Auditory stimuli as a method to deter kangaroos in agricultural and road environments

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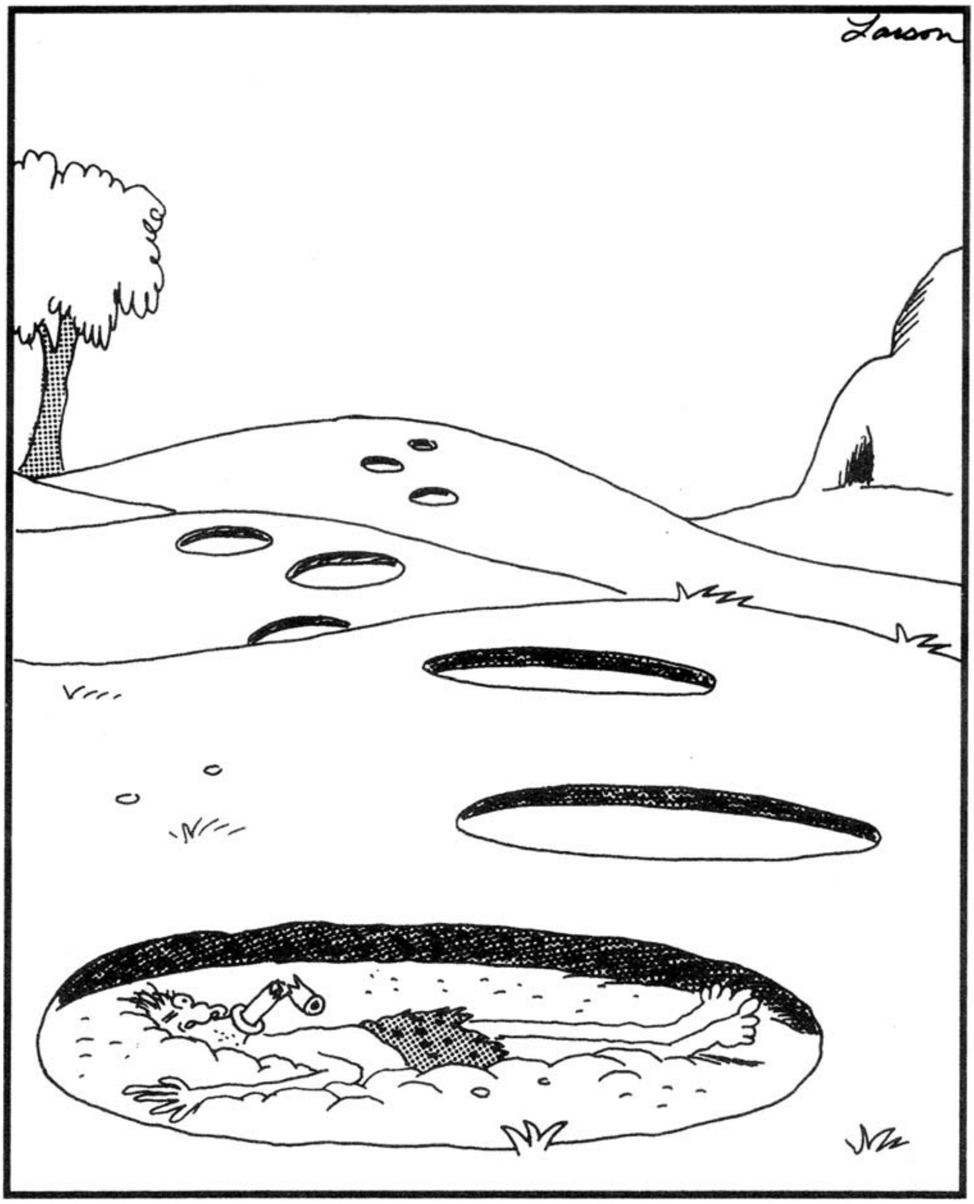

50,000 B.C.: Gak Eisenberg invents the first
and last silent mammoth whistle.

Frontispiece. A reflection of the dangers and triumphs that come with using sound for managing wildlife.

THESIS ABSTRACT

Abatement of damage caused by wildlife is an ongoing challenge throughout the world. Kangaroos are often considered problem species in Australia because they cause damage to vehicles and farm properties, as well as compete with livestock for food and water. Kangaroos are currently controlled in some areas by exclusion fencing, but mostly by shooting. The general public is applying pressure for the use of non-lethal methods of control with minimal pain to the animal and high target specificity. Deterrents are a common non-lethal method to control problem wildlife.

Auditory deterrence devices may use artificial or biologically-significant sounds to control problem wildlife by deterring the problem species from feeding, roosting, or resting sites. Artificial sounds may include a selection of frequencies in the audible, infra-, or ultra-sonic frequency range that have no social or other context (e.g., loud bangs and sirens). Biologically-significant sounds include alarm, distress, alert, or aggressive calls. I investigated the use and efficacy of artificial and biologically-significant sounds for deterring kangaroos from agricultural and road environments. In addition, I investigated the hearing abilities of the eastern grey kangaroo (*Macropus giganteus*) and the intended recipient of their alarm foot thump.

The ear structure of the eastern grey kangaroo results in amplification of frequencies between 1-18 kHz, but greatest sensitivity occurs at frequencies between 2-3.5 kHz. Eastern grey kangaroos have the capacity to hear ultrasonic frequencies (> 20 kHz), and may be able to hear up to 40-49 kHz, however, their sensitivity above 18 kHz is greatly reduced.

The high frequency signals produced by the Roo Guard and the Shu Roo, are artificial sounds at frequencies to which kangaroos are less sensitive. Captive trials with eastern grey and red kangaroos (*Macropus rufus*) found no change in vigilance level in response to the Roo Guard or Shu Roo. Field trials found the relative density of free-ranging eastern grey kangaroos also did not change in the

presence of the Roo Guard. Field trials with the Shu Roo did not result in a reduction in the rate of kangaroo-vehicle collisions, suggesting that artificial sounds that use high or ultrasonic frequencies are not effective for deterring kangaroos.

In contrast, a biologically-significant signal, the foot thump given by eastern grey kangaroos had a signal frequency below 7 kHz, which is within the more sensitive hearing range of the species. Adult kangaroos thumped when alone or in groups during the first few hops of flight, suggesting it was directed at the predator. Playbacks of the foot thump increased vigilance levels significantly, and resulted in flight. Just over 60% of kangaroos tested with the foot thump and the control signal took flight, but more fled in the first three seconds when the foot thump was played.

Together, these findings suggest a number of critical criteria for auditory deterrents: the signal must be audible to the target species and perhaps should be directed at their best hearing frequency; the signal must be of sufficient intensity to overcome attenuation; the signal should be meaningful to the target species, such as an alarm signal; the signal must generate an appropriate response, flight not freeze; and sufficient time must be allowed between playing of the auditory stimulus and the target species response.

DECLARATION

This is to certify that

(i) this thesis comprises only my original work, except where indicated in the preface,

(ii) due acknowledgement has been made in the text to all other materials used, and

(iii) this thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies, and appendices.

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Helena Bender

January 2005

PREFACE

The chapters presented in this thesis have been prepared as individual papers. Consequently, some repetition of material is inevitable and unavoidable, however, attempts have been made to keep any repetition to a minimum. The inclusion of a co-author on a paper acknowledges a supervisory role only. The interpretation, ideas and conclusions as presented reflects solely my own original work. Publication details of the co-authored paper presented in this thesis is indicated below:

CHAPTER 5

Bender, H. and Coulson, G. (2005). The effectiveness of an ultrasonic deterrent in reducing the rate of macropod-vehicle collisions. *Wildlife Research*.

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Firstly, I wish to express my thanks to the societal belief that higher education is important. Without this belief, I would not have had this amazing opportunity to explore my interests in animal behaviour in applied context.

Secondly, I wish to thank the many people who have provided their time, effort and support in assisting me to complete this thesis. I feel very fortunate to have been surrounded by such wonderful, caring people. Due to the number of years that this thesis has taken to complete, and the probability that I may miss someone out, I with to offer a collective ‘thank you’ to everybody who has contributed to the completion of this thesis. More specifically I would like to thank the people listed below.

Supervision

I find it difficult to find the words to thank Graeme Coulson (Department of Zoology, University of Melbourne), for he has been an outstanding supervisor, giving freely and generously of his time, advice, and support over many years. He has contributed enormously to my knowledge of kangaroo ecology, behaviour, and even statistical analyses. He has encouraged, challenged, guided, and motivated me throughout this thesis. He has been an excellent mentor in so many ways, fostering my confidence and involvement in critical discussions on far and ranging topics, strengthening and honing my ability to think and write clearly, logically, and critically, and modelling the benefits of approaching all challenges with good humour. For all of these things I am extremely thankful. I also wish to thank Graeme for always showing concern for my own well being during many difficult circumstances and obstacles, providing fatherly advice, and being a good friend. Thank you.

Funding

The completion of this project would not have been possible without the generous support of the following.

Research

Ethics approval for behavioural trials at Melbourne Zoo and Werribee Open Range Park in chapters 3 and 4 were provided by the Zoological Board of Victoria (Project # MZ94007 and WZ 97004). Ethics approval for the foot thump playback trials in chapter 6 was provided by the University of Melbourne Animal Experimentation Ethics Committee. The following groups kindly provided financial support: the Holsworth Wildlife Fund; the Royal Automobile Club of Victoria, New South Wales Road Traffic Authority, National Roads and Motorists' Association Limited, Transport South Australia; Department of Zoology, University of Melbourne; and the Faculty of Science, University of Melbourne.

Travel

I have been fortunate in receiving support to attend a number of national conferences during my candidature. For these experiences I am grateful for the support offered by the Department of Zoology, University of Melbourne; Australasian Wildlife Management Society Travel Award; and Australasian Mammal Society Student Travel Award.

Fieldwork

My research was conducted at various sites within Victoria, and I wish to thank the people who allowed me access to these sites. Chandra de Alwis and Peter Stroud for permitting access to the kangaroo enclosures at Melbourne Zoo and Werribee Open Range Park (Chapters 3 and 4); Anne and Neville Prowse-Brown, in Bairnsdale, who allowed access to their two ROO-Guard Mk II units in situ (Chapter 3); Anthony Simpson and Anthony Hall, who provided access to the Ford Proving Ground test tracks (Chapter 4); and R. Dunn, N. Pratt, and other

Melbourne Water staff who helped me get in and pulled me out of the Yan Yean Water Catchment (Chapter 3, 6, and 7).

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The Roo Guard trials (Chapter 3)

Bev Drake, Michael Andersen, Chris Rozon, Jane McKenzie, Michelle (the keeper), Peter Stroud, Sharon Downes, Dan Ramp, Phil Alviano, Fiona Manson, Inka Veltheim, and Sarah Way. In particular I would like to thank Natasha McLean for enduring horrible weather and monotonous propagation measurements.

The Shu Roo trials (Chapters 4 and 5)

Natasha McLean, Kirstin Long, Leanna Rosier, Jenny Martin, and David Semmens were excellent research assistants who did a marvellous job at tracking down, cajoling, and pursuing drivers in vehicle fleets to participate and return data for the Shu Roo road survey.

Mark Harrison, Niel Johnson, and Glenn Moss assisted in mounting and wiring the Shu Roo on Ford vehicles at the Proving Ground. Wes Malcolm drove the sedan and 4x4, Mark Harrison the truck, and David Steele the bus.

The foot thump efficacy trials (Chapter 6)

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Provision of advice and assistance

Many people were generous with their space, equipment, time, and advice. Murray Littlejohn and David Young both provided me with access to their laboratory space and acoustic equipment for the experiments completed in Chapter 2. Ian Temby and Simon Stirrat were instrumental in acquiring the ROO-Guard units tested in Chapter 3. For chapter 4, Bassett Acoustics (Melbourne) and the Ford Proving Ground NVH laboratory also loaned me acoustic equipment. The RACV purchased and provided a Shu Roo to test. Tom Kiebert and Carl Landgra assisted with organizing and running equipment while at the Ford Proving Ground in 1999. Jack Haley, Michael Case, and Michael White provided contacts and helpful comments. Charles Osborne provided additional technical advice.

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This work has taken a long time to complete and I am extremely grateful to my friends and family for their understanding, support, encouragement, and patience. At times, aspects of this project have often made me less than sociable, and a terrible correspondent, yet you have all persevered and kept me motivated with your good humour and empathy. I would especially like to thank my family, Vanessa, Teresa, Tofu, Kodo, Cora, and my late mother, for their love, support, stubbornness, and patience. These are traits that we all carry and make us better and stronger people.

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CHAPTER 1 - GENERAL INTRODUCTION

MANAGING OVER ABUNDANT SPECIES: EASTERN GREY KANGAROOS AS A MODEL

Abatement of damage caused by wildlife is an ongoing challenge throughout the world. Problem wildlife are known to consume cultivated or stored crops; feed in aqua-culture facilities; prey on domestic, threatened or endangered species; cause damage to urban and suburban property; are involved in aircraft or other vehicle collisions; significantly alter the composition of "natural" ecosystems; attack humans; or serve as reservoir host and /or vector of diseases communicable to humans and domestic animals (Wagner and Seal 1992). The general public is applying pressure for the use of non-lethal methods of control with minimal pain to the animal and high target specificity (Edwards and Oogjes 1998; Reiter *et al.* 1999). Deterrents are a common non-lethal method to control problem wildlife. Deterrents aim to stop an unwanted behaviour or to make the animal retreat from an area using >1 sense modalities.

Auditory deterrence devices may use biologically significant or artificial sounds to control problem wildlife. Biologically significant sounds include alarm, distress, alert, or aggressive calls. The purpose of the sounds is to either warn or deter the problem species from feeding, roosting, or loafing sites. These sounds have been used with some success in Europe and North America on birds and predatory mammals (e.g., Smith *et al*. 2000). Artificial sounds may include a selection of frequencies in the audible, infra-, or ultra-sonic frequency range that have no social or other context (e.g., loud bangs and sirens). Devices that use artificial sounds are available in the United States, Europe, and Australia for species including insects (e.g., Dryden *et al*. 1989), birds (e.g., Haag-Wackernagel 2000), marine mammals (Jefferson and Curry 1996), and land mammals, including marsupials such as possums (*Trichosurus vulpecula*) (e.g., Coleman and Tyson 1994) and wallabies (*M. rufogriseus*) (Statham 1993), and eutherians such as rodents (e.g., Lund 1984) and carnivores (e.g., Linhart *et al*. 1992). These devices claim to cause pain or fear, jam communication, or disorient, but are generally ineffective or have a short-lived effect. For example, pigeons (*Columba livia*) were not deterred from a vacant building by an audible electronic sound device (Woronecki 1988), whereas coyotes (*Canis latrans*) were deterred from lambs by gas exploders, but only for an average of 31 days (Pfeifer and Goos 1982).

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 1990a; Smith et al. 2000). Biologically significant sounds are 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 occurred for 6 months.

At least five species of large marsupials are considered problem species throughout most of Australia. These are the eastern grey kangaroo (*Macropus giganteus*), western grey kangaroo (*M. fuliginosus*), red kangaroo (*M. rufus*), red-necked wallaby (*M. rufogriseus*), and swamp wallaby (*Wallabia bicolor*). These species have been implicated in damage to crops and agricultural property (e.g., Gibson and Young 1987), competition with livestock for food and water (e.g., Edwards 1989), collisions with vehicles (e.g., Abu-Zidan *et al.* 2002), alteration of habitat quality (e.g., Coulson 2001), damage to urban and suburban property (Lavery 1985), and attacks on humans (Pountney 2000).

Most species of the family Macropodidae make an alarm signal, called a foot thump, by striking the ground with their hind feet, but none have been observed making a distress signal (Russell 1984; Coulson 1989). It is unclear whether the foot thump is a signal to conspecifics or a predator, and no studies have evaluated the use of the foot thump as biologically significant sounds for deterring kangaroos.

The aim of this thesis was to investigate the use of auditory deterrents for managing eastern grey kangaroos in agricultural and road environments. To achieve this aim I investigated the hearing abilities of the eastern grey kangaroo (Chapter 2) to provide some insight into whether the signals produced by commercial deterrent devices or alarm signals were detectable by the kangaroo. These hearing tests were interleaved between my evaluations of the only two electronic auditory deterrent devices available commercially at the time. The first was a static device, the Roo Guard, which claims to deter kangaroos from agricultural properties. I measured the acoustic characteristics of the device's signal, and tested the behavioural response of captive eastern grey and red kangaroos, and changes in density of free-ranging eastern grey kangaroos (Chapter 3). I tested a second dynamic deterrent device, the Shu Roo, which claims to deter kangaroos from roadways using a similar approach as that used for the Roo Guard (Chapter 4). I also conducted a driver survey that included vehicles from around Australia (Chapter 5). Lastly, I explored the eastern grey kangaroo's characteristic alarm foot thump as an alternate deterrent signal, initially to determine its intended receiver (Chapter 6), then also its efficacy as a deterrent signal in an agricultural context (Chapter 7).

CHAPTER 2 - HEARING IN THE EASTERN GREY KANGAROO

Submitted as -- Bender, H. (2005). Hearing in eastern grey kangaroos. *Hearing Research*.

Abstract: Deterrent devices that use sound are available for managing a wide range of problem species. Such devices are available for kangaroos and wallabies because they are considered a problem species throughout most of Australia. I investigated the hearing abilities of the eastern grey kangaroo to provide some insight into whether the signals produced by ultrasonic deterrent devices could be detected. Inter-aural measurements on 89 kangaroo heads, including both sexes, predicted the upper-frequency hearing-limit to be between 40-49 kHz. Measurements of the length and shape of the external ears of three dead kangaroos indicated the frequency of maximum sensitivity was 2.7 kHz. Measurements of the acoustic gain generated by the external ear of the kangaroo were greatest between 2.0-3.5 kHz, but gain decreased with increasing signal frequency to about 5 dB at 12.5 kHz. This suggests that auditory deterrents for kangaroos should target the kangaroo's best frequency (2.0-3.5 kHz), or other frequencies with high levels of gain, so that the signal is easier to detect.

INTRODUCTION

Deterrent devices that use sound are available for managing a wide range of problem species (Ezealor and Giles 1997), including domestic animals (e.g., Mills *et al*. 2000), predators of livestock (e.g., Smith *et al*. 2000), birds (e.g., Haag-Wackernagel 2000; Ross et al. 2001), marine mammals (e.g., Johnston 2002), fish (e.g., Popper and Carlson 1998), and fruit bats (e.g., van der Ree *et al*. 2002). Auditory deterrents are attractive to the public (Reiter *et al*. 1999) because they are promoted as benign, inexpensive, and simple to operate (Bomford and O'Brien 1990; Erickson *et al.* 1992).

Tests of many of these acoustic deterrent devices have found them to have no effect on the target species (Erickson *et al.* 1992; James *et al.* 1999; Travade *et al.* 1999). One explanation for this lack of effect is that the signal falls outside the hearing range or sensitivity of the target species. Devices that emit high or ultrasonic frequencies are the most commonly advertised, presumably because they are at the upper limit of, or above, the human hearing range, so are mostly inaudible to humans.

Kangaroos and wallabies (Macropodidae) are considered a problem throughout most of Australia (Cowan and Tyndale-Biscoe 1997) because they have been implicated in damage to crops and property (e.g., Gibson and Young 1987), competition with livestock for food and water (e.g., Edwards 1989), reduction of habitat quality (e.g., Coulson 2001), damage to vehicles (Kangaroo Advisory Committee 1997), mild injuries, and occasionally death during kangaroo-vehicle collisions (Abu-Zidan *et al*. 2002). More male kangaroos are killed on roads in kangaroo-vehicle collisions (Coulson 1982) but it is not known whether this is because their hearing differs from females that are smaller in size. Commercial devices that produce high or ultrasonic frequencies have been marketed for deterring kangaroos from agricultural (Roo-Guard, Shu Roo Pty. Ltd.) and road environments (Shu Roo, Shu Roo Pty. Ltd.). However, the Roo-Guard did not alter the behaviour of captive eastern grey (*Macropus giganeteus*) or red kangaroos (*M. rufus*), nor did it reduce the density of free-ranging kangaroos at open grassy sites (Bender 2003). Similarly, the Shu Roo did not alter the behaviour of captive eastern grey or red kangaroos, or reduce kangaroo-vehicle collision rates (Bender 2001).

High-frequency hearing is directly correlated with the functional distance between the two ears, where functional distance (Δt) is defined as the inter-aural distance divided by the velocity of sound (Heffner and Heffner 1981). Mammals with small heads and close-set ears are better able to hear high-frequency sounds than are species with large heads and wide-set ears, and their functional inter-aural distance is positively related to body weight (Masterton *et al.* 1969; Heffner and Heffner 1981; Fay 1994; Long 1994).

Eastern grey kangaroos are relatively large, sexually-dimorphic mammals, with adult females weighing 32 and adult males 66 kg on average (Poole 1983). They also have large, erect, highly-mobile pinnae, typical of many mammals. Only one study (Guppy 1985) investigated the acoustic gain created by the external ear of the eastern grey kangaroo and found that when a signal of 68-70 dB SPL (re 20 μPa), measured in free field conditions at the level of the tympanum, was presented to a small sample of adult female kangaroos there was a significant increase in sound pressure at the tympanum above 900 Hz, with peaks of 30 dB at 1.7-3.5 kHz, 10 dB at 16 kHz, and 17 dB at 18 kHz, above the free-field levels.

This study investigated the hearing abilities of the eastern grey kangaroo to provide some insight into whether the signals produced by these putative ultrasonic deterrent devices can be detected by this species. Specifically, I aimed to determine the predicted upper limit of hearing based on the inter-aural distance, the frequency of greatest sensitivity created by the structure of the ear canal and concha, and the acoustic pressure gain at the ear drum in a wide range of body sizes of kangaroo.

METHODS

Upper-frequency hearing-limit

I measured the inter-aural distance and head-to-snout length of skulls and heads of eastern grey kangaroo to estimate the upper limit of hearing. I made measurements on 54 intact skulls, in a range of sizes that included both sexes, and which had been collected at Yan Yean Reservoir between 1992 and 1995 (Coulson *et al*. 2000). I used a flexible measuring tape to measure the inter-aural distance, the shortest distance between the tragi of each ear across the dorsal portion of the frontal plate, which I assumed would be the same as the path of the sound from ear to ear at the front of the head, and an indication of which high frequency sounds would be shadowed by the head. I measured the head-to-snout length, with the same flexible measuring tape, from the crest between the frontal and occipital bones to the crest between the first two incisors (± 3 mm), as measures of the size of the specimens. I also measured 34 undamaged kangaroo heads collected from Government House, Canberra, during a population control project (Coulson 2001), using the same method as for the skulls, to increase the sample size and to measure the additional width contributed by muscle, connective tissue, and skin.

I calculated the inter-aural distance, or the maximum binaural time disparity (*maximum* Δt), by dividing the maximum inter-aural distance (around the head) by the velocity of sound in air (Masterton *et al*. 1969). I then calculated the high-frequency cut-off, assuming a signal intensity level of 60 dB, using the following equation provided by H. Heffner (personal communication): log (high frequency in kHz) = -0.431 * log(Δ t in μsec) + 2.695. I performed a linear regression analysis to determine if head size, measured as head-to-snout length, predicted the calculated upper hearing-limit. The α level for significance testing was set at 0.05.

Frequency of maximum sensitivity

I estimated the frequency of maximum sensitivity by measuring the length and shape of the external ears of three dead kangaroos collected at Government House, Canberra (Coulson 2001). I made paraffin moulds of all six ears, irrespective of whether the ears were oriented forward or away from the face. I thawed the kangaroo heads and cleaned the ears, placed the heads on one side, then used a syringe to inject melted paraffin wax into the external ear, starting with the inner regions to avoid air being trapped, until the paraffin was level with the notch of the ear. Once the paraffin had hardened, I removed the pinna from the head at its closest point to the skull using a scalpel, and extracted the paraffin mould. I cut the paraffin moulds into 2-mm slices perpendicular to the axis of the ear canal using a heated knife. I measured the greatest diameter on each slice and assumed that the length of the ear canal was the sum of the number of slices.

I calculated the frequency of maximum sensitivity as the fundamental frequency of the external ear, assuming an air temperature of 20° C, and therefore a speed of sound of 344 m/s.

Acoustic pressure gain in the external ear

I measured the acoustic gain in ears of ten eastern grey kangaroos at the University of Melbourne from 6 January – 8 March 1995. The ears were from culled kangaroos from the Government House, Canberra population. I divided the seven males and three females into body weight groups: three small kangaroos (10-29 kg), three medium kangaroos (30-49 kg), and four large kangaroos (50-89 kg). The smallest individuals were greater than 11 months of age, so should have had adult hearing patterns, because tammar wallabies (*Macropus eugenii*) have hearing thresholds and latencies the same as adults by 6 months of pouch life (Hill *et al*. 1998).

I made resin casts from the paraffin moulds of one of each of the ten pairs of ears (Figure 1). The paraffin moulds were made in the same way as for determining the best frequency of the ear. However, the pinnae were re-frozen after they were removed, and paraffin moulds were mounted, concha side down, on more paraffin in a plastic container. Clear embedding resin (Escon CR64), mixed with hardening catalyst (1% MEKP) at a ratio of 100 mL: 12 drops, was poured around the paraffin moulds until they were completely covered. Once the resin was set I removed the paraffin, and cleansed the resin with Histolene solvent (Dipentene 100%). I drilled a 0.6-mm hole from the base of each cast to the site where the tympanic membrane would have been located. The length of this hole varied between casts. Resin does not absorb acoustic signal energy significantly (Daws 1996), and the friction created by the ear structure itself is minimal so can usually be ignored (Fletcher 1992). During testing, the thawed pinnae were attached to the resin casts with a temporary adhesive (Blu-Tac) in a forward orientation (Figure 1).

