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Effectiveness of the eastern grey kangaroo foot thump for deterring conspecifics

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Abstract. Overabundant wild populations of herbivores often present challenges to primary industry, competing with stock, and damaging crops and property. Eastern grey kangaroos (*Macropus giganteus*) are one of seven macropodid species that are considered a problem in agriculture in Australia. Most deterrent devices available commercially use sounds that do not occur in nature (i.e. artificial sounds), which often have a short-lived or no effect on the target species, whereas trials with biologically significant sounds are often more effective and provide greater resistance to habituation. I used a playback trial of an eastern grey kangaroo foot thump, a biologically significant signal that is given in response to a predator and is usually followed by flight. I determined its effectiveness compared with a recording of background noise (control) for deterring kangaroos over a seven-week period. Kangaroos significantly increased their vigilance levels in response to the foot thump, but not in response to the control signal. Just over 60% of kangaroos took flight in response to the foot thump and the control signals, but more kangaroos took flight in the first 3 s when the foot thump was played. The foot thump shows potential as a deterrent of eastern grey kangaroos for primary industry, and is less likely to suffer from habituation because it is a natural sound.

Introduction

Abatement of damage caused by wildlife to primary industries is an ongoing challenge throughout the world. There is increasing pressure from the general public to use more humane methods of control that offer high target specificity and a low risk of eliminating the species (Edwards and Oogjes 1998; Reiter *et al*. 1999). One potential non-lethal method to control problem wildlife is the use of deterrents. Deterrents are designed to discourage the presence of an animal in a specific area (Smith *et al*. 2000), which may be achieved through one or more sensory modalities.

The eastern grey kangaroo is one of seven species of large marsupials, including the western grey kangaroo (*M. fuliginosus*), red kangaroo (*M. rufus*), common wallaroo (*M. robustus*), whiptail wallaby (*M. parryi*), red-necked wallaby (*M. rufogriseus*) and swamp wallaby (*Wallabia bicolor*), that are considered pest species by primary industry in parts of Australia. These species have been implicated in damage to crops and property (Gibson and Young 1987; Arnold *et al*. 1989; Barnes and Hill 1992; Montague 1996; Tanner and Hocking 2001), competition with livestock for food and water (Edwards 1989; Norbury *et al*. 1993; Baxter *et al*. 2001), as well as altering habitat quality (Cheal 1986; Edwards 1989; Norbury *et al*. 1993) sometimes to the extent that endangered species are further threatened (Coulson 2001).

Auditory deterrence devices may use artificial or natural sounds to control problem wildlife. Artificial sounds may include a selection of frequencies in the audible, infra- or ultrasonic frequency range that have no social or other context, including loud bangs and sirens. Manufacturers of devices that use artificial sounds often claim that the sounds cause pain or fear, jam communication, or disorient the receiver. However, tests suggest that such signals are generally ineffective or have a short-lived effect. For example, an audible electronic sound device did not deter pigeons (*Columba livia*) from a vacant building (Woronecki 1988), whereas gas exploders deterred coyotes (*Canis latrans*) from lambs, but only for an average of 31 days (Pfeifer and Goos 1982).

Devices that produce artificial sounds and that are marketed as kangaroo-deterrents have also been found to have no effect. A static device, the ROO-Guard®, was tested on captive and free-ranging eastern grey kangaroos in Victoria by Bender (2003), and on free-ranging Bennett's wallabies (*M. rufogriseus*) and pademelons (*Thylogale billardierii*) in Tasmania by Statham (1991, 1993), but no effect on behaviour or density was detected.

No studies have evaluated the use of natural sounds for deterring kangaroos. Natural sounds include any sound made in the natural world, including biologically significant sounds, such as alarm, distress, alert or aggressive calls (Klump and Shalter 1984). Trials with biologically significant sounds have deterred problem species such as gulls from feeding, roosting, or loafing sites with some success in Europe and the USA (e.g. Bomford and O'Brien 1990;

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Smith *et al*. 2000). Biologically significant sounds are also generally more resistant to habituation than artificial sounds. For example, Spanier (1980) observed that the number of black-crowned night herons (*Nycticorax nycticorax*) on a fishpond was reduced by more than 80% when a distress call was played, and no habituation was detected during the 6-month trial.

