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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 semiarid 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 phascogales with a view to understanding their current and likely future distribution and status.

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

Key results. Phascogales 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 phascogales typically had a greater canopy density and greater abundance of hollows than unoccupied sites. The presence of plants of the genus *Gastrolobium*, often cited as a key factor in the persistence of phascogales, did not appear to influence the presence or absence of phascogales.

Conclusions. Red-tailed phascogales 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 by owls, are key features of suitable phascogale habitat.

Implications. Suitable habitat for phascogales 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: connectivity, dasyurid, *Gastrolobium*, fire, fragmentation, salinity, tree hollows, wheatbelt.

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*), which has 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 semiarid 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 in press). 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 (Fig. 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

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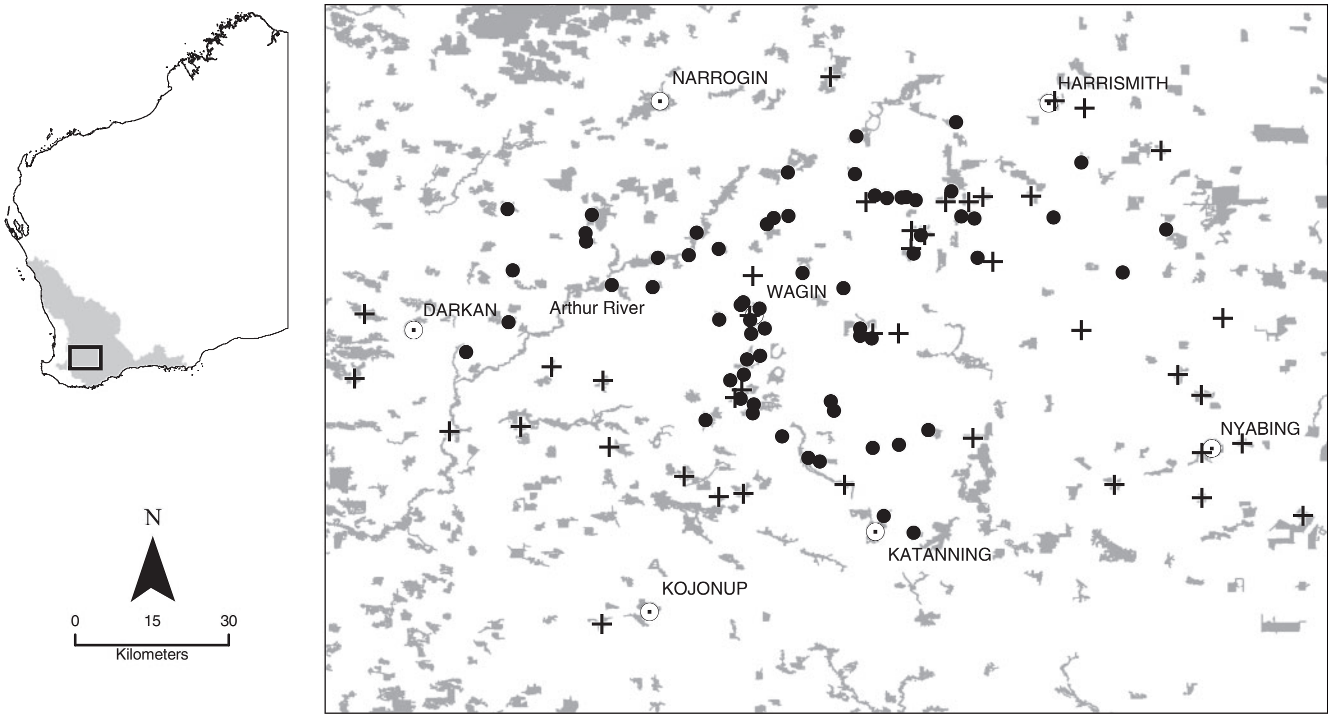

Fig. 1. The study region in the southern wheatbelt of Western Australia showing sites trapped. Closed circles are sites where red-tailed phascogales were trapped; plus symbols are sites that were trapped but where no phascogales were caught. Light shading shows major areas of remaining native vegetation among 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.

occurring after World War II to the early 1980s (Chapman 1978; Jarvis 1979; Lloyd 1998). Remaining habitat remnants are often small and fragmented. Phascogales 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 phascogales in just four. From these distributional data for phascogales, Kitchener (1983) suggested that the species was confined to reserves that exceeded 450 ha 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 limit the number of foxes by secondary poisoning (Bradley *et al*. 2008).

