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The integration of bioacoustic indicators and artificial fear cues for the strategic management of kangaroo herbivory following fire and mining

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

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Contents

Table of figure legends

List of table headings

Abstract

Western grey kangaroos (*Macropus fuliginosus*) have not previously been subject to tests for susceptibility to auditory based deterrents. This study presented a mob of western grey kangaroos with a series of treatments to determine behavioural responses towards artificial and biologically-significant acoustic deterrents. I observed and quantified nine common behaviours, including stable-state, feeding, vigilance, and alarm behaviour before, during and after presentation of each stimulus through three experiments.

In the first experiment, four sounds were tested individually (each pre-recorded sound played once) to evaluate potentially effective deterring signals. Two sounds were artificial (an aerosol can hiss and a bullwhip crack) and two were natural (a kangaroo alarm footstomp and a raven call, a presumed benign control). Despite the promising literature on the potential for natural alarm stomps as non-invasive deterrents, artificial sounds were at least as evocative as bioacoustic sounds. A whip crack was more efficient deterring western grey kangaroos than their alarm stomp at generating flight and vigilant behaviours. Foraging behaviour was reduced from 71% to 1% within one minute of play back, whereas the foot stomp reduced feeding from 57% to 22%. An artificial hiss reduced feeding effort from 89% to 65% and the raven call dropped percentage of time spent foraging from 70% to 47% in the first minute post- treatment.

In a second experiment, I tried to artificially enhance the rate of habituation to ascertain the likelihood of habituation to acoustic signals, by playing back the most fear-inducing sounds (the whip crack and the alarm foot stomp) at 5 s intervals for two full minutes. Feeding behaviour did not return to normal levels following either signal.

In the third experiment, to evaluate if rate of applications has an effect, I then focused on the most aversive signal (whip) and varied the rate at 3 s, 15 s and 30 s intervals. More animals left the area overall, with the highest rate of stimulus, though not significantly so. There were no other effects of rate of playback on behaviour.

The outcomes of these experiments suggest that artificial sounds may be at least as effective as bioacoustic sounds in generating alarm and flight among kangaroos while the rate of playback may influence a sound's ability to deter animals from a targeted area. Animals did not fully habituate to either signal during the timeframe of these experiments (three weeks; up to twice daily, but often less as dependent on weather; two minutes duration) despite my having replayed the signal repetitively at close intervals without reinforcing fear with any other effects.

Despite the failures of commercial ultrasonic kangaroo deterrents, I was unable to find any reason that auditory deterrents cannot successfully form part of a strategic repellent program for the non-lethal management of kangaroos, if managed appropriately. I have characterised and quantified changes in behaviour in response to several sounds, some that may be effective in fashioning an auditory based repellent. My results, mainly in regard to the whip crack, are promising, but the overall efficacy of auditory based deterrents requires further research, especially in regard to rate of habituation, alternation of different signals and to intensity, rate, frequency and duration of the signal.

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Chapter 1 General Introduction

Reversing the damaging effects humans have inflicted on nature is more on the minds of people in First World countries than ever. Thus restoration ecology is likely to become one of the most important disciplines in this millennium. In Australia, large areas are ecologically degraded or have been cleared which makes them susceptible to erosion, rising water tables, salinity, weed infestation and other ecological problems (Hobbs & Harris 2001).

Mining companies in Western Australia are legislatively obligated to undertake rehabilitation of disturbed lands to a high standard (Brearley 2003; DoIR 2006). Newly planted seedlings help restore the natural landscape by trapping soil, vegetative litter and water, returning organic material and providing habitats for fauna (Cramer & Hobbs 2002; Tongway & Hindley 2003; Yates et al. 2000). Unfortunately, seedling mortality is usually high due to the synergy between herbivory and drought (Norbury et al. 1993; Parsons et al. 2006). Plants are particularly vulnerable to predation during the early stages of regrowth as shoots are soft, moist, nutrient-enriched (Groom et al. 1997), have fewer defense mechanisms (Fenner et al. 1999) and are therefore preferentially grazed.

The control of herbivory is critical for restoration of disturbed areas in Western Australia (Norbury et al. 1993; Parsons et al. 2006; 2007a, b, d). Lethal approaches are under critique and government and industry are under increased pressure to use non-lethal and humane methods to mitigate effects of herbivory (Edwards & Oogjes 1998; Reiter et al. 1999). Mining companies could potentially gain positive publicity by supporting non-lethal management of kangaroos and deterrent research. Australia is valued internationally for its nature and wildlife. A report by Johnson et al. (2000) found that $1.8 and $3.5 billion of inbound tourist expenditure is contributed to the Australian economy by its wildlife (Johnson 2000). The mobs of wild kangaroos people can still encounter are unique to Australia. The kangaroo is recognised as a national symbol with strong tourist appeal and has high conservational value (Pople &

Grigg 1999). Martin-Lopez et al. (2007) found that human willingness to pay for conservation of an animal or plant is highly positively correlated to affection and familiarity towards the species. This especially applies to visible and iconic animals such as kangaroos.

The need to produce sonic deterrents has been increasingly recognised because they are cost effective, non-invasive, easy to operate, and have the potential for a large area effect (Bomford & O'Brien 1990). This project evaluates the potential of auditory signals to deter western grey kangaroos (*Macropus fuliginosus*) from areas where they actively forage.

1.1 Target herbivore: the western grey kangaroo, *Macropus fuliginosus*

The Macropodidae are a diverse group of about 47 extant species (estimations on how many species there exist varies considerably). They range from small rat-sized animals, through medium sized wallabies, up to gregarious large species commonly known as kangaroos. The target of this study is the western grey kangaroo (*M. fuliginosus*), one of the four largest species (the others are the red kangaroo *M. rufus*, antilopine kangaroo *M. antilopinus*, and eastern grey kangaroo *M. giganteus*) (Dawson1995). The western grey kangaroo weighs around 3 kg when first out of the pouch, to around 70kg for adult males; females usually weigh up to 34 kg (Massam et al. 2006).

Western grey kangaroos occur in the south-western parts of Australia, usually where rainfall exceeds 250mm (Dawson 1995; Massam et al. 2006; McCullough & McCullough 2000). Previously thought to be solely a grazer, studies have shown their dietary needs include browsing native bushes and various other plant species (Dawson 1995; Halford et al. 1984). *Macropus fuliginosus* is crepuscular (i.e. most active at dawn and dusk) with regard to feeding and social interaction, heavily relying on their sense of smell and hearing (Dawson 1995). Priddel (1986) found the most active foraging times to be the six hours after sunset and again few hours around sunrise, with seasonal variations due to different day length. While Priddel's study seems to relate feeding activities to day light, Arnold et al. (1988) found foraging to follow the cyclic pattern of radiant and ambient temperatures. Personal observations and communication with Lander (2009) found *Macropus fuliginosus* to also feed at other times if climatic conditions (e.g. rain and storms) mean feeding at dusk or dawn will be more difficult.

Mating activity in *M. fuliginosus* is seasonal, occurring between October and March. Breeding has been found to be significantly reduced (Norbury et al. 1988) and mortality increased in times of drought (Shepherd (1987), resulting in populations to be stagnant for years following the drought (Norbury et al. 1988). Dawson(1995) states that breeding even ceases in poor environmental conditions until conditions improve, which would consequently result in a decrease in numbers. *Macropus fuliginosus* have one young at a time and do not exhibit embryonic diapause like most macropods i.e. if the pouch joey dies, the next will be born after the following mating season. For these reasons, *M. fuliginosus* has a lower reproductive rate than the red kangaroo (*M. rufus*) or eastern grey kangaroo (*M. giganteus*) (Dawson 1995; Massam et al. 2006).

The locomotion of macropods is unique. Pentapedal movement (front paws, hind legs and tail on the ground for slow, walking movement) has a higher energy cost as compared to the quadrupedal (four legged walking) movements of similar-sized animals. However the bipedal movement of macropods (hopping on two hind legs) is the most efficient form of locomotion. Energy costs decrease with speed, making it more efficient for the animal, once moving, to be repelled relatively longer distances (Baudinette 1994; Clancy & Croft 1991; Dawson & Taylor 1973).

Studies relating to the mobility of *M. fuliginosus* appear contradictory. Coulson (1993) found a home range for individuals to vary between 221- 459 ha, Massam et al. (2006) suggested kangaroos home range to be between 30-200 ha, Arnold et al. (1992) determined woodland home ranges to vary from 39 to 70 ha, Priddel et al. (1988) conducted a study showing a home range of no more than 10 km^2, while (McCullough & McCullough 2000) found that individuals rarely move outside of their home ranges, which in their case study measured only 2.41-5.55 km^2 for females and 8.71-10.78 km^2 for males. Consistent amongst studies is the finding that kangaroo numbers and distribution are most significantly affected by food availability (Bayliss 1985; McCullough & McCullough 2000).

The climate and vegetation in Australia has been changed dramatically over the last few hundred years (Johnson 2006), with increased pasture and watering points available (Pople & Grigg 1999). Consequently, food and water restrictions, which previously controlled kangaroo numbers, have been lifted, and kangaroo numbers can reach very high densities locally (Coulson 2008). Increasingly, kangaroos are coming into conflict with Australian farming, forestry and mining restoration. Macropods are unique to Australia and New Guinea. In Australia, kangaroos are national icons, possessing high tourist appeal and conservation value. Therefore, management of these creatures must be well planned.

1.2 Landscape rehabilitation and the effects of herbivory

The mining and petroleum industry sector is estimated to expand by 50-75% over the next decade (SoE 2007). The need for rehabilitation of previously mined areas has been acknowledged for decades. One of the early examples is the reclamation of bauxite-mined lands in Western Australia, which began in 1966 (Gardner 2001; Tacey 1979; Tacey & Glossop 1980). The goals at that time were to establish a self-regenerating forest ecosystem for timber production and possibly recreation. The mining industry of Australia is now legislatively obligated to restore disturbed areas to near pristine conditions by recreating the landscape as it was before their activities (Brearley 2003; DoIR 2006). As part of this process, therefore, the importance of re-establishing native flora and fauna with high biodiversity values has been recognized in recent years (Gardner 2001; Ward et al. 1996). The development of native bushland is recognised as equally important as the development of pasture, since native bushland not only provides habitat for native flora and fauna, but also reduces rehabilitation costs (Hobbs & Harris 2001), stops weed infestation, loss of top soil and altered hydrology (Cramer & Hobbs 2002).

Successful seedling establishment is an essential component of landscape restoration, as a surface without vegetative cover is likely to experience erosion (thereby a loss of topsoil containing nutrients and seeds), salinisation, loss of soil porosity, increased evaporation, reduced carbon sequestration, rising water tables and contamination (Eberbach 2003; Hatton et al. 2003; Lal 2001; Turner & Asseng 2005); these processes will lead to degradation and loss of biodiversity (Cramer & Hobbs 2002; Tongway & Hindley 2003; Yates et al. 2000). Newly-planted seedlings are particularly sensitive, and one of the main issues in regard to their survival is grazing. Loss of vegetation, especially due to herbivory in disturbed areas and rangeland conditions, can therefore result in desertification (Tongway & Hindley 2003; Yates et al. 2000).

Using paired exclosure trials, several studies have quantified the impact of herbivory on newly established vegetation. There is higher plant survival and growth rate (Ludwig & Tongway 1996; Parsons et al. 2007d) and increased recruitment and establishment of tree, shrub and grass species in non-grazed sites (Gardiner 1986; Harrington et al. 1984; Spooner et al. 2002). Norbury et al. (1993) also found that species diversity is adversely affected by grazing, and restricting the extent and time of kangaroo grazing (if no other grazing occurred) was crucial to successful rehabilitation of degraded areas. Protecting newly rehabilitated landscapes from herbivory is therefore an important priority for restoration ecology. However, once the seedlings are established and strong enough to survive, grazing can have positive effects on the biodiversity. The absence of some herbage reduction like grazing leaves the dominant tussock grasses to become large and dense to an extent that many other plant species are out-competed and disappear, reducing the species diversity. Ingwersen (2001) demonstrated the importance of selective grazing in Namadgi National Park, where seven plant species persisted in grazing-free enclosure compared to 32 immediately outside the enclosure in grazed areas. Protection for seedlings, at least short term, is therefore desirable for newly revegetated areas like former mine sites and burned areas.

The costs of rehabilitation after disturbances like mining are considerable. Rehabilitation involves multiple steps and planning stages, site preparation (mechanical and/ or chemical), revegetating and maintenance. A report for the Forestry Division of the Australian National University (ANU) by Schirmer & Field (n.d.) assessed the costs involved in revegetation. The most expensive components of revegetation projects were identified as fencing materials to prevent herbivory, labour and seedlings (in projects where seedlings were used). The costs of spraying herbicides on sites with significant coverage of competing vegetation, and tree guards (where they were used), were also a significant proportion of the total revegetation costs.

The price of revegetating an area depends on the type of site, type of project, and project size etc. Future land use also influences costs; for example, if the land is to be used for pasture, silviculture, agriculture or native bush land. An example of costs of restoration of barren ground to pasture land has been established for the Bowen Basin, NSW, at around AUD40.000 per ha (Baker et al. 1995).

Another significant factor influencing revegetation costs is the type of previous land use. Additionally, the degree of isolation influences costs. The most expensive regions to revegetate are arid, tropical and/or remote regions (Schirmer & Field n.d.). Besides the initial site preparations and establishment of plants, successful protection from herbivores will determine the revegetation outcome.

1.3 Herbivore management

Lethal control of herbivores

The four abundant species of kangaroos, the eastern and western grey, red kangaroos and common wallaroos (*Macropus robustus*), are estimated to cost

AUD76 million annually due to reduced livestock carrying capacity, crop damage, fence maintenance and traffic accidents (McLeod 2004). Due to these costs, some proponents believe reducing the number of macropods is necessary. This can be done by shooting individuals or through the application of poisonous baits.

Shooting

Culling by shooting is the most widely used method for controlling macropod numbers in Australia. Macropod numbers are reduced in areas where the animals are considered over-abundant or where their presence interferes with human interests (seedling loss, grazing competition etc). Commercial kangaroo harvesting is different from culling as defined above as it is based on the economic value of kangaroo products i.e. meat and hides (Pople 1999). Kangaroo management plans have been introduced on a state-by-state basis, regulating the commercial harvest with quotas since the 1970's. Victoria, the Northern Territory and the ACT are not part of the commercial industry, but will reduce numbers where considered necessary. Four species are harvested in mainland Australia: the eastern and western grey, red kangaroos and common wallaroos. In Tasmania, Bennett's wallaby (*Macropus rufogriseus rufogriseus*) and the Tasmanian pademelon (*Thylogale billardierii*) are harvested commercially. Nationally, the two grey kangaroo species and the red kangaroo make up 90% or more of the harvest. The kangaroo industry is estimated to generate revenue of AUD200 million p.a., employing approximately 4,000 people, the majority of these people live in remote and regional areas (Johnson et al. 2000).

Kangaroo shooting has to be carried out by license. Shooters are issued permits by wildlife authorities to harvest on leasehold and freehold land that has been used for primary production. Commercial shooting is illegal in conservation reserves, national parks and state forests. The shooting must comply with the *Code of Practice for the Humane Shooting of Kangaroos* (last revised in 2008). The Code states a requirement to use 'powerful centrefire rifles and apply head- shots to ensure instant death' (Johnson 2000).

Shooting has been shown to decrease grazing levels significantly where kangaroos are the majority of grazers (Walsh & Wardlow 2005). However, the harvest of kangaroos does not affect biomass in semi-arid rangelands without concurrent reduction of both sheep and other feral herbivores, like rabbits and goats (Freudenberger 1995; Norbury et al. 1993).
Shooting is viewed more positively than poisoning, as shooting is species-specific and selective with only one animal at risk at a time and usually results in a quick death. Regulations apply to the number of kangaroos that can be shot in form of the annual quota. The quota is calculated from population estimates every year, and they follow the proportions specified in the state or territory specific Commercial Kangaroo Harvest Management Plan which is approved by the Australian Commonwealth Government. Annual quotas change from year to year as kangaroo populations change in response to the availability of feed and water (DECCW 2010). However, there are several problems to shooting that are commonly cited.The word used by industry to refer to a lethal reduction in numbers of kangaroos is culling (which means the removal of inferior animals; Veterinary dictionary 2007). However, commercial shooters are paid by the kg and hide size, thus there is a natural bias towards the selective removal of the largest and healthiest animals. Consequently, the older, more experienced animals with the best genetic makeup are at the highest risk of removal, altering the social structure and genetic make up of the population (Caughley 1994; Croft 2004; Dawson 1995; Driessen 1992; Gunn 2004; Pople & Grigg 1999).

The possible overestimation of kangaroo numbers is another issue widely referred to by environmentalists. It is difficult to estimate numbers of kangaroos, even though these estimates may be pre-requisite for licensed shooting. There is currently a large margin for error, and current techniques require improvement (Hauser et al. 2006; Humbert et al. 2009; Jonzen et al. 2010). Important and often underestimated are the factors that can quickly reduce population numbers such as climate or disease. Droughts have an especially detrimental effect on kangaroo numbers (Olsen & Braysher 2000). In the drought of 1982/3, kangaroos declined by ~40% over 12 months in the sheep rangelands of eastern Australia (Caughley *et al*. 1985). In 2002, drought reduced the average density of euros by 97.7%, while red kangaroos declined by 83.8% in Idalia National Park in central Queensland (Fukuda 2005). The relationship of population sustainability can not be ignored. Jonzen et al. (2010) predicts that a 10% decrease of annual rainfall will make the harvest at current red kangaroo quotas unsustainable. Due diligence must be exercised when providing kangaroo population estimates due to inaccurate methods of surveys, significant fluctuation in numbers and sensitivity to climate.

Additional problems are pouched joeys of a killed kangaroo left to starvation if not caught; non-lethal shots and unlicensed shooters without the skill for a head shot. Unlicensed shooting is also a problem because the numbers of killed animals are not recorded and, therefore, can not be taken into account in management plans.

Due to these problems, lethal control of kangaroos is facing public critique (Croft 2000, 2004; Edwards & Oogjes 1998; Reiter et al. 1999). A survey of Sydney and Melbourne residents found that only 31% of individuals thought shooting to protect seedling trees is acceptable (Coleman 2006).

Poisoning

Selective poisoning of marsupials has been used in pastoral and forestry areas of Australia (Dawson 1995). The poisoning of kangaroos is now illegal on mainland Australia, but is still reported to happen, especially on private properties where the owner does not regard legal culling and commercial harvesting as having removed sufficient numbers of animals (Grigg 2008; RSPCA 2002). Authorities in Tasmania still license the poison sodium monofluoroacetate, also known as 1080 to private stakeholders to target wallabies, possums and pademelons. It is the only vertebrate pesticide currently registered In 2004/05, an estimated 54.9% of the 1080 was used to protect planted seedlings, 41.9% to protect pasture and to a much lesser amount to protect fodder crops (1.9%), vegetables and poppies (0.7%) or to control ‘vermin’ (0.6%) (Coleman et al. 2006).

The use of poison is not considered humane due to the often long and painful death, and because poisoning is non-selective, thereby putting other animals besides the targeted at risk through secondary poisoning (Eason et al. 1994). The increased public criticism over 1080, and pressure from animal welfare groups, has resulted in a recent ban of targeted poisoning of native herbivores on stateland (1080 baits for foxes and cats are still utilised all over Australia). Tasmania, formerly using 1080 heavily to control browsing in forestry and agriculture, has had to review alternatives to the poison (Coleman et al. 2006).

Besides 1080, Australia and New Zealand also utilise other poisons against vertebrates e.g. Pindone (rabbit control), Warfarin (rats and feral pigs (Coman 1994), Feratox (encapsulated cyanide bait against tammar wallabies) and phosphorus paste (tammar wallabies) (Morris et al 2000). None of these poisons are known to be effective or to meet environmental and animal welfare attributes of an ideal mammalian pesticide, namely species specificity, no environmental contamination and a humane death (Coleman et al. 2006).

Other forms of lethal controls are lethal traps, live trapping and darting; the two latter often followed by a lethal injection. Lethal traps and snares are illegal, but where shooting is unsafe i.e. in close proximity to housing, live trapping and darting might be used (Coleman et al. 2006).

Non-lethal control of herbivores

The public consensus and many in industry are supporting non-lethal herbivore control methods (Edwards & Oogjes 1998; Reiter et al. 1999). Some of the non-lethal techniques include fertility inhibition, limiting water access, predator re-introduction and deterrents (Miller et al. 2006). Fertility inhibition can be temporary (contraceptive or immunocontraceptive) or permanent (i.e. sterilisation). Sterilisation is expensive and labour intensive, so only suited on a very small scale in captive populations.

For wild animals, an ideal (immuno) contraceptive product would have to be species-specific, not lead to undesirable consequences for the welfare of the individual and would have to be relatively easy to administer, preferably only once (Rodger 2003). Since many macropods are susceptible to post-capture myopathy (subsequently many die), a critical hindrance of this method is the delivery of the fertility control agent (Lentle et al*.* 1997).

It is difficult to lower kangaroo numbers by restricting water access because livestock rely on the same water sources and species-specific fencing has often been shown ineffective (Coleman et al. 2006). Various scientists are investigating the possibility of reintroducing mammalian predators like the dingo (Glen et al. 2009). In theory a positive method of biological control, there are significant issues to consider as dingoes most likely will prefer to prey on confined, slower-moving sheep than mobile kangaroos.

Exclusion fencing

Physical exclusion from areas and individual seedlings are the most popular non-lethal options for control of herbivory. Exclusion fencing has a positive effect on soil structure and the re-establishment of a biodiverse flora (Spooner et al. 2002). A review of fences designed to exclude feral animals from areas of high conservational value in Australia reached four relevant conclusions (Long & Robley 2004). Firstly, electrified wires have limited effectiveness due to the spacing between wires and the reliance on the earthed component critical to the shock delivery. Secondly, gates, gully or waterway crossings along with the base and corners of fences, are likely to be breached by animals. Third, non-target animals get entangled and killed in fencing. Finally, fences need regular maintenance and costly inspections (Long & Robley 2004). In regard to kangaroos, electric fencing becomes ineffective over time or during drought, whilst kangaroo-proof fencing is very expensive to erect (Lavery & Kirkpatrick 1985). The Landcare Research Report (2006), prepared to evaluate means to manage browsing in Tasmania by mammals, only recommends exclusion fencing for areas that are not too large or rugged. The report focused on evaluating the cost of fences 0.9-1.5 meter, which is not effective for the exclusion of kangaroos: *M. fuliginosus* easily jumps 2-meter high fences (pers. obs; C. Lander pers. comm. 2009). In conclusion, exclusion fencing is rarely recommended as a measure against kangaroo herbivory, due to high cost and impracticability in rough terrain.

Individual plant protection

Individual tree guards, protecting seedlings from browsing, come in various materials and qualities. The cost per guard ranges between AUD0.15 for seedling stockings (a flexible polyethylene netting cut to fit the seedling, which clings to the seedling and does not need stakes for support) (Miller et al. 2009), AUD0.20 for a milk carton with one stake, AUD0.90 for an open plastic sleeve with two or three stakes to finally, the most expensive option at AUD1-1.60, for firm gro-tubes (Schirmer & Field n.d).

These different methods offer varying levels of protection from a few days to a couple of months. Several studies have tested the different types of guards and the majority is shown to be ineffective (Basset et al. 2003; Coleman 1991; Miller et al. 2009; Montague 1993). Miller et al. (2009) tested the efficacy of tree stockings and showed a short time protection (approximately one month) for small seedlings; larger seedlings cannot be protected by the stockings as they are soft, without support and will fall sideways. The most effective plant protectors may be 1-m-tall rigid tubes (100% protection for the duration of the trial, 7 days) and wire-mesh guards (90% protected for 7 days) (Montague 1993). However, Montague (1993) concluded that the commercial potential for the 1 meter tubes was limited due to their cost, while the wire-mesh guards had the drawbacks of being difficult and time consuming to transport, assemble and install.

All plant protectors have disadvantages, for example they can be pushed over, animals can eat inside of the large opening (e.g. plastic sleeves), they can deform the plant, or the plant grows out of the protector. Most types of seedling guards (including the photo- degradable material) have to be removed eventually to avoid deforming the tree as they affect final tree form and growth rates, making them labour intensive (Coleman 1991). In conclusion individual plant guards overall are only a short term protection. They are labour intensive and often ineffective (dislodged by animals, blown away or grazing occurs on growth immediately above the guard) and therefore not likely to be beneficial in terms of cost-benefit ratio.

Animal deterrents

Due to the costs and disadvantages of fencing or individual plant protection, the ethical issues surrounding lethal control and ineffectiveness of the aforementioned non-lethal methods, animal repellents are gaining popularity and represent a billion dollar industry in Australia (Peter Murray, University of Queensland, pers. com.). Lethal methods are recommended as a last resort and the public supports non-lethal herbivore control methods (Edwards & Oogjes 1998; Gilsdorf et al. 2002; Massam 2006; Reiter et al. 1999). Representatives of the RSPCA, the World League for Protection of Animals (WLPA) and Against Animal Cruelty, Tasmania (AACT), also consider repellents as humane (Coleman et al. 2006). Benefits of animal deterrents include huge savings in habitat restoration due to a higher seedling success rate but, more importantly, have the potential to offer humane solutions to animal management. The Australian Government has acknowledged the importance of research into increasing the effectiveness of deterrents by making it one of the primary research agendas in the ‘Alternatives to 1080 Program’ in Tasmania (Coleman et al. 2006).