Alarm calls, as defined by Klump and Shalter (1984), are elicited when a predator is detected. These signals may function to warn conspecifics, or startle, or invite or deter pursuit by the predator (Klump and Shalter 1984). Nearby conspecifics may respond to distress or alarm calls by approaching, freezing or withdrawing from the site of disturbance. If withdrawal occurs then deterrence has been achieved. Most members of the Macropodoidea make a loud foot thump, which is usually given in the first few hops of flight after being disturbed by a predator, and nearby conspecifics will often take flight as well (Coulson 1997). The foot thump is believed to function as an alarm signal (Coulson 1996) that appears to be a signal directed to the predator that has been detected (Bender 2005*a*).

The overall aim of this study was to evaluate the effectiveness of the foot thump as a deterrent for eastern grey kangaroos in agricultural areas. This was achieved through two objectives: determining the propagation of the foot thump in field conditions, and examining how the foot thump altered vigilance levels and flight of free-ranging eastern grey kangaroos.

Materials and methods

Study site

This study was carried out at Yan Yean water catchment, 37 km north-east of Melbourne, Victoria, Australia. Yan Yean is 2250 ha in area and contains ~2000 kangaroos that occur throughout the area (Coulson *et al*. 2000). The catchment is closed to the public and has a 1.8-m chain-mesh security fence along the perimeter. Firebreaks, 30–40 m in width, run between the cyclone fence and the shrub and tree cover within the catchment. The vegetation within the catchment varies in structure from open grassland to woodland with a dense shrubby understorey (Coulson *et al*. 2000). Many of the kangaroos move between the catchment and the surrounding farmland to feed, using holes that they create at the base of the fence (Coulson *et al*. 1999).

Site selection

I selected three sites with holes in the cyclone fence, made by kangaroos, to test the effectiveness of the foot thump as a deterrent. Two of the holes (Holes 1 and 2) were located along the west boundary fence; the other (Hole 3) was located on the east boundary. Sites were a minimum of 850 m apart to reduce the likelihood of testing the same kangaroos on consecutive days. This distance falls within the measured home-range size of female eastern grey kangaroos at Yan Yean, 26.5–158.4 ha (Moore *et al*. 2002), which is equivalent to 581–1420 m in diameter if the home range is assumed to be circular.

Test signal

I selected one of 61 recordings of eastern grey kangaroo foot thumps, and a recording of background noise (the control), made while testing the function of the foot thump at the same site (Bender 2005*b*). I selected these recordings on the basis of their clarity during post-processing and playback, and because the selected foot thump recording was representative of foot thumps generally (Bender 2005*b*). The foot thump selected was made by a female eastern grey kangaroo at a distance of 51 m on 26 March 1997. The thump had two noisy pulses, was a low-frequency signal, with most of its energy below 7 kHz, and had a fundamental frequency of 818 Hz for the first pulse and 894 Hz for the second. The duration of the first pulse was 6.1 ms and the second was 4.5 ms. The interpulse duration was 32.1 ms, resulting in a total duration of 42.7 ms, slightly shorter than average (55.2 ± 3.2 ms) (Bender 2005*b*). The control signal was a continuous recording of background noise that was also low frequency, but with most of its energy below 1 kHz.

