Narrow-leaved Peppermint, a species considered to be preferred by Greater Gliders for foraging at particular times of the year (Kavanagh 1984, Bennett et al. 1991). Although we found no significant positive association between Greater Glider abundance and the abundance of Narrow-leaved Peppermint, this effect may have been masked by the widespread occurrence of this eucalypt species, as it was present on every transect surveyed, and comprised more than 50% of the total basal area of eucalypts on almost half of all the transects. Greater Gliders are known to eat the leaves of many different species of eucalypts but appear to prefer certain species over others depending on the locality (Henry 1995). This preference for the leaves of particular eucalypt species has been related to the levels of nutrients in the foliage, particularly nitrogen, avoidance of toxic metabolites, and the availability of young leaves which are an important and preferred component of the diet (Kavanagh 1984, Henry 1985, Kavanagh and Lambert 1990, Jensen et al. 2015). An increased diversity of eucalypt species may also be important as it increases the likelihood of a constant supply of young foliage (Henry 1985, Moore et al. 2004). We found significant positive relationships between the abundance of Greater Gliders and the basal areas of Blue Gum and Mountain Gum. Within the Strathbogie Ranges, Blue Gum and Mountain Gum are generally found on relatively fertile soils in higher rainfall areas (Marshall 2007) and are likely to be an indicator of high quality habitat for Greater Gliders. This is consistent with the findings of Bennett et al. (1991) who reported that in north-eastern Victoria, Greater Gliders occurred at a much higher frequency in wetter forests at higher elevations. In contrast, we found the abundance of Greater Gliders was negatively associated with the abundance of Broad-leaved Peppermint. In the Strathbogie Ranges, Broad-leaved Peppermint generally occurs on drier, less productive sites (Marshall 2007), which are most likely less suitable habitat for Greater Gliders. Whether this reflects a reluctance by the gliders to use Broad-leaved Peppermint as a food source, or other aspects of the suitability of this forest type is uncertain.

A visual assessment of the 24 trees sampled along each transect for the presence of hollows, found hollow-bearing trees on all but one site (average 2.9 hollow-bearing trees per transect, range 0–9). The average DBH of trees containing hollows was 99 cm (range 28–236 cm DBH). Generally, for all species of eucalypts, hollow-bearing trees were larger than those without hollows. Higher numbers of Greater Gliders were found on transects with larger trees (using DBH as an indicator of tree size), particularly trees that were >100 cm DBH. There were very few trees measured that were >150 cm DBH (1.3%). Larger trees are more likely to contain large hollows, which are used by Greater Gliders for diurnal shelter and breeding (Kehl and Borsboom 1984, Lindenmayer et al. 1991b, Lindenmayer et al. 2004, Smith et al. 2007). We found no significant relationship between the abundance of Greater Gliders and the number of trees with hollows. Most animals were observed when they were foraging, and hence it is not known where their den sites were in relation to the transect line. In addition, visual assessment of tree hollows from the ground can be highly inaccurate (Harper et al. 2004, Koch 2008, Stojanovic et al. 2012). Instead, tree diameter has been proposed as a useful, simple indicator of the presence and abundance of hollows (Lindenmayer et al. 2000). Our finding that there were more Greater Gliders on transects with more large trees further supports that these sites may have contained more hollows.

Overall, the results of our habitat assessments and analyses indicate that in the mixed species forests of the Strathbogie Ranges, higher-quality habitat for Greater Gliders includes areas containing a high proportion of Blue Gum and Mountain Gum, and with a high proportion of trees larger than 100 cm DBH.

4.3 The use of historical data to assess population change

We found no significant difference in the raw counts of Greater Gliders detected along spotlight transects surveyed in 1983 (3.46 per kilometre) and the number detected during our surveys in 2017 (5.69 per kilometre). Downes et al. (1997) reported Greater Glider densities of 2.77 per hectare in forest patches of 20–80 hectares in the west of the Strathbogie Ranges during surveys in 1994, which is within the range of our estimated densities of 2–4 gliders per hectare. Although there were differences in the methods used in 1983 and 1994 (Downes et al. 1997) compared to the current surveys (e.g. surveys off-track in 2017, along tracks in 1983), these results suggest that the Strathbogie Ranges population has not declined to the same extent as appears to have occurred in other areas of their Victorian distribution such as the Central Highlands (Lindenmayer et al. 2011) and East Gippsland (L. Bluff, Gippsland Region, DELWP, unpublished data), reinforcing the importance of the Strathbogie Ranges population. However, our assessment of temporal change has been based on very limited data, collected using different methods at different times. Accordingly, it should be interpreted cautiously.