Animal repellants utilise visual, olfactory, tactile, taste or auditory cues to ward off animals from target areas. Deterrents are usually based on a fearful reaction, since fear has been demonstrated to significantly alter most species’ behavior. In response to a fearful stimulus, animals increase their level of vigilance (Elgar 1989; Lima & Dill 1990), and decrease conspicuous behavioral display (Sih et al. 1990) and foraging (Abramsky et al. 2002; Hughes & Ward 1993). Additionally, various studies have shown animals shift their habitat utilisation and retreat away from ‘danger zones’ (Bergerud et al. 1983; Blumstein & Daniel 2002; Formanowicz & Bobka 1988; Heithaus & Dill 2002; Jordan 1997).

All animals sensing fear will respond to fearful cues. How rapidly a species initiates or relaxes fear-induced behavior is dependent on whether the response is learned or instinctive. Many antipredator responses are hard-wired (i.e. genetic) and therefore some species maintain antipredator behaviour (i.e. vigilance, crypsis) even in the absence of predation (Blumstein et al. 2000; Curio 1966; Pressley 1981). For example, antipredator behavior persists in pronghorn antelope (*Antilocapra americana*) despite the extinction of their predators during the last ice age (1.8 mya - 11,000 years ago) (Byers 1997) and in California ground squirrels (*Spermophilus beccheyi*) isolated from primary predators for 70,000-300,000 years (Coss 1999). Similarly, Kangaroo Island has been isolated from predators for ~9,500 years, but tammar wallabies on the island still respond to the sight of various predators (Blumstein et al. 2000).

During the last 4-5 million years, like other Australian native animals, kangaroos have adapted to a high degree of predation. Kangaroos were preyed on by a number of now extinct native marsupial predators including the marsupial lions (Thylacoleo), a monitor lizard (Varanidae) and the thylacine wolf (Thylacinus) (McCullogh & McCullogh 2000). About 3.500 years ago, the dingo (*Canis lupus dingo*) arrived in Australia with humans, both hunting kangaroos (Corbett 1995). The fox (*Vulpes vulpes*) was introduced in the mid-nineteenth century, preying with significant effect on young and small macropod species (Banks et al. 2000). This intense predatory pressure has continued into the modern epoch, as demonstrated by densities of kangaroos on either side of a dog fence that separates the far north-west of New South Wales from Queensland and South Australia (Pople & Grigg et al. 2000). The density of kangaroos inside the dog fence (where dog numbers are reduced) is significantly higher then the density outside (Dawson 1995; Pople et al. 2000). As a consequence of this extensive predation pressure, kangaroos demonstrate a number of antipredator behaviours: kangaroos are group foragers, flighty and demonstrate extreme levels of vigilance (Jarman & Coulson 1989).

The sensory modality by which a herbivore detects the presence of a predator is species specific (Apfelbach et al. 2005) and is not well known among macropods. It is believed that, for *M. fuliginosus,* the senses of smell and hearing are very well developed due to their crepuscular and/or nocturnal nature (Dawson et al. 1995). Generally speaking, optical and auditory cues may warn of imminent danger, whereas chemosensory signals may indicate past or present predator presence (Pusenius & Ostfeld 2002).

Visual deterrents

Visual deterrents include the well known scare-ravens, laser and light treatments, stuffed predators, artificial predator models, mirrors and colourful and/or moving elements (Koehler et al. 1990). Commercial strobe lights plus sirens (110 and 123 dB) effectively protect pastured sheep from coyote predation for the trial period of 3 months (Linhart et al. 1992). Tammar wallabies respond to the sight of taxidermic mounts of predators by stomping their alarm foot stomp, reducing foraging and increasing vigilance (Blumstein et al. 2000). A study by Soldatini et al. (2008) tested two people jumping up and down for its effectiveness to scare away two species of gulls. It was determined to be effective, but problems include the labour involved in having human visual deterrents.

Problems relating to visual deterrents include quick habituation and few methods to apply them to a larger area. Wolves, bears and coyotes quickly habituate to visual deterrents, but when used in combination with acoustic deterrents, visual deterrents showed promising effects, at least in the short term (Smith et al. 2000).

Olfactory deterrents

Olfactory deterrents are based on natural or synthetic predator odours intended to mimic the risk of predation and lead to changes in the animal’s behaviour, thereby preventing animals from entering a treated area, staying for less time, or reduced foraging. Urine from lions (*Panthera leo*) and Tasmanian devils (*Sarcophilus harrisii*) are effective deterrents for wallabies

(*Macropus rufogriseous*) and padamelons (*Thylogale billardierr*) in pen trials (Statham 1999). More recently, Parsons et al. (2007c) demonstrated that western grey kangaroos (*M.fuliginosus*) are repelled from target food patches using predatory smells; following 10 days of treatment, the animals did not return to the treated area (Parsons & Blumstein, unpublished data). Following a meta-analysis of trials presenting predator odours to prey, Apfelbach et al. (2005) identified several common difficulties with this method of deterrents, including habituation and a reduced period of effectiveness due to rainfall washing the agents off or diluting them. Ideally a weather- resistant system, delivering the repellent over a sustained period of time would need to be developed.

Tactile and taste deterrents

Numerous chemical compounds have been tested for their effectiveness to deter herbivores (Shafer & Bowles 2004). The majority of these work by causing adverse taste, pain/irritation or by inducing nausea. Several mammal species (e.g. rabbit, elk, deer, possum, beaver and wallaby) are deterred by bitter-tasting compounds based on active ingredients such as predator faeces or urine, and capsaicin, the active component of the chili pepper (Andelt et al. 1994; Gillingham et al. 1987; Epple et al. 1993; Kimball et al. 2005; Marks et al. 1995; Woolhouse & Morgan 1995). Jensen et al. (2003) showed capsaicin to be effective for reducing rodent foraging on grain, but found that an important influencing factor is whether alternative food sources are available; if no other feed is available, then adverse tasting compounds are ineffective.

A recent study by Miller et al. (2009) tested Sen-tree Browsing Deterrent (Suregro.com), an eggbased spray with a sandy grit (carborondum). It repels both due to the odour and palatability, as carborondum imitates naturally occurring silica from plants. Some animals will avoid this in high concentration as it wears down their teeth (Delbridge & Lutze 1998). Sen-tree was found to significantly delay browsing by macropods (Miller et al. 2009). The major problem with all chemically applied repellents is the weather, as they are easily washed away by rain. A second issue is that new shoots are no longer protected and are therefore palatable. Some spray-on repellents also have a negative effect on plant survival and development (Bergquist & Orlander 1996).

Another method to discourage herbivores is the selection of certain plant genotypes with a higher level of defenses (i.e. secondary metabolites) and/or manipulation of seedlings in the nursery. Applying different fertilizer regimes can modify plants to have lower nutritional value and/ or higher chemical defenses making them less desirable to the grazer (Close et al. 2004). Miller et al. (2009) studied the effect of different fertilizer applications and found a significant delay in browsing due to reduced fertilizer application. The same study shows that selecting genotypes has a more promising effect for a longer term protection than both different fertilizer treatments and chemical repellents as deterrents.

Acoustic deterrents

It is generally believed that acoustic deterrents have a potential of a great area effect and are easy and cheap to reproduce as the equipment only needs to be purchased once. Although replay is required (motion sensors can be applied), no need for labour intensive re-application occurs like with chemical agents. Acoustic deterrents can be divided into two categories: artificial sounds and bioacoustic sounds.

Artificial sounds

Artificial sounds can be any sound generated with no biological background, and include sudden novel sounds like gun shots, whip cracks, bangs, sirens or more continuous background noise including infrasound (< 20 Hz) and ultrasound (> 20,000 Hz).

Startle and flight response to sudden sounds have been demonstrated in a range of animals (e.g. rats *Rattus norvegicus*: Voipio 1997; porpoises *Phocoena phoecoena*: Teilmann et al. 2006; pigs *Sus domestica*: Talling et al. 1998; rhesus monkeys *Macaca mulatta*: Winslow 2002). Sudden noises are also effective in deterring animals from certain areas as shown for Canada geese *Branta canadensis* (Mott 1988) and coyotes *Canis latrans* (for at least 30 days, Pfeifer 1982). Kastelein et al. (2000) showed a continuous aversive response from harbour porpoises (*Phocoena phocoena*) to ‘pinger-like’ signals played over a month with no sign of habituation. Teilmann et al. (2006) found habituation to occur, but even minimal alterations to the signal would render it effective again.

Campo et al. (2005) demonstrated significantly altered behaviour from captive hens responding to background noise (including vehicle and aeroplane sounds). Groups of hens appeared frightened, and either piled up in the corners far away from the playback device, or were laying flat on the ground. The experiments suggested that noise was regarded as aversive, and the treated hens were significantly more fearful than control birds. Overall, as seen in most experiments, loud, sudden noises seem to be the most effective for all species, especially used in rotation with others overall.

Few studies on acoustic deterrents have been conducted on macropods. Bender (2001, 2003) tested the effectiveness of two ultrasonic devices manufactured to prevent vehicle collision (Shu-roo Mk II, Shu Roo Australia Pty Ltd) and protect agricultural areas (ROO-guard Mk I and II, Shu Roo Australia Pty Ltd). Muirhead et al. (2006) assessed the value of the Roo-guard MKII. Results of these studies indicated that the signals did not significantly alter kangaroo behaviour in regard to the aims of reducing browsing and preventing vehicle collision. It was suggested that the devices failed to elicit a fear response since they generated signals of a sound frequency outside the optimum hearing range for the animals.

Bioacoustic signals

Bioacoustic or biosonic sounds are recordings or reproductions of biologically meaningful signals, such as alarm calls, distress calls, predator sounds or any other sound produced by an animal with a meaning to other animals. These signals may be used to elicit a fear response in various animals.

Vocal distress and alarm calls are produced by a wide range of species (e.g. Gunnison's prairie dog, *Cynomys gunnisoni*: Perla & Slobodchikoff 2002; Richardson's ground squirrel, *Spermophilus richardsonii*: Sloan et al. 2005; white-faced capuchin monkeys, *Cebus capucinus*: Fichte et al. 2005; yellow-bellied marmots, *Marmota flaviventris*: Blumstein & Munos 2003). Vocal distress and alarm calls are often species-specific or even predator-specific (Wheeler 2008). Various hypothesis have been proposed and reviewed to explain the role of these alarm calls, including to attract other members of the group to help mob the predator, to let the predator know it has been detected and thereby discourage its attack as it has lost its advantage of surprise, to warn and save kin by attracting the predators' attention, or to create chaos to save yourself and/or kin (Ramp 2007; Wheeler 2008).

Some biologically-relevant alarm cues have the potential to deter animals. Spanier (1980) showed that alarm calls could deter 80% of night herons (*Nycticorax nycticorax*) from a targeted pond. Furthermore, the herons did not become habituated to this signal over a period of 6 months. Similarly, captive red-necked pademelons (*Thylogale thetis*) significantly changed their behavior in response to distress calls (Ramp 2007).

There are many ways in which animals can produce a sound that is biologically-meaningful to its conspecifics. Hingee & Magrath (2009) suggest that the flight take-off noise can signal alarm in many flocking species. Leaving in an alarmed state almost certainly changes how fast or steep an animal takes off. For example, crested pigeons (*Ocyphaps lophotes*) produce a distinct sound (a whistle) with their modified flight feathers in alarmed flight (Hingees & Magrath 2009). Playbacks of take-off sounds support the theory, with individuals only taking flight after the playback of alarm whistles. Interestingly the response depended not just on amplitude (i.e. volume), but on auditory structure of the whistle signal, (e.g. tempo) as well.

Many macropod species generate foot stomps when danger is detected, by hopping up and hitting the ground with their hindfeet upon landing, creating a one or two pulsed audible signal (Coulson 1989, Rose et al. 2006). In response to these stomps, conspecifics are more vigilant, decrease foraging time or take flight (Bender 2005; Blumstein 2000; Blumstein & Daniel 2002; Coulson 1989, 1997 ; Kaufmann 1975). Tammar wallabies (*M. eugenii*) increase vigilance and decrease foraging when foot stomps are played back (Blumstein et al. 2000). Similarly, captive red-necked pademelons and red-necked wallabies (*Macropus rufogriseus banksianus)* show significantly increased vigilance in response to foot stomp play back, however the authors reported that the sounds did not initiate a flight response (Ramp 2007). Bender (2005) trialed playback of alarm stomps as a deterrent for *M. giganteus*, and recorded flight response in 26% of animals and a 74% reduction in feeding time.

Biologically-relevant alarm cues (bioacoustic sounds) therefore have the potential to reduce herbivory (Bender 2005; Ramp 2007; Spanier 1980) and could become important as a management tool. The effect recorded in these studies was probably not maximised due to technical difficulties in regard to both an accurate recording and authentic playback. Besides technical inaccuracy, distance of recording may have been a limiting factor in Benders (2004) study, as wild kangaroo stomps were recorded at >50m and Ramp (2007) conducted his study in a restricted compound, which might have influenced the animals' movement/flight responses. Furthermore sample size may have influenced these responses. Ramp worked with a limited number of animals (10 pademelons and 14 wallabies). It has been recognized that these factors are probably significant determinants of success rate (Bender 2005; Ramp 2007) and should be the focus of future studies.

Kangaroo foot stomps can sound similar to the human ear, but there is evidence that the animals can detect differences. There is observational evidence that the stomp may have enough characteristics to at least reveal the age/size (and thereby experience) of the individual stomping, maybe even individuality. A juvenile stomping usually does not create a flighty reaction from surrounding individuals (pers. obs., com. Lander), which is consistent with findings about the alarm calls of the California ground squirrel, *Spermophilus beecheyi*, (Hanson & Coss 2001) and bonnet macaques, *Macaca radiate*, (Ramaksishnan & Coss 2000).

One of the reasons that previous studies may not have initiated flight in response to play back of foot stomps (e.g. Ramp 2007) may be due to the frequency range of the playback. *Macropus fuliginosus* foot stomps can sometimes be felt as well as heard, which indicates infrasound/seismic (<20 Hz) frequencies may be part of the signal. Furthermore, not all individuals produce a foot stomp which initiates following by the rest of the mob (pers. obs.; comm. C. Lander 2009), suggesting a distinct acoustic pattern for effective alarming foot stomps (i.e. frequency, duration, tempo etc). Ramp's (2007) speakers produced a frequency range of 50 - 21,000 Hz but auditory analysis shows that the lower limit of the foot stomps of both species tested drops below 50 Hz. Furthermore, Bender (2005) found that the majority of the energy in *M. giganteus* foot stomps was below 7 kHz, with a fundamental frequency of 652 ± 84 Hz for the first pulse and 901 ± 67 Hz for the second pulse. From inter-aural measurements and considering the shape and length of the outer ear, Bender (2005) predicted an upper hearing-limit of 40-49 kHz, with the best audible frequencies of 2-3.5 kHz, but ability to hear frequencies significantly lower.

Besides the audible signal, a seismic component is likely to play a role in the kangaroo foot stomp. Bender (2005) found the *M. giganteus* foot stomp waveform shape and structure supported the concept of a seismic component to the signal. Supporting this theory, Stewart & Setchell (1974) recorded seismic components at a distance of up to 100 m from hopping *M. fuliginosus*. To date, two species of macropods, the tammar wallaby (*M. eugenii*), and Tasmanian pademelon (*Thylogale billardieri*), have been shown to have vibration transducing lamellated corpuscles in their legs (Gregory et al.1986), further supporting the potential existence and importance of a seismic component in macropod foot stomps.

1.4 Aims of this study

It has been recognised for kangaroos that destruction should be viewed as the last resort after all other control options have been attempted (Massam 2006). Methods suggested by the Western Australian Department of Environment and Conservation (abbreviated DEC, formerly known as CALM) include limiting food and water, erecting exclusion fencing, or utilising deterrents. The possibility of acoustic deterrents with noise-generating devices has been identified as a humane, non-invasive means to encourage animals away from target areas such as newly replanted vegetation or specific watering points (DEC 2002).

The aim of this study is to investigate the efficacy of acoustic signals as possible fear-provoking stimuli in the western grey kangaroo (*M. fuliginosus*). The three aims refer to three experiments dealt with in separate chapters:

1. Do *M. fuliginosus* change behavior by ceasing foraging activities and moving out of the area in response to selected auditory signals (artificial and bioacoustic)?
2. Is there potential for habituation to a biologically-important signal (foot stomp) versus an artificial sound (bull whip crack)?
3. Does the rate of the signal with the highest fear response have an effect upon the kangaroos’ responses?

The ultimate aim of this study is to contribute towards management of herbivory and therefore successful rehabilitation of areas post mining, through the development of non-lethal acoustic deterrents that are cost effective, have a large area effect and are humane. The study investigates the means of eliciting a startle response in these animals which could therefore be used to ward animals away from target foraging areas at critical stages of seedling development post mining or fire.

Chapter 2 Methods

2.1 Study site and animals

Sound recordings and trials were carried out between October 2007 and April 2009 in Boyup Brook, WA at Roo Gully Wildlife Sanctuary (RGWS), a semi-natural setting, 270 km SE of Perth (33º 49´18.41 S, 116º 22’ 52.34 E). Forty-eight western grey kangaroos (*Macropus fuliginosus*) and 4 red kangaroos (*Macropus rufus*) had free range of a 9.7 ha (24 acre) fenced area. The study site was within the natural range of *M. fuliginosus* and comprised a mixture of grass paddock and bushland with a broad creek flowing through in winter. The region has a Mediterranean climate with cool, wet winters and hot, dry summers. Rainfall varies between 500-700 mm per annum. Average summer monthly minimum temperatures are 10^{o}C, while average summer maxima are 31^{o}C. Winter temperature ranges from an average of 4 ^{o}C minimum to 16 ^{o}C maximum . The dominant soil group is ferruginous gravels with sandy clay subsoil at depth (Brookman 2005; Churchwood & Dimmock 1989). Flora present included *Eucalyptus camaldulensis*, *E. globulus*, *Callistemon* spp., *Acacia* spp., *Melaleuca raphiophylla*, *Dryandra* spp., and a variety of native and introduced grasses and shrubs.

Kangaroos at RGWS ranged in age from approximately 12 mth to 12 yrs, with most individuals between the ages of 3 and 5 years. All animals were recognisable by differences in facial, tail, toe and/or fur features and through their behaviour. These patterns allowed easy identification for recording and observation. The majority of males have been castrated as they are physically impaired and can not be released into in the wild. Wild bucks however infrequently breach the fences and mate with captive animals. Male offspring are kept entire and are released when old enough. The mixed mob consists of kangaroos raised as orphans and animals born and raised in captivity at RGWS. Because some of the kangaroos have never been handled by humans, they tend to retreat rather than interact when approached. These timid kangaroos comprise one third of the mob. The remainder of the mob may be approached closely. Among these animals, about half can be touched.

Students, tourists and school groups regularly observe animals, but no food is distributed by hand and animals are free to choose or decline human interaction. All kangaroos at RGWS have *ad libitum* access to water, herbage and shrubs. Supplemental pellets and grains are freely available at appointed feeding stations close to the house. Animals are not deprived of any dietary substances. Animals that present symptoms of sickness are immediately taken to an onsite veterinarian.

All experiments were in compliance with the National Health and Medical Research Council (NHMRC) of Australia’s code of practice for protecting animal welfare during research; ethics approval was granted from Curtin University (AEC 02-08).

This experiment was designed to maximise the recording and playback of several acoustic signals, with particular reference to the hearing frequencies of *M. fuliginosus*. Bender (2005) showed the hearing of *M. giganteus* to be most sensitive between 1.7-3.5 kHz, although foot stomps travel at much lower frequencies. No similar study has been conducted for *M. fuliginosus*, but the two species are closely related evolutionary (Coulson 1989), displaying similar physical adaptations (Dawson 2005). We expect hearing range to be similar between conspecifics. No significant difference in hearing range between the two conspecifics was therefore anticipated.

2.2 Technical equipment for sound recording and playback

All hardware was selected and assembled by an experienced sound engineer (Scott Montgomery, SHOOSH!, Bayswater, WA) to maximise the accuracy and quality of sound capture and playback.

A Marantz PMD671 compact flash recorder with Ultrasone PRO750 headphones was used for recording and feedback. The sampling rate was set to 24 bit, 96 kHz (best quality possible). The recording device and microphones were used in conjunction with a Sound Devices 442 field mixer (20 Hz to 30 kHz). The mixer has a dynamic range of 115 dB, and a very low noise floor (-126 dB, i.e. no internal noise from the mixer). A handheld Sennheiser MKH816 shot-gun microphone (with a wind shield; range 40 Hz to 20 kHz) was used to detect and record sounds (fig 2.3). In order to maximise capture of foot stomp frequencies not obtained in former studies (Bender 2005; Ramp 2007), a Ravenn PZM-30D microphone (range 20 Hz to 20 kHz) with a 10 m long extension cable was placed at ground level to increase the angle of sound capture and to increase the chance of recording seismic sounds (i.e. vibrations produced and transported along the ground).

A heavy duty trolley (fig. 2.1) was assembled and modified to hold a large active subwoofer (Genelec 7060B; 20 Hz to 120 Hz with an output of 113 dB Sound Pressure Level, SPL). A smaller full-range speaker (Genelec monitor) was set to overlap with this range (120 Hz to 20 kHz; output of 106 dB SPL) giving an accurate frequency response of 20 Hz to 20 kHz. The Genelecs are designed for 240 V. A custom power supply was fashioned to maximise clean, transparent and distortion-free power and mobility. A battery (12 V 55 Ah) and a 700 W PURE! sinewave inverter produced 240 V output to power a KCC CF-2 power clean unit and speakers. The Marantz PMD671 Compact flash recorder was attached via a 30 m cable and was utilised as a remote control playback device. Intensity of the playback varied between 50-70 dB according to sound type. Playback intensity was measured by a digital sound level meter (Q 1264, IEC 651 Type II, 30-130 dB). Volumes were selected to match their natural levels and intensity. Speaker amplitude was adjusted depending on the individual signal and distance to the kangaroos.

Fig. 2.1 Sound trolley with playback devices

Fig. 2.2 Unique facial markings used to identify animals

Fig. 2.3 Sound recording equipment incl. shotgun microphone, excl. ground microphone (left)

Fig. 2.4 Recording the bull whip-crack (below)

Leads and connecting cables for were hand-made, with high quality cable and connectors. During the pilot trials, a small battery powered recording and playback device (Edirol R09; 20 Hz – 22 kHz) was used for recording and playing back wav files at 24 bit/ 48 kHz.

Raven Lite 1.0 (Ithaca, NY) enabled the researcher to examine spectral views of each signal, including frequency ranges, rate (applicable for repeated signals) and length of sound waves. AVS Audio Editor (Boston, Massachusetts) was used for spectral views and for sound splicing. Both processes were carried out under consultation with a professional sound engineer.

2.3 Field work preparations

2.3.1 Acoustic signal selection and recording

To limit the effects of repeated sampling on individuals, we selected the minimum number of sounds, including two artificial and two biologically relevant signals, from a range of sounds tested in a pilot study.

Natural sounds (raven calls and kangaroo foot stomps) were recorded between January 2008 and September 2008. Recordings were made during ideal weather conditions (dry, no wind gusts over 2 m/s).

Sound recordings of artificial sounds were obtained between October 2007 and December 2007. More than 100 artificial sounds were collected near Roo Gully Wildlife Sanctuary, WA. To maximise the range of sounds tested, several tools, gun shots, engine sounds, sirens, aerosol hissings and whip cracks were recorded. These sounds were evaluated by listening to them and examining at the sound wave profile in Raven Lite 1.0 (Ithaca, NY) software. Sounds with background noise or reduced clarity were discarded. Other sounds excluded were evaluated by the researcher and helper as too invasive (sirens) or likely to be ineffective (tranquilizer guns and small caliber rifles gave a dull, low intensity sound and some engines and tools might have been encountered by the animals in the past). The hissing sound of an aerosol spray was selected due to alarm behaviour displayed by animals in the vicinity of this sound (pers. obs.; comm. C. Lander). To choose the last sound to be tested, twelve artificial sounds were selected for a pilot:

1. shot of 22 rifle, hollow point bullet
2. rat shot in 22 rifle
3. shot with a bullet 10. Winchester rifle
4. bull whip crack
5. dog barking
6. reversing fire engine beep
7. explosion (obtained from sound engineers sound library)
8. sound from keyboard called *spaceship*
9. bouncing ball
10. two pot lids banged together
11. leaf blower (electric)
12. angle grinder (had to be excluded for experiments as animals tested showed high degrees of panic. In a restricted area such as RGWS this could prove lethal, or cause injury, to the kangaroos as they would take flight and either jump or hit the high fences).