I applied noise reduction of ~20 dB at 512 ppt fast Fourier transformation to the foot thump using CoolEdit 2000 (Syntrillium Software Corporation, USA), an IBM-compatible computer software package, and silence was added before and after to extend the length of the recording to 8 s. I also applied an envelope, using the same software package as for the noise reduction, such that the signal ramped up over 5 ms and down over 17.5 ms. Ramping reduced the suddenness of the signal, which might itself cause a response by the kangaroos. I extended the recording of the control signal by looping the signal with some overlap to create a signal 1 s long for the noise-level trials and 8 s long for the playback trial. I applied an envelope that ramped up over 1.8 s and then down again over the last 2.2 s. The recordings were dubbed onto an audiotape 11 times (6 foot thumps, 5 controls) in random order with SoundWave, an IBM-compatible software package, and a stereo cassette deck (Yamaha K-540, Hamamatsu, Japan) with the recording level set at 5 and Dolby on. I determined the frequency range, fundamental frequency (number of cycles per second in each pulse), signal duration (from peak to peak of the wave form) and interpulse interval (from the previous syllable to the subsequent syllable) of the foot thump during post-processing.

I conducted noise level measurements on the foot thump and the control, at Holes 1 and 2, over three days from 22 October to 21 November 1997, using a grid that had seven columns and 5–7 rows (Fig. 1). The grid began 4 m in front of the speaker, and had 4-m intervals between each column and row. The centre of the grid ran between the fence hole and the speaker, and wooden garden stakes or tent pegs with flagging tape were used to mark each column–row intersection (Fig. 1). The playback speaker (AD5060 Philips 5-inch high-power squawker, Holland) was placed on the ground directly opposite each fence hole, behind a small shrub to remove visual cues. The speaker was 24–28 m from the fence hole and connected to a tape deck (Sony Stereo Cassette-Corder TC-158SD, North Ryde, NSW, Australia), with a 120-W amplifier. The amplifier volume was set at 10 during all measurements and playback. By placing the speaker on the ground it was assumed that both ground- and air-borne vibrations were created, although no seismic measurements were taken to confirm this.

Noise-level measurements (dB) were made with a 1/3rd octave SPL meter (Bruel and Kjaer (B&K) 2209, North Ryde, NSW, Australia) set at impulse peak (root mean square peak). The microphone (B&K 4165) on an extension lead was clamped to a retort stand at 750 mm above the ground in a grazing incidence position. SPL measurements were taken from the needle meter (±2 dB) at 1 m from the front of the speaker and at each grid point. Ambient noise level measurements were made at the centre of each site with no tape playing.

Behavioural response

I made observations from $(1.5\text{-m})^2$ hides made out of hessian, star pickets and twine. Hides were erected at each of the test sites 15 m to the left of the speaker, at the boundary between the woodland and the firebreak (Fig. 1). Hides were placed so that no vegetation blocked the view of the fence hole and so that they were located outside the test grid. Hides were installed one week before trials to allow kangaroos to acclimatise to their presence.

I measured the behavioural response of 236 kangaroos on 15 occasions, between 11 December 1997 and 5 February 1998 at the three sites. I made observations at Holes 1, 2 and 3 on four, seven, and four nights, respectively. Only one site was tested per day, and the same site was never tested on consecutive days. Combined with the distance between the sites, this further reduced the likelihood of testing the same individuals at different holes on consecutive nights, despite individuals being unmarked. I made field observations until 9 January 1997, after which a field assistant made the observations.

Prior to each test night, I blocked all surrounding holes up to 300 m away with branches to encourage kangaroos to use the selected test site. The playback equipment was set up by 1830 hours (eastern summer time), ~1–1.5 h before observations commenced to ensure that the observer was in the hide before the kangaroos became active. A video camera (Sony DCR-VX1000E) was mounted on a tripod and aimed at the fence hole.

Video-recordings were made between 2000 and 2115 hours, or until there was insufficient light for an image. Any kangaroos that entered the sound grid were tested. As many kangaroos as possible were included in the video field of view. Video-recording commenced before playback of either of the test signals. Either a foot thump or a recording of background noise was played from the random playback tape each time a new kangaroo arrived at the site. The signal was played for 8 s.

