1   **Post-fire recovery of torpor and activity patterns of a small mammal**

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17   **Abstract**

18   To cope with the post-fire challenges of decreased availability of food and shelter, brown

19   antechinus (*Antechinus stuartii*), a small marsupial mammal, increase the use of energy

20   conserving torpor and reduce activity. However, it is not known how long it takes for animals

21   to resume pre-fire torpor and activity patterns during the recovery of burnt habitat. Therefore,

22   we tested the hypothesis that antechinus will adjust torpor use and activity after a fire

23   depending on vegetation recovery. We simultaneously quantified torpor and activity patterns

24   for female antechinus from three adjacent areas: (i) the area of a management burn one year

25   post-fire, (ii) an area that was burned two years prior and (iii) a control area. In comparison to

26 shortly after the management burn, antechinus in all three groups displayed less frequent and

27 less pronounced torpor while being more active. We provide the first evidence that only one

28 year post-fire antechinus resume pre-fire torpor and activity patterns, likely in response to the

29 return of herbaceous ground cover and foraging opportunities.

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1. Introduction

34 As large and destructive wildfires are increasing worldwide [1], management burns are

35 employed in many forested areas with the aim of reducing fire fuel loads. However, the time

36 between fires and their intensity can alter assemblages of plant and animal species [2,3].

37 Importantly, while leaf litter and some grasses/herbs often reappear quickly after a fire,

38 others, such as woody vegetation and tree hollows, can take up to 30-40 years to re-establish

39 [4].

40   In the long-term fires can help to increase habitat complexity, which is beneficial for

41 many small terrestrial mammals [2]. However, the initial loss of ground cover after a fire can

42 be detrimental because it leads to reduced foraging opportunities due to increased predation

43 pressure [5]. This is exacerbated for insectivorous mammals, as the abundance of ground-

44 dwelling arthropods often decreases after fire [6]. Hence, in the short to medium-term after

45 fire, some terrestrial mammals have been found to substantially curtail activity and enhance

46 the use of torpor - a pronounced reduction in energy expenditure via a controlled fall of

47 metabolic rate and body temperature (T_b) [6-9].

48   Given the slow recovery of some habitat features it remains unclear over what time

49 period such behavioural and physiological adjustments have to be employed for individuals

50 and populations to survive. While an increase in torpor use is beneficial during detrimental

51 conditions, it may reduce fitness by curtailing territorial defence and reproduction. Therefore,

52 as conditions improve animals should employ less torpor. We tested the hypothesis that

53 following the recovery of an herbaceous understory after a management burn, torpor use and

54 activity in brown antechinus (*Antechinus stuartii*), a small heterothermic terrestrial marsupial

55 [10], will return to pre-fire levels in response to more profitable and safer foraging

56 opportunities.

57

58 **2. Material and methods**

59 Our work was undertaken during May-June 2015, one year after a management burn at Guy

60 Fawkes River National Park, Australia (30°04'58.6"S, 152°20'0.9"E). We compared data

61 collected during the current study to those from our previous study in 2014 [9], with a total of

62 six groups of female antechinus (defined in table 1). All groups were measured in areas that

63 were in close proximity, ensuring that the general habitat and climate of the sites was the

64 same. The areas that burnt in 2013 and 2014 are burnt regularly to reduce fuel levels and the

65 intensity of wildfires, whereas the control area last burned in 1994 due to a wildfire and no

66 management burns have been implemented since [11]. Ambient temperatures (T_a) were

67 recorded with data loggers (± 0.5°C, iButton thermochron DS1921G, Maxim Integrated

68 Products, Inc., Sunnyvale, California, USA). We visually determined the percentage of

69 ground cover in 12 randomly selected $1m^2$ quadrats in each of the three study areas (36

70 quadrats total).

71   To measure T_b patterns including torpor and also to infer activity we implanted

72 temperature-sensitive radio-transmitters (2g, Sirtrack, Havelock North, New Zealand) into the

73 intraperitoneal cavity of each animal (for surgical details see [12]). A receiver/data logger

74 [13] was placed near each nest to record the presence/absence of animals and their T_b.

75 Throughout the study each individual used between 1 and 8 nest sites (mean = 3.7 nests) and

76   loggers were repositioned whenever antechinus moved to a new nest. Activity periods within

77   24 h (sunrise to sunrise) were calculated as the time animals spent away from the nest

78   site/logger for >30min. Days when an individual moved nests were excluded as the time the

79   animal arrived at the new nest was unknown. We calculated the torpor threshold of 31.5°C

80   using equation 4 [14] as previously [9]; torpor bouts were calculated from the time T_b fell

81   below and rose above this threshold for > 30 min.

