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Aversive behaviour by koalas (*Phascolarctos cinereus*) during the course of a music festival in northern New South Wales, Australia

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Abstract. The effects of short-term disturbances that result in changes to movement patterns and/or behaviour of wildlife are poorly understood. In this study the movements of seven koalas were monitored before, during and after a five-day music festival. During the monitoring program koalas occupied home-range areas of 0.6–13 ha with one or more core areas of activity. Aversive behaviour in the form of evacuation of known ranging areas was demonstrated by three koalas that had core areas within 525 m of the approximate centre of the festival area, the associated responses comprising movements that were perpendicular to and away from staging areas where music was played. Responses contained within known ranging areas were observed in three other koalas whose core areas were located up to 600 m away. The type of response appeared related to the proximity of koala home ranges to music-staging areas, while the maximum distance associated with an aversive response was 725 m. Six of the radio-tracked koalas returned to their home-range areas following the conclusion of festival activities. While the specific stimulus eliciting aversive behaviour was not identified, responses in all instances were initiated during the musical phase of the festival event. The potential for short-term disturbances such as music festivals to significantly influence the ranging patterns of koalas warrants recognition of possible longer-term ecological consequences for planning and management purposes.

Additional keyword: unconditioned aversive stimuli.

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Introduction

The extents to which acoustic disturbances of anthropogenic origin permeate natural environments are of increasing interest to ecologists because of their potential to modify aspects of animal ecology (Warren *et al.* 2006; Barber *et al*. 2010; Francis and Barber 2013). Types of acoustic disturbances vary from persistent background noises associated with transportation to short-term 'pulses' such as amplified performance music (Warren *et al.* 2006). As typified in conventional psychological texts (e.g. Gray 1987), the term 'unconditioned aversive stimuli' can be used to describe biologically harmful or damaging substances or events, examples of which include loud noise. In a wildlife management context, the use of noise as a stimulus to elicit a flight response and so deter target species from a particular area and/or undertaking certain activities is a well established practice, although the results are often of arguable benefit and tend to be short-lived because of habituation by the target species (Bomford and O'Brien 1990; Ramp *et al*. 2011; Roberts *et al*. 2011). Despite an increase in applied research focusing on the impacts of noise on natural systems, the effect of short-term disturbances that initiate a flight response that results in changes to the normal ranging patterns and/or behaviour of free-ranging wildlife remains poorly understood in the absence of long-term studies specifically designed to investigate the potential for associated impacts. In this context, while it is acknowledged that activities associated with high levels of anthropogenic noise can have the effect of restructuring animal communities, the independent contribution of noise *per se* to such effects remains uncertain (Barber *et al*. 2010).

The koala (*Phascolarctos cinereus*) is a well known arboreal marsupial distributed along the east coast of Australia from northern Queensland through to South Australia (Martin and Handasyde 2000). Breeding aggregations of koalas coexist in a matrix of overlapping home-range areas to which long-term site fidelity is generally maintained (Mitchell 1990). The social structure of stable, free-ranging koala populations is polygynous, with reproductive behaviour further influenced by the presence of male-dominance hierarchies (Mitchell 1990). Koalas spend as much as 20 h per day at rest, their low activity cycle a direct consequence of the low-nutrient quality of the *Eucalyptus* leaves on which the species feeds (Martin and Handasyde 2000). The low-nutrient diet places particular metabolic demands on lactating female koalas, one implication of which is a trend towards higher levels of site philopatry when compared with other koalas in the population (Mitchell 1990; Krockenberger 1993).

Throughout the greater part of their remaining range in Australia koalas face an uncertain future (Threatened Species Scientific Committee 2012). The species has long been regarded as one that reacts poorly to disturbance, one area of long-standing and particular research interest being the relationship between stressors such as habitat loss and the onset of diseases such as Chlamydiosis (e.g. Obendorf 1983; Weigler *et al*. 1988; Booth

et al. 1990; Hume 1990), with habitat fragmentation increasingly recognised as having the potential to further contribute to decline through population isolation and inbreeding (DECC 2008). In some inbred populations the stress response can compromise immunological processes, the end result of which can be an increased susceptibility to disease as well as reduced fitness of offspring (O'Brien and Evermann 1988; Hedrick and Kalinowski 2000).

