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Habitat requirements of the endangered red-tailed phascogale *Phascogale calura*

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Abstract

Context. The red-tailed phascogale once occurred widely across semi-arid and arid Australia, but is now confined to the southern wheatbelt of Western Australia. Its apparently extensive former range suggests a broad habitat tolerance, yet it is now reported primarily from remnant vegetation within farmland containing wandoo *Eucalyptus wandoo* and rock sheoak *Allocasuarina huegeliana* associations.

Aims. To establish the habitat requirements of phascogale with a view to understanding their current and likely future distribution and status.

Methods. We established presence or absence of phascogale at a range of sites within their current range, primarily by trapping, and then compared and contrasted habitat attributes between these two classes of sites to establish those of apparent significance to the species persistence.

Key results. Phascogale are widespread in suitable upland (wandoo - rock sheoak) and lowland habitat (riverine fringing vegetation of swamp sheoak *Casuarina obesa*, York gum *E. loxophleba* and wandoo). They occupy areas of remnant vegetation of varying sizes from very small to very large, many on private agricultural land. Large connected areas such as riverine corridors and clusters of upland remnants appear important to their long-term persistence. Sites isolated by increasing distance from another occupied site tended to be unoccupied. Habitats occupied by phascogale typically had a greater canopy density and greater abundance of hollows than did unoccupied sites. The presence of plants of the genus *Gastrolobium*, often cited as a key factor in the persistence of phascogale, did not appear to influence the presence or absence of phascogale.

Conclusions. Red-tailed phascogale currently occupy a broader range of habitats than identified in the literature and the role of some key aspects of habitat in protecting them from further decline may have been overstated. The presence of suitable hollows for nesting and shelter and a dense mid-storey canopy, perhaps to protect from predation from owls, are key features of suitable phascogale habitat.

Implications. Suitable habitat for phascogale appears widespread in the surveyed portion of the remaining range of the species, but is under threat over the longer term. Increasing salinity in lowland areas (which transforms woodland to samphire with a consequent long-term loss of nesting hollows), lack of fire in upland areas to maintain dense stands of rock sheoak, and the increasing loss of corridors of vegetation along roadsides due to the widening of roads by local councils are all contributing to loss of habitat and habitat connectivity.

Additional keywords: dasyurid, fragmentation, connectivity, wheatbelt, *Gastrolobium,* fire, tree hollows

Introduction

Loss of habitat and increasing isolation of remaining habitat patches are key forces affecting the fate of fauna worldwide (Diamond 1989; Andrén 1994; Fischer and Lindenmayer 2007). With fauna confined to ever smaller habitat patches, stochastic influences become more important (Lande 1998), and this may be particularly so for species such as the red-tailed phascogale *Phascogale calura* that have a life history characterised by a complete annual male die-off at the end of the first year of life (Cuttle 1982; Bradley 1997).

The red-tailed phascogale is a small semi-arboreal and insectivorous dasyurid that now persists only in the far south-west of Western Australia (Glauert 1933; Bradley *et al.* 2008). It formerly occurred patchily across much of semi-arid and arid Australia extending to the Murray-Darling junction in eastern Australia. It appears to have contracted from some areas of the central wheatbelt in Western Australia as recently as within the past 30 years (Short and Hide submitted). It is listed as 'endangered' under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 and as 'near threatened' by the IUCN Red List of Threatened Species 3.1 (2001).

Much of the current range of the species in south-west Western Australia coincides with a region of extensive agriculture - the wheatbelt (Figure 1). In excess of 90% of native vegetation in this region has been cleared for cropping in the past 100 years (Saunders 1989), with the last period of substantial clearing occurring after World War II to the early 1980s (Chapman 1978**;** Jarvis 1979; Lloyd 1998). Remaining habitat remnants are often small and fragmented. Phascogale typically occupy remnant woodlands where mature wandoo *Eucalyptus wandoo* and rock sheoak *Allocasuarina huegeliana* are adjacent, these habitats providing an abundance of hollows and a continuous canopy (Kitchener 1983).

Kitchener *et al.* (1980) surveyed 23 wheatbelt reserves for mammals in the 1970s, recording phascogale in just four. From these distributional data for phascogale, Kitchener (1983) suggested that the species was confined to reserves that exceeded 450 hectares in area and that fragmentation of habitat was a key threat. Other factors deemed significant were a requirement for a climax vegetation of long-unburnt habitat and the presence of poison plants *Gastrolobium* spp. to protect remnants from the direct and indirect effects of grazing by stock (Kitchener 1983) and to limit the number of foxes by secondary poisoning (Bradley *et al.* 2008).

We trapped for phascogale in remnants of native vegetation in the south-western portion of its current range. This is an area of about 16,000 km^2 (110 x 150 km) utilised for cereal growing and extensive grazing of sheep for wool. Despite broad agricultural use some substantial clusters of native vegetation persist. Roadsides and creeklines in at least some parts of the area retain reasonable amounts of native vegetation and there are scattered, often isolated, patches of native vegetation on farms. The larger retained patches in the landscape are often reserves. Trapping extended across three of the four biogeographic regions in which the species has been recorded over the past 50 years: Jarrah Forest, Avon Wheatbelt, and Mallee. We have used these data to establish:

- Attributes of habitat associated with the presence or absence of phascogale - tenure, remnant size and isolation, presence of and distance to hollow-bearing trees, extent of canopy cover, presence of poison plants *Gastrolobium* spp. and fire history;
- Key vegetation associations still occupied by the species; and
- The incidence of hollows in trees of different species common where phascogale occur, how this varies with tree girth, and whether the size distribution of trees of these species differs between sites with and without phascogale.

Methods

Trapping of phascogale

We trapped for phascogale over four seasons, commencing in late 2005 and continuing to early 2009. Our focus for trapping was primarily on (i) larger remnants that were not part of the Department of Environment and Conservation estate, but were in private ownership or vacant or other Crown land; or (ii) smaller remnants that were strategically located as stepping stones or were located on or adjacent to vegetation corridors connecting larger remnants; and (iii) locations where a community sighting suggested that phascogale might be present. Trapping was largely limited to woodland associations, as previous trapping in adjacent habitats in wheatbelt remnants (e.g. heath, laterite ridges) had shown few or no captures (Kitchener and Chapman 1978; Bradley 1997).

Each bushland remnant was assessed for the presence of phascogale by trapping along five transects. Transects were located in habitat within the remnant judged most likely to yield phascogale (as indicated by the presence, where possible, of hollow-bearing eucalypts or of rock sheoak or similar mid-storey species) and were located > 100 m apart. Each transect consisted of 25 Elliott traps (of size 33 x 10 x 10 cm) and three cage traps (of size 58 x 20 x 20 cm) set for two consecutive nights and spaced at intervals of approximately 15 m. Traps were baited with a mix of rolled oats, peanut butter and sardines and set in the late afternoon, left open overnight, and checked early the next morning. A handful of clean, raw wool was added to Elliott traps to allow animals extra protection from cold night-time conditions in late autumn and early winter. Trapping occurred between December and June in each year, targeted to avoid the period of lactation when dependent young are in the nest. The exception was in 2005 when trapping commenced in October. The presence or absence of phascogale for each remnant and captures of other species were recorded.

We also collated information on trapping for phascogale by others within our study area over the previous 25 years to allocate these sites as either positive or negative for the presence of phascogale. Trapping methodology varied between practitioners but all included Elliott trapping. These sites were assessed for habitat in the same way as those trapped in the current study.