I conducted all video analysis using freeze frames to maintain consistency in interpretation of flight type and vigilance postures. During video playback, I used freeze frames while recording the vigilance category of each kangaroo following Croft's (1981) definitions of body postures. Three non-vigilant and five vigilant postures, corresponding to increasing alarm, and ultimately flight, were scored. I measured kangaroo vigilance levels before any signal was played, and within 3 s of the signal being played. I continued to record until the kangaroo moved away either by flight or pentapedal walking. I allowed a 3-s response time to the test signals because there is evidence that this is the typical time required to process and respond to a signal (Gerstner and Goldberg 1994). I also measured the number of kangaroos that took flight, the flight distance, and the time to flight. Walking was not included as flight.

I tested a total of 112 adult kangaroos, 48 with the control signal and 64 with the foot thump. No young at foot were tested, and individual kangaroos were tested only once per session, with a single individual selected at random to represent a groups' response to the test signals in the statistical analyses. Kangaroos were not evenly distributed between the test sites (59% being observed at Hole 1) and there was a sex bias in the kangaroos tested (68% being female).

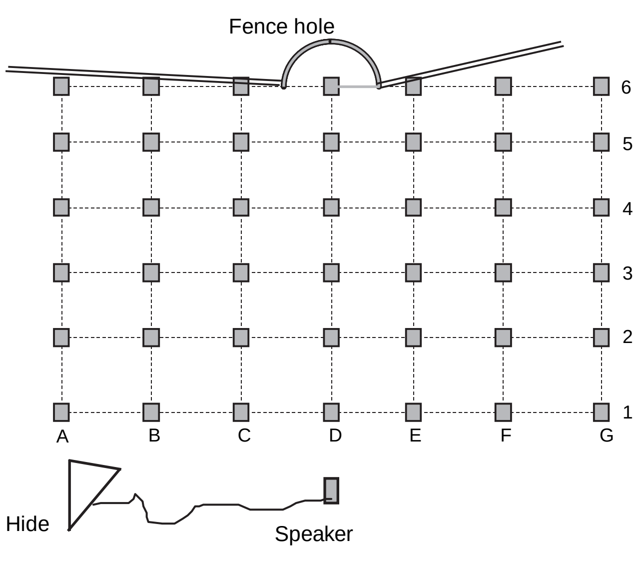

Fig. 1. Diagram of equipment arrangement for propagation measurements of the foot thump and control signal at Yan Yean Water Catchment, Yan Yean, Victoria, Australia.

Results

Noise-level tests

The sound pressure level of the selected stimulus and control recordings was 83–84 dB and 80.5–86.5 dB at 1 m respectively. Sound pressure levels decreased to either side of the central column ($x = 4$) and with increasing distance from the speaker along the y-axis, although the foot thump attenuated more quickly (Fig. 2).

The sound pressure level of the region in which most (77%) of the kangaroos were tested, on the central column and the back rows ($y = 5$ and 6) was 54. 6–56.4 dB for the foot-thump and 57–62.5 dB for the control signal. The ambient noise level, when no signal was played, was 22.5–34 dB.

Behavioural response

Vigilance

Vigilance response by the kangaroos to both the foot-thump and the control signal could be ranked on a scale that ranged from 'walking' to Croft's (1981) 'erect alert' posture, which is as an accentuation of the standing erect posture, where the back is vertical or even inclined back from the vertical and the forepaws are held rigid against the chest or sides, so that the animal is poised for rapid flight. The most frequent vigilance postures for both stimuli before playback and at playback were semi-erect (Fig. 3, vigilance levels 5 or 6).

To determine whether there was a significant change in vigilance level when the signals were played, each individual's vigilance rank score before playback was subtracted from its vigilance score after playback. A Mann–Whitney U test showed that the kangaroos' ranked vigilance postures changed more towards greater alertness after the foot thump than the control (U = 763, d.f. = 1, $P = 0.027$) (Fig. 3); there was no significant difference in change in rank scores between the two sexes in response to the thump (U = 302.5, d.f. = 1, $P = 0.503$).