We trapped for phascogales in remnants of native vegetation in the south-western portion of its current range. This is an area of ~16 000 km^2 (110 × 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 creek lines 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 used these data to establish:

- attributes of habitat associated with the presence or absence of phascogales – 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 where phascogales commonly occur, how this varies with tree girth and whether the size distribution of trees of these species differs between sites with and without phascogales.

Materials and methods

Trapping of phascogales

We trapped for phascogales 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 phascogales 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 phascogales by trapping along five transects. Transects were located in habitat within the remnant judged most likely to yield phascogales (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 (33 × 10 × 10 cm) and three cage traps (58 × 20 × 20 cm) set for two consecutive nights and spaced at intervals of ~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 phascogales for each remnant and captures of other species were recorded.

We also collated information on trapping for phascogales by researchers, consultants and community groups within our study area over the previous 25 years to allocate these sites as either positive or negative for the presence of phascogales. Trapping methodology varied between practitioners but all included Elliott trapping. Habitat assessments were carried out at these sites in the same way as trapping sites 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 at breast height (DBH). Also measured were: the percentage canopy cover (measured using a spherical densiometer when facing south from the 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 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 ~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 phascogales were compared using a Chi-square analysis to assess frequencies of categorical variables and either a one factor ANOVA or a general linear model (with presence or absence of phascogales as a fixed factor and site as a random factor nested within phascogale presence or 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 regressions were 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 phascogales were trapped. The presence or absence of hollows in trees of different sizes and species was modelled using binary logistic regression (logit link function).

Results

Trapping of phascogales

We trapped 84 remnants for phascogales over four trapping seasons between 2005 and 2009 (Table 1). All sites were in the southern wheatbelt in an area that extended ~150 km in an east–west direction from the forest margin near Darkan to Nyabing and 110 km north–south from Narrogin to Katanning and Kojunup (Fig. 1). In total, 303 phascogales were trapped over 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 (range: 0–14.9). Other species captured in low densities included the common brushtail possum (*Trichosurus vulpecula*), echidna (*Tachyglossus aculeatus*), house mouse (*Mus musculus*), black rat (*Rattus rattus*) and brush-tailed phascogale (*Phascogale*

Table 1. Remnants trapped for red-tailed phascogales by year

Year	Number of remnants trapped	Trap-nights	Phascogales captured	Mean trap success per 100 trap-nights
2005–06	18	4424	34	0.77
2006–07	25	6588	159	2.41
2007–08	25	6660	32	0.48
2008–09	16	4420	78	1.76
Total	84	22 092	303	1.37

tapoatafa). However, captures of species other than red-tailed phascogales were uncommon.

In addition, we were able to establish presence or absence of phascogales 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. Phascogales were detected in 65 of the 106 remnants (61.3%).

Tenure

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

Tenure area

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

Contiguous area

The median size of contiguous vegetation area, regardless of tenure, in which phascogales were trapped was somewhat smaller than the median of those that were trapped but where no phascogales were caught (Table 3). However, the difference in $\log_{10}$ areas was not significant ($F_{1,104} = 2.67$; $P = 0.105$). Phascogales were caught or observed in remnants ranging from 2 to 3080 ha and did not appear to be limited to remnants of any particular size. Phascogales were detected in 19 remnants of less than 70 ha in contiguous area.

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

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

	Private	DEC	OCR/UCR	Total
Phascogales present	29 (64%)	17 (57%)	19 (61%)	65 (61%)
Phascogales 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 phascogales were trapped or not trapped

All areas are in hectares

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

Proximity to occupied remnants

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

When community sightings or other records from after 1990 were included, the mean distance from a positive site to any other positive record was 3.3 km; the 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 phascogales, indicating greater isolation. The most distant positive records (a small remnant of 157 ha, 13 km south-east of Harrismith, and another of 107 ha 23 km south of Harrismith) were each 11.6 km from another positive record.