The pilot trial was performed between October and December 2007 with 5 kangaroos. The researcher approached either a foraging or relaxed kangaroo, positioned in the outskirts of a group, with the handheld Edirol R09 with inbuilt speakers. Sitting 2-5 m away from the kangaroo, a short time (5-10 min) of waiting ensured that the animal was not reacting to the human approach. After this elapsed time, one of the target sounds was played back, loud enough for the targeted animal to hear (but with little chance of farther away individuals responding to it) and the reaction noted. This was repeated over a two month period, playing each of the twelve sounds to the 5 animals. Among these sounds, the bull whip crack showed the highest frequency of flight or retreats from the vicinity. The 5 tested animals were not included in the three experiments conducted.

The four selected sounds for the final study include two artificial sounds and two biologically relevant sounds:

1. **Hiss** an artificial sound produced by an aerosol spray can (a 1 s burst). Kangaroos react to hissing aerosols by retreating with a high sideways or backward moving hop (pers. obs.; comm. Lander) and may associate this sound with a snake hiss. The hiss from various spray cans (100g) was recorded and the one considered to sound the most natural (some were quiet mechanical-sounding) was selected. With the speakers facing the animals, the hiss was reproduced at approximately 50 dB.

2. **Whip** bull whip cracks (fig. 2.4) were recorded and played back at approximately 70 dB.

Two bioacoustic sounds: one benign sound and one fear inducing sound was selected for further trials

3. **Raven** a benign bioacoustic sound: the communicative call of the Australian raven *Corvus coronoides* was selected as a natural, common, non threatening control sound. The signal recorded was neither a distress nor alarm call. The raven sound was recorded and reproduced at approximately 50 dB with the speakers facing the animals.

4. **Foot stomp** *M. fuliginosus* foot stomps were recorded of individuals at RGWS and surrounding bushland at dusk, dawn and night times. Various approaches were attempted to provoke foot stomps. Sudden sounds and olfactory stimulants, although know to provoke foot stomps in a different captive mob, (pers. obs.; Parsons 2007) these were found to be ineffective. Partial (less intense) stomps were obtained by opening a bright-coloured umbrella and/or waiting hidden in shrubbery and stepping out when approached by the animals; however none of these triggered a flight response by conspecifics during the recording; these noises were therefore disregarded.

The best foot stomp recordings (close proximity and with limited background noise) were obtained by walking transects during the late evening (in the dark). The researcher and assistant quietly approached as close as possible (whilst giving the animals enough room to navigate around the encountered danger and into the open or into cover) and then stop and wait in silence for several minutes. The assistant then continued walking around the shrubbery to focus the animals' attention away from the recorder. Animals often responded by walking pentapedally or hopping slowly away from the assistant. Most would move towards the researcher who would then switch on a torch to illuminate the fluffy windshield of the shotgun microphone (lighting up the person/researcher was less successful, probably due to the familiarity to humans). This approach often elicited a loud foot stomp from the approaching kangaroo (in the majority of occasions, the same male was identified as both moving first and stomping).

Although multiple foot stomps were recorded, only nine recordings were considered sufficient quality (being a typical representative and a clear recording) to become part of the sound library. With the speakers facing the animals, the stomp play back was reproduced at approximately 60 dB.

2.3.2 De-sensitising the animals

Animals were de-sensitised to equipment (to within 7 m) and two people (to within 20 m) 6 weeks prior to trial commencement. During the first 2 weeks, the trolley was taken to the grazing kangaroos twice daily (dusk and dawn) by the researcher or assistant. The trolley was left for a few hours so the animals could investigate. Acclimation was achieved after two weeks when the kangaroos showed little reaction (looked up briefly (about 3 s) before resuming foraging) to the approaching trolley. The trolley could be placed between 7-30 m of the animals.

Over the next four weeks, the researcher and/or helper would place the trolley and then sit for about 15-30 min at a distance of 10-30 m from the trolley (further away from the animals). After these four weeks, the kangaroos were evaluated to return to natural relaxed behaviour (i.e. did not move out of the area, did not seem alarmed, were not in the alert position, stopped looking at the equipment/people, and resumed foraging or relaxing) within 5 minutes of the trolley being placed and the researcher and helper taking up position.

During all trials, the researcher and an assistant standardised their approach in order to minimise influencing kangaroo behaviour (i.e. moving slowly, no perfume/ aftershave and camouflaged clothing). Bright, alarming colours, (e.g. orange and red) seem to have an effect on kangaroo alertness (pers. obs.; C. Lander pers. comm.).

2.3.4 Other preparations

Prior to the experiments, without animals present, the attenuations of the signals were tested by measuring volume with a sound level meter over various distances. For these trials, a non-windy day (16 °C) was selected and the site had no obstacles in the way of the sound. Subsequently during experiments in the field, the distance to the animals was estimated and the position of the volume button adjusted accordingly to ensure a constant signal level reached the animals.

The researcher learnt from Carol Lander (owner of RGWS) to identify the animals by their facial markings (fig. 2.2), ears, toes, tail and body shape.

2.4 Data collection

Behavioural data were extracted from video recordings of the field trials. A Sony mini DV Digital Handycam Camera (120x digital zoom, Carl Zeiss Vario-Sonnar, super steady shot, DCR-TRV22E) was used for all filming.

Three experiments were conducted and filmed between 12 December 2008 and 10 April 2009. As ambient conditions and wind are known to affect feeding patterns and vigilance behaviour (Blumstein & Daniel 2003; Hayes & Huntley 2005; Yasue et al. 2003), trials were only run when weather conditions were similar with temperatures ranging between 14-23°C and wind speeds, measured by an anemometer, between non-detectable and 4.5 m/s (gentle breeze). *Macropus fuliginosus* have their most active foraging time around dusk and dawn; thus trials were normally carried out between 6-9am and 6-8pm.

2.5 Experimental trials

Initiation of experimental trials followed the pattern of the de-sensitisation trials. The trolley was placed between 7 and 30 m of animals with both speakers facing the animals. The volume button was adjusted depending on distance. The researcher and assistant retreated up to 30 m away (depending on cover available). A resting period of at least 15 m was held, to ensure return of normal behaviour (i.e. mostly foraging and resting behaviours without any signs of agitation). Filming commenced with the purposes of identifying as many individuals in the group as possible (i.e. zooming in on face and different body parts like ears, tail and feet). When the animal identification filming was complete and the minimum resting period had elapsed, filming as a group shot was carried out for at least a minute. This first minute represents the pre-treatment behaviour of the kangaroos. After the first minute, the treatment (acoustic signal) was triggered by remote control (the Marantz device) and the group was filmed for a further two minutes to record changes in behaviour.

Three experiments were performed:

1. The first experiment determined which of the four signals had the greatest effect on *M. fuliginosus* behaviour. In each trial, the signal (trials for each sound were held in randomised order) was played once.
2. The second experiment focused on quantifying differences in time to habituation to an artificial (whip) and a bioacoustic (foot stomp)

signal. In this experiment, either signal was repeated every 5 s for 2 min.

3. The third experiment examined whether the rate of signal playback influenced behaviour. The whip (at that time identified as having the greatest potential deterring effect) was tested at 3 s, 15 s and 30 s intervals for 2 min.

2.5 Data analysis

Any kangaroo behaviours the researcher expected to potentially observe were collated in an ethogram (table 2.1). The ethogram was created in *J-Watcher V1.0,* linking each behaviour to a keystroke enabling the researcher to score video recordings, quantifying observed behaviours accurately. Before the videos were scored, maps were constructed displaying the exact position the individual kangaroos within the field of view to ensure the identity of each focal individual. To create the maps, 6.5 h of footage was reviewed between 2-5 times by the researcher and the owner of RGWS to ensure accuracy in the identification process.

Table 2.1. Ethogram of potential kangaroo behaviour to be collected between December, 2008 and April, 2009 at RGWS. Behaviours and their description created as an ethogram for J- Watcher to quantify individual's behaviour.

Symbols:
*: Variable analysed statistically
P: pooled behaviours for analyses (two pooled groups)
S: scarcely observed→ not analysed
NR: not recorded

Behaviour	Symbols	Description of behaviour
Sleep	NR	Animal lies on the ground, head down with eyes closed
Relax	*	Animal lies on the ground, head up with eyes open
Eating	P1	Any active uptake of food (grazing and browsing)
Chewing	P1	Animal chews its food
Regurgitate	P1	Animal regurgitates food
Crouched	P1	Animal is standing in pentapedal position
Grooming	*	Self grooming or interaction between animals grooming each other
Play	S	Playful boxing
Touch	NR	Any form of touching between individuals (non-aggressive)
Aggressive	NR	Any aggressive touch/movement or growl
Looking	*	Animal stands up on hind legs and tail and looks around, head and ears turning
Alert	*	Animal stands on hind legs and tail- more vertical body posture than looking, an almost frozen state, usually only ears are moving.
Walking	*	Pentapedal movement at a slow pace
Hopping	*	Bipedal movement, medium pace, animal hopping on hindlegs, body bend forward
Flight 10	P2	Fast bipedal movement, animal hopping and body held vertical/ upright. Up to 10 m distance before stop
Flight 25	P2	As above, but up to 25 m distance before stop
Flight 50	P2	As above, but up to 50 m distance before stop
Out of area	*	Animals moving more than 50 m away from the original position

Scoring videos in *J-Watcher* is performed by reviewing the video recordings and keystroke logging the start and end of any observed behaviour an individual displays (Blumstein & Daniel 2007). This was done as follows:

- Experiment 1: The 24 animals exposed to the 4 treatment signals once at the commencement of minute 2 were scored over a total of 3 minutes (1 minute pre-signal, 2 minutes post signal)
- Experiment 2: The 22 animals exposed to the 2 treatments (whip and foot stomp) every 5 seconds for two minutes were scored over a 3 min period (1 minute pre-signal, 2 minutes during the signal playback)
- Experiment 3: The 23 animals exposed to the 3 whip-signal rate treatments were scored over a 3 min period (1 minute pre-signal, 2 minutes during the signal playback)

Videos were reviewed up to 20 times per individual before scoring commenced to ensure individual position and movement was well known and could accurately be followed and scored.

With the key stroke log *J-Watcher* creates .dat files containing the behaviour time scores to the millisecond. These data were imported to Excel displaying the 3 scored minutes in time bins of 5 second intervals. Graphs displaying the 5 second intervals were constructed for each behaviour observed. It was not possible to carry out statistical analysis at the level of the 5 sec. time bins, since the majority of time bins involved zeros and this resulted in a lack of variance.

Due to too few data obtained for *crouched, chewing* and *regurgitating* and these behaviours being part of the foraging process, they were pooled with the data for *eating*, and all together are from now on termed *eating*. *Flight 10, 25* and *50* were combined into one *flight* category and re-scored. As soon as an animal took flight beyond 50 m it was scored as *out of area* (commencing as soon as the animal reached 50 m). Being scored *out of area* meant the animal was too far or completely out of view and the researcher was not able to observe individual behaviours. Only the individuals remaining within the field of view were assessed for other behaviour. Although *aggression, play, sleep* and *touch* were looked for during video reviewing, these behaviours were not observed (or very scarcely) and are therefore not analysed statistically.

The data for the final 9 behaviours to be analysed were transformed from milliseconds to a proportion of time spent occupied by the behaviour for a graphical display. Time bins were then pooled into minute intervals for analysis with repeated-measures ANOVA followed by Tukey's Post hoc tests for pair-wise comparisons (*Statistica 8.0*). Signal was the independent factor and data for each of the 3 minutes the repeated measure (time). Even with pooling the behaviours by minute, some behaviours were not displayed at all in some of the minutes and therefore could not be analysed due to the lack of variance (shown as NA in figure legend).

An additional analysis was carried out for the first experiment. A mixed-model ANOVA was run on the behaviours *alert* and *eating* as these were the only behaviours showing significance in the interaction between minute and signal. The analysis was to determine if group size (how many kangaroos were present in the mob tested), trial number (was it the first, second, third etc. time the signal was played to that particular animal) or group number (did animals tested at the same time, i.e. they were in the same group, react the same way as the rest of the group) had a significant influence on the behaviours. The covariate was *group size,* the random variable *group number* (i.e. the first group to be tested was assigned group no.1, the second group tested was group no.2 etc) and the independent variable was signal treatment. The dependent variable was the difference between minute 2 (i.e. post signal) and minute 1 (i.e. pre signal) in the amount of time spent *alert* or *eating*.

The level of significance for all analysis was accepted at $\alpha < 0.05$.

Chapter 3 Experiment 1: Effects of two artificial and two biologically-significant sounds on the behaviour of the western grey kangaroo (*Macropus fuliginosus*)

3.1 Introduction

Twenty-four western grey kangaroos were exposed to four sounds: *raven, hiss, stomp* and *whip.* The *raven* call was selected as a natural, common, non-threatening control sound. Foot stomps have been trialed with eastern grey kangaroos (Bender 2005) and red necked pademelons (Ramp 2007). However the results of these studies varied, possibly due to the quality of recording and playback.

Biologically-important sounds are regarded as having a high potential for success as a deterrent when captured and reproduced authentically (Ramp 2007). The equipment utilised in the present study was selected to improve the overall deterrent efficacy through accurately recording and playing back the western grey kangaroo's foot stomp. Artificial sounds may also have some benefit. The *whip* was selected due to its ability to deter kangaroos in the pilot trials and the *hiss* was chosen due to its threatening sound, reminiscent of a snake. Western grey kangaroos respond to the hissing sound of aerosols through short distance flight or retreats (pers. obs.; C. Lander pers. comm.). In other studies, sudden noises have been shown to have an aversive effect on several animal species (Kastelein et al. 2000; Talling et al. 1998; Teilmann et al. 2006; Voipio 1997; Winslow 2002).

3.2 Results

Prior to the playback of acoustic signals, western grey kangaroos demonstrated a high degree of relaxed feeding behaviour. The pre-stimulus time budget (i.e. minute 1) for the 24 kangaroos indicates that the animals spent the majority of their time eating (75% on average) and looking (average 16%). There was a minor amount of relaxing (average 5%), walking (average 3%) and grooming (average 2%) showing no significant difference between the four trials pre-signal (fig. 3.2).

Some interesting peaks in fig.3.1 show the initial response by the animals to the signal often starts with a stronger fearful response and transforms quickly to less fearful behaviours and that this change in behaviour is different in response to the four acoustic signals. The *whip* triggers the most fearful response, with a quarter of the animals taking *flight* in the first 5 seconds post-signal and subsequently moving *out of the area*. Animals that remain in the area are displaying alertness. For the *stomp*, the first response is mostly being *alert*, changing to *looking* after 10-20 seconds, while after the *raven* and *hiss* signal most animals spent a majority of their time *looking* and then turning back to *eating* or slow *walking*.

Analysis of the budgets after the four acoustic signals revealed significantly altered behaviour after the signal, which differed dramatically between the signals. Behaviours could be classified as those that were discontinued/decreased in response to the acoustic stimuli, whilst other activities were more prevalent or were only evident after the acoustic signals had been played.

Firstly, a number of activities decreased significantly in response to the signals. Most notably, animals demonstrated a significant drop in foraging behaviour, going from 71% (minute 1, pre-signal) to 1% (minute 2) and 11% (minute 3) in response to the *whip* signal, from 57% to 22% and 42% after the *stomp* signal and from 70% to 47% and 51% after the *raven* signal. The least response was noted for the *hiss* stimulus: the animals dropped *eating* from 89% (minute 1, pre-signal) to 65% for minute 2 but had all returned to *eating* at pre-signal levels (84% of the time) by minute 3. For *eating* behaviour, statistical significance was shown for time, signals and the interaction between the two (fig.3.1c).

Less *grooming* behaviour was evident after the acoustic signals (fig. 3.2b) with significantly less time spent in minute 3 compared to 1 (intermediate levels were recorded for minute 2, which was not significantly different from either minute 1 or minute 3). Grooming behaviour included all forms of self scratching and mutual grooming.

A behaviour that discontinued (at least temporarily) in response to the acoustic signals was *relaxing*. This behaviour was represented by animals reclined on the ground. Relaxing behaviour was present in the pre-trial time budget for *whip* (14%), *raven* and *hiss* (both average 4.2%, i.e. one individual out of the 24 was reclining in a relaxed position) treatments. However, no animal remained relaxed in minute 2 after the signals. For the *hiss* stimulus, one individual returned to a relaxed body position for the second half of minute 3 (contributing a minor percentage of the time budget: 2%).

The second group of behaviours increased significantly in response to the acoustic stimuli. In terms of the amount of time spent *looking*, significant effects of both time and signal were observed (fig. 3.2g) Kangaroos spent more time *looking* post- signal, and this effect was most pronounced for the *raven* and *hiss* signals (because a greater proportion of animals took *flight* or were classified as *alert* rather than simply *looking* for these treatments, see below). Compared to 18% pre-signal), kangaroos spent 44% (minute 2) and 28% (minute 3) of their time *looking* in response to the *raven* signal, 25% and 2% in response to the *hiss* (5% pre-signal), 46% and 44% in response to the *stomp* (30% pre-signal) and 17% and 24% for min 2 and 3 after the *whip* (11% pre-signal).

Alert activity differed from *looking* in that the body posture for animals was more upright and rigid. *Alert* activity was significantly affected by time, signal and the interaction between these two factors. On average less than 1% of time in minute 1 was classified as spent being *alert*, whereas this behaviour was identified for 42% (minute 2) and 34% (minute 3) of the animals time budgets after the *whip* signal, 27% and 7% post-*stomp* signal and 5% and 3% post-*raven* signal. Very little *alert* behaviour was identified for the *hiss* signal treatment, changing from 0% pre- signal to 1% and 1% post-signal.

The behaviours *flight* and *out of area* were not present before the acoustic signals. These behaviours were mainly triggered by the *whip* signal (fig.3.1f and 3.1i). The whip triggered flight in a quarter of the animals for the first 5 second time bin. After 10-20 seconds, the animals that remain are classified as *alert,* whilst a third of the individuals have moved out of the area.

These results indicate that the *whip* signal had the greatest effect on *Macropus fuliginosus*, followed by the *stomp*, the *raven* and to the least amount, the *hiss*.

Results obtained for several variables are displayed in table 3.2. A mixed model ANOVA investigated the behaviours *alert* and *eating* in regard to several variables. There was a significant effect of signal treatment on the degree of *alert* behavior shown in minute 2 compared with minute 1. There was also a trend for an effect of group number (p=0.059) upon *alert* behaviour, whilst group number significantly affected *eating* behaviour, i.e. each individual's response was linked to how the others in their group responded. Trial number was an important factor in terms of a measurement of habituation. There was no effect of trial number upon the degree of *alert* behaviour demonstrated (i.e. there was no indication that animals altered their degree of alertness in response to being tested over multiple days). The effect of trial number on *eating* behaviour showed a trend, however (p=0.055), with animals returning to *eating* earlier if they had already been subjected to multiple trials previously. Neither *alert* nor *eating* behaviour was affected by group size (number of individuals in the mob).

Table 3.1 time budget for each of the 9 behaviours recorded (named in descending order of appearance) in response to the four tested sounds: raven, hiss, stomp and whip played once

Signal	Minute 1 (pre-signal)		Minute 2 (post-signal)		Minute 3 (post-signal)	
raven	70.1%	eating	47.0%	eating	50.6%	eating
	17.6%	looking	43.8%	looking	28.3%	looking
	4.2%	relaxing	5.0%	alert	8.0%	out of area
	3.4%	grooming	2.0%	grooming	7.9%	walking
	2.7%	walking	1.1%	walking	3.4%	alert
	2.0%	alert	0.8%	hopping	1.2%	hopping
			0.3%	out of area	0.6%	grooming
hiss	89.0%	eating	65.3%	eating	84.4%	eating
	4.8%	looking	25.1%	looking	6.3%	out of area
	4.2%	relaxing	3.8%	out of area	3.3%	walking
	1.2%	grooming	1.8%	walking	1.9%	relaxing
	0.8%	walking	1.3%	hopping	1.6%	looking
			1.0%	grooming	1.3%	grooming
			0.9%	alert	0.9%	alert
			0.2%	flight	0.2%	hopping
stomp	56.9%	eating	45.5%	looking	44.4%	looking
	30.4%	looking	26.5%	alert	41.6%	eating
	5.8%	walking	21.6%	eating	6.9%	alert
	5.1%	grooming	2.6%	walking	6.5%	walking
	1.4%	alert and	1.9%	grooming	0.3%	hopping and
	0.4%	hopping.	0.6%	hopping	0.2%	grooming
			0.4%	flight		
whip	71%	eating	41.7%	alert	33.8%	alert
	13.5%	relaxing	19%	out of area	29%	out of area
	10.8%	looking	16.7%	looking	24.4%	looking
	2.8%	walking	7%	flight	10.7%	eating
	1.9%	grooming	1.2%	walking	2.0%	walking
			1.02%	hopping		
			1.01%	eating		

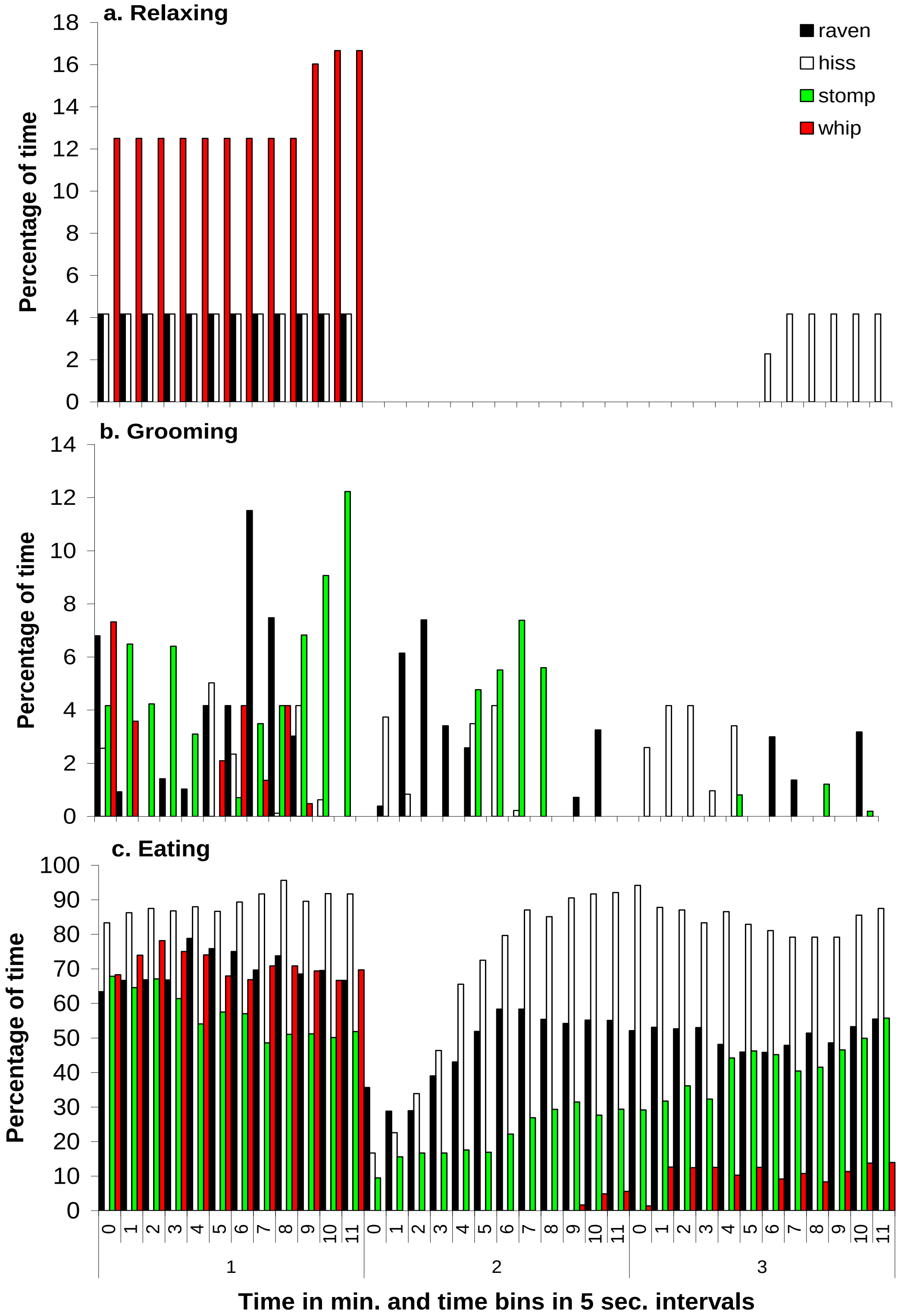
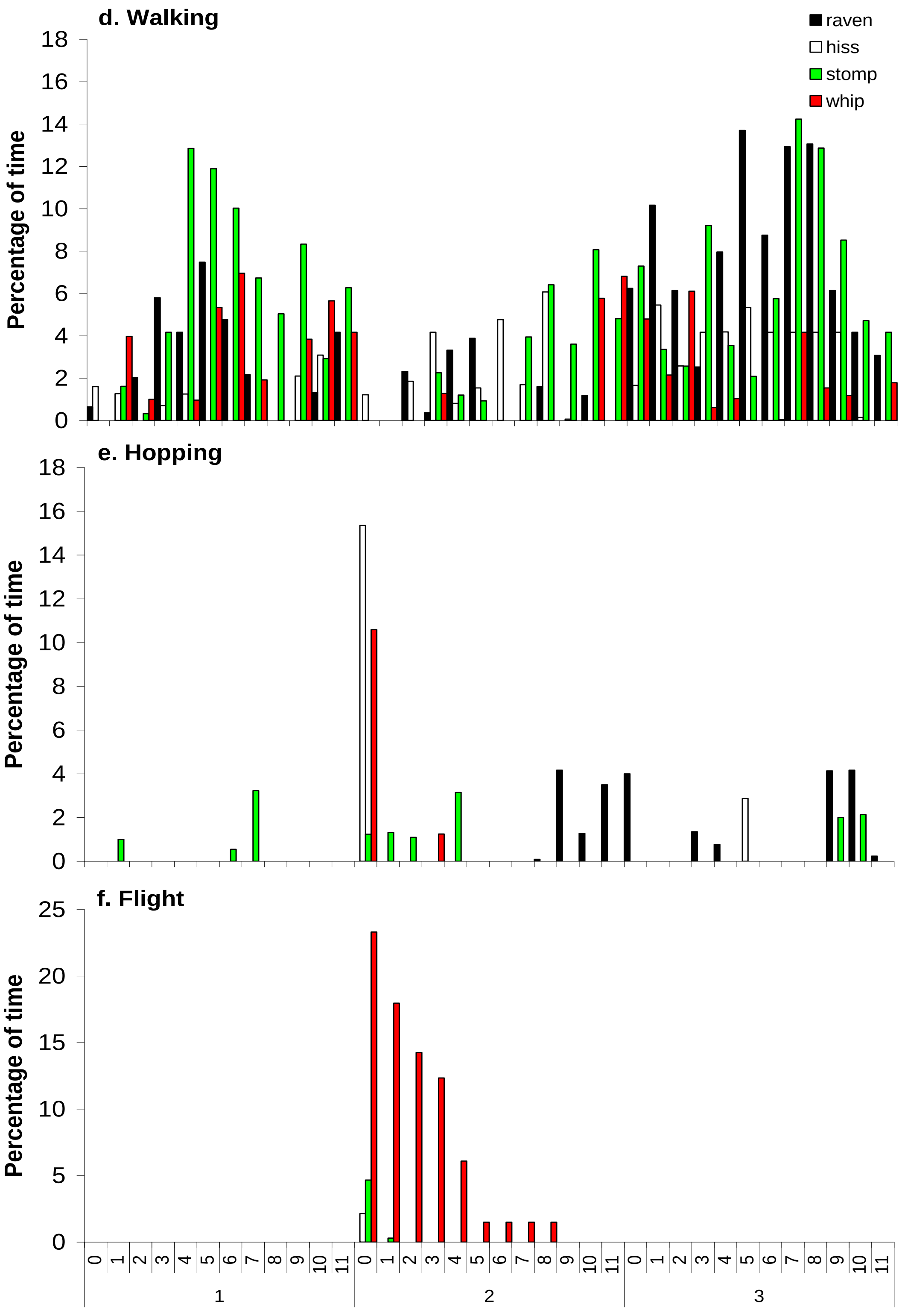


Fig. 3.1 The proportion of time spent in nine activities for 24 western grey kangaroos. The first minute is a representative of the general undisturbed behaviour (pre-stimulus) and the following two minutes showing how the four acoustic signals (played once at the beginning of minute 2) affected the animals' behaviour. The response is displayed in 5 second timebins.