Music 'festivals' whereby large numbers of people congregate to listen to amplified music over periods of consecutive days and nights are a widespread cultural phenomenon. In 2009, planning authorities approved the use of some land in northern New South Wales, Australia, for the purposes of annually conducting a five-day music festival event. Modification of cleared areas of the land to accommodate infrastructure such as car parking, camping areas, food and curio stalls along with construction of temporary staging areas for performing bands was required. Both the approved festival site and immediately adjoining lands were known to be used by koalas, and amongst consent conditions arising from the approval process was a requirement for studies investigating possible impacts of the event on biodiversity values of the immediate area. This study reports the influence of the music festival event on koalas as determined by a radio-tracking study that involved monitoring the movements of resident animals ~3 months before, during and for 3 months after the inaugural festival event in 2010. It was hypothesised that the lack of any deviation from pre- and post-festival ranging patterns (see below) would indicate a measure of tolerance and adaptability by koalas to the festival event, whereas indications to the contrary would suggest a negative impact and need for consideration of specific ameliorative measures. It was further hypothesised that any adverse responses would reflect how close the home-range areas of individual koalas were to the primary disturbance source.

Materials and methods

Study area

The study area comprised ~125 ha of land to the north of Byron Bay (28°38′35″S, 153°36′54″E) on the far north coast of New South Wales, Australia. Adjoining an area of natural bushland to the east, the greater proportion of the site had historically been managed for agricultural purposes that included tree plantings alongside internal track and fence lines as well as retention of linear stands of remnant native forest on either side of water courses/drainage lines.

Koala capture, radio-tracking and data analysis

Koalas inhabiting the festival site were located by searching vegetation remnants and adjacent bushland areas. Search effort was focussed on locating koalas within those areas of the site proposed to be utilised for festival activity. Koalas were captured by use of long poles with flagging attached (so as to encourage a descent to the ground) or by specially designed traps (Phillips 2011). Morphological, demographic and health data were collected from each captured koala, which was then fitted with a Micro-lite IB radio-frequency transmitter (Titley Electronics) before being released back into the tree from which it was captured. Individual koalas were assigned names for ease of communication and reporting.

Radio-collared koalas were located during daylight hours using an Australis 26K Scanning Receiver (Titley Electronics) and three-element Yagi antenna. Once located, Universal Transverse Mercator coordinates were recorded using hand-held Garmin GPS with an average accuracy of ~5 m, along with other information including behavioural observations. Each koala was located daily for at least the initial five days immediately following capture, the seven days leading up to the musical phase of the festival event, the five days of amplified music and the ensuing seven days. Outside of these times, animals were located every 2–3 days. The timing of the study and the sampling regime was designed to provide an adequate number of independent fixes (i.e. locations established a minimum of 18–24 h apart) for determining short-term home-range configurations such that any influence of festival activity on the movements and/or behaviour of the koalas being monitored could be evaluated. While the number of fixes required to best estimate the home range varies between species (Seaman *et al*. 1999), a minimum of 20–30 independent loci for each of the pre- and post-festival periods (i.e. a minimum total of 40–60 independent fixes per animal) was considered adequate to identify the home-range area being utilised during the monitoring period.

Following conclusion of the monitoring program the resulting radio-tracking data were partitioned as follows:

Pre-festival: January – 24 March 2010
Site preparation ('bump-in'): 25–31 March 2010
Festival event: 1–5 April 2010
Site reinstatement ('bump-out'): 6–12 April 2010
Post-festival: 13 April – July 2010

Home-range areas for individual koalas were estimated by combining pre- and post-festival radio-tracking data, which then became the subject of fixed-kernel analysis with Least-squares Cross Validation tool of the Animal Movement extension for ArcView 3.2 (Hooge and Eichenlaub 1997). Utilisation contours were created for the purpose of delineating that area within which the koala probabilistically occurred 50%, 90% and 95% of the time. To investigate the potential for any changes in the movement patterns of individual koalas the 'festival period' was defined as the period from the commencement of 'bump-in' to the conclusion of 'bump-out'; radio-tracking data collected over this period were not included in the fixed-kernel analyses, instead being examined as a separate spatial overlay.