Flight

There was a significant difference in the kangaroos' instant response (within 3 s) to the two signals ($\chi^2 = 6.647$, d.f. = 2, $P = 0.036$): 26% took flight with the foot thump ($n = 42$), whereas none responded with flight to the control ($n = 46$; Fig. 4). However, on average, 63.3% of kangaroos tested with either signal took flight, and their responses to the thump or the control did not differ ($\chi^2 = 2.483$, $n = 112$, d.f. = 3, $P = 0.478$). Kangaroos that did not take flight eventually walked away.

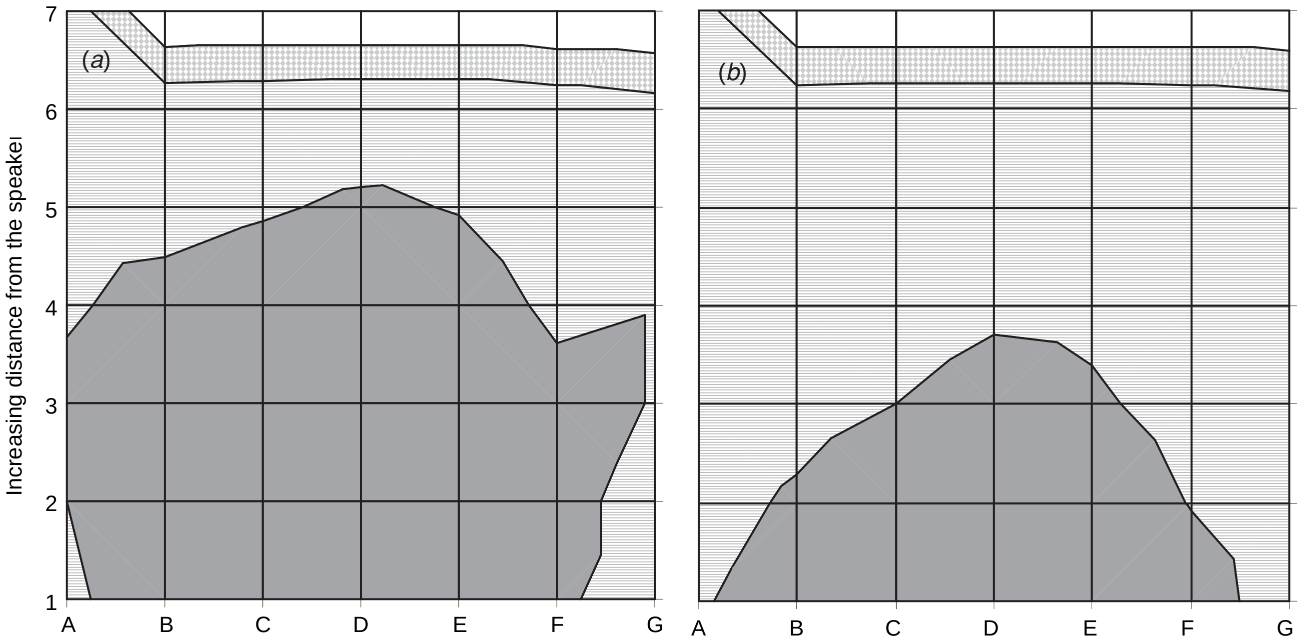

Fig. 2. Propagation pattern of (*a*) the control signal and (*b*) foot thump, showing mean sound pressure levels (dB; grey, 60–80; striped, 40–60, stippled, 20–40, open, 0–20) at two of the playback sites (1 and 2) at Yan Yean Water Catchment, Victoria Australia.

The data for time from playback to flight did not follow a normal distribution for either the foot-thump or the control signal. Therefore, a non-parametric test was used to compare median time to flight. Kangaroos had a mean time to flight of 25.1 s (±5.0 s, s.e.), and a median test showed no significant difference in time to flight between kangaroos exposed to the two signals (median test, $\chi^2 = 0.969$, $n = 112$, d.f. = 1, $p = 0.325$).

The closest distance from the speaker at which flight occurred was 12 m and the farthest 32 m. The average distance at which kangaroos took flight was 26 m (±0.2 m, s.e.), and there was no significant difference in the distances at which kangaroos took flight between those exposed to the foot thump and the control (ANOVA, $F = 0.840$, d.f. = 1, $P = 0.363$).