Position in landscape

Phascogales 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. Phascogales were present in 59% of upland sites, 67% of lowland sites and 60% of mixed sites (Table 4). Hence, phascogales 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 phascogales ($\chi^2_2 = 0.509$; $P = 0.775$).

Vegetation types

We looked for a relationship between vegetation association and presence or absence of phascogales (Table 5). We lumped like

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

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

Table 5. Beard's vegetation associations occupied by red-tailed phascogales 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)	Phascogales present	Phascogales absent	Total (% with phascogales)
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 and wandoo), medium forest (jarrah and 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 and scrub heath, and mosaic mallee shrubland and medium woodland (#952, 955, 1075, 1094 and 2048)	2	10	12 (17%)
Total	65	41	106 (61%)

associations to ensure that no more than one expected value was less than 5 in the Chi-square test. 'Succulent steppe with open woodland and scrub' and 'medium woodland' (York gum, wandoo and salmon gum) represented 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 phascogales ($\chi^2_3 = 29.00$; $P < 0.001$).

Red-tailed phascogales occupied a range of vegetation types associated with both upland and lowland parts of the landscape. They occurred most reliably at 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 have 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. Phascogales 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.

Tree species

In total, 2262 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.) occurred 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

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

Tree species	Number recorded	Mean diameter at 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 (75.0%)	1 (25.0%)
Flooded gum *E. rudis*	7	291 (99–477)	6 (86.0%)	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%)
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%)

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 phascogales, but were not particularly common at 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: $\chi^2_1 = 16.24$, $P = 0.00$).

The incidence of visible hollows as a function of size of tree is plotted in Fig. 2. The probability of presence of hollows increased with tree size. The 221 eucalypts that had hollows were significantly larger (had a significantly greater DBH) than the 790 eucalypts that had no detected hollows (mean of 148 cm vs 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 phascogales for the three most common 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 phascogales didn't obviously differ in size class of trees. Measured eucalypts were dominated by smaller size classes. The percentage of trees with a greater than 50% probability of having a hollow (Fig. 2) was 32% of wandoo (DBH > 40 cm), 14% of York gum (DBH > 45 cm) and 3.5% of salmon gum (DBH > 100 cm).

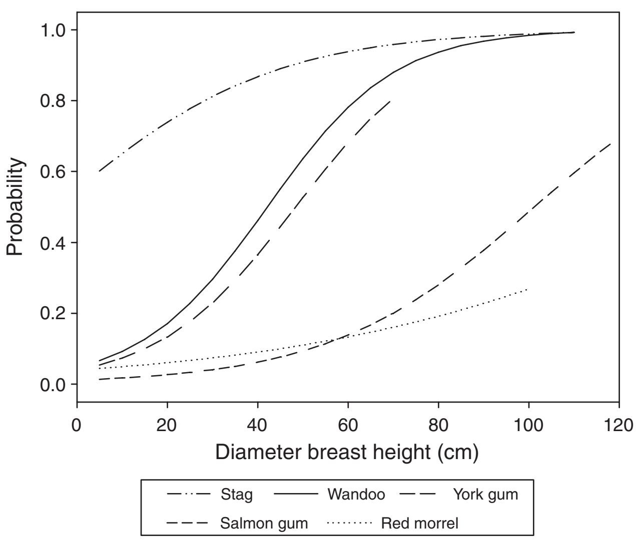

Fig. 2. The probability of occurrence of visible hollows in trees of a given DBH in typical tree species within the range of red-tailed phascogales in south-west Western Australia. Data are as for Table 6.

Hollows

Distance to the nearest detected hollow-bearing tree did not show a significant difference between sites with and without phascogales ($F_{1,104} = 1.84$, $P = 0.178$). Distance to the nearest hollow-bearing tree for sites with phascogales averaged 37 m; distance to nearest hollow-bearing tree for sites without phascogales was 44 m. Estimated density of hollow-bearing trees varied between 0 and 260 per hectare, but did not differ significantly between sites with and without phascogales.