Time in min. and time bins in 5 sec. intervals

Fig. 3.1 cont. The proportion of time spent in nine activities for 24 western grey kangaroos. The first minute is a representative of the general undisturbed behaviour (pre-stimulus) and the following two minutes showing how the four acoustic signals (played once at the end of minute 1) affected the animals' behaviour. The response is displayed in 5 second timebins.

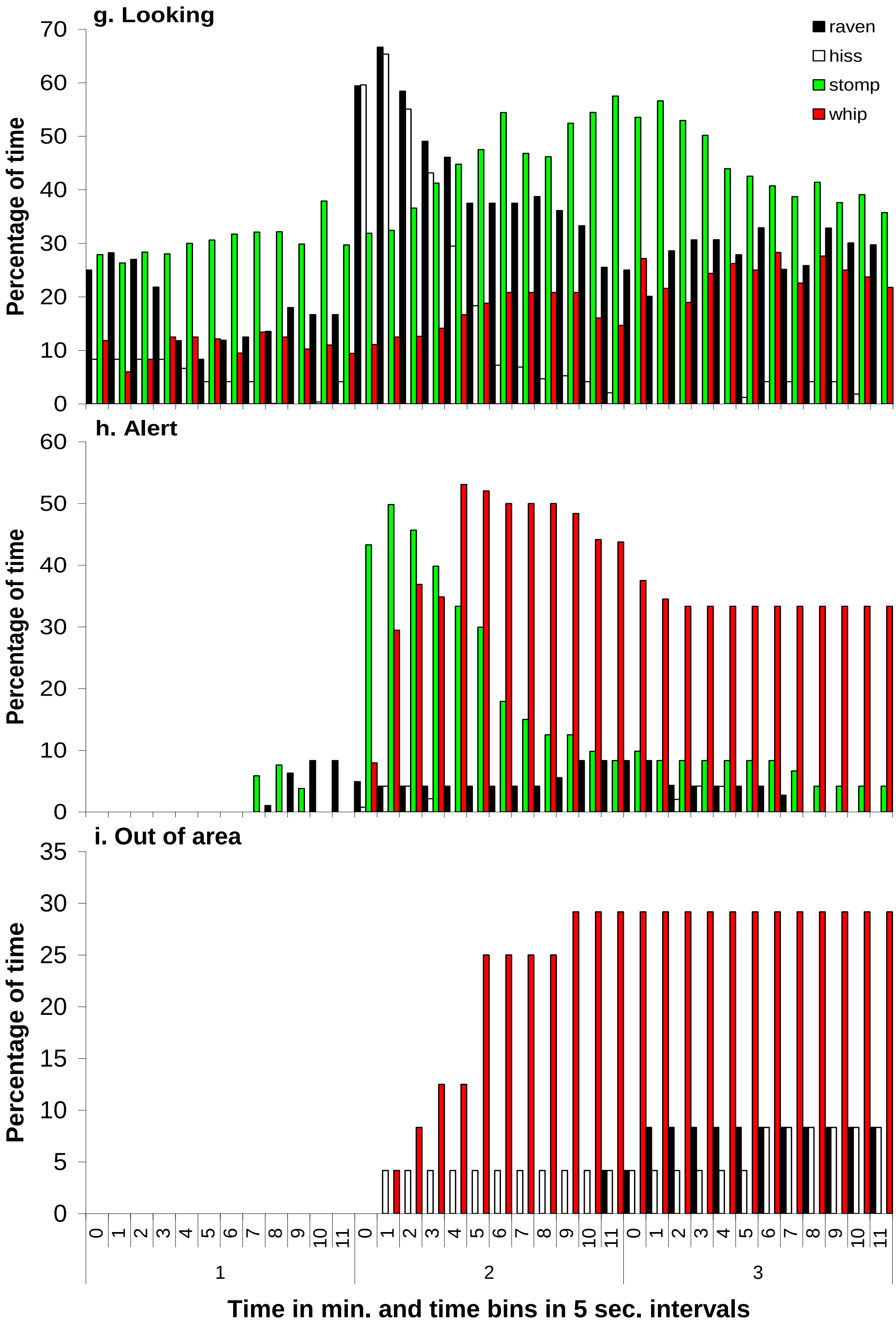
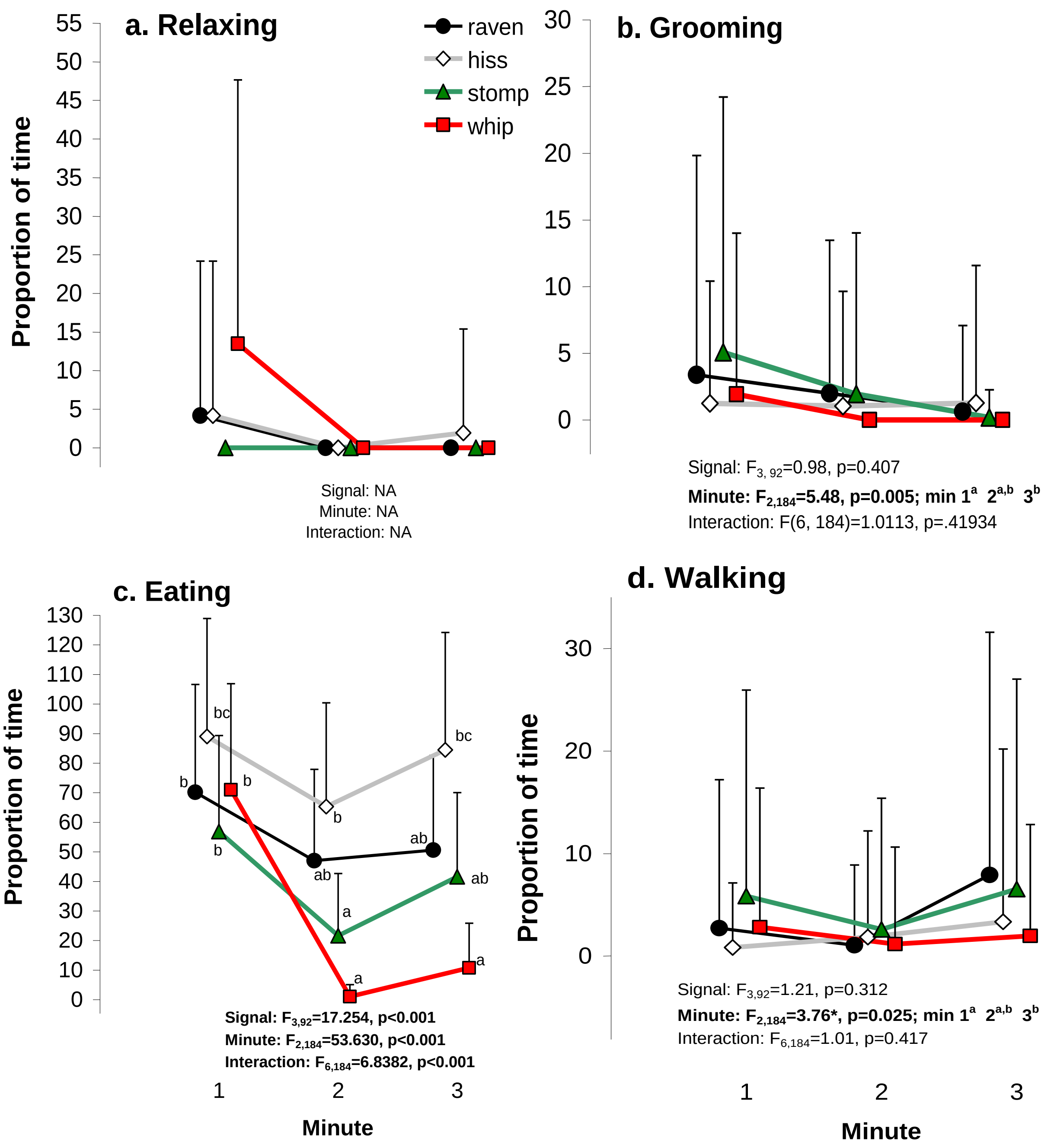


Fig. 3.1 cont. The proportion of time spent in nine activities for 24 western grey kangaroos. The first minute is a representative of the general undisturbed behaviour (pre-stimulus) and the following two minutes showing how the four acoustic signals (played once at the end of minute 1) affected the animals' behaviour. The response is displayed in 5 second timebins.



Signal: NA
Minute: NA
Interaction: NA

Signal: $F_{3,\,92}$=0.98, p=0.407
Minute: $F_{2,184}$=5.48, p=0.005; min 1^{a} $2^{a,b}$ 3^{b}
Interaction: F(6, 184)=1.0113, p=.41934

Signal: $F_{3,92}$=17.254, p<0.001
Minute: $F_{2,184}$=53.630, p<0.001
Interaction: $F_{6,184}$=6.8382, p<0.001

Signal: $F_{3,92}$=1.21, p=0.312
Minute: $F_{2,184}$=3.76*, p=0.025; min 1^{a} $2^{a,b}$ 3^{b}
Interaction: $F_{6,184}$=1.01, p=0.417

Fig. 3.2 The proportion of time spent in nine activities for 24 western grey kangaroos in the three recorded minutes. Statistical significance was tested for signal, minute and interaction between minutes and signal effect. NA indicates data are not available due to lack of variance

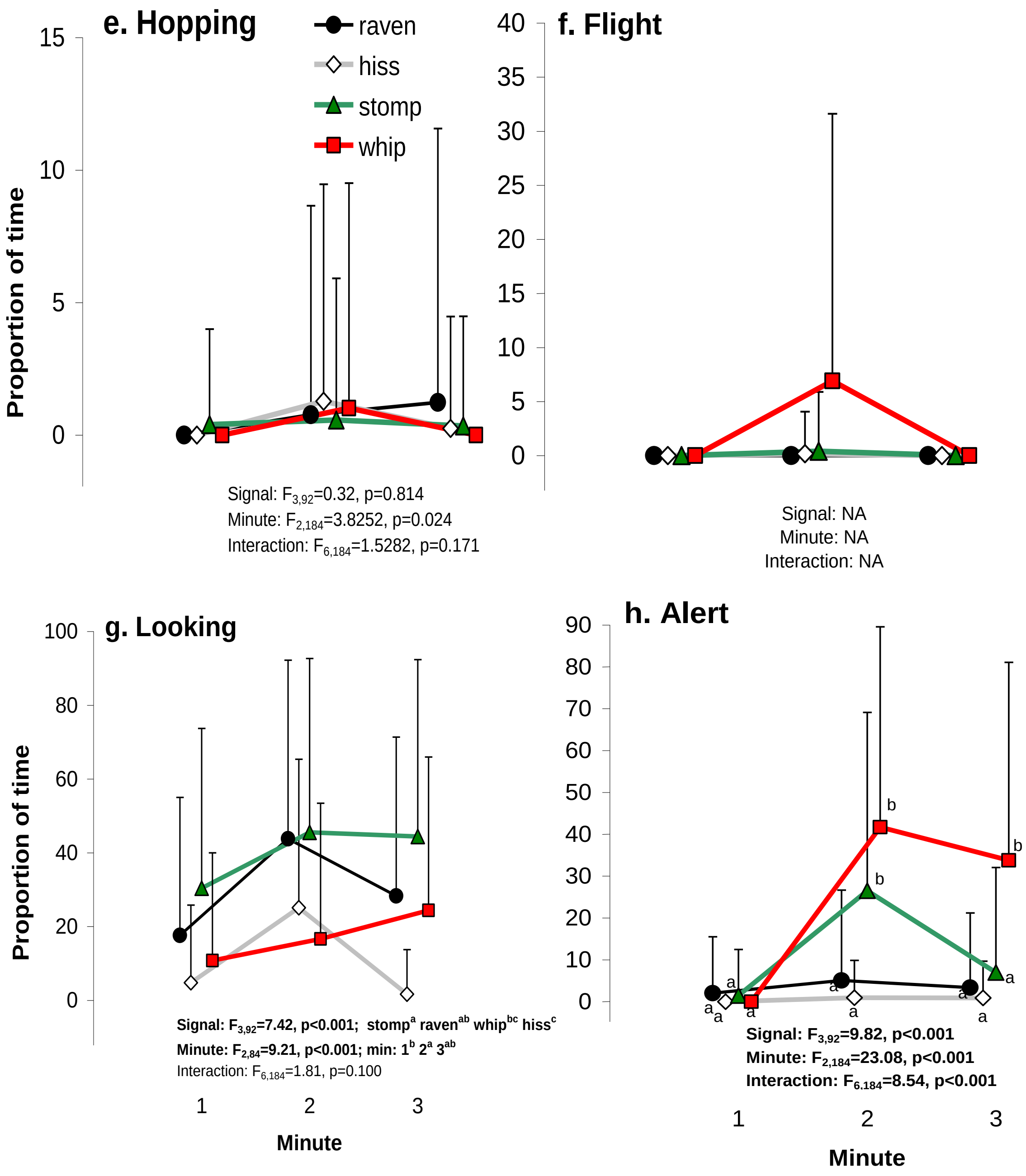


Figure 3.2 cont. The proportion of time spent in nine activities for 24 western grey kangaroos in the three recorded minutes. Statistical significance was tested for signal, minute and interaction between minutes and signal effect. NA indicates data are not available due to lack of variance

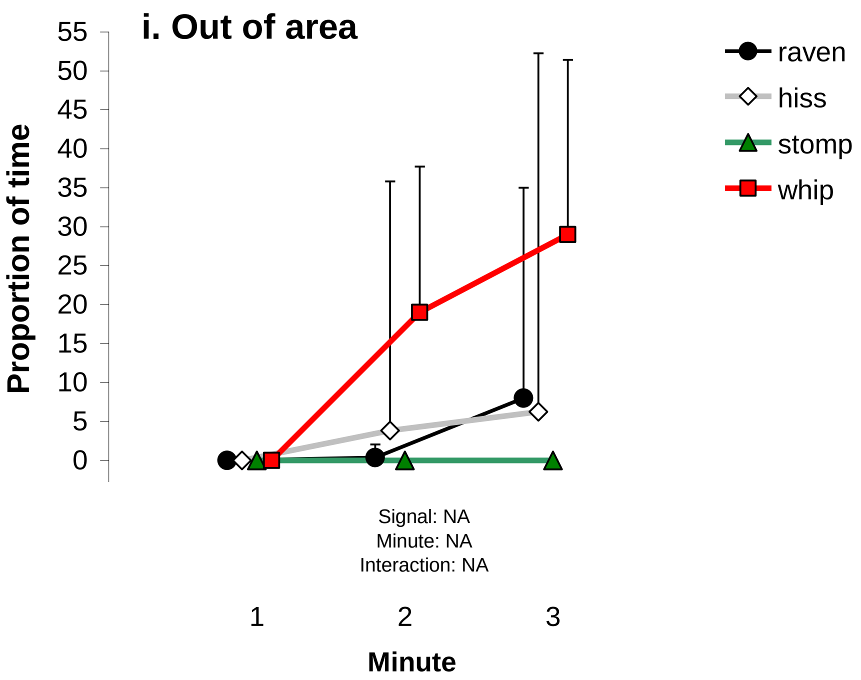


Figure 3.2 cont. The proportion of time spent in nine activities for 24 western grey kangaroos in the three recorded minutes. Statistical significance was tested for signal, minute and interaction between minutes and signal effect. NA indicates data are not available due to lack of variance

Table 3.2 Statistical results for the behaviours *alert* and *eating* analysed in a mixed model ANOVA. Values in bold indicate effects where $p<0.05$. Values in italics indicate a trend

	alert		*eating*	
	F	p	F	p
Stimulus (fixed independent variable)	**6.60**	**0.009**	2.50	0.112
Trial no. (covariate)	1.61	0.226	*4.41*	*0.055*
Group size (covariate)	0.161	0.70	<0.01	0.936
Group no. (random factor)	*1.73*	*0.059*	**2.13**	**0.015**

3.3 Discussion

The results indicate that the *whip* signal generated the most pronounced fear inducing or startling aversive effect on *Macropus fuliginosus*, followed by the *stomp*, the *raven* and to the least amount, the *hiss*. Most notably, animals demonstrated a significant drop in foraging behaviour. The main increased behaviour was *flight* with an increasing number of individuals moving *out of area*.. The *whip* signal was most evocative: time spent *eating* dropped from 71% to 1% by the second minute and by minute 3, one third of the animals had moved out of the area.

Surprisingly, playback of the foot *stomp* was less effective than the manmade whip signal in terms of altering behaviour of *M. fuliginosus*. The stomp caused *eating* to drop from 57% to 22% by the second minute and significantly increased vigilance (i.e. *looking* and *alert* behaviour, fig. 3.2g, h). Increased vigilance and decreased *eating* (fig. 3.2c) is consistent with findings for eastern grey kangaroos and tammar wallabies (Bender 2004; Blumstein 2000). In the present study, only 0.4% of the 24 kangaroos time was spent on *flight* in response to playback of the foot stomp. Bender (2004) found over 60% of animals took flight, but recorded this response to both the foot stomp play back as well as the control sound (background noise) with no significant difference between the two. Both studies predicted *flight* reaction in response to playback of the foot *stomp* by some (or all) conspecifics, as often observed when a kangaroo produces the stomp, but this expectation was not fulfilled. A possible explanation is that a foot stomp is usually utilised by the kangaroo which detected the danger first and then it subsequently takes flight. Thereby an additional visual stimulus is given to other members of the mob by the locomotion of this individual. The lack of movement after the playback of the stomp may therefore have been an influencing factor. Another issue in terms of response to the foot stomp could have been the quality of recording and play back. As Bender (2005) found through experiments and physiological analysis of macropods skulls and ears, kangaroos have exquisite hearing and differences in sound frequency and absence of the potentially important seismic component is likely to influence response to these signals.

A surprising result of this study was that the *raven* call (non-distress) had a significant effect upon behaviour: time spent *eating* was reduced from 70% to 47% by the second minute. The recording and play back of the *raven* call might have sounded artificial to the kangaroos compared to the natural raven calls. However it was noticed that kangaroos looked up in response to playback of the recorded raven call, which they also did for natural raven calls.

The least effective acoustic signal in terms of altering the kangaroo's behaviour was the *hiss.* The most notable behaviour was recorded in the first 5 seconds after the signal was played, when a large proportion of the animals hopped (away from the location of the signal. After the *hiss* was played, *eating* activities dropped from 89% to 65% by the second minute, due to time spent being diverted towards hopping and looking, but animals had all returned to *eating* at pre-signal levels approximately 35 sec. A snake would hiss at a kangaroo when it is in close proximity, but by getting out of the way, the snake would no longer be perceived as danger.

Interesting for the mixed model ANOVA is the significant effect of group number for the behaviour *eating*, while this variable for *alert* is on the borderline to being significant. This is consistent with theories about group foragers copying their neighbours behaviour i.e. when in the tested group one animal was more relaxed than the average, it may have influenced the other animals reactivity and the same for a more flighty animal (Clancy & Croft 1991, Kotler, Brown & Hasson 1991, Pays et al. 2007, Quenette & Gerard 1992). Expected was that trial number would have a significant effect as the more trials performed, the higher the chance for animals to overhear a trial and habituate to the sound. Trial number did not show significance, but there was a trend for animals to resume *eating* sooner the more trials had been performed. .

Summing up the findings from experiment 1:

- the four signals elicited different responses which were consistent amongst most individuals
- the *whip* triggered the strongest fear induced response out of the four signals

- significance and trends for effect of group number indicates that an animals reaction is likely to affect the behaviour of others in its group, which is supported by the hypothesis of allelomimesis: individuals tend to copy the behaviour in regards to feeding and vigilance of their neighbour (Pays et al. 2007; Quenette & Gerard 1992).
- no effect of group size suggests that western grey kangaroos feeding and vigilance behaviours are not depending on numbers as it is the case for some species ((Blumstein and Daniel 2002; Fernandez-Juricic et al. 2007; Pays et al. 2007).
- The *whip* shows the most promise as a deterrent as it reduced foraging and induced leaving of the area to a higher degree than the other signals.

Chapter 4 Experiment 2: High rate acoustic playback of a biologically- significant and an artificial sound cue to rapidly encourage habituation to aversive signals

4.1 Introduction

The efficacy of animal repellents is minimised when animals become familiar with, and no longer respond to, an aversive signal. Sounds that provoked a strong response take longer to habituate to than sounds initiating a weaker response (Voipo 1997). During the first experiment both the *stomp* and *whip* signal generated intense alarm responses and reduced browsing in western grey kangaroos. During the second experiment, the contexts of habituation towards these two signals, which represent both a bioacoustic (foot-stomp) and artificial (whip) signal, were investigated. It is beneficial to respond to a conspecific's warning of potentially fatal danger, therefore biologically-meaningful signals are regarded as having an increased potential for deterrence with reduced likelihood of habituation (Coleman et al. 2006). However, rate of habituation can be influenced by changing the rate of signal playback (Bomford & O'Brien 1990) as the more often animals hear the signal the sooner they get habituated to it. Therefore, this experiment artificially encouraged habituation by repeating the signals at 5 s intervals to provide the best chance of animals becoming acclimated to the signal within the two minutes playback.

4.2 Results

In experiment 2, the time budgets pre-signal (minute 1) differed slightly for the two treatments. Animals spent 80.1% on foraging related activities in minute 1 pre-*stomp*, but significantly less time *eating* in minute 1 pre-*whip* (48.5%). Although not significant, more animals were relaxing in minute 1 pre-*whip* (22.7%) compared to pre-*stomp* (3.8%). Overall, if these two (calm state) behaviours were pooled, no significant difference between the pre-signal treatments would have been obtained, i.e. although time was spent differently, the animals were not in a vigilant state. No other behaviour showed significant differences in minute 1 between the two treatments.

As seen in experiment 1, some behaviours decreased whilst others increased in response to the signal playback. A significant drop was registered for *eating* as time spent foraging dropped from 80.1% (minute 1, pre-*stomp*) to 11.3% in minute 2 and 4.5% in minute 3, whereas time spent foraging pre-*whip* was recorded to be 48.%, decreasing to 0% in both treatment minutes. Repeated measures ANOVA shows significant differences between the signals, between pre-signal minute 1 and treatment minutes 2 and 3 and the interaction between the minutes and signals (fig 4.1c).