Results

Koala capture and radio-tracking

Eleven koalas (five males, six females) were captured and radio-collared between 12 January 2010 and 2 April 2010; most of these were captured within 500 m of the approximate centre of the staging area (mean capture distance from approximate centre of staging area: 427 m ± 56 m (s.e.), range = 100–700 m). The mean weight of adult male koalas was 7.09 kg ± 0.62 kg (s.e.) and the mean weight of adult female koalas was 4.71 kg ± 0.3 kg (s.e.). The ages of captured koalas ranged between tooth-wear classes 2 and 6 of Gordon (1991) and were approximately normally distributed. Of the 11 captures, radio-tracking data for three male and four female koalas were considered most suited

for analysis because of the number (i.e. >20) of pre-festival period fixes (Table 1). One of the female koalas in this latter group was carrying an unfurred pouch young at the time of initial capture, another sharing her home-range area with a subadult male presumed to be her offspring from the previous year.

Utilisation of space and response to festival

Before and after the festival period (i.e. before commencement of 'bump-in' and following conclusion of 'bump-out') 100% of movements by each of the seven koalas with adequate data were contained within their respective 95% utilisation contours, with one or more core areas of activity defined by the 50% contour. During the festival period, however, two types of responses by resident koalas were apparent from the radio-tracking data. The first (Type 1) was typified by the movements of three animals (two female koalas and one male koala) into areas that were located outside of the 95% utilisation contour. This particular type of response was displayed by koalas with core activity areas within 500 m of the approximate centre of the music staging area, their directions of movement being perpendicular to and away from the music staging area and most commonly associated with the period when amplified music was being played (Table 2).

Further details of the Type 1 response are as follows:

Renee

The adult female 'Renee' occupied a small home range of 0.62 ha, the approximate centre of which was located 480 m to the north-east of the approximate centre of the staging area. She was one of the more predictable koalas in the program because of her small home-range area and sedentary movement patterns [mean interfix distance between daily sightings: 16.2 m ± 2.9 m (s.e.), $n = 13$]. Between 3 and 4 April 2010, Renee completed an uncharacteristic traverse of ~55 m to the north-east that placed her beyond the modelled 95% utilisation contour boundary (Fig. 1*a*). Renee ranged in this area until 6 April, after which she returned to her known home-range area wherein she stayed until being found dead at the base of a tree on 17 May 2010; the cause of death was not ascertained.

RMB

An adult female with pouch-young, 'RMB' maintained a home-range area of 3.11 ha, the approximate centre of which was located 350 m east of the approximate centre of the staging area. Between 1 and 2 April 2010, RMB travelled ~90 m to the south-east beyond the modelled 95% utilisation contour boundary (Fig. 1*b*). RMB remained outside of, and to the south-east of, her home-range area for the remainder of the musical phase of festival period and the ensuing four days of bump-out before returning to her home-range area, within which she was recorded for the remainder of the monitoring study. Upon recapture for collar removal on 13 July 2010 it was established that the aforementioned pouch-young was no longer present. The last confirmed sighting of the joey was on 3 May 2010.

Jeff

'Jeff' was an adult male with an estimated home-range area of 2.38 ha, the approximate centre of which was located 450 m south of the approximate centre of the staging area. Between 4 and 6

Table 1. Demographic, morphometric and associated radio-tracking details for seven radio-collared koalas inhabiting a music festival site in northern New South Wales

Estimates of short-term home-range size are based on calculation of the area within the modelled 95% utilisation contour using fixes obtained either side of the festival period. The number of independent fixes associated with each koala during key phases of the monitoring program are detailed in the right-hand columns (F_{pre} = pre-festival; B_{in} = bump-in; MF = music festival; B_{out} = bump-out; F_{post} = post-festival)

Name	Sex	Weight (kg)	Home-range size (ha)	F_{pre}	B_{in}	MF	B_{out}	F_{post}
'Jeff'	M	7.8	2.38	36	6	5	6	37
'RMB'	F	5.5	3.11	30	6	5	6	38
'Renee'	F	–	0.62	33	6	5	6	15[A]
'Etta'	F	5	2.58	23	1	1	4	38
'Sonny Boy'	M	7.5	1.24	36	5	5	6	1[A]
'Brownie'	M	7.8	13.06	5	6	5	6	40
'Emmylou'	F	4.25	1.74	–	–	4	5	30

[A]Curtailed by death of study animal during specified monitoring period.

