

Does artificial light influence the activity of vertebrates beneath rural buildings?

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Abstract. Interactions between humans and wildlife have increased dramatically over the past century as human populations increase and occupy areas formerly dominated by native animals. In Australia, increases in land clearing and farming close to riparian areas has brought humans into contact with the common wombat (*Vombatus ursinus*), a relatively large-bodied, semifossorial marsupial. The common wombat is regarded as a pest in some agricultural areas due to its habit of burrowing beneath buildings, destroying fences and destabilising stream banks. We examined the effectiveness of artificial lighting to deter wombats from using the subfloor cavity under an historic cottage at 'Bundanon' in southern New South Wales, Australia. The response of wombats to artificial light (10 weeks on followed by 10 weeks off) was assessed using heat- and motion-sensing cameras continuously over a period of 58 weeks. While the main focus was on light effects on wombats, the study also allowed us to record non-nuisance animals using the subfloor cavity. Of the total of 1086 animal detections over the 58-week period (2.67 detections day⁻¹), 965 (89%) were of mammals, 106 birds and 15 reptiles. Wombats (622; 57%) and kangaroos (228; 22%) made up 79% of all detections. Nocturnal activity of wombats remained unchanged in response to lighting (on: 266; off: 268), but there were significantly more diurnal detections when the lights were on (58) than off (30). For kangaroos, there were more nocturnal detections when lights were off, but more diurnal detections when lights were on. More antechinus were detected at night (night: 107; day: 8), and with the lights off (99 cf. 8), and insectivorous birds were detected almost entirely during the day, mostly with the lights on (66 cf. 39). Our study showed that, overall, the lighting regime we used was ineffective at reducing wombat activity under the building.

Additional keywords: camera trapping, common wombat, crepuscular, nocturnal, periurban, pest animals.

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Introduction

The spread of urbanisation into natural habitats has increased globally, bringing humans into closer contact with wildlife. These human–wildlife interactions, which are many and varied, come under the epithet 'human–wildlife conflict' (Madden 2004; Peterson *et al.* 2010), and arise out of the competing demands of humans and wildlife for resources. This results in a wide range of potential interactions, from animal damage to crops, livestock and transportation systems, to damage to gardens and human dwellings, to name just a few (Peterson *et al.* 2010).

Interactions between wildlife and humans often arise when animals use human structures such as roof and subfloor cavities in houses and sheds in urban and rural environments. These human structures can provide foraging sites for feral and native species, and shelter, warmth and protection from predators (McKinney 2006). In periurban areas in Europe, for example, Eurasian badgers (*Meles meles*) and stone martens (*Martes foina*)

thrive in large cities, using buildings and adjoining lands for burrow and den sites (Pavlaèik *et al.* 2004; Herr *et al.* 2010). Similarly, striped skunks (*Mephitis mephitis*), raccoons (*Procyon lotor*) and woodchucks (*Marmota monax*) in Canada and the United States take advantage of urban and rural structures for habitation (Bruleigh and Vandruuff 1998; Lariviere *et al.* 1999; O'Donnell and DeNicola 2006).

In Australia, pest animals that have come into close contact with humans range from the native common brushtailed possum (*Trichosurus vulpecula*) to the exotic black rat (*Rattus rattus*), both of which occupy roof cavities (Thompson 1984; Statham and Statham 1997; Roetman and Daniels 2009). These and many animals that occupy human dwellings are often excessively noisy while foraging at night, and often chew and destroy electrical cabling. Others, such as long-nosed bandicoots (*Perameles nasuta*) and Australian brush turkeys (*Alectura lathami*), cause damage to gardens and lawns through their digging (Jones and Goth 2008).