I conducted acoustic measurements in a fume hood (520 x 750 x 900 mm) lined with Sonex anechoic foam of 85 mm thickness. The fume hood had attenuation of about 40 dB SPL above 500 Hz. I played continuous sine waves with rise and fall times of 1-μsec and output amplitude of 10 V from a function generator (Tektronix FG501a), with an acoustic range of 0.002 Hz to 2.0 MHz, which was gated by a pulse generator (Tektronix PG 501). The signal was amplified (Toshiba Model SB-M30) with a volume setting of 4, and connected to a midrange loudspeaker (AD5060 Philips, 12.7 cm power squawker), which could produce frequencies between 1.0 and 12.5 kHz. I mounted the speaker on a retort stand 295 mm above the floor, at one end of the fume hood (Figure 2). I oriented the speaker so that it faced the resin casts, and was in line with the open face of the midline of the pinna. The speaker was 215-240 mm from the casts. I tested 12 different frequencies over a total spectrum of 2.0-12.5 kHz at 1/3 octave intervals. I monitored the frequency of the signal (± 0.02 Hz) using a multi-meter (Testlab M2365) that had previously been tested for accuracy against a universal counter (Tektronix DC503), and measured the voltage readings with a digital storage oscilloscope (Tektronix 2214).

Figure 1. A cast of an eastern grey kangaroo ear with the pinna attached in a forward orientation.

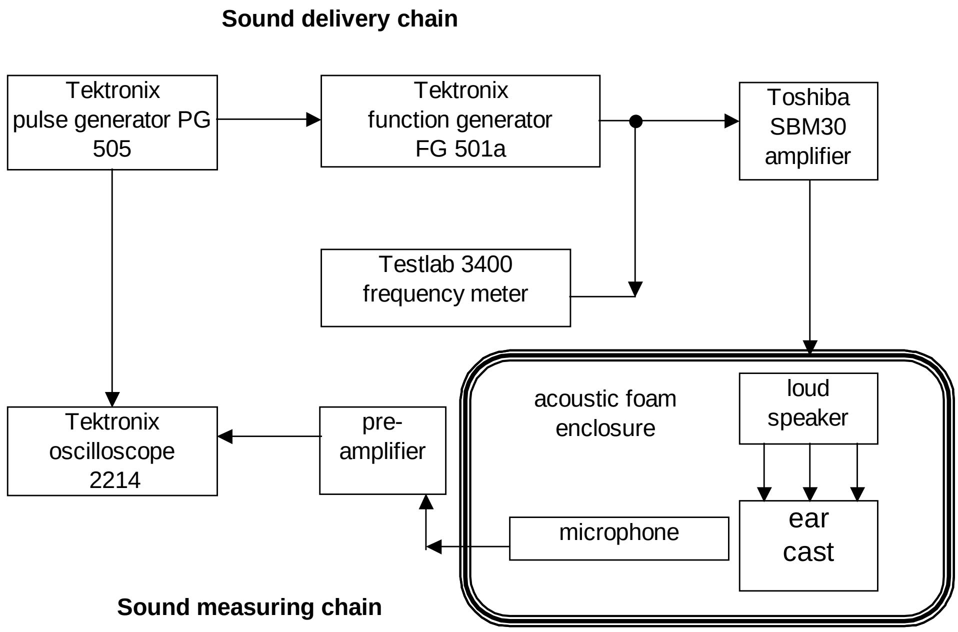


Figure 2. A block diagram of the apparatus used to deliver and measure sound pulses in plastic casts of ears of the eastern grey kangaroo (*Macropus giganteus*).

I made sound pressure level measurements with a calibrated omnidirectional 6-mm diameter microphone (Jaycar electret U-63), with a flat response between 1.0-12 kHz that was connected to a purpose built pre-amplifier set at -40 dB. The microphone was supported on a foam block (approximately 220 x 150 x 200 mm) that was placed at the centre of the fume hood. I measured the height of the microphone above the foam at the beginning of each test. When I placed a cast on the block, I covered it with a 20-mm thick layer of cotton wool, without obstructing the ear, to reduce echo effects upon the measurements. Previous tests made using this technique within this enclosure showed that echoes were 30-40 dB below the signals being measured (Daws 1996). I placed the microphone in the drilled hole at the base of the resin cast so that the protection grid was level with the location of the tympanic membrane. I made free-field grazing-incidence measurements of sound pressure in the anechoic conditions at the position of the ear cast. I converted the output voltage of the microphone to dBV (decibels relative to 1 volt), and took this value as the baseline response for that sound source. I obtained the acoustic pressure gain (L) in decibels (dB) from the external ear and pinna at the acoustic axis for a given sound frequency by calculating the difference between the sound pressure measured at the tympanic membrane and the free field (Chen *et al*. 1995) using the equation: $L = 20 * \log_{10}\left(V_1 / V_2 \right)$, where V_1 was the voltage measured at the tympanic membrane and V_2 was the voltage for the measurement in a free field.

An analysis of variance was used to test whether body size or sex affected the gain measured in the external ear as both were distributed normally. Acoustic pressure gain was the dependent variable; kangaroo sex, body size-class, and the 12 frequencies tested were fixed independent variables. The α level for significance testing was set at 0.05.

RESULTS

Head lengths of the kangaroos ranged from 116 to 270 mm. The average inter-aural distance was 91 mm (± 1.05, SEM), including an addition of 4 mm for soft tissue. The maximum binaural time disparity (maximum $\Delta\ t$) was 265 μs, indicating an upper-frequency hearing-limit between 40-49 kHz. Head length was negatively correlated with the upper hearing-limit (Pearson r = -0.256, df = 1, p = 0.05, n = 89) (Figure 3), and head length was positively correlated with weight class (Pearson, r = 0.787, df = 1, p = 0.01, n = 19).

The length and diameter of the ear canal were measured on five of the six paraffin moulds because one was damaged. The total length of the external ear canal from the tympanic membrane to the opening of the ear at the base of the pinna ranged from 16 to 76 mm. The length of the paraffin mould was affected by the orientation of the ear. Of the five paraffin moulds, four of the pinna were oriented towards the face and one away from the face. The one ear oriented away from the face had the longest paraffin mould, while ears from the same kangaroo in the same orientation had similar canal lengths (Figure 4). Canals from ears in the same orientation but from different individuals varied in length by as much as

24 mm (Figure 4). The average length of the auditory meatus for individuals with their ears oriented towards the face was 8 mm, and that of the concha was 22.5 mm, giving the external auditory meatus an average total length of 30.5 mm (Figure 4). The ear canal was narrowest at the tympanic membrane with a diameter of 1-8 mm, but flared to a diameter of 28-40 mm in the concha region of the ear (Figure 4). The shape of the canal was similar to a parabolic horn (Figure 5). The fundamental-frequency (f_1) for a conical horn was calculated as $f_1 = v/2L$ (Nave 2005), where v is the speed of sound (m/s), and L is the length of the cone (m), and consequently differs with length, so the fundamental-frequency range for these ears was 3.9 to 10.7 kHz.

The sound pressure level at the tympanic membrane was amplified relative to that in the free field, for frequencies between 2.0 and 12.5 kHz. The amount of gain decreased with signal frequency ($F = 3.732$, $df = 11$, $p = 0.003$), and varied between kangaroos (Figure 6). The gain ranged from -18 to 26 dB. The greatest gain was between 2.0 and 3.5 kHz (26 dB), with a second peak at 5 kHz (22 dB). At higher frequencies, 10.0-12.5 kHz, the gain was reduced to about 5 dB. Sex ($F = 0.521$, $df = 1$, $p = 0.478$) and weight class ($F = 1.828$, $df = 1$, $p = 0.189$) had no effect on the gain. The gain was altered with the height of microphone ($F = 4.659$, $df = 3$, $p = 0.011$), being lower at 3 mm ($n = 1$) than those at 4, 7, and 13 mm ($n = 6$) (Figure 7).

DISCUSSION

Measurements of the skulls and heads of eastern grey kangaroos indicated that the upper hearing-limit was 40 - 49 kHz, with a maximum Δt of 265 μs. This predicted frequency cut-off suggests that eastern grey kangaroos should be able to hear into the ultrasonic frequency range. However, where behavioural audiogram tests have been done to confirm the upper hearing-limit, the actual value was found to be lower than that predicted (Heffner and Masterton 1980). For example, the kangaroo rat (*Dipodomys merriami*) has a predicted upper limit of 74 kHz at 60 dB, but the actual value was found to be 52 kHz (Heffner and Masterton 1980).

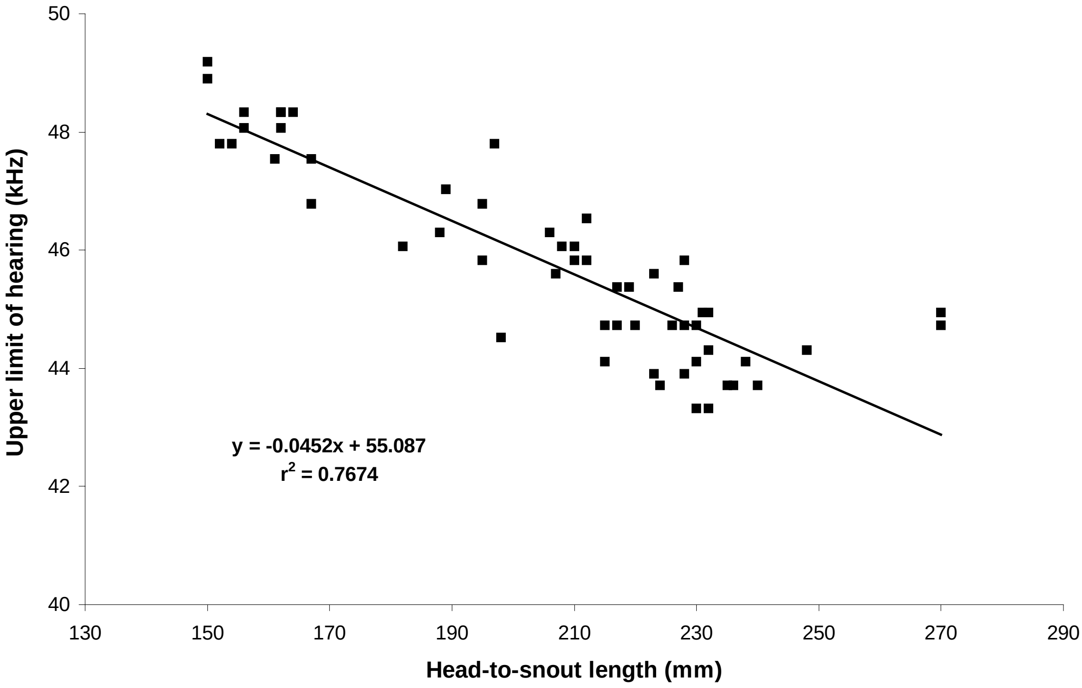


Figure 3. Linear regression of the calculated upper limit of hearing and head-to-snout length for the eastern grey kangaroo (*Macropus giganteus*).

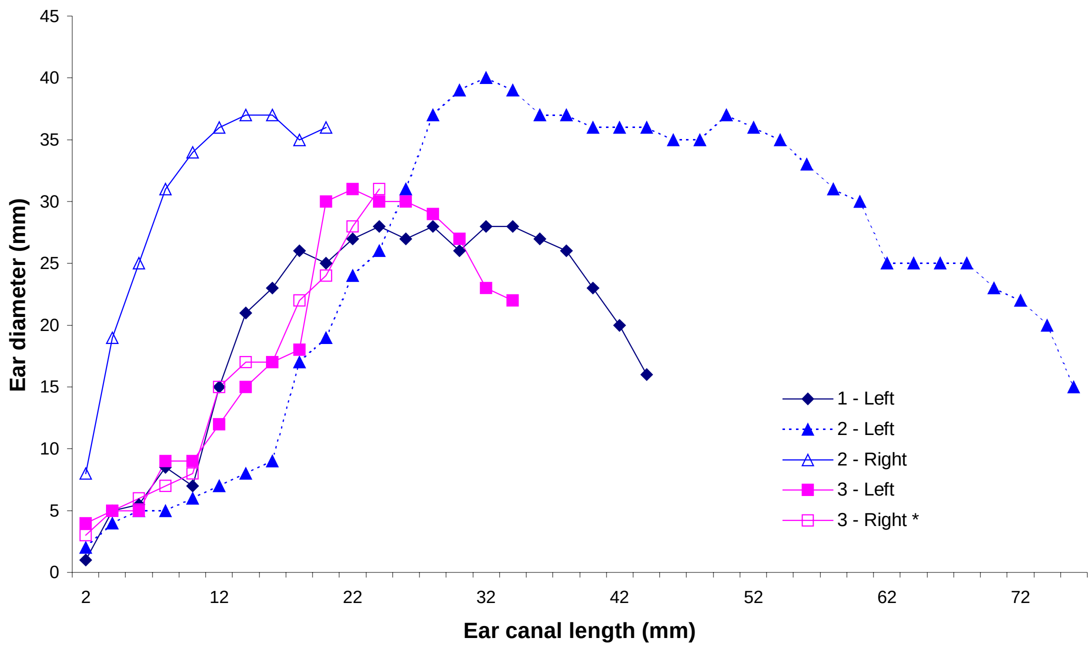


Figure 4. Cumulative lengths and diameters of the ear canals of three male eastern grey kangaroos (*Macropus giganteus*). Dashed line indicates ears oriented away from the face. Solid lines indicate ears oriented towards the face. The asterisk indicates an incomplete paraffin mould.

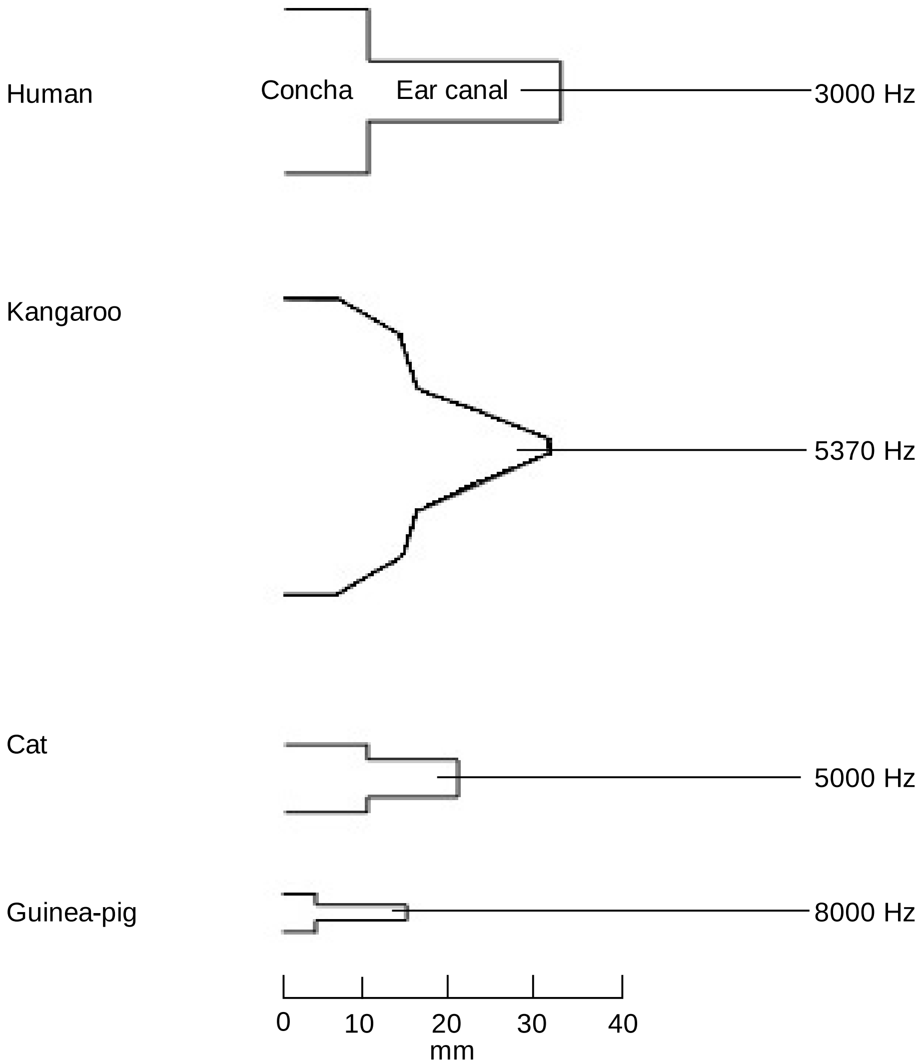


Figure 5. Sizes of the conchae and ear canals of the eastern grey kangaroo (*Macropus giganteus*) and three other species, as well as the frequency of maximum sensitivity calculated from the length of the ear canal. (Dimensions for other species taken from Rosenberg 1982).

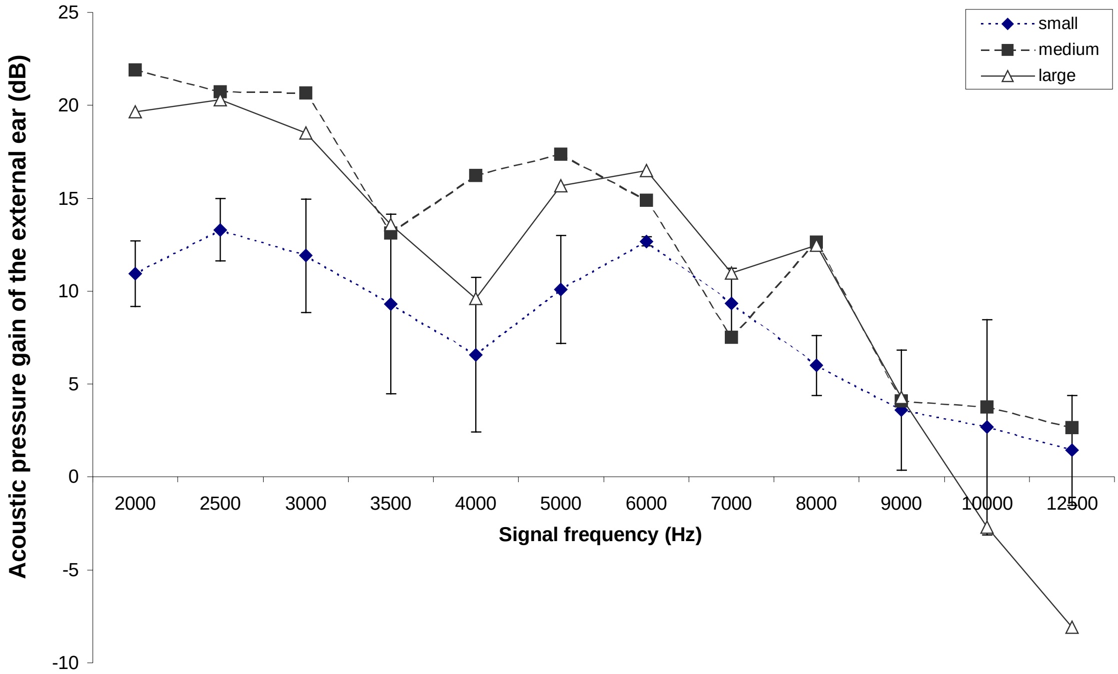


Figure 6. Mean gain in acoustic pressure in the external ear of eastern grey kangaroos (*Macropus giganteus*) for the three body sizes: small (10-29 kg), medium (30-49 kg), and large (50-89 kg). Microphone heights for the three body sizes were: 3 and 13 mm; 4, 7, and 10mm; and 4 and 5 mm, respectively. n = 10. Error bars show standard error of the mean.

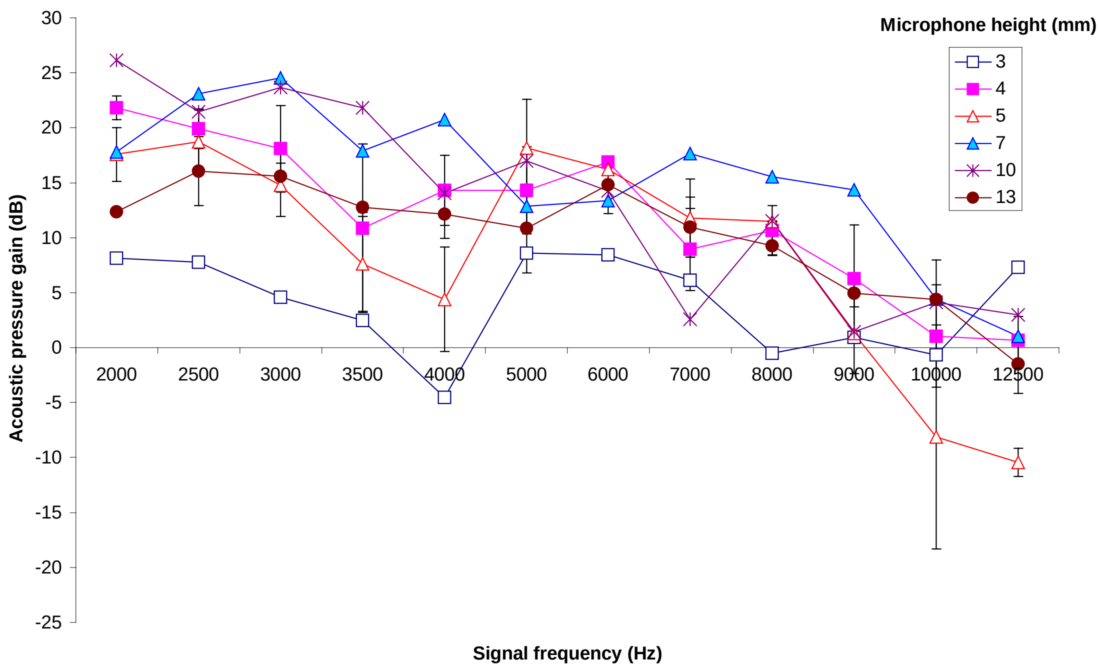


Figure 7. Mean gain in acoustic pressure in the external ear of the eastern grey kangaroo (*Macropus giganteus*) for different microphone heights. Error bars show standard error of the mean for microphone heights 4 (n=3), 5 (n=2), and 13 (n=2); n = 1 for the other three microphone heights.

The average length of the ear canal of the eastern grey kangaroo is 8 mm, and that of the concha is 22.5 mm, giving the external auditory meatus an average total length of 30.5 mm. Combined, the concha and ear canal are shaped like a finite conical horn but differ in shape, length, and width from that of the human, cat (*Felis catus*), and guinea-pig (*Cavia porcellus*) (Figure 5). I calculated the fundamental frequency for the average ear canal length of the eastern grey kangaroo to be 5.4 kHz. Guppy (1985) reported similar canal length and diameter for the eastern grey kangaroo, but calculated the fundamental frequency to be 2.7 kHz with a resonance peak at 9 kHz. Further measurements are needed to confirm the fundamental frequency of the kangaroo ear.

I detected acoustic pressure gain in the external ear of the eastern grey kangaroo for frequencies between 2.0 and 12.5 kHz (Figure 6). The greatest gain was observed between 2.0 and 3.5 kHz, which was lower than the calculated best frequency of 5.4 kHz, and the amount of gain decreased with signal frequencies higher than 3.5 kHz. The same pattern and similar levels of gain were described by Guppy (1985) for this frequency range. However, Guppy (1985) tested to 25 kHz, recording a peak in gain of 17 dB at 18 kHz, followed by a gain of 3 dB at 25 kHz. My results suggest that the external ear of the kangaroo provides frequency-dependent amplification for sound pressure reaching the eardrum, being most sensitive to signals that include frequencies between 2.0 and 3.5 kHz, for individuals that range in size from 10-89 kg; so deterrents should target these frequencies for greatest response.

Kangaroos are likely to be listening for vocalisations by conspecifics and perhaps also predators. Kangaroo vocalisations are harsh broadband signals with most of the signal energy below 12 kHz (Guppy 1985; Baker and Croft 1993; Coulson 1997). Vocalizations made by predators of the kangaroo also do not include ultrasonic frequencies; canid vocalizations are all below 8 kHz (Fox and Cohen 1977), and raptor vocalizations have the greatest acoustic energy between 1.1 and 6.0 kHz (Jurisevic 1998). The external ear of the kangaroo amplifies signals that include these frequencies, suggesting that kangaroos should be more sensitive to these vocalizations. To ascertain kangaroo sensitivity to these frequencies future studies should consider conducting a behavioural audiogram.

Kangaroos occur in a variety of habitats including forest, open woodland, and grassland. Different habitats appear to have different sound windows, or sections of the audible frequency range that are attenuated the least during transmission (Marten and Marler 1977) providing improved signal integrity and improved long distance communication. The height of the signaller above the ground and the signal frequencies, however, have been shown to be more important to signal transmission than the sound window itself (Marten and Marler 1977). Signals that are below 2 kHz and produced close to the ground (15 cm or 1 m) in temperate forest are excessively attenuated, but low frequencies that are transmitted above the ground are attenuated least (Marten and Marler 1977). Morton (1975) found the same pattern of transmission for low frequency signals in grasslands. Together, this suggests that the low frequency components of kangaroo vocalisations would be within the sound window of both habitats and should transmit with little attenuation over longer distances. However, the kangaroo foot thump, an alarm signal made by striking the feet on the ground, may be poorly transmitted over long distances.