82   We used R [15] to perform statistical analyses. As the duration of activity and torpor

83   are significantly correlated with T_a in antechinus [10], only data recorded when T_a was within

84   daily maxima (20.0°C) and minima (2.0°C) of our previous study were included [9]. We

85   employed linear mixed-effects models [16] to test for differences among the six groups for

86   the measured variables: torpor frequency, torpor bout duration, daily minimum T_b, time spent

87   active [17]. We used body mass and daily minimum T_a as covariates, individuals were

88   included as a random effect to account for repeated measures and we accounted for temporal

89   autocorrelation [17]. We used a residual plot to test for homoscedasticity and a normal Q-Q

90   plot to test for normal distribution. We employed a post-hoc Tukey test [18] to determine

91   which groups differed from each other. All proportions were arcsine transformed before

92   analysis. We assumed significance at $p < 0.05$.

93

94   **3. Results**

95   While ground cover had somewhat recovered a year after the burn in 2014 (figure 1), it was

96   patchy in those areas where the one year post-fire 2015 (range = 10-100%, mean = 50%, n =

97   12) and two years post-fire 2015 (range = 5-100%, mean = 39%, n = 12) groups were

98   measured. In contrast, the area where the control 2015 group was measured consisted of thick

99   and even ground cover unchanged from 2014 (range = 60-100%, mean = 87%, n = 12).

In all 2015 groups torpor was employed approximately half as often as by the post-fire 2014 group, and torpor frequency was therefore statistically identical to the pre-fire 2014 and control 2014 groups (figure 2a; table 2). Furthermore, in all 2015 groups mean torpor bout durations and the longest torpor bouts recorded per individual were significantly shorter (~50%) compared to the post-fire 2014 group (figure 2b; table 2). The mean daily minimum T_b displayed by groups in the 2015 study was ~3°C higher, and the lowest T_b recorded >3.4°C greater, than that of the post-fire 2014 group (figure 2c; table 2).

Antechinus from all three groups measured in 2015 spent an additional three hours active each day in comparison to individuals from the post-fire 2014 group (figure 2d; table 2). Further, while daytime activity was almost absent in the post-fire 2014 group (4.4% of total daily activity), it encompassed ~20% of the total daily activity of antechinus in 2015 and of those in the pre-fire 2014 and control 2014 groups (figure 2d).

4. Discussion

Our study provides the first evidence that within one year after a management burn a population of brown antechinus had resumed pre-fire torpor and activity patterns. Torpor bouts were shorter and shallower in individuals in the post-fire recovered landscape in comparison to shortly after the fire when ground cover was largely absent. Further, this decrease in torpor use one year after the fire was accompanied by an increase in total and especially daytime activity over levels measured just after the burn.

The late autumn management burns employed for our study were of low-intensity, but inflicted some mortality amongst antechinus nevertheless [9]. As the fires primarily consumed dead vegetation and dry leaf litter leaving the mid and upper storeys largely intact, a relatively quick recovery of some vegetative ground cover ensued. In particular *Lomandra* spp. (native Australian perennial herbs) had re-sprouted vigorously in the areas that had

5

125 burned both one and two years prior (figure 1). However, *Lomandra* is encouraged by fire,

126 and other types of ground cover such as small shrubs and decaying timber were still largely

127 absent. Yet, brown antechinus persisted and during early winter resumed daily torpor and

128 activity patterns similar to those recorded at the same time of year before the fire and in

129 unburnt habitat [9].

130   Firstly, it therefore appears that even sparse vegetation of limited diversity is

131 sufficient for antechinus to manage their daily energy needs without extensive torpor use.

132 This vegetative cover likely aids in protecting antechinus from predation while foraging.

133 Secondly, as the abundance of terrestrial arthropods often increases in the year following a

134 fire [6], for antechinus the prey base might have been elevated. Thirdly, it is likely that the

135 insulating properties of a tussock ground cover alters the microclimate of foraging areas. For

136 example, the retention of a boundary layer of warm air near the ground during the night

137 would reduce thermoregulatory costs while foraging, further decreasing the need to save

138 energy via torpor.

