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Habitat influence on activity patterns of brush-tailed rock-wallabies in Queensland

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Abstract. The brush-tailed rock-wallaby (*Petrogale penicillata*) is a nocturnal refuge dependent herbivore that can be found from south-east Queensland to East Gippsland in Victoria. Brush-tailed rock-wallaby colonies are situated in many different habitat types, and refuge within this habitat is important for their survival. Dingoes coexist with *P. penicillata* and are perceived to be a threat. This study aimed to determine the link between habitat and *P. penicillata* behaviour and their interaction with predators. Three *P. penicillata* colonies were studied within the Little Liverpool Range, Queensland. Images of *P. penicillata* and dingoes from camera traps were analysed for daily activity patterns and activity overlap between species. Dingo scats were collected and analysed to determine predation. The results indicated that different habitat types change the perceived predation risk and corresponding activity patterns of *P. penicillata*. Predation risk impacted foraging behaviour, with rock-wallabies in exposed habitat types exhibiting greater predator avoidance behaviours than those in more protected habitat types. The results indicate that brush-tailed rock-wallabies modified their activity patterns according to different habitat types to reduce their risk of predation.

Keywords: foraging, dingo, predator avoidance, brush-tailed rock-wallaby, *Petrogale penicillata*, scat analysis, camera trapping, predation risk, fox, *Vulpes vulpes*, *Canis lupus*.

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Introduction

Herbivores need to modify their behaviour if the risk of predation becomes a serious threat to their survival. This is particularly true for native Australian species threatened by introduced predators. The brush-tailed rock-wallaby (*Petrogale penicillata*), listed as a vulnerable species (*EPBC Act* Listing and Nature Conservation (Animals) Regulation 2020 (Queensland)), is a refuge dependent species known to display nocturnal behaviour of foraging during the night and sheltering amongst refuge during the day (Carter and Goldizen 2003; Tuft *et al*. 2011). Studies have shown that *P. penicillata* alters its foraging behaviour in response to predation risk (Tuft *et al*. 2011), and this could extend to other behaviours or even times of the day when *P. penicillata* are most active. This species has historically been widely distributed (Short 1982; Wong and Soderquist 2003) but now inhabits only rocky outcrops, rainforest gorges and mountain ridges throughout south-east Queensland, eastern New South Wales and East Gippsland in Victoria (Short 1982; Eldridge and Close 2008; Egerton and Lochman 2009; Department of the Environment 2018; Piggott *et al*. 2018).

The red fox (*Vulpes vulpes*) and dingoes or wild dogs (*Canis lupus* ssp.) are a major threat to *P. penicillata* populations throughout Australia (Menkhorst and Hynes 2011; Office of Environment and Heritage 2013; Taggart *et al*. 2015). Recent studies into the differences between wild dogs and dingoes have found that the majority of wild dogs contain a high proportion of 'pure' dingo DNA and occupy the same ecological niche in terms of diet and mesopredator supression (Letnic *et al*. 2012; Jackson *et al*. 2017). For the purposes of this study all dingoes/wild dogs will be referred to as dingoes.

Most studies that have examined predation risk responses have focussed on changes to *P. penicillata* foraging behaviour in conjunction with the importance of landscape safety features that restrict foraging distance (Tuft *et al*. 2011). This study aimed to close the knowledge gap in seeking a link between habitat values and predation risk and their effect on *P. penicillata* activity times. This change in activity is supported through evidence of other animal species altering their behaviour due to predation in different habitat types (Corp *et al*. 1997; Ellwanger and Gould 2011; Jaman and Huffman 2013; De Oliveira *et al*. 2014). Within Queensland, *P. penicillata* populations have been documented in the Little Liverpool, Teviot, Main and McPherson Ranges (Queensland Government 2014). These sites all have similar habitat features, comprising many short ledges, crevices, escape routes and caves (Short 1982; Murray *et al*. 2008). All of these Queensland sites also have populations of dingoes that have the potential to impact on *P. penicillata* (Department of Agriculture and Fisheries, The State of Queensland 2017).

Three distinct *P. penicillata* populations located within different habitat types were studied to determine their activity patterns and activity overlap with that of dingoes at each location, to see if predator avoidance behaviour was evident in *P. penicillata* in differing habitats. Predation rates by introduced predators on *P. penicillata* were examined through the collection and analysis of dingo and fox scats. The hypothesis tested in this study was that within different habitat types *P. penicillata* populations have different activity patterns that are dependent on predation risk.

Materials and methods

Study area

The study area was located on Aroona Station, a Queensland Trust for Nature property within the Little Liverpool Range, ~41 km south-west of Ipswich, Queensland (27°37.380′S, 152°45.600′E). The study area comprised 1999 ha on both undulating and steep terrain. Vegetation was a mix of eucalypt woodland and dry rainforest along rocky slopes and plains of native grasses utilised by cattle. Steep cliffs were present throughout the property along the ridgelines. A 2016 pilot study confirmed that *P. penicillata*, dingoes, and foxes all utilised the property. The study was conducted in two periods: between March and September 2016, and between April and June 2017. Three different habitat types were selected on the property to determine if habitat type influenced activity patterns of resident *P. penicillata*, dingoes and foxes in those habitats. Site A consisted of a rainforest gully comprising RE (Regional Ecosystem) type 12.8.9, and Sites B and C were on ridges that had exposed cliff faces dominated by *Eucalyptus crebra* open woodland in mosaics of RE types 12.8.16, 12.8.17, and 12.8.9 (Table 1) (Jeffers 2016). Each of these Regional Ecosystem types varied in vegetation structure as well as floristics (Table 1). The habitat in Site A was considerably different from that of Sites B and C. Sites B and C consisted of the same mosaic of Regional Ecosystem types 12.8.9, 12.8.16, and 12.8.17 (Table 1). However, the most noticeable habitat element that was different from Site A was that Sites B and C both encompassed open cliff faces and exposed rock shelves (Fig. 1). Therefore *P. penicillata* in Sites B and C were more exposed to predators and the elements than those in Site A.