The term 'pest species' is not confined to non-native species. In Australia, 17 native mammals have been described as pests (Cowan and Tyndale-Biscoe 1997), along with several native birds including the silver gull (*Chroicocephalus novaehollandiae*), which is hazardous to aviation near airports. In rural south-eastern Australia where forested riparian areas occur adjacent to farms and out settlements, common wombats (*Vombatus ursinus*) are often regarded as pests due to their habit of digging under buildings (Borchard and Collins 2001). It is the wombat that is the focus of this study because of its widespread nuisance status among landholders and property owners. During daylight hours, wombats retreat into deep burrow systems, which in riparian forests, are often under low-hanging vegetation or in streambanks (Borchard *et al.* 2008; Borchard and Eldridge 2011). At night, wombats emerge from their burrows and preferentially graze on introduced pasture grasses. During the evening they move many times between riparian forests and human settlements, earning them a reputation for damaging fencing, burrowing under buildings and creating large holes in the soil (Borchard and Collins 2001; Borchard *et al.* 2008; Borchard and Wright 2010b). Apart from two studies that have investigated the effectiveness of electric fencing and swinging gates to prevent wombats from damaging livestock fencing (Borchard and Wright 2010b), we are unaware of studies that have explored non-lethal techniques to manage wombats, which are perceived by landholders as being a nuisance.

A range of non-lethal techniques has been used globally to manage animals where they come into close contact with humans. Various frightening stimuli, primarily visual and acoustic, have been used to prevent or alleviate damage by mammals (Koehler *et al.* 1990; Gilsdorf *et al.* 2002). One of these methods is artificial lighting, which has been used to deter or move nocturnal pest species such as deer (*Odocoileus* spp.), raccoons and bears (*Ursus* spp.) (Koehler *et al.* 1990). Light is known to be an important modulator of circadian rhythms in animals and humans (Van Someren *et al.* 1997; Beier 2006). Laboratory studies have shown that the intensity of artificial light can disrupt circadian rhythm and reduce nocturnal activity of nocturnal rodents (Blair 1943; Kavanau 1968; DeCoursey 1986; Kramer and Birney 2001). Recent studies have also shown that artificial lighting in urban and rural landscapes can disrupt foraging behaviour and increase the risk of predation on a range of mammal species (Longcore and Rich 2004, 2006). In order to reduce predation by mountain lions (*Felis concolor*), Beier (1995) recommended the use of artificial light as a deterrent in areas occupied by humans.

Anecdotal reports suggest that artificial lighting may discourage wombats from using subfloor cavities. To date, however, there have been no tests of the effectiveness of artificial light for managing wombat activity. We aimed to test the hypothesis that wombats, our target 'nuisance' animal, would be deterred from using subfloor cavities when the normally dark space was illuminated, given that they generally avoid diurnal foraging, except when heavily affected by parasitic mange (Borchard *et al.* 2012). We acknowledge that many animals, such as the barn owl (*Tyto alba*), occupy or use human habitation without having negative effects on humans or their property. This study also allowed us therefore to test potential effects of artificial

lighting on non-target, non-nuisance species that might also use the subfloor cavity.

Study area

The study was carried out between August 2010 and August 2011 at 'Bundanon', a historically significant property in the Shoalhaven Region, ~160 km south of Sydney (34°52'S, 150°29'E), Australia. The Bundanon property is used for education and for supporting the international art community. The 1100-ha property is bounded on one side by the Shoalhaven River and contains a large section of river flat used for cattle grazing. The property is, however, largely made up of Sydney Coastal Dry Sclerophyll Forest containing species such as *Corymbia gummifera*, *Eucalyptus sclerophylla*, *Lambertia formosa*, *Banksia spinulosa*, *Lomandra obliqua* and *Patersonia sericea* (Keith 2004).