Habitat assessment

Each remnant was assessed to ascertain its tenure and whether it had been fenced to exclude stock. The tenure of sites trapped was designated as private, Department of Environment and Conservation (DEC), or other crown land (OCR). Habitat characteristics of remnants were assessed at random locations in the vicinity of each trap line broadly following the methodology of Friend and Friend (1993). Six survey locations were randomly chosen within each remnant. These were determined by walking in a random direction for a pre-determined number of steps from trapping lines. At each survey location the three closest trees were assessed. Measurements taken were: tree species, circumference at breast height (1.3 m), the presence of visible hollows (assessed by eye without the aid of binoculars), and whether the tree was alive or dead. The distances between each of the three trees at the survey site were recorded using the method of Ward (1991) to assess overall stem density. Tree circumference was converted to diameter breast height (DBH). Also measured were the percentage canopy cover (measured using a spherical densiometer when facing south from survey point); the interconnection of the canopy (the canopy was considered interconnected if > 3 trees had branches that extended to within 1 m or less of another); the presence of poison bush (*Gastrolobium* spp.); the amount of fallen logs and branches measured on a scale of 1-5 (1 = few or none, 5 = many, including hollowed logs); and a general indication of time since last fire based on a search for fire scars on trees and charcoal on stumps or fallen timber (a categorical variable scored as signs of recent fire, signs of fire in distant past, or no signs of fire evident) .

In addition to these measures, the distance to, and the species of, the nearest hollow-bearing tree were recorded for each assessment site, because many sites had dense stands of rock sheoak, swamp sheoak, or less frequently, of jam *Acacia acuminata*, so that hollow-bearing eucalypts at the site were often not picked up by the method above. An area with a diameter of *c*. 75 m around each site was searched and if no hollow-bearing trees were detected the distance to the nearest hollow-bearing tree was arbitrarily scored as 150 m, twice the distance searched. The mean value for each site was converted into a value for hollows per hectare by taking the reciprocal of the area of a circle with radius equal to the mean distance to hollows in metres divided by 10,000.

Data analysis

Habitat attributes for sites with and without phascogale were compared using a χ^2 analysis to assess frequencies of categorical variables and either a one factor ANOVA or a general linear model (with presence/absence of phascogale as a fixed factor and site as a random factor nested within phascogale presence/absence) for continuous variables. A variance test was performed to assess homogeneity of variance. Variables were transformed ($\log_{10}$) if they were not normally distributed and to improve homoscedasity. Proportions (percentages) were transformed using the arcsine transformation before analysis. Multiple logistic regression was performed using multiple variables to determine an equation of best fit and to assess the success of classifying sites into two classes based on whether or not phascogale were trapped. The presence/absence of hollows in trees of different sizes and species was modelled using binary logistic regression (logit link function).

Results

Trapping of phascogale

We trapped 84 remnants for phascogale over four trapping seasons between 2005 and 2009 (Table 1). All sites were in the southern wheatbelt in an area that extended about 150 kilometres in an east-west direction from the forest margin near Darkan to Nyabing and 110 kilometres north-south from Narrogin to Katanning and Kojunup (Figure 1). In total 303 phascogale were trapped in 22,092 trap nights (mean of 1.37 captures per 100 trap nights) in the 84 remnants employing a standardised trapping technique. However, captures per 100 trap nights varied widely between sites from zero to

14.9. Other species captured in low densities included common brushtail possum (*Trichosurus vulpecula*), echidna (*Tachyglossus aculeatus*), house mouse (*Mus musculus*), black rat (*Rattus rattus*) and brush-tailed phascogale (*Phascogale tapoatafa*). However, captures of species other than red-tailed phascogale were uncommon.

In addition, we were able to establish presence/absence of phascogale at a further 22 sites within our broad study area. Three sites were trapped by the government research organisation CSIRO (two nature reserves and a shire reserve) in 2003-04 and seven sites (mostly private land) were trapped in April 2006 by the Friends of Wagin Lakes community group. Other sites, all nature reserves, were trapped in the late 1980s and early 1990s - four by Ninox Wildlife Consulting (1987), four by the Department of Conservation and Land Management (now Department of Environment and Conservation), and two by a community group. An additional two sites on private land had positive sightings of nesting females by the authors in 2006.

Habitat assessment

All remnants trapped, as well as those trapped by others or where there was a positive sighting by the authors, were assessed for habitat. Thus 106 remnants were assessed for habitat attributes. Phascogale were detected in 65 of the 106 remnants (61.3%).

<u>Tenure</u>

The proportion of sites in which phascogale were present was similar across all tenure types (Table 2). There was no significant association between tenure and presence of phascogale (χ^2_2 = 0.459; P = 0.795).

<u>Tenure area</u>

The median size of tenure areas (area defined by single tenure) in which phascogale were trapped was somewhat smaller than the median of those that were trapped, but where no phascogale were caught (Table 3). However, the difference in $\log_{10}$ of areas was not significant ($F_{1, 104}$ = 3.24; P = 0.075).

<u>Contiguous area</u>

The median size of contiguous vegetation area, regardless of tenure, in which phascogale were trapped was somewhat smaller than the median of those that were trapped but where no phascogale were caught (Table 3). However, the difference in $\log_{10}$ areas was not significant ($F_{1, 104}$ = 2.67; P = 0.105). Phascogale were caught or observed in remnants ranging from 2 to 3,080 hectares and appeared to be not limited to remnants of any particular size. Phascogale were detected in 19 remnants of less than 70 hectares in contiguous area.

Proximity to occupied remnants

Trapped sites with phascogale (positive sites) were significantly closer to other sites where phascogale had been trapped than were trapped sites without phascogale ($F_{1, 104} = 20.07$, $P < 0.001$ for log data). This analysis employed a database containing all records of phascogale capture and occurrence (Short and Hide, submitted), including those beyond the margins of the current study. Mean distance from a trapped site with phascogale to another trapped site with phascogale was 4.2 km. This compared with a mean distance of 11.2 km between trapped sites without phascogale (negative sites) and the nearest trapped site with phascogale (positive site). Negative sites were typically on the western, eastern or southern margin of the established range of phascogale (Figure 1).

When community sightings or other records from post-1990 were included, the mean distance from a positive site as recorded by trapping to any other positive record was 3.3 km; mean distance from a negative site to any positive record was 8.6 km. The difference was again significant ($F_{1, 104} = 12.53$, $P = 0.001$ for log data). Hence, negative sites were typically further from any previous trapping or sighting record of phascogale, indicating greater isolation. The most distant positive records (a small remnant of 157 hectares, 13 kilometres south-east of Harrismith, and another of 107 hectares 23 km south of Harrismith) were each 11.6 kilometres from another positive record.

Position in landscape

Phascogale were present in upland sites (sites dominated by wandoo and rock sheoak), lowland sites (typically saline sites such as river flats or lake fringes often with York gum and/or swamp sheoak or swamp sheoak and stags), and sites that had a mixture of both. Phascogale were present in 59% of upland sites, 67% of lowland sites, and 60% of mixed sites (Table 4). Hence, phascogale were distributed widely across the landscape with respect to landscape position. No evidence exists for an association between position in the landscape and presence or absence of phascogale ($\chi^2_2 = 0.509$; $P = 0.775$).