However, six of the 41 sites without phascogales 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 phascogales 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 phascogales had some evidence of the presence of hollows. Hence, absence of hollows could not be invoked as the key cause of absence of phascogales in these cases. Yet, sites without phascogales 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 phascogales were detected compared with sites where they were not. Canopy densities, as assessed by densiometer, averaged 62.4% at sites with phascogales and 52.0% at sites where no phascogales were caught. There was a significant difference between sites with and without phascogales ($F_{1,104} = 10.74$, $P = 0.001$). 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 phascogales ($F_{1,104} = 8.47$, $P = 0.004$). Sites with phascogales 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

Phascogales occupied sites with a wide range of stem densities from very sparse (typically scattered old-growth wandoo without

Table 7. The number of remnants (and percentage) with and without phascogales 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

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

mid-storey, 400 stems per hectare) to very dense (typically dense regrowth of rock sheoak or swamp sheoak, >10 000 stems per 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 3700 stems per hectare; unoccupied sites averaged 3200.

Fallen timber index

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

Access by stock

Stock did not have access to the majority of sites surveyed. Department of Environment and Conservation 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 ~78% of sites assessed (Table 8). Phascogales were present at 61% of grazed sites. There was no significant association between presence of stock and presence of phascogales ($\chi^2_1 = 0.03$, $P = 0.960$).

Table 8. The number of remnants with and without phascogales grazed by stock

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

Poison plants

Poison plants (*Gastrolobium* spp.) were recorded at 37 of 106 sites surveyed (Table 9). Phascogales were trapped in a higher proportion of those sites with no poison plants detected. Of the 69 sites where there were no poison plants recorded, 46 (67%) contained phascogales. Nineteen of 37 sites at which poison plants were recorded (51%) contained phascogales. Of the eight sites where >5 phascogales 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 phascogales ($\chi^2_2 = 1.008$, $P = 0.604$). In this analysis (Table 10), fire histories were grouped as: no evidence of past fires, some evidence of patchy fires (either past or recent) or 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 per hectare' correctly classified 81% of sites – 92.3% of positive sites were assessed correctly, but only 63.4% of negative sites. The equation

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

Species	Number of sites	Number of sites containing phascogales (%)
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 phascogales were present

Species	Number of sites	Number of sites containing phascogales (%)
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%)

that predicted probability of phascogale presence was $y = 0.429–0.205$ distance (km) + 1.685 arcsin(sheoak) + 0.497 $\log_{10}$(hollows per hectare).

Discussion

Red-tailed phascogales were common in remnant bushland in the area surveyed, being detected in 65 of 106 survey locations. We determined presence or absence from 250 trap-nights at each site, enough to minimise false negatives. Red-tailed phascogales were readily trapped, in contrast with the difficulty reported for brush-tailed phascogales (Traill and Coates 1993). Our overall capture rate of 1.37 per 100 trap-nights, averaged across sites both with and without red-tailed phascogales, was substantially higher than that reported for brush-tailed phascogales at sites where they were known to be present (0.49 per 100 trap-nights: Traill and Coates 1993). Friend and Friend (1993) recorded red-tailed phascogales at 20 sites in the Western Australian wheatbelt: 17 from sites with less than 250 trap-nights of effort (a median of 120 trap-nights per site where phascogales were recorded). A small number of sites re-trapped over periods of several years have recorded different results for presence or absence in 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 phascogales.

Phascogales 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 sheoak 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 phascogales.

The incidence of phascogales 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 phascogales 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 in press), the presence of phascogales 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 seemed to decline.

Red-tailed phascogales 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 creek lines. Red-tailed phascogales are reported to have average home ranges of up to 8 ha in the non-breeding season and up to 103 ha 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 phascogales (Bradley 1997). Female brush-tailed phascogales are reported to require a home range of 20 to 60 ha, with males requiring even larger areas (Rhind 1993–1994; Traill and Coates 1993; Soderquist 1993). 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 numbers 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 phascogales 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 with the view of Friend and Friend (1993), who considered 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 are 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 phascogales 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 phascogales. Phascogales typically occurred at sites with a dense mid-storey canopy of rock sheoak, swamp sheoak or less commonly jam. However, there were many exceptions where phascogales 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 phascogales 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 phascogales occurred within the Tutanning Nature Reserve, 60 km north of the northern boundary of our study region.

