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Temporal fluctuations in yellow-footed rock-wallaby activity in western Queensland



A thesis submitted by

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Abstract

Cluster fencing is a recent innovation in largescale grazing operations in western Queensland, where predation and competition from native and feral species (dingoes, pigs and kangaroos) significantly impact the profitability of livestock enterprises. The main purpose of these fences is to reduce predation pressure on, and pasture competition with, domestic livestock. However, other native species might potentially be positively or negatively impacted by the fence.

Sightings of yellow-footed rock-wallaby (YFRW) *Petrogale xanthopus* colonies on properties within a cluster fence area and adjacent properties near Quilpie raise questions about the potential impact of such fences and associated pest control on this and other native species.

Survival of the threatened YFRW is primarily impacted by resource availability, intra- and interspecific competition (especially from feral goats) and predation by foxes.

This project aimed to establish baseline data for YFRW temporal activity and behaviour at sites inside and outside a cluster-fenced site in western Queensland through the use of *in situ* camera traps and to explore some of the potential causes for any observed differences between treatments or sites. This fence's construction finished in April 2017 so it was hypothesised that there would be no difference in YFRW temporal activity between treatments. It was also hypothesised that YFRW diel activity and behaviour would correlate with dingo and goat activity. Additionally, patterns in diel activity and behaviour of YFRW, and predators and competitors, were explored.

A total of 17 cameras were placed in areas where YFRW presence was evident (11 at the 3 sites inside the fence and 6 at the 3 sites outside the fence). These 'heat in motion' cameras took 75,607 photos during the 253-day study period, including 6176 photos of YFRW. Data, including absence, presence and number of any animals and additional behaviour and demographic information for YFRW were recorded, along with camera and site information. YFRW behaviours observed were recorded in four broad categories of resting, foraging, hopping and other. Dingoes were the only predator recorded and were only recorded at three of the six

sites but YFRW and feral goats were recorded at every site. YFRW and goat activity trends and diel activity patterns and behaviour were examined and compared. While two-tailed t-tests found YFRW activity did not differ between treatments, goat activity was significantly higher inside the fence and fluctuated greatly during the study period. Additionally, there was variation in diel activity and behaviour patterns for YFRW and goats but within-treatment variation appeared to be much greater than between-treatment variation, suggesting pooling the data from sites to consider effects of the fence was not useful. GLMs found mixed relationships between goat diel activity and YFRW diel activity and behaviour within each treatment and at most sites. This suggested other factors were also involved in influencing YFRW activity and behaviour, potentially including intraspecific competition, habitat type and land-use history, which were not assessed in this study. It was concluded that there was no difference in YFRW activity between treatments and the influences of goats on YFRW activity and behaviour was unable to be detected due to sample sizes and other constraints. This study has established that YFRW were present inside and outside the Quilpie cluster fence at the time the fence was constructed, at similar levels of activity inside and outside the fence. How this changes in the future as the fence effect and pest control become established will help pinpoint and highlight issues of conservation concern with this and other threatened species on grazing lands.

Declaration

I certify that the work reported in this thesis is entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not previously been submitted for assessment in any other course of study, at any other University.

Signature of candidate



Date 28/06/2018

Endorsement

Supervisor signature



Date 28/6/18

Co-Supervisor signature



Date 28/6/18

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I. Keywords

Activity

Arid zone

Behaviour

Camera trap

Canis lupus dingo

Capra hircus

Crepuscular

Diel activity patterns

Dog fence

Exclusion fence

Feral goat

Macropod

Marsupial

Nocturnal

Petrogale xanthopus celeris

Rock wallaby

Semi-arid zone

Threatened species

II. Abbreviations

EPBC = Environment Protection and Biodiversity Conservation Act 1999, the Australian Government's main environmental legislation

IUCN = International Union for Conservation of Nature and Natural Resources

YFRW = yellow-footed rock-wallaby

III. Glossary

Cluster fence: an exclusion fence built around more than one property to keep out pests and share the costs of construction and maintenance between properties.

Diel activity/behaviour: the activity and behaviour patterns of organisms within a 24-hour period (Kronfeld-Schor & Dayan 2003).

Euro: a name commonly used for the common wallaroo *Macropus robustus*.

Pest: animals perceived to negatively impact farmers' livelihoods through predation, competition or destruction of crops.

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Chapter 1: Introduction

Fences are used around the world as ways to protect farmers' livelihoods or as conservation measures (e.g. Hayward & Kerley 2009; Vanak *et al.* 2010; Dickman 2012; Bradby *et al.* 2014). In recent years, state-funded cluster fences have gained popularity in central-western Queensland (Crothers 2017). Each fence is a joint-initiative by multiple properties to build a pest-exclusion fence around their combined properties. The purpose of these cluster fences is mostly to protect livestock from predation by dingoes (*Canis familiaris*) and feral pigs (*Sus scrofa*) and competition from kangaroos at high densities (Burton 2015; Crothers 2015, 2017). However, fences also create barriers to movement for non-target native species and can disrupt important dispersal mechanisms needed for repopulation (Prevedello *et al.* 2013) and maintaining genetic diversity (Durant *et al.* 2015). This, in turn, may affect the population dynamics of predator, prey and competitor species which can alter interspecific relationships (Bradby *et al.* 2014) and potentially influence species' activity and behaviour (Killen *et al.* 2013).

The yellow-footed rock-wallaby (YFRW, *Petrogale xanthopus celeris*) is a threatened subspecies that occupies parts of central-western Queensland, including properties inside a cluster fence in the Quilpie region and on adjacent properties outside the fence; the other subspecies (*Petrogale xanthopus xanthopus*) is found in New South Wales and South Australia (Ride & Fry 1970). This fence should prevent the migration of dingoes and other problem species including feral goats, the most significant threatening competitor of YFRW (Hayward *et al.* 2011), into the cluster fence area. Thus, it is plausible that such a fence could be a good conservation measure for YFRW if these pest species can be removed from inside the fence. However, the positive or negative effects of cluster fencing on YFRW have not been examined. As a first step to measuring any longer-term effect of the fence on YFRW, this project established baseline data on YFRW temporal activity by observing how YFRW activity changed over time, comparing this between multiple sites inside and outside the fence, and comparing YFRW activity to the activity of potential predators and competitors. This fence's construction

finished in April 2017 so it was hypothesised that there would be no differences in YFRW activity between treatments. It was also hypothesised that dingoes and goats would influence YFRW activity and behaviour. Patterns in YFRW diel activity and behaviour were also explored. The following chapter (Chapter 2) reviews literature on the effects of fences as barriers to movement on population dynamics, interspecific relationships and activity and considers the potential effects on YFRW in light of that species' distribution, dispersal tendencies and factors that influence its survival. Chapter 3 outlines and explains the methods used in the study, including the experimental design, the appropriateness of camera traps, and how data were entered and analysed. Chapter 4 presents the results of the study, and Chapter 5 discusses the major findings, explores possible explanations for these findings and compares these findings to previously published literature on YFRW.

Chapter 2: Literature review

2.1 Introduction

The introduction and establishment of feral populations of carnivores (namely the fox and feral cat) (Woinarski *et al.* 2015) and herbivores (particularly the rabbit (*Oryctolagus cuniculus*) and feral goat) (McKenzie *et al.* 2007) following European settlement has impacted many native species, as well as domestic livestock, in addition to historical impacts of dingoes (Woinarski *et al.* 2015). In many areas, pest control and conservation management have become joint priorities, with the hopes of protecting farmers' livelihoods along with preserving and sustaining Australia's unique species (Woinarski *et al.* 2014; Burton 2015). Recently, the use of cluster fences around multiple livestock properties in Queensland became more feasible due to state government financial support (Crothers 2017). Cluster fencing is intended to exclude and aid control of pests, particularly dingoes and large macropods, thereby increasing land productivity and stocking capabilities (Burton 2015; Crothers 2017).

Such fences can also create barriers to the movement of native mammalian wildlife which may have unintentional or unpredictable impacts, particularly by disrupting important mechanisms such as dispersal and outbreeding (Groom *et al.* 2006; Hayward & Kerley 2009). These impacts could be beneficial for some species and/or detrimental for others, depending on many factors including resource availability, species' mobility, species' susceptibility to predation, and species' ability to adapt behaviour in response to predation and/or competition (Carnicer *et al.* 2012; Brodie & Giordano 2013; Prevedello *et al.* 2013; Bradby *et al.* 2014; Runge *et al.* 2014; Allen *et al.* 2018). Understanding the effects of cluster fencing on wildlife remains an important priority in conservation research.

The YFRW is one species that may be affected by cluster fencing. Substantial research has been carried out on YFRW and other rock-wallaby species in Australia. At least four PhD theses have been published specifically about YFRW concerning their ecology, biology and management, including one focused on a Queensland colony and another focused on the reintroduction biology

of both subspecies (Lim 1987; Lapidge 2001; Sharp 2002b; Lethbridge 2004). Of 70+ journal articles accessed, 14 were about the Queensland subspecies and another 28 about the New South Wales/South Australia subspecies or the species overall, regarding YFRW distribution, dispersal, home range dynamics, habitat use, behaviour, genetics, population dynamics and influences on survival. This literature review will examine some of the main underlying processes influencing the way fences affect population dynamics, predator-prey relationships, competitive relationships and species' temporal activity/behaviour and consider these in the context of YFRW, of which *P. x. celeris* has some colonies enclosed within a cluster fence on livestock properties in western Queensland. In particular, it will consider YFRW behaviour and interactions with living and nonliving components of the ecosystems they occupy, and how these might be affected by a cluster fence.

2.2 Fences as barriers to movement

Australia has many pest exclusion fences, including the Dingo Fence, built to protect sheep from dingoes in southern Australia, the Rabbit Proof Fence, the emu proof State Barrier Fences, and countless rural fences (Wallach *et al.* 2009; Ferronato *et al.* 2014). Fences have also been used as a conservation tool (Vanak *et al.* 2010) and have had success in protecting some native Australian species from threats, particularly predation by cats and foxes (e.g. Robley *et al.* 2007; Clayton *et al.* 2014; Woinarski *et al.* 2014; West *et al.* 2017). In recent years, Queensland graziers anticipated state-funded cluster fences would protect their sheep from dingoes and wild pigs, help control kangaroo populations and increase the land's livestock carrying capacity (Burton 2015).

The positive and negative impacts of fences on ecosystems and the economy are much debated, with Durant *et al.* (2015) identifying six research areas (i.e. economic cost-effectiveness, habitat edge permeability, reserve design, importance of connectivity, impact on ecosystem services, and benefits and costs to local human communities) where information on the effects of fencing

in dryland ecosystems were incomplete or poor. Durant *et al.* (2015) further state that, while fences erected to protect wildlife or people can be a useful conservation tool, they can also be counterproductive. Fences can potentially have unintended consequences on non-target animals by increasing mortality, disrupting movement, restricting access to important resources and isolating populations (Hayward & Kerley 2009; Vanak *et al.* 2010; Ferronato *et al.* 2014). Barriers to movement interact in complex ways with underlying ecological processes to affect species' population dynamics, alter predator-prey relationships and competitor relationships, and affect species' activity and behaviour (Killen *et al.* 2013; Bradby *et al.* 2014; Runge *et al.* 2014; Durant *et al.* 2015).

2.3 Impacts on population dynamics

Dispersal is an important mechanism for repopulation (Salau *et al.* 2012; Prevedello *et al.* 2013) and increasing the genetic diversity of subpopulations through outbreeding (Bradby *et al.* 2014; Durant *et al.* 2015). Larger populations and increased genetic diversity generally reduce the potential impacts of stochastic events on population abundance (Staudinger *et al.* 2013; Runge *et al.* 2014; Oliver *et al.* 2015). Dispersal can help maintain more consistent population sizes where cycles of overabundance and population crashes may otherwise occur during periods of high resource availability and reproduction (Hayward & Kerley 2009; Runge *et al.* 2014). Travelling long distances may also enable species to access more resources in poor environmental conditions and to escape wildfire and other environmental events (Olsson *et al.* 2008; Hayward & Kerley 2009; Durant *et al.* 2015). Impermeable barriers to dispersal, along with direct mortality through collisions with fences (Bradby *et al.* 2014; Ferronato *et al.* 2014), can significantly affect the population dynamics of large mobile wildlife species.

Factors which influence the impact of dispersal barriers on population dynamics include the species' tendency to be mobile or sedentary (Runge *et al.* 2014), its intrinsic rate of population growth and its ability to cope with decreased genetic variation within populations (Oliver *et al.*

2015). According to Runge *et al.* (2014), some species are migratory, others exhibit only limited dispersal tendencies, and others are more unpredictable, being nomadic and resource-driven. Emus (*Dromaius novaehollandiae*) are one far-ranging species whose movement is reported to be disrupted by barrier fences, reducing access to sufficient amounts of suitable habitat (Bradby *et al.* 2014). However, Carnicer *et al.* (2012) explain that species-specific behavioural barriers to dispersal exist in some species, particularly habitat specialists. For example, brush-tailed rock-wallabies *Petrogale penicillata* (and other *Petrogale* species) exhibit high site fidelity and rarely disperse between sites (Hazlitt *et al.* 2006). However, despite this limited gene flow between colonies, a study of a brush-tailed rock-wallaby colony in southeast Queensland found consistently high levels of genetic diversity and no signs of inbreeding (Hazlitt *et al.* 2006). The authors suggested late sexual maturation of females reported in other studies might help facilitate inbreeding avoidance in rock-wallabies. Those species that are naturally less mobile or have traits which enable them to cope with a lower gene pool should therefore be less likely to experience changes to their population dynamics when dispersal mechanisms are interrupted by barriers to movement such as fences.

2.3.1 YFRW background

YFRW are easily identified by their colourful and distinctive markings, particularly their white side stripes, banded tail and yellow feet (Strahan 1995) (Figure 1). They are a medium-sized sexually dimorphic macropodid averaging 8 kg for adult males (Lim *et al.* 1992; Sharp *et al.* 2006). The southern subspecies *Petrogale xanthopus xanthopus* was first described in South Australia in 1854 by J.E. Gray while the northern subspecies *Petrogale xanthopus celeris* was discovered in 1924 on Terachy Station north-west of Quilpie, Queensland (Eldridge 1997).



Figure 1. YFRW spotted near Camera Site 5, Ray Station, Qld. PHOTO: Mattea Taylor

Though reportedly abundant when Europeans first arrived, the species' range has greatly reduced since European settlement (Copley 1983). This reduction is thought to be partly due to human hunting, pastoral, agricultural and mining activities but is largely attributed to predation by the introduced European red fox and feral cat and competition with goats, rabbits and sheep (Copley 1983; Hayward *et al.* 2011; Lapidge & Munn 2012). Competition and predation by these species are still considered major threats to YFRW, though climate-influenced resource fluctuations, low levels of recruitment and stochastic effects due to small and isolated populations may also influence population declines (Sharp *et al.* 2006; Threatened Species Scientific Committee 2008; Sharp *et al.* 2014; Threatened Species Scientific Committee 2016). Currently, *Petrogale xanthopus* is listed as Near Threatened under the International Union for Conservation of Nature and Natural Resources (IUCN) Red List with its entire population estimated at fewer than 10,000 mature individuals in the wild and possibly declining (Copley *et al.* 2016). Both subspecies are listed as Vulnerable under the Environment Protection and Biodiversity Conservation (EPBC)

Act 1999 (Threatened Species Scientific Committee 2008, 2016). The Queensland subspecies *P. x. celeris* is listed as Vulnerable due to its limited extent of occurrence and presumed continuing population decline. The total number of mature *P. x. celeris* individuals in the wild is estimated to be between 4,000 and 6,000 (Threatened Species Scientific Committee 2016).

Both YFRW subspecies have a naturally patchy distribution in arid and semi-arid zones where they live on isolated rocky ranges and hills in areas of South Australia, New South Wales and Queensland (Lim *et al.* 1992; Hayward *et al.* 2011; Norton *et al.* 2011) (Figure 2). Queensland YFRW distribution is restricted to parts of the rocky ranges of central-western Queensland including Gowan, Grey, and McGregor ranges, and Mariala National Park, as well as several conservation reserves (Threatened Species Scientific Committee 2016) and a captive population in Charleville, Queensland, which has been used to source animals for successful reintroductions to areas within its former range (Lapidge 2005). Major studies have been carried out in Idalia National Park, particularly around the ‘Hill of Knowledge’ colony on the northern Grey Range (Sharp 2009), and Lambert Pastoral Station in the Wallaroo Ranges where YFRW were reintroduced to three locations in 1998 (Lapidge & Henshall 2001).

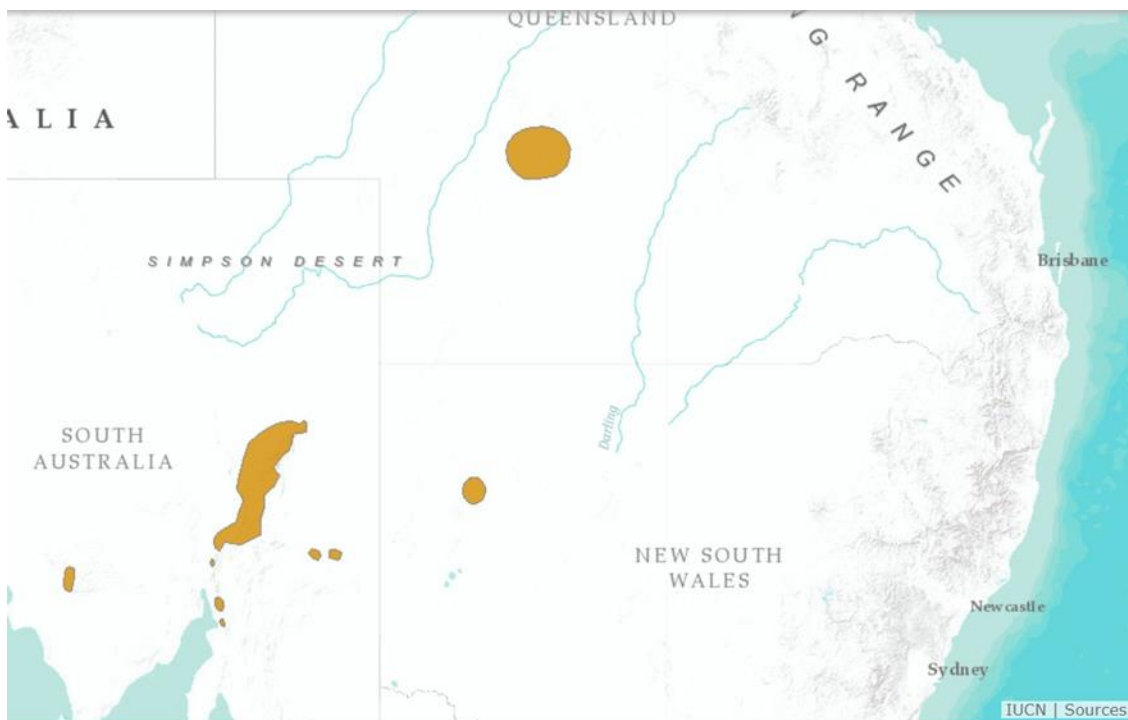


Figure 2. Map of *Petrogale xanthopus* distribution (IUCN 2016).

YFRW usually live in small colonies of fewer than 20 individuals (Copley *et al.* 2016), though larger colonies have been recorded (Lim *et al.* 1992; Sharp & McCallum 2010). Colony size is thought to be limited by habitat quality and structural complexity, available food resources, permanent water sources and suitable shelter sites (Lim *et al.* 1992; Lapidge 2005; Sharp & McCallum 2010). If the colony is large enough, YFRW live in a number of distinct social groups in small areas of rock-piles or cave systems (Lim *et al.* 1992; Sharp 2009; Sharp & McCallum 2010). These social groups are typically comprised of one or two older males and several adult females with offspring, and potentially transient individuals which move between the social groups or reside in peripheral habitat (Lim *et al.* 1992; Sharp & McCallum 2010). Young tend to disperse away from the group, particularly young males approaching sexual maturity (Lim *et al.* 1992).

YFRW are continuous breeders displaying lactation-controlled embryonic quiescence (Poole *et al.* 1985) and resource scarcity-induced embryonic diapause (Sharp & McCallum 2015). Both sexes attain sexual maturity from around 18 months old (Poole *et al.* 1985) and life expectancy is 3–6 years (Lim *et al.* 1992; Robinson *et al.* 1994).

YFRW survival is particularly affected by a combination of rainfall (Lethbridge & Alexander 2008), interspecific and intraspecific competition (Sharp *et al.* 2006), and predation (Sharp *et al.* 2014). Highest mortality occurs in juveniles as they have higher energy requirements and are more susceptible to predation, despite being left at refuge sites for better protection while their mothers forage on the slopes and flats (Lapidge 2001; Sharp *et al.* 2006; Sharp & McCallum 2015).

