Short-term impact of fire on a population of the red-tailed phascogale *Phascogale calura* (Marsupialia: Dasyuridae) in the Western Australian wheatbelt.

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Abstract

The impact of an autumn fire on a population of the threatened dasyurid marsupial *Phascogale calura* and its habitat were examined over 27 months at Tutanning Nature Reserve in the Western Australian wheatbelt. Although of only low to moderate intensity, the fire destroyed many hollow logs and much of the surface leaf litter layer, killed a high proportion of the dominant tree species (*Allocasuarina huegeliana, Acacia acuminata* and *Eucalyptus wandoo*), and consumed many dead trees and the remains of grasstrees (*Xanthorrhoea* spp.) used as nest sites by *P. calura*. The fire caused significant direct injury and mortality of *P. calura* individuals, all of which stayed within their pre-fire home ranges, but had only minimal impact on abundance, growth, reproduction and recruitment within the population. This is probably because of the small scale of the burn and the proximity of unburnt habitat which allowed rapid recolonisation. The impact may become significant in the longer term, however, as plant species composition and structure of the habitat change due to the combined effects of the fire, and a subsequent locust plague which eliminated much of the *Allocasuarina* regrowth.

This outcome shows the critical importance of the timing of prescribed burns in relation to other disturbance events like droughts and locust plagues, as well as scale and its capacity to interact with intensity to either exacerbate or moderate the longer-term impacts of fire on a potentially sensitive species.

INTRODUCTION

At the time of European colonization of Australia the red-tailed phascogale (*Phascogale calura* Gould, 1844) had a wide but patchy distribution throughout arid and semi-arid areas of the Northern Territory, South Australia and Western Australia. Like many other Australian mammals, however, the species subsequently underwent an enormous contraction in range, and is now confined to remnant patches of suitable habitat in the central and southern wheatbelt region (Beard 1990) in the south-west of Western Australia. It is listed under Schedule 1 as "rare or likely to become extinct" in Western Australia (W.A. Government Gazette, 1998), and as "endangered" by the Australian and New Zealand Environment and Conservation Council (ANZECC 1991). *P.calura* is also listed in Schedule 1, Part 1 under the Endangered Species Protection Act (1992) (ANCA 1994), and was included in the 1996 Action Plan for Australian Marsupials and Monotremes and the 1996 IUCN Red List of Threatened Animals as "endangered" (taxa facing a very high risk of extinction in the wild in the near future; Maxwell *et al.* 1996, IUCN 1996). In a review of the causes and conservation implications of the modern decline of Western Australia's vertebrate fauna, Burbidge and McKenzie (1989) listed *P. calura* as priority two, which species "require special protection, detailed research studies and the development of species management plans".

Apart from some work on breeding, diet and habitat preferences by Kitchener (1981), and field studies of the endocrinology of the annual male die-off (Bradley 1987) and water turnover (Green *et al.* 1989), there is little information available on the species' ecology and requirements for effective long-term conservation and management (Burbidge and McKenzie 1989; Maxwell *et al.* 1996). Available information suggests that, in the western part of its surviving range at least, *P. calura* inhabits long-unburnt tall and dense vegetation of the *Eucalyptus wandoo/Eucalyptus accedens* and *Allocasuarina huegeliana* alliances, with populations being most dense in the latter type (Bradley 1995). These vegetation types are highly flammable, but under natural conditions burn only infrequently, though at very high intensities. *A. huegeliana* is highly sensitive to fire, (Kessell *et al.* 1984) and there is generally complete mortality and replacement of stands after fire. Consequently, *A. huegeliana* habitat often comprises dense even-aged stands which self-thin over time, but which support little understorey development.

In these habitats poison plants (*Gastrolobium* spp.) occur which are toxic to introduced herbivores and predators and this may bestow some protection to *P. calura* and other native vertebrates

(Kitchener 1981; Bradley 1995). Within its remaining range, much of the habitat of *P. calura* is now on nature reserves where burning is infrequent (Muir 1985). These two factors may have contributed to the persistence of populations in the south-west of Western Australia. Such information needs to be carefully assessed, and data on the species' status, distribution, habitat usage and response to fire gathered before effective management can be undertaken.

To address these questions, the Western Australian Department of Conservation and Land Management (CALM) commenced a detailed program of research on the ecology of *P. calura* in early 1990. Part of this research aimed at assessing the impact of fire on a population of *P. calura* using an experimental approach combined with contemporaneous sampling of different-aged areas. This paper reports on population dynamics from regular live trapping on burnt and unburnt grids and on the movements, nest use and fate of radio-collared individuals throughout and after the fire, as well as the associated post-fire changes in habitat.