Vegetation types

We looked for a relationship between vegetation association and presence/absence of phascogale (Table 5). We lumped like associations to ensure no more than one expected value was less than 5 in the χ^2 test. 'Succulent steppe with open woodland and scrub' and 'medium woodland (York gum, wandoo and salmon gum)' represent the core habitats occupied in our study area. Other associations are increasingly prominent to the east (mallee shrublands and woodlands with salmon gum and mallet) and west (woodland and/or forest of marri and jarrah) of these core habitats. There was a strong link between vegetation association and the presence or absence of phascogale (χ^2_3 = 29.00; P < 0.001).

Red-tailed phascogale occupied a range of vegetation types associated with both upland and lowland parts of the landscape. They occurred most reliably in sites along major watercourses such as the Arthur River and the margins of the Wagin Lakes, here classified as 'succulent steppe'. Riverine locations, in particular, are now widely salt-affected. These areas often had a mid-storey of swamp sheoak in association with York gum and some wandoo (both often largely present as stags following tree death due to rising water tables). York gum, wandoo, and flooded gum *E. rudis* are present around lake margins. Phascogale were common also at upland sites with hollow-bearing trees, particularly wandoo. They were typically absent from vegetation associations dominated by eucalypt species with few or no hollows such as mallee e.g. *E. eremophila*, mallet e.g. *E. astringens*, flat-topped yate *E. occidentalis* and jarrah *E. marginata*, or in shrublands without ready access to hollows.

<u>Tree species</u>

In total, 2,262 trees were measured in the vicinity of trap lines (Table 6). The most commonly sampled trees were rock sheoak (850), wandoo (392) and jam (180). Rock sheoak, jam and swamp sheoak are mid-canopy species while wandoo, York gum, salmon gum *E. salmonophloia*, and red morrel *E. longicornis* are emergent or upper canopy trees. Mallee (Sand Mallee *E. eremophila* and other *E.* spp.) occured in woodland or shrubland as a sparse, semi-continuous or continuous canopy at mid-height so was structurally more similar to the mid-canopy species than the other eucalypts. Stags, almost invariably of eucalypts, had the highest incidence of hollows, followed by larger eucalypts, such as wandoo, York gum and salmon gum (Table 6). Some eucalypts had few or no recorded hollows including mallee, jarrah and flat-topped yate. Mid-storey trees, such as rock sheoak, swamp sheoak, jam and *Melaleuca* spp., also had few or no recorded hollows. Grass trees (*Xanthorrhoea preissii*) occasionally had hollow stems that provided potential nesting sites for phascogale, but were not particularly common in sites that we sampled. Consistent with the high number of hollows in stags of indeterminate species was the high numbers of hollows recorded in dead eucalypts for which a species was assigned. For example, 34% of live trees of wandoo had recorded hollows compared with 82% of dead wandoo (a significant difference: χ^2_1 = 16.24, p = 0.00).

The incidence of visible hollows as a function of size of tree is plotted in Figure 2. The probability of presence of hollows increased with tree size. The 221 eucalypts that had hollows were significantly larger (had a significantly greater diameter breast height (DBH)) than the 790 eucalypts that had no detected hollows (mean of 148 cm cf. 76 cm, $F_{1, 737} = 177.60$, $P < 0.001$). Most stags were likely to have been either wandoo or York gum, the two eucalypt species most recorded in habitat assessments. The independent variable (DBH measured in centimetres) had a significant effect on the probability of a tree having hollows for wandoo ($P < 0.001$), York Gum ($P < 0.001$), and salmon gum ($P = 0.001$), but not for stags ($P = 0.159$) or red morrel ($P = 0.151$). Stags had an overall probability of 0.72 for the presence of hollows; red morrel had an overall probability of 0.10 (Table 6).

There was no significant association between tree size (DBH cm) and the presence or absence of phascogale for the three commonest eucalypt species (wandoo: $\chi^2_3 = 2.324$; $P = 0.508$; York gum $\chi^2_2 = 0.618$; $P = 0.734$; and salmon gum $\chi^2_2 = 1.191$; $P = 0.551$). Thus sites with and without phascogale didn't obviously differ in size class of trees. Measured eucalypts were dominated by smaller size classes. The percentage of trees above that estimated to have a 50% probability of having a hollow (Figure 2) was 32% for wandoo (DBH of > 40 cm); 14% of York gum (DBH > 45 cm); and 3.5% of salmon gum (DBH >100 cm).

Hollows

Distance to the nearest detected hollow-bearing tree did not show a significant difference between sites with and without phascogale ($F_{1, 104} = 1.84$, $P = 0.178$). Distance to the nearest hollow-bearing tree for sites with phascogale averaged 37 m; distance to nearest hollow-bearing tree for sites without phascogale was 44 m. Estimated density of hollow-bearing trees varied between zero and 260 per hectare, but did not differ significantly between sites with and without phascogale.

However, six of the 41 sites without phascogale had no recorded hollow-bearing trees and a further four had a mean distance to hollow-bearing trees of ≥ 75 m (Table 7). In contrast, all sites with phascogale had at least some recorded hollow-bearing trees, and only five of 65 had a mean distance to hollow-bearing trees of ≥ 75 m. The difference was significant ($\chi^2_1 = 5.77$; $P = 0.016$). Sites with mean distance of ≥ 75 m to nearest hollow-bearing tree were either in habitats with eucalypts that typically have few recorded hollows (such as mallee or mallet) or were in sites that appeared to have been cleared in the distant past and where regrowing eucalypts were either absent or too small to support hollows.

In general, a substantial number of sites without phascogale had some evidence of the presence of hollows. Hence, absence of hollows could not be invoked as the key cause of absence of phascogale in these cases. Yet, sites without phascogale were more likely to have fewer or more distant hollows or be largely without hollows.

Canopy density

Measures of canopy density indicated a significantly thicker canopy at sites where phascogale were detected compared with sites where they were not. Canopy densities, as assessed by densiometer, averaged 62.4% at sites with phascogale and 52.0% at sites where no phascogale were caught. There was a significant difference between sites with and without phascogale ($F_{1, 104}$ = 10.74, P = 0.001). The subjective estimate of whether the canopy was interconnected (based on > 3 trees with apparently linked canopy) also showed a significant difference between sites with and without phascogale ($F_{1, 104}$ = 8.47, P = 0.004). Sites with phascogale had an average score of 0.70 (70% of sites had > 3 trees with linked canopy at assessment sites) versus those without which had a mean score of 0.55.

Stem density

Phascogale occupied sites with a wide range of stem densities from very sparse - typically scattered old-growth wandoo without mid-storey (400 stems/hectare) to very dense (typically dense regrowth of rock sheoak or swamp sheoak at > 10,000 stems/hectare). There was no significant difference in $\log_{10}$ of stem density between occupied and unoccupied sites ($F_{1, 104}$ = 0.18, P = 0.676). Occupied plots averaged 3,700 stems per hectare; unoccupied sites averaged 3,200.

Fallen timber index

There was no significant difference in the index of fallen timber between sites with and without phascogale ($F_{1, 104}$ = 0.00, P = 0.958). Sites with phascogale had an average index of 2.21 versus sites without phascogale with an average index of 2.23.

Access by stock

Stock did not have access to the majority of sites surveyed. DEC reserves, unallocated Crown Land, other Crown reserves and shire reserves were ungrazed. In addition, the majority of private sites were fenced and stock were entirely excluded from 25 of 45 such sites. Hence, stock were excluded from about 78% of sites assessed (Table 8). Phascogale were present on 61% of grazed sites. There was no significant association between presence of stock and presence of phascogale (χ^2_1 = 0.03; P = 0.960).