2.3.2 YFRW dispersal

YFRW tend to be relatively sedentary (Lethbridge & Strauss 2015), displaying high site fidelity and limited dispersal tendencies (Sharp & Norton 2000; Blumstein *et al.* 2001; Sharp 2009). Like other *Petrogale* species, successful inter-colony dispersal is limited and within-colony

dispersal (between social groups) is more common (Pope *et al.* 1996; Sharp 1997b, 2002b).

During a 34 month study period, only one juvenile male (of 120 YFRW monitored) dispersed between Queensland colonies (600 metres), but intra-colony dispersal was high and mostly by males (Sharp 1997b). The only other YFRW study where inter-colony dispersal was observed was with reintroduced *P. x. celeris* that appeared to be integrating into the local meta-population (Lapidge 2001). These dispersals were the furthest recorded for any *Petrogale* species with one male dispersing 7.3 km to join another colony, another travelling at least 27 km over a year, siring progeny at a different colony then returning, and three wild YFRW travelling 17.2 km from a natural colony to a reintroduced colony (Lapidge 2001).

While large distances of unsuitable habitat, high predation risks and little shelter or water make dispersal risky, low dispersal rates have been observed between colonies joined by continuous suitable habitat, suggesting behavioural and social limitations (even high habitat specificity) may be involved, and not just geographical and ecological barriers (Sharman & Maynes 1983; Pope *et al.* 1996; Lethbridge 2004). Evidence of successful 8 km dispersal by black-footed rock-wallabies (*Petrogale lateralis*) through a heavily-modified, hostile landscape also suggest that rock-wallaby dispersal could happen naturally if predation risk was low (Eldridge *et al.* 2001).

It is not yet well understood what triggers dispersal, and how YFRW move through the landscape, select sites and select mates (Lethbridge 2004). However, such low dispersal rates may have significant implications for conservation of this species, decreasing gene flow (hence, limiting genetic diversity), preventing replenishment of declining colonies, slowing the establishment of new colonies and potentially resulting in the extinction of isolated YFRW populations (Pope *et al.* 1996; Sharp 1997b; Lethbridge 2004). As suggested at the end of section 2.3, species that are naturally less mobile or have traits which enable them to cope with a lower gene pool should be less likely to experience changes to their population dynamics when dispersal mechanisms are interrupted by barriers to movement such as fences. Though the implications of low genetic flow between colonies are still being examined, it is possible YFRW

might be less directly affected by fences than other species such as the much more mobile feral goat.

2.4 Altered predator-prey relationships

The factors involved in the effect of fences on population dynamics apply to both predator and prey species (e.g. Tambling & du Toit 2005; Durant *et al.* 2015). In some cases, migratory prey species, such as blue wildebeest *Connochaetus taurinus*, may be at greater risk of predation in artificial closed systems because they have less ability to evade predators (Tambling & du Toit 2005). However, movement of apex and mesopredators could also be restricted (Bradby *et al.* 2014; Durant *et al.* 2015) which means those predators are unable to boost their population sizes through immigration (Prevedello *et al.* 2013). As livestock fencing in Australia is often coupled with control of dingoes and foxes (Saunders *et al.* 2010; Brook *et al.* 2012), this potentially further restricts predator populations, thereby altering predator-prey relationships and the impact on prey species. However, if apex predators (e.g. dingoes) are disproportionately affected by fences and pest control, loss of those predators might lead to trophic imbalance or mesopredator release (Bradby *et al.* 2014).

Trophic imbalances may result from removal of an apex predator that normally suppresses large native herbivores, such as kangaroos, with the result being that those large herbivores could increase in density and increase overgrazing, impacting pasture production, competing with livestock and altering the habitat of smaller native species (Bradby *et al.* 2014; Ford & Goheen 2015). Mesopredator release may also result from the removal of apex predators. Such mesopredator species (e.g. the introduced red fox) that are normally suppressed through predation or competition, may increase in abundance, resulting in increased predation pressure on their prey species (Bradby *et al.* 2014; Durant *et al.* 2015; Gordon *et al.* 2017).

In Australia, the role of the dingo as an apex predator and biodiversity regulator and the impacts of its control on trophic imbalance and mesopredator release are much debated. Some studies

suggest dingo removal results in higher cat or fox abundance (e.g. Brook *et al.* 2012; Gordon *et al.* 2017). However, others point out that differences in analytical approaches may produce variable results (Hayward & Marlow 2014), suggesting that available evidence for this is either unreliable or, at best, inconclusive (Allen *et al.* 2013). Other studies emphasise the effects of dingo predation on smaller native fauna species (Allen & Fleming 2012) or the role of dingoes in suppressing populations of feral goats and large native herbivores that degrade landscapes and compete with smaller herbivores when present in high densities (e.g. Allen *et al.* 2012; Letnic *et al.* 2012; Newsome *et al.* 2015). Predator control combined with a barrier to movement has the potential to alter or eliminate predator-prey relationships and result in trophic imbalances or mesopredator releases which will again alter those predator-prey relationships and competitive relationships.

2.4.1 YFRW predators

Predation exerts the most influence on YFRW population dynamics at higher predator densities (Sharp & McCallum 2015). Current known or suspected predators are foxes, cats, dingoes and wedge-tailed eagles (Lim *et al.* 1992).

Introduced foxes are opportunistic predators (Lapidge & Henshall 2001) and are considered a serious threat to YFRW (Lim *et al.* 1992), particularly preying on juveniles and adult females with pouch young (Sharp 2002b; Lapidge & Munn 2012). Being agile and excellent climbers, foxes can access juveniles left on outcrops while their mothers forage (Copley 1983; Lim *et al.* 1992; Sharp *et al.* 2014). The impact of fox predation on juvenile survival is considered the primary factor limiting smaller populations, preventing their recovery, with fox control contributing to improved YFRW populations in some areas (Kinnear *et al.* 2010; Sharp *et al.* 2014). Young YFRW are more vulnerable because adults are considered too large for fox predation (Sharp *et al.* 2014), though adult females have been attacked and killed by foxes (Lim *et al.* 1992; Lapidge & Henshall 2001).

In Queensland, fox predation is often considered less of a threat to YFRW than resource scarcity and competition with feral goats, because the Queensland YFRW population lies outside the dingo barrier fence where foxes are likely less abundant (e.g. Gordon *et al.* 1993; Sharp & McCallum 2010; Sharp *et al.* 2014). Those studies observed colonies in Idalia NP and Adavale, both of which are north of the dingo fence (Biosecurity Queensland 2010); however, YFRW also occur south of the dingo fence closer to Quilpie. Although the extent of fox predation on *P. x. celeris* on livestock properties south of the dingo fence is not currently known, *P. x. xanthopus* populations within the fence are considered in decline while the Queensland populations outside the fence are considered stable (Sharp *et al.* 2014), suggesting a potential impact due to differences on either side of the fence.

Dingoes are not considered serious threats to YFRW mostly due to their poor climbing ability, lack of agility and larger body size which hinders entry to YFRW's refuge sites (Lim *et al.* 1992; Sharp 2002a). However, Gordon *et al.* (1993) suggested dingoes might take adult YFRW in more open areas. Allen and Fleming (2012) considered dingoes to pose a high predation risk to YFRW at high dingo densities and suggested the rocky habitat that rock-wallabies now occupy is likely to be a niche developed over time in response to dingo predation. Conversely, in accordance with the popular mesopredator release theory discussed previously, Sharp and McCallum (2015) also suggested dingoes could limit fox and cat populations, reducing predation pressure on declining YFRW populations.

Feral cats are opportunistic predators which are widespread across Australia (Lapidge & Henshall 2001) and known to prey on rock-wallabies and similar-sized species (Fancourt 2015; Moseby *et al.* 2015). However, they are only considered a possible minor predator as there is little evidence of population-scale impact on YFRW (Threatened Species Scientific Committee 2016).

Wedge-tailed eagles nesting near YFRW colonies swoop at and chase YFRW (Lim *et al.* 1992), but again are considered only minor predators because YFRW constitute a minor portion of

wedge-tailed eagles' diet (Sharp 1997a). This is potentially due to YFRW's nocturnal behaviour, agility and complex habitat (Copley 1983; Sharp 1997a); however, Sharp (1997a) suggests the impact of wedge-tailed eagle predation on colonies in more open habitat should be investigated. The combination of fencing and dingo control might decrease dingo predation pressure on YFRW but might also result in an increase predation by cats and/or foxes or a trophic imbalance through allowing feral goat populations to increase inside the fence.

2.5 Altered competitive relationships

Competitive relationships may also change as a result of dispersal interruption and trophic imbalances associated with barriers to movement. As previously explained, fences prevent movement of more mobile species from one area to another (Wiens *et al.* 1993; Runge *et al.* 2014; Durant *et al.* 2015). This can either prevent population increases that normally result from immigration (Prevedello *et al.* 2013) or prevent population decreases that normally result from emigration in migratory or nomadic species (Runge *et al.* 2014). This could potentially lead to increases in population density of certain species which, for competitive herbivores, would decrease the availability of shared resources and increase intra-specific and inter-specific competition and potentially result in competitive exclusion (Krebs 2009; Hayward *et al.* 2011). This effect may be amplified under drier climate conditions when the resource base declines and/or species have to travel further to access sufficient resources (Stirrat 2003; Hayward *et al.* 2011).

Likewise, if population density of a large carnivore species decreases due to restricted dispersal or control as a consequence of fencing, potentially this could relieve predation pressure on the larger herbivores that are its preferred prey species (Bradby *et al.* 2014). In theory, this would lead to greater abundances and densities of larger herbivores that would then suppress plants through grazing pressure (Ford & Goheen 2015), increasing competition between herbivores. However, Ford and Goheen (2015) emphasised the need for hypotheses about trophic cascades

to be more rigorously and objectively tested to resolve some of the debate about the ecological roles of large carnivores.

Changes in movement patterns of larger mobile herbivores, particularly when combined with control of apex predators, has the potential to affect the local abundance of large herbivores and alter competitive relationships with smaller herbivore species.

2.5.1 YFRW diet and habitat

YFRW have a highly variable, opportunistic, herbivorous (browsing and grazing) diet (Copley & Robinson 1983; Lapidge 2000; Arman & Prideaux 2015). Forbs and grasses are generally the main component of YFRW's diet, but browse (shrubs and trees) becomes very important during dry seasons and drought (Dawson & Ellis 1979; Copley & Robinson 1983; Lapidge 2000; Sharp & McCallum 2010). Browse is high in nutrients and fibre, and young leaves are often highly digestible, becoming a good food source when others are unavailable (Dawson & Ellis 1994). In Queensland's Grey Range, dry *Acacia* foliage is a critical food resource for YFRW (Allen 2001, cited in Irlbeck & Hume 2003, p. 123) and they readily eat mulga in captivity at Charleville (Gordon *et al.* 1993). Gordon *et al.* (1993) reported that *P. x. celeris* heavily grazed small tufted grasses *Sporobolus caroli*, spindly forbs *Sida filiformis*, rock sedges *Scleria sphacelata*, and mulga *Acacia aneura* and bendee *A. catenulata* leaf fall. They suggested YFRW depended on browse such as mulga during droughts and summer months, but could survive in places with access to permanent water if browse was not available.

Their patchy distribution is largely due to reliance on complex rocky habitat for refuge in arid and semi-arid climatic zones (Norton *et al.* 2011). Remote, rugged hilly areas with cliffs, outcrops, caves, overhangs, jumbled boulders and vegetation provide protection from predators, shelter from extreme conditions, nursery sites for juveniles and temporary water sources (Wilson *et al.* 1976; Copley 1983; Triggs 1996; Blumstein & Daniel 2003). Optimal habitat seems to

have one or more of those rock formations, be within 2 km of water, have large boulders with smooth rock surfaces and provide shelter from direct sunshine (Lim & Giles 1987).

2.5.2 YFRW competitors

YFRW experience interference and exploitative competition (Dawson & Ellis 1994) with sympatric herbivores for food, water and shelter (Lim *et al.* 1992; Sharp & McCallum 2015).

While exploitative competition involves individuals competing for access to restricted common resources, in interference competition, individuals are harmed by others during the process of accessing resources, even when resources are not in short supply (Krebs 2009). Australia-wide, feral goats (*Capra hircus*) are considered the most significant competitor for food, water and shelter spots, though rabbits, euros, domestic livestock and other macropod species can increase competition pressure (Threatened Species Scientific Committee 2008; Sharp & McCallum 2015; Threatened Species Scientific Committee 2016).

Feral goats were considered a cause of YFRW population decline in NSW (Sharp 2002a) and, in some areas, are considered a greater threat to YFRW populations than predation as goat control combined with fox control helped boost numbers in some areas (Copley *et al.* 2016). Goats seriously threaten YFRW due to high levels of overlap in dietary and habitat requirements, and more so during dry seasons when dietary overlap of browse increases considerably (Dawson & Ellis 1979; Threatened Species Scientific Committee 2016). Goats' large aggregations, larger body size and ability to feed while standing on hind legs means they can deplete resources faster and reach higher than YFRW when lower browse stories are removed (Dawson & Ellis 1979; Lim *et al.* 1992). High densities of goats foraging on escarpment country and increasing grazing halos around colonies adversely affects YFRW juvenile survival (Sharp & McCallum 2015). Goats reproduce rapidly, are highly mobile and migrate long distances in herds (Lim *et al.* 1992). In some areas, goat control may have no effect because goats can quickly reinvade from nearby properties (Sharp *et al.* 1999). In semi-arid habitats, they prefer mountainous rocky areas to

shelter from temperature extremes (Mahood 1983). Goats have physically evicted YFRW from higher shelters, leaving them smaller or less accessible caves and marginal habitat with limited cover which carries more predation risk (Copley 1983; Lim *et al.* 1992). In Queensland's mulga lands, goats are seen by some graziers as pests but by others as a resource for overseas and domestic markets (Thompson *et al.* 2002; Threatened Species Scientific Committee 2016). Other species, such as rabbits, primarily interact with YFRW through food competition (Dawson & Ellis 1979) although two female YFRW in a captive colony were attacked and severely scratched by an adult male wild rabbit (Poole *et al.* 1985). Generally inhabiting plains and footslopes, rather than escarpments, rabbits have also reportedly intruded into YFRW habitat, (Dawson & Ellis 1979). In such instances, they may be effective competitors; their diets overlap considerably in all seasons and, like YFRW, browse intake may be significant in dry seasons (Dawson & Ellis 1979). Rabbits also decrease browse availability by eating seedlings and ringbarking plants (Lim *et al.* 1992) and can contribute to grazing halos around YFRW colonies, reducing YFRW fitness and juvenile survival (Sharp & McCallum 2015).

Macropods contribute to grazing pressure. In Queensland, red and grey kangaroos may occur on shrubby tablelands frequented by YFRW (Silcock & Fensham 2014); however, YFRW's main sympatric macropods are the common wallaroo (*Macropus robustus*, also called the euro) (Melzer *et al.* 2009). Primarily grass-eaters, euros mostly compete with the YFRW for water and shelter, especially when predator control or resource abundance increases their densities (Copley 1983; Lapidge & Henshall 2001). Large males aggressively gain and defend drinking spaces and shelters such as rock overhangs and caves (Lim *et al.* 1992). Euros dig creek bed scrapes when water is scarce and YFRW often utilise these, meaning euros also benefit YFRW (Hornsby & Corlett 2004).

Domestic livestock can threaten YFRW through habitat change and resource depletion (Threatened Species Scientific Committee 2016). They are considered unlikely to be major

competitors, except at high stocking rates, as they rarely frequent the higher-elevation and rockier parts of YFRW habitat (Lim *et al.* 1992; Silcock & Fensham 2014).

Unintentional entrapment of larger mobile herbivores, particularly feral goats, within a cluster fence could potentially intensify competitive relationships with YFRW, particularly if dingo control reduces predation pressure on goats.

2.6 Species' activity and behaviour

Through the effects of fences on predator, prey and competitor population dynamics, mammal species' diel activity and behaviour may also be affected. Here, the diel cycle refers to the activity and behaviour patterns of organisms within a 24-hour period (Kronfeld-Schor & Dayan 2003). Predators may change their diel activity to increase their predation efficiency and reduce energy expenditure (Harmsen *et al.* 2011; Foster *et al.* 2013). However, the diel activity of prey species is influenced by their need to minimise predation risk, maximise foraging ability, and minimise energy expenditure by avoiding competition for critical resources (e.g. through niche partitioning) and avoiding times of peak thermoregulatory demands (Curtis & Rasmussen 2006; Hochman & Kotler 2006; Ross *et al.* 2013; Lone *et al.* 2017). These conflicting demands vary in their intensity and priority; for example, the crepuscular or nocturnal behaviour of some species may be particularly influenced by avoidance of unfavourable temperature conditions (Curtis & Rasmussen 2006; Diete *et al.* 2017) while in others it might be due to lower predation risk at those times (Ross *et al.* 2013; Tambling *et al.* 2015).

There are many examples of species that temporally alter their behaviour in response to a change in predator-prey relationships. Studies of ungulate (Ross *et al.* 2013; Tambling *et al.* 2015) and small mammal (Eccard *et al.* 2008; Sale & Arnould 2009) prey species all observed shifts in diel activity in areas where predators were absent compared to those where predators were present. Norwegian roe deer, faced with a nocturnal and a diurnal predator species in different habitat, were found to alter their habitat selection between night and day to the extent that seasonal

conditions allowed (Lone *et al.* 2017). Comparisons of activity patterns of predators and medium-sized prey species, particularly in central and south American regions, found moonlight conditions increased prey activity in some studies (Prugh & Golden 2014) and decreased prey activity in others, presumably due to different species' perceived risks of exposure to predation (Harmsen *et al.* 2011; Pratas-Santiago *et al.* 2017). Conversely, a study of wolves and moose in Scandinavia found no correlation between the diel activities of the two species, with Eriksen *et al.* (2011) suggesting wolf abundance and associated predation risks might not have been high enough to outweigh the benefits of higher moose activity at periods more favourable for foraging or avoiding human hunters. Likewise, Swinnen *et al.* (2015) reported that reintroduced beavers maintained their crepuscular and nocturnal activity patterns despite the absence of predators in the new habitat; they suggested this was due to beavers' diel activity patterns developing under past selection pressures from human hunting. Those species which have the ability to alter their diel activity and/or behaviour in response to a change in predator-prey relationships might have a better chance of coping with the effects of fences.

It is suggested that predation is a bigger influence on temporal behaviour than competition (Curtis & Rasmussen 2006) and that competitors generally segregate by food or habitat use to reduce competition, rather than using temporal partitioning (Foster *et al.* 2013; Ross *et al.* 2013). However, some studies report that mesopredators may change their diel activity away from times when apex predators are most active, presumably to avoid competitive interference (Harrington *et al.* 2009; Hayward & Slotow 2009; Brook *et al.* 2012; Foster *et al.* 2013). Harrington *et al.* (2009), upon observing diel shifts in minks apparently in response to otters, suggested the mink might perceive the potentially lethal consequences of interspecific interference interactions to carry a risk similar to predation. There appears to be even less support for diel activity changes in response to herbivorous competitors with only one study (Ross *et al.* 2013) reporting low overlap in diel activity cycles of several deer species, with the same diet, which was not thought to be due to predation. In this case, the two diurnal muntjac species, the nocturnal greater mouse

deer species and the crepuscular lesser mouse deer species are all frugivorous and their activity patterns do not appear to be affected by the presence of clouded leopards. Instead, their activity patterns are likely due in part to the smaller mouse deer species avoiding contest competition with the larger muntjac species (Ross *et al.* 2013). While there is less support for species changing their diel activity in response to competition threats compared to changes in predation threats, it is possible the activity of some species could change in response to an increase or decrease in competition due to the presence of a cluster fence (through trophic imbalances, or reduced immigration or emigration of competitors).

2.6.1 YFRW activity and behaviour

Generally, YFRW are said to be nocturnal, though Hayward *et al.* (2011) found that individuals at a South Australian colony were crepuscular and similarly active during day and night. They suggested YFRW might behave nocturnally if they have to travel further from refuges to forage and it was safer to do so at night. Typically, YFRW sun themselves on rocks at dawn (and in the evening during winter), shelter during the hottest parts of the day, increase activity in the afternoon, and begin foraging independently or in groups in nearby areas by late afternoon/early evening before travelling further from their rocky outcrops to forage and drink (Sharman & Maynes 1983; Lim *et al.* 1992; Lapidge 2001; Blumstein & Daniel 2003). Dusk is reportedly a period of peak activity (Blumstein *et al.* 2001). Daylight behaviours mostly involve resting and grooming at refuge sites though other behaviours occur, including searching for mates (Sharp 2009).