139   Our results highlight the importance of even sparse ground cover for small terrestrial

140 mammals while foraging [19]. The general association of torpor with low T_a and the

141 reduction of torpor use as habitat conditions improve suggests that antechinus mostly employ

142 torpor in response to detrimental conditions, which is similar to other marsupials such as

143 sugar gliders (*Petaurus breviceps)* [9,10,13]. Importantly, antechinus are somewhat unusual

144 in being semelparous, reproducing only once a year towards the end of winter [20]. It is

145 therefore likely vital for them during autumn and early winter to invest time in protecting

146 resources, such as food and nests, to ensure reproductive success, and torpor decreases the

147 time available for these activities.

148   Nevertheless, it is evidently possible that fires do not pose a significant challenge for

149 some mammals, especially those that can avoid fires like volant bats [21]. Indeed, the only

other study we are aware of focussing on how individuals recover physiologically and

behaviourally in the years after a fire was conducted on bats [21]. Therefore, further studies

on different mammals are needed to understand how other species on other continents

respond physiologically and behaviourally to fires, including severe wildfires, in the short- to

long-term, particularly on longer-lived and homeothermic species that do not have the ability

to employ torpor for energy conservation.

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226   **Figure 1.** Photos of the study site depicting ground cover in the same area shortly after the

227   management burn in 2014 (*a*) and one year later in 2015 when *Lomandra* had recovered (*b*).
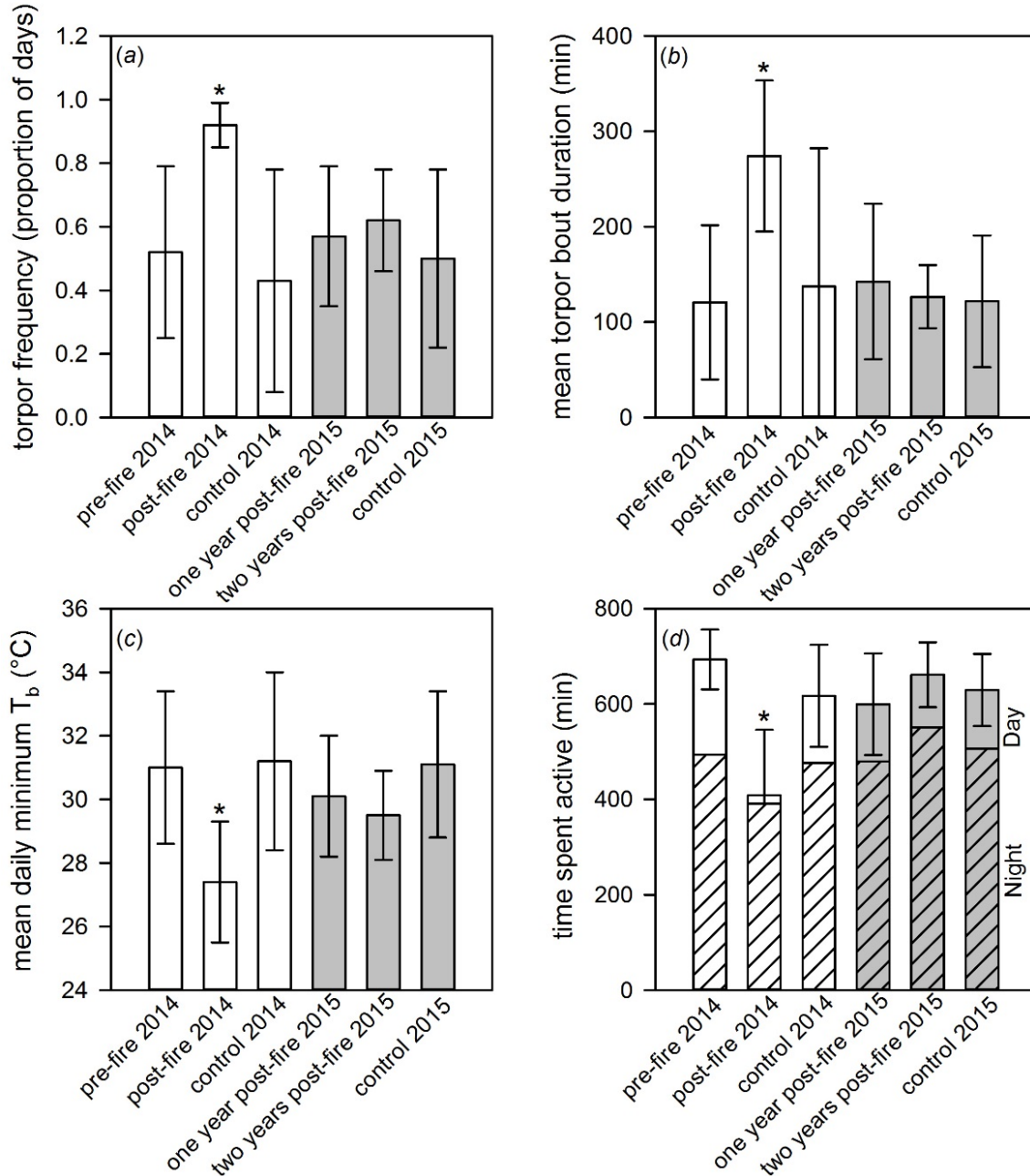
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Figure 2. Comparison of variables for female *Antechinus stuartii* from 2014 (white bars) and 2015 (grey bars). (*a*) torpor frequency (number of days with torpor/days measured), (*b*) mean torpor bout duration (min), (*c*) mean daily minimum T_b (°C) and (*d*) time spent active (min). For activity (*d*) the solid portion of the bar represents daytime (sunrise-sunset) activity and the hatched portion nocturnal (sunset-sunrise) activity. Means are shown ± 1 standard deviation, which for (*d*) represents whole day (24h, sunrise-sunrise) activity. Only the post-fire 2014 group differed significantly, denoted by the asterisk.