Camera trapping

A pilot study was conducted in 2016 in the three study sites (A, B and C). A total of 10 camera traps, comprising eight Reconyx Hyperfire HC600 covert cameras (Reconyx USA) and two UWay VH200HD cameras (Uway Canada), were deployed to monitor *P. penicillata*, dingoes and other species. In 2017 the number of camera traps deployed was increased to 27, comprising 21 Reconyx Hyperfire HC600 covert cameras and three Reconyx Ultrafire covert (Reconyx USA) and three UWay VH200HD cameras (Uway Canada). Nine cameras were used at each site with similar settings, e.g. per trigger five images were taken with no time delay between images. Distinguishing features, including size of the animal, scars and direction of travel, were used to identify individuals where possible. Cameras were set up 20 m apart around the perimeter of the *P. penicillata* colonies, focusing along the top and bottom of ridges, gullies, cliffs and gorges (Gowen and Vernes 2014). Camera traps were strapped to trees between 50 and 75 cm above the ground and aimed towards rocks or well used animal tracks where *P. penicillata* scats had been recorded and activity was expected to be high (Rowcliffe *et al*. 2008; Gowen and Vernes 2014). Although capture of *P. penicllata* behaviour was the primary focus the cameras also recorded occurrences of when dingoes and foxes visited these sites.

Table 1. Site habitat descriptions based on Regional Ecosystem type

Regional Ecosystem type	12.8.16[A]	12.8.17[A]	12.8.9[B]
Tree canopy height (m)	20	19	27
Tree canopy cover (%)	41	48	73
Tree subcanopy height (m)	8	10	14
Tree subcanopy cover (%)	17	20	23
Shrub canopy cover (%)	4	5	14
No. of large trees/ha	2	24	73
Dominant flora species	*Eucalyptus crebra* ± *E. tereticornis* and *E. melliodora.*	*E. melanaphloia* ± *Corymba tessellaris*, *E. crebra*, and *E. tereticornis.*	*Lophostemon confertus*, *C. intermedia*, *E. saligna*, *E. propinqua* and *Argyrodenron actinophyllum.*

[A] Ryan (2012).

[B] Ryan (2020).