MANAGEMENT IMPLICATIONS

The results of this study indicate that selecting a signal at the best acoustic frequency (2.0-3.5 kHz) to be detected by kangaroos, or at other frequencies with larger amounts of gain, would make it easier for the kangaroo to detect a deterrent signal. Signals at lower frequencies, and at higher sound pressure levels, are more effective at overcoming signal attenuation (Piercy *et al*. 1986). Eastern grey kangaroos appear to have the capacity to hear the output of devices that produce only high or ultrasonic frequencies in their signals (Guppy 1985), but a significantly greater signal level would be needed for the kangaroos to detect the signal, because the ear provides markedly less gain (3 dB) at these higher frequencies. Given these limitations, ultrasonic frequencies within the range of 20 to 40 kHz seem to be a poor choice for deterring kangaroos.

CHAPTER 3 - DETERRENCE OF KANGAROOS FROM AGRICULTURAL AREAS USING ULTRASONIC FREQUENCIES: EFFICACY OF A COMMERCIAL DEVICE

Published as – Bender, H. (2003). Deterrence of kangaroos from agricultural areas using ultrasonic frequencies - efficacy of a commercial device. *Wildlife Society Bulletin* 31: 1037-1046.

Abstract: The ROO-Guard® is an ultrasonic device designed to protect agricultural properties from kangaroos (*Macropus spp.*). The manufacturer claims that the signal produced by the ROO-Guard® covers a 250-m area, is audible to kangaroos, and results in kangaroos leaving the area. I conducted laboratory and field trials to evaluate these claims. Laboratory trials showed that the ROO-Guard® signal had only a small component of ultrasonic frequencies and could be detected using a SPL meter at 70 dB at 50 m. The ROO-Guard® did not alter the behaviour of captive eastern grey kangaroos (*M. giganteus),* or red kangaroos (*M. rufus)* in any way. The ROO-Guard® alone did not reduce the density of free-ranging eastern grey kangaroos at sites where the device was operating as compared to control sites, and I found no change in density with distance from the device. The ineffectiveness of the ROO-Guard® should caution against using other ultrasonic deterrent devices, particularly for kangaroos.

INTRODUCTION

Abatement of damage caused by wildlife to primary industries is an ongoing challenge throughout the world. The general public is applying pressure for the use of non-lethal methods of control with minimal pain to the animal and high target specificity (Edwards and Oogjes 1998; Reiter *et al.* 1999). Deterrents are a common non-lethal method to control problem wildlife. Deterrents aim to stop an unwanted behaviour or to make the animal retreat from an area using 1 or more sense modalities.

Auditory deterrence devices may use biologically-significant or artificial sounds to control problem wildlife. Biologically-significant sounds include alarm, distress, alert, or aggressive calls. The purpose of the sounds is to either warn or deter the problem species from feeding, roosting, or loafing sites. These sounds have been used with some success in Europe and the North America on birds and predatory mammals (e.g., Spanier 1980; Smith *et al.* 2000). Artificial sounds may include a selection of frequencies in the audible, infra-, or ultra-sonic frequency range that have no social or other context (e.g., loud bangs and sirens). Devices that use artificial sounds are available in the United States, Europe, and Australia for species including insects (e.g., Dryden *et al*. 1989), birds (e.g., Haag-Wackernagel 2000), marine mammals (Jefferson and Curry 1996) and land mammals, including marsupials such as possums (*Trichosurus vulpecula*) (e.g., Coleman and Tyson 1994) and wallabies (*M. rufogriseus*) (Statham 1993), and eutherians such as rodents (e.g., Lund 1984) and carnivores (e.g., Linhart *et al*. 1992). These devices claim to cause pain or fear, jam communication, or disorient, but are generally ineffective or have a short-lived effect. For example, pigeons (*Columba livia*) were not deterred from a vacant building by an audible electronic sound device (Woronecki 1988), whereas coyotes (*Canis latrans*) were deterred from lambs by gas exploders, but only for an average of 31 days (Pfeifer and Goos 1982).

Ultrasonic frequencies are those frequencies above the human hearing range (10 Hz-20 kHz). Ultrasonic frequencies have a short wave length, attenuate rapidly in air and with distance, and are extremely directional (Gould 1983). They have become a popular choice for deterrents because they are said to be humane, cost effective, easy to use, and scientifically sound (Bomford and O'Brien 1990b). Manufacturers of ultrasonic deterrence devices claim that their products deal with a variety of different target species, require little or no maintenance, and the sound produced is inaudible and therefore not irritating to nearby humans. Ultrasonic frequencies are audible to some animals such as dogs, bats, and rodents (Frings and Frings 1967). However, reviews by Bomford and O'Brien (1990a), Bomford (1992) and Erickson *et al.* (1992) found no evidence of a reduction in damage to property by birds or mammals.

At least 5 species of large marsupials -- the eastern grey kangaroo, western grey kangaroo (*M. fuliginosus*), red kangaroo, red-necked wallaby (*M. rufogriseus*), and swamp wallaby (*Wallabia bicolor*) -- are considered pest species by agriculturalists and stockists throughout most of Australia. These species have been implicated in damage to crops and property (e.g., Gibson and Young 1987), competition with livestock for food and water (e.g., Edwards 1989), and alteration of habitat quality (e.g., Coulson 2001).

The ROO-Guard® Mk I was invented in Australia in 1988 by Shu Roo (Sumner Park, Queensland, Australia) Pty. Ltd. A revised version, ROO-Guard Mk II, was released in 1992 and currently is available commercially. Pamphlets and instruction sheets produced by the manufacturer claim that both ROO-Guard versions produce a high frequency signal that is inaudible to humans. The manufacturers argue that the high frequency component of the ROO-Guard signal effectively masks the kangaroos' ability to hear their natural predators, making kangaroos uneasy. The ROO-Guard is claimed to have a signal noise level greater than 130 dB, with a sound pattern extending 30-40 m to the front and 125 m to either side of the device.

Statham (1991, 1993) tested the ROO-Guard on wallabies in forestry plantations in Tasmania and concluded it had no effect on wallaby behavior or feeding activity. However, no tests of active sonic devices like the ROO-Guard have been conducted on kangaroos. My objectives were to (1) determine the acoustic characteristics of the signals produced by both models of ROO-Guard, (2) examine the effects of the ROO-Guard signal on the behavior of captive eastern grey and red kangaroos, and (3) evaluate the ROO-Guard's efficacy as a deterrent for free-ranging eastern grey kangaroos.

METHODS

I tested 2 models of ROO-Guard: a ROO-Guard Mk I, purchased in 1990, and 4 ROO-Guards Mk II, purchased in 1992. Both models had 4 speakers encased in a metal housing 77 mm wide at the front and 179 mm wide at the back, 242 mm high, and 167 mm deep. Speakers were paired and arranged vertically on the 2 sides of the unit, pointing out at a 45° angle. The Mk I had round speakers that were uncovered; the Mk II had square speakers with vertical slats across them. Both models consisted of a master unit, with signal generator, and slave unit, with speakers only. Master and slave units had the same external appearance.

Acoustical characterization tests

I conducted laboratory tests of the master ROO-Guard Mk I with a fully charged battery in an office without anechoic properties. I made measurements at 1 m on both sides of the ROO-Guard. During post processing, I determined the signal structure (Eisenberg *et al*. 1975), frequency bandwidth (maximum minus minimum frequency), signal duration (from the start to the end of one syllable), and inter-pulse duration (from the previous syllable to the subsequent syllable).

I conducted field measurements of the propagation pattern of the ROO-Guard Mk I and Mk II on grass at 2 different sites. I tested the Mk I on an oval on 21 September and 10 October 1994. I tested one of the Mk II units on the same oval in 1995. I took noise level measurements (dB) every 5 m in the azimuth plane on bearings at 45° intervals, with 0° corresponding to the front of the unit. I tested the second Mk II unit in 2 separate rectangular-shaped paddocks near Bairnsdale, Victoria, in 1997. I took sound-pressure-level measurements in a similar way as for the Mk I (Appendix A).

Behavioural response

I measured the behavioural response of captive eastern grey kangaroos and red kangaroos to ROO-Guard® Mk I at 2 sites in Victoria: the fauna park enclosure at Royal Melbourne Zoological Gardens (Melbourne Zoo) on 8 and 12 September 1994 and 6-8 February 1995, and the kangaroo enclosure at Werribee Open Range Park on 6-8 March 1995. Prior to testing, the Titley Electronics ANABAT II was used to detect the presence and noise level of frequencies similar to those produced by the ROO-Guard Mk I. Noises that had ultrasonic frequencies were recorded onto a stereo radio cassette recorder (AIWA HS-J380), transmitted to a 486 PC laptop with a ZCAIM, and analyzed with ANABAT software. Noise levels were measured with a SPL meter (B&K 2209).

The fauna park enclosure at the Melbourne Zoo was a 1-ha triangle with a mix of open grass, clusters of native trees and shrubs, and a small dam near the centre. A curved pedestrian path through the enclosure ran adjacent to a designated kangaroo sanctuary area separated from the path by a single wood rail fence. Fourteen eastern grey kangaroos (5 female, 8 male, and 1 young-at-foot) were held in the enclosure. Kangaroos often divided into smaller groups within the enclosure, so a minimum test group size of 5 was set.

I made observations between 0800 and 1000 h, when kangaroos were often resting close together and few visitors were present. The ROO-Guard was mounted on either a wooden stake or a stand at a height of 1,200 or 1,750 mm, respectively, and powered by a 12-Volt battery.

The kangaroos at the Melbourne Zoo are habituated to the presence of humans in their enclosure (Coulson 1997b) so we made observations on foot. An assistant placed the master ROO-Guard pointing directly at the kangaroos and as close as possible without causing them to take flight. A trial did not begin until the majority of the kangaroos were in low or non-vigilant postures. A trial consisted of rapidly scanning the kangaroos once with the ROO-Guard either on or off. We ran a minimum of 5 trials each day, and continued until at least one off and one on trial was completed per day. This was a blind test, and the observer wore earplugs to ensure that he or she could not hear the ROO-Guard.

I measured vigilance levels to indicate the behavioural response of captive eastern grey kangaroos to the ROO-Guard Mk I. I recorded the vigilance category of each kangaroo on a scale from no reaction (1) to flight (8), following Croft's (1981a) definitions of body postures: kangaroos that were feeding or lying down were considered to be non-vigilant; those that were sitting, crouched, semi-erect, standing erect, or erect alert were considered to be exhibiting increasing levels of vigilance, which corresponded to alarm and ultimately flight.

I recorded onto a hand-held cassette recorder verbal descriptions of the species, group size, sex, and vigilance level of all kangaroos, as well as distance of the observer to each kangaroo. I made observations with 8 × 40 binoculars. If an individual changed location during a scan, it was tracked to avoid recording its response twice. I assumed that a kangaroo's response would be independent on subsequent days.

Werribee Open Range Park tests

The kangaroo enclosure at Werribee Open Range Park was a 4-ha rectangle consisting of an open grass plain with small clusters of trees along the perimeter. Zoo bus tours and maintenance and feeding vehicles regularly traveled through the enclosure. People on foot were not allowed in the enclosures, and bus tours viewed animals from a distance that did not disturb the animals.

Fourteen eastern grey kangaroos (6 female and 8 male) and 17 red kangaroos (6 female and 11 male) were held in the enclosure. There were no young at foot or pouch young in this population, as all males had been castrated. Kangaroos often divided into smaller groups within the enclosure, so I set a minimum test group size of 5.

We made observations between 0900 and 1300 h, when kangaroos were often resting close together and fewer visitors were present. We used a utility vehicle similar to those used by zoo staff for transport and observations and placed the master ROO-Guard at a point 25-50 m from the kangaroos.

We made observations using the same method described for Melbourne Zoo, except that an assistant and I remained in the vehicle. We measured distance between the kangaroos and the vehicle with either a Sokkishia optical range finder (30 cm base) (Sokkishia Co., Ltd., Tokyo, Japan) or a Lytespeed 400 Laser range finder (Busnell, Overland Park, Kans.). Kangaroo vigilance levels were measured as before.

I used chi-square contingency table analyses to test for patterns in vigilance between treatment (ROO-Guard active) and control (ROO-Guard inactive) trials at both captive sites. I included only the observations from the first inactive and the first active trial for each day in the statistical analyses and used standardized residuals to determine the significance of individual cells in chi-square analyses. The α level for all significance tests was adjusted to 0.01 using the Bonferroni correction for repeated testing.

Free-ranging kangaroo response

We measured the relative density of kangaroos at Yan Yean Reservoir Catchment, southern Victoria, Australia (145°09′E, 37°32′S) from 5 December 1995 to 21 January 1996. The catchment is situated on the rural fringe of Melbourne, Victoria, in southeastern Australia, 37 km northeast of the Central Business District. The 2,250-ha catchment is closed to the public. The population of eastern grey kangaroos in the catchment was estimated as 2109 in 1995 by Coulson *et al.* (1999). Female kangaroos at this site have a maximum home range size of 158 ha (G. Coulson, B. Moore, S. Way, personal communication). If a circular home range were assumed, the diameter would be 1.4 km.

I tested ROO-Guard Mk II units in 10 randomly selected open grassy areas with a diameter of at least 100 m. Half of the sites were treatment sites with the master ROO-Guard active; the remainder were control sites with the slave ROO-Guard inactive. Treatment and control sites were paired and tested simultaneously to control for weather and other confounding factors. Treatment and control sites were assigned randomly with a minimum distance between sites of 850 m to reduce the likelihood of individuals using more than one site. I tested each site only once.

We mounted ROO-Guard Mk II units on star pickets at 1,750 mm above the ground. At treatment sites, we installed a master ROO-Guard unit with solar panel. At control sites, a mock solar panel and a slave ROO-Guard unit, which was externally identical to the treatment unit, were used. We placed the ROO-Guard at the centre of each site with 3 predetermined sound contours based on the propagation pattern of the ROO-Guard Mk II: 60, 45, and 35 dB (Figure 8). The contours represented increasing distance from the ROO-Guard, although the distance from the ROO-Guard changed slightly when the site was located on a slope, extending farther down and contracting up the hill.

Faecal-pellet accumulation was used as an index of kangaroo density (Southwell 1989). We randomly allocated 54 faecal-pellet plots to each site, 17 on the inner, 19 on the middle, and 18 on the outer contour line. Faecal-pellet plots were circular with a radius of 1.78 m, resulting in a 10-m^2 plot. We placed plots on contours by randomly selecting an angle, and any overlapping plots were re-allocated. Wooden stakes marked the plots.

Pellet plots were cleared of all fecal pellets prior to testing the ROO-Guard. We counted individual fecal pellets 5-10 days after clearing to allow sufficient time for deposition, but not excessive time in which decomposition of pellets may result (Perry and Braysher 1986; Johnson and Jarman 1987; Southwell 1989).

Faecal-pellet data were cube-root-transformed prior to data analysis to correct for a non-normal distribution. I used a split-plot nested Analysis of Variance (ANOVA) to determine whether differences existed in individual faecal-pellet densities, between treatment and control sites, between sites within a treatment, and across dB contours. I used a Dunett T3 post-hoc test to determine significant differences between sites. The α level for all tests was set at 0.05.

RESULTS

Acoustical characterization tests

Both ROO-Guard models produced a repeating single syllable signal that was composed of a descending sweep followed by a noisy burst. The syllable can be classified as a Type 1 sound form with descending modulation (*sensu* Eisenberg *et al*. 1975). The Mk I signal was variable but ranged from a maximum frequency of 27 kHz to a minimum of 17 kHz (Figure 9). The Mk I signal therefore contained a mix of audible and ultrasonic frequencies, which could be described onomatopoeically as “zip zip”. The syllables were long (0.75-0.88 s), and repeated continuously with an inter-syllable duration ranging from 0.12-0.33 s. Hence, syllables were repeated approximately once per second. The signal produced by the Mk II was similar to that of the ROO-Guard Mk I, but its frequency range was consistent and narrower (22.8-15.5 kHz) and the syllable (1.13 s on average) and inter-syllable (0.45 s on average) duration were longer (Figure 9). Therefore, the Mk II also produced a signal of a mix of audible and ultrasonic frequencies, but produced 2 syllables every 3 seconds.

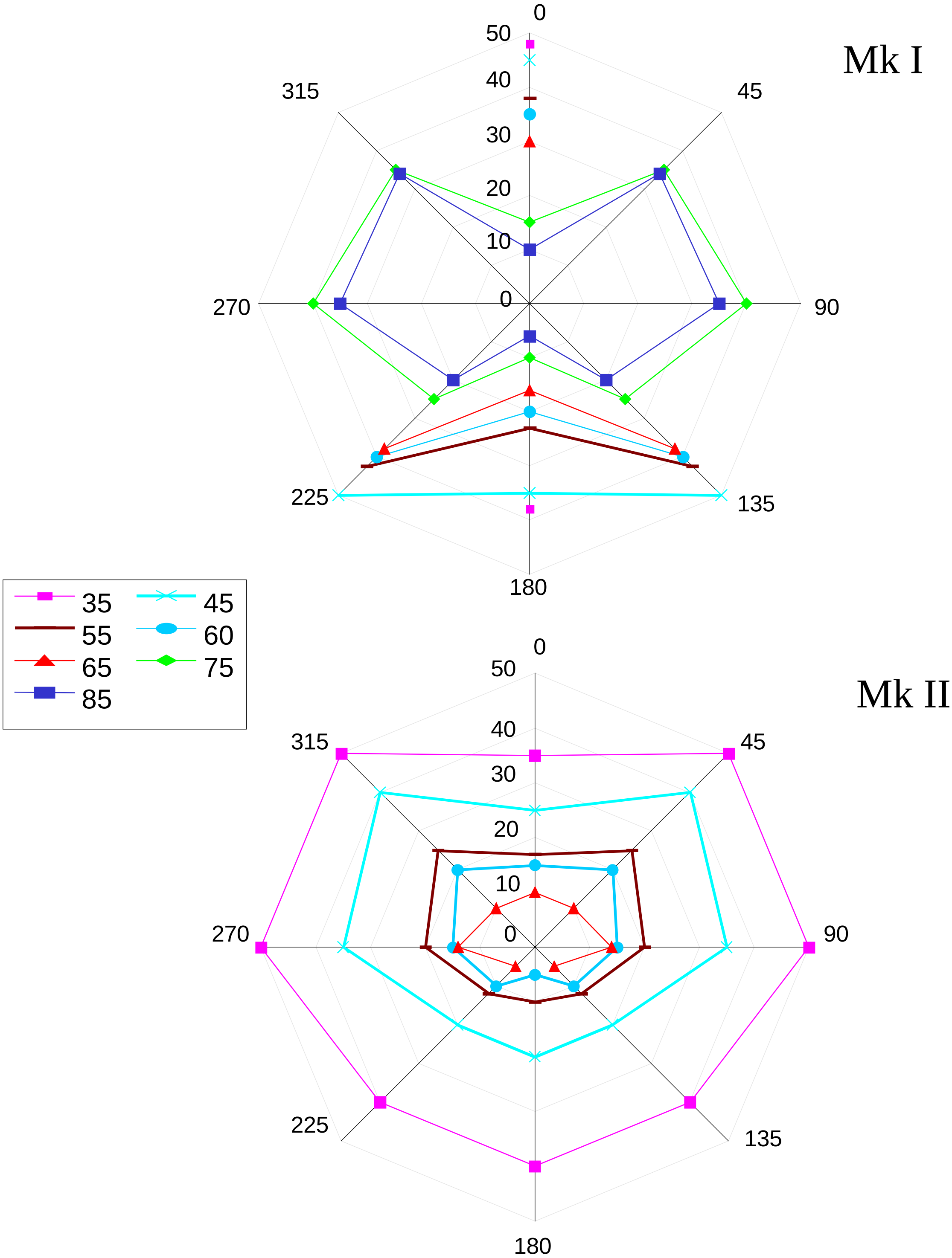


Figure 8. Polar diagrams showing the propagation pattern of the ROO-Guard Mk I and ROO-Guard Mk II signals on grass. The background noise level was 20-30 dB for the Mk I, and 57 dB for the Mk II. 0° is at the front of the unit.

Field noise levels were displayed as polar diagrams to show the propagation pattern of the signals for both ROO-Guard models, with interpolation between points with the same sound level on different bearings to create dB contours (Figure 8). Background noise levels at the football oval ranged from 20 to 30 dB when filtering for 16 kHz and in Bairnsdale were 20.5 dB when filtering for 20 kHz.

The ROO-Guard Mk I signal was loudest to the sides of the unit (90°and 270°) and quietest at the front and back (0° and 180°). The signal was 70 dB at 50 m on the 90° and 270° bearings. The ROO-Guard Mk II had the greatest noise levels to the sides (45°, 90°, 270°, 315°) and was quietest to the front of the unit (0°; Figure 8). The sound level was 35 dB at 50 m on the 45, 90, 270, and 315° bearings.

Behavioural response

The background noise levels at Melbourne Zoo ranged from 13 - 33 dB. Ultrasonic frequencies that overlapped with the signal produced by the ROO-Guard occurred at Melbourne Zoo -- tram squeals (2.4 to 22.3 kHz) and dusky moorhen (*Gallinula tenebrosa*) vocalizations (1.90 to 19.5 kHz, dominant frequencies 5.5 to 11.5 kHz). The background noise levels at Werribee ranged from 10-13 dB, and I detected no ultrasonic frequencies.

Flight was not observed during any of the behavioral trials with the ROO-Guard on or off. The proportion of eastern grey kangaroos at different vigilance levels did not differ significantly between the ROO-Guard Mk I treatment and control trials at either captive site (Melbourne zoo: $\chi^2_{0.01,4}$ = 0.125, p = 0.928; Werribee Park: $\chi^2_{0.01,4}$ = 0.191, p = 0.782). Similarly, the proportion of red kangaroos at different vigilance levels did not differ significantly between the treatment and control trials ($\chi^2_{0.01,4}$ = 0.090, p = 0.953). However, significantly more grey kangaroo were lying down when the ROO-Guard was off ($\chi^2_{0.01,4}$ = 19.995, p = 0.001), whereas significantly more red kangaroos crouched when the ROO-Guard was on ($\chi^2_{0.01,4}$ = 19.275, p = 0.001; Figure 10).

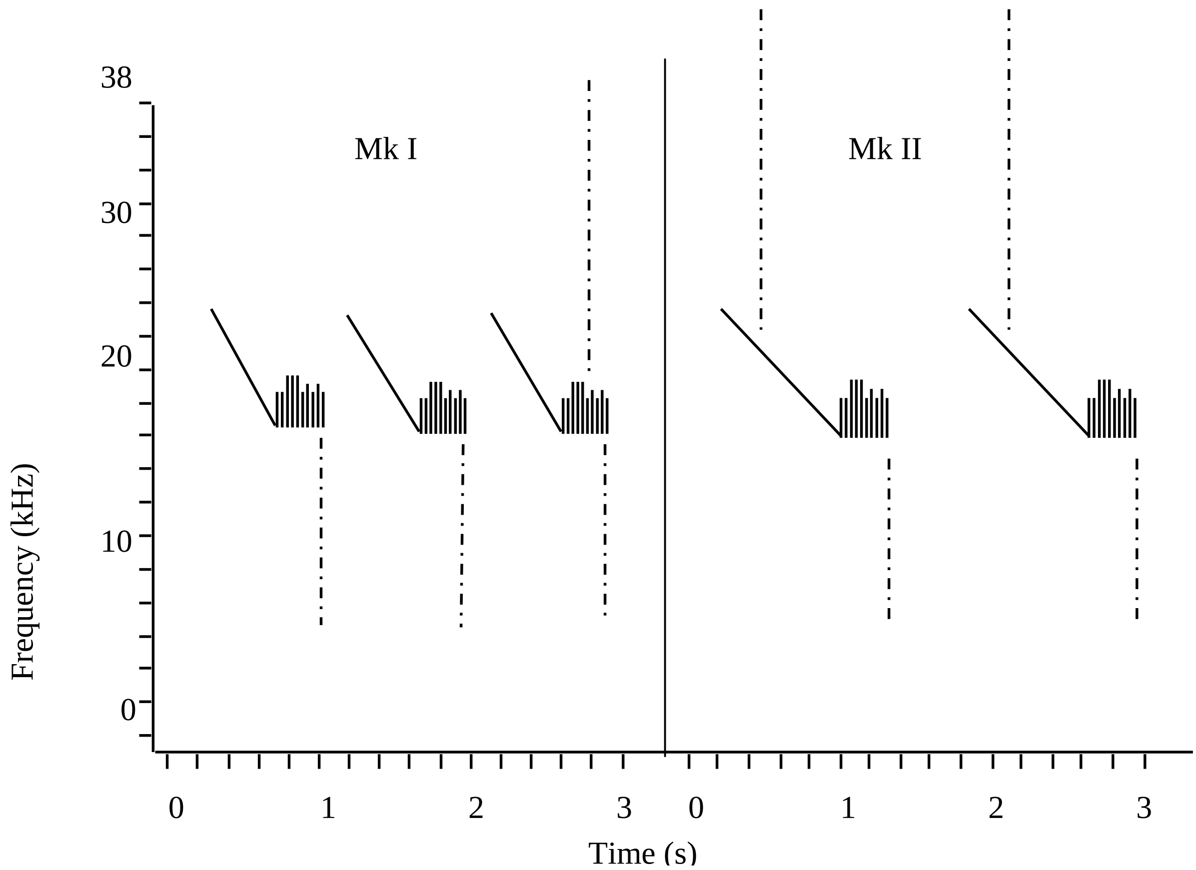


Figure 9. Diagrammatic representation of 3 syllables in the ROO-Guard Mk I and 2 syllables in the ROO-Guard Mk II signals recorded with ANABAT II at 1m from the device. ANABAT was set with a division ratio of 16, sensitivity of 8.5 and volume of 7.