Table 2. Details of Type 1 aversive responses (as measured by departures from known home-range areas) by three free-ranging koalas during key phases of a music festival event in northern New South Wales

Filled cells indicate dates in April 2010 on which locations outside of known home ranges were recorded. Pre-festival, bump-in and post-festival monitoring phases are not shown. B_1 = closest compass bearing (in degrees) from approximate centre of home range to approximate centre of staging area; B_2 = closest compass bearing indicating general direction of movement; D_1 = distance (m) from approximate centre of home range to approximate centre of staging area; D_2 = maximum distance (m) recorded from approximate centre of staging area

Date	B_1	B_2	D_1	D_2	Festival 1	2	3	4	5	6	7	8	9	Bump-out 10	11	12
'Jeff'	N	SE	450	510												
'RMB'	W	ESE	350	510												
'Renee'	SW	NE	480	525												

April 2010 Jeff was located outside the modelled 95% utilisation contour at the far south-eastern periphery of his range (Fig. 1*c*) before returning to his home-range area where he remained until recaptured for collar removal on 12 July 2010.

A second and arguably lower-order (Type 2) response that did not result in evacuation of known home-range areas was recorded for three other koalas ('Etta', 'Brownie' and 'Emmylou') that had home-range areas further away from the centre of the staging area (Table 3). In common with the first type of response, these movements also occurred during the musical phase of the event, the associated traverses also in a direction perpendicular to and leading away from the approximate centre of the staging area. Of these, radio-transmitter failure during the musical phase of the festival period resulted in only a single observation at the extreme southern edge of the known home-range area for one animal, while two others similarly moved to the southern edges of their known home-range areas. Behavioural observations on the fourth animal ('Sonny Boy') implied a measure of morbidity during the musical phase of the event (recorded in same tree over three consecutive days). This lethargy, followed by occasional short traverses in the immediate area, ultimately manifested itself in the animal being found deceased near the base of a tree during the transition from bump-out to post-festival phase. The cause of death was not ascertained.

Discussion

Although aspects of the effect of noise and other disturbances on various wildlife species are being increasingly documented, this is the first study to document directional movement patterns by koalas in response to an unconditioned stimulus in the form of noise. Of the seven koalas for which adequate data were available, six displayed aversive ranging patterns evidenced by movements that were perpendicular to and away from an identifiable source of disturbance, in this instance a staging area playing amplified music. While the influence of other variables, such as a large human presence at the site, cannot be ruled out unequivocally, that amplified music was likely to be the primary stimulus for the aversive response is a reasonable conclusion given the strong association of the behaviour with this particular phase of the festival event.

The ecological significance of the aversive response in terms of potential impacts upon the resident koala population at the site is difficult to predict in the absence of ongoing monitoring and/or knowledge gained from studies of other species/populations. In behavioural terms the aversive response appeared in two forms, the first (Type 1) resulting in the evacuation of modelled home-range areas, the second (Type 2) measurable by movement patterns that similarly led away from the source of the disturbance but which were otherwise contained within modelled home-range areas. On the basis of the spatial configuration of home ranges in this study, the difference between the two types of response can be differentiated by the proximity of individual home ranges to the source of the disturbance, the 'evacuation' response being exhibited by animals with home ranges closest to the source of the disturbance. A critical distance of at least 525 m is indicated, based on the maximum distance that evacuating koalas were