METHODS

Study area

Studies were carried out at Tutanning Nature Reserve, 150 km south-east of Perth (32° 31'S, 117° 23'E) and complemented longer-term fire ecology research on small vertebrates and invertebrates which began in 1986. This 2 310 ha reserve encompasses a diverse range of habitat types including several types of shrublands, eucalypt open woodlands, sheoak woodlands and granite outcrops (Brown and Hopkins 1983). Climate in the area is mediterranean with an annual average rainfall of 450 mm, and temperatures varying between a mean maximum of 31.7°C in January and a mean minimum of 5.6°C in August.

Transect-based reconnaissance trapping in September 1989 had indicated the presence of a population of *P. calura* in a block scheduled for burning in the following autumn. The present work began in February 1990, only six weeks before the prescribed burn which was carried out as part of the longer-term research.

Trapping

The *P.calura* population was sampled regularly on three trap-grids on a capture-mark-recapture system. All grids were in rock sheoak *Allocasuarina huegeliana* habitat. Two (grids 1 and 2) were within the 100 ha block that was prescription burnt under low-moderate intensity on 20 March

1990. The other (grid 3) was situated in similar habitat in a block which remained unburnt. Vegetation on grids 1 and 2 had last been burnt in 1965, probably as a result of an escaped clearing burn. Prior to this, all of the southern area of the reserve (including all three study sites) had been burnt in a high intensity wildfire in 1940. Fires earlier than this are not documented for these blocks. Vegetation on grid 3 was thus 50 years old with many large *A. huegeliana* and occasional old wandoo *Eucalyptus wandoo* trees forming a relatively open habitat. Grids 1 and 2, by contrast, supported quite dense 25-year-old *A. huegeliana* and some jam wattle *Acacia acuminata* with only the very occasional large sheoak or wandoo. These two grids were separated only by a narrow track from a larger block of *A. huegeliana* which was last burnt in 1932.

Each of the grids comprised 64 trap-stations at 20 m spacing in an 8 x 8 array. Trap sessions were conducted monthly between February 1990 and March 1991, and every second month thereafter until July 1992 (except for an extra sample in December 1991). In each session, Elliott traps (Type A) were baited with a mixture of peanut butter, rolled oats and sardines, and set for two or three nights depending on weather conditions. Animals are very susceptible to low temperatures and only short trap-runs, with each trap enclosed in a plastic bag, were carried out over the winter months (June-August). Animals were marked using a system of ear notching, and were weighed and measured for head length, with scrotal width measured for males, and pouch condition and number and crown-rump length of young recorded for females.

For each grid, the minimum number of animals (males, females and total) known to be alive (KTBA) at each trap session was calculated as those caught at that time plus those previously marked individuals subsequently caught. These values were plotted against time to enable comparison of numbers and trends between grids. Mean weights of males and females were also plotted against time for the whole study, and over twelve months. Twelve-month plots were also done for mean scrotal widths of males. To assess any changes in condition of the animals following the fire, and to compare animals on the three grids, the mean weights of males and females in the samples taken immediately before and immediately after the fire were compared using Tukey's multiple comparison test (Zar 1984).

Radio-tracking

Radio-tracking was carried out before and immediately after the fire in March 1990 and 12 months later in order to (a) monitor the survival of individual *P. calura*, (b) compare individual home range sizes before and after fire, (c) determine the fate of nesting sites in the fire and (d) determine whether nest site preferences changed after fire.

March 1990 – pre and post-fire

In early March during a regular trapping session, ten animals from grid 2 (six females and four males) and six from grid 3 (four females and two males) were fitted with radio transmitters. The single-stage transmitters (SM-1, AVM Instrument Company, California) were encapsulated in acrylic and mounted on a plastic cable-tie used as a collar. The whip antenna was 5cm of plastic-coated braided wire that passed around the collar inside heatshrink plastic to a point above the nape of the neck, before turning posteriorly and lying parallel to the animal's spine. The maximum weight of each collar was 6g, and the transmitter-battery combination gave an estimated life of 19 days.

Nocturnal movements of all 16 animals were monitored during the first ten days after collars were fitted. Three-element or four-element Yagi antennas were mounted on 4m masts positioned at two points near grids 2 and 3. Bearings to each animal were recorded simultaneously by the two operators every 15 minutes from 1900 to 2400 hrs. Problems encountered with this method necessitated the collection of further fixes by radio-tracking on foot using hand-held three-element Yagi antennas. One tracker worked on each grid collecting fixes by recording bearings in quick succession from two points so that the angle subtended by the animal was at least 45° and ideally 90°. Fifty to eighty acceptable fixes were collected for most animals during the nights of pre-fire radio-tracking.

By day, each animal was located and its nest location and type was recorded and mapped. If visible, nest structure and nesting material were also noted. During the fire, the animals on grid 2 were located by radio-tracking on foot as opportunity permitted. After the fire, nocturnal radio-tracking was carried out for two nights on grid 2 in the burnt block. To improve data collection, all four masts were sited around the grid and mast height increased to 6m. This ensured that at least two operators received signals from each animal at almost all appointed times.