The behaviour *relaxing* decreased significantly in response to the *whip* signal, going from 22.7 % of time spent lying down to 0% in the two treatment minutes. Time spent *relaxing* in minutes 2 and 3 post-*stomp* also decreased from 3.8% pre-*stomp* to 0%. No significant effect of the signal was found, whilst minute 1 was significantly higher than minute 2 and 3 (fig. 4. 2 a).

Other behaviours decreasing were *grooming* and *walking*. As seen in fig. 4.1 b, *grooming* was not displayed during the signal treatments for either sound (before *whip* treatment 4.5% of time was spent on *grooming* and 1.3% before the *stomp* treatment). *Walking* pre-signal was 4.3% of the time before the *stomp* and 3.5% before the *whip*. No *walking* appeared in the two treatment minutes for the *whip*, and only to a lesser degree for the *stomp* treatment minutes (1.2% in minute 2 and 1.4% in minute 3). The only factor that tested significantly for an effect was minute for the activity *walking* (fig. 4.2 d)

The behaviour *looking* both increased significantly in the 2nd minute of the *stomp* trial (from 9.7% to 68.3%) and then decreased again (to 17.6%). During the *whip* trials, time spent looking decreased during the signal treatments as animals were generally moving and leaving the area – see below (in minute 1 20.6% of the time was spent *looking*, decreasing to 1.6% in minute 2 and 0% in minute 3). The tests for effect of signal, minute and interaction were all significant (fig 4.2 g).

Activities that increased were *flight*, time spent *out of area*, *hopping* and being *alert*. Statistical tests only revealed significance in regard to *hopping* (fig.4.2 e) as the other increasing behaviours all had too many zero values to test for differences. *Hopping* was only recorded for a small amount of time in the *whip* trial, minute 2, while the *stomp* trial shows a steady increase in *hopping* over time (minute 1 0.7%, minute 2 5,8% and minute 3 7.0%).

The *flight* response was recorded significantly more due to the *whip* signal than to the *stomp* (see figure 4.1 f). The *whip* treatment triggered a *flight* response, especially during the first 10-20 seconds when the animals moved *out of area* (minute 2 in the whip trial shows 71.2% of time spent *out of area* whereas minute 2 for the *stomp* trial only shows and average of 4.2%). Both treatments show a large amount of time spent *out of the area* in especially the last minute (62.1% in response to the *stomp*, 100% in response to the *whip*).

Table 4.1 time budget for each of the 9 behaviours recorded (named in descending order of appearance) in response to a whip signal played at three different rates over two minutes.

Signal	Minute 1 (pre-signal)	Minute 2 (post-signal)	Minute 3 (post-signal)
5 s stomp	80.1% Eating 9.7% looking 3.8% relaxing 3.5% walking 1.3% grooming	68.3% looking 11.3% eating 5.8% hopping 4.2% out of area 3.0% relaxing 1.9% alert 1.2% walking 1.0% flight	62.1% out of area 17.6% looking 7.0% hopping 4.5% relaxing 4.5% eating 1.4% walking 0.6% flight
5 s whip	48.5% eating 20.6% looking 22.7% relaxing 3.5% walking 4.5% grooming	71.2% out of area 9.6% flight 2.7% hopping 1.6% looking 1.0% alert	100% out of area.

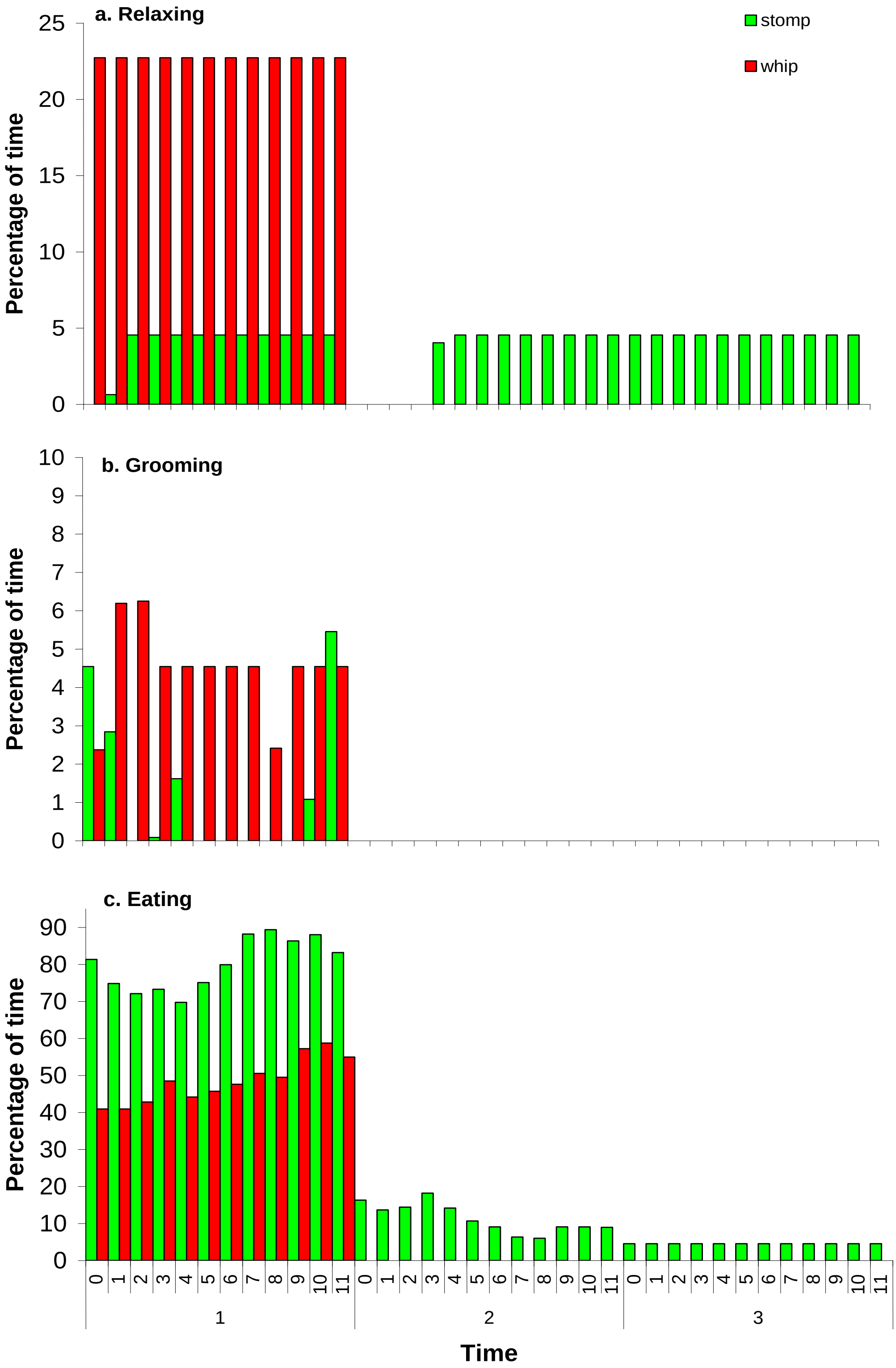


Fig. 4.1 The proportion of time allocated to nine activities for 22 western grey kangaroos. Minute 1 is undisturbed behaviour (pre-stimulus).Minutes 2 and 3 are sequential treatment periods. Cues are played every 5 s for 120 s Response is displayed in 5 s timebins.

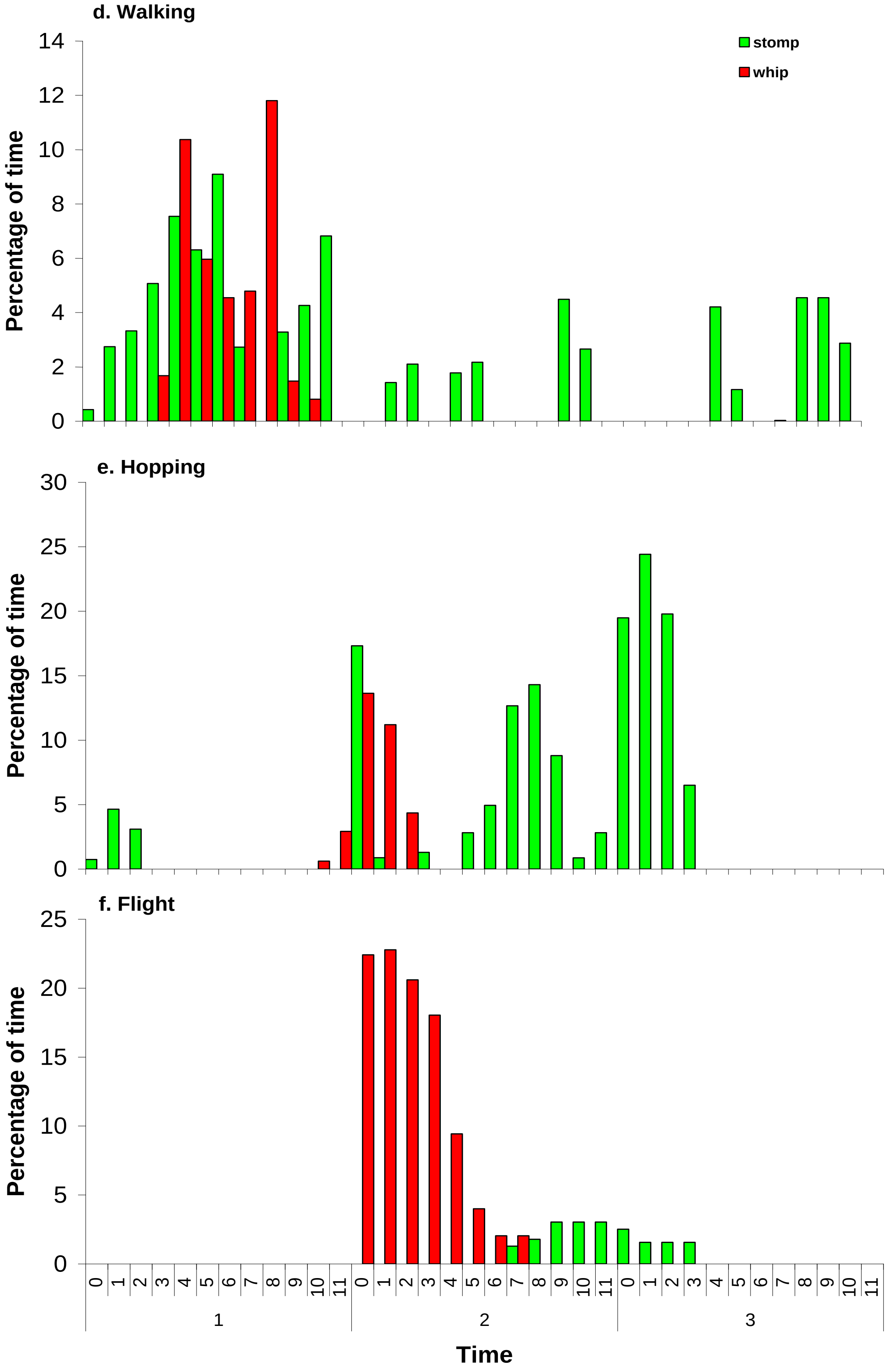


Fig. 4.1 cont. The proportion of time allocated to nine activities for 22 western grey kangaroos. Minute 1 is undisturbed behaviour (pre-stimulus).Minutes 2 and 3 are sequential treatment periods. Cues are played every 5 s for 120 s Response is displayed in 5 s timebins.

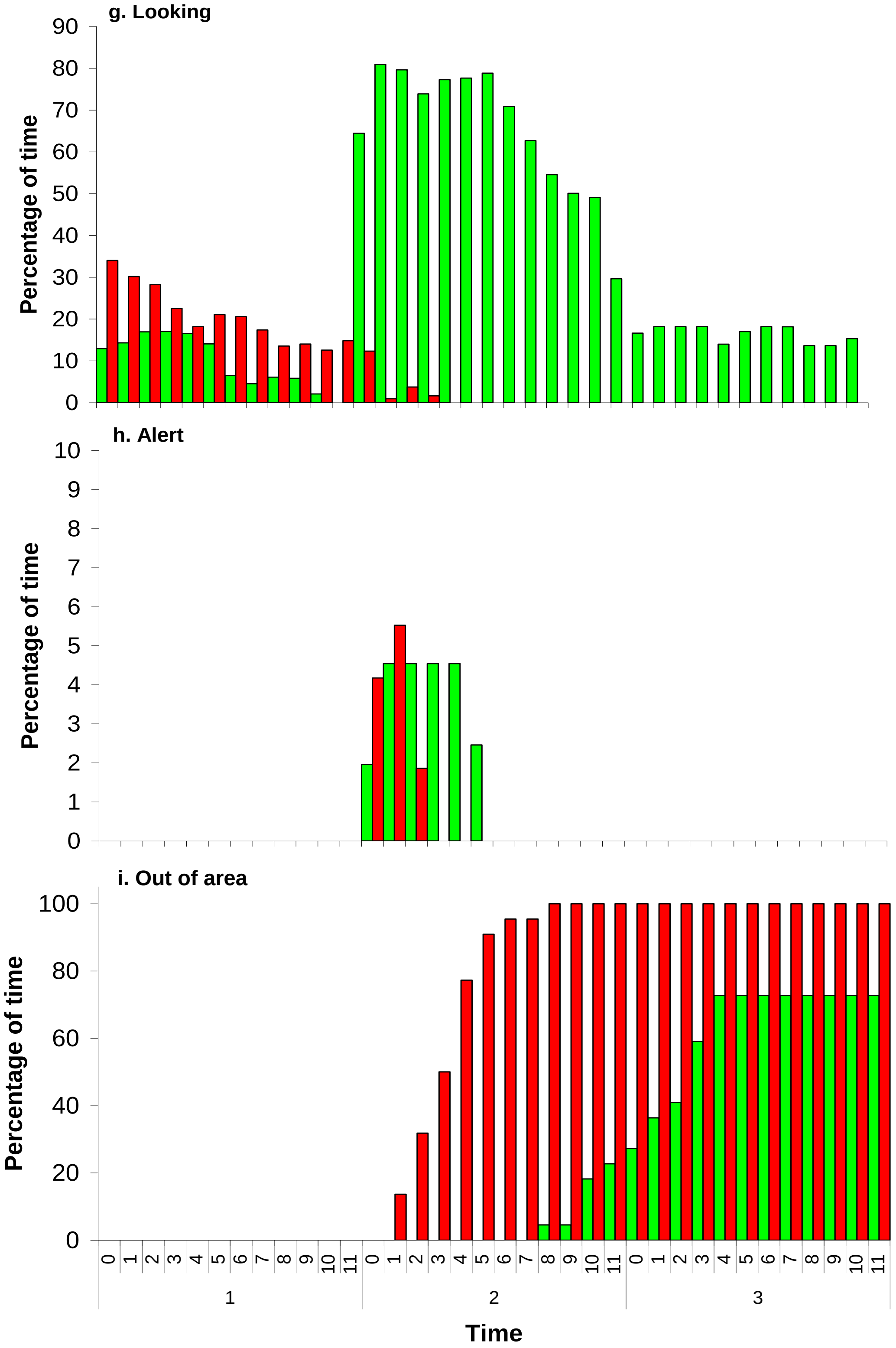


Fig. 4.1 cont. The proportion of time allocated to nine activities for 22 western grey kangaroos. Minute 1 is undisturbed behaviour (pre-stimulus).Minutes 2 and 3 are sequential treatment periods. Cues are played every 5 s for 120 s Response is displayed in 5 s timebins.

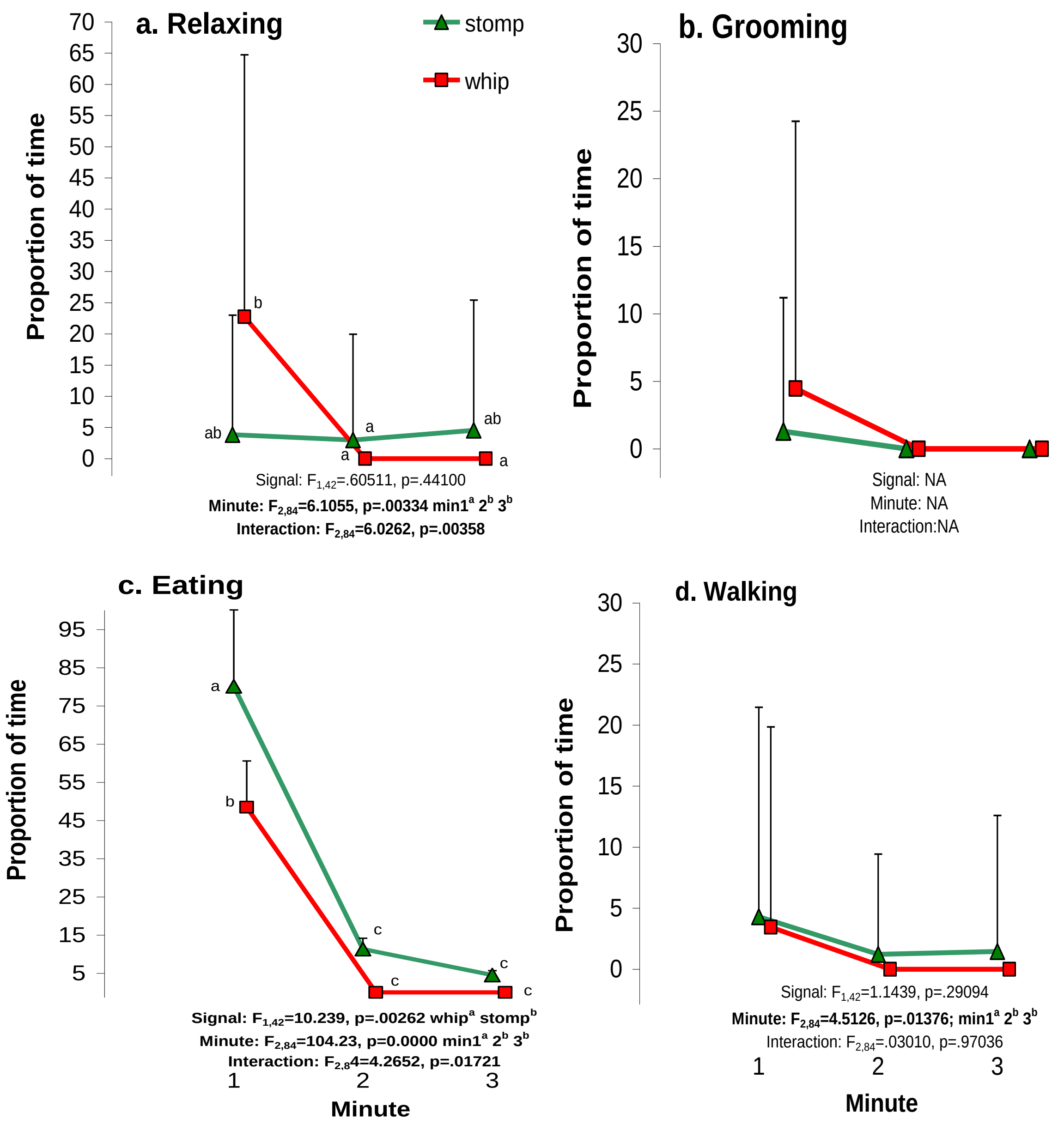


Fig. 4.2 The proportion of time spent in nine activities for 22 western grey kangaroos. Signal, minutes and interaction between the two was tested for significant effect.

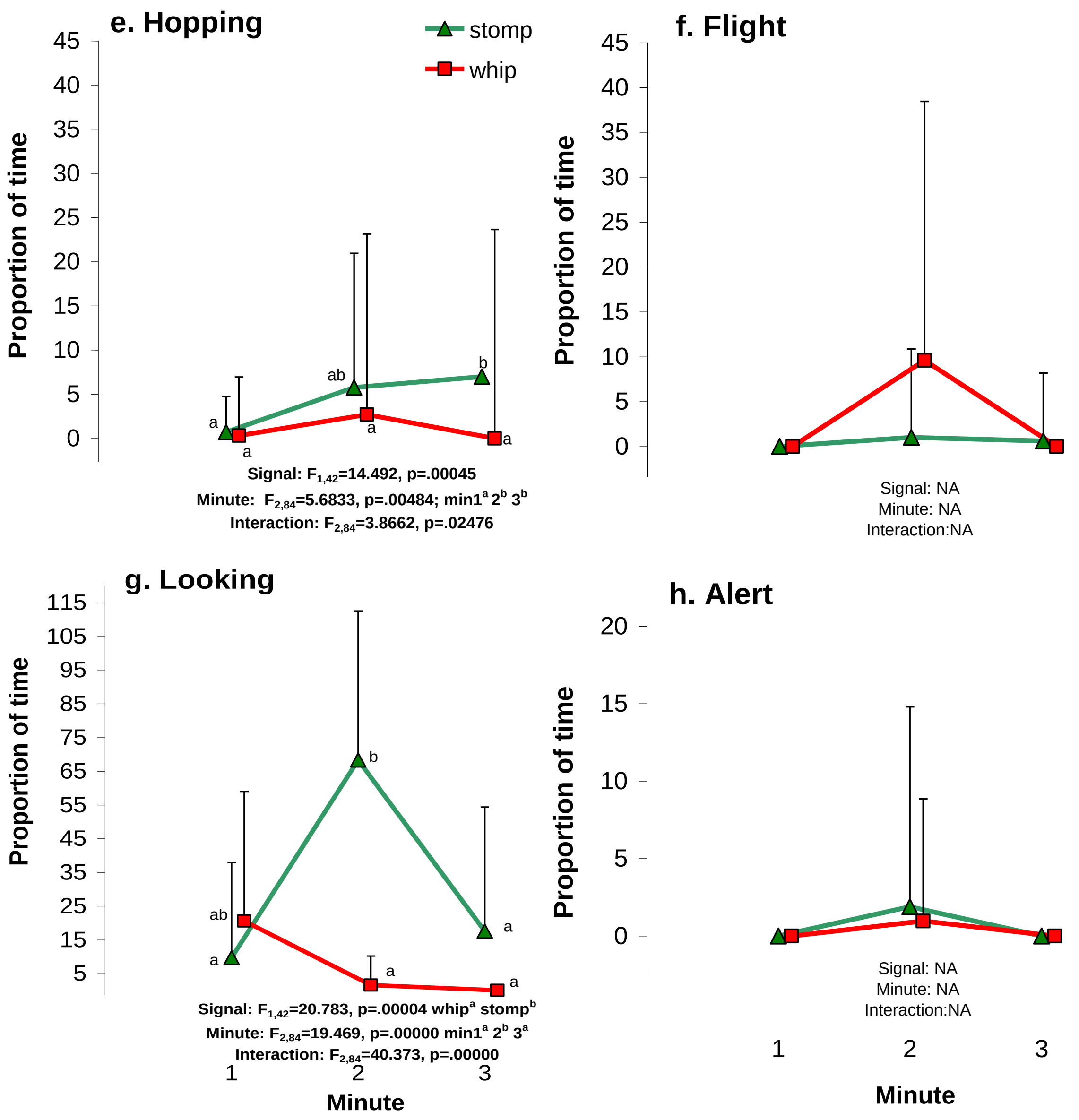


Figure 4.2 cont. The proportion of time spent in nine activities for 22 western grey kangaroos. Signal, minutes and interaction between the two was tested for significant effect.

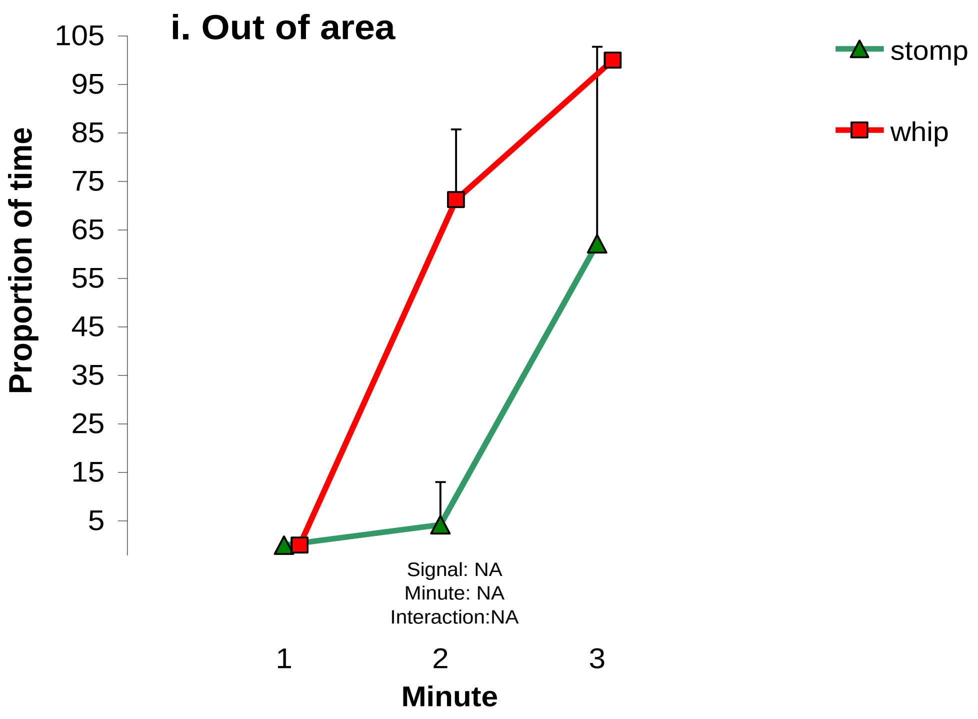


Figure 4.2 cont. The proportion of time spent in nine activities for 22 western grey kangaroos. Signal, minutes and interaction between the two was tested for significant effect.