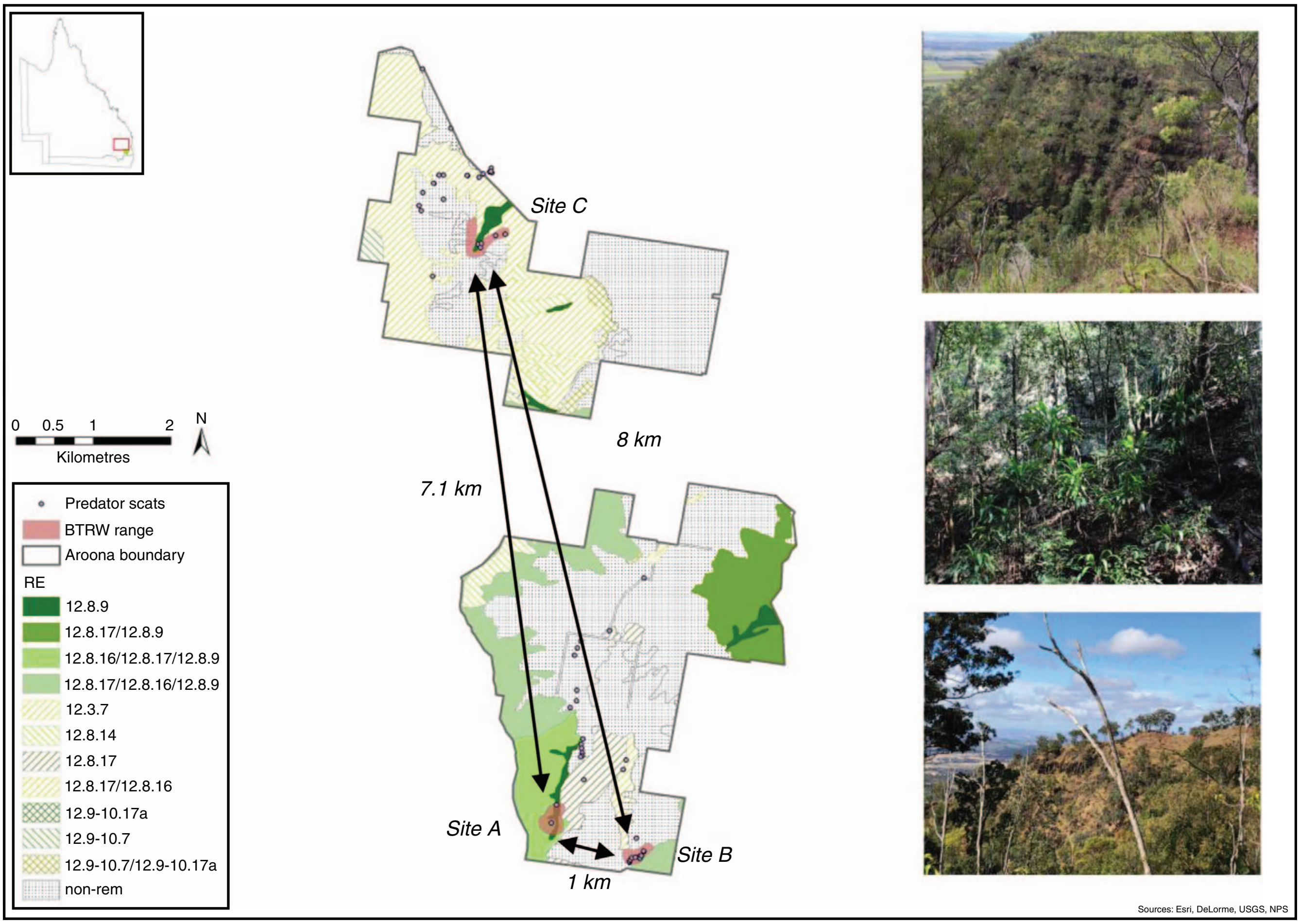

Fig. 1. Study site, Aroona Station, showing locations and images of Sites A (middle), B (bottom) and C (top) with distance (km) between sites, and Regional Ecosystems present around each colony.

Scat collection and analysis

Scats from dingoes and foxes were collected opportunistically throughout the study area in 2017. Scats were collected along roads, animal tracks, walking tracks, and around the *P. penicillata* colony sites within the boundaries of Aroona Station in accordance with ethics approval conditions, following the collection methodology of Lunney *et al*. (1996). Due to the difficult terrain of the study sites, search methods were adapted to suit the conditions. Adopting the adaptive cluster sampling technique, additional radii searches were conducted around the location of a discovered scat, where the unit of interest was a scat and replacing transects was the opportunistic collection method (Thompson 1991; Keiter *et al.* 2016). Scats were sent to ‘Scats About’ for analysis of prey species and their percentage composition within the scat, and confirmation of the scat’s source (i.e. dingo or fox) (Triggs 2004).

Statistical analyses

The camera trap data were used to determine the activity overlap between *P. penicillata*, dingoes and foxes in the three different habitat types. The images from the camera traps were sorted and instances of *P. penicillata*, dingoes or foxes were recorded. Each picture was analysed to ensure each new individual was recorded as a separate event, along with information about its date, and time and time decimal. Converting image capture times to a time decimal changed the time to a percentage of the overall 24-h period, to standardise for presentation in graphs.

The percentage of activity overlap for *P. penicillata*, dingoes and foxes was examined using R (The R Foundation 2018). The R studio package ‘Estimate of Coefficient of Overlapping for Animal Patterns’ was utilised to measure the distance between high densities in the data to measure the percentage overlap (Ridout and Linkie 2009). The overlap coefficient was based on the equation (Weitzman 1970):

$$\Delta(f,\ g) = \min \int \{f(x),\ g(x)\} dx$$

where $f(x)$ and $g(x)$ are two probability density functions for the two species.

The information from the time decimal records was used to form kernel density plots, from which non-parametric estimators were used to label the coefficient of overlap between the different populations and the separate *P. penicillata* colonies against dingoes and foxes (Meredith and Ridout 2017). The Dhat1 non-parametric estimator was used to explain the percentage of overlap (Ridout and Linkie 2009). The prey species and their percentage composition within the scats, from the dingo and fox scats, were used to compile presence/absence results of different prey species.

Results

Camera trap data

Across all study sites at Aroona Station there were 728 trap-days during the pilot study in 2016 and 2318 trap-days during 2017. In 2016, the cameras recorded 87 dingoes (0.12 dingoes per 100 trap-nights) and 317 *P. penicillata* (0.435 per 100 trap-nights) despite the smaller number of trapping nights. In contrast, in 2017 932 *P. penicillata* (0.402 per 100 trap-nights) were recorded on camera traps and fewer dingoes (25: 0.011 per 100 trap-nights). Images of dingoes were captured on 55% of the cameras in 2016, and 46% in 2017. Camera traps recorded 11 foxes in both 2016 and 2017.

Activity patterns of P. penicillata*, dingoes and foxes situated in the three habitat types*

The evaluation of activity times of *P. penicillata* in each of the sites showed that individuals at Sites B and C had the highest percentage overlap in activity time in 2016 (67.6%) and in 2017 (86.3%). In contrast, the percentage overlap in activity time for Sites A and B were 47.4% and 22.1% in 2016 and 2017 respectively, and for Sites A and C they were 40.9% and 31.1%.

Animal events per camera were calculated for all species to standardise the different number of camera trap days for each year. Instances for dingoes per camera were lower in 2017 than 2016 across all sites, with average events per camera ranging from 3 to 9.6 in 2016, and 0.78 to 1 in 2017 (Table 2).

In contrast, instances of *P. penicillata* events per camera were higher in 2017 than 2016 across all sites, ranging from 6.8 to 61 events per camera in 2016, and 22.9 to 42.1 events per camera in 2017 (Table 2). Activity patterns produced from images at each site showed that *P. penicillata* had consistent activity patterns (i.e. higher (peaks) or lower (troughs) throughout the different times of the day) in both 2016 and 2017 specific to the site (Figs 2*a*, 3*a* and 4*a*).

At Site A *P. penicillata* was mostly active at dawn and dusk, which was different to the peak in activity during night-time hours of *P. penicillata* at Sites B and C (Figs 2*a*, 3*a* and 4*a*). Dingo activity patterns were most similar for all sites at Site A in 2016 and 2017 (Fig. 2*b*). Activity patterns of dingoes at Sites B and C had less overlap in 2016 and 2017 (Figs 3*b*, 4*b*).

The spike in activity observed at Site C at 0800 hours can be attributed to the low numbers skewing the results and has been included to present data from all sites for both years.