Poison plants

Poison plants (*Gastrolobium* spp.) were recorded at 37 of 106 sites surveyed (Table 9). Phascogale were trapped in a higher proportion of those sites with no poison plants detected. Of the 69 sites where there was no poison plants recorded, 46 (67%) contained phascogale. Nineteen of 37 sites at which poison plants were recorded (51%) contained phascogale. Of the eight sites where >5 phascogale were captured per 100 trap nights during standardised surveys, only two had poison plants recorded in vegetation assessments.

Fire

There was no evidence of any association between fire history and the presence or absence of phascogale (χ^2_2 = 1.008; P = 0.604). In this analysis (Table 10), fire histories were grouped as: no evidence of past fires, some evidence of patchy fires (either past or recent), and some evidence of widespread fire (either past or recent).

Classification of sites using multiple logistic regression

An analysis (employing the variables 'distance to closest trapping record', 'proportion of assessed trees at each site that were sheoak - either *Casuarina* or *Allocasuarina*', and 'hollows/hectare') correctly classified 81% of sites – 92.3% of positive sites were assessed correctly, but only 63.4% of negative sites). The equation that predicted probability of phascogale presence was y = 0.429 - 0.205 distance (km) + 1.685 arcsin(sheoak) + 0.497 $\log_{10}$(hollows/hectare).

Discussion

Red-tailed phascogale were common in remnant bushland in the area surveyed, being detected in 65 of 106 survey locations. We determined presence/absence from 250 trap nights at each site, enough to minimise false negatives. Red-tailed phascogale were readily trapped, in contrast to the difficulty reported for brush-tailed phascogale (Traill and Coates 1993). Our overall capture rate of 1.37 / 100 trap nights, averaged across sites both with and without red-tailed phascogale, was substantially higher than that reported for brush-tailed phascogale at sites where they were known to be present (0.49 / 100 trap nights: Traill and Coates 1993). Friend and Friend (1993) recorded red-tailed phascogale at 20 sites in wheatbelt Western Australia; 17 from sites with less than 250 trap nights of effort (a median of 120 trap nights per site where phascogale recorded). A small number of many sites re-trapped over periods of several years have recorded different results for presence/absence on successive surveys (Short and Hide in press). It is unclear whether this is due to the vagaries of sampling or whether it represents local extinction and/or recolonisation of sites by phascogale.

Phascogale were found to utilise both upland and lowland habitats. Upland areas included vegetation widely considered to be the core habitat of the species – wandoo and rock sheoak associations (Kitchener 1981; Bradley *et al.* 2008). This habitat type is included in the 'medium woodland (York gum, wandoo and salmon gum)' category in Beard's broad scale (1: 250,000) regional mapping of vegetation in Western Australia (e.g. Beard 1980). However, the species was also common in fringing vegetation along rivers and lakes at the bottom of the landscape catena (described as 'succulent steppe with open woodland and scrub' by Beard 1980). Often York gum as well as wandoo provided hollows in such habitats. Much of this habitat was impacted by rising salt and there were many dead eucalypts (stags) and often these had hollows. Dense and often extensive stands of swamp oak were common in these habitats providing a continuous mid-canopy. This fringing vegetation along rivers and lake chains provided extensive areas of interconnected habitat. However, most areas are threatened over the longer term by increasing salinity that will likely transform much of this habitat into low open samphire flats unsuitable for phascogale.

The incidence of phascogale tended to decline at sites around the periphery of our study area to the east, west and south. This was in part because of a change in habitat and in part the result of increasing isolation of such sites because of greater distance and habitat fragmentation. Red-tailed phascogale appear to move widely around the landscape, particularly in areas where linking corridors of vegetation remain. Evidence for such movements included community sightings often in and around buildings that were distant from substantial patches of remnant vegetation (Short and Hide submitted), the presence of phascogale in small remnants with an area less than that recorded for home range suggesting they utilise multiple patches or travel between patches, and evidence from radio-telemetry and trapping studies of substantial short-term movements (e.g. a male moved 800 m between captures on successive nights: Bradley 1997). However, as distances increased beyond about five kilometres from another occupied remnant the likelihood of establishment or re-colonisation seems to decline.

Red-tailed phascogale were common in remnants of all sizes from very small (< 20 ha) to comparatively large (> 200 ha). This may be largely due to the landscape being relatively well connected with corridors of native vegetation along roadsides and creeklines. Red-tailed phascogale are reported to have average home ranges of up to 8 hectares in the non-breeding season and up to 103 hectares for males in the breeding season (Friend and Friend 1993), suggesting a need for considerable areas of contiguous habitat. Movements of up to 800 m in one night have been recorded for a male red-tailed phascogale (Bradley 1997). Female brush-tailed phascogale are reported to require a home range of 20 to 60 hectares, with males requiring even larger areas (Traill and Coates 1993; Soderquist 1993; Rhind 1993-94). One male was reported to have travelled 17 km in the breeding season (Soderquist and Lill 1995). However van der Ree *et al.* (2001) reported much smaller home ranges for this species in a fragmented agricultural landscape in central Victoria. They attributed this to greater number of larger and older trees and the fertile soils relative to nearby conservation and forest production areas. van der Ree *et al.* (2001) also observed this species of phascogale regularly crossing > 200 m of farmland to access paddock trees and remnants.

Tenure appeared not to be important - red-tailed phascogale were equally likely to be present in remnant vegetation on farmland as non-DEC reserves (areas maintained under native vegetation for some purpose other than nature conservation) or nature reserves controlled by DEC. This is in contrast to the view of Friend and Friend (1993), who considered that much of the remaining occurrence of the species to be in nature reserves. The presence across tenures may be in part because many of the larger farm remnants are now protected from grazing by stock. Hence differences in management across tenures is now quite limited. In addition, the planting of corridors of mallee eucalypts across farmland in some parts of the region is a significant positive land use change that may provide additional foraging opportunities for phascogale and facilitate their movement across open farmland from remnant to remnant (Nicholls 2008).

Canopy density was one of the stronger habitat attributes that separated sites with and without phascogale. Phascogale typically occurred at sites with a dense mid-storey canopy of rock-oak, swamp oak, or less commonly jam. However, there were many exceptions where phascogale occupied sites with little or no mid-storey canopy. We recorded a mean value of 62% canopy cover (range 39 – 94%) for positive sites. Kitchener (1981) reported that phascogale preferred denser vegetation or vegetation with a continuous canopy of the species *E. wandoo*, *E. accedens*, *E. gardner*, *E. falcata* and *Gastrolobium* and *Casuarina huegeliana* alliance – either occurring adjacent to each other or as a community. Friend and Friend (1993) recorded mean canopy cover values of between 92.7 and 95% on three trapping grids on which phascogale occurred within Tutanning Nature Reserve, some 60 km north of the northern boundary of our study region.