237   **Table 1.** Descriptions of each of the groups measured, including number of individuals and

238   animal days measured.

group name	group description	individuals	animal days
pre-fire 2014	individuals measured in 2014 before the burn	4	25
post-fire 2014	individuals measured in 2014 after the burn	4	56
control 2014	individuals measured in 2014 in an unburnt area	2	17
one year post-fire 2015	individuals measured in 2015 one year after the management burn in 2014	7	136
two years post-fire 2015	individuals measured in 2015 in an area that was burnt two years prior in 2013	4	89
control 2015	individuals measured in 2015 in an unburnt area	6	135

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Table 2. Torpor variables, body temperatures (T_b) and time spent active (whole day) of female *Antechinus stuartii* and ambient temperatures (T_a). Means are shown $\pm$ 1 standard deviation and significant differences between groups are identified by different letters.

	pre-fire 2014	post-fire 2014	control 2014	one year post-fire 2015	two years post-fire 2015	control 2015
torpor frequency (proportion of days)	0.52 ± 0.27^a	0.92 ± 0.07^b	0.43 ± 0.35^a	0.57 ± 0.22^a	0.62 ± 0.16^a	0.50 ± 0.28^a
torpor bout duration (min)	120.8 ± 80.8^a	274.2 ± 79.2^b	137.5 ± 102.5^a	142.6 ± 81.4^a	126.7 ± 33.1^a	121.9 ± 69.1^a
longest torpor bout recorded (min)	330	650	310	380	340	340
minimum T_b (°C)	31.3 ± 2.2^a	27.4 ± 1.9^b	31.2 ± 2.8^a	30.1 ± 1.9^a	29.5 ± 1.4^a	31.1 ± 2.3^a
lowest T_b recorded (°C)	24.3	19.8	27.6	24.0	23.2	25.1
time spent active (min)	693.2 ± 62.7^a	408.2 ± 137.6^b	617.1 ± 107.0^a	599.6 ± 106.6^a	661.2 ± 68.1^a	629.3 ± 75.7^a
daily T_a (°C)	8.3 ± 2.8^a	11.1 ± 1.2^b	10.9 ± 1.1^b	9.6 ± 1.1^b	9.9 ± 1.0^b	9.9 ± 1.3^b
maximum T_a (°C)	13.5 ± 2.6^a	16.5 ± 1.7^b	16.3 ± 2.0^b	15.8 ± 0.8^b	15.4 ± 1.2^b	15.7 ± 1.3^b
absolute highest maximum T_a (°C)	17.5	20.0	19.5	18	18.5	18
minimum T_a (°C)	4.8 ± 2.8^a	7.4 ± 1.4^b	7.0 ± 1.4^b	6.8 ± 1.5^b	7.1 ± 1.4^b	7.1 ± 1.7^b
absolute lowest minimum T_a (°C)	2.0	5.5	5.0	5.5	5.5	5.0