Bundanon consists of a large homestead and several adjacent buildings, all of which receive a high level of nuisance wombat activity as previously described. One building, the Musicians' Cottage, constructed in the 1870s, appeared to receive more wombat activity than the other buildings, as evidenced by an active burrow at the rear of the building and a layer of wombat scats in the subfloor cavity. This high level of use was probably due to its close proximity to surrounding bushland (~30 m) and the subfloor area providing levels of subdued light similar to shrub canopies in the surrounding bushland (Borchard *et al.* 2008). The Musicians' Cottage is elevated by sandstone piers ~800 mm off the ground at the front of the building, tapers to ground level at the rear, and therefore provides easy access for wombat monitoring with minimal disturbance to its human occupants (Fig. 1).

Artificial lighting experiments

We report here an experiment where two floodlights (150 W per floodlight) were mounted beneath the building ~3 m apart and illuminated continuously for 10-week periods, then off for 10 weeks and so on over the course of 12 months. The floodlights were sufficient to illuminate ~90% of the subfloor cavity. We selected an interval of 10 weeks because it was a compromise between being (1) long enough to ensure that we recorded



Fig. 1. The Musicians' Cottage, showing the sandstone piers and floodlight mounted underneath the veranda to the right of the stairs.

wombats returning to their burrow under the cabin (given that they often use multiple burrows, and switch between four or five active burrows), and (2) short enough to ensure that we had sufficient replicate periods to allow statistical analyses.

Monitoring wombat activity using camera traps

Although our emphasis was on wombats, we opportunistically recorded the activity of all fauna using the subfloor cavity with six passive infrared digital cameras. The cameras used were three Moultrie Game Spy I40 cameras (Moultrie Feeders, Alabaster, AL, USA), two Reconyx HC500 cameras and one Scoutguard SG550 V camera (Faunatech, Vic., Australia). Cameras were secured to the sandstone piers supporting the cottage at a height of 500 mm above the ground using Master Lock 'Python Locks'. Two cameras were positioned on the outer sandstone piers at the front of the building towards the rear of the cottage. With a spacing of 1600 mm between sandstone piers, cameras were sufficiently spaced to avoid any overlap of the field of view of each camera. Two cameras were positioned in the same manner at the sides of the building facing under the building but angling towards the rear. Two other cameras were positioned in the same manner but beneath the building (1640 mm in from the front alignment of the building) and facing towards the rear of the cottage. Positioning the cameras in this way ensured that any animal entering the subfloor cavity would be detected by a camera.

Cameras were set to record a single image when triggered by movement, followed by a delay of 1 min following the detection throughout the 24-h period. All cameras remained active in this position for 12 months and were downloaded and had rechargeable batteries changed over every two weeks. Downloaded images were checked for consistency between cameras and double records, i.e. where the same animal was recorded by more than one camera, were removed. All images were viewed by both authors.

Statistical analyses

We separated all images into nocturnal and diurnal records based on the timing of sunrise and sunset during different times of the year, and scored all observations according to the species and number of animals present. We recorded only independent observations, ensuring that we did not overestimate the detection of animals that were recorded on more than one camera at the same time.

We used permutational multivariate analysis of variance (PERMANOVA: Anderson and Gorley 2008) to test for differences in (1) the total density of all animals and (2) composition of different animals, in relation to time (diurnal versus nocturnal), lighting (on versus off) and their interaction. Data used were the sum of the number of independent daily observations for (1) all animals combined (density) or (2) independent records for different animals (composition). The same analyses were repeated using bird and mammal data separately. We used Chi-square analysis to examine potential differences in the number of observations between diurnal/nocturnal and lights on/off for wombats and kangaroos, for which we had sufficient data. Tests of Proportions, reported as Fisher's Exact Test (Minitab 2007), were used to test the probability that the proportion of insectivorous birds and the marsupial *Antechinus* detected at night differed from the proportion detected during the day. This test allowed us to examine potential lighting effects on attributes that had too few (<10) observations to allow more rigorous analyses.