A key predator of phascogale and other small dasyurids is likely to be owls (Van Dyck and Gibbons 1980; Cockburn and Lazenby-Cohen 1992; McNab 2002; Fulton 2010). Southern boobook (*Ninox novaeseelandiae*) and barn owls (*Tyto* spp.) were commonly observed at sites with phascogale (J. Short and A. Hide, pers. obs.). Southern boobook owls were the most common owl species recorded in south-west woodlands, including wandoo woodlands (Liddelow *et al.* 2002). A dense, cluttered, and interconnected canopy is likely to provide some protection to phascogale while foraging at night. Further to the east, beyond our study area, the species has been observed to occupy scrub habitat dominated by tammar bush *Allocasuarina campestris* to about 2 m

(Kitchener and Chapman 1977). This has a similar dense canopy structure, albeit at a lower height. A dense canopy, as well as providing greater protection from avian predators, is likely also to provide more sites for insects to shelter and consequently a greater density of potential food for phascogale. It may also provide more opportunity to escape carpet pythons (*Morelia spilota*), feral cats (*Felis catus*) and foxes (*Vulpes vulpes*).

Red-tailed phascogale use tree hollows to shelter during the non-breeding season and as nest sites during spring for the rearing of young. Hollows for diurnal shelter and particularly for nesting are likely to be a scarce resource, as evidenced by their frequent use of nest boxes when available in the wild, their frequent use of man-made structures in and around farm houses, and the strong association between the presence of phascogale and tree species with a high frequency of hollows (particularly wandoo and York gum). Our assessment of the presence of hollows was crude and likely to overestimate availability as it took no account of the structural suitability of hollows for phascogale or of competition for their use.

Red-tailed phascogale are likely to have very specific requirements for breeding hollows. Two nests examined in the Wagin area (one is a closed suitcase in a disused woolshed and another in an external wall cavity behind a grate in a building) suggested that females require a substantial chamber to accommodate their large nest of wool, bark, feathers and grass, but a small entrance, presumably to prevent entry by other hollow-nesting species (for example, parrots) and potential predators such as carpet python. Red-tailed phascogale may share nests (Friend and Friend 1993; Short and Stone 2009) and, like other small arboreal marsupials (Smith and Lee 1984; Cockburn and Lazenby-Cohen 1992), may huddle together to maintain warmth. This suggests a requirement for a nest chamber of reasonable size. These observations are consistent with those of nests of brush-tailed phascogale, where natural entrances were small (mean of 15 cm^2) with widths ranging from 24 – 55 mm (Soderquist 1993). The cavity size of five natural hollows utilised by brush-tailed phascogale averaged 9,885 cm^3 and cavities were filled with large volumes of nest material of bark strips, feathers and fur (Soderquist 1993). This suggests approximate dimensions of 20 x 20 x 25 cm. Competition for hollows with other arboreal mammals (sugar gliders *Petaurus breviceps* and squirrel gliders *P. norfolcensis*) was a major issue in eastern Australia. Nest boxes used by red-tailed phascogale in south-west Western Australia (Short and Stone 2009) for breeding and shelter have an entrance of 32 mm in diameter and a nest chamber of *c.* 12,000 cm^3.

Friend and Friend (1993) recorded red-tailed phascogale using a wide range of shelter sites in the non-breeding season. These included hollows in wandoo (alive and dead), rock sheoak (alive and dead), *Xanthorrhoea* stumps, and logs on the ground. Hollows in wandoo were used when available in preference to hollows in rock sheoak. Phascogale have been observed to shelter under the skirt of *Xanthorrhoea*, in the hollow stem of dead and decaying *Xanthorrhoea*, in a fissure formed by a broken branch in fallen rock sheoak (Hide and Short, pers. obs.), and in a 'burrow-like hole in the ground' immediately post-fire (Friend and Friend 1993). Such flexibility in use of shelter is likely to greatly aid widespread dispersal across the landscape through areas of unfavourable habitat. In an area where hollows were in short supply, phascogale were forced to travel distances of up to 400 m to feeding areas each night (Friend and Friend 1993).

The different tree species common in our study area showed different incidences of hollow formation. Dead eucalypts (stags) showed the highest incidence, with about 70% having visible hollows and the incidence being not significantly related to DBH. Stags have been shown to be a vital nesting resource for other arboreal dasyurids (72% of nests of *Antechinus stuartii* were found in dead trees: Cockburn and Lazenby-Cohen 1992). Wandoo and York gum showed a relatively high incidence of hollows with about 30% of trees of DBH of 40 cm having hollows and with this percentage rising steadily for larger and presumably older trees. Trees with a DBH of 60 cm had > 60% incidence of hollows. Wandoo of this size are likely to be *c.* 200 years old (Rose 1993). This is consistent with results from other studies. Bradley (1997) found that red-tailed phascogale released after trapping would run directly to large (basal diameter of 0.5 m) mature wandoo to seek shelter in hollows at from 1 – 8 m above ground. Similarly, when *Antechinus stuartii* nested in live trees they would invariably be in very large trees, presumed to be of great age (Cockburn and Lazenby-Cohen 1992).

Salmon Gum also had a relatively high incidence of hollows (> 40% with a DBH > 100 cm), but because of their height and size appeared to be rarely used by phascogale. Red-tailed phascogale were observed to have difficulty climbing large-boled, smooth-barked and upright trees (J. Short and A. Hide, pers. obs.) and generally sought other pathways into the canopy if available. This is consistent with observations by Soderquist *et al.* (1996) who suggested that brush-tailed phascogale had an aversion to smooth-barked eucalypts as they had difficulty climbing them.

Non-eucalypts, including rock sheoak and swamp sheoak, had few or no hollows. This is consistent with the observations of Bennett *et al.* (1994) who found that hollows suitable for fauna rarely formed in smaller species that did not exceed 30 cm DBH. Bradley (1997) considered that rock sheoak decayed far too quickly to form nest hollows.

Both occupied and unoccupied sites in this study showed a wide range of tree stem densities from very sparse to very dense with an average of *c.* 3,500 stems per hectare. Sparse stem densities largely included sites with widely spaced eucalypts and little or no mid-storey. High stem densities were largely due to dense growth of rock sheoak, swamp sheoak or jam. Friend and Friend (1993) trapped phascogale at Tutanning Nature Reserve on three grids ranging between 2,500 and 5,900 stems per hectare across all tree species. An area burnt 25 years previously had dense sheoak, in contrast to an area unburnt for 50 years which had many large rock sheoak and the occasional old wandoo (*c.* 400 / ha) forming a relatively open habitat (Friend and Friend 1993). Friend and Friend (1993) suggested that these long unburnt areas of relatively open habitat only supported phascogale during periods of maximum activity and movement prior to the breeding season. We would suggest that this links to the higher risk of predation from avian and cursorial predators and is tied to canopy density – a significant factor in our comparison of occupied and unoccupied sites.

Our index of fallen timber showed no significant difference between occupied and unoccupied sites. This may be in part because overstorey trees, the chief source of fallen logs and branches, were typically widely spaced and scarce at many sites relative to mid-storey species. Hence our localised sampling based on the closest trees of any species to a random point would miss localised concentrations of fallen logs and branches centred on overstorey trees. Red-tailed phascogale do a considerable amount of their foraging on the ground (L. Rakai and A. Hide, unpublished data). Hence ground cover of fallen logs might be expected to be a key habitat component for them. Mature wandoo communities have an abundance of hollow logs and limbs that provide numerous rest sites (Kitchener 1983). Kitchener (1981) reported released animals being tracked to the hollows of fallen logs.