Home ranges were plotted using the NUMTRACK program (developed by Paul Gioia and Norm Hall) and RANGES IVm (Kenward 1987, 1990). Harmonic mean distance isopleths (Dixon and Chapman 1980) were plotted to include 50% and 95% of fixes for each animal. The area of each home range estimate at 50% and 95% was calculated by a subroutine of RANGES. The reliability of each home range estimate was tested by plotting cumulative home range estimate against number of fixes. Comparisons of home range size between groups of animals (e.g. males vs. females, before fire vs. after fire) were made by paired and unpaired t-tests.

March 1991

A radio-tracking session was conducted in March 1991 to further examine movement patterns and nest usage of animals resident in the burnt block on grids 1 and 2. The initial trapping was carried out from 13-15 March and 13 animals (6 males and 7 females) were fitted with radio-collars. Each animal was located in its nest during daylight hours on most days from 14-25 March and the type of nest site and its location were recorded. Intensive radio-tracking using the mast-mounted aerials was carried out on the nights of 18-21 March. After 25 March the phascogales were captured when possible in order to remove their transmitters.

Several improvements were made to equipment and methodology during this radio-tracking period. Firstly, transmitter aerial whip length was increased from 5 cm to 10 cm, resulting in a range increase of 50-100%. Transmitters were repotted using less acrylic so that mean weight was reduced to 2-3g. Secondly, a null-peak receiving antenna system (Telonics, Mesa, Arizona) incorporating paired 12-element Yagi antennas mounted on the 6m mast at each of three tracking stations was employed, replacing the three-element single antennas previously used. This antenna system gave more accurate fixes and a substantially greater range than the old system. The overall effect of these two changes was to increase average range from 400 to 1500 metres.

Thirdly, the software package LOCATE (Pacer, Truro, Nova Scotia, 1990) was used to calculate animal locations from two or more bearings, to map fixes and to generate input files for the RANGES IVm program (Kenward, 1987, 1990) which was again used to generate home range maps.

Habitat assessment

Structural attributes of the habitat within each trap-grid were recorded in an attempt to identify those attributes which influence habitat preferences and distribution of *P. calura*. Unfortunately, due to the timing of the commencement of the project, no habitat data were able to be obtained prior to the prescribed burn. However, a considerable amount of information on the impact of fire on habitat attributes could be gleaned from *a posteriori* measurement. The main attributes assessed were tree stem density and overstorey species composition, leaf litter and shrub density and canopy cover.

Estimates/measurements of habitat were made at each trap-station and over each 20 x 20m area enclosed by the trap stations (recorded on a plan of the grid) in June and August 1990, as detailed below.

Trap-point data

(a) At each of the 64 trap-points on each grid the triangular tessellation method of estimating stem density (Ward 1990) was carried out. The three trees forming the shortest perimeter triangle enclosing the trap-point were chosen, and the lengths of the three sides were recorded. These data were then converted to a measure of stem density (stems/ha; Ward 1990).

(b) The species represented by the above three trees was also recorded (*viz. Allocasuarina huegeliana* (rock sheoak), *Eucalyptus wandoo* (wandoo), *Acacia acuminata* (jam wattle), *Eucalyptus loxophleba* (York gum) and *Xanthorrhoea drummondii* (grasstree)), and their condition categorized as alive (after fire), killed by fire or dead before fire.

(c) Leaf-litter cover in a one-metre square around each trap-point was assessed according to the following categories: 0 = 0 - 1% cover; 1 = 2 - 25% cover; 2 = 26 - 50% cover; 3 = 51 - 99% cover; 4 = 100% cover but <3cm thick; 5 = 100% cover but >3cm thick. The pre-fire litter cover was also able to be estimated from burnt duff and scorch.

(d) Presence or absence (±) of shrubs within 1m of each trap-point was recorded, and any evidence of shrubs being consumed by the fire (e.g. stems) was noted.

(e) Canopy cover (mostly of *Allocasuarina*) was assessed using a spherical densiometer. While the operator was facing south the densiometer was held level at chest height and the number of squares on the spherical mirror with any foliage visible was recorded (maximum of 25).

(f) On the two burnt grids the average height of scorch on several of the *Allocasuarina* trees nearest to each trap-point also was estimated.

Quadrat data

In each 20 x 20m quadrat enclosed by the trap-stations the number and condition (young with no obvious hollows, old with visible hollows, or dead) of all tree species were counted. The numbers of hollow or partially hollow logs on the ground were counted in four diameter classes: 10 -

20cm, 21 - 50cm, 51 - 100cm and > 100cm. For the two grids that were burnt the number of larger logs (>10cm diameter) consumed by the fire was able to be estimated by ash beds and coals.

Pre-fire densities (stems/ha) of the three main tree species (*A. huegeliana, E. wandoo* and *A. acuminata*) were calculated for all grids. For the burnt grids, the densities of live and dead *A. huegeliana* trees before and after the fire and the percentage killed were also tabulated. Total abundance of the co-dominant species in the various condition categories and the number of hollow logs and burnt logs over each grid area (1.96 ha) were also calculated and tabulated. The frequencies of litter cover classes were calculated before and after the fire and plotted as histograms.