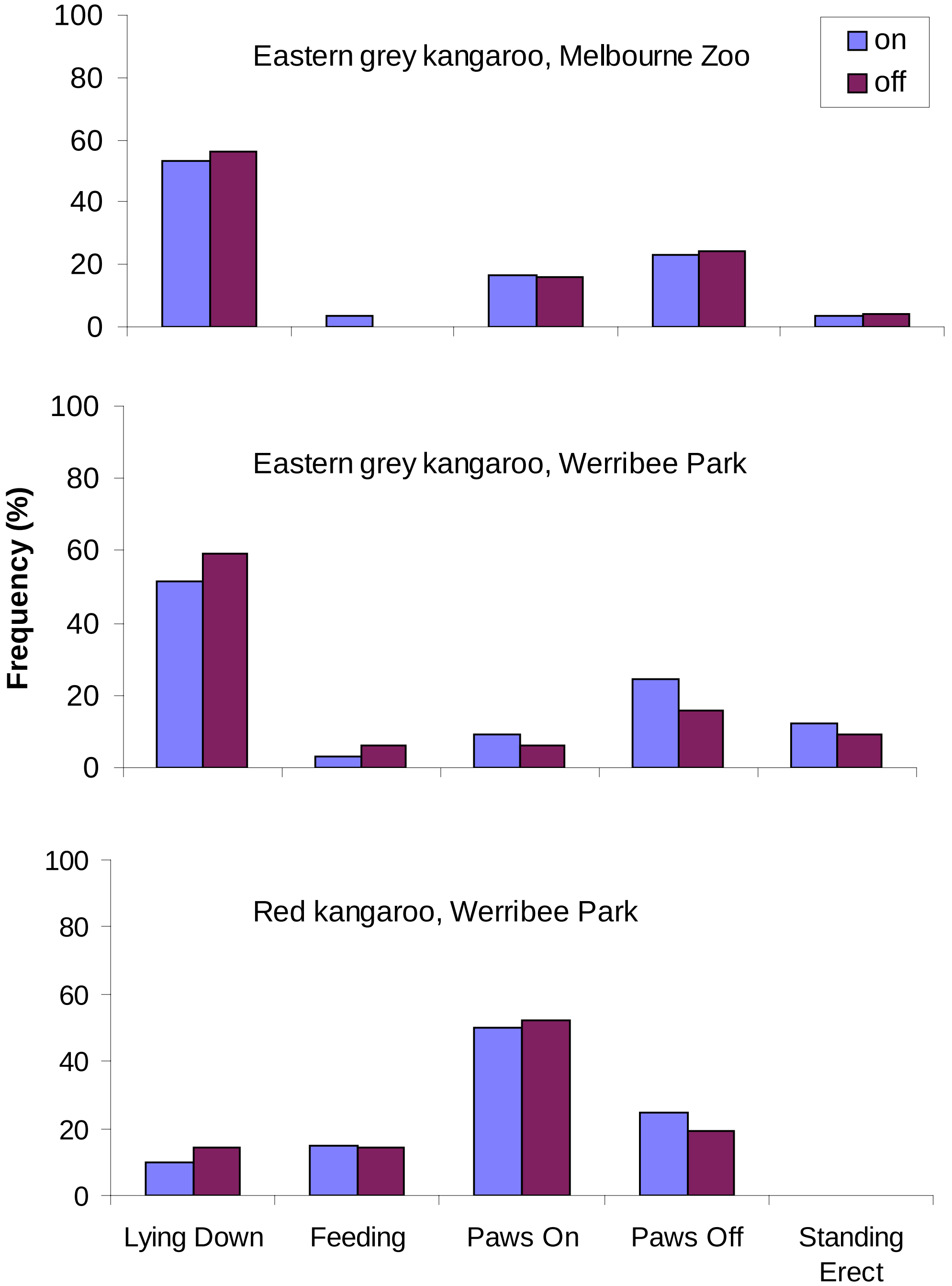


Figure 10. Frequency of non-vigilant and vigilant postures exhibited by kangaroos at the 2 captive sites in response to the ROO-Guard Mk I. Observations were made on 4 occasions between 8 September 1994 and 8 February 1995 at Melbourne Zoo, and between 6 and 8 March 1995 at Werribee Park, Victoria, Australia.

Free-ranging kangaroo response

The linear background noise levels at Yan Yean Reservoir were 84-106 dB, whereas the 16 kHz filtered noise levels were 36-59 dB. I detected no ultrasonic frequencies.

Fecal pellet densities did not differ between the treatment and control sites ($F_{1, 8} = 0.974$, $p = 0.353$; Figure 11 suggesting that no significant difference occurred in the relative density of kangaroos at sites where the ROO-Guard was on or off. Within treatments, however, site faecal-pellet densities differed ($F_{8, 549} = 55.675$, $p < 0.001$). I found 4 statistically separate groups of sites based on faecal-pellet densities; one treatment site was an influential outlier, with significantly less faecal pellets than any other site (Dunnet T3, $p < 0.001$). When the outlier was excluded from the data set, I found a significant difference in the relative faecal-pellet densities at treatment and control sites ($F_{1, 7} = 13.610$, $p = 0.008$); higher densities of faecal pellets occurred at the sites where the ROO-Guard was on.

Faecal-pellet densities did not differ significantly across the 3 sound contours ($F_{2, 549} = 0.823$, $p = 0.440$), and there was no interaction between treatment and contour ($F_{2, 549} = 1.352$, $p = 0.260$; Figure 11). Therefore, kangaroo relative density did not differ with distance from the ROO-Guard.

DISCUSSION

My study does not support the claim made by the manufacturer that both models of the ROO-Guard produce a high frequency signal that is inaudible to humans; both ROO-Guard models produced audible frequencies. Other sonic deterrence devices advertised as ultrasonic also have been found to produce either a combination of audible and ultrasonic frequencies (Mills *et al*. 2000) or purely audible frequencies (e.g., Scheifele *et al*. 1998).

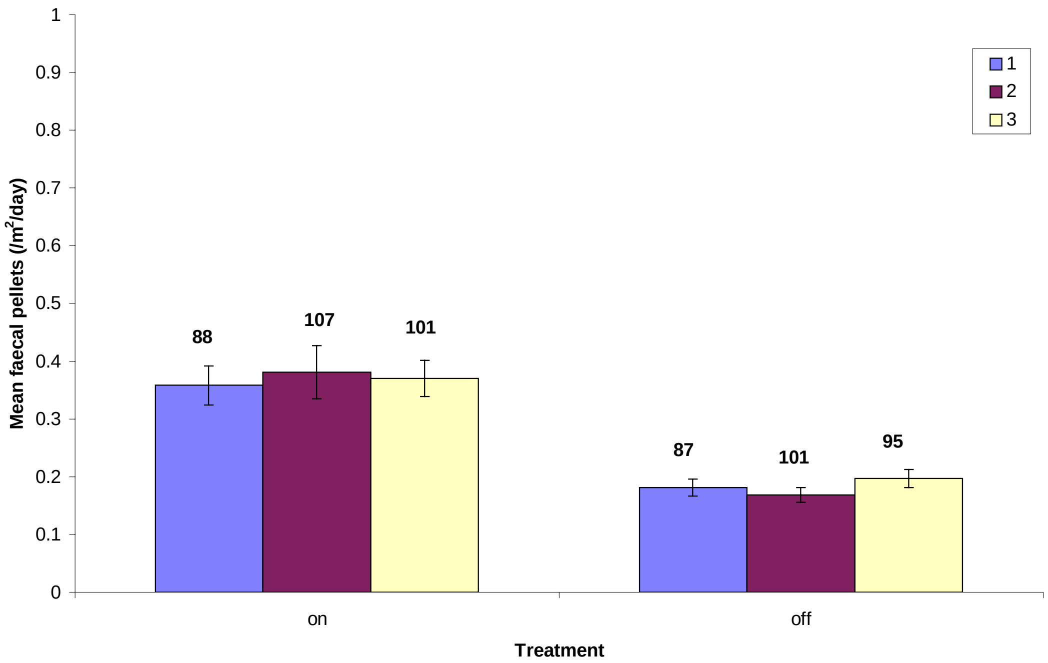


Figure 11. Differences in mean faecal-pellet density between the treatments ($F_{1, 8} = 0.974$, $p = 0.353$) and across contours ($F_{2, 549} = 0.823$, $p = 0.440$). Contours 1, 2, and 3 are equivalent to 60, 45, and 30 dB, respectively. Faecal pellets were collected between 12 December 1995 and 21 January 1996 at open grass sites within Yan Yean water catchment, Victoria, Australia. The numbers of faecal pellet plots sampled (*n*) are shown.

Ultrasonic frequencies are extremely directional (Gould 1983), their noise levels attenuate inversely to the square of the distance in air (e.g., Kinsler *et al*. 1982), and they attenuate exponentially with increasing frequencies above 8 kHz (Beranek 1971; Manning 1981). Thus, producing and radiating sounds at a sufficient signal level is difficult and expensive. A signal loss of at least 20 dB from 20 to 50 m at the test condition temperature (18º C) was observed in this study, resulting in the signal noise levels dropping from 100 to 70 dB from 2 to 50 m for ROO-Guard Mk I, and 70 to 35 dB from 5 to 50 m for the Mk II. This signal loss was consistent with other studies that have measured attenuation in ultrasonic devices (Woronecki 1988; Bomford 1990; Scheifele *et al.* 1998). The ROO-Guard did not produce a signal that was loud enough to overcome attenuation at the advertised distance, limiting it to a range of 80-100 m, depending on the model used. In windy conditions, the signal-to-noise ratio is likely to decrease further.

Captive responses

The ROO-Guard MK II had no detectable effect on captive eastern grey kangaroos or red kangaroos at either site, as we observed no significant change in vigilance or flight. This is contrary to the manufacturer's claims, but consistent with other devices tested on other species (e.g., Dryden *et al.* 1989; Romin and Dalton 1992; Haag-Wackernagel 2000).

Guppy (1985) showed that the gain created by the external ear of the eastern grey kangaroo was greater than 5 dB between 0.7 and 25 kHz, exceeding 15 dB between 1.5 and 12 kHz and having an additional peak at 18 kHz, suggesting that the lower frequencies produced by the ROO-Guard are within the kangaroo's hearing range. The propagation tests indicate that the ROO-Guard was at a distance that should have resulted in an audible signal for the kangaroos. Kangaroos looked towards the ROO-Guard, but this occurred whether the ROO-Guard was on or off, indicating that the sound produced by the ROO-Guard was not attracting their attention.

The ROO-Guard manufacturer claims that kangaroos respond to the ROO-Guard signal because it resembles the sound of their predators when they are hunting. Dingoes (*Canis familiaris dingo*) at night, and wedge-tailed eagles (*Aquila audax*) in the day, are the main non-human predators of kangaroos (Robertshaw and Harden 1986). However, spectral analyses of canid vocalizations show that they do not extend above 8 kHz (Fox and Cohen 1977). Raptor vocalizations generally are harsh or harmonic, of wide frequency range, with the greatest acoustic energy between 1.1-6 kHz (Jurisevic 1998). Moreover, predators generally do not vocalize while hunting (e.g., Corbett 1995). Incidental noises made as predators move across the ground (e.g., Henry 1986) may have ultrasonic elements, but are unlikely to concern kangaroos because dingoes do not use stealth while hunting (e.g., Corbett 1995). Kangaroos have been observed to respond to auditory signals given by conspecifics (e.g., Coulson 1997b). Vocalizations made by kangaroos tend to be harsh broadband signals below 12 kHz (Guppy 1985; Coulson 1997b) and are made during either courtship or agonistic encounters (Kaufmann 1975a; Croft 1981a), neither of which results in alarm or flight. The only kangaroo signal associated with alarm and flight is not a vocalization but a low-frequency foot thump. A relatively high-frequency signal, such as that produced by the ROO-Guard, is therefore unlikely to convey any social meaning to kangaroos and result in flight.

The distance between the kangaroos and the ROO-Guard may have affected their response. Jarman and Wright (1993) observed an overall mean flight distance (± SE) of 121.4±9.5 m for eastern grey kangaroos when responding to a terrestrial disturbance, either a dingo or a human. All behavioral tests in my study, however, fell within this range, so it is unlikely that kangaroos did not respond because the source of disturbance was outside their flight distance. However, captive kangaroos possibly did not respond to the ROO-Guard because they had been previously exposed to similar frequencies and had become habituated to them. Background recordings at Melbourne Zoo showed the presence of some of the frequencies produced by the ROO-Guard, but I found no such overlap at Werribee Open Range Park at the time that the trials were undertaken. The similarity in response between the 2 captive sites suggests that habituation was unlikely.

Free-ranging responses

Contrary to the manufacturer's claims, similar relative faecal-pellet densities at the Yan Yean treatment and control sites suggest that the ROO-Guard signal did not deter kangaroos. The absence of any significant decline in faecal-pellet densities on sound contours at increasing distance from the source is additional evidence contradicting the manufacturer's claim that the device will deter kangaroos. The background noise levels at Yan Yean Reservoir around the frequencies produced in the ROO-Guard signal (16 kHz filter) were 36-59 dB, but no ultrasonic frequencies were detected using the ANABAT. Consequently, the signal-to-noise ratio should have been good in the frequency range of the ROO-Guard and kangaroos should have been able to hear the signal above any background noise.

MANAGEMENT IMPLICATIONS

The promotional literature proclaiming the scientifically proven efficacy of the ROO-Guard grossly exaggerates the capabilities of both models. The results of the signal characteristics, captive behavioral responses, and kangaroo density trials generate 4 clear conclusions: (1) The ROO-Guard Mk I and Mk II do not produce pure ultrasonic frequency signals; (2) the ROO-Guard Mk I and Mk II do not produce signals that are detectable by the testing equipment at 125 m in any direction around the devices; (3) the ROO-Guard Mk I does not alter the behavior of captive eastern grey or red kangaroos; and (4) the ROO-Guard Mk II does not reduce the number of free-ranging eastern grey kangaroos feeding at open grassy sites.

The ROO-Guard is marketed as being effective for kangaroos and wallabies. My study found that eastern grey kangaroos and red kangaroos did not alter their behavior when presented with the ROO-Guard. Statham (1991, 1993) found that the ROO-Guard had the same lack of impact on Bennett's wallabies

(*M. rufogriseus*), Tasmanian pademelons (*Thylogale billardierii*), European rabbits (*Oryctolagus cuniculus*) and brushtail possums (*Trichosurus vulpecula*).

The ineffectiveness of the ROO-Guard should caution against the use of other ultrasonic deterrent devices for kangaroos. The results of my study also adds to the increasing evidence that ultrasonic devices for other species generally do not provide persistent effects on the behaviour of animals (Dryden *et al.* 1989; Bomford 1992; Coleman and Tyson 1994; Haag-Wackernagel 2000).

CHAPTER 4 - DETERRENCE OF KANGAROOS FROM ROADWAYS USING ULTRASONIC FREQUENCIES – EFFECTIVENESS OF THE SHU ROO®

Submitted as – Bender, H. (2004). Deterrence of kangaroos from roadways using ultrasonic frequencies – effectiveness of the Shu Roo. *Wildlife Research*.

Abstract: The Shu Roo® is a commercial ultrasonic deterrent device designed to protect vehicles from collisions with kangaroos. The manufacturer claims the Shu Roo covers a 400-m area ahead of the vehicle, is audible to kangaroos and results in kangaroos moving from the path of the vehicle. I conducted laboratory and field trials to evaluate these claims. The Shu Roo signal had only a small component of ultrasonic frequencies and could be detected on grass and bitumen only to a maximum distance of 50 m, and was not detectable above the noise produced by 4 different moving vehicles. In static tests, the Shu Roo signal did not alter the behavior of captive eastern grey kangaroos (*Macropus giganteus*) or red kangaroos (*M. rufus*) in any way. The ineffectiveness of the Shu Roo should caution people against using other ultrasonic deterrent devices, at least for kangaroos.

INTRODUCTION

Animal-vehicle collisions raise economic, welfare, and conservation concerns. The economic costs of animal-vehicle collisions can be considerable when large animals are involved. For example, in 1993 it was estimated that US $280 million worth of property damage resulted from collisions with deer (*Odocoileus spp.*) in Germany each year (Putman 1997). The risk to humans from animal-vehicle collisions depends greatly on the species of animal involved. Large animals, particularly large ungulates such as moose (*Alces alces*), pose greater risk of serious injury to vehicle occupants than smaller animals. Threatened species are also at particular risk from animal-vehicle collisions. For example the extinction of a population of brush-tailed rock wallabies (*Petrogale penicillata*) in the Warrumbungle Ranges, New South Wales, Australia, has been attributed to the construction of a road at the base of a mountain near the population (Fox 1982).

At least 5 species of large macropodid marsupials are considered problem species on roadways in Australia: eastern grey kangaroo, western grey kangaroo (*M. fulginosus*), red kangaroo, red-necked wallaby (*M. rufogriseus*), and swamp wallaby (*Wallabia bicolor*). It has been estimated that a kangaroo causes a similar amount of damage to a vehicle as does a deer (AUS $3000 / vehicle) (Kangaroo Advisory Committee 1997). There are no estimates for the total number of macropodid marsupials killed in Australia annually. In New South Wales, Australia, wildlife information and rescue service (WIRES) volunteers counted 66 eastern grey kangaroos and 16 swamp wallabies dead on 199 km of road in a 6 - week period (Cooper 1998). In the Australian Capital Territory, Australia, a total of 1,394 eastern grey kangaroos, swamp wallabies and common wallaroos were killed in animal - vehicle collisions on 42 km of road between July 1990 - December 1993 (Woodward 1994).

One potential method of preventing animal-vehicle collisions is to use sonic deterrents. These deterrents have become a popular choice because they are promoted as humane, cost effective, easy to use, and scientifically sound (Bomford and O'Brien 1990b). There are many brands of passive, wind-driven whistles that are distributed widely in North America, Europe, and Australia. To date there is no evidence that these whistles can be heard above vehicle noise (Scheifele *et al*. 1998), they significantly alter behaviour of target species (Muzzi and Bisset 1990; Romin and Dalton 1992), or they reduce animal-vehicle collisions (Bruinderink and Hazebroek 1996). The author is aware of only 1 active (electronic) device for vehicles, the Shu Roo, which is marketed in Australia for deterring kangaroos from roadways.

The manufacturer claims that the Shu Roo is ‘the ultimate deterrent’ to clear the road of kangaroos and other wildlife. The Shu Roo Mk I® was released in Australia in 1985. A revised version, the Shu Roo Mk II® (hereafter referred to as Shu Roo) was released in 1994, and the Shu Roo Mk IV® is currently available commercially. Pamphlets and instruction sheets produced by the manufacturer claim that the device produces a high - frequency signal inaudible to humans with a frequency range of 17-26 kHz. The high frequency component of the Shu Roo signal is claimed to move kangaroos from the path of the vehicle and warn kangaroos of impending danger because the frequency range produced by the device is used by kangaroos to detect their predators. The Shu Roo is claimed to have a signal noise level greater than 130 dB and to extend 400 m ahead of the vehicle, and 50 m to either side.

My objectives were to: (1) determine the acoustic characteristics of the Shu Roo when mounted on a stationary and a moving vehicle, and (2) to examine how the Shu Roo signal altered flight and vigilance levels of captive eastern grey and red kangaroos.

METHODS

The Shu Roo Mk II® has a signal generator and 2 speakers encased in a rectangular metal housing that is 300-mm wide, 70-mm high, and 70-mm deep. The forward-facing speakers are positioned at each end of the device and covered with a fine mesh grille. At purchase, the Shu Roo comes with an installation instruction sheet stating the device should be mounted on the front of a vehicle 300-1,000 mm above ground in an unobstructed position. One Shu Roo was purchased from a dealer by the Royal Automobile Club of Victoria (anonymously) in July 1997 and used in all laboratory and field tests.

Acoustical characterization tests

I conducted laboratory tests on the Shu Roo in a small anechoic chamber at the University of Melbourne. I made measurements at 1 m from the Shu Roo on 27 July 1997. During post-processing, I determined the signal structure (Eisenberg *et al*. 1975), frequency bandwidth (maximum minus minimum frequency), dominant frequencies (> 70 dB), signal duration (peak to trough on the waveform), inter-pulse duration (from the previous syllable to the subsequent syllable) and signal intensity (amplitude from a power spectrum) (Appendix B).

I conducted field measurements of the propagation pattern of the Shu Roo on 2 different surfaces at 2 sites. I tested the Shu Roo on grass at the University of Melbourne sports oval over 11 days between July and September 1997. I took noise level measurements (dB) every 2 m in the azimuth plane on bearings at 45° intervals, with 0° corresponding to the front of the unit. Microphones were calibrated before and after all measurements, and a wind guard was always used. Background noise levels were measured before each session. Weather conditions during field measurements varied between days, but no measurements were taken when it was raining, to avoid damage to the equipment.

I tested the Shu Roo on a straight bitumen road with grassed verges at the Ford Proving Ground, You Yangs, Victoria on the 18 November 1999. I took noise level measurements (dB) along the centre line of the road at 9 distances in the azimuth plane with the microphone oriented to 0, 45, and 90°, with 0° corresponding to the front of the unit. It was assumed that the noise levels would be the same on both sides of the unit. The microphone and background noise preparations and precautions were the same as those used at the University of Melbourne sports oval (Appendix B). The static propagation pattern and dynamic tests of the Shu Roo when mounted on 4 different vehicles were made at the Ford Proving Ground, You Yangs, Victoria on 14 and 17 November 2000. The Shu Roo was mounted on the fender of each vehicle (Figure 12). I tested 4 types of vehicles: Ford Falcon sedan, Ford Courier 4x4, Ford Cargo Tipper truck, and a Mazda 18-seat bus. All vehicles were positioned close to the centre of the road so that the front right tire of the vehicle was on the centre line and the perpendicular distance from the Shu Roo to the road edge was 3 m (Figure 13)

The microphone was used to represent a kangaroo’s position on the side of the road, either with head down feeding (600 mm) or in a semi-alert posture (1100 mm). I made recordings of 10 s duration at 7 distances from the microphone: 20, 30, 40, 50, 100, 200 and 400 m. I measured distances with a measuring tape, and marked with orange traffic cones on both sides of the road. The 30 and 40-m points were added on the second day due to a rapid drop-off in detection of the signal between 20 and 50 m. Temperature, humidity, wind direction, and wind speed were recorded at the weather station on site.

An assistant drove the vehicles. Three combinations of recordings were made at each distance: (i) Shu Roo off and engine on, (ii) Shu Roo on and engine off, and (iii) Shu Roo on and engine on. I determined the noise level produced by the Shu Roo from post-processing using the same method described for determining static acoustic characteristics.

Figure 12. Shu Roo mounted on the fender of a Ford Cargo Tipper truck at Ford Proving Ground, You Yangs, Victoria, Australia.

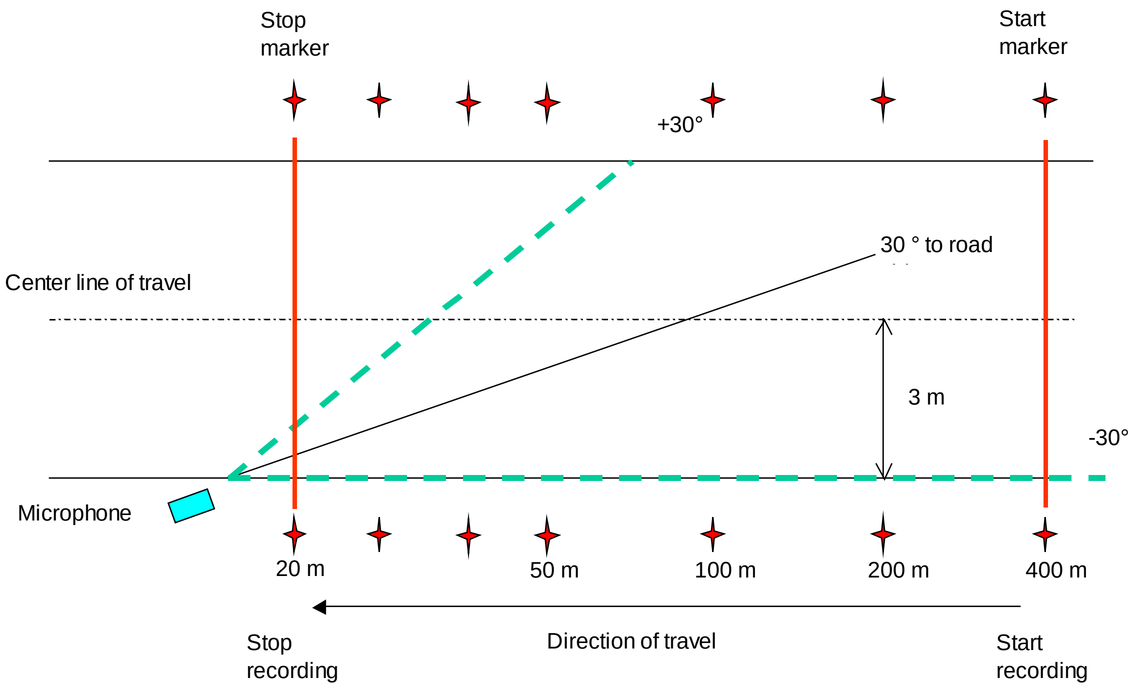


Figure 13. Diagram of equipment arrangement for static and dynamic acoustic characterization tests of the Shu Roo signal on bitumen at the Ford Proving Ground, You Yangs, Victoria, Australia.

I modelled dynamic acoustic characteristics using Microsoft Excel and measured drive-by tests in the field. The same equipment, vehicles, and set-up used in stationary testing were used for the drive-by tests. The static and drive-by tests were run on the same days, providing confirmation that all equipment was functioning correctly (Appendix B).