YFRW do not move far from refuges, usually return to the same resting sites after foraging each night and do not visit other colonies during the day or night (Sharp 2009). In Queensland, Sharp (2002b) found YFRW travelled up to 1.5 km to forage and drink and had a mean home range size of 23.5 hectares while some South Australian colonies were reported to travel up to 2 km to waterholes or artificial water points especially during drier seasons or droughts despite

considerable predation risk (Lim 1987, cited in Sharp 2011). YFRW conserve water by sheltering during the day in caves where it is cooler and more humid and appear to get most water from forage or dew (Sharman & Maynes 1983; Lim *et al.* 1992).

These environmental factors likely influence YFRW diel activity and behaviour but it is possible that dingo and goat activity might also influence YFRW activity, which suggests YFRW activity and/or behaviour might become different on either side of the fence in response to changes in dingo or goat activity and abundance.

2.7 Overview of current project

There is much debate about the use of fences for livestock and conservation purposes regarding their positive or negative effects on population dynamics, interactions and activity of wildlife enclosed within the fences. In 2015, three Quilpie properties – Ray Station, Canaway Downs and Bunginderry Station – began constructing a 330 km cluster fence that would span 242,811 hectares, cost \$1.2 million in materials and enclose their properties, enabling better dingo control and theoretically increasing the livestock carrying capacity of each property (Crothers 2015).

The final part of the fence was completed in May 2017. In early 2017, YFRW were sighted near the part of the fence that was constructed in 2015 on two properties inside the fence and on another property directly outside the cluster fence. These sightings raise some general questions about the impacts of the cluster fence and pest control on the YFRW sub-populations: whether these fences and associated dingo control could act as a tool for conserving the YFRW subspecies by reducing the predation risk to YFRW, or whether they might increase harmful competition with feral goats.

Since changes in predator-prey relationships can potentially affect species' diel activity patterns, with research suggesting some prey species will resort to more nocturnal behaviour to avoid predator activity patterns (Tambling *et al.* 2015) or because they feel safer from predators when

active in darker conditions (Harmsen *et al.* 2011), this led to my research question: What is the effect of a Quilpie cluster fence on YFRW temporal activity and/or behaviour?

Key sub-questions addressed in this experiment were:

- What times are YFRW most active within each treatment?
- Is there a substantial difference in YFRW temporal activity between treatments?
- How does YFRW diel behaviour vary within each treatment?
- Is there a difference in the proportions of behaviour displayed between treatments?
- Could predator or competitor activity explain any observed activity or behavioural differences?
- Is there a correlation between YFRW temporal activity or behaviour and dingo temporal activity and does this differ between treatments?
- Is there a correlation between YFRW temporal activity or behaviour and goat temporal activity and does this differ between treatments?

In this context, activity of any animal refers to the number of records of that species/camera/day and YFRW behaviour refers to the way the species acts, as observed in each photo, with four main behaviours of resting, foraging, hopping and other. The aims of this project were to measure temporal fluctuations in YFRW activity and behaviour at sites inside and outside the cluster fence, and explore some of the potential causes (e.g. predator and competitor activity) for any observed differences between treatments. As construction of the fence only began three years ago and was finished in 2017, it was hypothesised that there would be no differences in YFRW activity between treatments. It was additionally hypothesised that dingoes and goats would influence YFRW activity and behaviour. Diel activity and behaviour patterns of YFRW, dingoes and goats were also explored. Over time, it might be expected that YFRW activity would become more crepuscular inside the fence than outside the fence, if the fence and accompanying pest control reduces dingo and feral goat populations. This project contributes to knowledge of YFRW and goat activity in Queensland and provides baseline data for comparison

in future research on the indirect effects of fences on rock-wallaby population dynamics and behaviour.

Chapter 3: Methods

3.1 Study area

The study was undertaken in the Mulga Lands Bioregion of western Queensland (Thackway & Cresswell 1995) on mesas (flat-topped hills) located between 26°15'18.7"S, 143°59'31.1"E (northern and western-most points) and 26°00'21.0"S, 143°54'02.9"E (southern and eastern-most points). These rocky hills are situated on four livestock properties in Quilpie shire where one of Queensland's many cluster fences is located (Figure 3). Two of the properties included in the study are inside the 242,811 hectare cluster fence (Crothers 2015) and the other two border the eastern side of the fence. Quilpie and surrounding areas are located at the northern end of the Grey Range, which is composed of Tertiary sandstone (Silcock & Fensham 2014) and contains boulder opal, for which mining has taken place in some areas (Jenkins 2001), including on three of the properties in this study.

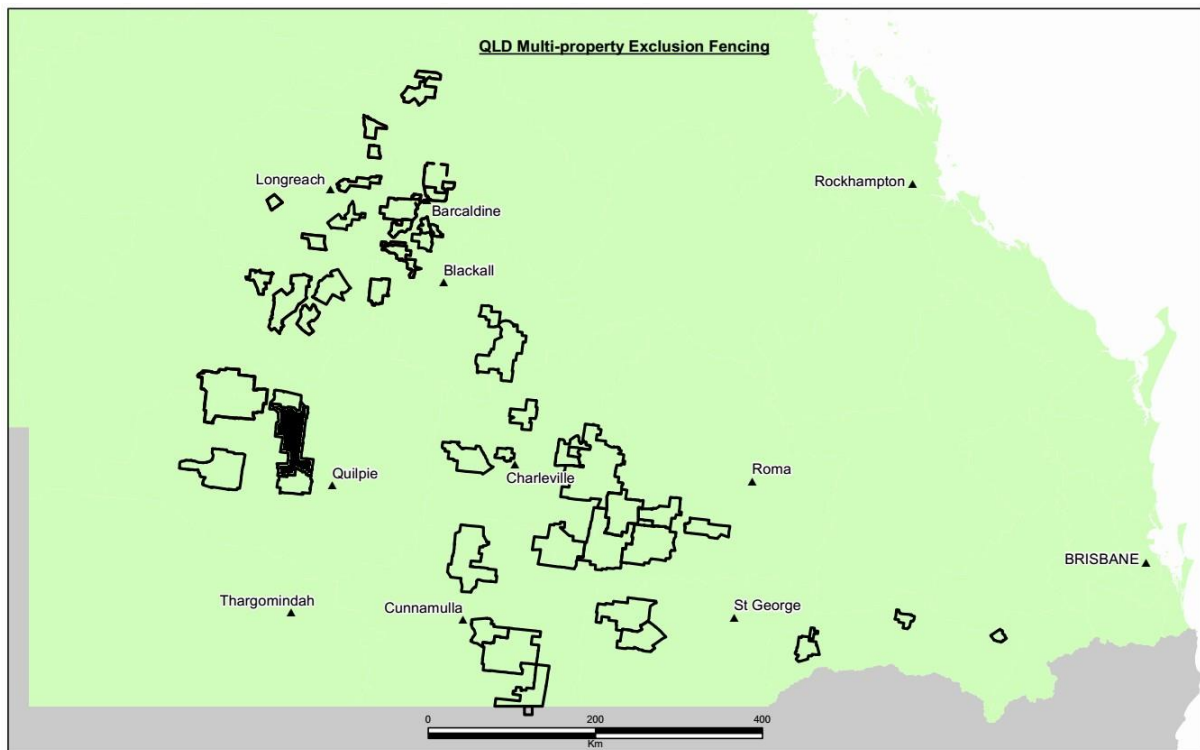


Figure 3. Queensland cluster fences (Queensland Government 2017) with YFRW project cluster fence shaded black.

The area's semi-arid climate (Silcock & Fensham 2014) is characterised by cool, dry winters and hot, wet summers (Sharp 2011). Quilpie Airport (26.61°S, 144.26°E), the weather station closest to the study area, has mean daily minimum and maximum temperatures of 6.3°C (July) and 37.5°C (January) respectively and mean annual rainfall of 377.1 mm, with the highest rainfall occurring between November and February (Bureau of Meteorology 2018). Minimum and maximum temperature (Figure 4) and rainfall (Figure 5) for the study site during the study period were obtained from SILO (2018) for coordinates 26°12'00.0"S, 143°54'00.0"E. Between 26 April 2017 and 4 January 2018, the minimum temperature reached 2°C (8 June) and maximum temperature reached 44°C (25 December). Total rainfall was 127.5 mm with rainfall events more than 5 mm occurring in May, October and December 2017.

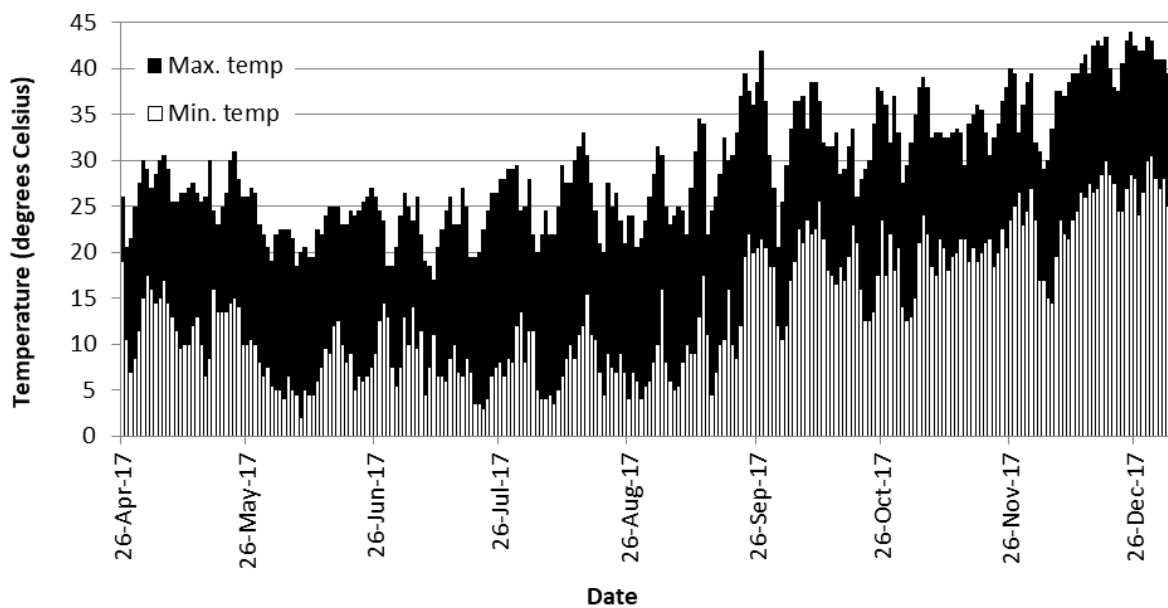


Figure 4. Minimum and maximum temperatures at YFRW project site between 26 April 2017 and 4 January 2018.

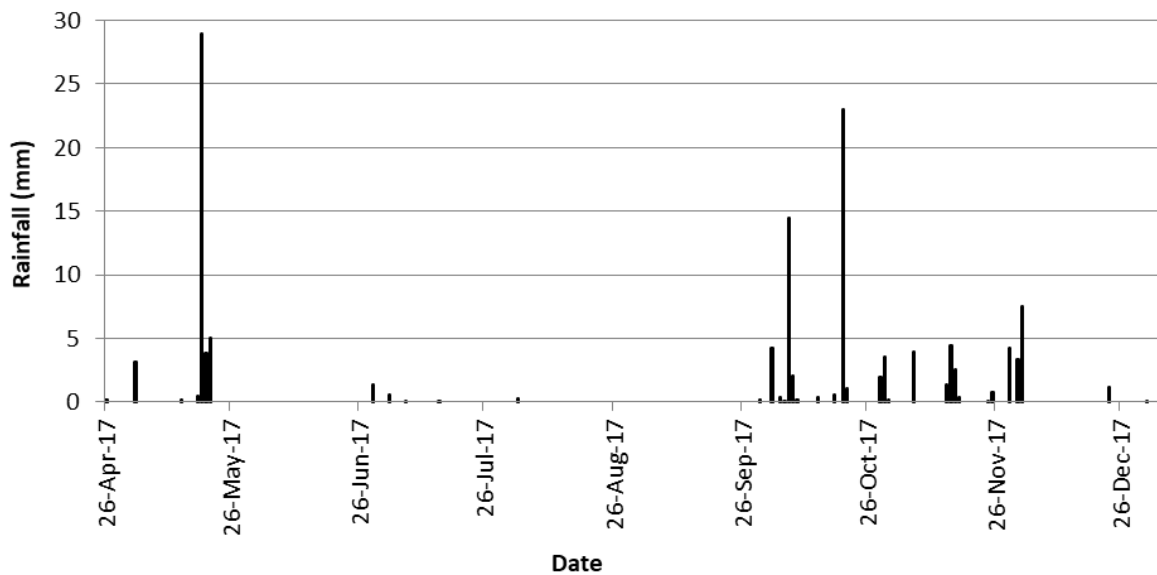


Figure 5. Rainfall at YFRW project site between 26 April 2017 and 4 January 2018.

3.2 Site selection

Initial scouting in early 2017 identified hills on properties inside and outside the cluster fence that appeared to be suitable YFRW habitat due to hill height, caves, boulders, broken rocks, vegetation and the presence of YFRW faecal pellets. In April 2017, cameras were placed on isolated mesas or connected plateaus where YFRW or their droppings were seen. These hills were located on Canaway Downs and Ray Station inside the cluster fence and on Alaric and Fifteen Mile stations outside the cluster fence (Figure 6). The two sites on Ray Station were on different parts of the same plateau with their closest cameras being 700 metres apart so it is possible these sites are not independent as YFRW have been observed to move up to 1.5 km to forage and drink (Sharp 2002b).

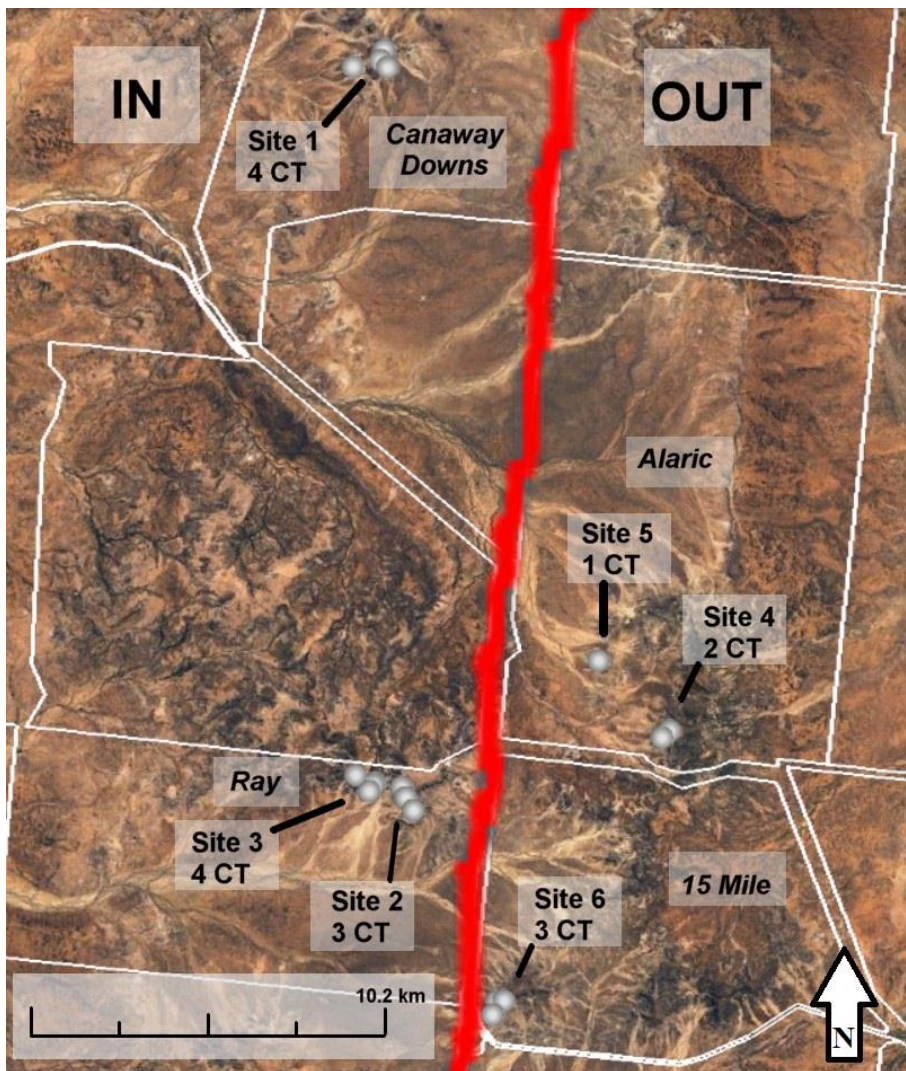


Figure 6. Map of sites with number of camera traps (CT) at each, inside and outside the cluster fence (thick red line), Quilpie, Queensland.

3.3 Camera placement

Cameras were intentionally placed at points intended to maximise detection of YFRW, the target species. These were areas that appeared to have a high degree of YFRW activity (YFRW sightings, YFRW droppings, animal pads) and included locations at the top of cliff faces (7 cameras inside and 3 outside) and at the bottom of cliff faces (4 inside and 3 outside). Cameras were tied to trees at ~50 cm above the ground, facing along an animal pad or toward an area where YFRW droppings were found. Fourteen ReconyxTM HC600 HyperfireTM infrared camera traps were placed across five sites in April 2017 and set to RapidFireTM (up to 2 images per second) with no delay between triggers. Three ReconyxTM XR6 UltrafireTM infrared cameras

were placed at a sixth site in August 2017, set to the minimum interval between images (1 second) with no delay between triggers. Camera locations and walking and driving tracks used were recorded to a handheld GPS and an iPad equipped with GIS software. Camera traps were chosen over other censusing techniques because they are durable, remotely-triggered, record time and date, can take multiple photos per trigger, and record behavioural data, making them an appropriate method for the remote location of the study site and type of data (temporal animal activity and behaviour) to be collected. Many other studies of animal activity have used camera traps (e.g. Harmsen *et al.* 2011; Brook *et al.* 2012; Foster *et al.* 2013; Ross *et al.* 2013; Swinnen *et al.* 2015; Tambling *et al.* 2015; Zapata-Ríos & Branch 2016; Pratas-Santiago *et al.* 2017).

3.4 Experimental design

The experimental design regarded the cluster fence as the treatment with the sites outside the cluster fence being the control group and the sites inside the cluster fence being the experimental group (Figure 7). While it would have been ideal to have replicated the study across multiple clusters, this was not financially or temporally viable. The aim of the experiment was to compare YFRW temporal activity and behaviour between treatments. Activity and behaviour at sites within each treatment were also compared in order to explore if within-treatment variability was greater or lesser than between-treatment variability. The research question was: what is the effect of a Quilpie cluster fence on YFRW temporal activity and/or behaviour?

The first hypothesis tested in this study was that there would be no difference in YFRW activity between treatments. The second hypothesis was that dingo and goat activity would influence YFRW activity, with YFRW being less active when dingoes or goats were more active. The third hypothesis was that dingo and goat activity would influence YFRW behaviour, with more ‘flighty’ hopping behaviour and less foraging behaviour observed during times when dingoes or goats were more active. Patterns in diel activity of YFRW, dingoes and goats (and diel behaviour of YFRW) were also explored.

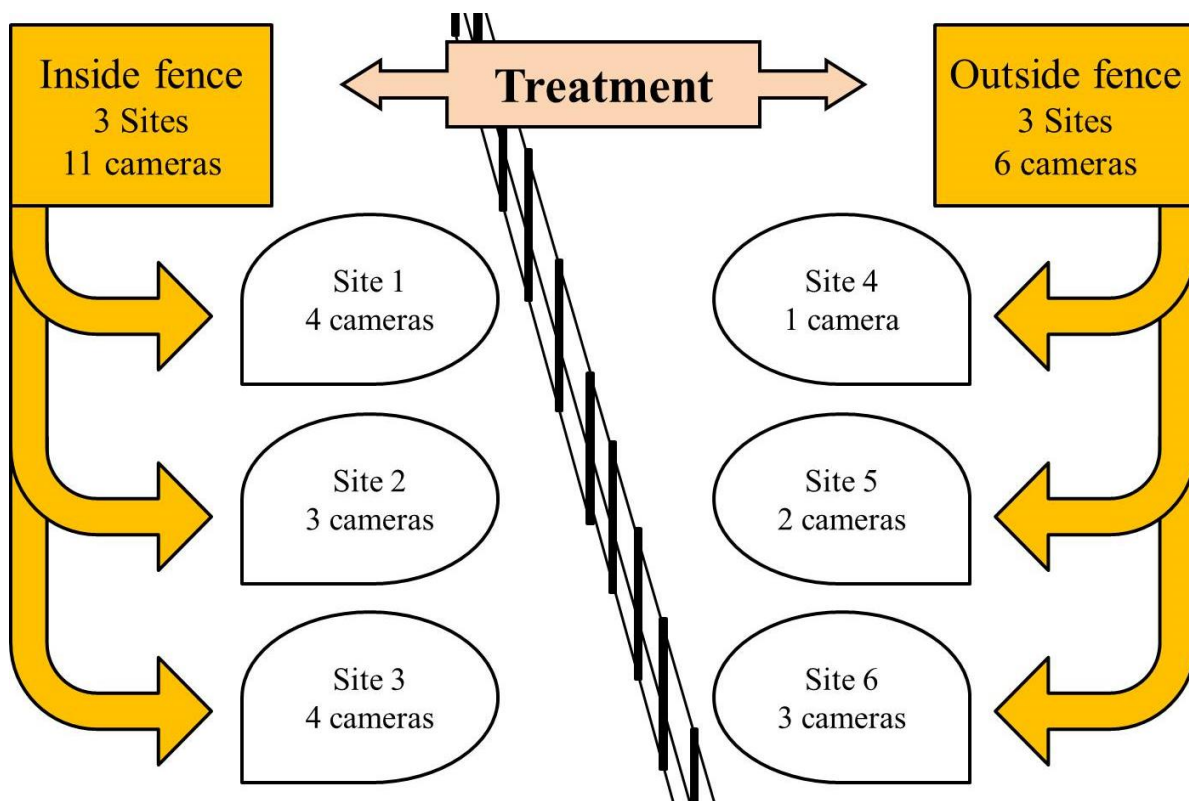


Figure 7. Conceptual diagram of my experimental design showing treatment, sites and cameras.