Our survey results indicate that phascogale are found widely across the study region and not confined to the few remaining reserves with substantial understorey of poisonous *Gastrolobium* shrubs. The presence of poison plants of the genus *Gastrolobium* in the understorey has long been considered a key factor in the persistence of phascogale in the southern wheatbelt (Kitchener 1981), and it is considered that their presence played a role in excluding stock from reserves (Lloyd 1998). The wandoo alliance has abundant poison plants *Gastrolobium* spp. (Leake 1962; Kitchener 1981) and many of the larger areas of remaining remnant vegetation in the southern wheatbelt where phascogale persist have high densities of *Gastrolobium* shrubs in the understorey. These include Dongolocking Nature Reserve, Tutanning Nature Reserve, and Dryandra Forest. However, in remnant vegetation remaining on farmland, much of the former *Gastrolobium* understorey is likely to have been removed in the past to protect sheep (Lloyd 1998).

Almost all sites assessed by us – both occupied and unoccupied – were long unburnt. Fire is actively suppressed thoughout the region and is no longer used for clearing of bushland as it was in the past (Lloyd 1998). Kitchener (1981) observed that phascogale were almost always caught in climax vegetation: at Yornaning, Tutanning and Dongolocking Nature Reserves in areas unburnt for 40 years; West Bendering (now Bendering) Nature Reserve in areas unburnt for 25 years; and Bendering (now North Karlgarin) Nature Reserve in areas unburnt for 10-20 years. However, he observed that they were captured at Dryandra Woodland in areas that had been recently burnt by 'cool' fires.

Friend and Friend (1993) reported the immediate death of 3 of 10 (33%) radio-collared phascogale in an experimental fire across an area of 100 hectares within Tutanning Nature Reserve, but little long term impact at a population level. The fire was sufficiently intense to kill 70% of rock sheoak trees and 22-90% of jam trees, but few wandoo trees. Many nest sites, particularly those in rock sheoak, grass tree stumps, or under grass tree skirts were destroyed resulting in a shift in use of shelter sites in response to the fire to a greater use of wandoo hollows.

Red-tailed phascogale currently appear relatively secure and widespread in our region of study. This is in contrast to areas in the eastern and likely south-eastern wheatbelt where the species appears to have suffered substantial decline and may only persist in a few isolated locations (Friend and Friend 1993; Short and Hide submitted). Despite widespread past land clearing in our study region, much upland and lowland habitat suitable for phascogale persists. There remains a reasonable level of connection between habitat remnants, formed by riverine corridors, vegetation around lake margins, and by remaining roadside and on-farm vegetation. Significant negative forces across our region that may impact on the species include: loss of tree stags over time in salt-affected areas along riverine corridors and along lake margins; ongoing reduction in roadside vegetation by local government as part of maintaining and widening roads; lack of occasional small-scale fires within remnants to renew areas of dense rock sheoak over time; and loss of mature wandoo in paddocks adjacent to bushland as farmers remove these to facilitate the use of larger cultivation machinery. Significant positive forces include: increased number of farm remnants that are fenced to exclude stock and the increased planting of corridors of trees between isolated farm remnants by farmers and community groups; the increased use of corridors of oil mallees across farmland that may facilitate movement of phascogale around the landscape; the greater awareness of farmers about phascogale; and the increased ownership of and involvement in phascogale conservation by rural communities in the region.

The potential loss of lowland habitat to salinity over time is likely to have a major detrimental impact on this species, reducing the area available to it and the quality of connections across the landscape. Hence, the likely long-term prognosis for red-tailed phascogale in this core area of its surviving range is likely to be significant decline.

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References

Andrén, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat - a review. *Oikos* **71**, 355-366.

Beard, J.S. (1980). 'The vegetation of the Dumbleyung area, Western Australia.' Vegmap Publications, Applecross.

Bennett, A.F., Lumsden, L.F., and Nicholls, A.O. (1994). Tree hollows as a resource for wildlife in remnant woodlands: spatial and temporal patterns across the northern plains of Victoria, Australia. *Pacific Conservation Biology* **1**, 222-235.

Bradley, A.J. (1997). Reproduction and life history in the red-tailed phascogale, *Phascogale calura* (Marsupialia, Dasyuridae): the adaptive-stress senescence hypothesis. *Journal of Zoology* **241**, 739-755.

Bradley, A.J., Foster, W.K., and Taggart, D.A. (2008). Red-tailed Phascogale. In 'The Mammals of Australia'. (Eds S. Van Dyck and R. Strahan.) pp. 101-102. (Reed New Holland: Australia.)

Chapman, A. (1978). Introduction to Dongolocking Nature Reserve. *Records of the Western Australian Museum Supplement* **6**, 9-16.

Cockburn, A. and Lazenby-Cohen, K. (1992). Use of nest trees by *Antechinus stuartii*, a semelparous lekking marsupial. *Journal of Zoology* **226**, 657-680.

Cuttle, P. (1982). Life history strategy of the dasyurid marsupial *Phascogale tapoatafa*. In *'Carnivorous Marsupials'*. (Ed. M. Archer.) pp. 13-22. (Royal Zoological Society of New South Wales: Sydney).

Diamond, J. (1989). Overview of Recent Extinctions. In 'Conservation for the Twenty-first Century '. (Eds D. Western and M.C. Pearl.) pp. 37-41. (Oxford University Press: New York.)

Fischer, J. and Lindenmayer, D.B. (2007). Landscape modification and habitat fragmentation: a synthesis. *Global Ecology and Biogeography* **16**, 265-280.

Friend, J.A. and Friend, G. (1993). Conservation of the Red-tailed Phascogale (*Phascogale calura*). Unpublished final report to ANCA Endangered Species Program. Department of Conservation and Land

Management, Wanneroo, WA.

Fulton, G.R. (2010). Predation of a mardo *Antechinus flavipes leucogaster* by a southern boobook, and mobbing of boobooks by other birds. *Australian Field Ornithology* **27**, 38-41.

Glauert, L. (1933). The distribution of marsupials in Western Australia. *Journal of the Royal Society of Western Australia* **19**, 17-32.

Jarvis, N.T. (1979). 'Western Australia: an atlas of human endeavour, 1829-1979.' (Education and Lands and Survey Departments of Western Australia: Perth, Western Australia.)

Kitchener, D.J. (1981). Breeding, diet and habitat preference of *Phascogale calura* (Gould, 1844) (Marsupialia: Dasyuridae) in the southern wheatbelt, Western Australia. *Records of the Western Australian Museum* **9**, 173-186.

Kitchener, D.J. (1983). Red-tailed Phascogale *Phascogale calura*. In 'The Australian Museum Complete Book of Mammals of Australia'. (Ed. R. Strahan.) pp. 36-37. (Angus & Robertson Publishers: Sydney, NSW.)

Kitchener, D.J. and Chapman, A. (1977). Mammals of Bendering and West Bendering Nature Reserves. *Records of the Western Australian Museum, Supplement No. 5,* 17-30.

Kitchener, D.J. and Chapman, A. (1978). Mammals of Dongolocking Nature Reserve. *Records of the Western Australian Museum, Supplement No.6*, 53-58.

Kitchener, D.J., Chapman, A., Muir, B.G., and Palmer, M. (1980). The conservation value for mammals of reserves in the Western Australian wheatbelt. *Biological Conservation* **18**, 179-207.

Lande, R. (1998). Anthropogenic, ecological and genetic factors in extinction and conservation. *Researches on Population Ecology* **40**, 259-269.

Leake, B.W. (1962). 'Eastern Wheatbelt Wildlife.' (B. W. Leake: Perth.)