In Victoria, wildfire has been implicated in the decline of the Greater Glider in some parts of their range, notably the Central Highlands (Lindenmayer et al. 2013, Berry et al. 2015) and the eastern Goulburn-Broken catchment (McNabb et al. 2012). There have been no major bushfires throughout most of the Strathbogie

Ranges since the Black Thursday bushfires in 1851 (DELWP Corporate Spatial Data Library Fire History spatial data 2018). As a result, extensive bushfires have not impacted the Greater Glider population of this area as they have in some other parts of the species' Victorian range. Planned burning is undertaken throughout the Strathbogie Ranges to reduce the risk and impact of bushfires to local communities. Planned burning can significantly increase the collapse rate of hollow-bearing trees (Bluff 2016), and where incineration of the canopy occurs, can at least temporarily destroy or limit food resources. Hollow-bearing trees may also be removed if assessed as 'hazardous' to fire crews before or during ignition, or may become hazardous and pose a risk to public safety if affected by fire (DSE 2011b). Therefore, planned burning has been identified as a potential threat to Greater Gliders and their habitat (SAC 2017). Although the direct impact of this threat is unknown it is currently being investigated in this area (S. Smith, Hume Region, DEWLP pers. comm.).

4.4 Future directions

While our results suggest that the scheduled timber harvesting operations in the three coupes assessed may not have a significant impact on the overall Greater Glider population of the Strathbogie Ranges, the operations could affect a substantial number of individuals, and could have a local impact on populations. Greater Gliders are sedentary and occupy small home ranges of 1–4 hectares, which for males do not overlap (Henry 1984, Pope et al. 2004). Animals present within the area harvested are highly unlikely to move into undisturbed areas of forest after harvesting, and their survival will depend on the amount of suitable habitat remaining within each individual home range (Tyndale-Biscoe and Smith 1969b, Kavanagh 2000). The method being used to harvest the timber on these coupes is single-tree selection, involving the removal of individual or small groups of trees (VicForests 2017a). To date there is only limited information from New South Wales available to assess the potential immediate or longer-term impact of such operations (Kavanagh and Webb 1998, Kavanagh 2000). Our study has provided a robust baseline of Greater Glider abundance within the three coupes. Post-harvest surveys on these coupes using the sampling protocol we developed could provide valuable information to assess the short-term impact of these operations on the local glider population, and the potential impact of harvesting in mixed-species forests in other areas of the species' range. However, the detection models devised pre-harvest may not be directly applicable in a post-harvest context, as removal of trees will likely alter habitat use by Greater Gliders, and will almost certainly change the characteristics of the detection process due to differences in visibility. As a consequence, gliders may become more or less detectable post-harvest. Accordingly, sufficient survey effort would need to be expended post-survey to allow estimation of new distance-detection models, specific to a post-harvest environment. This may necessitate undertaking a large amount of survey effort (probably more than was undertaken in the coupes pre-harvest) to obtain an adequate number of detections for fitting a suitable model to the post-harvest data.

In addition to any assessment of short-term impacts from timber harvesting, it will be important to consider longer term impacts. Although some animals may survive in retained habitat after timber harvesting, the availability of resources may not be sufficient to support viable populations over a longer period (Possingham et al. 1994), as there may be lower survival or reproductive rates, implications from a potential increase in home range size to locate sufficient foraging habitat, edge effects and potential increased predation rates in forest that is more open. These longer-term effects, which may play out at a temporal scale of decades to centuries cannot be addressed using short-term, pre- and post-harvest surveys.

As MRDS methods have been shown to be a practical and reliable means of assessing the abundance of Greater Gliders, we recommend that in future, this approach be routinely used for assessing abundances of Greater Gliders for survey, monitoring and management purposes.

Further surveys conducted elsewhere in the species' range in Victoria are recommended, to determine overall patterns of variation in abundance. By relating observations of abundance to habitat and management variables, further insight can be gained into the processes driving variation in abundance at a statewide scale. Furthermore, such surveys can provide a solid baseline for future monitoring of Greater Glider populations for conservation risk assessment, and to assess the effectiveness of management interventions aimed at improving the conservation status of the Greater Glider.