3.5 Data collection and entry

Data was collected between 26 April 2017 and 4 January 2018. Site visits were made in August and September 2017 and January 2018, when cameras were checked and batteries and SD cards changed. Due to time constraints in August, only sites 2 and 3 were visited in addition to the placing of three cameras on Site 6. Over the study period, data gaps occurred for five cameras when they were moved out of alignment or their batteries died.

Following data collection, photos were downloaded and renamed to distinguish camera number, trip number and photo number. Photos taken of researchers during set-up or data collection were not included in the dataset. Photo metadata (photo names, dates and times) were copied into an Excel spreadsheet using Command Prompt. Columns were added for camera-days, camera name, site name, geographical coordinates, animal species photographed, and extra columns about YFRW demographics and behaviour. The number of each animal species visible, in part or whole, in each photo was recorded in the appropriate column of the spreadsheet. Photos that

were clear but contained no animals (false triggers) were recorded as 'bush' while 'blanks' were defined as photos that were not clear due to rain or vegetation obstructing the lens or the camera facing the wrong direction.

Mutually exclusive YFRW behavioural categories were developed, guided by Blumstein *et al.* (2001). Resting was defined as lying down or sitting on their rump with their feet out in front of them (Figure 8). Standing meant YFRW were upright with their back quite straight, while crouching meant YFRW were less straight and either crouched on their back legs or on all fours. YFRW were recorded standing and looking or crouching and looking when their head was elevated and eyes fixated. They were recorded as foraging when their nose was to the ground or they were crouched holding food items in their paws. Moving was distinguished from hopping by slower (less blurred) pentapedal movement. Additional behaviours recorded were grooming (licking or scratching its own body), affiliative social interactions (noses touching, allogrooming, juvenile getting into the pouch), aggressive social interactions (fighting, paws up, grabbing one another) and other social interactions (attempted mating or interactions unclear as to whether they were affiliative or aggressive). Behaviours hard to categorise were recorded as 'other' but when YFRW were not visible enough in the picture to define their behaviour, this behaviour was recorded as 'unknown'.



Figure 8. Resting female YFRW with pouch young photographed by camera RW005.

3.6 Data treatment

Two cameras failed due to batteries dying, including camera RW018 which failed twice after taking thousands of false triggers. Another three cameras failed because they were accidentally moved (e.g. by goats) to the extent that they were pointing in very different directions from their original field of view. Photos taken by two of those cameras after being moved were recorded as blanks until readjustment on the next visit because their ability to record images was compromised, but photos from the third camera (RW015) were not recorded as blanks initially. However, images taken by any cameras after they were substantially moved were not included in the analysis and the camera-days for those cameras were recalculated to exclude the days they were not operating properly, as other studies have done (e.g. Thomas 2014; Townsend *et al.* 2014).

A third issue, particularly problematic for analysis, was the number of photos taken per trigger were not consistent, with cameras set to either take 3 photos per trigger or 5 photos per trigger, and one was set to take 10 photos per trigger. Subsequent visits to the sites did not manage to correct this, with some photos per trigger being increased and others being decreased. While

some studies used the number of trigger events in analysis of animal activity (e.g. Story *et al.* 2014), the lack of consistency in number of photos per trigger excluded this method or only counting the first three photos taken by each trigger, as active animals may trigger a camera twice under a lower setting but only once under a higher setting. One suitable way of overcoming this issue would be to convert raw activity counts into individual ‘events’. However, while this would have been ideal, only raw activity counts (and standardised activity indices) were used in this study. Previous studies have found events and raw activity indices to be highly correlated, potentially negating the need to correct for variable trigger rates or conversion to events (Allen 2011).

As sunrise and sunset were found to vary between 5.34 am to 7.13 am and 5.40 pm to 7.22 pm over the year (Geoscience Australia 2018), 6 am and 6 pm were used as the sunrise and sunset times overall to simplify analysis. Dawn and dusk were defined as two hours before and three hours after sunrise and sunset, so 4 am to 9 am and 4 pm to 9 pm respectively. Four behaviour columns were added to simplify the data into ecologically-meaningful groups and increase sample sizes of each behaviour observed. Resting, crouching, standing and grooming were placed in the ‘Resting’ column, foraging and moving in the ‘Foraging’ column, hopping in the ‘Hopping’ column, and interactions, other and unknown behaviour in the ‘Other’ column.

Prior to analysis, data for YFRW and goat activity trends, at each camera, site and treatment, were standardised by dividing the number of individuals photographed (number of records) by the number of available cameras for day, week, and month, at each camera, site or treatment.

Diel activity and behaviour (time period and hour) data, for each camera, site and treatment, were standardised by dividing the number of individuals photographed (number of records) by the total camera-days at that camera, site or treatment, using the general activity index paradigm described by (Engeman 2005) of photos/camera/day.

3.7 Data analysis

Initial data analysis used pivot tables to generate sample sizes of total photos, photos with any animal, and photos with each animal of potential significance (YFRW, dingo, goat, rabbit, euro, other macropodids) to see which species had large enough sample sizes to be considered in analysis.

Total YFRW sightings by each camera were graphed by day and four individual points of unusually high YFRW daily activity were identified from cameras 5, 14, 15 and 14 on 23 June, 2 July, 1 August and 9 December 2017 respectively (Figure 9). Each of those points contained an event (the same or different individual/s sighted in sequential photographs with no more than 10 minutes between triggers) of more than 120 YFRW sightings/camera/day which accounted for most of that day's activity. The largest of these was on 2 July where two YFRW fought in front of Camera 14 for more than 10 minutes resulting in 289 photos containing 455 YFRW sightings between them (Figure 10). These four unusual events totalling 525 photos (containing 879 YFRW sightings between them) were removed prior to data analysis so they would not disproportionately influence outcomes and were not included in any of the results, including sample sizes, for the sake of consistency and simplicity.

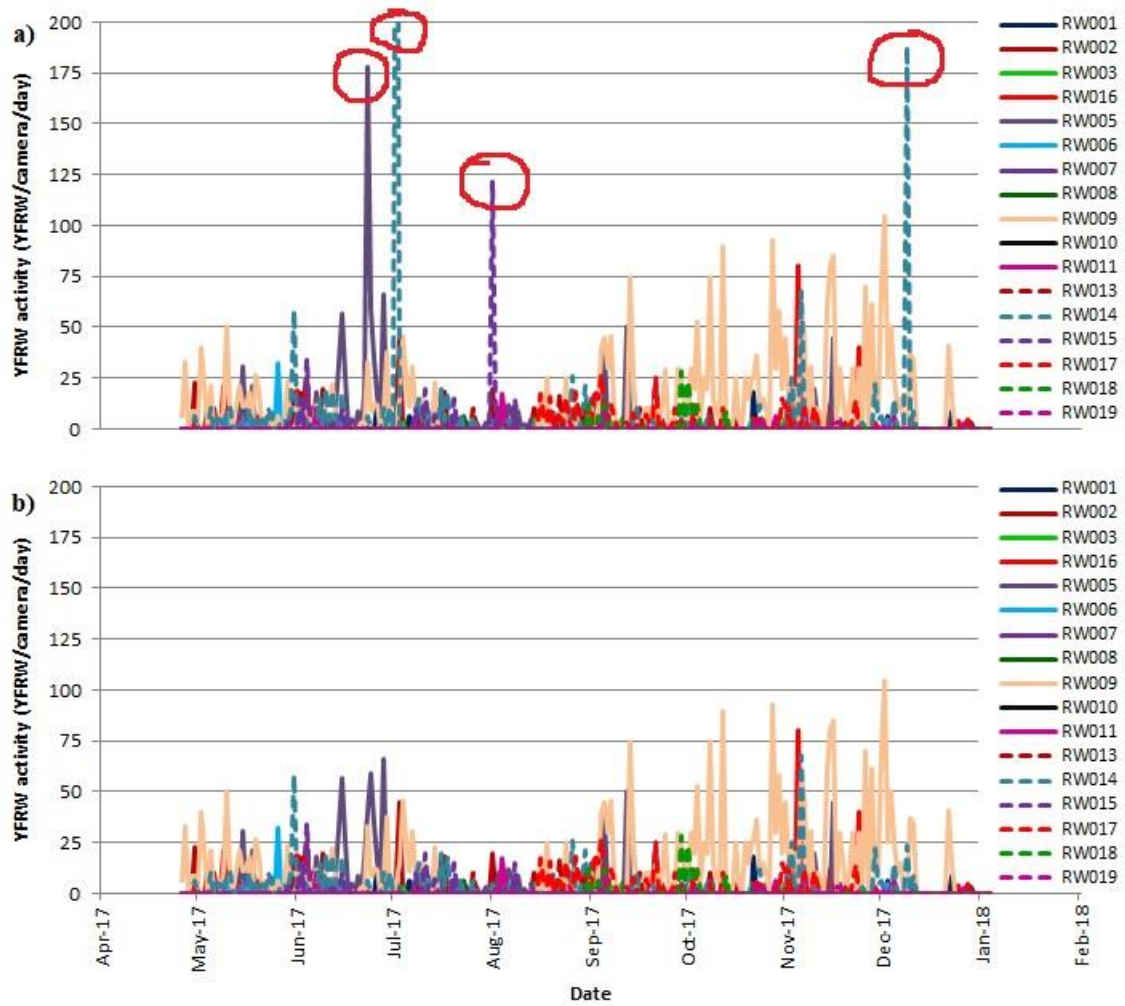


Figure 9. YFRW activity (YFRW sightings/camera/day) at each camera for each day of the study period (26 April 2017 to 4 January 2018). Four events of unusually high YFRW activity were identified (a) and removed (b).

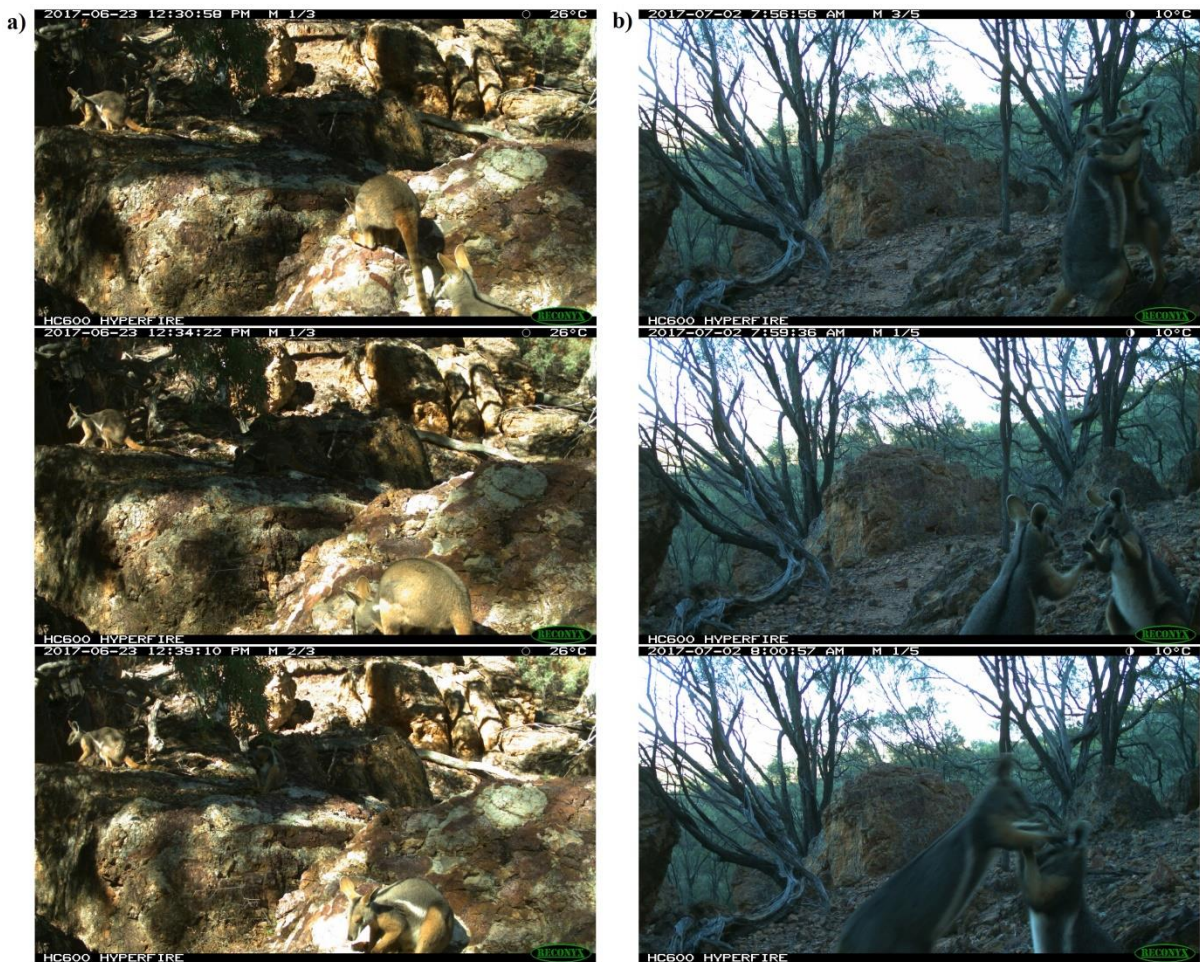


Figure 10. Events of unusually high YFRW activity at Camera 5 on 23 June 2017 with 69 photos containing 138 YFRW sightings (a) and Camera 14 on 2 July 2017 with 289 photos containing 455 YFRW sightings (b).

YFRW activity (YFRW photographed per camera) by day, week, month, time period and hour at each camera placement (top and bottom of cliffs) were compared first, to ensure it was not an influential factor and to justify pooling of cameras into sites and treatments. Then YFRW activity was compared between treatments and sites by the same temporal periods. Two-tailed t-tests assuming unequal variances were conducted to determine whether there were differences in mean YFRW activity between camera placements and between treatments on a daily, weekly or monthly basis (Appendix B). This was considered to be a reliable method for analysing the data based on recent advances in understanding non-normal and heterogeneous data (Shulman *et al.* 2016). Goat activity was compared in the same manner. GLMs, with Pearson's correlation

coefficients, were conducted between goat activity and YFRW activity and between goat diel activity and YFRW diel behaviour. Goat activity was the predictor variable in both instances.

Chapter 4: Results

4.1 Sample sizes

In total, seventeen camera traps were deployed between six sites and two treatments during a 253-day study period between 26 April 2017 and 4 January 2018 (Table 1).

Table 1. Timeline of camera deployment by month during the study period with total camera-days for each camera, site and treatment (dark cells indicate the months when the cameras were active).

	2017								CAMERA DAYS
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
IN									2597
Site 1									856
RW001									251
RW002									215
RW003									251
RW016									139
Site 2									759
RW005									253
RW006									253
RW007									253
Site 3									982
RW008									253
RW009									223
RW010									253
RW011									253
OUT									981
Site 4									502
RW013									251
RW014									251
Site 5									152
RW015									152
Site 6									327
RW017									141
RW018									45
RW019									141

During this study, the cameras took 75,607 images between them, with 29,435 of those photos containing images of animals (Table 2). Inside the fence, eleven cameras were deployed for a total of 2,597 camera-days while outside the fence, six cameras were deployed for a total of 981 camera-days. Dividing the number of animal photos by camera-days gives a mean of 10.184 animal photos per day inside the fence and 3.044 animal photos per day outside the fence, or

roughly three times as many animal photos per day inside the fence than outside the fence. There were many false triggers, particularly during windy periods, with 45,602 photos containing only bush. The remaining 570 photos were recorded as unknown or blank (photos so blurred or the camera's field of view so obstructed that it prevented seeing if there were any animals in the photo). Fifty photos containing the only event of goat activity at Camera 10 (76 goat sightings on 23 December 2017) were incorrectly recorded in 'goat kids' instead of in 'total goats'. These false negatives were not discovered until after analysis had been completed.

Table 2. Photos taken at each camera, site and treatment sorted by total number of photos taken, number of photos containing any animal, and number of photos containing YFRW or animals that potentially impact YFRW.

	Total photos	Any animal	YFRW	Dingo	Goat	Euro	Red Kangaroo	Rabbit
Total IN	29,326	26,449	4,717	49	18,282	1,875	223	213
Site 1	11,035	9,722	728		7,269	700	49	130
RW001	1,185	1,089	121		767	15		14
RW002	2,829	2,281	179		1,996	1		39
RW003	3,066	2,676	124		1,422	438	44	56
RW016	3,955	3,676	304		3,084	246	5	21
Site 2	10,682	9,973	797	24	8,707	331	10	
RW005	881	719	661	4	3	25		
RW006	9,021	8,667	96	13	8,410	95		
RW007	780	587	40	7	294	211	10	
Site 3	7,609	6,754	3,192	25	2,306	844	164	83
RW008	519	339	42	5		255	7	
RW009	6,221	5,726	3,078		2,106	373	58	83
RW010	387	264	3	20		91	79	
RW011	482	425	69		200	125	20	
Total OUT	46,281	2,986	1,459	103	1,020	240	5	
Site 4	1,472	961	759		21	135		
RW013	220	189	102		21	35		
RW014	1,252	772	657			100		
Site 5	282	244	132		106			
RW015	282	244	132		106			
Site 6	44,527	1,781	568	103	893	105	5	
RW017	1,074	687	414	36	139	57	5	
RW018	29,833	223	116	48		48		
RW019	13,620	871	38	19	754			
Total ALL	75,607	29,435	6,176	152	19,302	2,115	228	213

The three most-photographed animals were feral goats, YFRW and the euro (Table 3). More sightings of each of these species occurred inside the fence than outside and activity was still higher inside the fence than outside once the activity of each species had been standardised as records/camera/day. Inside the fence, cameras recorded an overall mean of 15.742 goats/camera/day, 2.005 YFRW/camera/day and 0.850 euros/camera/day. Outside the fence, cameras recorded an overall mean of 4.943 goats/camera/day, 1.593 YFRW/camera/day and 0.272 euros/camera/day. Dingoes were only photographed at Site 2 and Site 3 (an overall mean inside the fence of 0.025 dingoes/camera/day), and at Site 6 (an overall mean outside the fence of 0.129 dingoes/camera/day). More than 75% of dingo activity occurred during dawn within each treatment, however, there were an insufficient number photographed (152 photos containing 192 dingo sightings between them) to compare YFRW activity with dingo activity, as I had initially planned. No other predators (e.g. cats, foxes, eagles) were photographed by any camera during the study period. As there were plenty of goat sightings and goats are considered a major threat to YFRW elsewhere, both YFRW and goat activity trends, diel activity and diel behaviour were considered.

Table 3. Number of sightings of important animals at each site, each treatment and overall.

	IN				OUT				Total ALL
	Site 1	Site 2	Site 3	<i>TOTAL IN</i>	Site 4	Site 5	Site 6	<i>TOTAL OUT</i>	
YFRW	815	1060	3333	5208	815	147	601	1563	6771
Dingo	0	24	41	65	0	0	127	127	192
Goat	16695	21011	3177	40883	26	253	4570	4849	45732
Euro	866	353	989	2208	152	0	115	267	2475

4.2 YFRW activity trends

Camera placement

Before considering YFRW activity between sites and treatments, two-tailed t-tests were used to explore potential differences in daily and weekly YFRW activity between cameras placed at the

bottom of cliffs and cameras placed at the top of cliffs (Figure 11). No difference was found in mean YFRW activity between camera placements on a daily ($t=1.176$, $df\ 470$, $p = 0.240$) or weekly basis ($t = 0.812$, $df = 67$, $p = 0.420$). Mean daily activity at the bottom of cliffs was 2.085 ± 0.192 YFRW/camera/day (SE) and mean activity at the top of cliffs was 1.803 ± 0.144 YFRW/camera/day (SE). Mean weekly activity at the bottom of cliffs was 14.313 ± 1.932 YFRW/camera/day (SE) and mean activity at the top of cliffs was 12.358 ± 1.439 YFRW/camera/day (SE). So, for the rest of the results for YFRW activity, data from bottom- and top-placed cameras were pooled into their respective sites and treatments.