Three speeds were used for the sedan and 4x4: 80, 100 and 110 km/h. The bus and truck were tested at only 80 km/h because they were unable to reach the other target speeds in the 700 m available. Recording commenced at 400 m and stopped as the vehicle passed the 20-m mark. The 400-m markers were not clearly visible from the recording position, so the driver radioed when reaching this point. I made 2 recordings at each speed, one with the Shu Roo on, the other off. Vehicles were driven at a constant speed over the 380-m course.

Behavioural response

I measured the behavioural responses of captive eastern grey kangaroos and red kangaroos on 15 occasions between 22 July – 11 September 1997 in the kangaroo enclosure at Werribee Open Range Park. Prior to testing, I used the ANABAT II, a heterodyne bat detector that has a flat response to approximately 50 kHz (R. Coles personal communication), to detect the presence and noise level of frequencies similar to those produced by the Shu Roo. I recorded sounds that had ultrasonic frequencies onto a stereo radio cassette recorder (AIWA HS-J380), transmitted to a 486 PC laptop with a Zero Crossing Analysis Interface Module, and analysed with ANABAT software. I measured noise levels with a SPL meter (B&K 2209).

The kangaroo enclosure at Werribee Open Range Park was a 4-ha rectangle consisting of an open grassy field with small clusters of trees along the perimeter. Zoo bus tours and maintenance and feeding vehicles travelled regularly through the enclosure. People on foot were not allowed in the enclosures, and bus tours viewed animals from a distance that did not disturb the animals.

Fourteen (6 female and 8 male) eastern grey kangaroos, and 17 (6 female and 11 male) red kangaroos were held in the enclosure. There were no young at foot or pouch young in this population, as all males had been castrated. Kangaroos often divided into smaller groups within the enclosure, so I set a minimum test group size of 5.

I made observations between 0900 and 1300 h, when kangaroos were often resting close together and there were fewer visitors. The Shu Roo was mounted on the front fender of 3 models of white utility truck following manufacturer's instructions at different heights: 2 Toyota Hilux twin-cabs (540 and 800 mm respectively) and a Toyota Hilux twin-cab 4WD (830 mm). These vehicles were similar to those used for feeding and maintenance within the enclosure, allowing closer approaches during playback trials. The Shu Roo was powered by the vehicle's 12-V battery.

A keeper accompanied the author and an assistant in the vehicle to ensure that the kangaroos were not unduly disturbed by either the vehicle or the sound trials. The assistant drove the vehicle along the circular track near the periphery of the enclosure. Each circuit was considered one trial, with the Shu Roo either being on or off for the entire circuit. The assistant determined whether the Shu Roo was on or off, using a random number table. A minimum of 5 circuits were driven each day, continuing until at least 1 off and 1 on trial was completed. On some circuits the vehicle was taken off the track to point the Shu Roo directly towards a group of kangaroos, although at times the Shu Roo was oblique to the kangaroos. The vehicle was brought to a stop in front of the group at a distance of 20-50 m. The distance was dependent on the kangaroos not becoming overly alarmed. I did not begin a trial until the majority of the kangaroos were in low or non-vigilant postures, and wore earplugs to ensure the Shu Roo could not be heard.

I recorded the vigilance category of each kangaroo once the vehicle had been stopped. Vigilance categories followed Croft's (1981a) definitions of body postures. Three non-vigilant and 5 vigilant postures, corresponding to increasing alarm and ultimately flight, were scored. I made observations with 8 x 40 binoculars from left to right. If an individual changed location during a scan, its movements were noted to avoid recording its response twice. It was assumed that a kangaroo's response would be independent on subsequent days.

I used Chi-square contingency table analyses to test for patterns in the categorical variable, vigilance, between treatment (Shu Roo on) and control (Shu Roo off) trials. Only the observations from the first inactive and the first active trial for each day were included in the statistical analyses, and only one randomly-selected focal animal from each trial was included in the data set. Adjusted residuals were used to determine the significance of individual cells in Chi-square analyses. The α level for all significance tests was set at 0.05, but the Bonferroni correction for repeated testing changed the significance level for all tests to 0.01.

RESULTS

Acoustical characterization

The Shu Roo produced a noisy, descending, single-syllable signal that was repeated approximately 2 times per s (Figure 14). The signal descended from 24 - 15 kHz, with the greatest energy (73 dB) at 17 kHz (Figure 14). It therefore contained a mix of audible and ultrasonic frequencies that could be described onomatopoeically as "zip zip." Its short syllable (< 0.6 s) was repeated continuously, with each syllable 0.45 s on average, and an inter-syllable duration of 0.15 s on average. Signal intensity at 1 m was 73 dB at 17 kHz in the laboratory, and 85 dB at 17 kHz on bitumen.

Field measurements of the Shu Roo noise levels are displayed as polar diagrams to show the propagation pattern of the signal, with interpolation between points with the same sound level on different bearings to create dB contours (Figure 15). Noise levels were greatest in the static tests using the 16 kHz 1/3 rd octave filter, so diagrams using this filter only are presented here. Background noise levels were similar for both the grass and bitumen tests (15 dB). It was assumed that there was excess attenuation of 5 dB over 10 m based on an ambient temperature of 20º C and 50% relative humidity. Consequently, a theoretical reduction in signal level of 10 dB at 20 m and 24 dB at 50 m was expected.

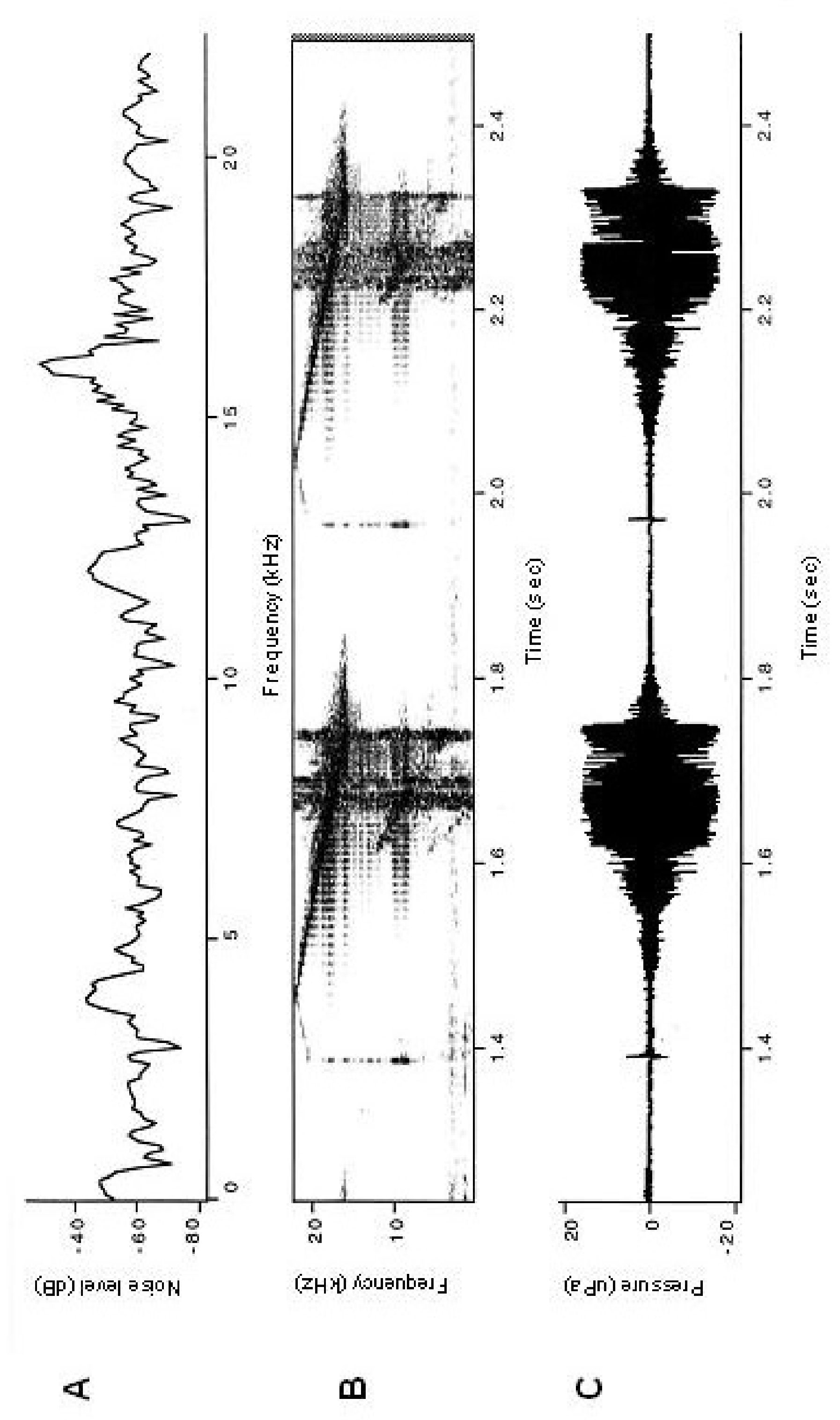


Figure 14. Acoustic characteristics of the Shu Roo signal: power spectrum (A), sonogram (B), and waveform (C).

The signal propagation pattern was similar over grass and bitumen. The signal noise levels were similar on both sides of the device, loudest to the front (0°), and quietest at the back of the unit (180°). The signal could be detected at 50 m between 0 and 90° on grass and on bitumen (Figure 15). There was no significant difference in the mean noise level of the Shu Roo at 50 m when played on grass or bitumen ($F_{1,270} = 0.126$, $p = 0.726$).

The dynamic tests with the Shu Roo active showed that there was no increase in the sound pressure level of the signal frequencies, compared to when the Shu Roo was inactive, for all vehicles and speeds except the sedan at 100 km/h and the truck at 80 km/h (Table 1).

Behavioural response

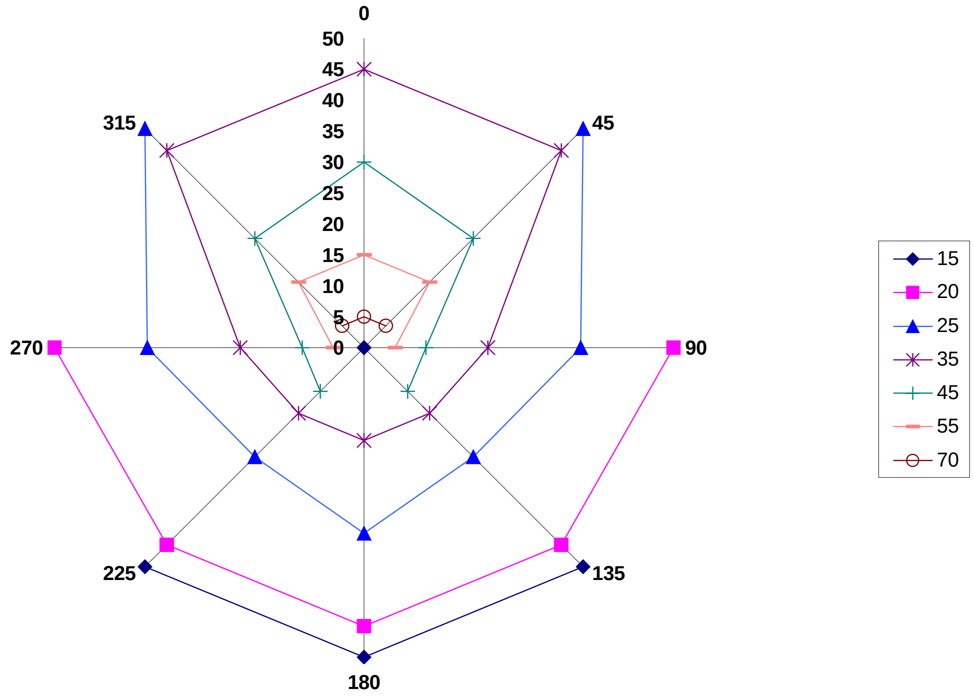
Vigilance response did not differ significantly between Shu Roo treatments for the eastern grey or red kangaroos ($\chi^2 = 0.667$, df = 1, $p = 0.414$, $\chi^2 = 0.202$, df = 1, $p = 0.653$), respectively (Figure 16). Background vigilance levels were high for both kangaroo species, with over 40% in a crouch or higher vigilance posture when the Shu Roo was off (Figure 16). However, no kangaroos took flight.

DISCUSSION

Acoustical characterization

Static tests of the Shu Roo showed that many of the claims made by the manufacturer were not supported. The dominant frequency in the Shu Roo signal was 17.1 kHz, which is audible and therefore not ultrasonic. The average sound pressure level produced by the Shu Roo was 85 dB resulting in detection to a maximum of 100 m on bitumen, a quarter of that claimed by the manufacturer.

A



B

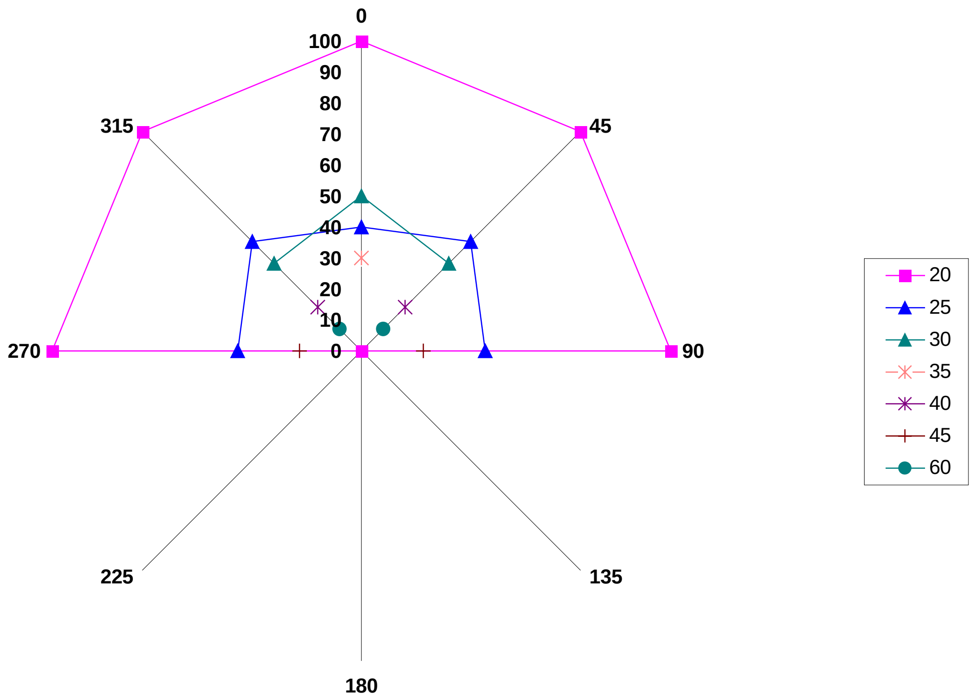


Figure 15. Polar diagrams showing the propagation pattern of the Shu Roo signal on grass (A) and on bitumen (B) when mounted on a retort stand at the Ford Proving Ground, You Yangs, Victoria, Australia. The background noise level on the grass and the bitumen was 15 dB. The Y axis shows distance (m) and the legend sound pressure level (dB).

Table 1. Sound pressure levels (dB) of dominant frequency when the Shu Roo was inactive and active in dynamic drive-by tests, filtering for the 1/3 rd octave surrounding 18 kHz.

Vehicle	Speed (km/h)	Shu Roo off	Shu Roo on
		Sound pressure level (dB re 20 uPa)	
Sedan	80	45	42
	100	38	44
	110	42	37
4 x 4	80	46	38
	100	40	40
	110	39	39
Truck	80	38	46
Bus	80	35	34

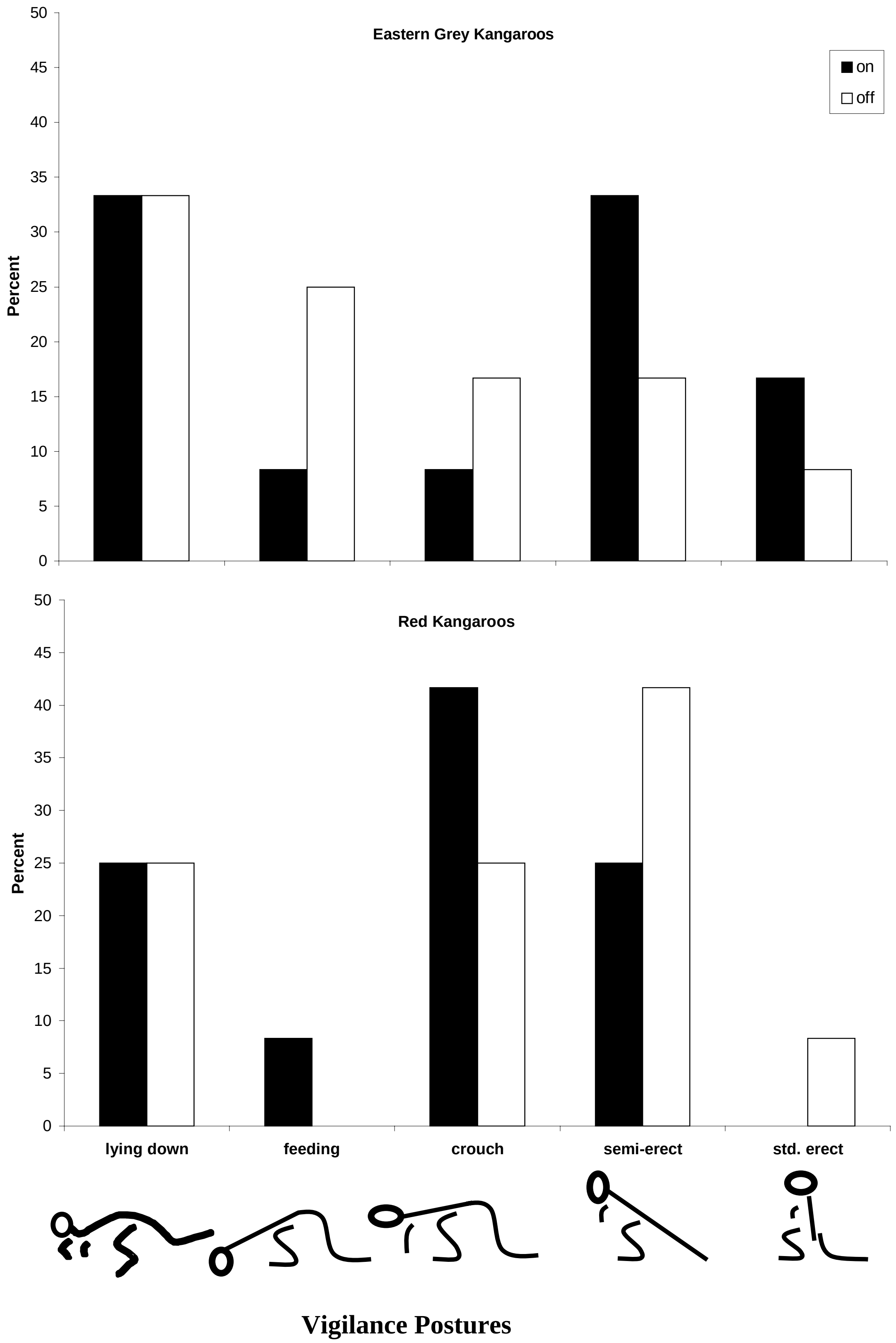


Figure 16. The proportion of captive eastern grey and red kangaroos that were vigilant in response to the Shu Roo when active and inactive. *n* is 12 for the Shu Roo on and off.

Dynamic tests of the Shu Roo also found the manufacturer's claims were not supported. The dominant frequency remained within the human hearing range (20 Hz – 20 kHz). The Doppler effect due to the compression of sound waves as a sound source moves forward in space so that a stationary receiver perceives a higher frequency signal as the sound source approaches, would increase the apparent frequency to only 18 kHz at 100 km/h. No detectable coverage was provided by the Shu Roo signal during dynamic tests on bitumen, because the sound pressure level recorded was fully attributable to road and engine noise produced by the vehicle, despite the manufacturer claiming the device provided 400-m coverage in front of the vehicle. Signal attenuation results from geometrical spreading (cylindrical and spherical) from a coherent source (Piercy *et al*. 1986) as well as absorption (Scheifele *et al*. 1998), and increases exponentially with increasing frequencies above 8 kHz (Beranek 1971; Manning 1981), resulting in higher frequency signals having reduced propagation distance. Attenuation could be overcome by having a much louder source signal (e.g., > 130 dB), but the Shu Roo produced a signal of only 85 dB at the dominant frequency in the static environment, which was inadequate to overcome attenuation in a dynamic situation.

Other studies that have evaluated commercial ultrasonic deterrents have found that the signals also do not contain ultrasonic frequencies, and the coverage is less than that claimed (e.g., Bender 2003). Similarly, tests of dynamic ultrasonic devices have also found no detectable coverage because the road and engine noise were greater than that produced by the device (e.g., Scheifele *et al*. 1998).

Behavioural response

Captive eastern grey and red kangaroos did not become alert or take flight in response to the Shu Roo signal contrary to the manufacturer's claims. Based on the static trials, the Shu Roo was at a distance that should have resulted in a signal audible to the kangaroos. The kangaroos did look towards the device, but this occurred both when it was on and off, suggesting it was not the auditory signal that was attracting their attention. Behavioural trials with ultrasonic deterrent devices on eastern grey kangaroos (Bender 2003), Tasmanian pademelons (*Thylogale billardierii*) and Bennett's wallabies (*M. rufogriseus*) (Statham 1993) and other species (Bomford and O'Brien 1990a; Mills *et al.* 2000; Tanner *et al.* unpublished data) have also found that they do not result in increased alertness or flight..

Guppy (1985) showed that the gain created by the pinna of the eastern grey kangaroo was 30 dB at 1.7-3.5 kHz, 10 dB at 16 kHz, and had a local peak in gain of 17 dB at 18 kHz. The sound intensity level of the Shu Roo, at the maximum playback distance of 50 m, was 35 dB, approximately equivalent to a whisper (Lara-Saenz 1986). With the gain created by the pinna, the dominant frequency of the Shu Roo signal would be amplified to 52 dB at the eardrum. This signal level is approximately equivalent to a quiet electric shaver (Lara-Saenz 1986) and unlikely to be aversive.

A flaw of this study was to test only one Shu Roo. It is possible that this device was faulty; consequently, caution should be taken in interpreting the results and extrapolating the findings reported here. Future studies should test multiple units including subsequent Shu Roo models.

MANAGEMENT IMPLICATIONS

The promotional literature proclaiming the scientifically proven efficacy of this ultrasonic deterrence device, the Shu Roo, was not supported by this study. The static and dynamic acoustic characterization and the behavioural response trials generate four clear conclusions: (1) The Shu Roo does not produce a pure ultrasonic signal in either the static or dynamic context, (2) The Shu Roo does not produce sound detectable at 400 m, (3) The Shu Roo signal cannot be detected at any distance above the road and engine noise generated by a moving vehicle, and (4) The Shu Roo does not alter behaviour of eastern grey kangaroos or red kangaroos.

The Shu Roo is marketed as being effective for kangaroos and wallabies. I found that eastern grey kangaroos and red kangaroos did not alter their behaviour when presented with the Shu Roo. Similarly, Bender (2003) and Statham (1993) found that the ROO-Guard®, a static ultrasonic deterrent device marketed for control of kangaroos and wallabies in agricultural areas, did not alter the behaviour of eastern grey kangaroos, red kangaroos, Bennett's wallabies, Tasmanian pademelons, European rabbits (*Oryctolagus cuniculus*) or common brushtail possums (*Trichosurus vulpecula*).

The ineffectiveness of the Shu Roo should caution against the use of other ultrasonic deterrent devices on moving vehicles for kangaroos. This study further supports the increasing evidence that ultrasonic devices do not provide persistent effects on the behaviour of animals (Dryden *et al.* 1989; Bomford 1992; Coleman and Tyson 1994; Haag-Wackernagel 2000).

CHAPTER 5 - THE EFFECTIVENESS OF AN ULTRASONIC DETERRENT IN REDUCING THE RATE OF MACROPOD-VEHICLE COLLISIONS

Submitted as – Bender, H. and Coulson, G. (2005). The effectiveness of an ultrasonic deterrent in reducing the rate of macropod-vehicle collisions. *Wildlife Research*.

Abstract: Collisions between vehicles and macropods, particularly the larger kangaroo species, are a management problem in rural Australia. These collisions cause damage to vehicles, may injure the occupants of the vehicle (sometimes fatally), and raise concerns for animal welfare and conservation of threatened species. A popular approach to reducing the risk of macropod-vehicle collisions is to install acoustic deterrents with an ultrasonic frequency range. We tested the efficacy of one active ultrasonic device, the Shu Roo, which is marketed in Australia specifically to deter kangaroos from roadways. We contacted private transport companies and government departments that operated fleets of similar vehicles travelling consistent routes over long distances in rural areas, some fitted with Shu Roos and others not. A total of 31 fleet operators agreed to participate in the study, which ran from 1997 to 2000. We asked drivers to keep a log of the number of collisions with kangaroos and wallabies over the total distance they travelled, and whether or not they had a Shu Roo operating on the vehicle. The vehicles involved in the survey travelled an average of 49,612 km. and there was no significant difference in distance travelled by vehicles with a Shu Roo and the controls (no Shu Roo). Only 16% of vehicles hit a macropod ($n = 26$) over the survey period, and there was no significant difference in the proportion of vehicles with and without a Shu Roo that hit macropods. The overall mean (± SE) rate of collisions with macropods was 10.86 ± 3.52 hits km^{-6}, and again there was no significant difference between vehicles with and without a Shu Roo. Our study is the first systematic evaluation of the effectiveness of the Shu Roo, covering long distances over a range of seasonal conditions, moon phases and times of day. We conclude that the Shu Roo is not effective in reducing collisions with macropods.