Results

We recorded a total of 1086 detections over a 58-week period, representing an average of 2.67 detections day⁻¹. Of total detections, 965 (89%) were of mammals, 106 birds and 15 reptiles. Wombats (622; 57%) and kangaroos (228; 22%) made up 79% of all detections (Table 1). We detected no effects of lighting on either the density or composition of all animals

Table 1. Total abundance of bird, mammal and reptile fauna recorded at night and day with lights on and off

Species	Group	Day		Night	
		On	Off	On	Off
Common wombat (<i>Vombatus ursinus</i>)	Mammal	58	30	266	268
Eastern grey kangaroo (<i>Macropus giganteus</i>)	Mammal	120	70	11	27
Brown antechinus (<i>Antechinus stuartii</i>)	Mammal	1	7	8	99
Grey shrike-thrush (<i>Colluricincla harmonica</i>)	Bird	19	4		
Splendid fairywren (<i>Malurus splendens</i>)	Bird	4	19		
White-browed scrubwren (<i>Sericornis frontalis</i>)	Bird	16	3		
Satin bower bird (<i>Ptilonorhynchus violaceus</i>)	Bird	10	5		
Variegated fairywren (<i>Malurus lamberti</i>)	Bird	12			
Common mynah (<i>Acridotheres tristis</i>)	Bird		5		
Australian magpie (<i>Gymnorhina tibicen</i>)	Bird	2	1		
Laughing kookaburra (<i>Dacelo novaeguineae</i>)	Bird	1	1		
Magpie-lark (<i>Grallina cyanoleuca</i>)	Bird		1		
Tawny frogmouth (<i>Podargus strigoides</i>)	Bird			1	
Willie wagtail (<i>Rhipidura leucophrys</i>)	Bird	1			
Eastern whipbird (<i>Psophodes olivaceus</i>)	Bird	1			
Lace monitor (<i>Varanus varanus</i>)	Reptile	6	4	3	
Red-bellied black snake (<i>Pseudechis porphyriacus</i>)	Reptile		1		
Common blue-tongue (<i>Tiliqua scincoides</i>)	Reptile		1		
Grand total		251	152	289	394

($P > 0.05$) when the data were expressed as animals day⁻¹. Similarly, there were no significant effects of lighting on either total mammal densities or total bird densities ($P > 0.05$).

When we partitioned our total dataset between diurnal and nocturnal detections in relation to the effect of lighting, we found generally more detections at night (394) than during the day (152) when the lights were off, but similar values between night and day when the lights were on ($\chi^2 = 40.43$, d.f. = 1, $P < 0.001$) (Fig. 1a). Overall, there were twice as many wombat detections (534) at night than during the day (88). We found no difference in wombat activity in relation to lighting during the night, but significantly more detections when the lights were on during the day ($\chi^2 = 7.84$, d.f. = 1, $P = 0.005$) (Fig. 1b).

For kangaroos, we detected a different light effect between night and day, with more kangaroo detections during the day when the lights were on, but more detections at night when lights were off ($\chi^2 = 15.16$, d.f. = 1, $P < 0.001$) (Fig. 1c). Insectivorous birds were detected almost entirely during the day (105 cf. 1), with almost twice as many birds detected with the lights on (66) than with the lights off (39) (Fisher's Exact Test, $Z = -3.86$, $P < 0.001$). This was the opposite for the native marsupial *Antechinus*, with 107 at night and only eight during the day. Significantly more of the nocturnal detections of *Antechinus* occurred with the lights off (99 cf. 8) (Fisher's Exact Test, $Z = 23.65$, $P < 0.001$).