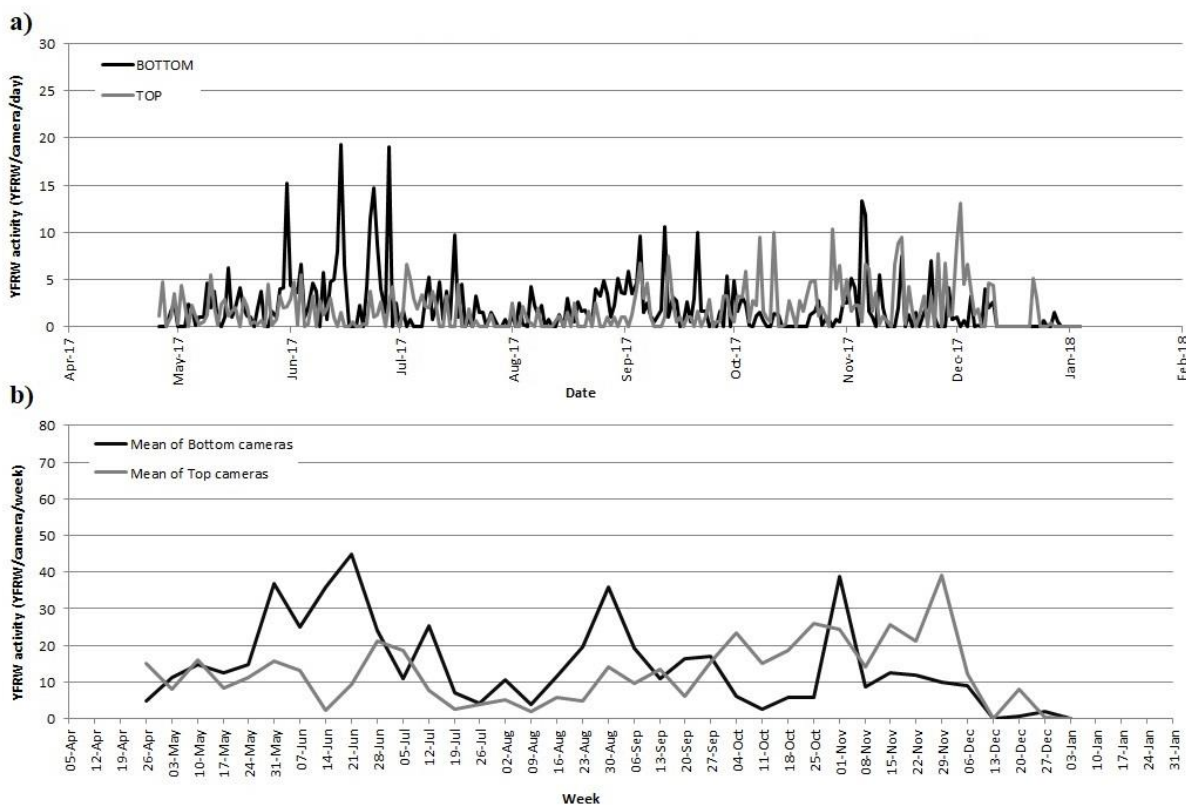


Figure 11. YFRW activity for each camera placement on a daily (a) and weekly basis (b).

Sites and treatments

By day

While there were peaks in YFRW activity at different sites throughout the year, there appeared to be no strong trends in activity for any sites (Figure 12). There was no difference in mean YFRW activity by day between treatments ($t=1.643$, $df = 476$, $p = 0.101$). Mean 'IN' activity

was 1.966 ± 0.141 YFRW/camera/day (SE) and mean 'OUT' activity was 1.590 ± 0.180 YFRW/camera/day (SE).

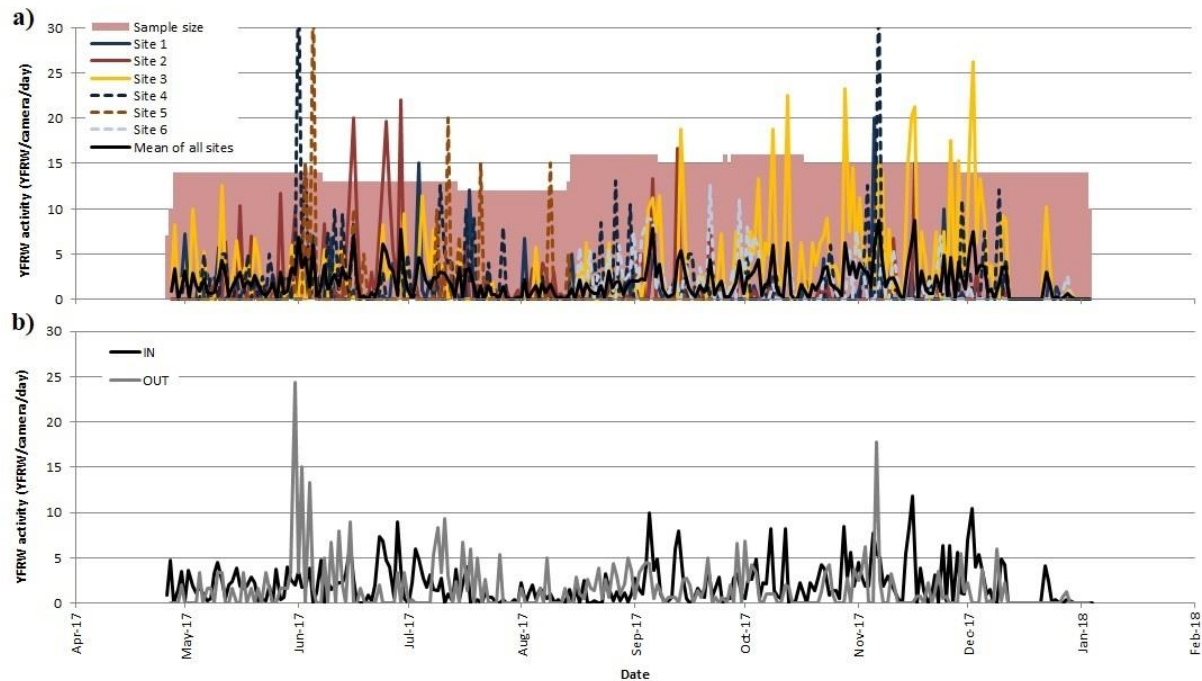


Figure 12. YFRW activity by day between 26 April 2017 and 4 January 2018: For each site (a) with three truncated values exceeding 30 YFRW/camera/day (36,35,34); and for the mean of sites within each treatment Inside and Outside the fence (b).

By week

Weekly trends in YFRW activity were no clearer, though activity at Site 3 increased substantially between the end of August and middle of December and Site 2 activity decreased slightly during the same period (Figure 13). No difference was found in the mean weekly activity of YFRW between sites inside and outside the fence ($t = 1.163$, $df = 66$, $p = 0.249$). The mean activity inside the fence was 13.481 ± 1.359 YFRW/camera/week (SE) and outside the fence was 10.832 ± 1.827 YFRW/camera/week (SE).

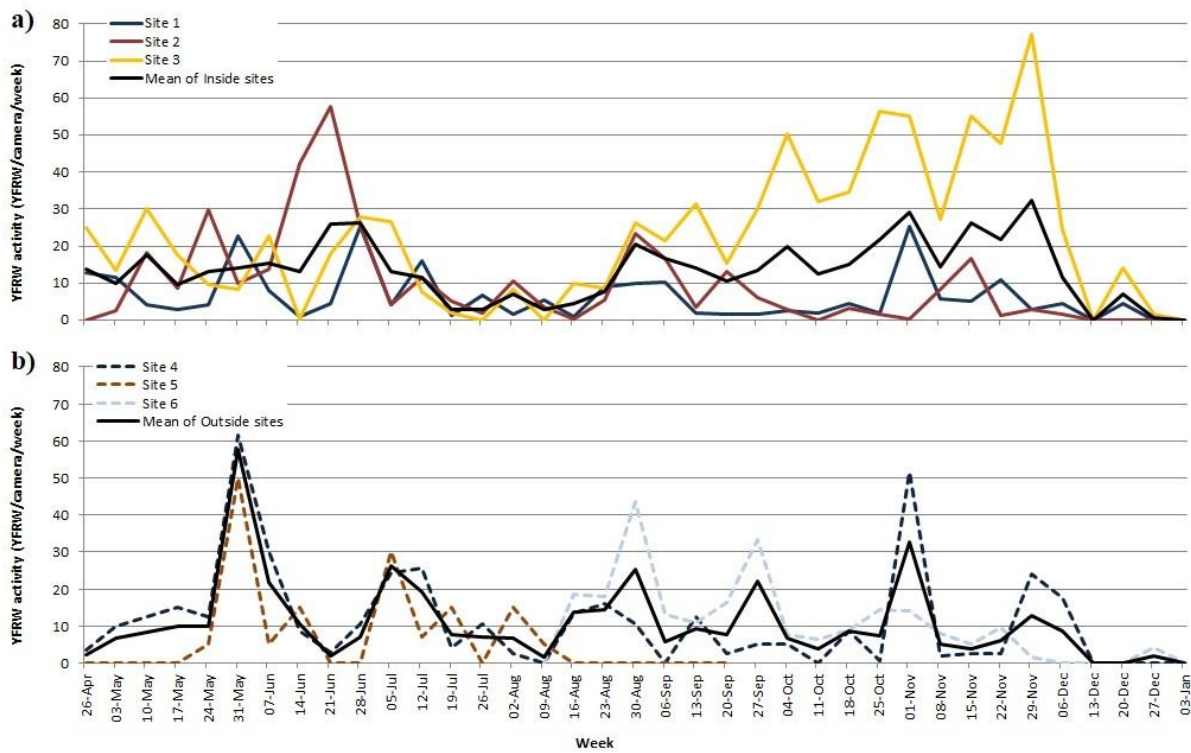


Figure 13. YFRW activity by week for the 37 weeks of the study period inside the fence (a) and outside the fence (b).

By month

By month, YFRW activity at Site 3 was higher in the last few months of the year, and Site 2 activity was lower during the same period, but there did not appear to be any persistent patterns in activity for sites or treatments (Figure 14). There was no difference in YFRW monthly activity between treatments ($t = 0.811$, $df = 17$, $p = 0.429$) with mean activity inside the fence being 50.005 ± 9.750 YFRW/camera/month (SE) and outside the fence being 39.782 ± 7.996

YFRW/camera/month (SE). After establishing that there was no real difference in YFRW activity trends between treatments by day, week or month, data from all days during the study period were pooled for analyses of YFRW diel activity and behaviour between treatments and sites.

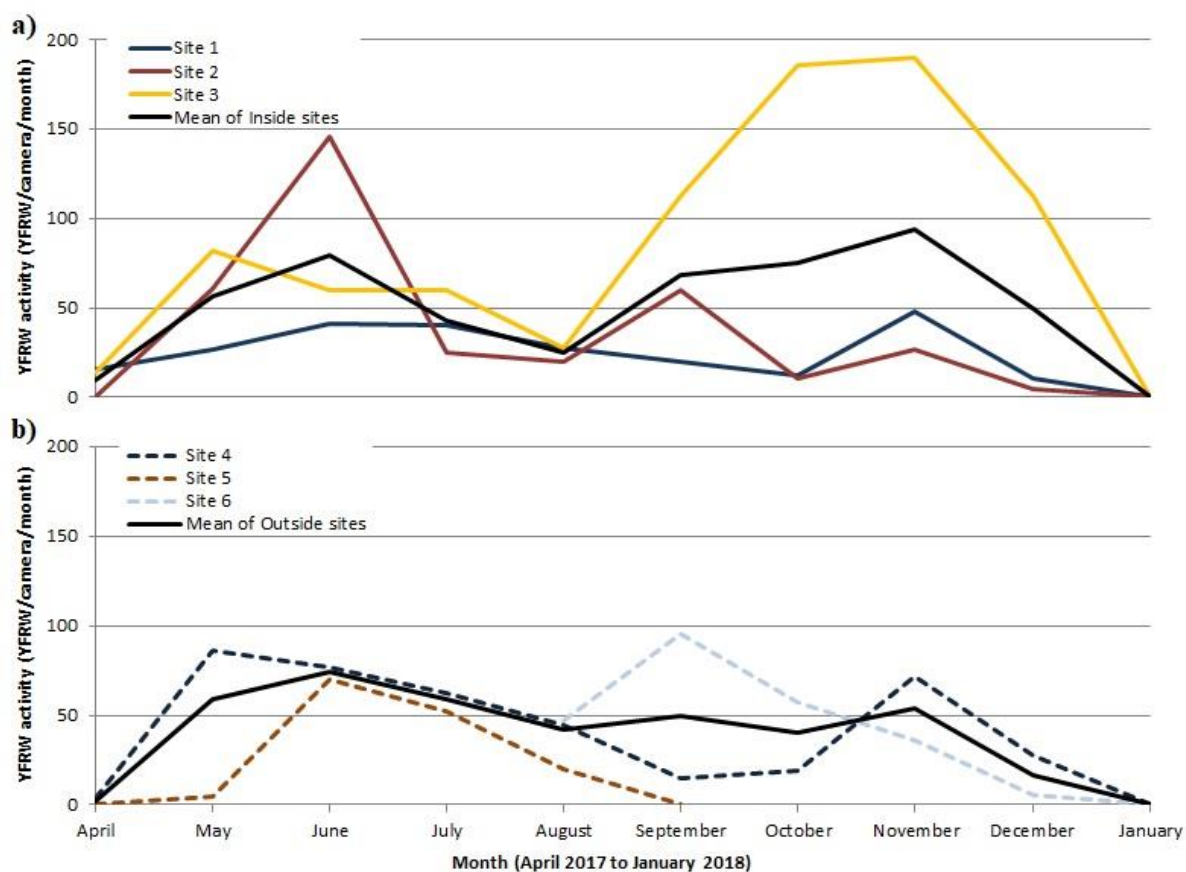


Figure 14. YFRW activity by month for the 10 months of the study period inside the fence (a) and outside the fence (b). April and January only contributed nine days between them due to placement and collection times.

4.3 YFRW diel activity for treatment and sites

YFRW diel activity by period of day

YFRW were most active at Site 3 (Figure 15a). There appeared to be some differences in the time periods YFRW were most active within each treatment and at each site (Figure 16). YFRW were more active overall inside the fence during darker periods. Nearly 50% of activity occurred during the night (9 pm to 4 am) and 25% around dusk (4 pm to 9 pm). Outside the fence, YFRW were similarly active during lighter and darker periods with 32% of activity occurring around dawn (4 am to 9 am) and 31% during night. More activity occurred during the day (9 am to 4 pm) than around dusk. At Sites 3 and 6, most activity occurred during the darker periods with more than 50% occurring during the night and more than 25% during dusk with some dawn activity. Only 2% of activity occurred during the day. By contrast, most activity at Sites 2 and 4

were recorded during lighter periods (67% and 83% for the sites respectively), with both sites having similar proportions of day activity (more than 30%). Site 4 had substantially more dawn activity and less dusk activity than Site 2. Proportions of diel activity at Sites 1 and 5 were more evenly divided with 58% and 54% respectively of site activity occurring during dusk and night. Site 5 had more day activity and less dawn activity than Site 1.

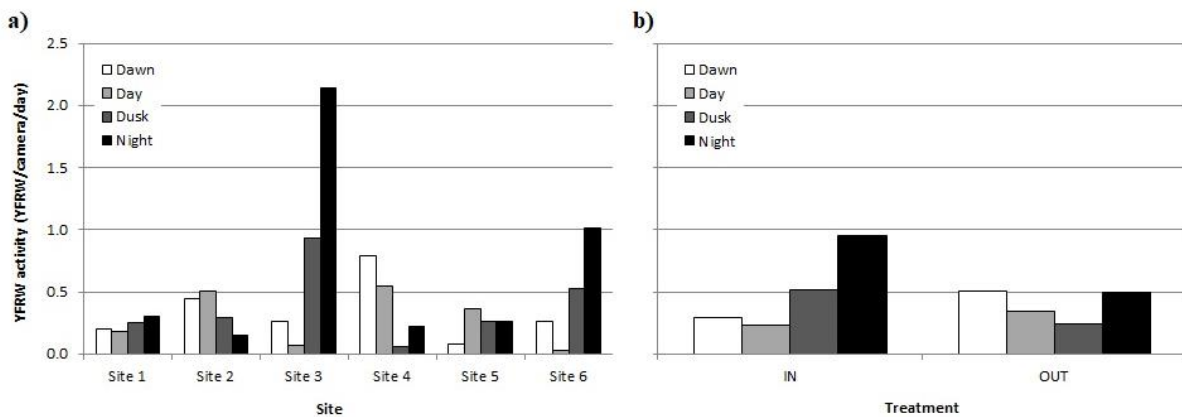


Figure 15. YFRW diel activity by time period for each site (a) and within each treatment (b). Sample sizes for sites were: Site 1 = 856 camera-days, Site 2 = 759 camera-days, Site 3 = 982 camera-days, Site 4 = 502 camera-days, Site 5 = 152 camera-days, Site 6 = 327 camera-days. Sample sizes for treatments were: IN = 2597 camera-days and OUT = 981 camera-days.

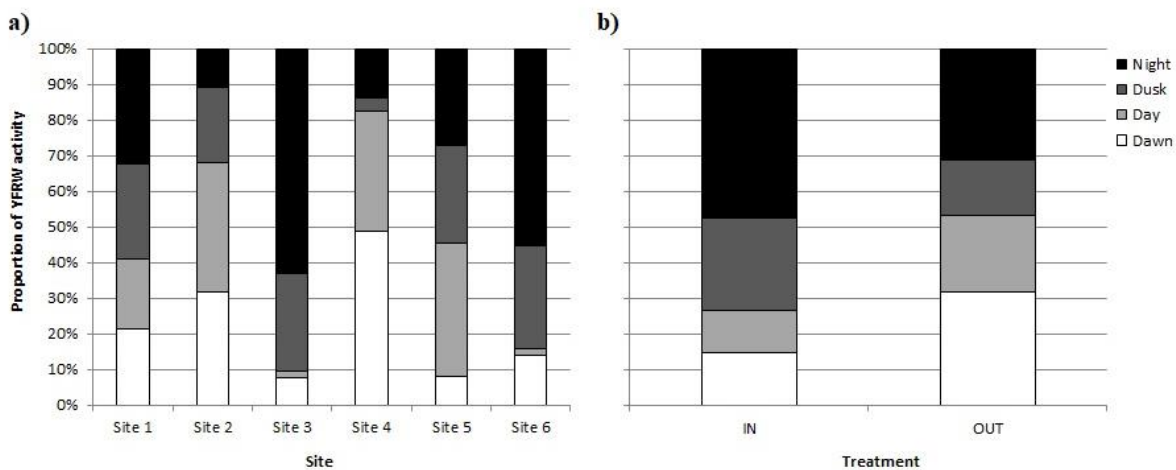


Figure 16. Proportions of YFRW diel activity by time period for each site (a) and within each treatment (b).

By hour

There were some differences in the hours YFRW were most active between treatments and appeared to be substantial differences in the hours YFRW were active between sites (Figure 17).

Inside the fence, more nocturnal activity was observed than outside the fence, where more crepuscular activity was observed. Outside the fence, YFRW were similarly active between 11 pm and 2 am and between 8 am and 12 pm but most activity occurred between 6 am and 8 am. Inside the fence, most activity occurred between 6 pm and 2 am, with a minor diurnal peak at 9 am. Crepuscular peaks were observed at Sites 1, 2 and 4, particularly between 6 am and 9 am for Sites 2 and 4. The evening crepuscular peak occurred later at Site 1 (6 pm) than Site 2 (4 pm). No evening crepuscular peak was observed for Site 4 but there was a minor diurnal peak at 2 pm. Little nocturnal activity occurred at Sites 2 and 4. Sites 3 and 6 had major nocturnal peaks between 8 pm and 1 am and between 11 pm and 1 am respectively. Activity patterns were unclear at Site 5 where there was a diurnal peak at 1 pm, early afternoon crepuscular peak at 4 pm and a nocturnal peak at 1 am, with little activity in between.