INTRODUCTION

Collisions between vehicles and macropods, particularly the larger kangaroo species, are a management problem in rural Australia (Domico 1993). In Victoria, for example, collisions with macropods make up almost 60% of insurance claims, and it is believed that the collision rate is increasing (Anderson 2003). These collisions can cause significant damage to the vehicle, resulting in estimated financial costs of $3000 per incident (Kangaroo Advisory Committee 1997). They can also cause injury to the occupants of the vehicle and occasional human fatalities, typically when the driver tries to avoid the animal on the road

(Abu-Zidan, Parmar et al. 2002). The consequences for the macropod involved in the collision are less clear, since documentation of collisions is often incomplete, but these incidents raise obvious animal welfare concerns, and may contribute to threats against endangered species such as the Proserpine rock-wallaby, *Petrogale persephone* (Johnson, Nolan et al. 2003). However, the macropod species most often involved in collisions are common and widespread: eastern grey kangaroo, *Macropus giganteus*, western grey kangaroo, *M. fuliginosus*, red kangaroo, *M. rufus*, common wallaroo, *M. robustus*, red-necked wallaby, *M. rufogriseus*, and swamp wallaby, *Wallabia bicolor* (Coulson 1997; Lee, Klocker et al. 2004).

The most common method of protecting the vehicle and its occupants from collisions with macropods is by fitting impact bars, which are also known as 'bull bars' or 'roo bars'. Impact bars are generally effective in reducing the damage from collisions, but the role of these bars is contentious because of their effect on other vehicles and pedestrians, particularly in urban areas (Jones 1994, Tomas 1994). Primary safety methods, which are aimed at reducing the occurrence of collisions, so far show little promise. Studies of wildlife warning signs have shown no reduction in the rate of kangaroo road kills or driver speed (Coulson 1982, 1985; Kangaroo Advisory Committee 1997). Wildlife reflectors such as Swareflex, which are designed to discourage macropods from entering roads, have also been found to be ineffective under field conditions (Aspinall 1995, Lintermans and Cunningham 1997).

Another primary safety technique is the use of acoustic deterrents with an ultrasonic frequency range that can be fitted to vehicles. These devices are popular with the general public (Domico 1993), presumably because they apparently do not harm the animal and, as they operate above the range of human hearing, do not irritate the occupants of the vehicle. Ultrasonic deterrents may be passive (wind-driven) or active (electronic). There are a number of brands of passive whistles that are distributed widely in the United States, Europe, and Australia (e.g., Muzzi and Bisset 1990; e.g., Romin and Dalton 1992; Bruinderink and Hazebroek 1996). We are aware of only one active device for vehicles, the Shu Roo, which is marketed in Australia specifically to deter kangaroos from roadways. The Shu Roo is claimed to have a signal noise level greater than or equal to 130 dB, and to form a ‘pear shaped sound pattern’ that extends 400 m ahead of the vehicle, and 50 m to either side (Gore 1994). The high frequency output (16-24 kHz) is said to be in the range that kangaroos use to detect their predators, encouraging them to flee from the path of the vehicle (Gore 1994). Despite these claims, the performance of the Shu Roo in deterring free-ranging macropods from roadways remains untested. Our study aimed to test the efficacy of the Shu Roo in a field setting, by comparing the rate of collisions with macropods by vehicles fitted and not fitted with a Shu Roo.

METHODS

We identified possible users of the Shu Roo through the Yellow Pages, internet listings, list servers of the Australasian Wildlife Management Society and Ecology Society of Australia, and through referrals. We sought private companies or government departments that operated fleets of similar vehicles travelling consistent routes over long distances in rural areas. Routes were chosen because there was a high risk of collision, and owners of vehicles had invested in the Shu Roo because of the risk of collision with macropods.

We considered issuing drivers with a random set of disabled Shu Roos, however, two ethical issues prohibited this obvious scientific approach. The first was based on the assumption that if the Shu Roo was effective in deterring kangaroos from roadways, then fitting a disabled Shu Roo to the front of a vehicle increased the risk of a kangaroo being injured or killed by a vehicle. Following from this, it was considered ethically inappropriate to put drivers at risk of a potentially dangerous collision with a kangaroo by disabling the Shu Roo that they would believe to be functioning correctly. Consequently, we sought vehicles that were fitted with Shu Roos and others not, ideally within the same fleet and operating in the same areas. We targeted bus and truck companies in particular, but a range of other operators such as ambulance, police, local council and state wildlife agencies, also met these criteria. We initially restricted our survey to

Victorian-based fleet operators for ease of communication, then expanded our search to all Australian states and territories.

We initially contacted the fleet operator either by letter, telephone, email, or facsimile. We contacted the first operators in 1997 and continued until late 2000, contacting a total of 278 operators. At initial contact, we outlined the project and requested participation in a field survey to the efficacy of the Shu Roo, but offered no financial remuneration. It was difficult to locate and then convince fleet operators to participate in the survey: many replied that they were too busy, or did not provide access to appropriate staff within the organisation, and some operators refused to participate because of their previous negative experience with the Shu Roo. Many of the fleets that used Shu Roos had them on all their vehicles, resulting in an absence of controls; we found it hard to convince other operators, who were not using Shu Roos, of the benefits of participating in the survey to balance the design.

When a fleet operator agreed to participate, we sent a letter outlining the purpose of the study, and a sample data sheet. We made a follow-up telephone call shortly after to ensure the operator was still willing to participate, and to acquire information about the number of vehicles that would be involved and how many were fitted with the Shu Roo. The fleet manager was generally the point of contact. Managers typically expressed enthusiasm when first contacted, but some withdrew from the survey when they or their drivers found the task too onerous. A number of managers withdrew because their drivers refused to record their odometer readings, presumably to avoid inconsistency with their records for transport authorities. In the early stages of the project we also visited some fleet depots to outline the project directly to the drivers, and to obtain their feedback on methods for recording data. In August 2000, we sent an information sheet to all participants, which outlined the project, introduced the staff involved, summarised the results to date and sought contacts for potential new participants.

A total of 31 fleet operators agreed to participate in the survey, although we received data from only 15. Their vehicles and the routes they covered included heavy trucks on interstate routes, buses from Melbourne to regional centres in Victoria and Southern NSW, ambulances and police vehicles in western Victoria, passenger vehicles operated by two rural shire councils, and a rural taxi company. The survey ran from August 1999 to 30 January 2001, and operators joined and left the survey over this time. Each operator was based in one of four states, most being based in Victoria (Table 2). All participating fleets included at least one vehicle fitted with a Shu Roo (treatment), but many also had vehicles without a Shu Roo (control). Table 2 lists the number of operators in the survey and the proportions of and vehicles with and without Shu Roo. Some vehicles were reported to have been driven with the Shu Roo not functioning during part of the road survey, so we transferred them to the control group for that period.

We asked fleet managers whether they were aware of the Shu Roo, whether they had fitted the device to their vehicles and, if so, their level of satisfaction with it. Through the managers, we asked drivers to keep a log of the number of collisions with kangaroos and wallabies over the total distance they travelled. Near misses with kangaroos were not included as they could suggest that the Shu Roo was effective. We did not ask drivers to distinguish between macropod species. We requested copies of their data sheets once per month, or whenever collisions occurred. Our method of receiving this data was flexible to make this process as convenient as possible for the drivers and manager; some submitted their data by email, others by telephone or facsimile.

RESULTS

The number of fleet operators contacted in each state per state, and operators' responses to our contact are summarised in Table 2. Only 6.3% of respondents stated that they were unaware of the Shu Roo, but there were mixed views about its efficacy. For example, one operator based in Victoria stated that they had used the Shu Roo for six years without hitting a kangaroo, while another respondent in South Australia said that they had used the Shu Roo for only one day when they hit a kangaroo, destroying the Shu Roo and damaging the radiator.

Overall, the vehicles involved in the survey travelled an average of 49,612 km. The distributions of distance travelled by treatment and control vehicles were not normal and their variances were unequal, so we used the non-parametric Mann-Whitney U test to compare the two groups. This analysis showed that there was no difference in distance travelled by vehicles fitted with the Shu Roo and the controls ($U = 1010.0$, $df = 94$, $p = 0.278$). Most trucks travelled between Melbourne, Sydney, Adelaide and Brisbane, but vehicles that drove shorter distances generally did not specify their routes. We treated each vehicle as an independent sampling unit, regardless of type, distance or route. Of these vehicles, only 16% were reported to hit a macropod over the survey period. There were two obvious outliers in this data set, both in vehicles fitted with a Shu Roo: one Victorian-based driver reported hitting 39 kangaroos in one night, and a Queensland-based driver reported 25 hits. When we excluded these outliers (giving $n = 96$ vehicles and $n = 26$ hits) there was no difference in the proportion of vehicles with and without a Shu Roo that were reported to hit macropods (Chi-square 2 x 2 contingency table, $\chi^2 = 2.762$, $df = 1$, $p = 0.097$). When we considered the distance travelled by these vehicles, the overall mean (± SE) rate of collisions with macropods was 10.86 ± 3.52 hits km^{-6}. The high proportion of zeroes in the data for individual vehicles necessitated a non-parametric test to compare the hit rates of vehicles with and without a Shu Roo, showing that there was no difference between them (Mann-Whitney $U = 990.5$, $df = 94$, $p = 0.117$).

DISCUSSION

There is a general perception that collisions with kangaroos are common and perhaps even increasing (Lintermans and Cunningham 1997; Anderson 2003) on mainland Australia, but this perception was not supported by our study. Although each vehicle travelled over 49,000 km on average, 84% of participating vehicles did not hit any macropods during the survey period. This contrasts the hit rate observed in Tasmania, where the density of macropods is much higher (Magnus *et al.* 2004).

Table 2. The number of fleet operators in each state contacted from August 1997 to November 2000, their response to an invitation to participate in the Shu Roo road survey, and their response when asked if they were aware of the Shu Roo.

	State								
Response	VIC	NSW	QLD	WA	SA	ACT	NT	National	**% of Total**
Use Shu Roo - participant in survey	12	4	2	1	5	1	0	0	9.0
Use Shu Roo – unwilling to participate	9	0	0	0	1	0	0	0	3.6
Have used Shu Roo, but no longer have any fitted	11	3	2	1	0	0	0	0	6.1
Aware of Shu Roo, but have never fitted any	70	41	32	9	13	4	1	0	61.2
Not aware of Shu Roo	5	3	4	2	1	0	0	1	5.6
Do not use Shu Roo, but awareness not specified	2	0	4	8	0	0	0	2	5.6
Did not respond	11	5	4	2	2	0	0	0	8.6
Total	120	56	48	23	22	5	1	3	278

Despite the low rate of collisions with macropods, the efficacy of the Shu Roo could still be assessed from the 26 hits recorded. Whether compared simply in terms of the proportion of vehicles that hit macropods, or the rate of hits per distance travelled by each vehicle, there was no difference between vehicles with or without a Shu Roo. This finding for the active Shu Roo device conforms with studies of passive ultrasonic whistles, which have found no evidence that whistles can be heard above vehicle noise (Scheifele, Browning et al. 1998), or significantly alter behaviour of mule deer, *Odocoileus hemionus*, (Romin and Dalton 1992), or reduce ungulate/vehicle collisions in Europe (Bruinderink and Hazebroek 1996). However, in a study similar to ours, Muzzi and Bisset (1990) compiled reports by train crews operating on a line in Ontario, Canada, and concluded that trains fitted with whistles hit fewer moose, *Alces alces*, than did trains without whistles, and that moose and white-tailed deer, *O. virginianus*, were more likely to flee from trains with whistles.

This study was not a formal experiment, so we could not match or randomise the participants in terms of their vehicle type, route travelled or driver behaviour, particularly whether the drivers were more or less cautious when driving a vehicle fitted with the device. We were also reliant on drivers and fleet managers reporting their distances and macropod hits accurately, as were Muzzi and Bisset (1990) in their study of train crews. However, the long duration of the survey allowed us to haphazardly cover a range of seasonal conditions, moon phases and times of day that were likely to influence the rate of collisions with macropods (Coulson 1982; Coulson 1989; Osawa 1989; Lee, Klocker et al. 2004). The vehicles also passed through habitats perceived by the fleet operators to have high densities of macropods, so the field conditions were realistic.

Our study is the first systematic evaluation of the effectiveness of the Shu Roo. Contrary to the manufacturer’s claims (Gore 1994), the signal produced by the Shu Roo is not detectable above vehicle noise at 400 m (Chapter 4). Trials of the Shu Roo in a static situation have shown that the signal does not alter the behaviour of either captive eastern grey kangaroos or red kangaroos (Chapter 4).

Our study shows that the Shu Roo is also not effective in reducing the rate of collisions between vehicles and macropods.

CHAPTER 6 - STRUCTURE AND FUNCTION OF THE EASTERN GREY KANGAROO FOOT THUMP

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Abstract: Most species of the family Macropodidae (kangaroos and wallabies) make a distinctive foot thump by striking the ground with their hind feet when they detect potential danger. I used the eastern grey kangaroo, *Macropus giganteus*, as a model to examine (1) the acoustic characteristics and structure of the thump, (2) the social context in which free ranging kangaroos thumped when approached by a human observer on foot, and (3) the intended recipient of the signal. Thumps were about two-thirds of a second in length, generally composed of two noisy pulses, and had the majority of the signal energy below 7 kHz. Only adult kangaroos, of both sexes, were observed to thump. A higher proportion of solitary kangaroos thumped than grouped kangaroos, and a higher proportion of kangaroos thumped when visibility was poor, either because of habitat type or low light levels. Given the context in which thumps were given, the foot thump appears to be a signal to a potential predator with three possible functions: to startle, signal detection, or deter pursuit.

INTRODUCTION

Alarm signals are generally defined as signals given by a prey animal prior to or during an attack by a predator (Klump and Shalter 1984). Such signals are often associated with flight into cover and/or freezing of the caller (Klump and Shalter 1984). Signalling alarm may lower or increase the risk of the caller, or that of its kin, to predation by drawing attention to the signaller (Blumstein *et al.* 1997). The function of the signal may depend on who the signaller is, the medium of the signal, the context in which the signal is given, and the receiver, intended or otherwise (e.g., Busnel 1977; Gould 1983). The context of the alarm signal may vary with the predator type, the prey's social system and sex, distance between the predator and the prey, and the habitat in which the encounter occurs (e.g., Busnel 1977; Zuberbuhler *et al.* 1997). The intended receiver may be other conspecifics, including kin, or a predator. Unintended receivers may include all species within range of the alarm signal.

Drumming or thumping is one form of signalling alarm in a wide variety of taxa, including African and Asian elephants, *Loxodonta africana* and *Elephus maximus* (O'Connell-Rodwell *et al.* 2001), white-tailed deer, *Odocoileus virginianus* (Caro *et al.* 1995), spotted skunks, *Spilogale putorius* (Crabb 1948), banner-tailed kangaroo rats, *Dipodomys spectabilis* (Randall and Stevens 1987), great gerbils, *Rhombomys opimus* (Randall *et al.* 2000), European rabbits, *Oryctolagus cuniculus* (Ewer 1968), Eurasian coots, *Fulica atra* (Richardson 1982), and damp wood termites, *Zootermopsis nevadensis* (Kirchner *et al.* 1994). It has also been reported in marsupials such as the brush-tail phascogale, *Phascogale tapoatafa* (Cuttle 1982), Tasmanian devil, *Sarcophilus harrasii* (Eisenberg *et al.* 1975), and tammar wallaby, *M. eugenii* (Blumstein *et al*. 2000). Percussive signals like these have a seismic component in addition to the air-borne signal (Hill 2001). Studies of foot drumming have concluded that this signal may serve to warn juveniles of danger, as it does in the great gerbil (Randall *et al.* 2000), or may deter pursuit by predators, as in the banner-tailed kangaroo rat (Randall and Matocq 1997).

Most species of the family Macropodidae also make a distinct foot thump by striking the ground with their hind feet when they detect potential danger (Russell 1984; Coulson 1989). Three adaptive functions have been suggested for thumping in macropods: (1) warning nearby conspecifics of potential danger (Croft 1981; Aguero *et al.* 1991; Coulson 1996), (2) startling the predator to momentarily distract it and increase the probability of escape, and (3) deterring pursuit by a predator by signalling to the predator that it has been detected (Coulson 1996). Whether the foot thump is a signal to conspecifics or the predator, or both remains unclear.

Eastern grey kangaroos make a particularly loud and conspicuous foot thump when they detect a potential predator (Kaufmann 1974, 1975a, b; Coulson 1997b). Typically, a disturbed kangaroo will take flight, producing the thump in the first couple of hops. Nearby conspecifics either become alert or take flight (Kaufmann 1974, 1975a, b; Coulson 1997b). In this paper, I examine the acoustic characteristics of the thump, describe the age and sex classes of kangaroos that thump in the presence of a human observer, the context in which thumps were emitted, such as habitat and light conditions, and the intended recipient of the thump: kin or predator.

METHODS

Study site

This study was conducted at Yan Yean Water Catchment, which is located in Victoria, Australia, 37 km north-east of Melbourne. Yan Yean is 2250 ha in area and supports approximately 2000 kangaroos (Moore *et al.* 2002). The vegetation within the catchment varied in structure from open grassland to woodland with a dense shrubby understorey (Coulson *et al.* 2000). The western side of the catchment has non-uniform tree cover with many small clearings. Large parts of the study area are covered by relatively undisturbed forest, although there are a range of other habitat types in small areas, including a mature plantation of Monterey pine, *Pinus radiata* (Moore *et al.* 2002). Lower-lying and less well-drained areas, particularly in the south-east of the catchment, have a moderately dense understorey. Higher elevations, particularly in the north-east of the catchment, have a substantial understorey. An extensive network of vehicle tracks, and well-worn trails made by kangaroos, allowed access, and facilitated observation throughout the study site.

Recording technique

Eastern grey kangaroos are most active at dawn and dusk (Clarke *et al.* 1995), therefore I collected observational data and audio recordings when walking at dusk (15:30 – 18:30) over a 15-week period from mid-March to early September 1997. I made audio recordings and observations while walking along vehicle tracks and kangaroo trails. I sampled all of the vehicle tracks within the catchment, which ranged in length from 3.75 – 7.0 km, at an average speed of 3.5 km/h. Vehicle tracks occurred along the perimeter of eight areas. I sampled areas 3 and 5 only once, areas 1, 4 and 6 twice, and areas 2, 7 and 8 three times (Figure 17). I walked along tracks more than once because of the greater number of kangaroo encounters. At least two days were left between each walk, and given the large population size it is unlikely that individuals were sampled more than once. Walking on these tracks was relatively quiet and quick, reducing the auditory stimuli and time available to kangaroos to respond to my presence.

I sampled six kangaroo trails in the northern section of the water catchment (Figure 17). I walked three trails more than once, with a minimum of one day between each walk to reduce habituation. Trails ranged in length from 1.5 – 4.5 km, and I walked them at a slower average speed of 2.6 km/h, because some clearing of vegetation was required.

Whenever I detected a kangaroo or kangaroos I approached them at a steady pace, until they fled and/or thumped. I assumed that I would be perceived as a predator by the kangaroos because humans are one of their major terrestrial predators (Robertshaw and Harden 1989). At each encounter I noted the group size, age and sex composition, as well as the habitat type, wind direction, time of day, and ambient light levels. To ensure that the kangaroos had detected my presence, I only considered animals that fled. I noted whether the kangaroos thumped, the distance to the thumping kangaroo before it took flight, and if other kangaroos in the vicinity responded by thumping or taking flight. Foot thumps were categorised as either a single or series of thumps, where a series was when more than one thump occurred in a row, with a few hops in between. When kangaroos that I could not see gave a thump, I noted their approximate location. Context data was not recorded in early samples (17-29 March 1997) because the emphasis then was to make as many audio recordings of thumps as possible.

Acoustic characterization

I made audio recordings of thumps from 21 May 1996 – 19 May 1997 using a shot-gun microphone (Sennheiser MZW-816), with a range of 40 Hz – 20 kHz, with a powering module (K 3 N) attached to an audiotape recorder (Sony Stereo Cassette-Corder TC-D5 Pro II), with a range of 40 Hz – 16 kHz, set at an average recording level of 8.5.

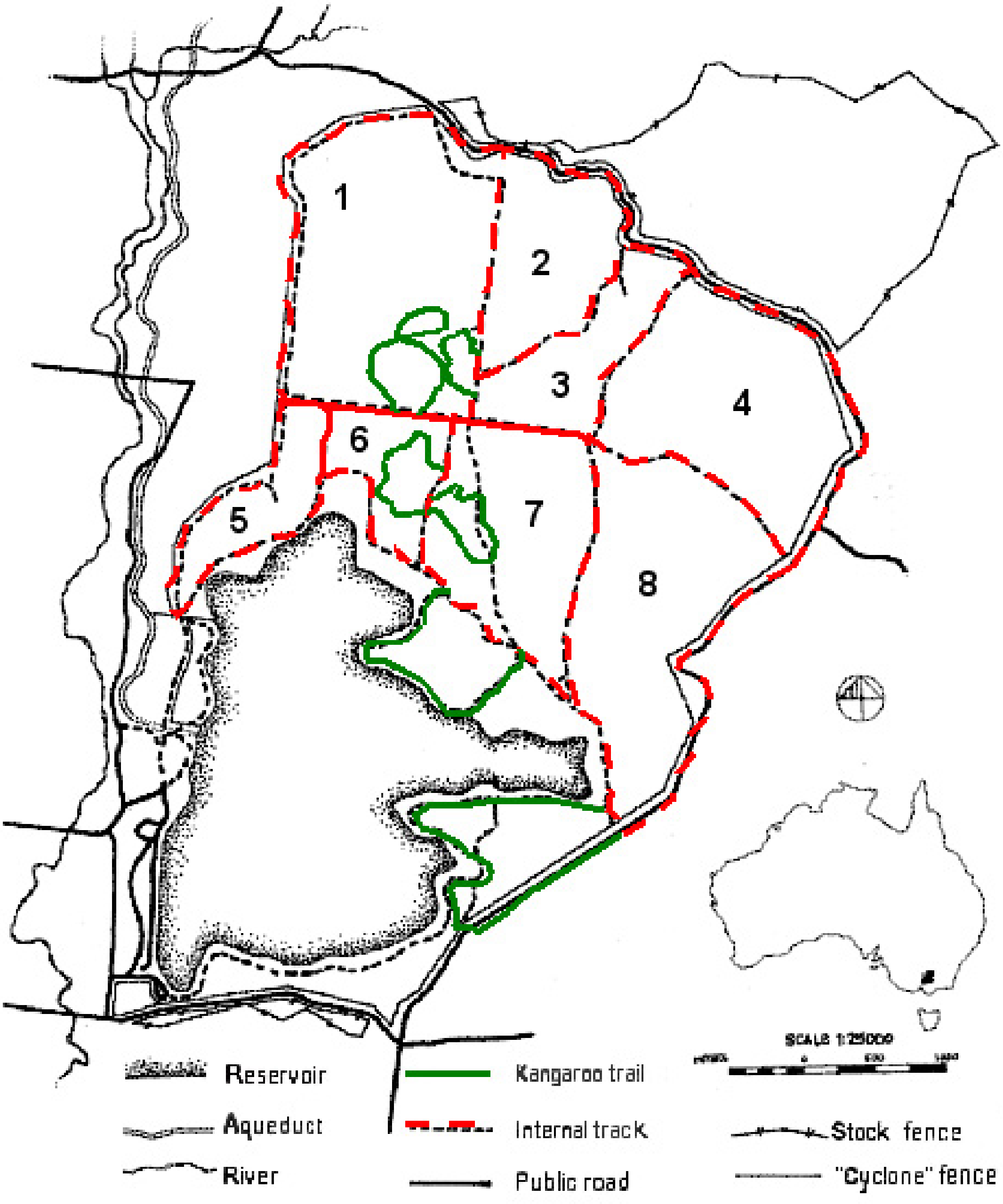

Figure 17. Map of the Yan Yean Water Catchment showing the maintenance and kangaroo tracks.

I recorded a total of 48 single thumps, 13 repeated thumps, and 48 hops. Recordings were digitally transferred using a system adapter kit (Sony RM-D100K) and Sound Forge (XP 4.0d) software with a sampling rate of 48 kHz and 16 bit resolution sample size. A resistor was used to control for varying levels of background noise; as background noise increased, resistance was increased. During post-processing, 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 inter-pulse interval (from the previous syllable to the subsequent syllable) for each foot thump and hop recording.

Contextual observations

I determined the sex of the thumping kangaroo and classed it either as young-at-foot, sub-adult, or adult. If the sex and age class was uncertain then the individual was categorized as unidentified. I categorised individuals as either solitary, paired, or in a group, where a group was ≥ 3 individuals. I made distance measurements to the location of the kangaroo at the initiation of flight, or the approximate thump source, with a Bushnell Lytespeed 400 laser rangefinder, and estimated distances less than 21 m (the lower limit of the rangefinder) by eye.

Four habitat categories were used: open grassland, woodlands, pine forest and undergrowth. Open grassland included clearings of various sizes with grass but no tree cover. Woodlands were defined as having trees with rounded crown foliage and visibility to greater than 200 m, with a predominance of *Eucalyptus*. Pine forest was defined as a stand of Monterey pine trees with no understorey or ground cover. Undergrowth was predominantly drooping cassinia, *Cassinia arcuata*, and was further categorized by its height: low, medium or high. Low undergrowth allowed visibility through and over the scrub, medium could only be seen over by an erect kangaroo, or myself, and high obstructed all visibility. Undergrowth was also observed in woodland and grass habitats but was in small clumps.