References

Bennett, A.F., Lumsden, L.F., Alexander, J.S.A., Duncan, P.E., Johnson, P.G., Robertson, P. and Silveira, C.E. (1991). Habitat use by arboreal mammals along an environmental gradient in north-eastern Victoria. *Wildlife Research* 18, 125–146.

Berry, L.E., Driscoll, D.A., Banks, S.C. and Lindenmayer, D.B. (2015). The use of trophic fire refuges by the greater glider (*Petauroides volans*) and the mountain brushtail possum (*Trichosurus cunninghami*) following a landscape-scale fire. *Australian Mammalogy* 37, 39–45.

Bluff, L. (2016). Reducing the effect of planned burns on hollow-bearing trees. Department of Environment, Land, Water and Planning, Melbourne.

Borchers, D.L., Laake, J.L., Southwell, C. and Paxton, C.G.M. (2006). Accommodating unmodeled heterogeneity in double-observer distance sampling surveys. *Biometrics* 62, 372–378.

Borchers, D.L., Zucchini, W. and Fewster, R.M. (1998). Mark-recapture models for line transect surveys. *Biometrics* 54, 1207–1220.

Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, J.L. (2005). *Distance Sampling*. Wiley, London.

Burnham, K.P. and Anderson, D. (2002). Model selection and multi-model inference. *A Practical Information-theoretic Approach*. Springer, New York.

Burt, M.L., Borchers, D.L., Jenkins, K.J. and Marques, T.A. (2014). Using mark-recapture distance sampling methods on line transect surveys. *Methods in Ecology and Evolution* 5, 1180–1191.

Causton, D.R. (1988). *An Introduction to Vegetation Analysis. Principles, Practice and Interpretation*. USA Allen & Unwin (Australia) Ltd, North Sydney, NSW.

Department of Environment, Climate Change and Water (DECCW) (2010). *Techniques for measuring stand basal area. Private Native Forestry Code of Practice Guideline No. 5*. DECCW, Sydney, NSW.

Department of Natural Resources and Environment (NRE) (1995). *East Gippsland - Forest Management Plan*. NRE, Melbourne.

Department of Sustainability and Environment (DSE) (2011a). *Approved Survey Standards: Greater Glider.* DSE, Melbourne.

Department of Sustainability and Environment (DSE) (2011b). *Hazardous Tree Management: Pictorial Guide.* DSE, Melbourne.

Department of Sustainability and Environment (DSE) (2013). *Advisory List of Threatened Vertebrate Fauna in Victoria*. DSE, Melbourne.

Downes, S.J., Handasyde, K.A. and Elgar, M.A. (1997). The use of corridors by mammals in fragmented Australian eucalypt forests. *Conservation Biology* 11, 718–726.

Harper, M.J., McCarthy, M.A., van der Ree, R. and Fox, J.C. (2004). Overcoming bias in ground-based surveys of hollow-bearing trees using double-sampling. *Forest Ecology and Management* 190, 291–300.

Henry, S.R. (1984). Social organisation of the Greater Glider (*Petauroides volans*) in Victoria. Pp. 221–228 In: Smith, A. and Hume, I. (Eds) *Possums and Gliders*. Surrey Beatty and Sons and the Australian Mammal Society. Chipping Norton, New South Wales.

Henry, S.R. (1985). *The diet and socioecology of gliding possums in southern Victoria*. Ph.D. Thesis, Monash University, Melbourne.

Henry, S. R. (1995). Greater glider *Petauroides volans*. Pp. 118–120 In: Menkhorst, P.W. (Ed) *Mammals of Victoria: Distribution, Ecology and Conservation*. Oxford University Press, Melbourne.

Jensen, L.M., Wallis, I.R. and Foley, W.J. (2015). The relative concentrations of nutrients and toxins dictate feeding by a vertebrate browser, the Greater Glider *Petauroides volans*. *PLoS ONE* 10 e0121584.

Kavanagh, R.P. (1984). Seasonal changes in habitat use by gliders and possums in southeastern New South Wales. Pp. 527–543 In: Smith, A. and Hume, I. (Eds) *Possums and Gliders*. Surrey Beatty and Sons and the Australian Mammal Society. Chipping Norton, New South Wales.