Dingo and fox scat composition

Eighty dingo scats and 18 fox scats were collected on Aroona Station. No *P. penicillata* remains were found within these scats (Fig. 5). Eastern grey kangaroo (*Macropus giganteus*) formed a large part of dingo diet, along with northern brown bandicoot (*Isoodon macrourus*) and swamp wallaby (*Wallabia bicolor*) (Fig. 5). In contrast, based on the scats, northern brown bandicoot (*Isoodon macrourus*) was the major source of prey for foxes (Fig. 5).

The scats were collected adjacent to the camera locations. The results from Aroona Station were compared with those from three similar studies that examined dingo or fox predation on *P. penicillata*. The other studies were of *P. penicillata* colonies in Armidale, NSW (Lunney *et al*. 1996), Upper-Macleay and Aspley River Gorges, NSW (Robertshaw and Harden 1985) and the Grampians, Victoria (Lobert 1988) (Table 3). Lunney *et al*. (1996) and Robertshaw and Harden (1985) examined over 300 predator scats, but both studies showed that less than 3.1% of the scats contained *P. penicillata* (Table 3).

Discussion

The results from this study support the hypothesis that brush-tailed rock-wallabies modify their activity patterns according to different habitat types to reduce their risk of predation. *Petrogale penicillata*, as a refuge dependent herbivore, is known to alter its foraging behaviour (specifically distance ventured away from refuge) in response to predation risk and the presence of specific landscape habitat features.

At Sites B and C *P. penicillata* had similar activity times, demonstrating that its activity in these two sites was consistent with current knowledge, with activity times highest between 1800 and 0600 hours for 2016 and confirmed in 2017 with

Table 2. Instances of dingoes and *P. penicillata* recorded on camera traps, and the average number of events per camera, at the three sites in 2016 and 2017

Animal	Year	Parameter	Site A	Site B	Site C	Total
Dingoes	2016	Total events	30	48	9	87
		Average	7.5	9.6	3	
	2017	Total events	7	9	9	25
		Average	0.78	1	1	
P. penicillata	2016	Total events	244	34	39	317
		Average	61	6.8	13	
	2017	Total events	347	379	206	932
		Average	38.6	42.1	22.9	

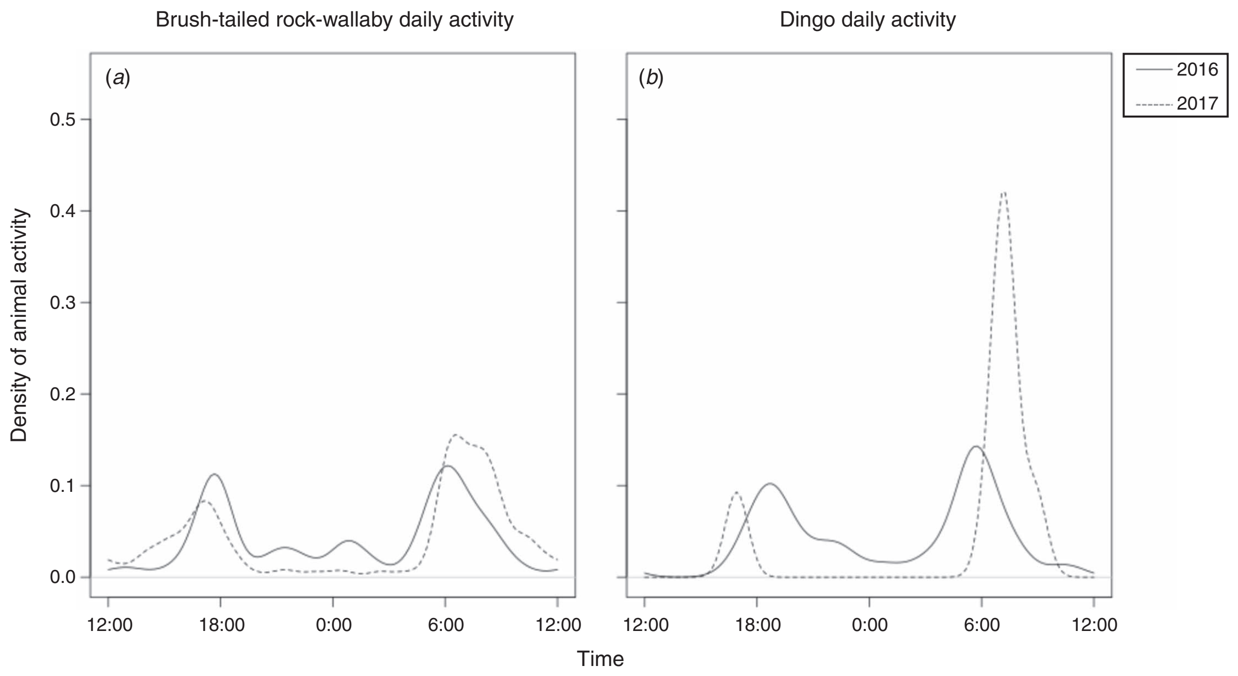

Fig. 2. Comparison of activity peaks in 2016 (—) and 2017 (- - -) between (*a*) *P. penicillata*, and (*b*) dingoes at Site A.