RESULTS

Burning conditions

Weather conditions on the day of the burn were fine with clear skies, temperature 24 - 26°C, relative humidity 45 - 50% and wind speeds at 2 m in the open of 8 - 9 km/hr from the south-west (L. McCaw, *personal communication*). Twenty-nine millimetres of rain had fallen a week prior to the burn (12 - 13 March), but fuel moisture contents were still low at 7% (oven dry weight) for shallow litter and 9% ODW for elevated dead foliage (L. McCaw, *personal communication*).

The burn carried out at Tutanning was of much lower intensity than planned. In denser parts of the *A. huegeliana* stand high fire intensities with crown fires developed, but over most of this habitat type the intensity was quite low with rates of spread estimated at 200 m/hr and fireline intensity peaking at about 720 kW/m (ie. moderate intensity, Cheney 1981). By contrast, most of the adjacent sclerophyllous shrublands (kwongan) burnt at high intensity (~4000-6000 kW/m) because of the nature of the fuel and better wind penetration (L. McCaw, *personal communication*). However, in all habitat types the low soil dryness and dry condition of the vegetation led to fairly long flame residence times and there was a significant impact on much of the habitat in the week or so after the main fire front as old *A. huegeliana* and *E. wandoo* trees and hollow logs were slowly consumed.

Scale of burn

Only about 50% of the 100 ha block set aside for this experiment was directly affected by fire, the habitats affected being the kwongan shrublands, young *E. wandoo/E. accedens* woodlands and the *A. huegeliana* stands around the northern and eastern edges of the block. The remaining areas of the block which supported older and very open *E. wandoo* woodland proved too sparsely vegetated to carry the fire. The area burnt was thus surrounded by unburnt habitat on all sides, separated only by a narrow track along the eastern and northern boundaries. This emphasises the small scale of this burn (~ 50 ha) in relation to the overall size (2 310 ha) of the reserve.

***P. calura* population dynamics**

The numbers of *P. calura* known to be alive (KTBA) on the three grids are shown in Fig 1. These data suggest that abundance trends were quite similar on all three grids. Numbers of both males and females peaked during the March-May period in all three years as young, recently independent animals entered the trappable population. Numbers then declined markedly over the late autumn-early winter period (May-June) as animals established territories and the population stabilised prior to the June-July breeding season. Following this, adult males underwent the die-off characteristic of this group of dasyurids (Bradley 1987, 1995), so that KTBA numbers were low on all grids during August-December each year as young were raised and weaned. New adult males and females entered the trappable population during December-February and the population cycle began again. Thus, in the period August to April the population comprised three distinct classes of animals: juvenile/subadult males, juvenile/subadult females and adult parous females. For the remainder of the year all animals were adult, but both parous and nulliparous females were present.

The only differences in population trends between the unburnt control grid (grid 3) and the two burnt grids were:

- population peaks were later in 1990 and 1991 on the control grid (April-May, grid 3; February-March, grids 1 and 2; Fig 1).
- males disappeared slightly earlier on the unburnt grid (before July) than on the two burnt grids (after July but before August-September).
- numbers were generally lower on the unburnt grid (Fig 1).

These trends may reflect some qualitative differences in habitat between the burnt area and the 50-year-old unburnt area. Although peak KTBA numbers (and recruitment) were lower on both burnt grids in 1991, this trend was also evident on the unburnt grid (Fig 1), indicating considerable year-to-year seasonal variation rather than any effect of the fire.

A plot of mean male body weight against time on the unburnt grid showed that young males entered the trappable population in December and grew rapidly to peak in May at about 50g, then lost weight (and condition) even more rapidly over the next three months prior to death in July-August (Fig 2). Scrotal widths followed a similar pattern with maximum sizes of about 15 mm reached in May before the onset of breeding, followed by a rapid decline in size as the animals lost condition prior to death. This timing corresponds to the sharp increase in plasma testosterone during May recorded by Bradley (1987). Females, on the other hand, did not gain weight as rapidly as males during the January-May period on the unburnt grid, but remained relatively stable at about 30 g (Fig 3). Then, following a slight decline in June (probably associated with high activity levels during the breeding season), mean weights rose over the July-November period as females became pregnant, carried pouch young and later put on condition to feed young in the nest. Mean weights then fell in December (but variability markedly increased), reflecting the new cohort of young trappable animals which joined the parous adults in the population (Fig 3).

Comparison of mean body weights for the burnt and unburnt grids (Figs 2 and 3) does not indicate any marked difference in age structure of populations between the treatment and control. There was, however, a tendency for animals on the burnt grids to be generally heavier than those on the unburnt grid at most times of the year. Furthermore, there was no marked decline in mean weights in November/December 1991 on any of the grids, indicating a low level of juvenile recruitment that year. Mean weights of males and females immediately before and after the fire were not significantly different for any of the grids, but females on grid 3 were significantly lower in weight than those on grid 2 before the fire ($p < 0.01$), and those on both burnt grids after the fire ($p < 0.05$; Table 1). These results again indicate that between-grid differences in weight and year-to-year seasonal variations in recruitment outweigh any effects due to fire.