Liddelow, G., Wheeler, I.B., and Kavanagh, R.P. (2002). Owls in the southwest forests of Western Australia. In 'Ecology and conservation of owls'. (I. Newton, R.P. Kavanagh, J. Olsen, and I. Taylor, Eds.) pp. 233-241. (CSIRO Publishing: Melbourne.)

Lloyd, T. (1998). History of the Dongolocking area. In 'Landscape Planning for Biodiversity Conservation in Agricultural Regions.' (Ed. K. Wallace.) pp 35-44. (Environment Australia: Canberra.)

McNabb, E.G. (2002). Notes on the diet and observations of the southern boobook (*Ninox novaeseelandiae*) in southern Victoria. In 'Ecology and conservation of owls'. (I. Newton, R.P. Kavanagh, J. Olsen, and I. Taylor, Eds.) pp. 192-198.

Nicholls, C. (2008). http://www.futurefarmcrc.com.au/documents/Oilmalleesnativefaunasanctuaries.pdf

Ninox Wildlife Consulting (1987). 'A vertebrate fauna survey of Reserves 19085, 19091, 20069, 20070 in the Shire of Dumbleyung, Western Australia.' (Ninox Wildlife Consulting: Perth.)

Rhind, S. (1993-1994). Fascinating Phascogales. *Landscope* **9**, 35-40.

Rose, P.W. (1993). Production of habitat hollows by wheatbelt eucalypts. Rose and Bending Forest and Environmental Consultants, Manjimup, Western Australia. Unpublished report: Save the Bush Research Grant 1991/92 - Project R053.

Saunders, D.A. (1989). Changes in the avifauna of a region, district and remnant as a result of fragmentation of native vegetation: the wheatbelt of Western Australia. A case study. *Biological Conservation* **50**, 99-135.

Short, J. and Hide, A. (submitted). Distribution and status of the red-tailed phascogale *Phascogale calura*. *Australian Mammalogy*.

Short, J. and Stone, M. (2009). Farmers befriend phascogale. *Landscope* **25**, 22-28.

Smith, A. and Lee, A.K. (1984). The evolution of strategies for survival and reproduction in possums and gliders. In 'Possums and Gliders.' (Eds A.P. Smith and I. Hume.) pp. 17-33. (Surrey Beatty & Sons: Sydney.)

Soderquist, T.R. (1993). Maternal strategies of *Phascogale tapoatafa* (Marsupialia: Dasyuridae). II. Juvenile thermoregulation and maternal attendance. *Australian Journal of Zoology* **41**, 567-576.

Soderquist, T.R. and Lill, A. (1995). Natal dispersal and philopatry in the carnivorous marsupial, *Phascogale tapoatafa* (Dasyuridae). *Ethology* **99** , 297-312.

Soderquist, T.R., Traill, B.J., Faris, F., and Beasley, K. (1996). Using nest boxes to survey for the brush-tailed phascogale *Phascogale tapoatafa*. *Victorian Naturalist* **113**, 256-261.

Traill, B.J. and Coates, T.D. (1993). Field observations on the brush-tailed phascogale *Phascogale tapoatafa* (Marsupialia: Dasyuridae). *Australian Mammalogy* **16**, 61-65.

van der Ree, R., Soderquist, T.R., and Bennett, A.F. (2001). Home range use by the brush-tailed phascogale (*Phascogale tapoatafa*) (Marsupialia) in high-quality spatially limited habitat. *Wildlife Research* **28**, 517-525.

Van Dyck, S. and Gibbons, D. (1980). Tuan predation by Powerful Owls. *Victorian Naturalist* **97**, 58-63.

Ward, D. (1991). Triangular tesselation: a new approach to forest inventory. *Forest Ecology and Management* **44**, 285-290.

Table 1: Remnants trapped for red-tailed phascogale by year.

Year	Number of remnants trapped	Trap nights	Phascogale captured	Mean trap success / 100 trap nights
2005-06	18	4,424	34	0.77
2006-07	25	6,588	159	2.41
2007-08	25	6,660	32	0.48
2008-09	16	4,420	78	1.76
Total	84	22,092	303	1.37

Table 2: The tenures of land on which red-tailed phascogale were trapped.

DEC - Department of Environment and Conservation; OCR - other Crown land; UCR - unallocated Crown land.

	Private	DEC	OCR/UCR	Total
Phascogale present	29 (64%)	17 (57%)	19 (61%)	65 (61%)
Phascogale absent	16 (36%)	13 (43%)	12 (39%)	41 (39%)
Total	45	30	31	106

Table 3: The range in remnant size (assessed for discrete tenure and for total contiguous area of bushland) and the median size of those remnants in which red-tailed phascogale were trapped or not trapped.

All areas are in hectares.

Treatment	Tenure area		Contiguous area	
	Range	Median	Range	Median
Phascogale trapped (n = 65)	2 - 1185	116.0	2 - 3080	158.0
Phascogale not trapped (n = 41)	10 - 1593	186.0	17 - 1952	240.0

Table 4: The position within the landscape of sites trapped for red-tailed phascogale.

	Upland	Mixed	Lowland	Total
Phascogale present	36	9	20	65
Phascogale absent	25	6	10	41
Total	61	15	30	106

Table 5: Beard's vegetation associations occupied by red-tailed phascogale in south-west Western Australia.

Derived from a GIS layer based on broad scale regional mapping of vegetation by Beard (1980)

Vegetation association (with brief description and vegetation association numbers)	Phascogale present	Phascogale absent	Total (% with phascogale)
Succulent steppe with open woodland and scrub (wandoo, salmon gum and swamp sheoak) #1074 and 1083	9	1	10 (90%)
Medium woodland (York gum, wandoo and salmon gum) #1023	48	16	64 (75%)
Medium woodlands (marri /wandoo), medium forest (jarrah / wandoo), and medium woodland (wandoo with mallet and/or yate and/or morrel) #4, 142, 992, 947, 967, 1073, 1085 and 1092	6	14	20 (30%)
Shrublands (mallee or Dryandra heath), mosaic shrublands / scrub heath, and mosaic malleeshrubland/ medium woodland (# 952, 955, 1075, 1094 and 2048)	2	10	12 (17%)
Total	65	41	106 (61%)

Table 6: Tree species recorded in remnants assessed for red-tailed phascogale with their size and the incidence of hollows. Species are ordered by incidence of hollows.