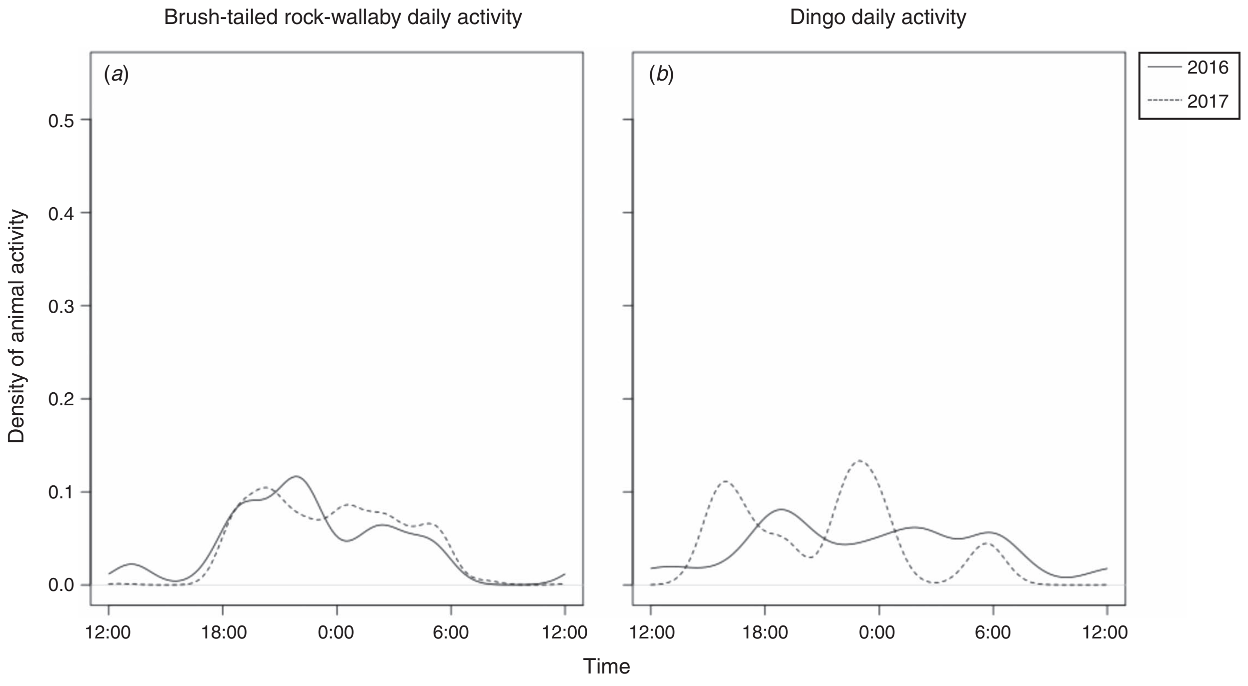

Fig. 3. Comparison of activity peaks in 2016 (—) and 2017 (- - -) between (*a*) *P. penicillata*, and (*b*) dingoes at Site B.

more data (Figs 3*a*, 4*a*). However, along with its difference in habitat, *P. penicillata* at Site A was active mostly during the crepuscular hours of dawn and dusk: the results show two distinct peaks from 1500 to 1900 hours and from 0500 to 0930 hours (Fig. 2).

From the difference in habitat features at Site A, compared with the other two sites, it can be hypothesised that Site A had less protection for *P. penicillata*, increasing its predation risk, and thus its behaviour was different from that of *P. penicillata* at Sites B and C. Changes in animal behaviour in response to

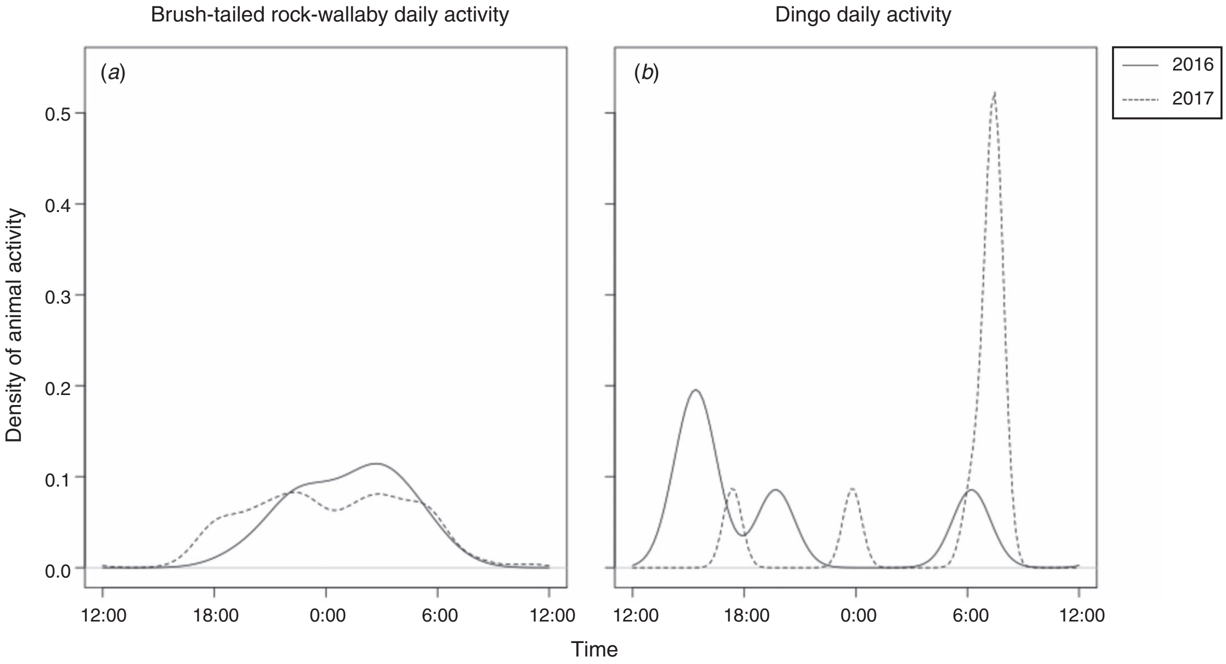

Fig. 4. Comparison of activity peaks in 2016 (—) and 2017 (- - -) between (*a*) *P. penicillata*, and (*b*) dingoes at Site C.