Kavanagh, R.P. (2000). Effects of variable-intensity logging and the influence of habitat variables on the distribution of the greater glider *Petauroides volans* in montane forest, southeastern New South Wales. *Pacific Conservation Biology* 6*,* 18–30.

Kavanagh, R.P. and Lambert, M.J. (1990). Food selection by the Greater Glider, *Petauroides volans*: Is foliar nitrogen a determinant of habitat quality? *Australian Wildlife Research* 17, 285–299.

Kavanagh, R.P. and Webb, G.A. (1998). Effects of variable intensity logging on mammals, reptiles and amphibians at Waratah Creek, southeastern New South Wales. *Pacific Conservation Biology* 4, 326–347.

Kehl, J. and Borsboom, A. (1984). Home range, den tree use and activity patterns in the Greater Glider, *Petauroides volans.* Pp. 229–236 In: Smith, A. and Hume, I. (Eds) *Possums and Gliders*. Surrey Beatty and Sons and the Australian Mammal Society. Chipping Norton, New South Wales.

Koch, A.J. (2008). Errors associated with two methods of assessing tree hollow occurrence and abundance in *Eucalyptus obliqua* forest, Tasmania. *Forest Ecology and Management* 225, 674–685.

Laake, J.L., Borchers, D., Thomas, L., Miller, D. and Bishop, J. (2017). mrds: Mark-recapture distance sampling. R package version, 2.1.18. https://cran.r-project.org/web/packages/mrds/index.html

Land Conservation Council (LCC) (1984). *North-eastern Area (Benalla-Upper Murray) Review*. LCC, Melbourne.

Lindenmayer, D.B., Blanchard, W., McBurney, L., Blair, D., Banks, S.C., Driscoll, D., Smith, A.L. and Gill, A.M. (2013). Fire severity and landscape context effects on arboreal marsupials. *Biological Conservation* 167, 137–148.

Lindenmayer, D.B., Cunningham, R.B., Donnelly, C.F., Incoll, R.D., Pope, M.L., Tribolet, C.R., Viggers, K.L. and Welsh, A.H. (2001). How effective is spotlighting for detecting the greater glider (*Petauroides volans*)? *Wildlife Research* 28, 105–109.

Lindenmayer, D.B., Cunningham, R.B., Pope, M.L., Gibbons, P. and Donnelly, C.F. (2000). Cavity sizes and types in Australian eucalypts from wet and dry forest types–a simple rule of thumb for estimating size and number of cavities. *Forest Ecology and Management* 137, 139–150.

Lindenmayer, D.B., Cunningham, R.B., Tanton, M.T. and Nix, H.A. (1991a). Aspects of the use of den trees by arboreal and scansorial marsupials inhabiting montane ash forests in Victoria. *Australian Journal of Zoology* 39, 57–65.

Lindenmayer, D.B., Cunningham, R.B., Tanton, M.T., Smith, A.P. and Nix, H.A. (1991b). Characteristics of hollow-bearing trees occupied by arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, south-east Australia. *Forest Ecology and Management* 40, 289–308.

Lindenmayer, D.B., Pope, M.L. and Cunningham, R.B. (2004). Patch use by the Greater Glider (*Petauroides volans*) in a fragmented forest ecosystem. II. Characteristics of den trees and preliminary data on den-use patterns. *Wildlife Research* 31, 569–577.

Lindenmayer, D.B., Wood, J.T., McBurney, L., MacGregor, C., Youngentob, K. and Banks, S.C. (2011). How to make a common species rare: a case against conservation complacency. *Biological Conservation* 144(5), 1663–1672.

Marshall, R. (2007). *Conservation Plan for the Strathbogie Landscape: Biodiversity Action Planning in the Mid Goulburn*. Department of Sustainability and Environment, Benalla.

McNabb, E., Cheers, G. and Loyn, R. (2012). *Persistence of owls and arboreal mammals after severe wildfire in the Goulburn Broken Catchment.* Arthur Rylah Institute for Environmental Research unpublished client report for Caring for our Country and Goulburn Broken Catchment Management Authority.