Radio-tracking

March 1990 – pre and post-fire

Behaviour and fate of individuals

On the morning of the prescribed burn nine of the ten radio-collared phascogales were in the burn block and the other (adult male - AM22) was in a nest in an adjacent block. Wind was from the opposite quarter of the block to the phascogale trapping grids, so the main fire was lit there. A backburn was started on the edge of the block near grid 2 at about 1100hr, while the main fire was started at 1330hr and met the backburn at about 1600hr.

After the backburn was lit logs near the edge of the block caught fire quickly and by 1150hr an *A. huegeliana* log in which AM83 was nesting had burnt and the radio signal had stopped. By 1250hr the standing dead *A. huegeliana* in which adult female 21 (AF21) was nesting had burnt, and that signal also had stopped. The *E. wandoo* log in which AM24 was nesting caught fire at 1250hr and was alight inside by 1320hr. At 1530 AF24 was seen in the *A. huegeliana* foliage above the burning log; evidently she had left the log at some stage after it caught fire. The live *A. huegeliana* in which AM70 was nesting caught fire, but went out before the entrance was affected by heat. AF95 was nesting in a dead *A. huegeliana* which caught fire and she also left the tree at some time before 1715hr, but stayed nearby. She was still within 15m of the burning remnants of the tree at 2150hr, and at 0940hr the next day was found unharmed on the ground, cowering between the roots of another *A. huegeliana* within 10m of the burnt nest tree.

The dead *A. huegeliana* in which AF83 and AF23 spent the day of the fire was alight at the base by 1740hr. At 2200hr, AF83 was still in the smouldering tree, but AF23 was found dead on the ground about 20m away, her fur quite scorched. This nest tree burnt through at the base and fell, to lean against other trees as it continued to burn from the base. AF83 was still in the nest the next day at 0850hr and 1630hr. She was caught in the next night's trapping session and returned to the nest in the burning tree when released at 0730hr. The next morning, however, she was in another nest.

Thus, although no deaths were recorded amongst the 16 radio-collared animals during the period 9-19 March, three (one male and two females) of the nine phascogales that nested in the burn block on 20 March died during the fire that day. Between 2145hr and 2230hr on the night after the fire, only one (AF66) of the seven collared survivors was active in the burnt block, whilst two were active in an adjacent unburnt block. All the surviving animals were active within their old home ranges 36 hours after the fire.

A futher two female animals died during the week following the fire, one of these being in the unburnt block. AF24 was taken by a bird of prey, probably an owl, between 23 - 29 March, the animal's remains being found beyond the eastern extremity of her recorded home range. This female had been found on 22 and 23 March nesting in burrows in the burnt block. AF29's undamaged radio-collar was found on 21 March on the ground in her home range in the unburnt control block. She was not caught subsequently, despite having been captured regularly in previous trapping sessions. On 24 April, traps were placed around this animal's two most frequently-used nest trees with no success. It appears most likely that AF29 was also taken by a predator, but it is possible that the animal removed its own collar.

Home range analysis

Table 2 shows the home range areas for each animal tracked in 1990 and the number of fixes on which each estimate is based. Before the fire the mean 95% home range size was 3.7 ha ($n = 16$). Female and male 95% home ranges were 2.8 ha ($n = 10$) and 5.3 ha ($n = 6$) respectively and these were significantly different ($t = 2.5$, $df = 14$; $p < 0.05$). The relative locations of phascogale home ranges (95%) before the fire in the vicinity of grid 2 are shown in Fig 4. Female 95% home ranges showed a greater tendency to overlap each other than did male 95% home ranges, but there was considerable overlap between male and female 95% home ranges. When 50% ("core") home ranges were examined, there was no overlap between males, but females still shared some common areas. Indeed, the home ranges of two females in the burn block, AF24 and AF66, coincided almost totally.

After the fire, the mean home range sizes of surviving animals decreased significantly (50% home ranges, $t = 3.52$, $df = 6$, $p < 0.05$; 95% home ranges, $t = 3.31$, $df = 6$; $p < 0.05$). In our sample of four females and three males, 50% home range decreased from 0.8 ha to 0.4 ha, and 95% home range decreased from 5.1 ha to 2.6 ha. The range of movement also decreased after the fire but there was very little shift in home ranges (Fig. 5).