Tree species	Number recorded	Mean diameter breast height (range) mm	Number alive	Number (%) with hollows
Stags (indeterminate eucalypt)	36	375 (67-879)	0 (0%)	26 (72.2%)
Wandoo *Eucalyptus wandoo*	392	331 (32-1241)	374 (95.4%)	139 (35.5%)
Grass tree *Xanthorrhoea preissii*	4	239 (143-337)	3 (75%)	1 (25%)
Flooded gum *E. rudis*	7	291 (99-477)	6 (86%)	2 (28.6%)
York Gum *E. loxophleba*	143	259 (64-716)	140 (97.9%)	29 (20.3%)
Salmon gum *E. salmonophloia*	93	483 (29-1114)	91 (97.8%)	12 (12.9%)
Red morrel *E. longicornis*	104	393 (80-1082)	103 (99.0%)	10 (9.6%)
Marri *Corymbia calophylla*	13	208 (64-509)	11 (84.6%)	1 (7.7%)
Yate *E. occidentalis*	19	171 (80-598)	17 (89.5%)	1 (5.3%)
Mallet *E. astringens, E. gardneri*, and *E. falcata*	67	201 (45-668)	67 (100%)	1 (1.5%)
Jam *Acacia acuminata*	180	119 (22-477)	150 (83.3%)	2 (1.12%)
Rock sheoak *Allocasuarina huegeliana*	850	137 (9-576)	770 (90.6%)	7 (0.82%)
Swamp sheoak *Casuarina obesa*	125	182 (19-1082)	125 (100%)	1 (0.8%)

25

Mallee *E. eremophila* and *E.* spp.	116	75 (6-166)	115 (99.1%)	0 (0%)
Jarrah *E. marginata*	21	248 (16-1273)	20 (95.2%)	0 (0%)
Melaleuca spp.	47	64 (13-207)	38 (80.9%)	0 (0%)
Other non-eucalypts	45	81 (10-213)	43 (95.6%)	0 (0%)
Total	2262			232 (10.3%)

Table 7: The number of remnants (and percentage) with and without phascogale that had a mean distance to hollows of < 75 m as assessed from six random locations within the remnant

* includes site with no recorded hollows, arbitrarily scored as 150 m

	Mean distance to tree with hollow		Total
Phascogale	< 75 m	≥ 75 m*	
Present	60 (92%)	5 (8%)	65
Absent	31 (76%)	10 (24%)	41
Total	91	15	106

Table 8: The number of remnants with and without phascogale grazed by stock

	Grazed by stock		Total
Phascogale	Yes	No	
Present	14	51	65
Absent	9	32	41
Total	23	83	106

Table 9: The occurrence of red-tailed phascogale at sites with and without poison plants (*Gastrolobium* spp.).

Species	Number of sites	Number of sites containing phascogale (%)
York Road Poison (*Gastrolobium calycinum*) only	11	4 (36%)
Prickly Poison (*Gastrolobium spinosum*) only	9	6 (67%)
Box Poison (*Gastrolobium parviflorum*) only	8	5 (63%)
Bullock Poison (*Gastrolobium trilobum*) only	1	0
Sandplain Poison (*Gastrolobium microcarpum*) only	0	0
Thick leaved Poison (*Gastrolobium crassifolium*) only	0	0
Multiple species of the above	8	4 (50%)
No species of *Gastrolobium* recorded	69	46 (67%)
Total	106	65 (61%)

Table 10: **The number of sites containing some evidence of fire and the number of each of these sites where red-tailed phascogale were present.**

Species	Number of sites	Number of sites containing phascogale (%)
No fire recorded at all locations sampled	38	23 (58%)
Fire at some time in the distant past (< 50% of samples at a site)	33	22 (67%)
Fire at some time in the distant past (≥ 50% of samples at a site)	33	19 (58%)
Recent sign of fire (recorded at < 50% of samples at a site)	1	1 (100%)
Recent sign of fire (recorded at ≥ 50% of samples at a site)	1	0 (0%)
Total	106	65 (61%)

Figure 1: The study region in the southern wheatbelt of Western Australia showing sites trapped. Closed circles are sites where red-tailed phascogale were trapped; plus symbols are sites that were trapped but where no phascogale were caught. Light shading shows major areas of remaining native vegetation amongst cleared farmland (shown as white). The location of the study region within Western Australia and relative to the extent of the wheatbelt (shaded) are given in the inset at left.

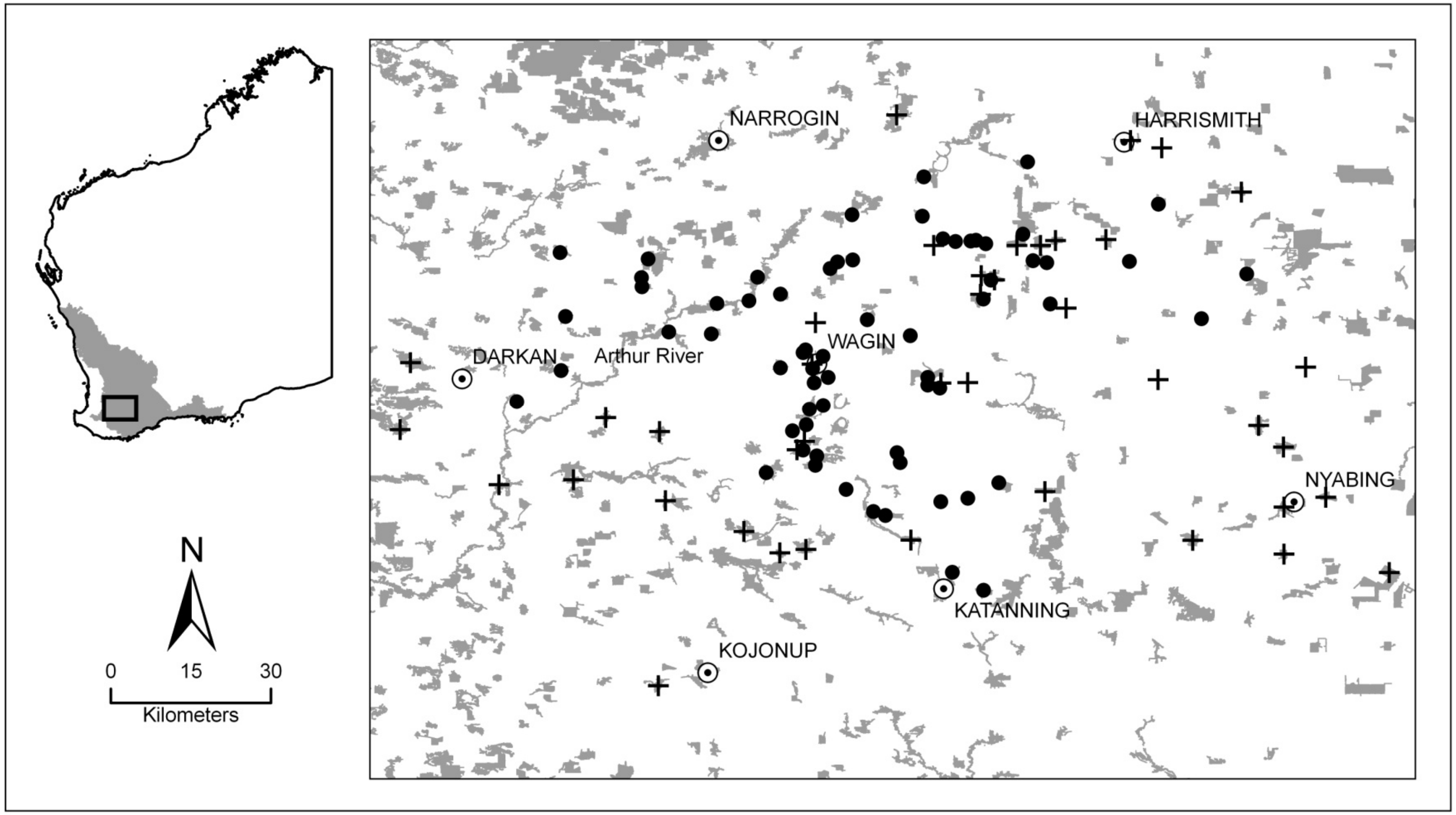

Figure 2: The probability of occurrence of visible hollows in trees of a given DBH in typical tree species within the range of red-tailed phascogale in south-west Western Australia. Data are as for Table 6.