Discussion

Contrary to our expectations, artificial lighting failed to produce a noticeable decline in wombat activity under the Musicians' Cottage at night. Rather, our data suggest that artificial lighting may enhance wombat activity during the day. The reasons for these effects are thought to relate to the effects of light on the circadian cycle (Sharma *et al.* 1997). For example, in a study of photopollution impacts on the nocturnal behaviour of the sugar glider (*Petaurus breviceps*), Barber-Meyer (2007) found that sugar gliders exposed to artificial light were unable to distinguish between dusk and dawn, thereby altering their usual pattern of crepuscular activity and reducing foraging activities. It is possible that a similar lack of discrimination between dusk and dawn may have occurred in our study when wombats were exposed to artificial light. The cue used to synchronise the circadian clock in mammals (zeitgeber), is a change in the quantity, and perhaps the spectral quality, of light at dawn and dusk (Foster and Provencio 1999). It is conceivable, therefore, that the constant application of artificial light across dawn and dusk in our study disrupted the circadian clock in wombats, causing them to be more active during the day, a period previously noted for wombat inactivity (Borchard and Wright 2010a).

The lack of effect of artificial lighting on wombat activity during the night could also be explained by the fact that wombats rely mostly on their acute sense of smell rather than their poorly developed eyesight when foraging (Triggs 2009). Wombats are strongly habitual, and their movement patterns in the landscape are highly conditioned by many generations of animals. Wombats have been shown therefore to use the same well worn tracks over their lifetime; sometimes using the tracks of cattle and sheep (Borchard and Wright 2010a; Borchard and Eldridge 2011). It is likely therefore that wombats are strongly cued to

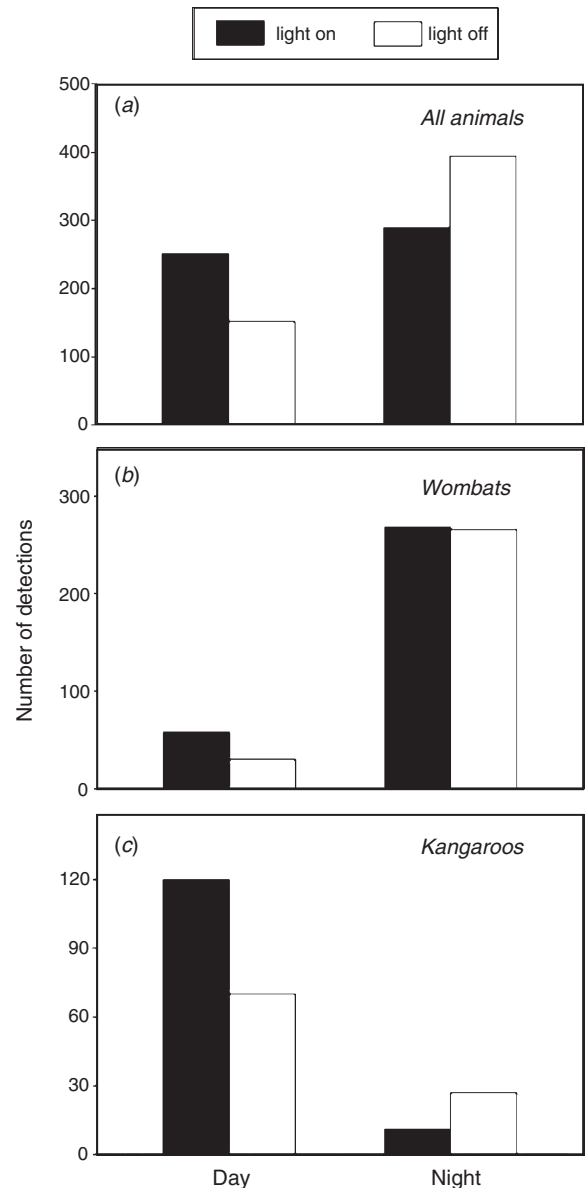


Fig. 2. Number of independent detections for (a) all animals, (b) wombats and (c) kangaroos by day/night and with the lights on or off.



Fig. 3. A wombat detected under the cottage at night with the lights on.

follow familiar paths, irrespective of lighting. Further, we are unable to explain the increased number of diurnal detections when the lights were on. This could have been due to the need to seek warmth during cold days, but examination of our data shows that these events were not skewed towards days with low temperature, but occurred throughout the year.