4.3 Discussion

As in the first experiment, both *whip* and *foot stomp* treatments were effective in terms of altering behaviour of *Macropus fuliginosus*, reducing feeding behaviour (no foraging was recorded post stimulus) and causing the animals to retreat from the vicinity. All the animals retreated from the area in response to the *whip* signal (compared with 70% in response to the *foot stomp* signal), which is the result required for a suitable auditory repellent, i.e. stop the *eating* behaviour and induce the animals to leave. The *whip* signal showed a significantly quicker and larger *flight* response (i.e. the animals seem to perceive this signal as a more acute danger) compared with the *foot stomp* signal.

It would be expected that if the kangaroos had become habituated to the regular (5 second interval) playback of acoustic signals, then the calmer, relaxed state behaviours (that decreased immediately after the onset of playback treatments) would increase again to pre-signal levels, whilst the fear induced (increasing) behaviours would decrease to pre-signal levels. Both experiment 1 and 2 showed a tendency for the *whip* to induce stronger responses than the *stomp*. Habituation to the *whip* signal was not achieved in this current experiment, since all the animals left the study area over the two minutes of signal treatment. Therefore, no direct comparison can be made in regard to rate of habituation to a bioacoustic (*foot stomp*) vs an artificial (*whip*) signal.

For the *stomp* signal, two behaviours showed at least partial return to pre-signal levels: *relaxing* and *looking*. It seems counterintuitive that animals would habituate to their own alarm signal but, as discussed earlier, the quality of the recording and playback might influence the outcome or the missing visual cue of a conspecific taking flight could be an explanation for weaker fear-induced responses.

Although not in this experiment, some habituation to the acoustic signals was noted over the course of this study, since there was reduced response to the *whip* playback in experiment 3 (see next chapter). Understanding and avoiding habituation is, besides the initial efficiency of a deterrent, the main focus of developing a successful deterrent. If a deterrent is habituated to rapidly, no long term effect can be obtained, which is what most deterrents are aiming for. A review of sonic deterrents by Bomford & O'Brian (1990) suggests delays in habituation can be obtained by using a range of different sounds and randomise the intervals and order they are played at. Choosing sounds that provoked a strong response to begin with are to be preferred as a study showed that they take significantly longer to habituate to than sounds initiating a weaker response (Voipo 1997). Synergistic effects have been shown where multiple deterrents are available (Darrow & Shivik 2009; Mikheev et al. 2006), so to maximise the efficacy of fear based herbivore deterrents and avoid habituation, deterrents should be used in conjunction with others i.e. reinforcing each other by using acoustic incorporated with olfactory or visual repellents. Further studies regarding kangaroo deterrents should consider targeting two or more senses.

The next experiment aims to detect if change of play back rate for an effective deterring sound (the *whip*) will influence the response of the kangaroos and rate thereby should be considered when developing successful acoustic deterrents.

Chapter 5 Experiment 3: Effects of acoustic playback rate on the behaviour of western grey kangaroos (*Macropus fuliginosus*)

5.1 Introduction

Several aspects of sound signals need to be closely examined in the quest to find working acoustic deterrents. Besides determining what sounds are effective and how rapidly they are habituated to, structural characteristics of the potential signals should also be considered when evaluating potential acoustic deterrents. The rate of an aversive sound may relate to overall efficacy (Bomford & O'Brien 1990). For example when an alarm call is repeated in a number of species (e.g. California ground squirrels *Spermoperhlius beecheyi*, Leger et al. 1979, Columbia ground squirrels, *S. columbianus*, Harris et al. 1983; MacWhirter 1992, golden marmots *Marmota caudate*, Olympic marmots, *M. olympus* and yellow-bellied marmots, *M. flaviventris*, Blumstein 1995; Blumstein & Armitage 1997), rate has been shown to influence behaviour. Rates of alarm calls increase in these species in response to increased level of perceived risk, stressing the urgency of danger. Therefore, for experiment 3, three rates of playback (3 s, 15 s and 30 s intervals) for an aversive acoustic signal (the *whip)* were investigated.

5.2 Results

The pre-stimulus (minute 1) time budgets for all nine recorded behaviours showed no significant difference between the three treatments investigated. As in the two previous experiments, e*ating* was the behaviour the animals spent their majority of their time on pre-signal (average 69.6%). Other behaviours displayed pre-signal included *relaxing* and *grooming*. All of these (calm state) behaviours decreased post-stimulus. All three signal rate treatments caused individuals to alter their behaviour, so that there was no *relaxing* recorded during the signal playback (fig.5.1a). *Grooming* showed a similar pattern dropping to 0% in the 3-second and 30-second rate trial and to 0.1% in the 15-

second rate trial. *Grooming* dropped significantly for minute 2 (fig. 5.1 b and 5.2 b). The most obvious decrease in the percentage of time the animals spent was evident for *eating* (fig 5.1 c and 5.2 c), dropping from between 63-77% of the time budgets in minute 1 to 8.5% (3-second rate) 12.3% (15-second rate) and 3.3% (30-second rate) in minute 2. However, a significant return to *eating* behaviour was evident in minute 3 to 12.3% (3-second rate), 29.7% (15-second rate) and 13.7% (30-second rate) of the animals' time budgets.

Some behaviours both increased and decreased during these trials (*walking*, *hopping* and *looking*). All three behaviours showed a significant effect for minutes. The amount of time spent *walking* decreased from minute 1 to minute 2 and then increased again in minute 3, but *hopping* and *looking* showed the opposite by increasing from minute 1 to 2 to then decreasing again in minute 3 (fig. 5.2 d, e and g). Besides the significance for all three behaviours in regard to time, *looking* showed significance for the interaction between signal and time, whereas *hopping* showed a signal effect with significantly more *hopping* recorded in minute 2 of the 15-second rate compared to the 3- and 30- second rates.

Due to too many zero values in *flight, alert* and *out of area* (none of these behaviours were demonstrated during minute 1) no statistical analyses could be carried out. *Alert* only showed minor changes with no alertness registered in the 3-second rate trials, and only a rise from 0 (minute 1) to 0.5% in minute 2 for the 15-second rate, and from 0% (minute 1) to 4.4% for the 30-second rate. However, *flight* behaviour was observed during the signal playbacks with 7.7% (3-second rate), 2.6% (15-second rate) and 5.3% (30-second rate) recorded for minute 2. Minute 3 did not register any times spent in *flight* as animals had moved *out of area* by this time. Steadily more animals moved *out of area* during these signal playbacks. For the 3-second rate, 46.4% and 65.2% (minute 2 and 3, respectively) of the animals moved *out of area*. For the 15-second rate, this was 5.1% and 24.6%, and 33.7% and 43.5% for the 30-second rate.

Table 5.1 time budget for each of the 9 behaviours recorded (named in descending order of appearance) in response to a whip signal played at three different rates over two minutes.

Signal	Minute 1 (pre-signal)		Minute 2 (post-signal)		Minute 3 (post-signal)	
3 s whip	68.5%	eating	46.4%	out of area	65.2%	out of area
	22.6%	looking	23.9%	looking	21.3%	looking
	3.3%	relaxing	8.5%	eating	12.3%	eating
	3.6%	walking	7.7%	flight	1.2%	walking
	2%	grooming	1.0%	hopping		
			0.7%	walking		
15 s whip	77.2%	eating	69.3%	looking	40.1%	looking
	16.1%	looking	12.3%	eating	29.7%	eating
	4.3%	relaxing	5.1%	out of area	24.6%	out of area
	1.1%	walking	3.6%	hopping	2.7%	walking
	0.9%	grooming	2.6%	flight	1.5%	hopping
	0.5%	hopping	0.8%	walking	1.0%	grooming
			0.5%	alert	0.1%	flight
			0.1%	grooming		
30 s whip	63.1%	eating	44%	looking	42.3%	looking
	21.7%	relaxing	33.7%	out of area	43.5%	out of area
	5.8%	looking	5.3%	flight	13.7%	eating
	5.1%	walking	4.4%	alert	0.3%	grooming
	2.3%	grooming	3.3%	eating	0.2%	walking
			0.8%	hopping		

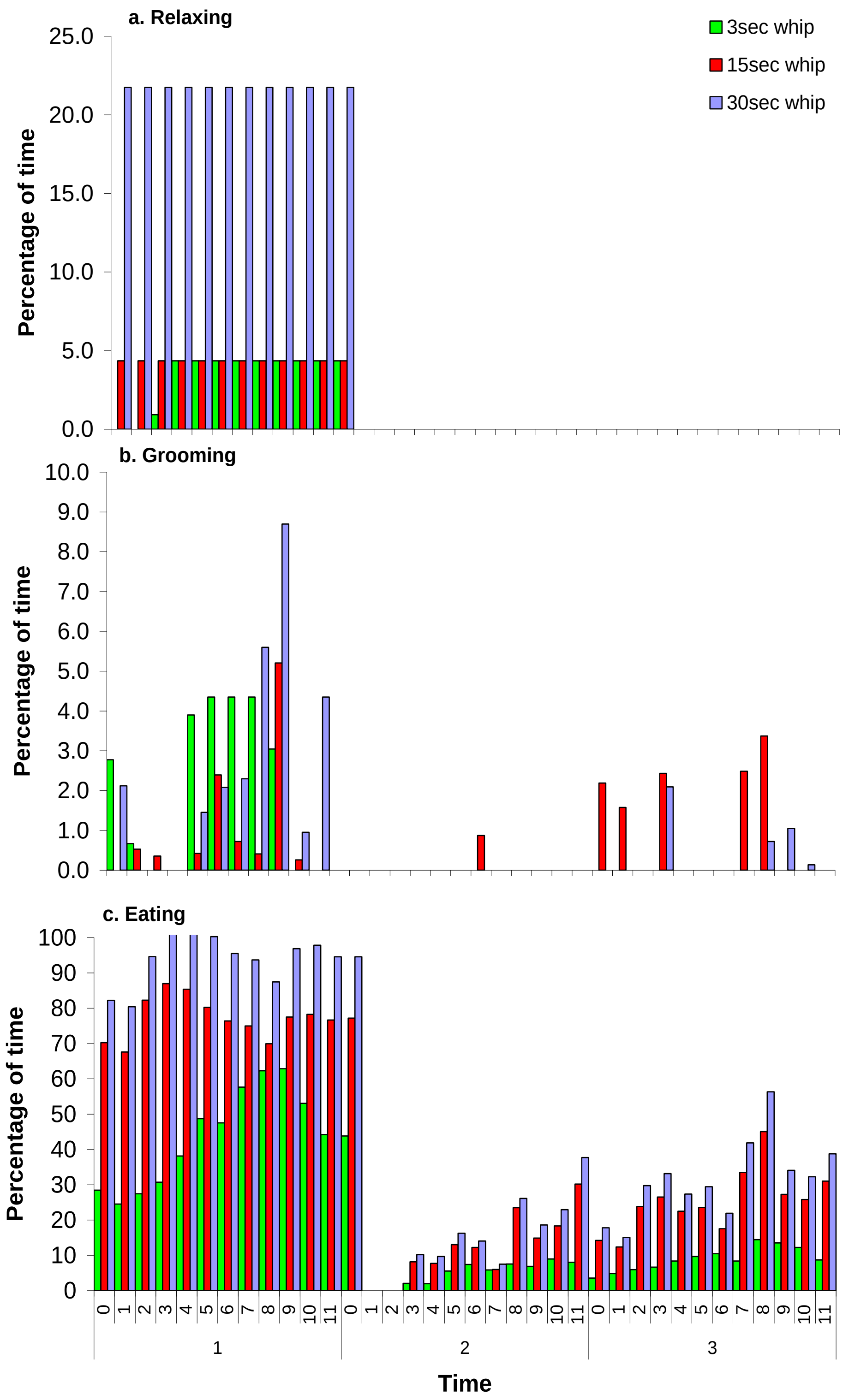


Fig. 5.1 The proportion of time spent in nine activities for 23 western grey kangaroos. The first minute is a representative of the general undisturbed behaviour (pre-stimulus) and the following two minutes showing how the three acoustic signals (the whip played at three different rates at the end of minute 1) affected the animals' behaviour. The response is displayed in 5 second timebins.

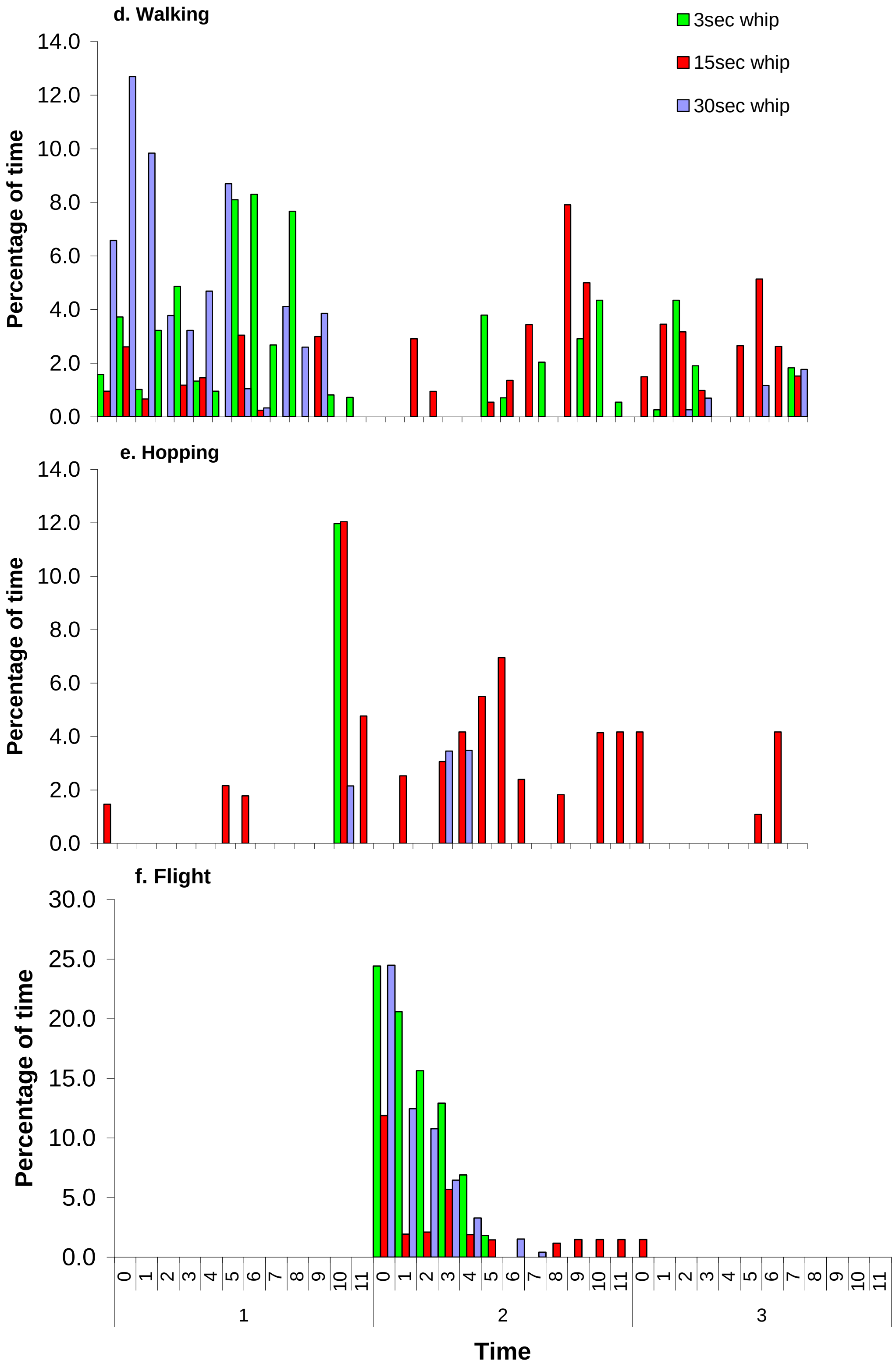


Fig. 5.1 cont. The proportion of time spent in nine activities for 23 western grey kangaroos. The first minute is a representative of the general undisturbed behaviour (pre-stimulus) and the following two minutes showing how the three acoustic signals (the whip played at three different rates at the end of minute 1) affected the animals' behaviour. The response is displayed in 5 second timebins.

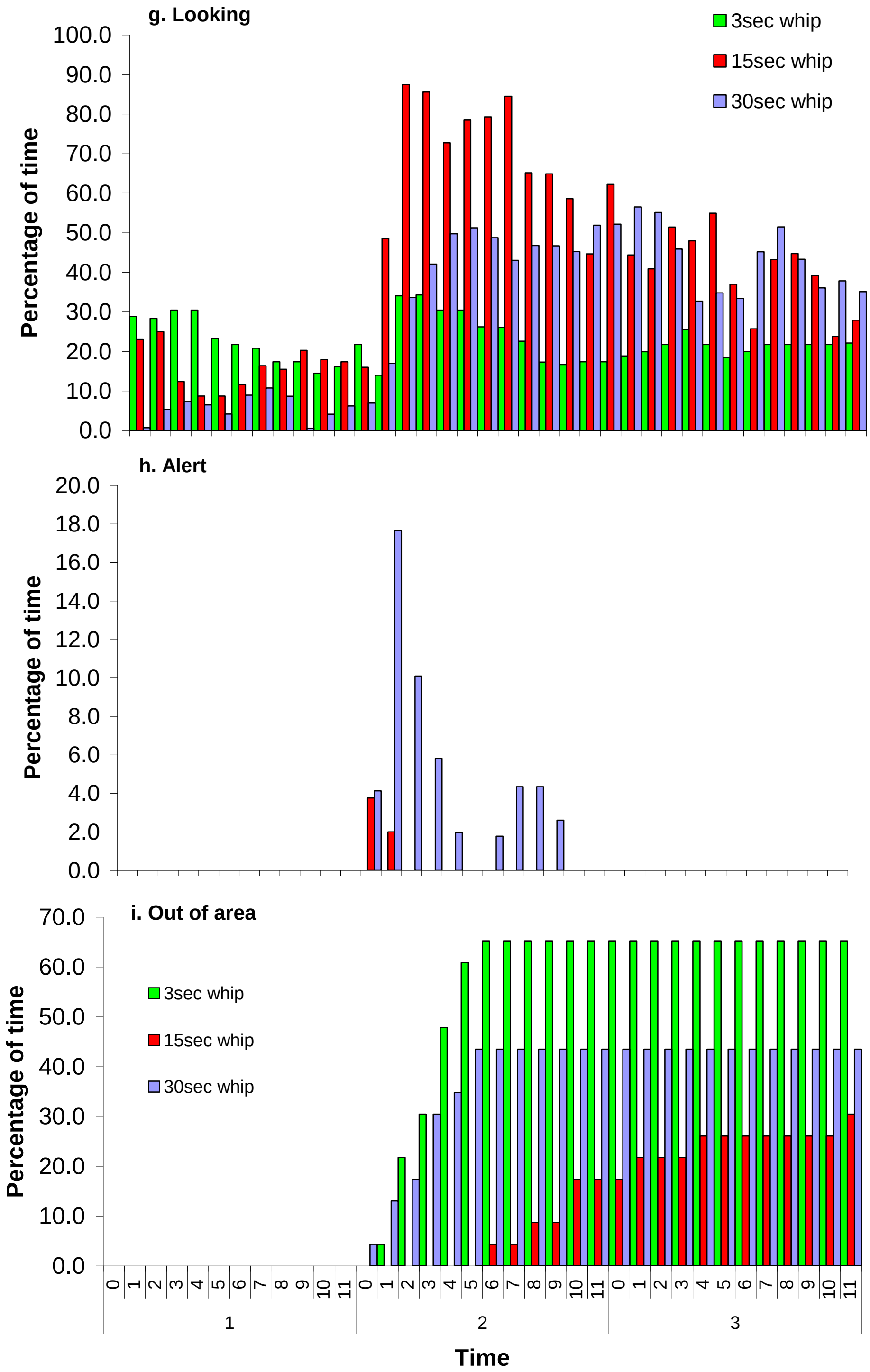


Fig. 5.1 cont. The proportion of time spent in nine activities for 23 western grey kangaroos. The first minute is a representative of the general undisturbed behaviour (pre-stimulus) and the following two minutes showing how the three acoustic signals (the whip played at three different rates at the end of minute 1) affected the animals' behaviour. The response is displayed in 5 second timebins.

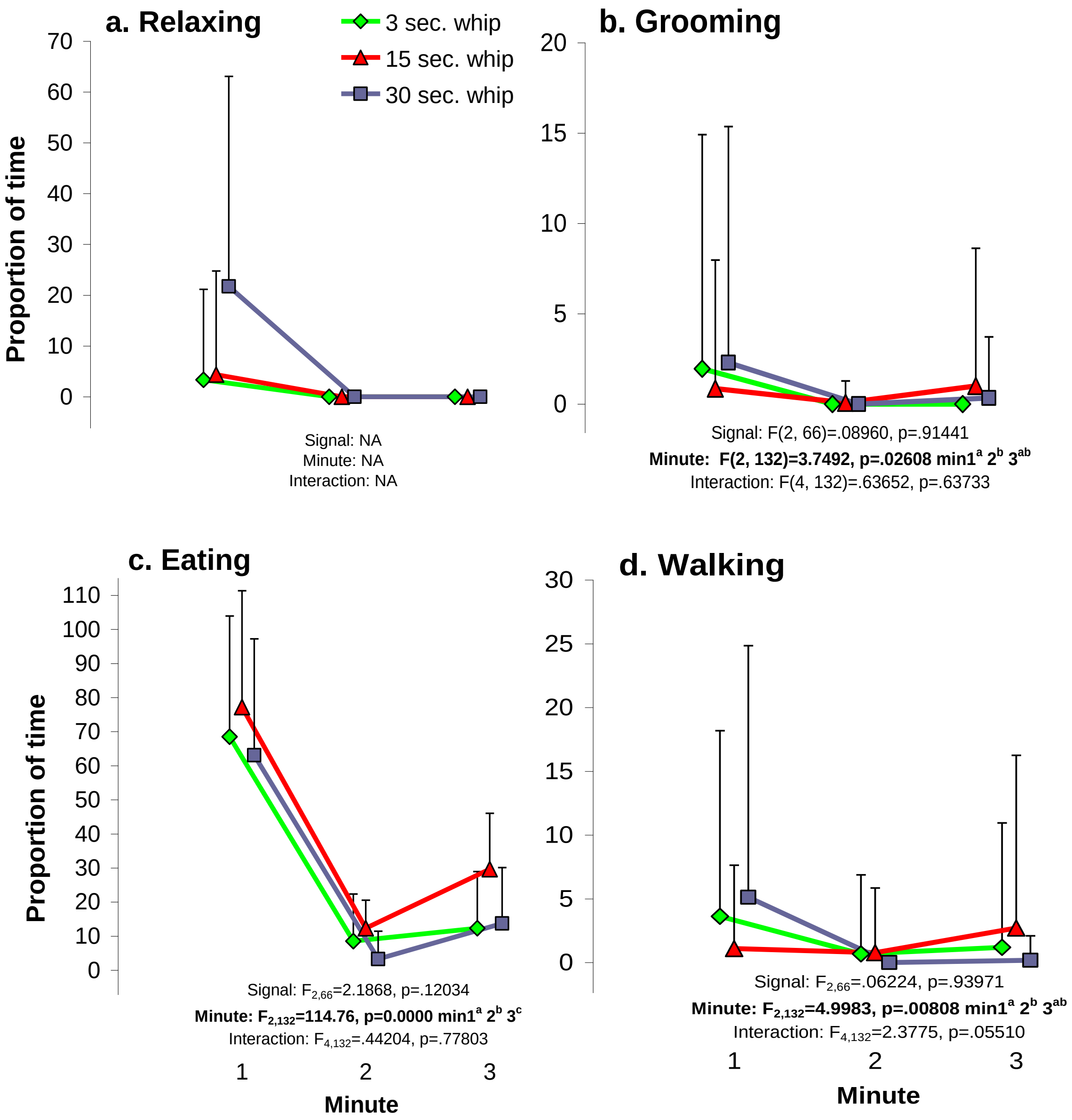


Figure 5.2 The proportion of time spent in nine activities for 23 western grey kangaroos displayed in minutes. Signal, minutes and interaction between signal and minutes was tested for significant effects.