Discussion

Acoustic characteristics

The signal-to-noise ratio for the control and foot-thump signals relative to the ambient noise level at the distance at which most of the kangaroos were located during playback was 1 : 1.9–1 : 2.5 for the control, and 1 : 1.7–1 : 2.4 for the foot thump. This suggests that both signals would have been

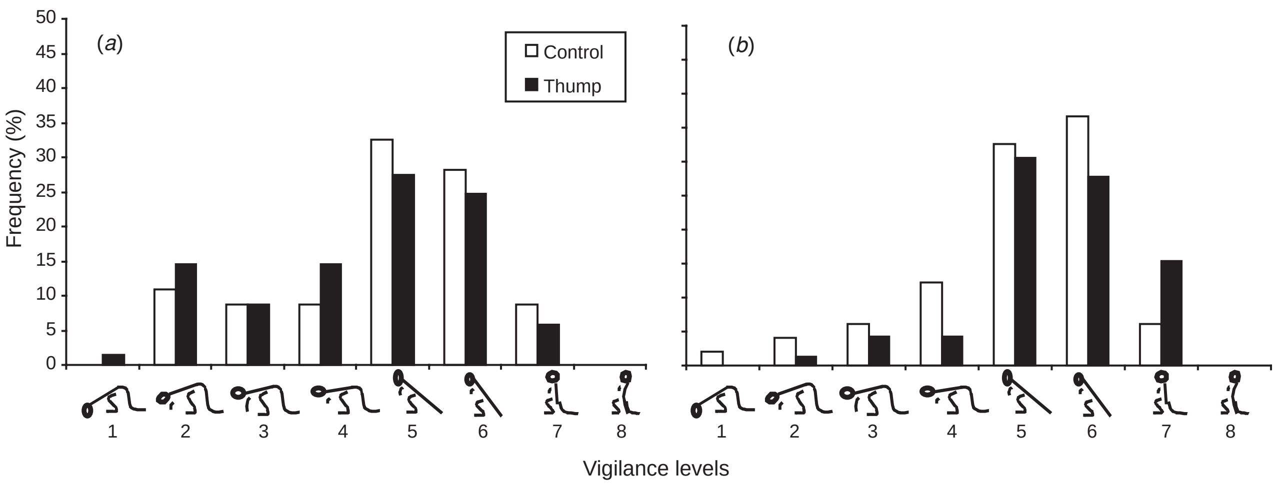

Fig. 3. Frequency of different vigilance levels adopted by eastern grey kangaroos in response to the thump and control recordings (*a*) before and (*b*) when the signals were played back.

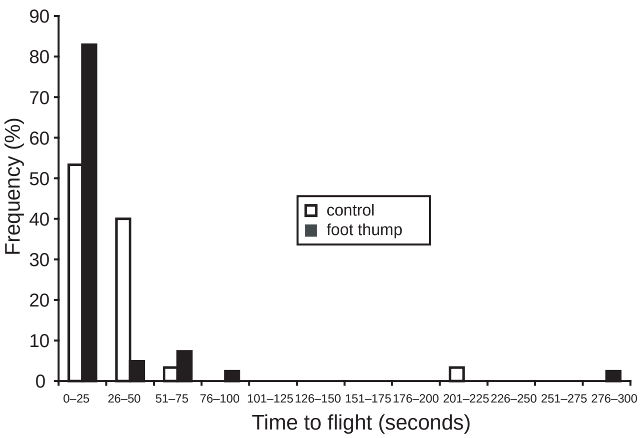

Fig. 4. Differences in kangaroo time to flight when the control and foot-thump recordings were played at Yan Yean Water Catchment, Victoria, Australia. $n = 48$ for the control and $n = 64$ for the foot thump.

detectable by the kangaroos. The control signal included frequencies below 1 kHz, whereas the foot thump included frequencies below 7 kHz. The gain created by the pinnae of the eastern grey kangaroo rises rapidly from 2 dB at 400 Hz to a maximum gain of 30 dB between 1.7 and 3.5 kHz, followed by a gradual decline to a gain of 10 dB at 16 kHz (Guppy 1985). The pinnae provide maximal gain, and therefore increased sensitivity, at the frequencies within the foot thump, whereas there will be only a slightly greater sensitivity to the frequencies in the control signal.