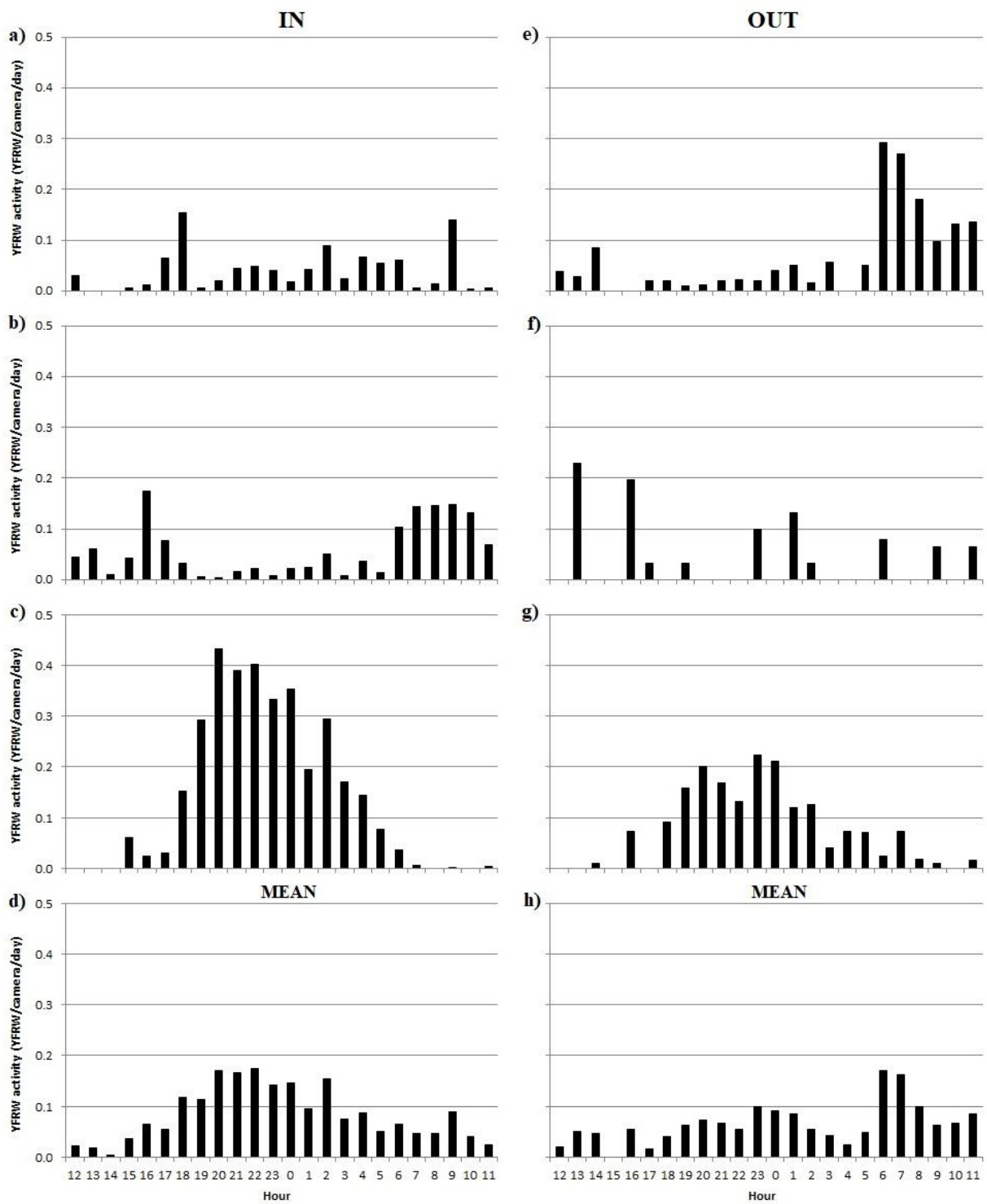


Figure 17. YFRW diel activity by hour for Sites 1 (a), 2 (b) and 3 (c), mean of inside sites (d), Sites 4 (e), 5 (f) and 6 (g), and the mean of outside sites (h).

4.4 YFRW diel behaviour for each treatment and site

There was some variation in the diel behaviours of YFRW between treatments and more so between sites (Figure 18). Similar proportions of resting behaviour occurred within each treatment but more foraging behaviour was observed inside the fence than outside. A much higher proportion of hopping behaviour was observed outside the fence than inside (27% versus 7%). The highest proportion of resting occurred at Sites 1, 3 and 4, the highest proportion of foraging at Sites 3 and 5, the highest proportion of hopping at Site 6 and the highest proportion of ‘other’ behaviour (including unknown behaviour and social interactions) at Sites 3 and 4.

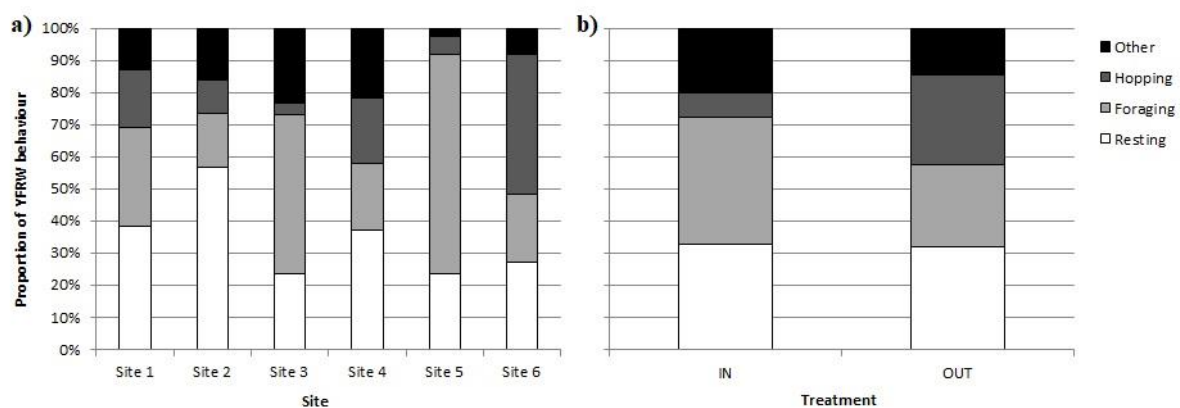


Figure 18. Proportion of YFRW diel behaviour for each site (a) and each treatment (b).

By time period

The proportions of YFRW behaviour that occurred during each time period varied between treatments and sites (Figure 19). Overall, inside the fence, dawn and day were dominated by resting behaviour while dusk and night were dominated by foraging behaviour and contained larger proportions of ‘other’ behaviour than dawn and day, with very little hopping behaviour observed during any time period. Outside the fence, the highest proportion of behaviour at dawn was resting while the highest proportion of behaviour at night was hopping. Similar proportions of foraging behaviour occurred during each time period with dusk containing a slightly higher proportion. For sites, the most common behaviour around dawn was resting at Sites 2 and 4, foraging at Sites 1, 3, and 5, and resting, hopping and ‘other’ behaviour in similar proportions at

Site 6. Most day behaviour was resting at Sites 1, 2 and 6, foraging at Sites 3 and 5, and slightly more hopping behaviour than resting or 'other' at Site 4. During dusk, the most common behaviour was resting at Sites 1, 2 and 4, foraging at Sites 3 and 5, and hopping at Site 6. Most night behaviour was resting at Site 4, foraging at Sites 3 and 5, hopping at Site 6 and resting and foraging in similar proportions at Site 1. The highest proportions of resting behaviour were observed during day and dusk at Site 1, dawn, day and dusk at Site 2, dawn at Site 4, and day at Site 6. Foraging behaviour was most commonly observed during dawn at Site 1 and during all time periods at Sites 3 and 5. Hopping was most commonly observed during the day at Site 4, during dawn at Site 5 and during dusk and night at Site 6. 'Other' behaviour was most commonly observed during the night at Site 2.

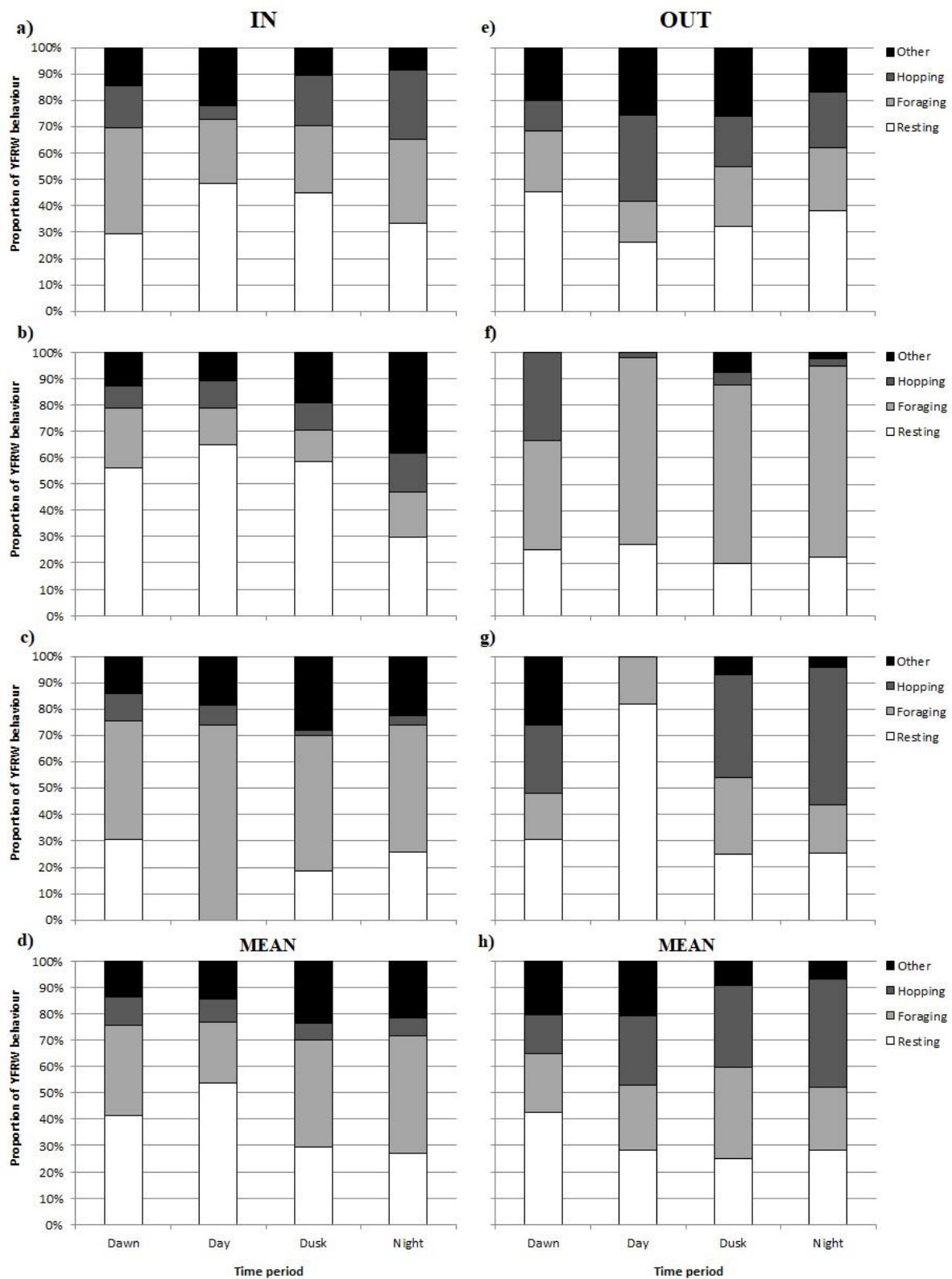


Figure 19. Proportion of YFRW diel behaviour by time period for Sites 1 (a), 2 (b), and 3 (c), mean of inside sites (d), Sites 4 (e), 5 (f), and 6 (g), and mean of outside sites (h).

By hour

YFRW diel behaviour was also considered by hour (Figure 20). The crepuscular-nocturnal peak inside the fence (6 pm to 3 am) consisted mostly of foraging behaviour with high levels of ‘other’ and resting behaviours while the same peak outside the fence had higher levels of hopping than any other behaviour though substantial amounts of foraging or resting behaviour was observed between 11 pm and 2 am. Inside the fence, behaviour between 6 am and 12 pm was mostly resting, while outside the fence, resting occurred most between 6 am and 9 am, and at 11 am, with substantial amounts of foraging, hopping and ‘other’ behaviour also occurring between 6 am and 12 pm. While YFRW at Site 3 & 6 were most active during similar crepuscular-nocturnal hours (between 6 pm and 5 am), the behaviours at Site 3 during those hours were mostly foraging as well as high levels of resting and ‘other’ behaviour while the predominant behaviour at Site 6 during those same hours was hopping. Sites 2 and 4 also were active during similar hours of the day (mostly early morning hours between 6 am and 12 pm) but most YFRW behaviour during those hours at Site 2 was resting while YFRW behaviour at Site 4 between 6 am and 9 am consisted of high levels of resting, foraging and ‘other’ behaviour and between 9 am and 12 pm consisted of higher levels of hopping, ‘other’ and resting behaviour. YFRW behaviour at Site 1 for each hour was fairly evenly divided between any three of the four behaviours. Foraging was the dominant behaviour during any hour at Site 5.

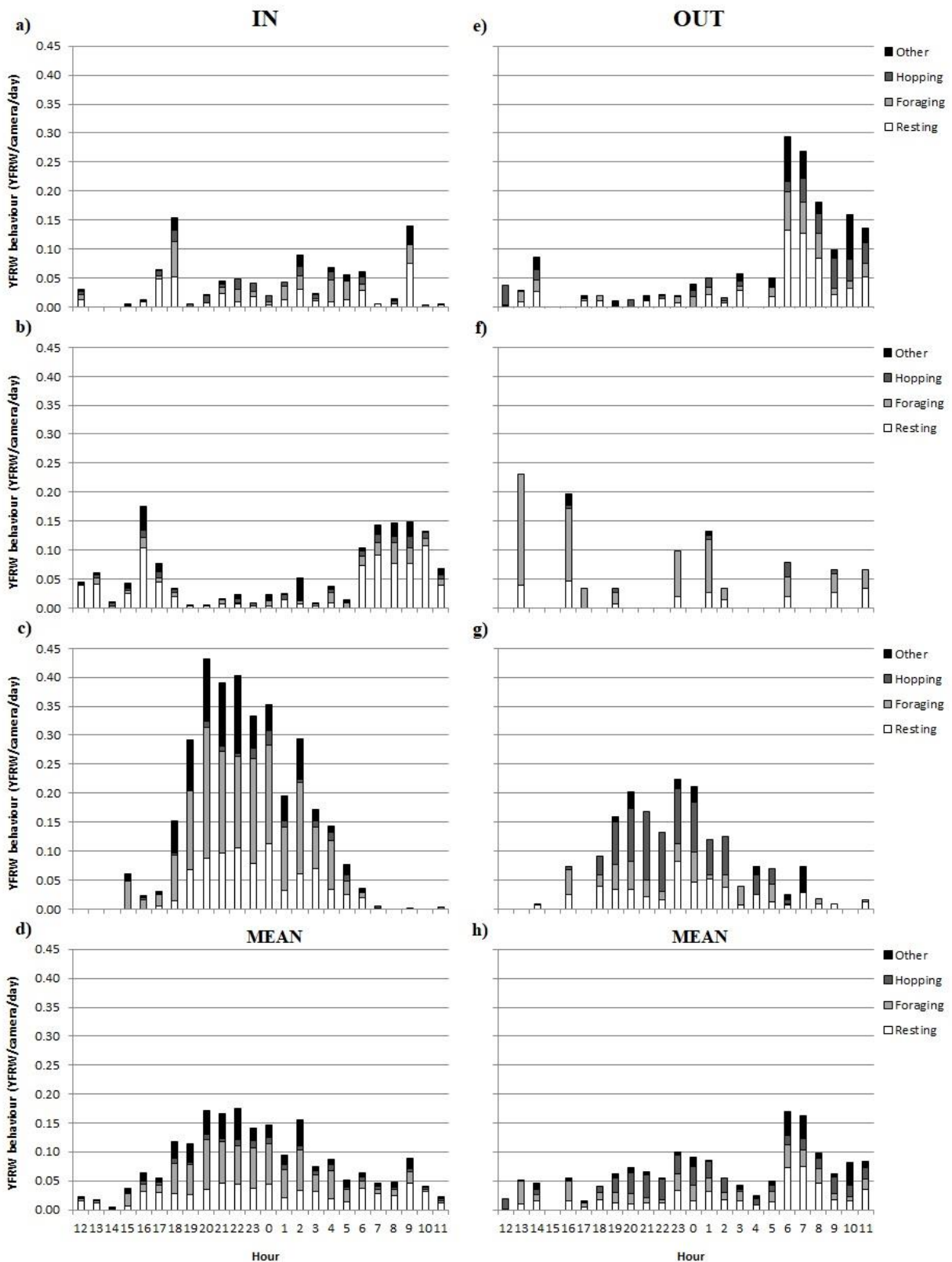


Figure 20. YFRW diel behaviour by hour for Sites 1 (a), 2 (b), and 3 (c), mean of inside sites (d), Sites 4 (e), 5 (f), and 6 (g), and mean of outside sites (h).

4.5 Goat activity trends

By day

Goat activity varied greatly between sites, treatments, and camera placements throughout the study period (Figure 21). There was a difference in mean goat activity inside and outside the fence on a daily basis ($t = 3.858$, $df = 447$, $p = 0.0001$). Mean goat activity inside the fence (15.124 ± 2.412 goats/camera/day (SE)) was much higher than outside the fence (3.853 ± 1.649 goats/camera/day (SE)). Goat activity on a daily basis was then assessed according to camera placement (bottom or top of cliff) and found there was a difference ($t = -2.083$, $df = 505$, $p = 0.038$). Mean goat activity on the top of cliffs (15.686 ± 2.617 goats/camera/day (SE)) was much higher than at the bottom (7.828 ± 2.716 goats/camera/day (SE)).

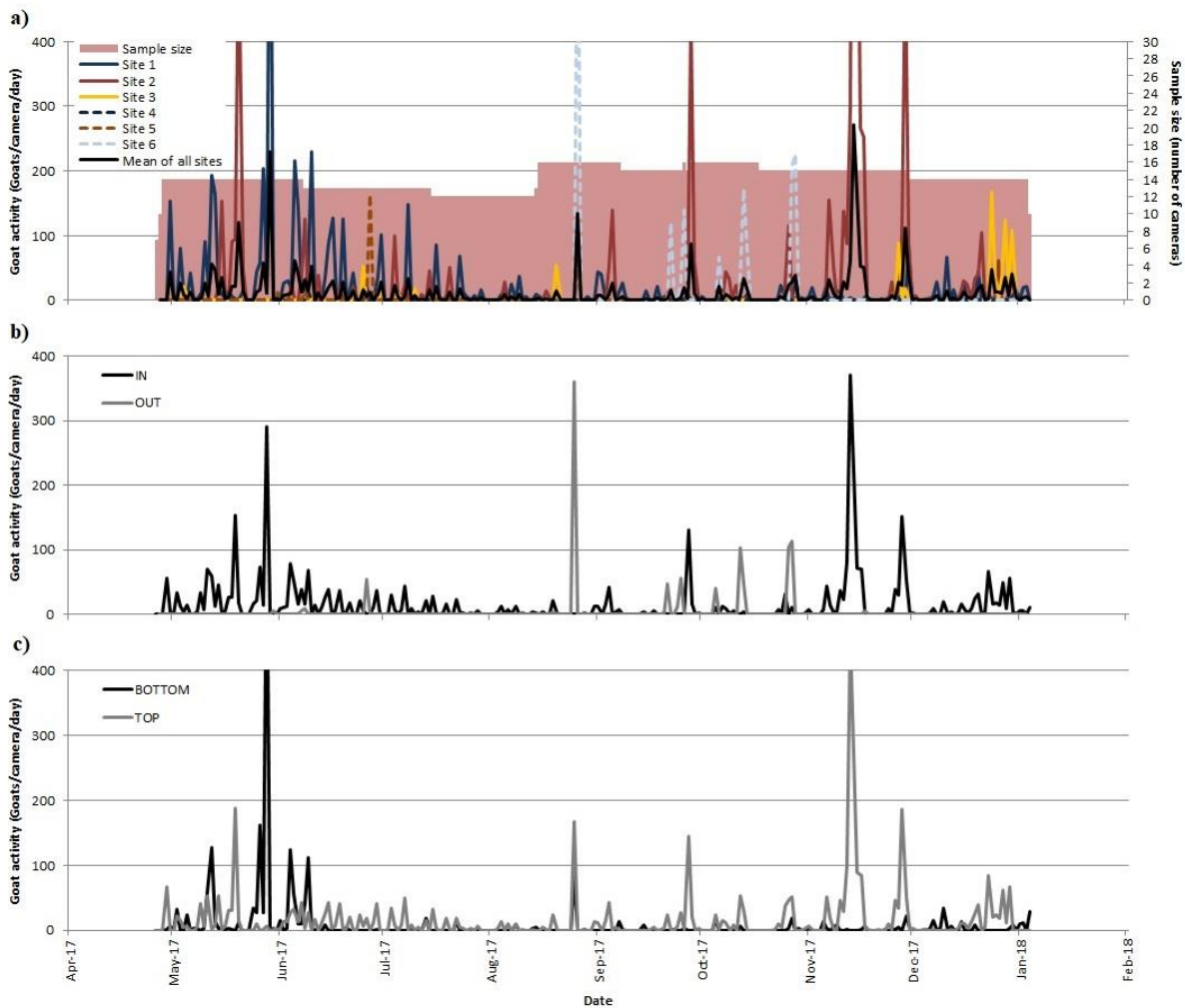


Figure 21. Goat activity by day between 26 April 2017 and 4 January 2018 at each site and overall with six values exceeding 400 goats/camera/day (562, 800, 699, 436, 1358, 530) truncated (a), at each treatment (b), and at each camera placement with two values exceeding 400 goats/camera/day (628, 453) truncated (c).