Our study also identified a large number of non-nuisance species that use the subfloor cavity, mainly during the day, but also at night. Use of buildings and human-constructed structures in periurban environments by animals has been well documented globally. For example, striped skunks (*Mephitis mephitis*) are known to inhabit farmsteads (Lariviere *et al.* 1999), Eurasian badgers and raccoons inhabit suburban residences and garages (Pavlaëik *et al.* 2004; O'Donnell and DeNicola 2006), and common brushtail possums inhabit the roof spaces of urban buildings (Statham and Statham 1997). However, we were unable to find published data on studies recording the range of species that have used human structures for shelter or foraging. Our motion-activated cameras, which were active for more than a year, enabled us to detect 18 species, mainly birds, that used the subfloor cavity with either the lights on or off (Fig. 2). Although these animals used buildings, they could hardly be described as nuisance species and therefore would be unlikely to elicit human intervention.

Of all birds detected by our cameras, mostly insectivorous birds were detected when the lights were on, suggesting that foraging for insects is probably the reason for use of the subfloor cavity. Artificial lighting attracts large numbers of a wide range of invertebrates, with moths being the best known for this behaviour (Bruce-White and Shardlow 2011), and regularly activated our cameras at night when the lights were on. The grey shrike-thrush (*Colluricincla harmonica*) was the most common bird detected under the cottage under illumination. This species is a common insectivorous resident of the surrounding forests (Schodde and Tidemann 1986) and is often found in semirural environments. While artificial light can attract insects and birds at night (Bruce-White and Shardlow 2011; Dwyer *et al.* 2013), invertebrates attracted to polarised light (Horvath *et al.* 2009) and reflected light (Long *et al.* 2011) in daylight can suffer greater predation by birds.

Unlike birds, most of the detections of antechinus in the subfloor cavity were when the lights were off. *Antechinus stuartii* is nocturnal and hunts for arthropods during the night (Strahan 1988). Our study shows that the activity pattern of antechinus closely follows that of the species in its natural forest environment. Its usage of the subfloor cavity was less than that of wombats. It is possible, therefore, that low use of the subfloor cavity and low exposure to artificial light has not disrupted the biological clock of antechinus (Beier 2006). An unexpected consequence of our study was that artificial lighting provided a useful mechanism for reducing antechinus activity. Antechinus can be a pest in buildings close to natural bushland (Garden 2006), and artificial lighting may be a useful strategy for discouraging antechinus from entering buildings.

The effect of lighting on kangaroos was day–night dependent. Kangaroos were mainly active in daylight, and the doubling of diurnal detections under illumination indicates that kangaroos are advantaged by being close to the artificial light source. Alternatively, because kangaroos are diurnal and crepuscular,

lighting may provide an environment that is closer to their diurnal range. Potential reasons for this are the warmth generated by the artificial lighting or temperature regulation associated with a cooler environment in the subfloor cavity. Although eastern grey kangaroos (*Macropus giganteus*) have excellent thermoregulatory abilities, they tend to seek shade in summer because they suffer from high levels of evaporative heat loss during periods of high temperature (Dawson *et al.* 2000). Conversely, we were unable to find literature to support the notion that kangaroos are attracted to warm areas when temperatures are low. Unlike eastern grey kangaroos, wombats have a low energy expenditure and low field metabolic rate (Evans *et al.* 2003), enabling them to cope with high and low temperatures for the time spent out of their burrows and negating the need for shade or warmth provided by the cottage.

Overall, our study has shown that the activity and movement patterns of wombats could not be reduced effectively using artificial light (Fig. 3). Motion-sensing cameras, however, provided us with a unique opportunity to simultaneously examine what other fauna use subfloor cavities and how they might respond to artificial light. Our data suggest that there is a relatively large number of animals that use human structures in agricultural and periurban environments. With our main focus on managing wombat activity, there remains a need to examine alternative methods to manage wombats where they come into contact with humans and their infrastructure.

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