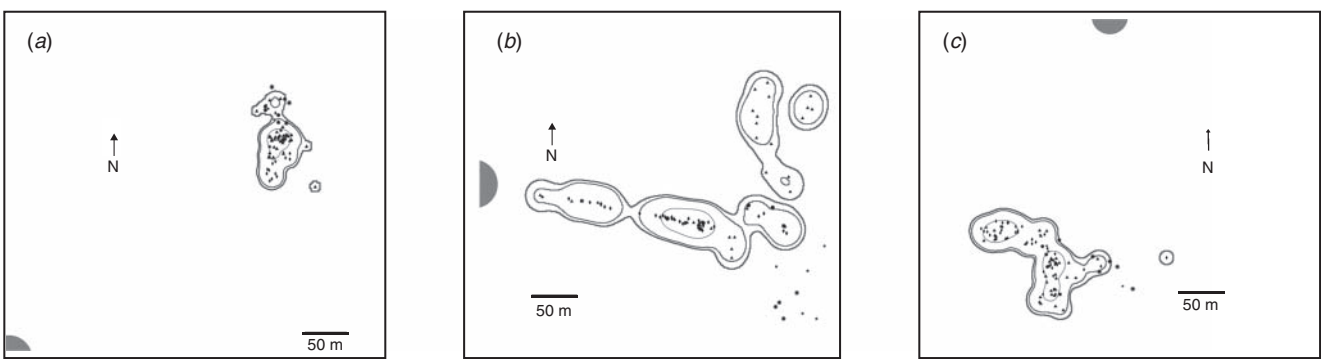

Fig. 1. (*a–c*) Movements beyond modelled short-term home-range areas by three free-ranging koalas (left to right: 'Renee', 'RMB' and 'Jeff') during the course of a five-day music festival event near Byron Bay, New South Wales. Activity contour intervals (50%, 90% and 95%) are illustrated, as is the approximate centre of the music-staging area (solid grey circle or part thereof). For each animal, note the location of fixes outside of the 95% activity contour in terms of the location of the music-staging area.

Table 3. Details of Type 2 aversive responses contained within known home ranges for three free-ranging koalas during the musical phase of the festival program

B_1 = compass bearing from centre of home range to approximate centre of staging area; B_2 = compass bearing best indicating general direction of movement; D_1 = distance (m) from approximate centre of known ranging area to approximate centre of staging area. Numbers 1–5 represent dates in April 2010 that constituted the musical phase of the festival

Koala	B_1	B_2	D_1	1	2	3	4	5
'Etta'	NW	SE	550	–	–	–	620[A]	–
'Emmy-lou'	NW	SE	700	670	680	700	725	725
'Brownie'	NW	SE	550	510	515	515	610	635

[A]Southernmost known ranging point.

recorded from the source of disturbance. However, for home ranges that were located further away, the arguably lesser 'aversive' response involved movements up to 725 m away from the source of disturbance. Lactating female koalas are known to be highly site philopatric (Mitchell 1990; Krockenberger 1993). Thus, any disturbance that results in a significant alteration of ranging patterns by this particular cohort merits investigation, more so if it is subsequently accompanied by joey mortality. In this regard it is not known whether the loss of pouch young and/or the death of the male koala 'Jeff' so soon after the musical phase of the festival are a direct consequence of the disturbance created by the festival, or were coincidental events.

Concerns about anthropogenic noise are that it could work to limit distributions or negatively affect reproductive success of particular animal species that are intolerant (Warren *et al*. 2006). The observation that koalas generally returned to their core activity areas soon after the cessation of festival activity implies a relatively short-term influence on ranging behaviour. However, while the observations reported herein identify two types of aversive response distinguishable by whether or not the evacuation of the home range occurred, it is likely that both carry some physiological and/or fitness cost, more so when considered in the context of ongoing but episodic disturbance events that do not enable habituation. Elevated cortisol levels have been reported in some wildlife species exposed to noise (Owen *et al*. 2004; Blickley *et al*. 2012) and the issue of 'stress' and its potential for impact on free-ranging koala populations has long been of interest to researchers because of a perceived link between elevated stress levels and the onset and/or progression of diseases such as Chlamydiosis. Elevated cortisol levels in koalas have been reported as a consequence of capture (Hajduk *et al*. 1992) and dietary stress (Davies *et al*. 2013), with other studies establishing excretory lag times of 24–48 h in addition to episodic and delayed peak response times of up to nine days (Narayan *et al*. 2013).

The results of this study coupled with knowledge regarding complexities of the koala's stress response present an interesting challenge to the design and undertaking of monitoring programs and/or further investigations into the impacts of anthropogenic noise on the species. To this end the inclusion of experimental controls into any future studies of this kind would potentially increase confidence in the outcomes, as would such things as the benign monitoring of cortisol levels; well designed long-term monitoring programs over several years would also facilitate a better understanding of ecological consequences. Support for the hypothesis that aversive behaviour occurred in response to the music festival include both the timing of the particular responses and the directions of movement that were exhibited by the affected animals. This requires sensitivity in the management of festival events in or near forested areas where koalas occur. Measures that may assist a lessening of the potential impact upon koalas include:

(1) applying a minimum 725 m noise buffer/exclusion zone around habitat areas known to be supporting resident populations, and/or
(2) assessing the amount of habitat captured within the 725 m radius of the approximate centre of staging areas to be lost to koalas and thereafter requiring compensation by way of habitat re-creation elsewhere on the site or in the immediate area, and
(3) ensuring that amplified music is directed away from areas known to be supporting resident populations, and
(4) restricting the timing of festival events so as to minimise potential for aversive behaviour during the peak of the koala breeding season from the beginning of September through to the end of March.

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