Nest selection and impact of fire on nest hollows

The ten phascogales fitted with collars on grid 2 occupied a total of 22 nest hollows before the fire. Of these, four were outside the burn block. Many hollows were occupied on several successive days by the same animal, and sharing of nests was frequently observed. Nests were found in a variety of types of hollow, and in descending order of occurrence were in: dead *A. huegeliana* (6), dead *E. wandoo* (4), live *E. wandoo* (3), stumps of *Xanthorrhoea drummondii* (3), *E. wandoo* logs on the ground (3), live *A. huegeliana* (2) and an *A. huegeliana* log on the ground (1). The six collared phascogales on grid 3 utilised 17 nest hollows during this same period. They were located in live *E. wandoo* (7), dead *E. wandoo* (4), *E. wandoo* logs on the ground (3), *E. wandoo* fallen branches (2) and in a stump of *X. drummondii* (1).

Eucalyptus wandoo trees were much more abundant in the vicinity of grid 3 than grid 2. Such trees offered many hollows as a result of being attacked and hollowed out by termites. Their predominant use as nest sites by phascogales on grid 3 probably reflects this greater availability of hollows, whilst dead *A. huegeliana* were apparently not used on this grid to any significant degree.

On the day after the fire, AF24 was found in a burrow-like hole in the ground in her home range and on the next day was in another hole in the ground nearby. This was the first recorded use of burrows by red-tailed phascogales, and may have been a response to loss of nest hollows, although a number of hollows in her area survived the fire.

During the fire, eight of the 18 recorded nest sites were burnt and one burnt away slowly over the next three days. Of the remaining nine nest sites on the burn area, one was alight but the fire went out, one was broken by falling trees, and seven remained intact. The survival of the various types of nest site is shown in Fig 6. Clearly, phascogales nesting in dead *A. huegeliana* are at risk even during low intensity fires, whereas animals using *E. wandoo* have a much greater chance of surviving.

March 1991

Home range analysis

Table 3 shows the home range areas for each animal tracked in March 1991, and the number of fixes on which each estimate was based. Female and male 95% home ranges were 8.5 ha ($n = 5$) and 7.8 ha ($n = 5$) respectively, which are not significantly different ($t = 2.43$, $df = 8$, $p = 0.8$). This differed from the situation in March 1990 before the fire when there was a significant difference between male and female home range size using data for animals from both the burnt and unburnt blocks.

No significant differences were found in the 95% home range sizes of animals from the burn block for any of the four combinations of male versus female and pre-fire versus one year after fire. If male and female data are pooled, however, mean home range size was found to be significantly larger one year after the fire than just before it (1990 mean 4.7 ha, 1991 mean 8.1 ha; $t = 2.56$, $df = 18$, $p = 0.02$).

Changes in nest selection

The comparative frequencies of each type of nest hollow in which radio-collared phascogales were located during March 1990 and March 1991 are shown in Fig 7. These data show the greatly increased importance of dead wandoo trees as nests in the post-fire period. Before the fire, dead *A. huegeliana* trees were more commonly used on grid 2, where *E. wandoo* trees were scarce. With the reduction in the number of dead *A. huegeliana* following the fire, the phascogales began to nest in *E. wandoo* trees (many of which were killed in the fire) far from their feeding areas and to travel up to 400 metres each way at night. Whether red-tailed phascogales moved along the ground or in the canopy during these long movements is not known, but they appeared to move rapidly, covering 200 metres in 10-15 minutes in several cases monitored at dusk. The effects of these changes in nesting behaviour are not known. It is likely, however, that the increased movement each night may have resulted in a greater exposure to both avian and mammalian predators. The death of a collared animal from predation following the fire adds some support to this hypothesis.

Habitat changes

Measurement of stem densities and other habitat components showed that the two grids in the burnt block differed considerably from that in the older unburnt area. Before the fire, grids 1 and 2 had a high density of *A. huegeliana* stems (both alive and dead), while grid 3 supported only about half this density, but had a relatively high density of *E. wandoo* trees (Table 4) with a large proportion being old hollow individuals (Table 6). *Acacia acuminata* was virtually absent from grid 3 but was an important sub-dominant component of the vegetation on the two younger grids (Tables 4 and 6), while hollow logs and *Xanthorrhoea drummondii* were more abundant on the former grid (Table 6). Mean canopy cover values were quite similar on the three grids, being 95%, 95.2% and 92.7% for grids 1, 2 and 3 respectively.

Although the fire was only of low to moderate intensity within the trap grids (crowning in only a few isolated patches off the grids), it killed about 70% of the *Allocasuarina* (Table 5) and between 22% and 91% of the *A. acuminata* on the two grids, but only a small proportion of the wandoo trees. Mean scorch heights were 0.55 ± 0.07m (s.e.) and 0.51 ± 0.04m (s.e.) on grids 1 and 2 respectively, but fire intensity varied considerably over both grid areas, reaching maximum values in the upslope parts of grid 1. Comparison of scorch height and stem density distributions suggests that fire intensity was not greatly influenced by density of the overstorey vegetation.