I measured wind direction using the cardinal points of the compass, and recorded it in relation to the position of the observer and the kangaroos. I measured ambient light levels using a Minolta Flash Meter IV.

Analyses

I determined the relative frequency of foot thumps, for different group sizes, sex/age classes, and habitat types using Chi-square and standardised residual analysis. I used the same analysis for the frequency of males and females, and of group size in each habitat type. I tested the relative frequency of thumps at different flight distances using a Median test due to the non-normal distribution of the flight distance data. I tested the relationship between foot thumping and wind direction and light levels using an ANOVA because the wind direction and light level data were symmetrically distributed and sampled at random. I grouped reaction distances into 20-metre classes, and excluded pine forests from the analysis because there were only two observations.

RESULTS

Acoustic characteristics

I analysed 46 of the 61 recordings of foot thumps for their acoustic characteristics. Thumps were generally composed of two low frequency noisy pulses (*sensu* Eisenberg *et al.* 1975) created by each foot striking the ground separately (Figure 18). The majority of the signal energy was below 7 kHz, but part of the signal merged with the background noise, making the minimum frequency indeterminate. Each pulse had a different fundamental frequency (Wilcoxon sign rank test $z = -2.264$, $p = 0.024$): the first was 652 ± 84 Hz (mean ± SE) and the second was 901 ± 67 Hz. The average duration of the two pulses did not differ (Wilcoxon sign rank test: $z = -1.312$, $p = 0.189$). There was a great deal of variation in the inter-pulse interval (9 – 109 ms), with an average of 55.2 ± 3.2 ms. The total duration of the thump, including both pulses, ranged between 18 - 119 ms, but on average a thump was 66.7 ± 3.3 ms in length. In contrast, the inter-pulse duration of a hop was 555 ± 18 ms ($n = 48$) and it was relatively quiet compared to the thump, although the sound intensity of the two were not measured.

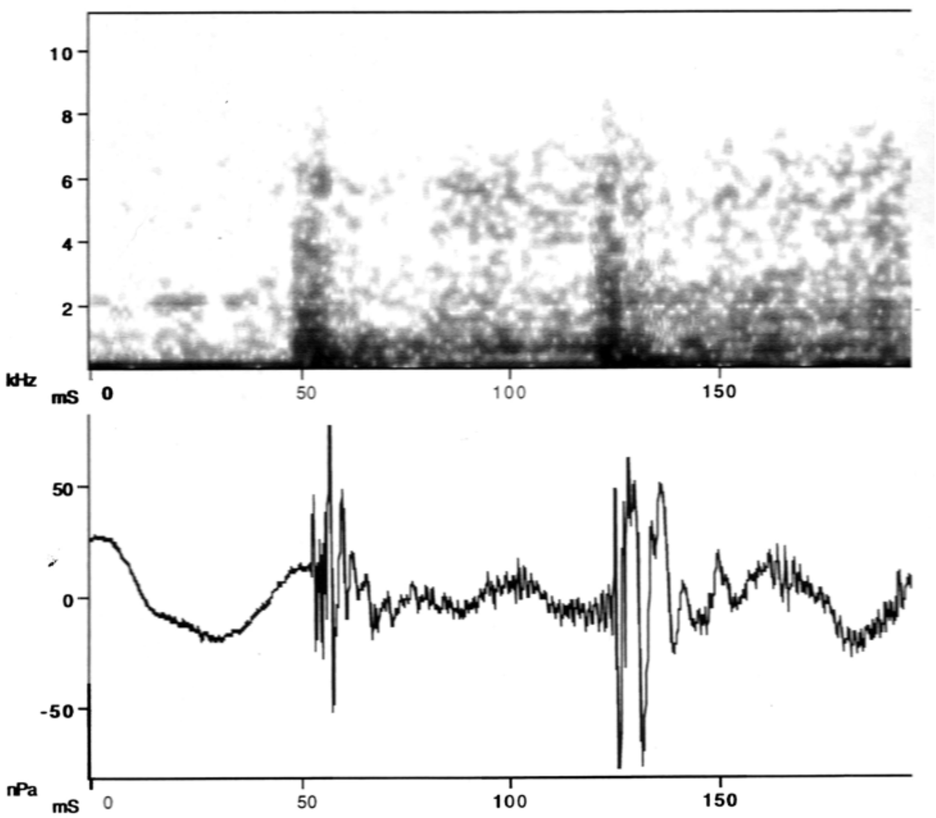

Figure 18. Sonogram and waveform of a female eastern grey kangaroo's foot thump recorded at Yan Yean Water Catchment.

Contextual observations

I observed 734 kangaroos in the 280 encounters recorded, of which there were 70 single thumps, 24 repeated thumps, and 186 flights without a thump. I observed more hops on the vehicle tracks, and more single and series thumps, on the kangaroo trails (Table 3, $\chi^2 = 35.883$, df = 2, $p < 0.001$).

I observed individuals of all age classes, although only 6 kangaroos were sub-adults, and 37% could not be sexed. Only adult kangaroos thumped. Males and females gave thumps, but males were more likely to take flight without making a thump (Figure 19, χ^2 = 14.874, df = 4, p = 0.005). Of the 52 pairs encountered, 30 included a female, and of these 15 also included a young at foot. In only 4 instances did a female with young at foot give a thump.

Table 3. Summary of context variables for hopping, single and series of foot thumps emitted by eastern grey kangaroos at Yan Yean water catchment. Direction of significance (α = 0.05) from adjusted residuals indicated by + or -, and significance differences between samples ($p < 0.05$) from ANOVA post hoc tests are indicated with an ***a***.

	Hop		Single thump		Series of thumps		n
Relative frequency on							
vehicle tracks	73.7	+	21.5	-	4.8	-	228
kangaroo trails	34.6	-	40.4	+	25	+	47
Relative frequency in							
grassland	41.9	+	27.1	-	16.7	-	101
woodland	41.4		45.7		50		121
undergrowth	6.5	-	18.6	+	33.3	+	33
Mean light level (ev)	10	α	8.8		6.9	α	198
Median distance (m)	57.5		49.5		47		211

Of the total contacts, 43% of the kangaroos observed were alone, 22% were in groups of two, and 34% were in groups ranging in size from 3-22. Within a group, only one kangaroo thumped. The response of kangaroos to the approach of the observer varied with group size (χ^2 = 19.334, df = 2, p < 0.001). Solitary kangaroos were more likely to produce single thumps and less likely to take flight without thumping than expected by chance. Kangaroos in groups of two were more likely to take flight without thumping, and less likely to give single foot thumps than expected by chance (Figure 20).

The reaction distance of kangaroos was also variable, ranging from 4-270 m. Most kangaroos took flight between 21-80 m, with 57% of the kangaroos taking flight between 40 and 60 m. There was no difference in the proportion of different foot thumps with reaction distance (Table 3, Median test $\chi^2 = 0.217$, df = 1, p = 0.642). Male and female kangaroos did not differ in their reaction distance (Median test $\chi^2 = 0.352$, df = 1, p = 0.553), and reaction distance did not vary with group size (Median test $\chi^2 = 5.393$, df = 2, p = 0.067).

Males and females differed in their habitat use ($\chi^2 = 27.6$, df = 8, p = 0.001), female kangaroos being observed more frequently than expected in grass habitats and less frequently in woodlands. Group size varied with habitat (χ^2 = 23.208, df = 8, p = 0.003), with more large groups and fewer solitary individuals than expected in grass habitats, fewer pairs in undergrowth, and more single and fewer grouped kangaroos in woodland. The response of the kangaroos to the approach of the observer varied with different habitat types (χ^2, df = 8, p = 0.001, Table 3), with kangaroos taking flight without foot thumping more often in grassland, and giving single and series of foot thumps more often in undergrowth. Kangaroo reaction distance varied with habitat type (Median test $\chi^2 = 10.043$, df = 2, p = 0.007), with kangaroos taking flight at greater distances in grass habitats than in scrub or woodland.

Wind direction relative to the observer had no effect on the likelihood of a foot thump being emitted (ANOVA, F = 0.138, df = 1, p = 0.710), whereas, light had an effect on the flight response (ANOVA, F = 4.104, df = 1, p = 0.045, Table 3). A Tukey's post hoc test showed that foot thumps in series were more likely to be emitted in low light levels as compared to flight without a thump.

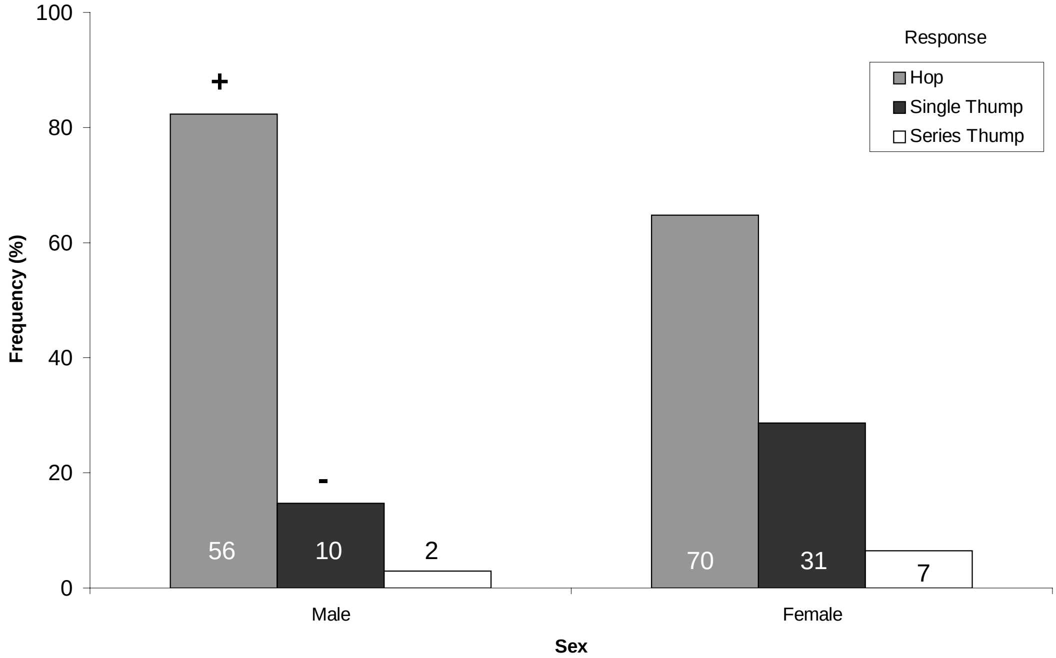

Figure 19. Relative frequency of foot thumps produced by male and female kangaroos. The numbers in or above the bars are the numbers of kangaroos observed in each category. Direction of significance (α = 0.05) from adjusted residuals indicated by + or -.

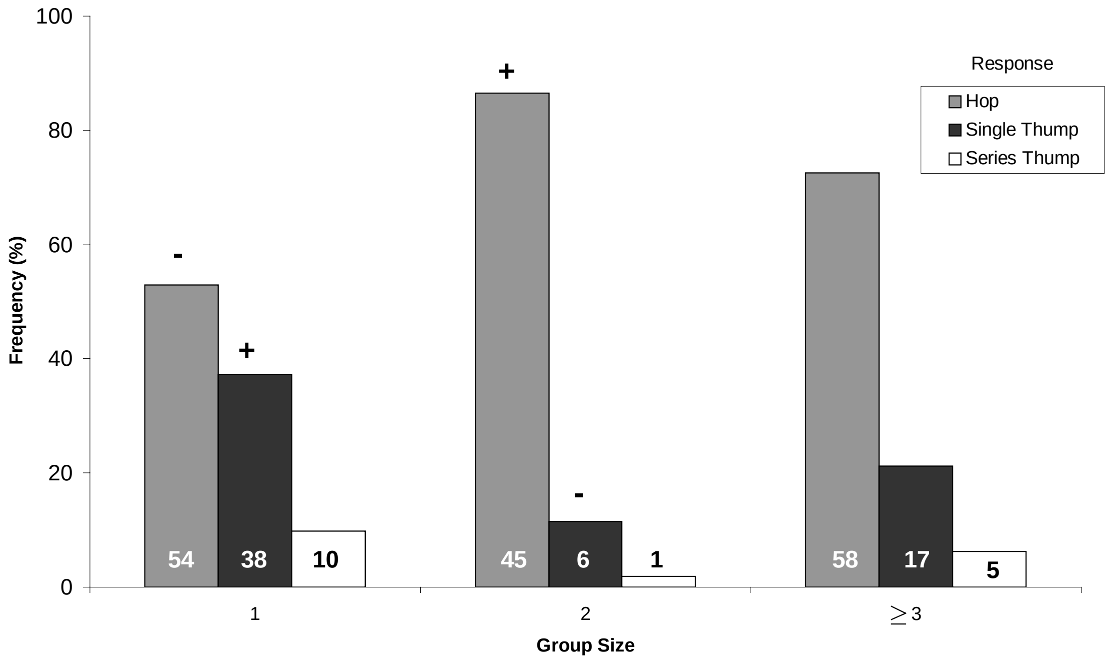

Figure 20. Relative frequency of foot thumps elicited by individual kangaroos in different sized groups. The numbers in or above the bars are the numbers of kangaroos observed in each category. Direction of significance (α = 0.05) from adjusted residuals indicated by + or -.

DISCUSSION

Signal content – acoustic structure of the foot thump

The shape and spectrum of the eastern grey kangaroo foot thump waveform was similar to the envelope of the airborne call made by the thumping white-lipped frog, *Leptodactylus albilabris*, which shows deep amplitude modulations, and has an accompanying seismic component to the signal (Lewis *et al.* 2001). Seismic recordings have been made of western grey kangaroos hopping at distances of up to 100 m while monitoring kangaroo activity (Stewart and Setchell, 1974). Together this suggests the kangaroo foot thump may also have a seismic component that accompanies the air-borne signal.

The seismic components produced by such a signal, may be received by pacinian or lamellated corpuscles. These are pressure receptors that act by transducing vibrations (O'Connell-Rodwell *et al.* 2001) that are believed to be common among mammals in general (Mason and Narins 2001). Lamellated corpuscles are found in the legs of tammar wallabies, *M. eugenii*, and Tasmanian pademelons, *Thylogale billardierii* (Gregory *et al.* 1986), and may transduce vibrations like those created by foot thumps and hopping. To receive these seismic signals the foot must be in contact with the ground, so these signals could be received only when the kangaroo is stationary.

Signals with frequencies below 7 kHz, like the kangaroo foot thump, suffer less attenuation than high frequency signals (Marten and Marler 1977). The propagation pattern should be circular because low frequency signals are relatively omni-directional (Gould 1983) and because the foot striking the ground acts as a point source. Therefore, receivers in all directions from the signaller could potentially receive the signal and determine the location of the signaller by detecting differences in phase (time of arrival) and amplitude between the two feet or ears (Klump and Shalter 1984).

Eastern grey kangaroo ears provide significant amplification of sound pressure above 900 Hz with a peak of about 30 dB between 1.7-3.5 kHz when a signal of 60-70 dB is played (Guppy 1985). The eastern grey kangaroo should be particularly sensitive to the foot thump because the frequency range of the signal falls within this amplification zone.

The domestic dog, *Canis familiaris*, a predator of kangaroos, has a hearing range of 2-32 kHz, with greatest sensitivity at 12 and 16 kHz (Poncelet *et al.* 2002; Ter Haar *et al.* 2002), indicating that dogs should also be able to detect the kangaroo thump. Humans, a longer term predator of kangaroos, may be more sensitive to the kangaroo thump than dogs because they have a hearing range of 1-20 kHz, with greatest sensitivity at 4 kHz (Zwicker 1986).

Repetition was seen in the use of the foot thump as a signal, and in the structure of the thump. Kangaroos were observed to emit thumps multiple times resulting in repetition of the signal. Repeating a signal can overcome the disadvantages of almost instantaneous fading that result from using the sound channel, while maintaining the advantage of rapid transit (Hockett 1960; Fletcher 1992). Repeating a signal can also indicate increased alarm (e.g., Boero 1992).

The species-specific separation of the foot thump, in the eastern and western grey kangaroos, results in two pulses (Coulson 1996), as well as an additional component, the inter-pulse duration. The inter-pulse duration may be varied in length thereby encoding information about the signaller's state of alarm. Roe deer, *Capreolus capreolus*, banner-tailed kangaroo rat, and damp-wood termites increase their repetition rate, and correspondingly decrease their inter-pulse duration, when the risk of predation increases (Kirchner *et al.* 1994; Coulson 1996; Randall and Matocq 1997; Reby *et al.* 1998). The thump inter-pulse duration was observed to vary in length in this study, suggesting that individual kangaroos may have some control over the information conveyed by this variable, such as increased urgency when the inter-pulse duration was reduced (e.g., Randall and Matocq 1997), or high level of fitness, when the inter-pulse duration was longer, as the kangaroo would need to remain suspended in the air for longer, like when gazelles stott (Caro 1986).

Signal context

Like the structure of an alarm signal, the frequency and context in which the signal is given can provide insight into its function. Just over 70% of the kangaroos in this study were observed to take flight without thumping, making foot thumping more common in this population of eastern grey kangaroos, than observed by Coulson (1996) for western grey kangaroos in north-west Victoria (< 1%). Of the eastern grey kangaroos that thumped, 9.5% made single thumps, and 3.3% made thumps in series.

Habitat type, time of day, distance to a predator, the number of conspecifics present, and the sex and age class of the signaller will impact on the perceived level of risk and therefore the relative frequency of foot thumping. The structural elements of a habitat can result in two inversely-related variables corresponding to the relative risk of that habitat: visibility and noise. For example, visibility is good in grasslands making them less risky on a visual scale, but they also result in the least noise, making it more difficult to detect the approach of a predator, and thus more risky on an auditory scale. Woodlands provide moderate visibility and noise, and undergrowth the poorest visibility and the greatest amount of noise. Kangaroos took flight without foot thumping more in grassland but thumped more in undergrowth, suggesting that kangaroos thump more when their visibility is compromised and they receive strong auditory stimuli.

Light levels are affected by time of day, habitat and cloud cover, and are known to alter the behaviour of many species (e.g., Coulson 1997a). Significantly more thumps were emitted during low light levels, suggesting again that conditions with reduced visibility are more likely to result in kangaroos thumping. Reby *et al.* (1999) also found an inverse correlation between counter-barking by roe deer and ambient luminosity, which they concluded was a result of the greater difficulty in assessing danger when visibility was low.

Intended recipient of foot thump

Kangaroos were observed to foot thump over a range of distances. Single thumps were given at distances ranging between 19-154 m, which encompassed the average flight distance of 121.4 ± 9.5 m observed for eastern grey kangaroos in the presence of dingoes (Jarman and Wright 1993). If the foot thump indicates perceived risk, then thumping should occur at distances less than flight distance, as the risk of capture will be greater. Single thumps were given at a median distance of 49.5 m, and thumps in series at a median distance of 47 m, this lends support to the thump being a graded signal, although the difference in distance is small. In all instances of thumps at short distances, I was not aware of the kangaroo until it had thumped, and presumably it was not aware of me until I was much closer than average. This further suggests that the thump may be being used to startle the predator at shorter distances, and signal to the predator that it has been detected when at greater distances.

Foot thumps were given by solitary kangaroos and by only one kangaroo within a group. Solitary kangaroos gave significantly more single thumps than kangaroos that were in groups of two or more, suggesting that the intended receiver of the thump was not a conspecific, thereby reducing support for warning conspecifics. Furthermore, kangaroos in groups of two gave significantly fewer single thumps than solitary or grouped kangaroos, and were significantly more likely to take flight without thumping. This suggests that female kangaroos with young at foot, which made up 58% of the kangaroos in groups of two, were electing not to signal alarm in the presence of a predator, but simply to flee. This also reduces support for the hypotheses that suggests kin benefit from the thump and lends support to the thump being a signal to the predator.

Both sexes of kangaroo were observed to foot thump during this study. Male kangaroos are not involved in caring for young and tend not to associate with young (Jaremovic and Croft 1991b) so it is unlikely that they gave thumps to warn kin. Moreover, adult male kangaroos usually disperse from their natal range as sub-adults (Oliver 1986; Jaremovic and Croft 1991a), and so are unlikely to have kin other than young they have sired within their home range. This suggests the thump is more likely to be a signal that benefits the individual and is directed at the predator.

CHAPTER 7 - BEHAVIOURAL RESPONSE OF EASTERN GREY KANGAROOS TO A CONSEPCIFIC'S FOOT THUMP

Submitted as – Bender, H. (2004). Behavioural response of eastern grey kangaroos to a conspecific's foot thump. *Wildlife Research*.

Abstract: Overabundant wild populations of herbivores often present challenges to primary industry, competing with stock, damaging crops and property. Eastern grey kangaroos (*Macropus giganteus*) are one of five 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, which is given in response to a predator and is usually followed by flight. I determined its effectiveness as compared to 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 three seconds 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 with one or more sensory modalities.

The eastern grey kangaroo is one of five species of large marsupials including the western grey kangaroo (*M. fuliginosus*), red kangaroo (*M. rufus*), red-necked wallaby (*M. rufogriseus*) and swamp wallaby (*Wallabia bicolor*), that are considered pest species by primary industry throughout most 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 ultra-sonic 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, 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 marketed for kangaroos that produce artificial sounds 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. Similarly, the Shu Roo®, a device marketed for deterring kangaroos from roadways, did not alter the behaviour of captive eastern grey or red kangaroos, and did not reduce the number of vehicle collisions with kangaroos during a 17-month trial (Bender 2001).

No studies have evaluated the use of natural sounds for deterring kangaroos, although tammar wallabies, *Macropus eugenii*, that were played sounds of predators did not alter their responses, those played a recording of a foot thump foraged less and looked more (Blumstein *et al*. 2000). Similarly, Blumstein *et al*. (2002) observed that red-necked pademelons, *Thylogale thetis*, responded to a broad range of acoustic stimuli including predator calls and foot thumps. 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; 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 occurred for 6 months.

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, 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) and appears to be a signal to the predator that it has been detected (Bender 2005).

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.

METHODS

Study site

This study was carried out at Yan Yean water catchment, which is located in Victoria, 37 km north-east of Melbourne, Australia. Yan Yean is 2250 ha in area and contains approximately 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 created at the base of the fence by kangaroos (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 (1 and 2) were located along the west boundary fence; the other (hole 3) was located along the east boundary. Sites had a minimum distance of 850 m between them 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). I selected these recordings based on their clarity during post-processing and play back, and because the selected foot thump recording was representative of foot thumps generally (Bender 2005). 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 the majority 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 msec and the second was 4.5 msec. The inter-pulse duration was 32.1 msec, resulting in a total duration of 42.7 msec, slightly shorter than average (55.2 ± 3.2 ms) (Bender 2005). 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 approximately 20 dB at 512 ppt FFT to the foot thump using Cool Edit 2000, an IBM-compatible computer software package, and silence was added before and after to extend the length of the recording to 8 s in duration. 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), with a range of 25 Hz – 17 kHz, 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 inter-pulse 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 - 21 November 1997, using a grid that had seven columns and five to seven rows (Figure 21). 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 (Figure 21). The playback speaker (AD5060 Phillips 5-inch high power squawker) with a range of 400 Hz – 5 kHz 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) with a range of 40 Hz – 10 kHz, 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 (B&K 2209) set at impulse peak (RMS peak). The microphone (B&K 4165) with a range of 3 Hz – 20 kHz was mounted on an extension lead and 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.

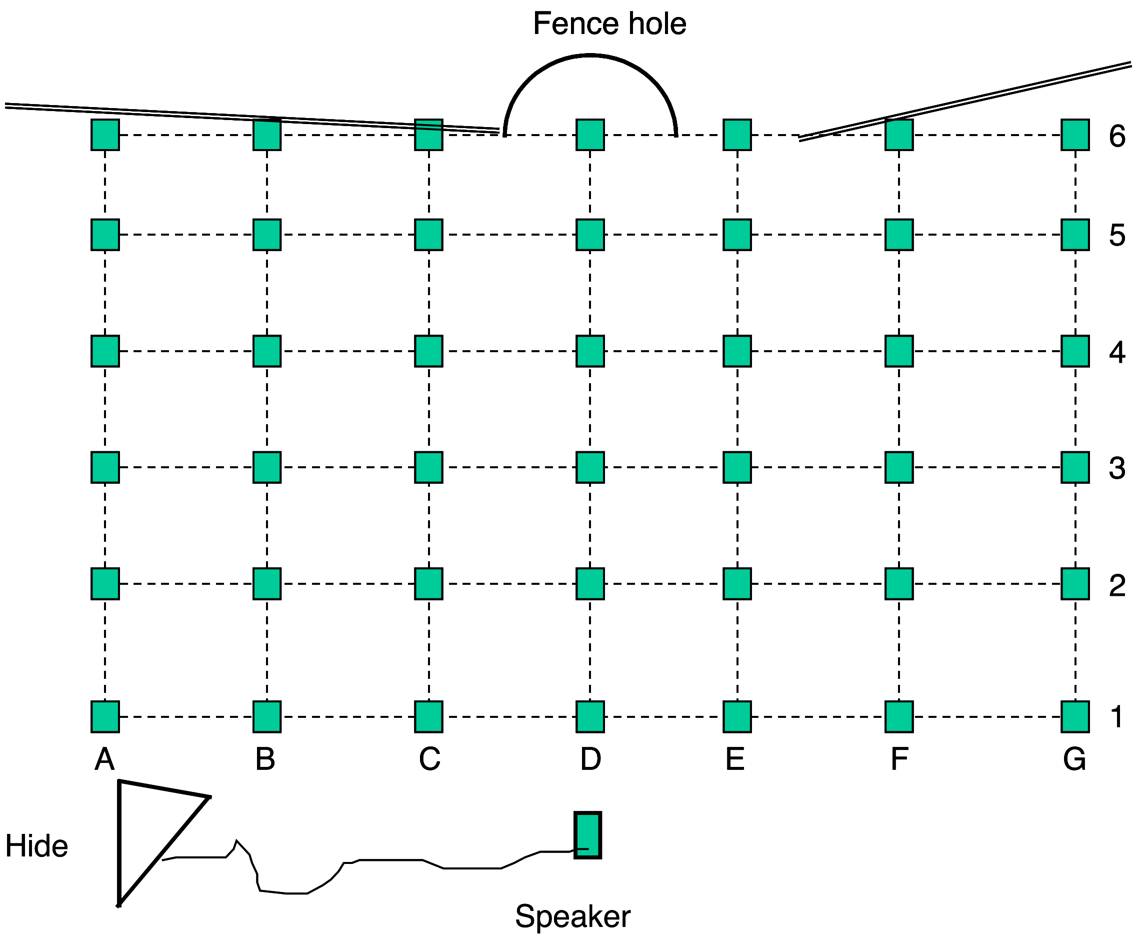

Figure 21. Diagram of equipment arrangement for propagation measurements of the foot thump and control signal at Yan Yean Water Catchment, Yan Yean, Victoria, Australia.