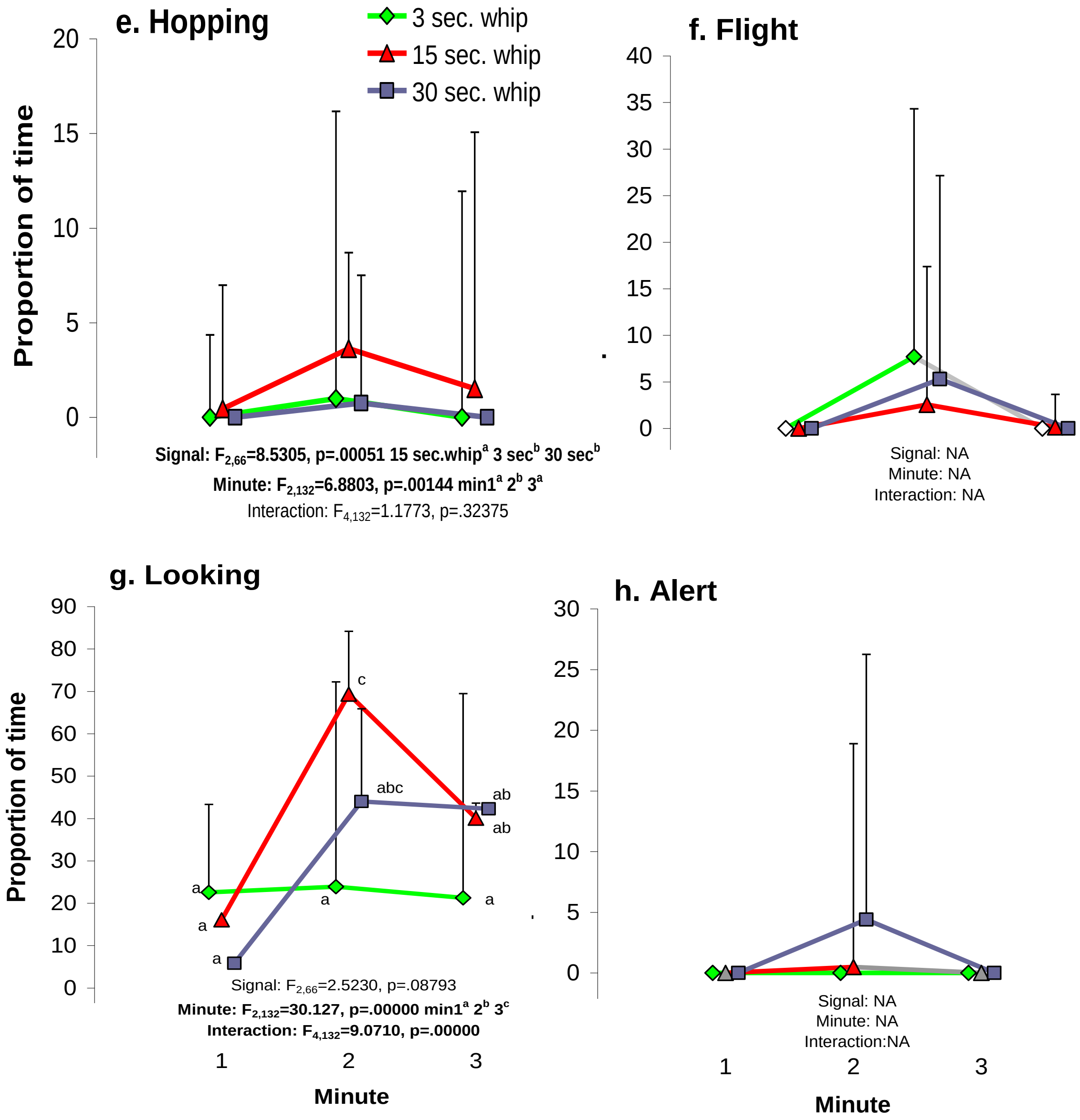


Figure 5.2 cont. The proportion of time spent in nine activities for 23 western grey kangaroos displayed in minutes. Signal, minutes and interaction between signal and minutes was tested for significant effects.

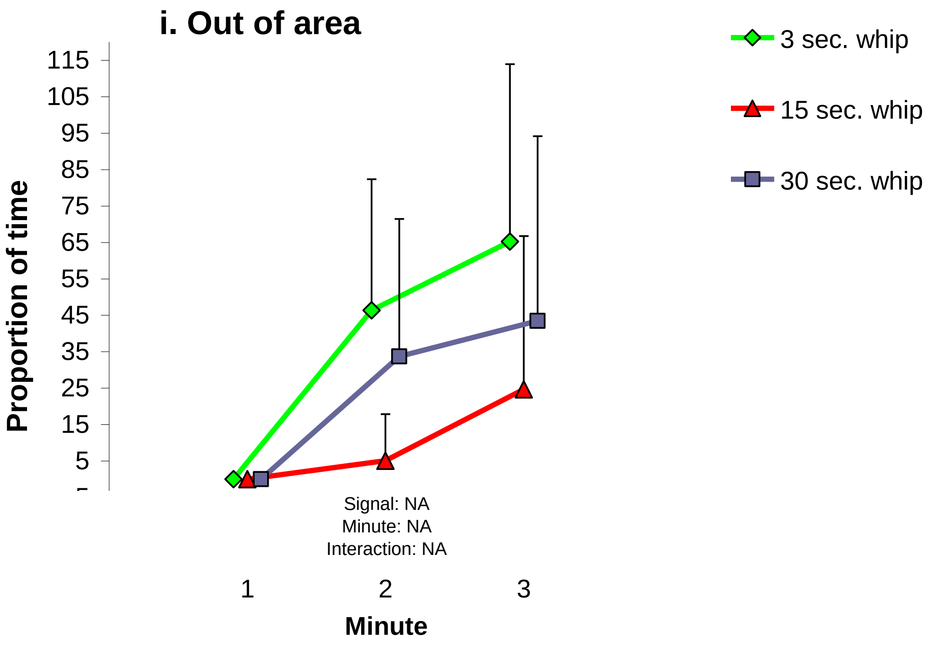


Figure 5.2 The proportion of time spent in nine activities for 23 western grey kangaroos displayed in minutes. Signal, minutes and interaction between signal and minutes was tested for significant effects.

5.3 Discussion

As in the first two experiments, the prerequisite for initiating trials was recognition that the animals were behaving in a calm manner after the researcher had approached the mob with the sound- and video-recording equipment. The principal behaviours observed pre-signal, therefore, included *relaxing, grooming* and *eating*. Most notably, these calm state behaviours decreased as soon as auditory treatments commenced, whilst behaviours linked to fear or startling (*flight, looking, hopping, alert* and *out of area*) increased when the signals were played.

The most obvious decrease in the animals' time budgets was the amount of time spent *eating*. A significant drop in foraging behaviour from minute 1 to minute 2 occurred (fig. 5.2c) whilst some *eating* is resumed again by minute 3. Although not quite to pre-stimulus levels, the increase was significant (fig.5.2c).

An interesting result of these trials was that only one behaviour (*hopping*) showed a significant signal effect; the behaviour *looking* showed significant interaction effect between time and signal. It had been expected that the strongest behavioural response would be recorded for the faster (3-second intervals) rate. However, both behaviours showed the 15-second rate to differ from the other two treatments: more *hopping* and *looking* was recorded for the 15-second interval treatment than the other two signal intervals. Due to lack of variance *flight, alert* and *out of area* could not be analysed statistically, but looking at fig. 5.2f, h and I, the only behaviour seeming to potentially differ in regard to signal rate is *out of area*. Time spent *out of area* is highest for the 3-second signal rate, which is consistent with expectations (but it is followed by the 30-second rate and not the 15-second rate as would be predicted). Overall, this experiment cannot conclude if any of the rates would work better as a potential deterrent than the other. It appears that the 3-second rate triggers more *flight*, causing more animals to move *out of area*, consistent with the alarm call theory that increasing rates are positively correlated with urgency, but statistical confirmation could not be obtained due to difficulties of working with behaviours that demonstrate no variance.

A possible factor influencing results of this study (in terms of less *flight*, *alertness*, *leaving the area* and return to *eating*) compared with the first experiment, is the lack of surprise the whip might create. In experiment 1, twenty-four animals were tested that were naïve to the *whip* signal (unless overheard during pilot trials). In the second experiment,14 of the 22 animals had participated in the first experiment and therefore only 8 were potentially naïve to the sound treatments. By this third experiment, only 3 animals were potentially naïve as the other 20 had either participated in one or both of the former two experiments. In experiment 2, playback of the whip signal at 5-second intervals caused all the individuals studied to move out of the area, whereas the largest response in this third experiment was to initiate 65% of individuals to move out of the area (3-second interval treatment). Some degree of habituation is therefore likely to have influenced the results of this last experiment.

General conclusion

This study has shown that artificial sounds have potential to work as kangaroo repellents, however the structure and rate of a sound may influence efficacy. High intensity, intermittent rate and randomly, alternating sounds with short rise times, show the most promising results (Talling et al. 1998; Teilmann et al. 2006; Voipoi 1997; Winslow 2002). These characteristics may also delay habituation. Sounds that provoke a strong response are to be preferred to begin with, as they take significantly longer to habituate to. The *whip* was very efficient at the commencement of this study (a single stimulus caused 29% of animals to move out of the area, experiment 1; or 100% of animals to move out of the area when played back repeatedly at 5-second intervals, experiment 2), however animals indicated some reduced sensitivity to the *whip* by the end of experiment 3 (the greatest response being 65% of animals moved out of the area when played back at 3-second intervals).

Biologically-meaningful sounds, such as alarm signals, are often complex and difficult to reproduce in a quality that animals will regard as authentic. My study has shown high levels of *looking* and *alert* behaviour in response to the kangaroo *foot stomp*, but this signal was not effective in moving all individuals out of the target area. None of the individuals moved *out of area* in response to a single stimulus playback (experiment 1) whereas 62% of individuals moved *out of area* in response to repeated 5-second interval playback (experiment 2). In order to successfully repel western grey kangaroos from target areas with a *foot stomp*, further study is still required.

A pilot trial (carried out after this study had concluded) showed great potential of alternating sounds as a deterrent. Since the whips efficiency as a deterrent decreased the more often the animals encountered it, I wanted to see if I had desensitised the animals to any sound disturbances. Five sounds unknown to the animals where tested on random groups of kangaroos with a small hand held device with inbuilt speakers (Edirol R-09). The sounds were: a bursting balloon, the starting of a whipper snipper, a chainsaw, a siren and a drill. Although just anecdotal observations, this pilot study showed a strong flight response, which in my opinion is comparable to what the *whip* induced at the beginning of this study (majority of animals or all left the area). These findings support work by Teilmann et al (2006) who found different sounds to be the most effective and that sounds animals had habituated to remained efficient when altered even slightly. Further investigation of alternating signals is worthwhile. Furthermore, synergistic effects have been shown where multiple deterrents are available (Darrow & Shivik 2009; Mikheev et al. 2006). To maximise the efficacy of fear based herbivore deterrents and avoid habituation, therefore, deterrents should be used in conjunction with others to reinforcing each other, e.g. by using acoustic incorporated with olfactory or visual repellents.

Besides finding successful deterrents, many other factors have to be taken into account in terms of ecological management of kangaroos. Cover can be a hindrance to animals to detect potential danger or it can have a protective effect. The presence of vegetation cover may therefore either lead animals to become more cautious or more complacent, according to their use of such cover. Therefore indirect factors like cover need to be considered as well as direct cues in future studies. Group size also affects foraging and vigilance in some species (Blumstein & Daniel 2002; Fernandez-Juricic et al. 2007; Pays et al. 2007), although I detected no effect of group size on *eating* and *alert* behaviour in my trials (experiment 1). The hypothesis of allelomimesis suggests that individuals tend to copy their neighbour’s behaviour in regard to feeding and vigilance (Pays et al. 2007; Quenette & Gerard 1992). This was supported by my finding of significant differences in *eating* and *alert* behaviour in regard to group number (experiment 1).

In addition to controlling kangaroo numbers and behaviour, it is possible to improve revegetation outcomes by careful selection of plant species and varieties. Knowledge to be taken into account when planning the revegetation of an area is that some plant species compensate grazing with higher growth rates whereas others are more sensitive to being grazed. Furthermore, some plants benefit from neighboring plants being eaten. The chemical properties of plants and their frequency across the landscape will influence food selection by macropods. If plants are not very desirable to the kangaroos, then the animals are likely to be more readily deterred. Knowing which plants are avoided by kangaroos and which cope well with some level of grazing can guide the selection of plant species suited for revegetation. Finally, alternative food sources must be within relatively easy travel distance for the animals, as they will otherwise face the choice between habituating to deterrents or starvation. In summary, therefore, many factors need to be considered to effectively protect newly revegetated areas from kangaroo grazing.

In conclusion, the results of this study show promising results in terms of development of an acoustic deterrent for western gray kangaroos. Up to 100% of the kangaroos could be made to move out of an area with repeated playback of the whip crack. Additionally, the target behaviour for successful revegetation, reducing the amount of time animals spent *eating,* was significantly reduced in the whip treatments. These results were obtained while testing a semi-wild mob in Roo Gully Wildlife Sanctuary, where two thirds of the animals are hand raised and all animals are regularly exposed to various sounds, smells and human encounters. It is expected that these effects may be even greater on wild kangaroos that have not been exposed to as much human contact. Acoustic deterrents have the potential to provide at least short- (or even medium-) term protection until seedlings have matured sufficiently to cope with grazing and/ or produce self defense mechanisms. Development of kangaroo deterrents therefore should be possible to achieve using various auditory signals as an auditory-only deterrent, or in combination with additional methods like visual or olfactory deterrents.

References

Andelt, W.F., Burnham, K.P., Baker, D.L. (1994). Effectiveness of capsaicin and bitrex repellents for deterring browsing by captive mule deer. *Journal of Wildlife Management,* **58**, pp. 330–334.

Apfelbach, R., Blanchard, C.D., Blanchard, R.J., Hayes, R.A. & McGregor, I.S. (2005). The effects of predator odors in mammalian prey species: A review of field and laboratory studies. *Neuroscience and Biobehavioral Reviews,* **29**, pp. 1123-1144.

Arnold, G.W., Lecrivain, E., Johnson, K.G. & Grassia, A. (1988). Effects of weather conditions in summer on the maintenance behaviour of western grey kangaroos. *Aust. Wildl. Res.,* **15**, pp. 129-38.

Arnold, G.W, De Grassia, S.A. & Weeldenburg, J. (1992). Home-range size and fidelity of western grey kangaroos (*Macropus fuliginosus*) living in remnants of Wandoo woodland and adjacent farmland. *Wildlife Research,* **19**, pp. 137-143.

Baker, S.R., Gardner, J.H. & Ward, S.C. (1995). Bauxite mining environmental management and rehabilitation practices in Western Australia. In *Proceedings of the Australian Institute of Mining and Metallurgy, World's Best Practice in Mining and Mineral Processing Conference.* Sydney, Australia, 17-18 May 1995.

Banks, P.B., Newsome, A.E. & Dickman, C.R. (2000). Predation by Red Foxes limits recruitment in populations of Eastern Grey Kangaroos. *Austral Ecology,* **25**, pp. 283-291.

Bassett, O., DeLeeuw B., McKenzie, L. (2002). An operational trial of guards for the protection of planted *E. globulus* seedlings from browsing on the Stanley Plateau, Victoria. In: Bassett, O.D. ed..Proceedings of the South-Eastern Australia Native Forest Browsing Workshop, Ballarat, Victoria, 27–29 April 1999. East Melbourne, Department of Natural Resources and Environment. Pp. 55–57.

Baudinette, R.V. (1994). Locomotion in macropoid marsupials: Gaits, energetics and heat balance. *Australian Journal of Zoology,* **42**, pp. 103- 123.

Bayliss, P. (1985). The population dynamics of red and western grey kangaroos in arid New South Wales, Australia. I. Population trends and rainfall. *Journal of Animal Ecology*, **54**, pp. 111-125.

Bender, H. (2001). Deterrence of kangaroos from roadways using ultrasonic frequencies-efficacy of the Shu Roo. Melbourne, Australia: Department of Zoology, University of Melbourne. Report nr 1. Melbourne, Australia.

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

Bender, H. (2005). Auditory stimuli as a method to deter kangaroos in agricultural and road environments. *PhD thesis,* Department of Zoology. Melbourne, University of Melbourne

Bennett, M.B. (1999). Foot areas, ground reaction forces and pressures beneath the feet of kangaroos, wallabies and rat-kangaroos (Marsupialia: Macropoidea). *J. Zool. Lond.*, **247**, pp. 365-369.

Bergerud, A.T. & Miller, D.R. (1983). Antipredator tactics of calving caribou: dispersion in mountains. *Canadian Journal Zoology,* **62,** pp. 1566–1575.

Bergquist, J. & Orlander, G. (1996). Browsing deterrent and phytotoxic effects of roe deer repellents on *Pinus sylvestris* and *Picea abies* seedlings. *Scandinavian Journal of Forest research,* **11**, pp.145-152.

Blumstein, D.T. (1995) Golden-marmot alarm calls. I. The production of situationally specific vocalisations. *Ethology,* **100**, pp. 113—125.

Blumstein, D.T. & Armitage, K.B. (1997): Alarm calling in yellow-bellied marmots: I: The meaning of situationally variable alarm calls. *Anim. Behav.* **53**, pp. 143—171.

Blumstein, D.T. & Daniel, J.C. (2002). Isolation from mammalian predators differentially affects two congeners. *Behavioural Ecology,* **13,** pp. 657-663.

Blumstein, D.T., Daniel, J.A., Griffin, A.S. & Evans, C.S. (2000). Insular tammar wallabies (*Macropus eugenii*) respond to visual but not auditory cues from predators. *Behavioural Ecology,* **11**, pp. 528-535.

Blumstein, D.T. & Munos, O. (2005). Individual, age and sex specific information is contained in yellow-bellied marmot alarm calls. *Animal Behaviour*. **69**, pp. 353-361.

Blumstein, D.T., Runyan, A., Seymour, M., Nicodemus, A., Ozgul, A., Ransler, F., Im, S., Stark, T., Zugmeyer, C. & Daniels, J.C. (2004) Locomotor ability and wariness in yellow-bellied marmots. *Ethology*, **110**, pp. 615-634.

Bomford, M. & O´Brien, P.H. (1990). Sonic deterrents in animal damage control: A review of device tests and effectiveness. *Wildlife Society Bulletin,* **18**, pp. 411-422.

Brearley, D. (2003). Developing completion criteria for rehabilitation areas on arid and semi-arid mine sites in Western Australia. PhD Thesis WCU20031210.154733).

Brinkerhoff, R.J., Haddad, N.M. & Orrock, J.L. (2005) Corridors and olfactory predator cues affect small mammal behavior. *J. Mamm*. **86**, pp. 662-669.

Brockman, H. (2005). Resource Management Technical Report 319 Boyup Brook-Upper Warren Area CATCHMENT APPRAISAL 2005 The South West ARM Region Appraisal Team, Department of Agriculture and Food, Government of WA

Byers, J.A. (1997). American pronghorn: social adaptations and the ghost of predators past. Chicago: University of Chicago Press.

Campo, J.L., Gil, M.G. & Da´vilam S.G. (2005). Effects of specific noise and music stimuli on stress and fear levels of laying hens of several breeds *Applied Animal Behaviour Science*, **91**, pp. 75–84.

Caughley, G. 1994. Directions in conservation biology. *Journal of Animal Ecology,* **63**, pp. 215-244.

Caughley, G., Grigg, G.C., Caughley, J. & Hill, G. J. E. (1980). Does Dingo predation control the densities of kangaroos and emus? *Australian Wildlife Research,* **7**, pp. 1-12.

Caughley, G., Grigg, G.C. & Smith, L. (1985). The effect of drought on kangaroo populations. *Journal of Wildlife Management,* **49**, pp. 679–685.

Clancy, T.F. & Croft, D.B. (1991). Differences in habitat use and grouping behaviour between macropods and eutherian herbivores. *Journal of Mammalogy,* **72**, pp. 441-449.

Close, D.C., McArthur, C., Pietrzykowski, E., Fitzgerald, H. & Paterson, S. (2004). Evaluating effects of nursery and post-planting nutrient regimes on leaf chemistry and browsing of eucalypt seedlings in plantations. *Forest Ecology and Management,* **200**, pp. 101–112.

Coleman, M. (1991). An overview of tree guards. *Trees and Natural Resources*, **33**, pp. 29–30.

Coleman, J.D., Pech, R.P. & Warburton, B. (2006). *Review of Research into Alternatives to the use of 1080 for Management of Browsing Damage by Mammals in Tasmania.* Landcare Research Contract Report: LC0506/144

Coman, B.J. (1994). A review of methods for the mitigation of browsing damage in Tasmania. Vernox Pest Management report to the Browsing Animal Review Committee, Hobart (unpubl.). pp 44.

Comer, C.E., Kilgo, J.C., D'Angelo, G.J., Glenn, T.C. & Miller, K.V. (2005). Fine-scale genetic structure and social organization in female white-tailed deer. *Journal of Wildlife Management,* **69, pp.** 332–344.

Conover, M.R. (1984). Comparative effectiveness of avitrol, exploders and hawk-kites in reducing blackbird damage to corn. *Journal Wildlife Management*, **48**, pp. 109-116.

Corbett, L. (1995). *The Dingo in Australia and Asia*. University of New South Wales
Press, Sydney.

Coss, R.G. (1999). Effects of relaxed natural selection on the evolution of behavior. In: *Geographic variation in behavior: perspectives on evolutionary mechanisms* Oxford:Oxford University Press: pp. 180-208.

Coulson, G. (1989). Repertoires of social behaviour in the Macropodoidca. In *Kangaroos, wallabies and rat kangaroos:* pp. 457-473. Grigg, G., Jarman, P. & Hume, I. (eds), New South Wales, Surrey Beattie & Sons.

Coulson, G. (1993). Use of heterogenous habitat by the western grey kangaroo, *Macropus fuligenosus. Wildlife Research,* **20**, pp.137-149.

Coulson, G. (1997). Repertoires of social behaviour in captive and free-ranging grey kangaroos, *Macropus giganteus and Macropus fuligenosus* (Marsupialia: Macropodidae). *Journal of Zoology*, **242**, pp. 119-130.

Coulson, G. (2008). Western Grey Kangaroo. In Van Dyck, S. & Strahan, R. (eds), *The Mammals of Australia*, 3rd edn, Reed New Holland, Sydney.

Coulson, G. (2009) Behavioural ecology of red and grey kangaroos: Caughley's insights into individuals, associations and dispersion. *Wildlife Research*, **36**, pp. 57–69.

Croft, D.B. (2004) Kangaroo management: individuals and communities. *Australian Mammalogy,* **26**, pp. 101–108.

Cramer, V.A. & Hobbs, R.J. (2002). Ecological consequences of altered hydrological regimes in fragmented ecosystems in southern Australia: Impacts and possible management responses. *Austral Ecology*, **27**, pp. 546-564.

Croft, D.B. (2000). Sustainable use of wildlife in western New South Wales: possibilities and problems. *The Rangeland Journal,* **22**, pp. 88–104.

Croft, D.B. (2004). Kangaroo management: individuals and communities. *Australian Mammalogy,* **26**, pp. 101–108.

Curio, E. (1966). How finches react to predators. *Animals,* **9**, pp. 142-143.

Darrow, P. & Shivik, J. (2009). Bold, shy, and persistent: Variable coyote responses to light and sound stimuli. *Applied Animal Behaviour Science*, **116**, pp. 82-87.

Dawson, T.J. (1995). *Kangaroos: biology of the largest marsupials*. Sydney, University of New South Wales Press.

Dawson, T.J. & Taylor, C.R. (1973). Energetic cost of locomotion in kangaroos. *Nature*, **240**, pp. 313-314.

DeCalesta, D.S. & Hayes, J.P. (1979). Frightening devices prevent bird damage. *Pest Control,* **47**, pp. 18-20.

Department of Conservation and Land Management DCLM. (2002). Western Grey kangaroo *(Macropus fuliginosus)* Management plan for Western Australia 2003-2007

DECCW (Department of Environment, Climate Change and Water). 2010. *Handbook for kangaroo harvesters* DECCW 2010/160. Sydney South: ISBN 978 1 74232 569 9

Delbridge, J., Lutze, M, 1998. *An evaluation of the effectiveness of WR-1 repellent for browsing control in HEMS forest.* Forests Service, Department of Natural Resources and Environment, Victoria. Report nr 365.

DoIR. (2006). Department of Industry and Resources annual report 2005-06. DoIR, Perth.

Driessen, M.M. (1992). Effects of hunting and rainfall on Bennett's wallaby and Tasmanian pademelon populations. Hobart, Tasmania, Parkes and Wildlife Service. pp. 175.

Eason, C.T., Gooneratne R., Rammell, C.G. (1994). A review of the toxicokinetics and toxicodynamics of sodium monofluoroacetate in animals. In: Seawright AA, Eason C.T. (eds) *Proceedings of the science workshop on 1080*. The Royal Society of New Zealand Miscellaneous series **28**, pp. 82–89.

Ebensperger, L.A. & Hurtado, M.J. (2005). On the relationship between herbaceous cover and vigilance activity of degus (*Octodon degus*). *Ethology,* **111**, pp. 593-608.

Eberbach, P.L. (2003). The eco-hydrology of partly cleared, native ecosystems in southern Australia: a review. *Plant and Soil,* **257**, pp. 357–369.