Despite its low-moderate intensity, the fire destroyed many of the potential nesting sites of *P. calura*. Skirts of *Xanthorrhoea* burnt fiercely during the main fire, and some old *Allocasuarina* and hollow *E. wandoo* fell down and were consumed, along with other hollow logs, over the week following the fire. Surface leaf litter was considerably reduced, reflected in the marked increases in the frequency of the lower litter cover classes and a skewed frequency distribution after the fire (Figs 8 and 9). In many places, however, the duff layer adjacent to the mineral soil was not completely burnt, and it is likely that the fire had only a short-term impact on litter and soil-dwelling invertebrates.

DISCUSSION

The habitat and refuge requirements of *P. calura* suggest that this species is likely to be severely affected by moderate to high intensity fire burning under dry conditions over a significant proportion of any preferred habitat. The rock sheoak (*A. huegeliana*) thickets in which *P. calura* feeds, and the old *E. wandoo* and dead *A. huegeliana* in which they preferentially shelter are extremely flammable. Even low intensity fire will kill *A. huegeliana* trees, and if a further fire affects the area within the primary juvenile period before the even-aged regrowth stand has matured and set seed, the area will be converted to an entirely different habitat type. Fire is also likely to burn out potential nest hollows in old *E. wandoo* trees, though it may also create new hollows.

The life history characteristics of *P. calura* also suggest high potential sensitivity to fire, particularly those in spring. With the semelparous Type 1 breeding strategy (Lee, Woolley and Braithwaite 1982) of *P. calura* and many *Antechinus* species, males die off following the winter breeding season (Bradley 1987). There is thus complete replacement of the male population each year, (although some females may breed in a second season), and a critical period (August - December) when there are only dependent young and adult parous females present in the population. A marked reduction in shelter and/or food following a disturbance such as fire could lead to increased stress on animals, resulting in pre-breeding mortality and a failure to breed, or, in the case of a moderate to high intensity spring fire, high mortality rates of females and their dependent young. This could lead to local extinction of populations.

The scale and intensity of any fire, however, may have a significant bearing on the outcome for *P. calura* populations. Moderate to high intensity fire that affects only a small percentage of any preferred habitat type within a reserve or region may have no more an impact on *P. calura* at the population level than low intensity fire over a much larger proportion of the available habitat. These attributes of a fire, and to a lesser extent the season, are critical in placing both the short and longer-term impacts in perspective.

Such a context is necessary in examining the Tutanning data. The fire, although of only low to moderate intensity around the two grids, caused significant injury and mortality in the *P. calura* population and destruction of their nests. Radio-tracking studies confirmed the direct death of three of the nine collared animals which were nesting in the block on the day of the fire and the death of a further animal from predation over the subsequent week. Eleven of 18 known nest sites were either destroyed or significantly damaged as a result of the fire, the majority of these being in dead *A. huegeliana* trees. Regular trapping over the subsequent 27 months, however, indicated no marked longer-term changes in population dynamics or condition of animals as a result of the fire. Breeding in 1990 did not appear to be disrupted by the fire, and the poor breeding and recruitment recorded on all grids in the 1991 season was clearly a general phenomenon related to seasonal and year-to-year differences rather than to fire.

Most disruption therefore seems to have been only short-term, occurring during and soon after the fire as a result of direct death of individuals and destruction of nest sites. The lack of a significant longer-term impact is no doubt related to the low fire intensity, but is also probably attributable to (a) the presence of *E. wandoo* trees near the grids which provided refuge to compensate for the loss of *A. huegeliana* trees in the fire, and (b) the small area affected by the fire (~50ha) which allowed rapid recovery of the population through recolonisation from surrounding unburnt habitat, and/or enabled animals to live in unburnt areas but utilise the burnt stand for feeding.

The major differences in the phascogale populations monitored on the trap grids were between the 50-year-old unburnt area and the area that was burnt. These differences were unrelated to the experimental fire *per se*, but rather, probably to attributes reflecting the age and fire history of the two areas. The older area appeared to be less favourable habitat for *P. calura*. Animals only occurred in numbers there during the period of maximal activity and movement prior to the breeding season, following which numbers rapidly declined again. These trends may be related to the more open stand structure of the older site which may not facilitate easy movement through the vegetation compared with the dense younger stand, or to differences pertaining to food or other resource availability which were not quantified in this study. Refuge availability is unlikely to be a factor contributing to these differences, however, since old hollow *E. wandoo* trees were more abundant in the 50-year-old area.

Although *P. calura* individuals continued to use the burnt *A. huegeliana* habitat after the fire, this area may become increasingly unsuitable for the species as the dead overstorey collapses. Furthermore, regenerating seedlings of *A. huegeliana* were selectively grazed and their abundance reduced by a severe locust plague during the 1990/91 summer. This may have dramatic long-term effects on the structure and composition of the habitat. With the elimination of the rock sheoak regeneration, the stand is likely to change to one with a few old surviving trees, some younger *A. acuminata* and a sparse layer of shrubs. Since our data suggest that *P. calura* favour areas with a moderate to high density of *A. huegeliana* trees, it is likely that this area will become unsuitable for phascogales in the longer term. This outcome shows the critical importance of the timing of prescribed burns in relation to episodic (and partly predictable) events like droughts and locust plagues, as well as scale and its capacity to interact with intensity to either exacerbate or moderate the longer-term impacts of fire on a potentially sensitive species.