By week

Weekly goat activity was higher inside the fence than outside ($t = 3.072$, $df = 55$, $p = 0.003$;

Figure 22). Mean goat activity was 104.761 ± 22.602 goats/camera/week (SE) inside and 26.154 ± 11.998 goats/camera/week (SE) outside.

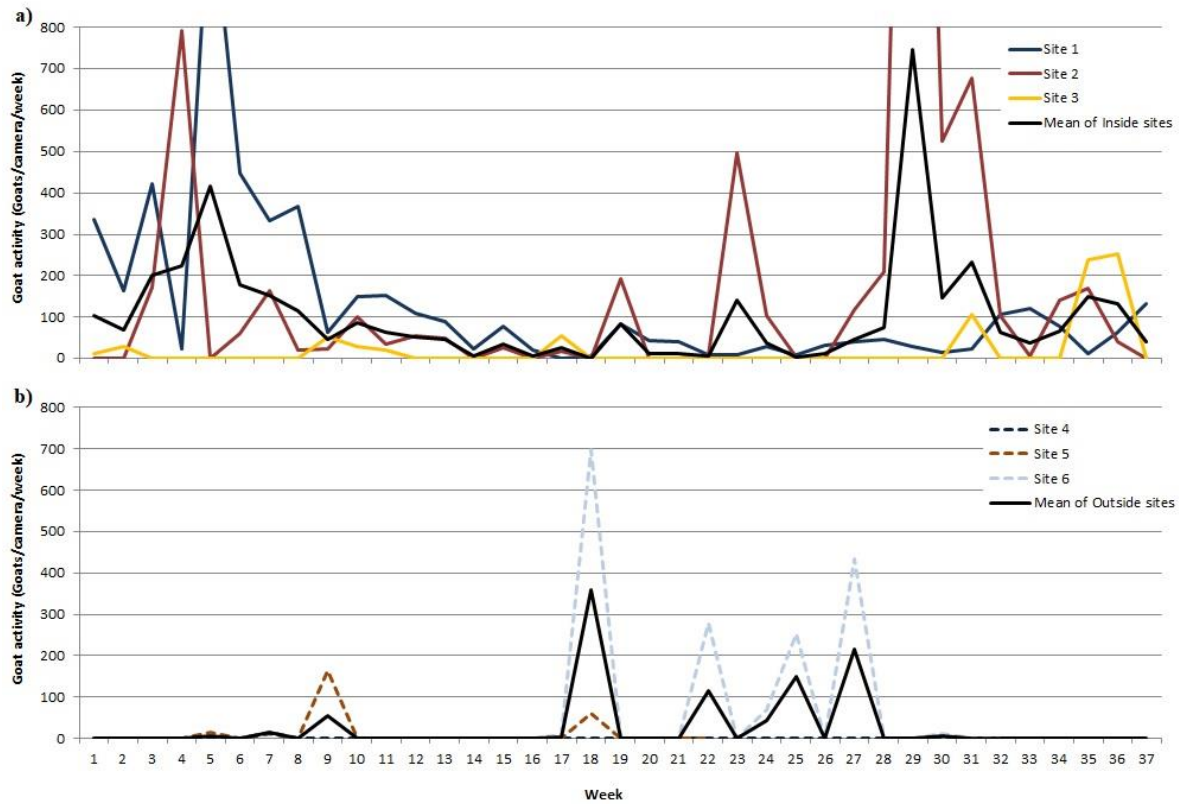


Figure 22. Goat activity by week between 26 April 2017 and 4 January 2018 for sites inside the fence with two values exceeding 800 goats/camera/day (1144, 2693) truncated (a) and for sites outside the fence (b).

There was no difference in weekly goat activity between camera placements ($t = -1.513$, $df = 72$, $p = 0.135$; Figure 23). Goat activity averaged 55.247 ± 24.539 goats/camera/week (SE) at bottom-placed cameras and 108.054 ± 24.811 goats/camera/week (SE) at top-placed cameras.

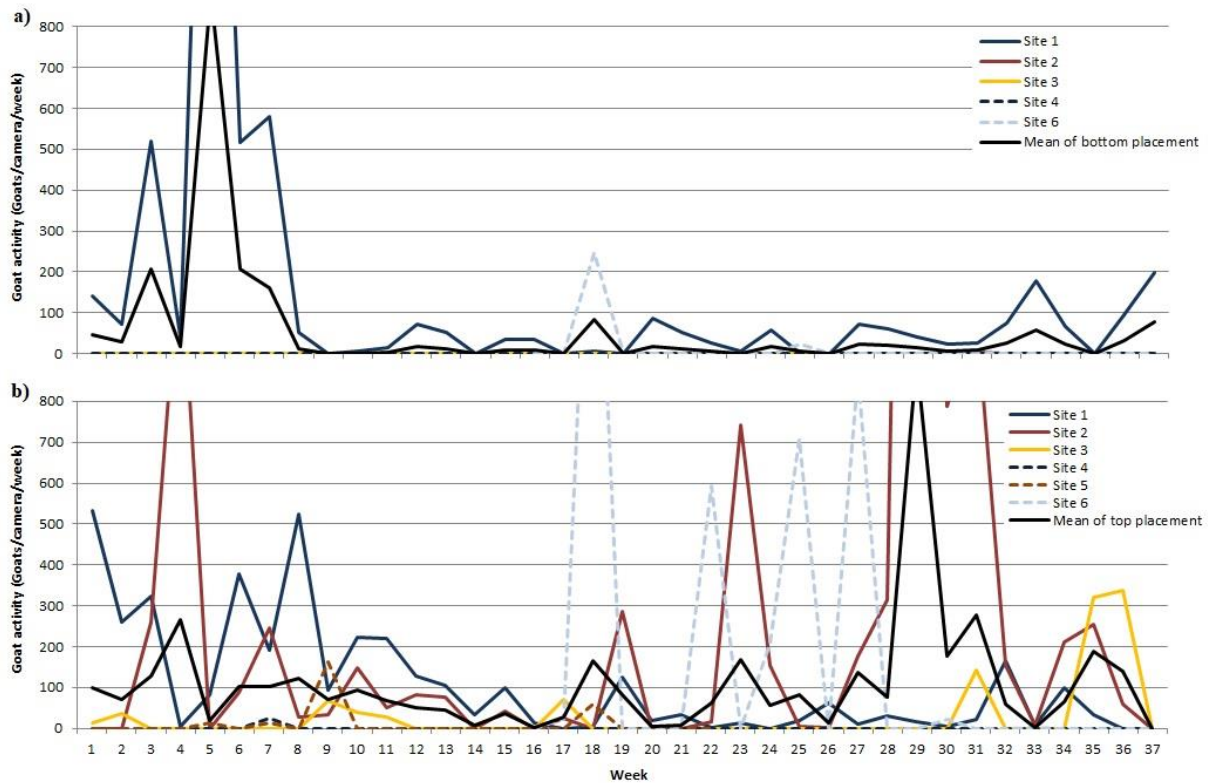


Figure 23. Goat activity by week between 26 April 2017 and 4 January 2018 for cameras at sites placed at the bottom of cliffs (a) with two values exceeding 800 goats/camera/day (2206, 882) truncated; and for sites placed at the top of cliffs (b) with six values exceeding 800 goats/camera/day (1189, 1600, 866, 4040, 902, 1015) truncated.

By month

Mean monthly goat activity was assessed between treatments and there was no clear difference ($t = 2.072$, $df = 11$, $p = 0.063$). Monthly goat activity averaged 386.595 ± 131.354 goats/camera/month (SE) inside the fence and 95.796 ± 49.388 goats/camera/month (SE) outside.

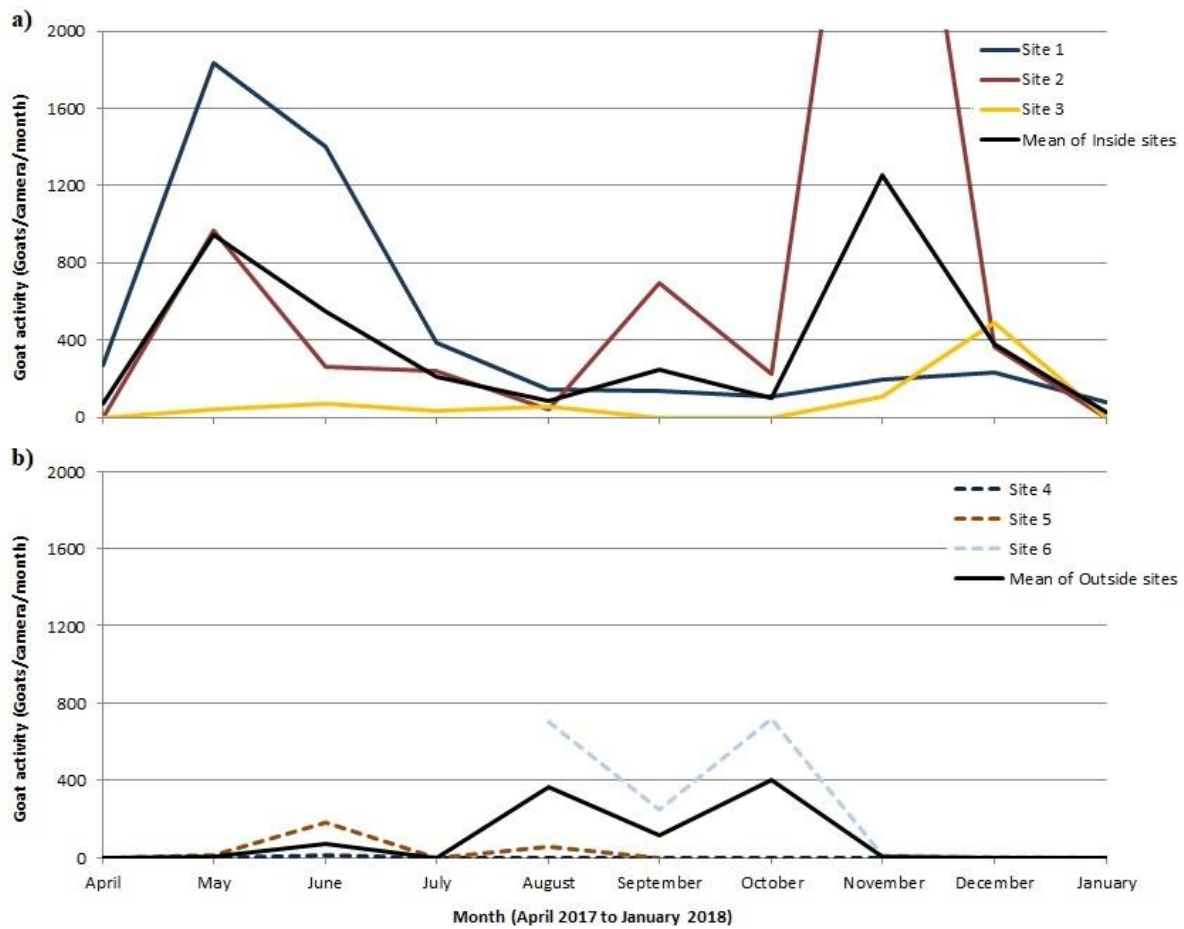


Figure 24. Goat activity by month for the 10 months of the study period for sites inside the fence (a) with one value exceeding 2000 goats/camera/month (4196) truncated; and for sites outside the fence (b). April and January only contributed nine days between them due to placement and collection times.

4.6 Goat diel activity

By time period

There appeared to be differences in the periods goats were active within each treatment and at each site. Goats exhibited more nocturnal and dawn activity inside the fence than outside (Figure 25b). More nocturnal activity was observed at Site 2 and more dusk activity at Site 6 than any other sites (Figure 25a). Goats were active at similar proportions during dawn, dusk and night and least active diurnally inside the fence, while outside the fence, goats were most active during dusk (almost 70% of activity) with a moderate proportion of diurnal activity, very little dawn activity and no nocturnal activity (Figure 26b). Goats were most active nocturnally at Site 2, most active during dawn at Site 3 and Site 5 and most active during dusk at Site 4 and Site 6. Goats were active in similar proportions during dawn, day and dusk at Site 1. Very little or no nocturnal activity occurred at Sites 3, 4, 5 or 6 and very little or no diurnal activity occurred at Site 2, 4 or 5.

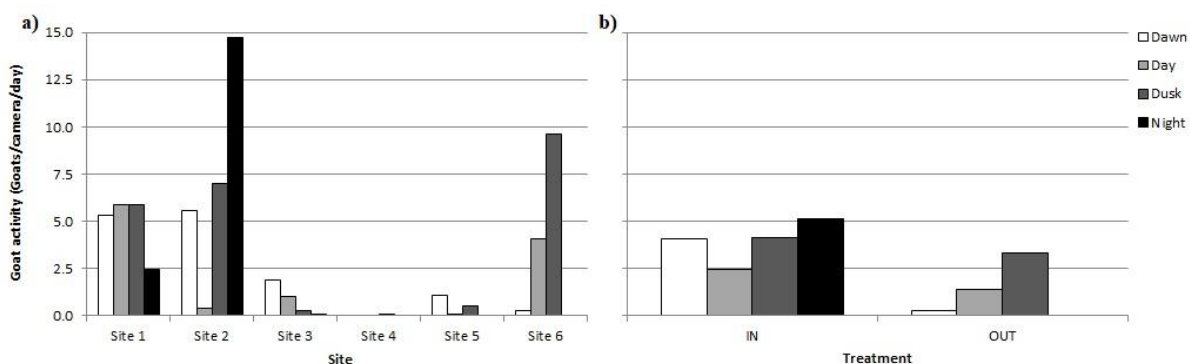


Figure 25. Goat diel activity by time period at each site (a) and within each treatment (b). Sample sizes are as follows: Inside the fence – Site 1 = 856 camera-days, Site 2 = 759 camera-days, Site 3 = 982 camera-days; Outside the fence – Site 4 = 502 camera-days, Site 5 = 152, Site 6 = 327 camera-days.

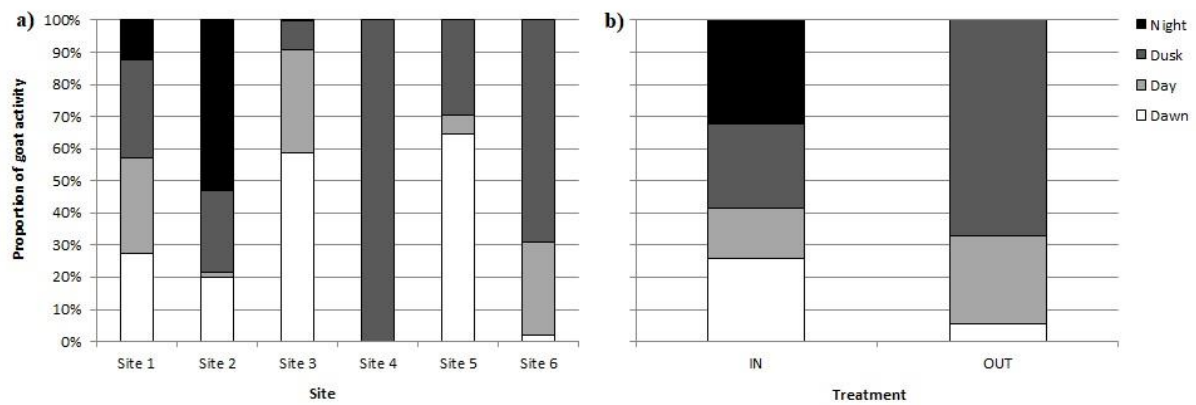


Figure 26. Proportion of goat diel activity by time period at each site (a) and within each treatment (b).

By hour

Goats exhibited crepuscular peaks within each treatment and at all sites, but also had a nocturnal peak at Site 2 (Figure 27). Peaks of activity occurred between 3 pm and 6 pm both inside and outside the fence, with another crepuscular peak at 7 am inside the fence and a minor diurnal peak at 9 am outside the fence. There was much more activity during those hours inside the fence than outside. Goats were most active at Site 1 between 3 pm and 6 pm, and 7 am and 9 am; at Site 2 between 6 pm and 4 am, and 6 am and 8 am; and at Site 3 between 6 am and 9 am. There was very little goat activity outside the fence, particularly at Site 4, but most activity at Site 6 occurred between 3 pm and 6 pm.

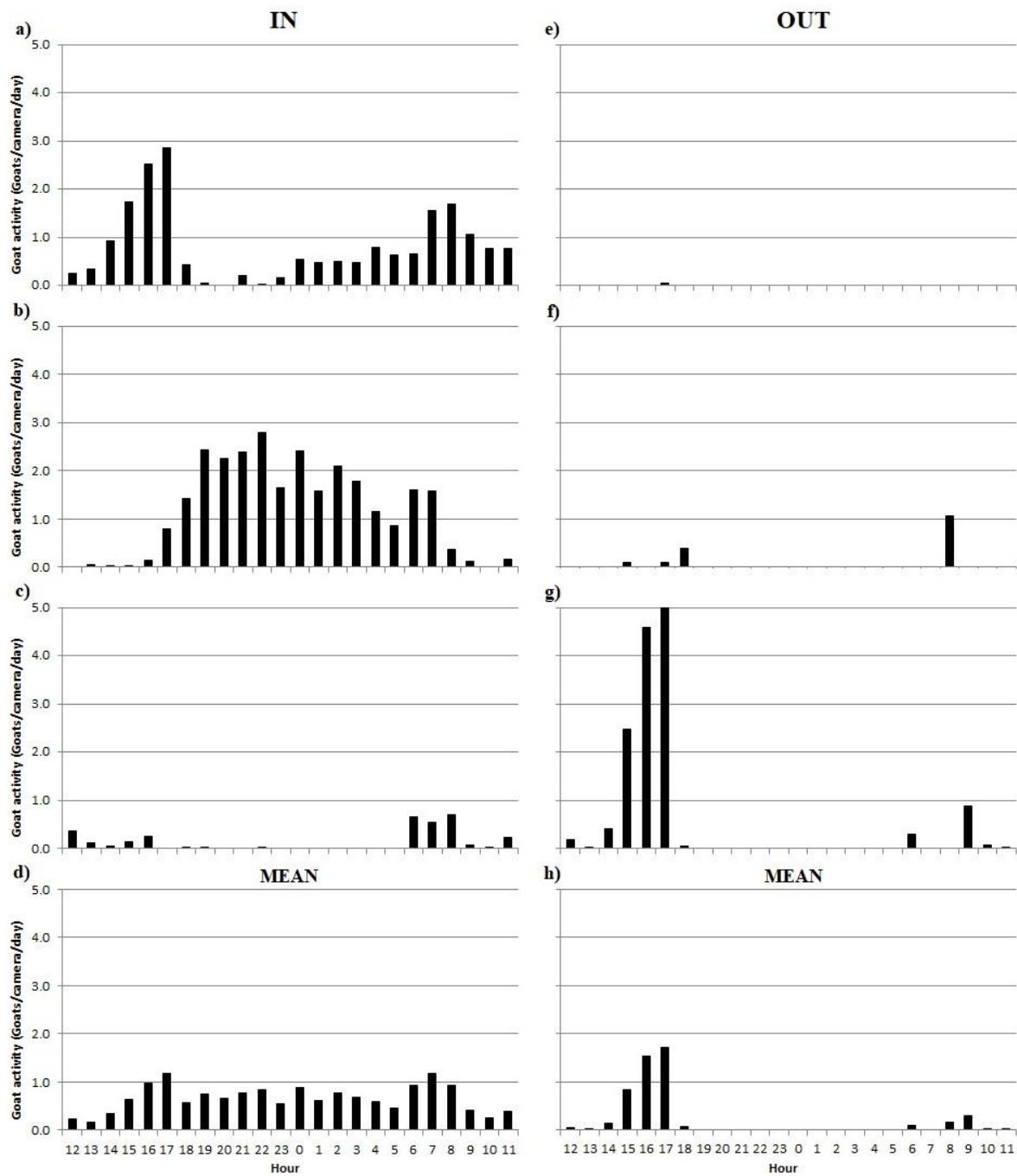


Figure 27. Goat diel activity by hour for Sites 1 (a), 2 (b), and 3 (c), the mean of inside sites (d), Sites 4 (e), 5 (f), and 6 (g), and the mean of outside sites (h).