Edwards, K. & Oogjes, G. (1998). *Management of native animals- animal welfare and rights.* Proceedings of a symposium held at the Society for Conservation Biology Conference, Sydney, Australia.

Epple, G., Mason, J.R., Nolte, D.L. & Campbell, D.L. (1993). Effects of predator odors on feeding in the mountain beaver (*Aplodontia rufa*). *Journal of Mammalogy*, **74**, pp. 715–722.

Fenner, M., Hanley, M.E. & Lawrence, R. (1999). Comparison of seedlings palatability in annual and perennial plants. *Functional Ecology,* **13**, pp. 546-551.

Formanowicz, B.M. (1988). Predation risk and microhabitat preference: an experimental study of the behavioral responses of prey and predator. *American Midland Nature,* **121**, pp. 379–386.

Freudenberger, D. (1995). Separating the sheep from the roos: do we know the difference? In: Grigg, G. C., Hale, D. & Lunney, D. eds *Conservation through sustainable use of wildlife,* Centre for Conservation Biology, University of Queensland.

Fukuda, Y. (2005). *Closing Watering Points to Limit Populations of Large Macropods and Rehabilitate Degraded National Park*. PhD thesis, University of Queensland.

Gardiner, H.G. (1986). Dynamics of perennial plants in the mulga (*Acacia aneura* F. Muell.) zone of Western Australia. I. Rates of population change. *Australian Rangeland Journal,* **8**, pp. 21-28.

Gardner, J. (2001) Rehabilitating mines to meet land use objectives: bauxite mining in the jarrah forest of Western Australia. Rehabilitation of degraded sites, *Unasylva* 207, **52**, pp. 2-8.

Gillingham, M.P., Speyer, M.R., Northway, S. & McLaughlin, R. (1987). Feeding preference and its relation to herbivore repellent studies. *Canadian Journal of Forest Research*, **17**, pp. 146–149.

Glen, A.S., Len, C.R., Dickman, M. E., Soule & Mackey, B.G. (2007). Evaluating the role of the dingo as a trophic regulator in Australian ecosystems. *Austral Ecology* **32**, pp. 492–501.

Government, W. A. (2007). Towards sustainability- Mining and Petroleum. State of the Environment Report 2007, Western Australia, Government of Western Australia.

Groom, P.K., Lamont, B.B. & Markey, A.S. (1997). Influence of leaf type and plant age on structure and sclerophylly in Hakea (*Proteaceae*). *Australian Journal Botany*, **45**, pp. 827-838.

Grigg, G. (2008) Kangaroos on defence lands – another view (Science Alert Australia and New Zealand) Viewed 5/9/2008 *ACT Kangaroo Management Plan Final Draft (February 2009)* http://www.sciencealert.com.au/opinions/20081404-17184.html

Gunn, I. (2004) Preservation Of Our Macropods Now And In The Future Australian Wildlife Protection Council, A voice for Wildlife. Viewed 12/12/2009 http://www.awpc.org.au/kangaroos/book_files/preservationofourmacropods.htm

Halford, D. A., Bell, D. T. & Loneragan, W. A. (1984). Diet of the western grey kangaroo (*Macropus fuliginosus* Desm.) in a mixed pasture-woodland habitat of Western Australia. *Journal of the Royal Society of Western Australia,* **66**, pp. 119-128.

Hanson, M.T. & Coss, R.G. (2001). Age differences in the response of California ground squirrels (*Spermophilus beecheyi*) to conspecific alarm calls. *Ethology*, **107**, pp. 259–275.

Harrington, G.N., Wilson, A.D. & Young, M.D. (1984). *Management of rangeland ecosystem.* Management of Australia´s Rangelands. CSIRO, Melbourne, pp. 3-13.

Harris, M.A., Murie, J.O. & Duncan, J.A. (1983) Responses of Columbian ground squirrels to playback of recorded calls. *Z. Tierpsychol*., **63**, pp. 318—330.

Hatton, T.J., Ruprecht, J. & George, R.J., (2003). Preclearing hydrology of the Western Australia wheatbelt: target for the future? *Plant and Soil,* **257**, pp. 341–356.

Hauser, C.E., Pople, A.R. & Possingham, H.P. (2006). Should managed populations be monitored every year? *Ecological Applications*, **16**, pp. 807-819.

Heithaus, D.L. (2002). Food availability and tiger shark predation risk influence bottlenose dolphin habitat use. *Ecology,* **83**, pp. 480–491.

Hickman, A.H.,. Smurthwaite, A.J., Brown, I. M. & Davy, R. (1992). *Bauxite Mineralization in the Darling Range, Western Australia*. Geological Survey of Western Australia. Report 33.

Hingee, M. & Magrath, R.D. (2009). Flights of fear: a mechanical wing whistle sounds the alarm in a flocking bird. Proceedings of the royal society B-biological sciences, **276**, pp. 4173-4179.

Hobbs, R.J. & Harris, J.A. (2001). Restoration Ecology: Repairing the Earth´s ecosystems in the New Millennium. *Restoration Ecology,* **9**, pp. 239-246.

Humbert, J., Mills, L.S., Horne, J.S. & Dennis, B. (2009) A better way to estimate population trends. *OIKOS*, **118**, pp. 1940-1946.

Ingwersen, F. (2001) '*Sundry nameless ranges': the landscape ecology of the Naas–Gudgenby catchment*. Unpubl. PhD thesis (Australian National University, Canberra).

Jarman, P.J. 1987. Group size and activity in eastern grey kangaroos.

Animal Behaviour, **35**, pp. 1044-1050.

Jarman, P.J. & Coulson, G. (1989). Dynamics and adaptiveness of grouping in macropods. pp. 527-547 in: G. Grigg, P. Jarman & I. Hume (eds) *Kangaroos, Wallabies and Rat-Kangaroos*, **1**. Surrey Beatty and Sons, Sydney.

Jensen, P.G., Curtis, P.D., Dunn, J.A., Austic, R.E. & Richmond, M.E. (2003). Field evaluation of capsaicin as a rodent aversion agent for poultry feed. *Pest Management Science,* **59**, pp. 1007–1015.

Johnson, C. 2006. *Australia's mammal extinctions, a 50.000 year history.* Cambridge University Press. Port Melbourne.

Johnson, M. (2000). *An Analysis of the Contribution that Marsupials and Marsupial Research Make to the Australian Economy,* Report to the Marsupial CRC.

Jonzen, N., Pople, T., Knape, J. & Skold, M. (2010) Stochastic demography and population dynamics in the red kangaroo *Macropus rufus*. *Journal of Animal Ecology*, **79**, pp 109-116.

Jordan, F., Bartolini, M., & Nelson C. (1997). Risk of predation affects habitat selection by the pinfish *Lagodon rhomboides* (Linnaeus). *Journal of experimental marine biology and ecology,* **208,** pp. 45-56.

Kastelein, R.A., Vaughan, A.D., Schooneman, N.M., Verboom, W.C. & DeHaan, D. (2000). The effect of acoustic alarms on the behavior of harbor porpoises (*Phocoena phocoena*) in a floating pen. *Marine Mammal Science,* **16**, pp. 46-64.

Kaufmann, J.H. (1975). Field observations of the social behaviour of the eastern grey kangaroo, *Macropus Giganteus. Animal Behaviour,* **23**, pp. 214-221.

Kimball, B.A., Nolte, D.L. & Perry, K.B. (2005). Hydrolyzed casein reduces browsing of trees and shrubs by white-tailed deer. *HortScience*, **40**, pp. 1810–1814.

Koehler, A. E., Marsh, R. E. & Salmon, T. P. (1990). Frightening methods and devices:stimuli to prevent mammal damage – A review. *Proc. Vert. Pest Conf*. **14**, pp. 168–173.

Kotler, B.P., Brown, J.S. & Hasson, O. (1991). Factors affecting gerbil foraging behavior and rates of owl predation. *Ecology,* **72**, pp. 2249-2260..

Lal, R. (2001). Potential of desertification control to sequester carbon and mitigate the greenhouse effect. *Climatic Change,* **51**, pp. 35–72.

Lamont, B.B., Groom, P.K., Richards, M.B. & Witkowski, E.T.F. (1999). Recovery of *Banksia* and *Hakea* communities after fire in mediterranean Australia - the role of species identity and functional attributes. *Diversity and Distributions*, **5**, pp. 15-26.

Lavery, H.J. & Kirkpatrick, T.H. (1985). Kangaroos as pests. pp. 103-134 in: Lavery. H.J. (ed) *The Kangaroo Keepers*. University of Queensland Press, St Lucia.

Leger, D.W., Owings, D.H. & Boal, L.M. (1979) Contextual information and differential responses to alarm calls in California ground squirrels. *Z. Tierpsychologie,* **49**, pp. 142-155.

Lentle, R.G., Potter, M.A., Springett, B.P. & Stafford, K.J. (1997). A trapping and immobilisation technique for small macropods. *Wildlife Research,* **24**, pp. 373–377.

Linhart, S.B., Sterner, R.T., Dasch, G.J., Roberts, J.D. & Packham, C.J. (1992). Electronic frightening devices for reducing coyote predation on domestic sheep: efficacy under range conditions and operational use. *Proc. Vert. Pest Conf.* **15**, pp. 386–392.

Long, K. & Robley, A. (2004). *Cost effective feral animal exclusion fencing for areas of high conservation value in Australia.* Report to the Department of the Environment and Heritage, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg (unpubl.). pp. 54

Ludwig, J.A. & Tongway, D.J. (1996). Rehabilitation of semiarid landscapes in Australia .2. Restoring vegetation patches. *Restoration Ecology*, **4**, pp. 398-406.

MacFarlane, A.M. & Coulson, G. (2005). Synchrony and timing of breeding influences sexual segregation in western grey and red kangaroos (*Macropus fuliginosus* and *M. rufus*). *Journal of Zoology,* **267**, pp. 419-429.

MacWhirter, R.B. (1992) Vocal and escape responses of Columbian ground squirrels to simulated terrestrial and aerial predator attacks. *Ethology*, **91**, pp. 311—325.

Marks, C.A., Fisher, P., Moore, S. & Hague, N. (1995). Techniques for the mitigation of plantation seedling damage by the European rabbit (*Oryctolagus cuniculus*) and swamp wallaby (*Wallabia bicolor*). In: Statham, M., Buggy, K. (Eds.), 10th *Australian Vertebrate Pest Control Conference-Proceedings,* DPIF, Launceston,Tasmania, pp. 155–160.

Martin-Lopez, B., Montes, C. & Benayas, J. (2007). The non-economic motives behind the willingness to pay for biodiversity conservation. *Biological conservation*, **139**, pp. 67-82.

Masataka, N. (1983). Categorical responses to natural and synthesized alarm calls in Goeldi's monkeys (*Callimico goeldi*). *Primates*, **24**, pp. 40–51.

Mason, J.R., Hollick, J., Kimball, B.A. & Johnston, J.J. (1999). Repellency of Deer Away Big Game Repellent® to eastern cottontail rabbits. *Journal of Wildlife Management*, **63**, pp. 309–314.

Massam, M., Bennell, T., Chapman, T. & Norbury, G. (2006). *Western Grey kangaroo*. Fauna Note No. 29/2006, Department of Conservation and Land Management.

McCullough, D.R. & McCullough, Y. (2000). *Kangaroos in outback Australia. Comparative ecology and behaviour of three coexisting species.* Columbia University Press, New York.

McFarlane D.J. (1993). Changes in the hydrologic cycle. Reintegrating fragmented landscapes: towards sustainable production and nature conservation. Pp. 146-89.

McLeod, R. (2004) *Counting the Cost: Impact of Invasive Animals in Australia 2004*. Cooperative Research Centre for Pest Animal Control. Canberra.

Mikheev, V.N., Wanzenbock, J. & Pasternak, A.F. (2006) Effects of predator-induced visual and olfactory cues on 0+ perch (*Perca fluviatilis* L.) foraging behaviour. *Ecol. Freshwater Fish*, **15**, pp. 111-117.

Miller, A.M., O'Reilly-Wapstra, J.M., Potts, B.M. & McArthur, C. (2009) Non-lethal strategies to reduce browse damage in eucalypt plantations. *Forest Ecology and Management*, **259**, pp. 45–55.

Montague, T.L. (1993). An assessment of the ability of tree guards to prevent browsing damage using captive swamp wallabies (*Wallabia bicolor*). *Australian Forestry*, **56**, pp. 145–147.

Morriss, G.A., O'Connor, C.E., Warburton B. & Eason, C.T (2000). *Alternative toxicants for dama wallaby (Macropus eugenii) control.* Landcare Research Contract Report LC9900/81 to the Animal Health Board (unpubl.). Pp. 11.

Mott, D.F & Timbrook, S.K. (1988). "Alleviating nuisance Canada goose problems with acoustical stimuli." Proceedings Vertebrate Pest Conference **13**: 301-305.

Murray, P.J., Burns, A.C. & Davy, J.R. (2006). Development of an animal repellent - selection, efficacy and presentation. *Australian Journal of Experimental Agriculture*. **46**, pp. 851-856.

Norbury, G.L., Coulson, G.M & Walters, B.L. (1988). Aspects of the Demography of the Western Grey Kangaroo, *Macropus fuliginosus melanops,* in Semiarid North-west Victoria. *Aust. Wildl. Res.,* **15**, pp. 257-66.

Norbury, G.L., Norbury, D.C. & Hacker, R.B. (1993). Impact of Red kangaroos on the pasture layer in the Western Australian arid zone. *Rangeland Journal*, **15**, pp. 12-23.

Olsen, P. & Braysher, M. (2000). *Situation Analysis Report: Current State of Scientific Knowledge on Kangaroos in the Environment, Including Ecological and Economic Impact and Effect of Culling*. Report for the Kangaroo Management Advisory Committee.

Parsons, M.H., Koch, J.M., Lamont, B.B, Vlahos, S. & Fairbanks, M.M. (2006). Planting density effects and selective herbivory by kangaroos on species used in restoring forest communities. *Forest Ecology and Management,* **229**, pp. 39-49.

Parsons, M.H. & Mella, V. (2006). The use of novel deterrents for reducing herbivory by kangaroos: A multidisciplinary assesement. Perth, Minerals and Energy Research Institute Western Australia, *MERIWA***, 67**.

Parsons, M.H., Lamont, B.B., Koch, J.M. & Dods, K. (2007a). Disentangling Competition, Herbivory, and Seasonal Effects on Young Plants in Newly Restored Communities. *Restoration Ecology,* **15**, pp. 250-262.

Parsons, M.H., Lamont, B.B., Koch, J.M., Fairbanks, M. & Vlahos, S. (2007b). Using multiple indices to disentangle drought, herbivory, and competition effects. *Restoration Ecology,* **15**, pp. 250-262.

Parsons, M.H., Lamont, B.B., Kovacs, B. & Davies, S.J.J.F. (2007c). Effects of novel and historic predator urines on semi-wild western grey kangaroos. *Journal of Wildlife Management,* **71**, pp. 1225-1228.

Parsons, M.H., Rafferty, C.M.L., Lamont, B.B., Dods, K. & Fairbanks, M. (2007d). Relative effects of mammal herbivory and plant spacing on seedling recruitment following fire and mining. *BMC Ecology,* **7.** Viewed 10/03/2008 http://www.biomedcentral.com/1472-6785/7/13.

Pays, O., Jarman, P.J., Loisel. P. & Gerard, J. (2007). Coordination, independence or synchronization of individual vigilance in the eastern grey kangaroo? *Animal Behaviour*, **73**, pp. 595-604.

Perla, B.S. & Slobodchikoff, C.N. (2002). Habitat structure and alarm call dialects in Gunnison's prairie do (*Cynomys gunnisoni*). *Behavioural Ecology*, **13**, pp. 844-850.

Pfeifer, W.K. & Goos, M.W. (1982). Guard dogs and gas exploders as coyote depredation control tools in North Dakota. *Proceedings Vertebrate Pest Conference*, **10**, pp. 55-61.

Pople, T. & Grigg, G. (1999). *Commercial Harvesting of Kangaroos in Australia*.

Environment Australia, Canberra. Department of Environment and Water Resources, Canberra. Viewed 10.03.2009. http://www.environment.gov.au/bg/plants/wildlife/roo/roobg.htm

Pople, A.R., Grigg, G.C., Cairns, S.C., Beard, L.A. & Alexander, P. (2000). Trends in numbers of red kangaroos and emus on either side of the South Australian dingo fence: evidence for predator regulation? *Wildlife Research,* **27**, pp. 269-276.

Pressley, P.H. (1981). Parental effort and the evolution of nest-guarding tactics in the threespine stickleback, *Gasteroteus aculeatus*. *Life Evolution*, **35**, pp. 282-295.

Priddel, D. (1986). The diurnal and seasonal pattern of grazing of red kangaroos, *Macropus rufus,*and the western grey kangaroo, *M. fuliginosus. Aust. Wildl. Res.* **13**, pp. 113-20.

Priddel, D., Shepherd, N. & Wellard, G. (1988). Home Ranges of Sympatric Red Kangaroos *Macropus rufus,* and Western Grey Kangaroos *M. fuliginosus,* in Western New South Wales. *Aust. Wildl. Res.*, **15**, pp. 405-11.

Pusenius, J. & Ostfeld, R.S. (2002). Mammalian predator scent, vegetation cover and tree seedling predation by meadow voles. *Ecography,* **25**, pp. 481-487.

Quenette, P.Y. & Gerard, J.F. (1992). From individual to collective vigilance in wild boars (*Sus scrofa*). *Canadian Journal of Zoology*, **70**, pp. 1632-1635.

Ramakrishnan, U. & Coss, R.G. (2000). Age differences in the responses to adult and juvenile alarm calls by bonnet macaques (*Macaca radiata*). *Ethology*, **106**, pp. 131–144.

Ramp, D. (2007). *Evaluation of acoustic repellants, Behavioural responses of red-necked pademelons (Thylogale thetis) and red-necked wallabies (Macropus rufogriseus banksianus) to acoustic stimuli:the feasibility of developing an acoustic deterrent.* Final report to Forestry Tasmania.

Reby, D. & McComb, K. (2003). Anatomical constraints generate honesty: acoustic cues to age and weight in the roars of red deer stags. *Animal Behaviour,* **65**, pp. 519-530.

Reiter, D.K., Brunson, M.W. & Schmidt, R.H. (1999). Public attitudes toward wildlife damage management and policy. *Wildlife Society Bulletin,* **27**, pp. 746-758.

Robinson, S.R. (1980) Antipredator behaviour and predator recognition in Belding's ground squirrels. *Anim. Behav*. **28**, pp. 840—852.

Rodger, J.C. (2003). Fertility control for wildlife. In: Holt, W.V., Pickard, A.R., Rodger, J.C., Wildt, D.E. (eds) *Reproductive science and integrated conservation, Conservation Biology 8.* Cambridge, University Press, UK. pp. 281–290

Rose, T.A., Munn, A.J., Ramp, D. & Banks, P.B. (2006). Foot-thumping as an alarm signal in macropodoid marsupials:prevalence and hypotheses of function. *Mammal Review,* **36,** *pp.* 281–298.

RSPCA Australia (1985). *Incidence of Cruelty to Kangaroos.* Report to the Australian National Parks and Wildlife Service

RSPCA, Australia (2002) *Kangaroo Shooting Code Compliance: A Survey of the Extent of Compliance with the Requirements of the Code of Practice for the Humane Shooting of Kangaroos*. Prepared for Environment Australia (Canberra). Viewed in ACT Kangaroo Management Plan Final Draft (February 2009)

<http://www.environment.gov.au/biodiversity/tradeuse/publications/kangaroo-report/index.html>

Shafer, E. W. & Bowles, W. A. (2004). Toxicity, repellency or phytotoxicity of 979 chemicals to birds, mammals and plants. United States Department of Agriculture, Animal and Health Inspection Service, Wildlife Services, National Wildlife Research Center, Research Report No. 04-01, pg. 123

Shepherd, N. (1987) Condition and recruitment of kangaroos, in 'Kangaroos: Their Ecology and Management in the Sheep Rangelands of Australia'. (Eds G. Caughley, N. Shepherd and J. Short.) pp. 50-68. (Cambridge University Press: Cambridge.)

Shrader, A.M., Brown, J.S. & Kerley, G.I.H. (2008) Do free-ranging domestic goats show 'landscapes of fear'? Patch use in response to habitat features and predator cues. Journal of arid environments, 72, pp. 1811-1819.

Schirmer, J. & Filed, J. (n.d). The cost of revegetation. final report ANU forestry

Schmidt, K.A. (2006) Non-additivity among multiple cues of predation risk: a behaviorally driven trophic cascade between owls and songbirds. *Oikos,* **113**, pp. 82-90.

Smith, M.E., Linnell, J.D.C., Odden, J. & Swenson J.E. (2000) Review of Methods to Reduce Livestock Depredation II. Aversive conditioning, deterrents and repellents *Acta Agric*. *Scand*., *Sect*. *A*, *Animal Sci*. **50**, pp. 304–315.

SoE (2007). State of the Environment (SoE) Report, Western Australia 2007. chapter 9, Towards sustainability. 9.5 Mining and Petroleum

Soldatini, C., Albores-Barajas, Y.V., Torricelli, P. & Mainardi, D. (2008) Testing the efficacy of deterring systems in two gull species. *Applied Animal Behaviour Science*. **110,** pp. 330–340.

Spanier, E. (1980). The use of distress calls to repel night herons (*Nycticorax nycticorax*) from fish ponds. *Journal of Applied Ecology*, **17**, pp. 287-294.

Spooner, P., Lunt, I. & Robinson, W. (2002). Is fencing enough? The short-term effects of stock exclusion in remnant grassy woodlands in southern NSW. *Ecological Management and Restoration,* **3**, pp. 117-126.

Standish, R.J., Cramer, V.A. & Wild, S.L. (2007) Seed dispersal and recruitment limitation are barriers to native recolonization of old-fields in Western Australia
Journal of Applied Ecology, **44**, pp. 435-445.

Tacey, W. H. (1979). Landscaping and Revegetation Practices used in Rehabilitation after Bauxite Mining in Western Australia. *Reclamation Review,* **2**, pp. 123-132.

Tacey, W.H. & Glossop, B.L. (1980). Assessment of Topsoil Handling Techniques for Rehabilitation of Sites Mined for Bauxite within the jarrah forest of Western Australia. *Journal of Applied Ecology,* **17**, pp. 195-201.

Talling, J.C., Waran, N.K., Wathes C.M. & Lines, J.A. (1998). Sound avoidance by domestic pigs depends upon characteristics of the signal. *Applied Animal Behaviour Science,* **58,** pp. 255-266.

Teilmann, J., Tougaard, J., Miller, L.A., Kirketerp, T., Hansen, K. & Brando, S. (2006). Reactions of captive harbor porpoises (*Phocoena phocoena*) to pinger-like sounds. *Marine Mammal Science,* **22,** pp. 240-260.

Thorson, J.M., Morgan, R.A., Brown, J.S. & Norman, J.E. (1998) Direct and indirect cues of predatory risk and patch use by fox squirrels and thirteen-lined ground squirrels. *Behav. Ecol*. **9**, pp. 151-157.

Tongway, D. & Hindley, N. (2003). *Indicators of ecosystem rehabilitation success.* CSIRO Systainable Ecosystems, Stage two- Verification of EFA Indicators, Final Report.

Turner, N.C. & Asseng, S. (2005). Productivity, sustainability, and rainfall use efficiency in Australian rainfed Mediterranean agricultural systems. *Australian Journal of Agricultural Research,* **56**, pp. 1123–1136.

Veterinary Dictionary, (2007) Viewed 02/12/2009 http://medical-dictionary.thefreedictionary.com/culling Saunders Comprehensive Veterinary Dictionary, 3 ed. © 2007 Elsevier

Voipio, H.M. (1997). How do rats react to sound? *Scandinavian Journal of Laboratory Animal Science,* **24**, pp. 1-12.

Walsh, A.M. & Wardlaw, T.J. (2005). *An integrated pest management strategy to manage mammal browsing on state forest in Tasmania.* 13th Australasian Vertebrate Pest Conference, Wellington, NewZealand. pp. 48–55.

Ward, S.C., Koch, J.M. & Ainsworth, G.L. (1996). The Effect of Timing of Rehabilitation Procedures on the Establishment of a Jarrah Forest after Bauxite Mining. *Restoration Ecology,* **4**, pp. 19-24.

Wheeler, B.C. (2008) Selfish or altruistic? An analysis of alarm call function in wild capuchin monkeys, *Cebus apella nigritus, Animal behaviour*, **76**, pp. 1465-1475.

Winslow, J.T., Parr, L.A. & Davis, M. (2002). Acoustic startle, prepulse inhibition, and fear-potentiated startle measured in rhesus monkeys. *Biological Psychiatry,* **51**, pp. 859-866.

Woods, L. E. (1984). *Land Degradation in Australia*. 2nd Edition, AGPS, Canberra.

Woolhouse, A.D. & Morgan, D.R., 1995. An evaluation of repellents to suppress browsing by possums. *Journal of Chemical Ecology*, **21**, pp. 1571–1583.

Yates, C.J., Norton, D.A. & Hobbs R.J. (2000). Grazing effects on plant cover, soil and microclimate in fragmented woodlands in south-western Australia: implications for restoration. *Australian Ecology,* **25,** pp. 36-47.