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TABLE 1

Weights of male and female *Phascogale calura* immediately before and after fire (mean ± s.e.)

		BEFORE	AFTER
MALES	Grid 1	39.1 ± 0.9	43.9 ± 0.6
	Grid 2	40.0 ± 0.9	42.1 ± 1.2
	Grid 3	39.3 ± 1.8	40.4 ± 1.3
FEMALES	Grid 1	29.5 ± 1.1	30.4 ± 0.6[b]
	Grid 2	31.1 ± 0.5[a]	30.7 ± 0.4 [c]
	Grid 3	27.2 ± 0.8[a]	27.9 ± 0.6[b,c]

Significant differences (Tukey multiple comparison test); a, $p = 0.005$; b, $p = 0.040$;c, $p = 0.018$.

TABLE 2

Home range areas (ha) of radio-collared *Phascogale calura* at Tutanning in March 1990 before and after fire calculated as area enclosed in isopleths of harmonic mean distance including 50% and 95% of fixes.

	BEFORE FIRE		AFTER FIRE		NUMBER OF FIXES	
	50%	95%	50%	95%	BEFORE FIRE	AFTER FIRE
BURN BLOCK						
Females						
AF21	0.34	1.93	-		53	-
AF23	0.78	3.35	-		58	-
AF24	0.56	4.56	0.33	2.03	49	28
AF66	1.06	6.49	0.36	1.50	54	46
AF83	0.67	2.49	0.38	0.96	50	35
AF95	0.55	3.08	0.15	1.25	80	38
Mean ± SD	0.66±0.24	3.65±1.65	0.31±0.11	1.44±0.45		
Males						
AM22	0.74	4.27	0.78	5.23	63	40
AM19	1.20	8.83	0.26	4.10	51	29
AM70	0.93	6.27	0.47	2.97	52	31
AM83	0.53	5.20	-	-	82	-
Mean ± SD	0.53±0.28	6.14±1.97	0.50±0.21	4.10±1.13		
UNBURNT BLOCK						
Females	50%	95%				
AF1	0.23	0.93			44	
AF19	0.47	2.10			76	
AF28	0.37	2.21			32	
AF29	0.19	0.50			32	
Mean ± SD	0.32±0.13	1.44±0.85				
Males						
AM4	0.38	1.85			50	
AM23	0.73	5.37			65	
Mean ± SD	0.56±0.25	3.61±2.49				

TABLE 3

Home range areas (ha) of radio-collared *Phascogale calura* radio-tracked in March 1991, calculated as area enclosed in isopleths of harmonic mean distance including 50% and 95% of fixes.

	50%	95%	NO. OF FIXES
FEMALES			
AF44	3.03	17.86	84
AF46	1.30	6.46	79
AF49	1.30	5.53	78
AF50	1.22	5.25	78
AF92	0.97	7.22	89
Mean ±SD	1.56 ±0.83	8.46 ±5.31	
MALES			
AM32	2.02	8.62	83
AM33	1.29	8.62	86
AM35	1.69	9.43	82
AM38	1.56	4.93	85
AM39	0.92	6.54	84
Mean ±SD	1.50 ±0.42	7.80 ±1.79	

TABLE 4

Pre-fire densities (stems/ha) of main tree species on grids estimated by triangular tessellation

SPECIES		GRID 1	GRID 2	GRID 3
Allocasuarina huegeliana	alive	2923	2870	1631
	dead	2030	516	362
Eucalyptus wandoo	alive	308	83	336
	dead	31	0	39
Acacia acuminata	alive	61	206	0
	dead	277	289	0
MEAN ± S.E.# (stems/ha)		5908 ± 1017	3965 ± 509	2485 ± 476

mean includes stems of other species

TABLE 5

Densities (stems/ha) of live and dead *Allocasuarina huegeliana* before and after fire estimated by triangular tessellation

		GRID 1	GRID 2
PRE-FIRE	alive	2923	2870
	dead	2030	516
POST-FIRE	alive	707	908
	dead	4246	2478
% KILLED		76	68

TABLE 6

Total abundance and condition of co-dominant species (excluding *Allocasuarina huegeliana*) and hollow logs and burnt logs over each grid area (1.96ha).

COMPONENT	GRID 1 (burnt)	GRID 2 (burnt)	GRID 3 (unburnt)
Young *Eucalyptus wandoo*	267	98	179
Old hollow *Eucalyptus wandoo*	2	0	110
Xanthorrhoea drummondii	25	146	357
Young *Acacia acuminata*	55	54	2
Old *Acacia acuminata* (alive)	16	16	0
Dead *Acacia acuminata*	255	428	1
No. of hollow logs	25	20	73
No. of logs burnt	46	17	-

LIST OF FIGURES