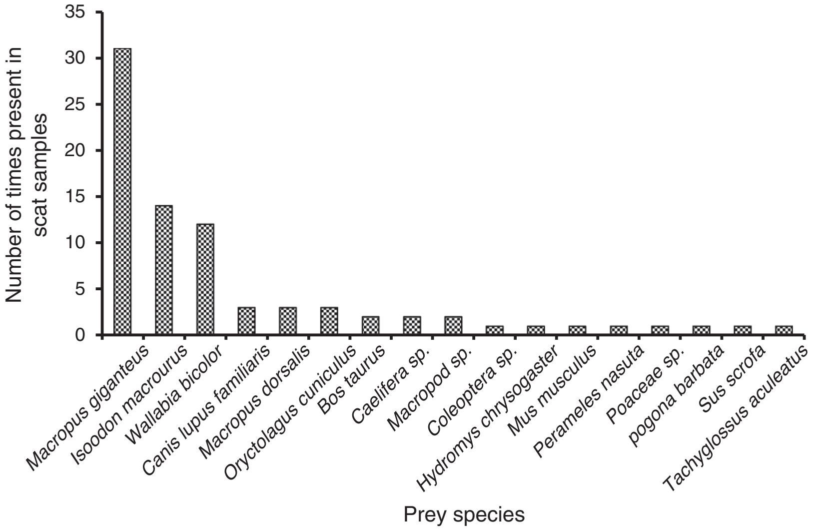

Fig. 5. Frequency of prey species found within dingo and fox scats at Aroona Station.

Table 3. Comparison of results from other studies on *P. penicillata* predation based on analysis of predator scats

Study	Total no. of predator scats collected	*P. penicillata* predation	Percentage of scats containing *P. penicillata*
Aroona Station	83	0 fox; 0 dog	0
Lobert (1988)	144	0	0
Lunney *et al*. (1996)	310	1 dog; 0 fox	3.1
Robertshaw and Harden (1985)	358	3–5 depredated[A]	1–2

[A] Study did not differentiate between dog and fox predation.

habitat and perceived predation risk have been documented in multiple studies (e.g. Ellwanger and Gould 2011; Tuft *et al*. 2011; De Oliveira *et al*. 2014). Foraging is a behaviour that can be indirectly affected by predation pressure; therefore this change in *P. penicillata* activity times follows this same concept (Tuft *et al*. 2011).

The assumption that the habitat features were an influencing factor of *P. penicillata* activity times is strengthened by the fact that the peaks in dingo activity at dawn and dusk (Allen *et al*. 2013, 2014) mostly overlapped with the peak activity times of *P. penicillata* at site A. In contrast, activity patterns of *P. penicillata* at Sites B and C showed that they avoided periods when the dingoes were most active (Figs 3, 4). The activity patterns from Sites B and C show that *P. penicillata* activity was highest during the night, whereas dingoes at those sites were generally crepuscular. Predation risk ultimately changes the foraging behaviour of *P. penicillata* as it is a foraging compromise (Gutman and Dayan 2005; Hammerschlag 2009). Thus two species that coexist in the same area can use temporal partitioning of activity to avoid each other (Gutman and Dayan 2005). At Sites B and C *P. penicillata* seems to actively avoid periods when dingo activity increases (Figs 3, 4) to lower the predation risk, and possibly also due to differences in site structure.

Temporal partitioning may also be reflected in the differing numbers of dingoes and *P. penicillata* captured on camera traps in 2016 and 2017 (Table 2). In 2016 there were fewer *P. penicillata*, on average, per camera trap, and greater numbers of dingoes (Table 2). This reversed in 2017, with an increase in *P. penicillata* numbers recorded per camera trap, and fewer dingoes. *Petrogale penicillata* could actively be avoiding predators when predators were more abundant. Temporal partitioning was particularly obvious at Sites B and C, where the higher level of exposure of both sites seemed to impact on *P. penicillata* activity levels when dingoes were present (Figs 3, 4).

Foxes were present within the landscape; however, there were not enough camera trap images to determine their activity and how it compared with that of *P. penicillata*. The lack of foxes in the same areas where dingoes were caught on camera could suggest that the foxes may be actively avoiding the areas frequented by the dingoes (Letnic *et al*. 2012; Jackson *et al*. 2017).

The results of the scat analysis showed no evidence of predation on *P. penicillata* by dingoes during the study. These findings are similar to those of three studies elsewhere in Australia where rock-wallabies were frequently sighted (Lunney *et al*. 1996) – Upper-Macleay and Aspley River Gorges (Robertshaw and Harden 1985) and the Grampians (Lobert 1988) (Table 3) – with all studies showing low predation rates. Although fewer scats were collected at Aroona Station for analysis compared with the Victorian and NSW studies (Aroona Station: 80 dingo scats and 18 fox scats), the results were similar. In each study, *P. penicillata* did not form a large part of dingo or fox diets (Table 3). However, the activity of the prey species that were actually present in the dingo scats was not analysed. Thus the overlap in activity of *P. penicillata* and dingoes may be coincidental, and they may be responding to a landscape of fear.

A study on dingo movement showed that daily average travel distance was 16.7 km (Harden 1985). It is possible that the above studies, including this one at Aroona Station, are potentially missing predator scats that contain *P. penicillata*, as scats could be deposited outside the search areas from each of the study sites. However, due to the observed regular movements of the dingoes along roads and tracks throughout Aroona Station, it is likely that the scats collected during the study represented the dingo diet well, indicating low levels of predation on *P. penicillata*. This is further supported by the study of Lunney *et al*. (1996), which collected scats up to a distance of 60 km from a *P. penicillata* colony, with very few scats found to contain *P. penicillata* remains within that range.