A key predator of phascogales and other small dasyurids is likely to be owls (Van Dyck and Gibbons 1980; Cockburn and Lazenby-Cohen 1992; McNabb 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 for phascogales while they forage 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 ~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 phascogales. It may also provide more opportunity to escape carpet pythons (*Morelia spilota*), feral cats (*Felis catus*) and foxes (*Vulpes vulpes*).

Red-tailed phascogales 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 phascogales 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 phascogales or of competition for their use.

Red-tailed phascogales are likely to have very specific requirements for breeding hollows. Two nests examined in the Wagin area (one in 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 phascogales 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 phascogales, where natural entrances are small with widths ranging from 24–55 mm (mean 15 cm^2) (Soderquist 1993). The cavity size of five natural hollows utilised by brush-tailed phascogales averaged 9885 cm^3 and cavities were filled with large volumes of nest material of bark strips, feathers and fur (Soderquist 1993). This suggests hollows of approximate dimensions of $20 \times 20 \times 25$ cm. Competition for hollows with other arboreal mammals (sugar gliders *Petaurus breviceps* and squirrel gliders *P. norfolcensis*) is a major issue in eastern Australia. Nest boxes used by red-tailed phascogales 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 ~12 000 cm^3.

Friend and Friend (1993) recorded red-tailed phascogales 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. Phascogales 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 (A. Hide and J. Short, pers. obs.) and in a ‘burrow-like hole in the ground’ immediately after 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, phascogales 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 exhibited different incidences of hollow formation. Dead eucalypts (stags) showed the highest incidence, with ~70% having visible hollows regardless of DBH. Stags have been shown to be a vital nesting resource for other arboreal dasyurids (72% of *Antechinus stuartii* nests were found in dead trees: Cockburn and Lazenby-Cohen 1992). Wandoo and York gum showed a relatively high incidence of hollows with ~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 ~200 years old (Rose 1993). This is consistent with results from other studies. Bradley (1997) found that red-tailed phascogales released after trapping would run directly to large (basal diameter of 0.5 m) mature wandoo to seek shelter in hollows 1–8 m above the 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 DBH >100 cm), but because of their height and size, appeared to be rarely used by phascogales. Red-tailed phascogales 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 phascogales 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 ~3500 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 phascogales at the Tutanning Nature Reserve on three grids ranging between 2500 and 5900 stems per hectare across all tree species. An area burnt 25 years previously had dense sheoak, in contrast with an area unburnt for 50 years, which had many large rock sheoaks and the occasional old wandoo (~400 per 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 phascogales during periods of maximum activity and movement before the breeding season. We would suggest that this may be related 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 phascogales do a considerable amount of their foraging on the ground (L. Rakai and A. Hide, unpubl. 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 phascogales are found widely across the study region and are not confined to the few remaining reserves with a 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 phascogales 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 phascogales 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 throughout the region and is no longer used for clearing of bushland as it was in the past (Lloyd 1998). Kitchener (1981) observed that phascogales 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 phascogales in an experimental fire across an area of 100 ha 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 to a greater use of wandoo hollows.

Red-tailed phascogales currently appear relatively secure and widespread in our region of study. This is in contrast with 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 in press). Despite widespread past land clearing in our study region, much upland and lowland habitat suitable for phascogales persists. There remains a reasonable level of connection between habitat remnants, formed by riverine corridors, vegetation around lake margins and 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: an increased number of farm remnants that are fenced to exclude stock; increased planting of corridors of trees between isolated farm remnants by farmers and community groups; increased use of corridors of oil mallees across farmland that may facilitate movement of phascogales around the landscape; greater awareness of farmers about phascogales; and 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 phascogales in this core area of its surviving range is likely to be significant decline.

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