Behavioural response

I made observations from 1.5-m square 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 (Figure 21). 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 prior to trials to allow kangaroos to acclimatise to their presence.

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 18:30 h, Eastern Summer Time, approximately 1-1.5 h before observations commenced to ensure 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. A longer-term trial with infra-red beam detectors to monitor passage through the fence holes was considered but theft and vandalism of equipment were a problem at the study site.

Video recordings were made between 20:00 and 21:15 h, 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 prior to 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 to maintain consistency in interpretation of flight type and vigilance postures. During video playback, I recorded 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 prior to any signal being played, and within 3 seconds 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. 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.

I determined if the vigilance level of the kangaroos changed significantly by subtracting the scores prior to playback from those at playback and comparing these scores using a Mann-Whitney U test. Vigilance scores were independent of each other, taken at random, and had a similarly shaped distribution. I tested the relative frequency of kangaroos that took flight when the two test signals were played at the different observation periods using a Chi-square test. The proportion of kangaroos that took flight was non-normally distributed across the observation period. The variability of the distance at flight data was similar when the foot thump and control signal were played. Therefore, an ANOVA was used to test the differences.

RESULTS

Noise level tests

The sound pressure level of the selected stimulus and control recordings ranged from 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 (Figure 22).

The sound pressure level of the region in which most of the kangaroos (77%) 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.

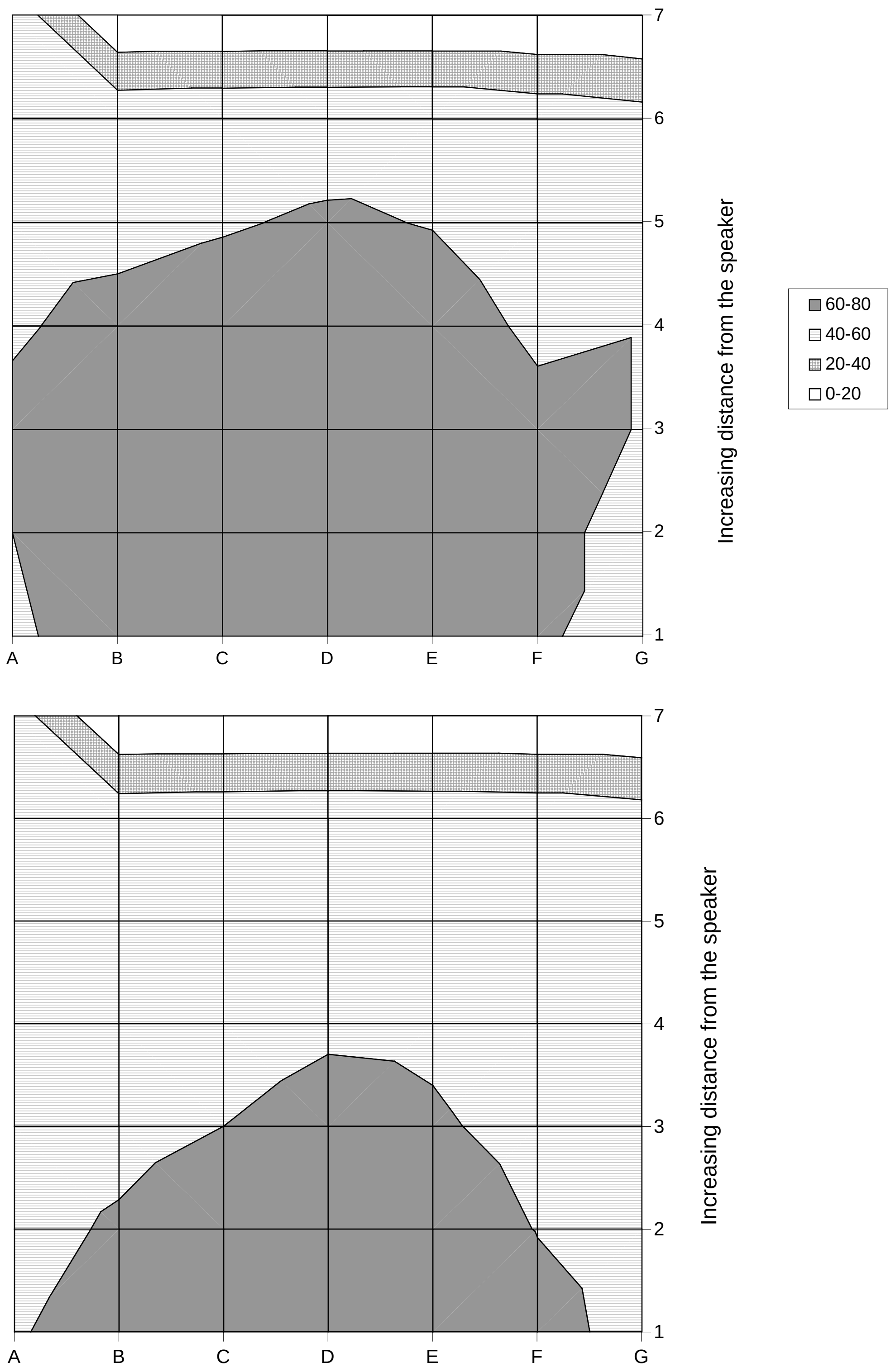

Figure 22. Propagation pattern of the control signal (top) and foot thump (bottom), showing mean sound pressure levels (dB) at two of the playback sites (1 and 2) at Yan Yean Water Catchment, Victoria Australia.

Behavioural response

Vigilance

Vigilance response by the kangaroos to both the foot thump and the control signal could be ranked on a scale which 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 posture for both stimuli prior to playback and at playback was semi-erect (Figure 23).

To determine whether there was a significant change in vigilance level when the signals were played, the vigilance rank score prior to playback was subtracted from the vigilance score at playback. A Mann-Whitney U test showed a greater difference in the kangaroos’ ranked vigilance postures after the foot thump than the control ($U = 763$, $df = 1$, $p = 0.027$) (Figure 23), but there was no significant difference in rank scores between the two sexes in response to the thump ($U = 302.5$, $df = 1$, $p = 0.503$).

Flight

There was a significant difference in the instant response (within 3 s) to the two signals ($\chi^2 = 6.647$, $df = 2$, $p = 0.036$): 26% took flight with the foot thump ($n = 42$), while none responded to the control ($n = 46$, Figure 24). However, an average of 63.3% of kangaroos tested with each signal took flight over the entire observation period, and there was no significant difference in response to the thump or the control ($\chi^2 = 2.483$, $n = 112$, $df = 3$, $p = 0.478$). Kangaroos that did not take flight, eventually walked away.

The data for time 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 SE), and a median test showed no significant difference in time to flight between the two signals (Median test $\chi^2 = 0.969$, $n = 112$, $df = 1$, $p = 0.325$).

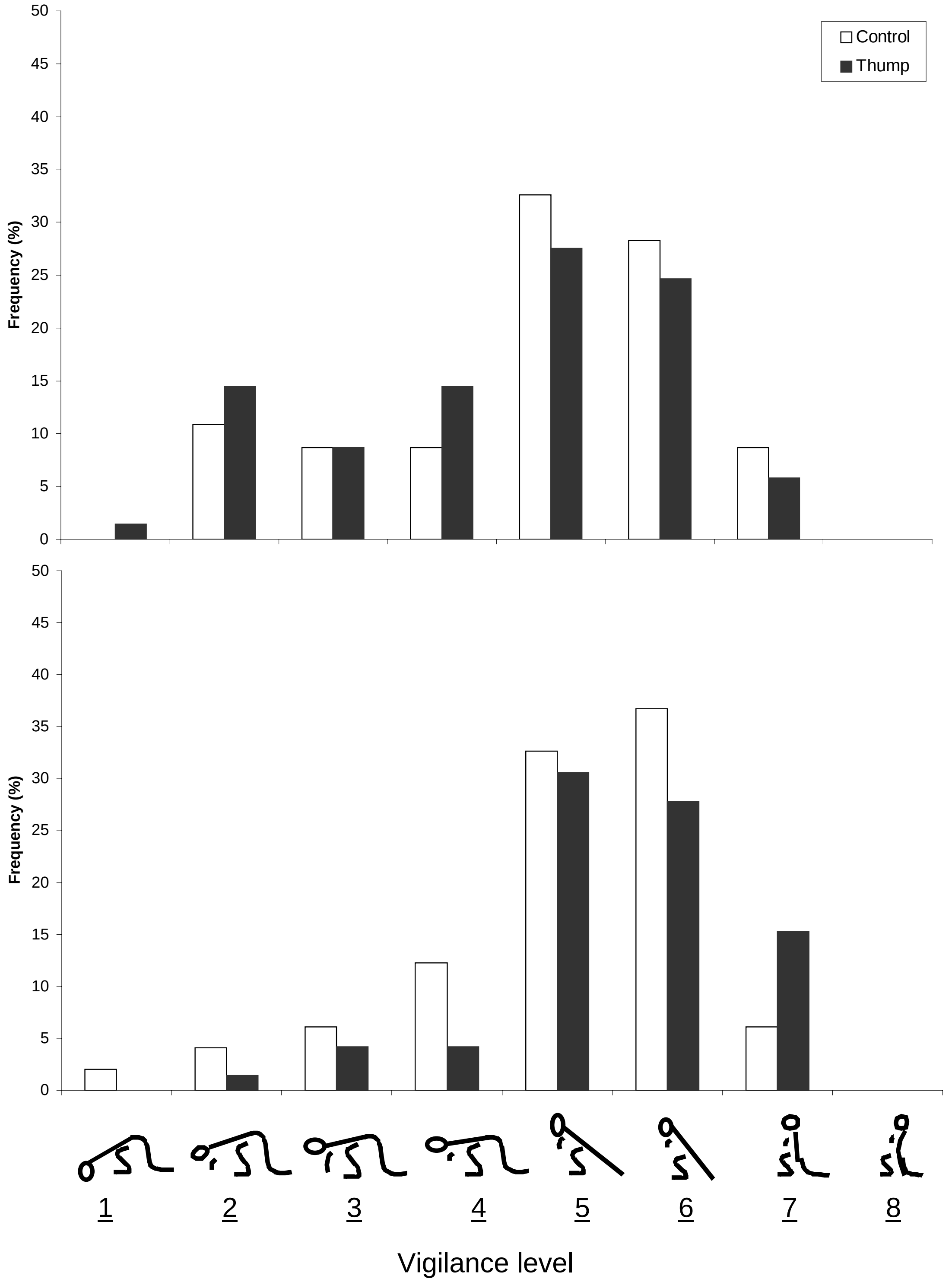

Figure 23. Frequency of different vigilance levels adopted by eastern grey kangaroos in response to the thump and control recordings prior to (above) and when the signals were played back (below).

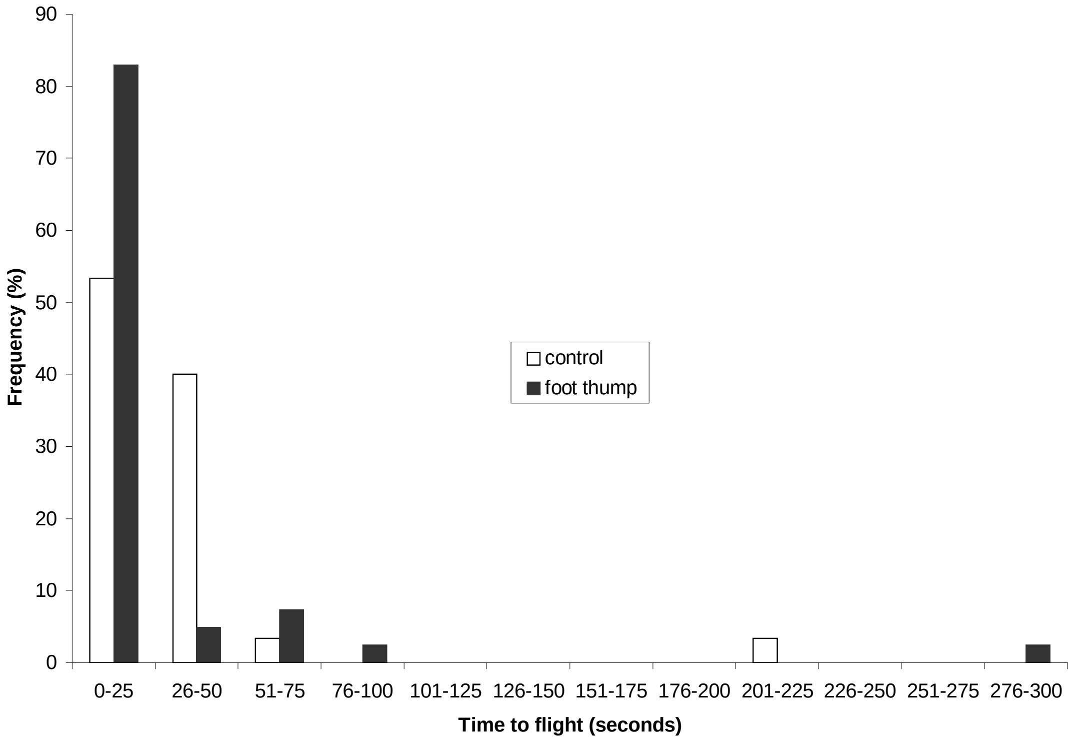

Figure 24. Differences in kangaroo time to flight when the control and foot thump recordings were played at Yan Yean Water Catchment, Victoria, Australia. n = 48 for the control and n = 64 for the foot thump.

The closest distance that flight occurred was 12 m and the farthest 32 m. The average distance that kangaroos took flight was 26 m (± 0.2 m SE), and there was no significant difference between the distances that kangaroos took flight when the foot thump and control were played (ANOVA F = 0.840, df = 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 where 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 detectable by the kangaroos. The control signal included frequencies below 1 kHz, while 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 – 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 only be a slight increase in sensitivity to the frequencies in the control signal.

Behavioural response

In this study, the kangaroos' ranked vigilance postures were significantly greater 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, whether airborne, seismic, or both, and that they respond with increased alertness to playback of a foot thump recording. Kaufmann (1974) also observed eastern grey kangaroo conspecifics, and other species of kangaroo (euro (*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 as a signal that alerts the predator that it has been detected (Bender 2005). 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, the proportion of kangaroos feeding is reduced. 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.

However, greater 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 signal 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 was played. 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.

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 the 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), 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 is 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, like 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 2000). Future trials with the foot thump should determine if habituation occurs, and 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.

CHAPTER 8 - GENERAL DISCUSSION

THE USE OF SOUND FOR MANAGING EASTERN GREY KANGAROOS

This thesis has investigated the use of auditory deterrents for managing kangaroos in agricultural and road environments. Auditory deterrents aim to stop an unwanted behaviour or to make an animal retreat from an area using sound. The best hearing frequency of the eastern grey kangaroo is between 2.0-3.5 kHz, and they have the potential to hear a broad range of frequencies, with positive gain being created by the external ear between 2.0-12.5 kHz and an upper hearing limit of 40-49 kHz (Chapter 2). However, the amount of gain created in the external ear falls rapidly above 25 kHz (Guppy 1985), indicating that eastern grey kangaroos have reduced sensitivity at these upper frequencies. Tammar wallaby hearing shows similar patterns to the eastern grey kangaroo (Coles and Guppy 1986, Cone-Wesson *et al.* 1997), suggesting that ultrasonic frequencies are a poor choice for macropods generally, and that frequencies between 2-3.5 kHz show greater potential for future trials of signals for deterring kangaroos.

Confirmation that ultrasonic or near-ultrasonic frequencies are a poor choice for deterring kangaroos was provided by the evaluation of the Roo-Guard (Chapter 3). My evaluation of the Roo-Guard showed that both models of this device (Mk I and II) were emitting high frequency signals that included a mix of audible and ultrasonic frequencies (17-27 kHz and 15.5-22.8 kHz, respectively), with a signal noise level greatly below that claimed by the manufacturer. Trials with captive eastern grey and red kangaroos found no change in the behaviour of the kangaroos in response to the device, and no change in the relative density of free-ranging eastern grey kangaroos on open grassy sites. Trials by Statham (1991, 1993) on free-ranging red-necked wallabies and pademelons (*Thylogale billardierii*) also found there was no change in their behaviour or relative density when the Roo Guard was on or off. This suggests that, despite kangaroos having the ability to hear the frequencies being emitted by the device, the signal this device emits does not have any biological meaning, so was not effective in deterring kangaroos.

A similar pattern was observed for the Shu Roo (Chapter 4 and 5). The device again produced a signal including a mix of audible and ultrasonic frequencies (15-24 kHz), with a noise level greatly below that claimed by the manufacturer, and not sufficient to be detected above the noise created by a moving vehicle. Consequently, it was not surprising that there was no difference in the behaviour of captive eastern grey or red kangaroos in response to the Shu Roo. The field trials indicated that, the Shu Roo made no difference to the number of collisions with kangaroos recorded by professional fleet drivers in vehicles with or without a Shu Roo.

Both the Roo Guard and Shu Roo used artificial sounds that appear to have had no social or other context for the kangaroos. In contrast, the kangaroo foot thump is a biologically-significant sound that is usually followed by flight. Acoustic analysis of foot thump recordings found that the majority of the signal energy was below 7 kHz, where eastern grey kangaroos have greater positive gain generated by their ears (Chapter 6). Field observations of free-ranging kangaroos found that only adult kangaroos, of both sexes thumped, nearby conspecifics always became vigilant or took flight in response to a foot thump, and that a higher proportion of solitary kangaroos thumped than grouped kangaroos, suggesting that the foot thump is a signal to a potential predator that may also have potential as a deterrent.

The playback trial with the foot thump (Chapter 7) resulted in a significant increase in vigilance levels, which was not seen 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 three seconds when the foot thump was played. These findings support Bomford and O'Brien’s (1990b) suggestion that natural sounds are a better choice than artificial sounds for auditory deterrents.

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 1990b), 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 is not coupled with a salient aversive reinforcing stimulus (Conover 1994, Ross *et al.* 2001, Stevens and Clark 1998). However, the use of a biologically-significant signal, like 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 2000).

Some general criteria for auditory deterrents for kangaroos can be deduced from the findings of this thesis. (1) Signals must be audible to the target species. Ultrasonic frequencies should not be used for kangaroos; instead frequencies around the best frequency should be investigated. (2) Signals must be of sufficient intensity to overcome signal attenuation, which can best be achieved by using low frequency and louder signals. (3) The signal should be meaningful. Use of natural, biologically-significant signals should reduce the likelihood of habituation as compared to artificial signals, so an alarm-type signal is probably most appropriate for kangaroos given their response to the foot thump. (4) The signal must generate an appropriate response. A deterrent would be most effective if flight occurred, rather than freezing. (5) In a road context, the signal must also allow enough time for a response. Given that sound travels at 340 m/s and most vehicles travel on freeways at 100 km/h, a signal that could be projected 400 m ahead of a vehicle would give a kangaroo only 12.0 s to respond. Unless all of these conditions are met an auditory deterrent for kangaroos is unlikely to be effective.

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APPENDIX A - ROO GUARD TECHNICAL METHODOLOGY

Acoustical characterization tests

Measurements of the master ROO-Guard Mk I were made using ANABAT II, a heterodyne bat detector that has a flat response to approximately 50 kHz (R. Coles, personal communication). A Zero Crossing Analysis Interface Module (ZCAIM) was used to digitally transfer recordings of the master ROO-Guard Mk I to an IBM-compatible 486 laptop using ANABAT II software.

The master ROO-Guard Mk I and Mk II units were mounted on a stand at a height of 1,750 mm above the ground in the centre of the grass oval. Noise-level measurements were made using 2 different measuring devices: ANABAT II or a precision integrating sound pressure level (SPL) meter. Measurements were taken to 50 m with the ANABAT II held at chest height (1,280 mm). The ANABAT II was set with a division ratio of 16, and a sensitivity level that ranged from 1.5 to 10. The SPL meter was mounted on a tripod at a height of 900 mm. The SPL meter (B&K 2066) was set to root mean square (RMS), using frontal sound incidence and linear frequency weighting, and the filter was set to 16 kHz. Sound pressure level (dB) measurements were taken from the SPL digital meter (± 2 dB) every 2 m along the azimuth bearings using the same method described for the ANABAT II. Results from ANABAT II and the SPL meter were used to create a standard curve so that the ANABAT II sensitivity results could be converted to dB values.

APPENDIX B - SHU ROO TECHNICAL METHODOLOGY

Acoustical Characterization Tests

Laboratory

I recorded measurements of the Shu-Roo® Mk II using a sound pressure level (SPL) meter (B&K 2209) with a microphone (B&K 4165) and a digital tape recorder (Sony TCD-D8). I used a system adapter kit (Sony RM-D100K) to digitally transfer recordings of the Shu Roo to an IBM-compatible Pentium 1 computer using Sound Forge (XP 4.0d) software with a sampling rate of 48 kHz and 16-bit sample size. I used Cool Edit 2000 software to analyse the duration and frequency aspects of the signal, as well as the amplitude of the signal (± 2 dB). I measured frequency and amplitude with a 44,100 Hz sampling rate, a Fast Fourier Transform (FFT) value of 16,384, overlap of 50%, time resolution of 170.67 μsec, and a Hanning smoothing filter.

Mounted on a Retort – Grass.

I mounted the Shu Roo on a tripod at three different heights (300, 600, and 1200 mm) above the ground in the center of a grass oval. I made noise level measurements using a precision integrating sound pressure level (SPL) meter (B&K 2209), microphone (B&K 4165) and a 1/3 rd octave filter (B&K 1616). I mounted the SPL meter on a retort stand at 300, 600 and 1200 mm. The SPL meter was set to root mean square (RMS), using frontal sound incidence and linear frequency weighting, and the filter was set at one of three settings: 16, 20 and 25 kHz. I took sound pressure level (dB) measurements from the SPL digital meter (± 2 dB) every 2 m along the azimuth bearings. I took measurements to 50 m.

Mounted on a Retort – Bitumen.

I mounted the Shu Roo on a retort stand at a height of 600 mm above the ground on the 'ADR 28/00 noise drive'. The ADR 28/00 noise drive is a straight bitumen road with grass road verges. I made noise level measurements using a precision integrating sound pressure level (SPL) meter (Prosig P5600), an amplifier (B&K 2610), and a microphone (B&K 4133) with a preamplifier (B&K 2619) and stored on a computer (IBM Thinkpad 570). The microphone was mounted on a retort at 600 mm.

The Prosig (P5600) was set to root mean square (RMS), using frontal sound incidence and linear frequency weighting, for the following 1/3 rd octave filters: 16, 20, 25 and 40 kHz. I took measurements in the azimuth plane at 9 distances: 1, 2, 4, 10, 20, 30, 40, 50 and 100 m. RMS levels were background corrected. The reference value was the sound pressure level measured on grass at 20 m (51 dB re 20 μPa).

I used two computer software programs, Prosig acquisition (DATS acquisition) and Prosig processing (DATS for windows), for recording and analysis. The DATS acquisition software was set with a sensitivity of 262 mV/Pa and a sampling rate of 80,645 samples/sec with linear weighting.

Mounted on a Vehicle.

I recorded noise level measurements of the Shu Roo signal when mounted on 4 different vehicles on a straight ABS test surface, the 'Brake Test & N.V.H. Road', using a SPL meter (B&K 2209), a tunable filter set at the 1/3 octave around 18 kHz (B&K 1621), a digital tape recorder (TCD-D8) and a microphone (B&K 4165). The microphone was mounted on a retort stand at a height of either 600 or 1100 mm with a clamp. It was oriented 30° to the side of the road. The SPL meter was set so a reading was given between 30 and 50 dB. The DAT record level was set so that a reading of – 4 to –2 dB was shown on the digital meter. This resulted in DAT record levels of 5-8.5. Only recordings with the same SPL meter and DAT recorder settings were compared. All measurements were background corrected, and the background levels on the respective days used as reference values (re 20 μPa).

I tested four types of vehicle: Ford Falcon (AU2 Forte) sedan, Ford Courier (2000 PE Utility) 4x4, Ford Cargo Tipper truck, and a Mazda 18 seat bus. Fender heights were 315, 800, 840 and 620 mm, respectively. The Shu Roo was mounted on the fender of each vehicle using electric tape, and connected to the vehicle's battery.

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