Although this study did reveal some interesting behavioural patterns of *P. penicillata* and its response to predators in different habitat types, several limitations need to be acknowledged. First, it would be valuable to replicate the study over a different period, as seasonality could play an important role in *P. penicillata* activity and behaviour. The scat collection and analysis covered a period when young *P. penicillata* joeys were beginning to leave their mothers' pouches. An increase in more vulnerable *P. penicillata* within the landscape may potentially change predation levels on this species. It is possible that predation levels could change during the dispersal season in spring and summer when young are weaned (Eldridge and Close 2008) and this should be an area of future research. Additionally, increasing the number of predator scats collected would have strengthened the results. Although the study site was intensively surveyed, it would have been preferable to expand the study area to encompass a wider landscape and collect scats that might have been deposited outside of the immediate colony range.

Conclusions

Understanding interactions between introduced predators and *P. penicillata* is crucial for its conservation. Changes in behaviour through the use of predator avoidance strategies and temporal partitioning, and the lack of remains in dingo scats, indicate that *P. penicillata* has modified its behaviour in response to predators to decrease predation pressure. The results of this study show that the complexity of its habitat and exposure of colony sites can alter the perceived risk of predators within the landscape, which also influences *P. penicillata* behaviour and the level of avoidance of the times of the day that predators are most active.

Data availability statement

The data that support this study will be shared upon reasonable request to the corresponding author.

Conflict of interest

The authors declare no conflicts of interest.

Declaration of funding

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References

Allen, B. L., Goullet, M., Allen, L. R., Lisle, A., and Leung, L. K. P. (2013). Dingoes at the doorstep: preliminary data on the ecology of dingoes in urban areas. *Landscape and Urban Planning* **119**, 131–135. doi:10.1016/j.landurbplan.2013.07.008

Allen, B., Engeman, R., and Leung, L. (2014). The short-term effects of a routine poisoning campaign on the movements and detectability of a social top-predator. *Environmental Science and Pollution Research International* **21**, 2178–2190. doi:10.1007/s11356-013-2118-7

Carter, K., and Goldizen, A. W. (2003). Habitat choice and vigilance behaviour of brush-tailed rock-wallabies (*Petrogale penicillata*) within their nocturnal foraging ranges. *Wildlife Research* **30**, 355–364. doi:10.1071/WR02095

Corp, N., Gorman, M. L., and Speakman, J. R. (1997). Ranging behaviour and time budgets of male wood mice *Apodemus sylvaticus* in different habitats and seasons. *Oecologia* **109**, 242–250. doi:10.1007/s004420050079

De Oliveira, S. G., Lynch Alfaro, J. W., and Veiga, L. M. (2014). Activity budget, diet, and habitat use in the critically endangered Ka'apor capuchin monkey (*Cebus kaapori*) in Pará State, Brazil: a preliminary comparison to other capuchin monkeys. *American Journal of Primatology* **76**, 919–931. doi:10.1002/ajp.22277

Department of Agriculture and Fisheries, The State of Queensland (2017). 'Wild dog *Canis familaris*.' Available at: https://www.daf.qld.gov.au/__data/assets/pdf_file/0003/74487/IPA-Dingo-Wild-Dog-Control-PA10.pdf [accessed 20 October 2017].

Department of the Environment (2018). *Petrogale penicillata.* In 'Species Profile and Threats Database'. (Department of the Environment: Canberra.)

Egerton, L., and Lochman, J. (2009). 'Wildlife of Australia.' (Jacana Books: Crows Nest, NSW)

Eldridge, M., and Close, R. (2008). Brush-tailed rock-wallaby, *Petrogale penicillata*. In 'The Mammals of Australia'. (Eds S. Van Dyck and R. Strahan.) pp. 382–384. (Reed New Holland Publishers: Sydney.)

Ellwanger, N., and Gould, L. (2011). Variations in behavioural patterns between *Lemur catta* groups living in different forest types: implications for conservation. *Endangered Species Research* **14**, 259–270. doi:10.3354/esr00362

Gowen, C., and Vernes, K. (2014). Population estimates of an endangered rock-wallaby (*Petrogale penicillata*) using time-lapse photography from camera traps. In 'Camera Trapping: Wildlife Management and Research'. (Eds P. Meek, and P. Flemming.) pp. 61–68. (CSIRO: Collingwood, Vic.)

Gutman, R., and Dayan, T. (2005). Temporal partitioning: an experiment with two species of spiny mice. *Ecology* **86**, 164–173. doi:10.1890/03-0369

Hammerschlag, N. (2009). Nocturnal fish distribution, feeding and predation risk in relation to a mangrove–seagrass ecotone. (Ed. J. E. Serafy.) (ProQuest Dissertations Publishing.)

Harden, R. H. (1985). The ecology of the dingo in north-eastern New South Wales. I. Movements and home range. *Wildlife Research* **12**, 25–37. doi:10.1071/WR9850025

Jackson, S. M., Groves, C. P., Fleming, P. J. S., Aplin, K. P., Eldridge, M. D. B., Gonzalez, A., and Helgen, K. M. (2017). The wayward dog: is the Australian native dog or dingo a distinct species? *Zootaxa* **4317**, 201–224. doi:10.11646/zootaxa.4317.2.1

Jaman, M., and Huffman, M. (2013). The effect of urban and rural habitats and resource type on activity budgets of commensal rhesus macaques (*Macaca mulatta*) in Bangladesh. *Primates* **54**, 49–59. doi:10.1007/s10329-012-0330-6

Jeffers, B. (2016). Assessment for advanced offset values for the Koala (*Phascolarctos cinereus*) on the 'Aroona' Property, Mount Mort, Queensland. Ausecology report.