Behavioural response

In this study, the kangaroos' ranked vigilance postures indicated significantly greater alertness in response to playback of the foot thump than to the control signal. This confirmed that the kangaroos were able to detect the foot-thump signal, and that they more often responded with increased alertness to playback of this foot-thump recording. Kaufmann (1974) also observed eastern grey kangaroo conspecifics, and other species of kangaroo (common wallaroo (*M. robustus*), whiptail (*M. parryi*) and red-necked wallabies), to increase their vigilance levels and take flight when a foot thump was emitted. The foot thump is usually given in response to the presence of a predator (Coulson 1996) and appears to function primarily to signal to the predator that it has been detected (Bender 2005*b*). Therefore, it would benefit conspecifics to be alert once a predator had been detected, as they would reduce their chances of becoming prey themselves.

With an increase in the proportion of kangaroos in an alert state and a vigilance score of more than 5, the proportion of kangaroos feeding was reduced by 74%. Reduction of feeding is the aim of many deterrents for agricultural contexts (Ezealor and Giles 1997) in order to reduce damage to crops or reduce competition with livestock. Blumstein *et al.* (2000) observed a similar decrease in time spent feeding with an increase in vigilance levels in tammar wallabies (*Macropus eugenii*) when their foot thump was played back. This suggests that the macropod foot thump may be useful as a signal for reducing time spent feeding for more than one macropod species. Further experiments using a range of recorded thumps would be needed to confirm the generality of the eastern grey kangaroo response.

However, greater damage-abatement effect could be achieved if the species left the area. Over the observation period, 63% of the kangaroos tested with the foot-thump and the control signal took flight. This suggests that either of these signals could be used for a sizeable reduction of kangaroo presence and potential damage on an agricultural property. However, a faster departure should minimise damage, and significantly more kangaroos in this study left the area in the first three seconds after the foot thump than after the control. Tests to determine the direction and length of flight are still needed so the relative success of this signal as a deterrent in an agricultural context can be determined.

As the individuals in this population were not marked, and could not be individually identified, it is possible that subjects experienced repeated exposure to the playbacks, which may have resulted in a lack of independence and some systematic bias. Future studies at sites where individuals are unmarked should consider conducting only a single playback per night at a location to avoid the possibility of testing the same individuals repeatedly on a given night.

Management implications

Trials with artificial sounds on eastern grey kangaroos in agricultural contexts have had no measurable effect (Bender 2003), and similar findings have been made for Tasmanian pademelons and Bennett's wallabies (Statham 1993). In contrast, this study has found that this foot thump, a natural sound, increased vigilance levels and induced rapid flight in some kangaroos. These findings support the suggestion that natural sounds are a better choice than artificial sounds for auditory deterrents (Bomford and O'Brien 1990).

Many deterrents lose their efficacy over time because animals become habituated to them. Habituation to a deterrent may occur when the signal lacks biological significance (Bomford and O'Brien 1990), when the target species is continually exposed to the treatment (Bomford 1990; McLennan *et al.* 1995), when tactics fall into a predictable pattern (Stevens and Clark 1998), or when the stimuli are not coupled with a salient aversive reinforcing stimulus (Conover 1994; Stevens and Clark 1998; Ross *et al.* 2001). However, the use of a biologically significant signal, such as the foot thump, is a particularly good way to avoid habituation because there are normally serious consequences to the receiver if the signal is ignored (Bergstrom and Lachmann 2001). Future trials with the foot thump should determine whether habituation occurs; if so, alterations of the signal or pairing of the signal with other aversive stimuli such as a model of a predator should be considered.

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