Moore, B.D., Wallis, I.R., Marsh, K.J., and Foley, W.J. (2004). The role of nutrition in the conservation of the marsupial folivores of eucalypt forests. Pp. 549–575. In: Lunney, D (Ed). *Conservation of Australia's Forest Fauna II*. Royal Zoological Society of NSW. Mosman.

Pope, M.L., Lindenmayer, D.B. and Cunningham, R.B. (2004). Patch use by the Greater Glider *(Petauroides volans*) in a fragmented forest ecosystem. I. Home range size and movements. *Wildlife Research* 31, 559–568.

Possingham, H.P., Lindenmayer, D.B., Norton, T.W. and Davies, I. (1994). Metapopulation viability analysis of the Greater Glider *Petauroides volans* in a wood production area. *Biological Conservation* 70, 227–236.

Scientific Advisory Committee (SAC) (2017). *Final recommendation on a nomination for listing. Petauroides volans subsp. volans Kerr 1792 – Greater Glider.* Flora and Fauna Guarantee Act 1988 – Scientific Advisory Committee, Melbourne.

Smith, G.C., Mathieson, M. and Hogan, L. (2007). Home range and habitat use of a low-density population of greater gliders, *Petauroides volans* (Pseudocheiridae: Marsupialia), in a hollow-limiting environment. *Wildlife Research* 34, 472–483.

Standards Australia (2009). *AS 4970-2009, Australian Standard – Protection of trees on development sites. Committee EV-018, Arboriculture*. Council of Standards Australia, Sydney.

Stojanovic, D., Webb, M., Roshier, D., Saunders, D. and Heinsohn, R. (2012). Ground-based survey methods both overestimate and underestimate the abundance of suitable tree-cavities for the endangered Swift Parrot. *Emu – Austral Ornithology* 112, 350–356.

Strathbogie Forest Citizen Science Project (2017). https://strathbogiesustainableforests.wordpress.com/2017/10/16/strathbogie-ranges-greater-glider-hotspot/

Suckling, G.C. (1982). Value of reserved habitat for mammal conservation in plantations. *Australian Forestry* 45, 19–27.

Taylor, A.C., Tyndale-Biscoe, C.H. and Lindenmayer. D.B. (2007). Unexpected persistence on habitat islands: genetic signatures reveal dispersal of a eucalypt-dependent marsupial through a hostile pine matrix. *Molecular Ecology* 16, 2655–2666.

Threatened Species Scientific Committee (TSSC) (2016). *Approved conservation advice for* Petauroides volans *(Greater Glider).* Environment Protection and Biodiversity Conservation Act 1999 – Threatened Species Scientific Committee, Canberra.

Tyndale-Biscoe, H. and Smith, R.F.C. (1969a). Studies on the marsupial glider, *Schoinobates volans* (Kerr): II. Population structure and regulatory mechanisms. *Journal of Animal Ecology* 38, 637–650.

Tyndale-Biscoe, H. and Smith, R.F.C. (1969b). Studies on the marsupial glider, *Schoinobates volans* (Kerr): III. Response to habitat destruction. *Journal of Animal Ecology* 38, 651–659.

van der Ree, R., Ward, S.J., and Handasyde, K.A. (2004). Distribution and conservation status of possums and gliders in Victoria. Pp. 91–110 In: Goldingay, R.L. and Jackson, S.M. (Eds)*The Biology of Australian Possums and Gliders.* Surrey Beatty and Sons, Chipping Norton, Australia.

VicForests (2017a). Small scale timber harvesting in the Strathbogies. Media release December 2017. http://www.vicforests.com.au/static/uploads/files/media-release-small-scale-timber-harvesting-operations-wfgpummgyfzf.pdf.

VicForests (2017b). Timber Release Plan (Including Approved Changes) – January 2017. VicForests, The State of Victoria, Melbourne. http://www.vicforests.com.au/planning-1/timber-release-plan-1/approved-trp-jan-2017.

Wintle, B.A., Kavanagh, R.P., McCarthy, M.A. and Burgman, M.A. (2005). Estimating and dealing with detectability in occupancy surveys for forest owls and arboreal marsupials. *Journal of Wildlife Management* 69(3), 905–917.

Woinarski, J.C.Z., Burbidge, A.A., and Harrison, P.L. (2014). *The Action Plan for Australian Mammals 2012*. CSIRO Publishing, Collingwood, Victoria.

www.ari.vic.gov.au