Keiter, D. A., Cunningham, F. L., Rhodes, O. E., Irwin, B. J., and Beasley, J. C. (2016). Optimization of scat detection methods for a social ungulate, the wild pig, and experimental evaluation of factors affecting detection of scat. *PLoS One* **11**, e0155615. doi:10.1371/journal.pone.0155615

Letnic, M., Ritchie, E. G., and Dickman, C. R. (2012). Top predators as biodiversity regulators: the dingo *Canis lupus dingo* as a case study. *Biological Reviews* **87**, 390–413. doi:10.1111/j.1469-185X.2011.00203.x

Lobert, B. (1988). The brush-tailed rock-wallaby (*Petrogale penicillata*) in the Grampians National Park and the Black Range, Victoria. Part 1 – Survey. National Parks and Wildlife Division, Department of Conservation, Forests and Lands, Victoria. Arthur Rylah Institute For Environmental Research report.

Lunney, D., Law, B., and Rummery, C. (1996). Contrast between the visible abundance of the brush-tailed rock-wallaby, *Petrogale penicillata*, and its rarity in fox and dog scats in the gorges east of Armidale, New South Wales. *Wildlife Research* **23**, 373–379. doi:10.1071/WR9960373

Menkhorst, P., and Hynes, E. (2011). National recovery plan for the brush-tailed rock-wallaby *Petrogale penicillata*. Victorian Government Department of Sustainability and Environment.

Meredith, M., and Ridout, R. (2017). Overview of the overlap package. Available at: https://cran.r-project.org/web/packages/overlap/vignettes/overlap.pdf [accessed 24 November 2018].

Murray, J. V., Low Choy, S., McAlpine, C. A., Possingham, H. P., and Goldizen, A. W. (2008). The importance of ecological scale for wildlife conservation in naturally fragmented environments: a case study of the brush-tailed rock-wallaby (*Petrogale penicillata*). *Biological Conservation* **141**, 7–22. doi:10.1016/j.biocon.2007.07.020

Office of Environment & Heritage (2013). Brush-tailed rock-wallaby – profile. Available from http://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=10605 [accessed 3 August 2017].

Piggott, M. P., Hansen, B., Soderquist, T., Eldridge, M. D. B., and Taylor, A. C. (2018). Population monitoring of small and declining brush-tailed rock wallaby (*Petrogale penicillata*) colonies at the extreme of their range using faecal DNA sampling. *Australian Mammalogy* **40**, 58–66. doi:10.1071/AM16056

Queensland Government (2014). Species profile – *Petrogale penicillata* (Macropodidae). Available at: https://www.legislation.qld.gov.au/view/pdf/inforce/2000-09-15/act-1999-090 [accessed 20 October 2017].

Ridout, M., and Linkie, M. (2009). Estimating overlap of daily activity patterns from camera trap data. *Journal of Agricultural Biological & Environmental Statistics* **14**, 322–337. doi:10.1198/jabes.2009.08038

Robertshaw, J., and Harden, R. (1985). The ecology of the dingo in north-eastern New South Wales. 2. Diet. *Wildlife Research* **12**, 39–50. doi:10.1071/WR9850039

Rowcliffe, J. M., Field, J., Turvey, S. T., and Carbone, C. (2008). Estimating animal density using camera traps without the need for individual recognition. *Journal of Applied Ecology* **45**, 1228–1236. doi:10.1111/j.1365-2664.2008.01473.x

Ryan, T. S. (ed.) (2012). Technical descriptions of regional ecosystems of southeast Queensland (May 2012). Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Ryan, T. S. (ed.) (2020). Technical descriptions of regional ecosystems of southeast Queensland, Draft RE12.8.9 (May 2020). Queensland Herbarium, Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Short, J. (1982). Habitat requirements of the brush-tailed rock-wallaby, *Petrogale penicillata*, in New South Wales. *Wildlife Research* **9**, 239–246. doi:10.1071/WR9820239

Taggart, D. A., Schultz, D. J., Corrigan, T. C., Schults, T. J., Stevens, M., Panther, D., and White, C. R. (2015). Reintroduction methods and a review of mortality in the brush-tailed rock-wallaby, Grampians National Park, Australia. *Australian Journal of Zoology* **63**, 383–397. doi:10.1071/ZO15029

The R Foundation (2018). The R Project for statistical computing. Available at: https://www.r-project.org/ [accessed 24 November 2018].

Thompson, S. K. (1991). Adaptive cluster sampling: designs with primary and secondary units. *Biometrics* **47**, 1103–1115. doi:10.2307/2532662

Triggs, B. (2004). 'Tracks, Scats and Other Traces: a Field Guide to Australian Mammals.' Rev. edn. (Oxford University Press: South Melbourne, Vic.)

Tuft, K., Crowther, M. S., Connell, K., Muller, S., and McArthur, C. (2011). Predation risk and competitive interactions affect foraging of an endangered refuge-dependent herbivore. *Animal Conservation* **14**, 447–457. doi:10.1111/j.1469-1795.2011.00446.x

Weitzman, M. (1970). Measure of the overlap of income distribution of white and negro families in the United States. (U.S. Department of Commerce and of the Census: Washington, DC.)

Wong, V., and Soderquist, T. (2003). Warrumbungle Brush-tailed Rock-wallaby Endangered Population Recovery Plan. NSW National Parks and Wildlife Service, Hurstville, NSW.

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