4.7 Goat activity vs. YFRW activity

GLMs were performed between goat activity and YFRW activity by day, week, month and hour for each site and treatment to consider whether goat activity could be a useful predictor variable for YFRW activity (Table 4). There were both negative and positive relationships between goat and YFRW activity at some sites and treatments but these relationships were weak. The strongest were negative relationships between goat and YFRW diel activity at Sites 2 ($r=0.501$, $p<0.001$) and 3 ($r=0.519$, $p<0.001$).

Table 4. Pearson's correlation coefficients and p-values for predictor variable 'goat activity' against response variable 'YFRW activity' for each site and treatment. Statistically significant positive relationships are italicised and bolded and significant negative relationships are italicised and underlined.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Mean of IN	Mean of OUT
By day	<i>$r=0.052$</i> <i>$(p<0.001)$</i>	<i><u>$r=0.029$</u></i> <i><u>$(p<0.001)$</u></i>	<i>$r=0.031$</i> <i>$(p=0.030)$</i>	$r=0.090$ ($p=0.683$)	$r=0.028$ ($p=0.139$)	$r=0.025$ ($p=0.093$)	<i>$r=0.079$</i> <i>$(p<0.001)$</i>	<i><u>$r=0.035$</u></i> <i><u>$(p=0.022)$</u></i>
By week	<i>$r=0.126$</i> <i>$(p=0.036)$</i>	<i><u>$r=0.035$</u></i> <i><u>$(p=0.046)$</u></i>	<i><u>$r=0.139$</u></i> <i><u>$(p=0.048)$</u></i>	$r=0.233$ ($p=0.913$)	$r=0.163$ ($p=0.116$)	$r=0.171$ ($p=0.370$)	$r=0.104$ ($p=0.073$)	$r=0.049$ ($p=0.092$)
By month	$r=0.362$ ($p=0.735$)	$r=0.029$ ($p=0.259$)	$r=0.213$ ($p=0.638$)	$r=0.393$ ($p=0.728$)	$r=0.719$ ($p=0.988$)	$r=0.496$ ($p=0.721$)	$r=0.663$ ($p=0.777$)	$r=0.130$ ($p=0.543$)
By hour	<i><u>$r=0.076$</u></i> <i><u>$(p<0.001)$</u></i>	<i><u>$r=0.501$</u></i> <i><u>$(p<0.001)$</u></i>	<i><u>$r=0.519$</u></i> <i><u>$(p<0.001)$</u></i>	$r=0.122$ ($p=0.272$)	$r=0.185$ ($p=0.100$)	<i><u>$r=0.296$</u></i> <i><u>$(p=0.021)$</u></i>	<i>$r=0.315$</i> <i>$(p<0.001)$</i>	<i><u>$r=0.346$</u></i> <i><u>$(p=0.015)$</u></i>

4.8 Goat activity vs. YFRW behaviour

GLMs were also performed between goat diel activity (by hour) and YFRW diel behaviours (resting, foraging, hopping and other) for each site and treatment (Table 5), to determine whether or not goat activity influenced the expression of YFRW behaviour. There were also some negative and positive relationships between goat activity and YFRW behaviour at some sites and treatments, but these relationships were also weak. The strongest of these were negative relationships between goat activity and YFRW resting behaviour at Site 2 ($r=0.532$, $p<0.001$), YFRW foraging behaviour at Site 3 ($r=0.533$, $p<0.001$), and YFRW hopping behaviour outside the fence ($r=0.522$, $p=0.001$).

Table 5. Pearsons’s correlation coefficients and p-values for predictor variable ‘goat activity’ against each ‘YFRW behaviour’ response variable – resting, foraging, hopping, other – for each site and treatment. Significant positive relationships are italicised and bolded and significant negative relationships are italicised and underlined.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Mean of IN	Mean of OUT
Resting	<i>$r=0.156$</i> <i>$(p=0.002)$</i>	<i>$r=0.532$</i> <i>$(p<0.001)$</i>	<i>$r=0.470$</i> <i>$(p<0.001)$</i>	$r=0.087$ ($p=0.309$)	$r=0.207$ ($p=0.089$)	<i>$r=0.247$</i> <i>$(p=0.032)$</i>	<i>$r=0.463$</i> <i>$(p=0.006)$</i>	<i>$r=0.236$</i> <i>$(p=0.032)$</i>
Foraging	<i>$r=0.233$</i> <i>$(p<0.001)$</i>	<i>$r=0.375$</i> <i>$(p<0.001)$</i>	<i>$r=0.533$</i> <i>$(p<0.001)$</i>	$r=0.119$ ($p=0.275$)	$r=0.166$ ($p=0.110$)	$r=0.049$ ($p=0.120$)	<i>$r=0.200$</i> <i>$(p<0.001)$</i>	$r=0.043$ ($p=0.190$)
Hopping	<i>$r=0.361$</i> <i>$(p<0.001)$</i>	<i>$r=0.430$</i> <i>$(p<0.001)$</i>	<i>$r=0.417$</i> <i>$(p<0.001)$</i>	$r=0.182$ ($p=0.201$)	$r=0.121$ ($p=0.131$)	<i>$r=0.327$</i> <i>$(p=0.014)$</i>	<i>$r=0.307$</i> <i>$(p<0.001)$</i>	<i>$r=0.522$</i> <i>$(p=0.001)$</i>
Other	<i>$r=0.013$</i> <i>$(p<0.001)$</i>	<i>$r=0.196$</i> <i>$(p<0.001)$</i>	<i>$r=0.456$</i> <i>$(p<0.001)$</i>	$r=0.083$ ($p=0.313$)	$r=0.083$ ($p=0.147$)	<i>$r=0.222$</i> <i>$(p=0.031)$</i>	<i>$r=0.264$</i> <i>$(p<0.001)$</i>	<i>$r=0.204$</i> <i>$(p=0.032)$</i>

Chapter 5: Discussion

5.1 General discussion

The major findings of this study were that YFRW temporal activity and behaviour did not differ between treatments (i.e. inside and outside the cluster fence) and there were mixed relationships between goat diel activity and YFRW diel activity at most sites and each treatment. Additionally, there was variation in diel activity and behaviour patterns for YFRW and goats but within-treatment variation appeared to be much greater than between-treatment variation, suggesting pooling the data from sites to consider effects of the fence was not useful.

Studies of barriers to movement suggest fences and similar barriers can affect population dynamics of multiple species (e.g. Hayward & Kerley 2009; Salau *et al.* 2012; Durant *et al.* 2015) and alter predator-prey relationships (e.g. Tambling & du Toit 2005; Bradby *et al.* 2014) and competitive relationships (e.g. Wiens *et al.* 1993; Bradby *et al.* 2014), particularly when coupled with control of certain species (e.g. Hayward *et al.* 2011; Brook *et al.* 2012). However, as construction of this Quilpie cluster fence began in 2015 (Burton 2015) and was only recently completed in 2017, we did not expect to find major differences in YFRW temporal activity between treatments associated with the presence of the fence. As a baseline study, the results of this study suggest YFRW activity currently does not differ inside and outside the fence. There does appear to be variation in YFRW diel activity and behaviour between sites and between treatments but these were not statistically analysed. This variation could be due to different levels of predation threats or competition at different sites, or a combination of these and other factors including habitat differences and land-use history on different properties. However, only competition with feral goats was assessed in this study.

5.2 YFRW activity and behaviour

5.2.1 YFRW activity trends

YFRW mean activity did not differ between treatments. There were also no apparent daily, weekly or monthly trends in YFRW activity for sites or treatments. As YFRW are reported to exhibit high site fidelity (Blumstein *et al.* 2001; Sharp 2009), this result was expected and supports the null hypothesis that there would be no difference in YFRW temporal activity between treatments. However, it is worth noting that activity at Site 3 increased noticeably in October until the end of the year (even when taking the July-August dip into consideration which was likely due to failure of Camera 9 between mid-July and mid-August) while activity at Site 2 decreased slightly during the last half of the year (Figure 13 and Figure 14). This could be due to cliff-face orientation, suggested to be a significant factor in determining optimal habitat for YFRW in NSW by Lim and Giles (1987). When observing tagged YFRW at a colony during several winters on the Gap Range in New South Wales, Sharp *et al.* (2006) noted that YFRW sheltered on the western side in mid-morning hours and eastern side in the afternoon. As north-west and westward-facing slopes receive more prolonged direct sunlight while south-facing slopes are more sheltered from the sun (Lim 1987, cited in Short 1982; Lim *et al.* 1992), it is possible the YFRW at Site 2 are more active on the westward-facing side of the plateau, where cameras were placed (see Appendix C), during the cooler part of the year to make the most of the winter sun and move to more eastern-facing areas, where direct sunlight is less prolonged (and where no cameras were placed), during hotter times of the year. As most cameras at Site 3 are on a south-eastward-facing slope, this provides more shelter from the sun during the hotter months of the year, starting in September or October, so this might explain the increase observed in YFRW activity between October and December.

5.2.2 YFRW diel activity

While the general diel activity patterns of YFRW were similar between treatments, crepuscular activity appeared to be higher than nocturnal activity outside the fence while nocturnal activity appeared to be higher than crepuscular activity inside the fence. There was greater variance in YFRW activity patterns between sites than between treatments with Sites 1, 2 and 4 displaying crepuscular activity and Sites 3 and 6 displaying more nocturnal activity. Given this high within-treatment variability, the between-treatment comparisons cannot reliably be attributed to treatment effects, so considering YFRW diel activity at the treatment level is likely not accurate or useful. The generally lesser observed daytime activity of YFRW in this study is consistent with other studies which report that, like many native mammals in semi-arid Australia, YFRW have adapted to the harsh environment by sheltering in the shade of caves, rock piles, rocks or trees during the day when thermoregulatory demands are highest (Blumstein & Daniel 2003; Sharp & McCallum 2010; Lapidge & Munn 2012). Studies of YFRW movements and activity patterns in Queensland (Sharp 2009) and South Australia (Lim 1987, cited in Hayward *et al.* 2011) found YFRW exhibited nocturnal behaviour. Conversely, a study of the same South Australian site at Middle Gorge in Buckaringa Sanctuary more than 20 years later, following fox and goat control and sheep removal, found YFRW to be crepuscular (Hayward *et al.* 2011). Hayward *et al.* (2011) hypothesised that sheep removal and goat control increased the quality of food sources closer to YFRW refuges through decreased resource competition, reducing the distance YFRW had to travel to forage thereby reducing their predation risk. Consequently, they suggested the observed crepuscular activity might be due to this shorter distance to travel and that YFRW might shift towards more nocturnal activity if they have to forage much further from refuge areas. A similar suggestion was made by Sharp (2011) in observing YFRW travelling to an artificial water source 1.5 km from a colony in Idalia National Park, Queensland. While most individuals visited the tank in the early hours of the night, some only began travelling to the tank in the middle of the night. Sharp (2011) suggested distance to nearby outcrops and the risk of

predation likely influenced the times that YFRW moved to the water source. If lower goat activity resulted in improved foraging resources closer to YFRW refuge areas at certain sites, it would be expected that YFRW would display more crepuscular activity at those sites in this current study.

A key difference in the studies previously mentioned is they all used tracking collars to record YFRW movements and activity patterns, compared to this current study which used camera traps. Those studies were able to record YFRW activity on the plains as well as the hills whereas my study was restricted to the hills. Lower slopes and plains below the hill are where YFRW's main foraging activities are reported to occur after sunset, though foraging usually begins on upper slopes closest to refuge areas during the afternoon (Lim *et al.* 1992; Sharp *et al.* 2006; Hayward *et al.* 2011; Sharp & McCallum 2015). With this study, then, crepuscular activity should be most commonly observed at any site or treatment as this is the time YFRW are considered to be most active on the slopes closest to their refuge areas. The primary difference should be whether crepuscular peaks occur earlier or later in the evening since earlier evening activity peaks might suggest YFRW spent more time foraging on the lower slopes and plains and perhaps felt safer to do so.

Interestingly, this was not the case. While little nocturnal activity was observed at Site 2 and Site 4, with early evening and morning crepuscular peaks at Site 2 and a morning crepuscular peak at Site 4, YFRW at Site 3 and Site 6 were most active during late evening and the night. This could be due to lower levels of goat activity or increased predation risk on the plains near those sites as suggested by Hayward *et al.* (2011) and Sharp (2011). Dingoes were observed at Site 2, 3 and 6, and, while foxes and cats were not recorded on camera, it is possible they were present on the plains. In a study of fox and cat diets on Lambert Station near Adavale, further north of the Quilpie study area, Lapidge and Henshall (2001) observed that feral cats were normally seen in open paddocks while YFRW carcasses known to be killed by foxes were found near the base of the hill. Foxes and cats are primarily nocturnal mammals (Gordon *et al.* 2017). Predation risk is

likely higher on the plains as YFRW can escape these predators less easily there than in their steeper rocky refuge areas (Hayward *et al.* 2011). However, we could not assess this in the current study. Alternatively, it could just be that the YFRW were more active during crepuscular peaks in other parts of these sites and so that activity was not recorded on camera.

For the sites where crepuscular peaks did occur in the evening, they occurred 2 hours later at Site 1 (6 pm) than Site 2 (4 pm), while Site 4 had a small diurnal peak in activity between 2 pm with little activity from there until 6 am. If applying the same reasoning as in the previous paragraph, these findings would suggest YFRW at Site 2 and Site 4 experienced lower predation risk than Site 1 as they were more active earlier in the afternoon. However, Site 2 and Site 3 are on different branches of the same plateau with the closest cameras at Site 2 and Site 3 being 700 metres apart. This would make it unlikely that the predation risk was very different unless the topography of the landscape surrounding Site 2 provided more escape routes and places of refuge (Sharp 2011) for cautious foraging YFRW than the topography of Site 3.

5.2.3 YFRW diel behaviour

As the majority of nocturnal activity at Site 3 was foraging, this supports the previously discussed suggestion that YFRW may prefer to forage on top of the plateau rather than on the plains beneath for some reason, potentially due to a higher risk of predation on the plains. However, while most foraging at Site 6 occurred around dusk and during the night, hopping was by far the most common activity between 6 pm and 3 am. While dingoes were not recorded frequently enough to perform reliable analyses, it is worth noting that dingo activity was highest at Site 6 and almost double the total dingo activity recorded inside the fence. Of the outside sites, goat activity was also highest at Site 6. The more ‘flighty’ behaviour of YFRW at Site 6 could be due to increased predation risk, although most dingo activity occurred around dawn – this concords with other studies which suggest that dawn is a time of peak dingo activity (e.g. Brook *et al.* 2012; Allen *et al.* 2014) – and much less YFRW activity occurred during that time. Goats

were most active at Site 6 between 3 pm and 6 pm, again a period of time when YFRW were much less active at Site 6. This could suggest YFRW avoided times when competitors and predators were most active. Alternatively, there could be other factors influencing the frequency of behaviours observed as camera traps only record the behaviour of those individuals in the vicinity of the lens. Individual YFRW display high site fidelity to particular outcrops and refuges, and dominant females often get the best areas (Blumstein *et al.* 2001). These cameras may be located in core areas of the YFRW colonies, which may frequently photograph the same couple of dominant individuals; or may be in peripheral habitat (Lim *et al.* 1992; Sharp & McCallum 2010), which may photograph a greater number of individuals but less frequently; or may be in areas where food resources diminish quickly, including due to intraspecific competition, resulting in YFRW spending more time in areas where the cameras are not present. Substantial amounts of hopping were also observed at Site 4 between 6 am and 12 pm but YFRW spent more time resting and exhibiting ‘other’ behaviours during those times at that site. The first couple of hours following sunrise are reported to be when YFRW spend most time grooming and basking in the sun (Lim *et al.* 1992; Sharp *et al.* 2014). This appeared to be the case for the sites which had crepuscular activity peaks (Sites 1, 2 and 4) and within each treatment, with YFRW mostly resting (including grooming) between 6 am and 10 am. The similarities in diel behaviour patterns at sites on opposite sides of the fence and variations in diel behaviour patterns at sites within each treatment, suggest the barrier fence currently does not play a major role in influencing YFRW behaviour. Certain areas of habitat can be more conducive for certain behaviours (e.g. basking in the sun around dawn) or favoured by particular individuals (e.g. dominant females in core refuge spots (Blumstein *et al.* 2001; Blumstein & Daniel 2003)). So habitat characteristics of topography, vegetation or cliff-face direction might be more important factors influencing YFRW diel behaviour patterns than fence effects from predation or competition.

5.3 Goat activity

5.3.1 Goat activity trends

Goat activity fluctuated greatly and was significantly lower outside the fence than inside the fence. This variability fits with other sources which suggest goats are highly mobile mammals (Lim *et al.* 1992; Freudenberger & Barber 1999) which move from hill to hill (Sharp *et al.* 1999; Thompson *et al.* 2002). In a study of feral goats in the mulga lands of south-western Queensland, Thompson *et al.* (2002) suggested topography, habitat quality, harvesting pressure and feed availability might all influence the movement of feral goats. They also noted that goats in rocky and hilly areas tended to move between hills and did not display much fidelity to a particular area. In South Australia, goats were reported to move away from rock-wallaby habitats onto the plains to feed during drier seasonal conditions (Copley 1981, cited in Copley 1983). It is possible the difference found in this study could be due to different land-use practices on the properties on either side of the fence which have affected the land's carrying capacity for goats or that there were other hills more favourable to goats than the sites where cameras were placed, perhaps due to factors such as cliff height (Silcock & Fensham 2014), size of caves (Lim *et al.* 1992) or vegetation type (Thompson *et al.* 2002).

5.3.2 Goat daily activity

Goats exhibited predominantly crepuscular activity patterns inside and outside the fence, and for all sites, though goats were active over a greater number of hours inside the fence than outside. There were crepuscular peaks at 5 pm and 7 am inside the fence, and a crepuscular peak at 5 pm outside the fence. Some nocturnal activity was recorded at Site 1 and a high proportion of nocturnal activity at Site 2 but very little diurnal activity was recorded at any site or treatment except for a minor diurnal peak at 9 am outside the fence. At first, this appeared to conflict with reports that goats are diurnal (e.g. Piccione *et al.* 2008) but, in their study of YFRW

demographic traits at Idalia National Park, Sharp and McCallum (2015) reported that goats rested on escarpment country at night and left the hills at dawn to forage. That might explain this study's findings as the peaks in activity between 7 am and 10 am and between 4 pm and 5 pm could potentially be when goats left the hills in the morning to forage and returned in the afternoon. Site 2 recorded high nocturnal activity by goats but this was likely mostly due to Camera 6 which faced an area frequented by sleeping goats during the night. Dusk activity peaks were higher than dawn activity peaks at Sites 1, 2 and 6 and outside the fence overall which might be due to goats spending more time foraging on the tops of hills in the evening or taking a different route in the evening than the morning.

5.4 Goat activity versus YFRW activity and behaviour

5.4.1 Goat activity versus YFRW activity

There is some evidence to suggest that weaker competitors might change temporal activity patterns to avoid harmful competition with stronger carnivorous (Harrington *et al.* 2009; Hayward & Slotow 2009) or herbivorous (Ross *et al.* 2013) competitors if other options to change diet or habitat use (Foster *et al.* 2013; Ross *et al.* 2013) are not available. As goats often aggregate in large numbers (Lim *et al.* 1992; Thompson *et al.* 2002), they strongly compete for space and food when occupying the same hills as YFRW (Hayward *et al.* 2011), particularly during drier seasons when the two species have a higher degree of dietary overlap (Dawson & Ellis 1979). Goats have also been observed to physically evict YFRW from caves (Lim *et al.* 1980, cited in Copley 1983). This intense and potentially harmful competition might result in YFRW changing their diel activity patterns to avoid temporal overlap with feral goats.

In this study, there appeared to be a negative relationship between goat diel activity patterns and YFRW diel activity and behaviour. Goats exhibited crepuscular activity peaks early in the evening and morning inside the fence (contrasting with YFRW crepuscular-nocturnal peaks late in the evening and during the night) and only a substantial crepuscular peak early in the evening

outside the fence (contrasting with YFRW nocturnal peak around midnight and a crepuscular peak early in the morning). GLMs indicated weak mixed relationships between goat activity and YFRW activity or behaviour at some sites and within both treatments. The strongest of these were negative relationships between goat and YFRW diel activity at Site 2 where YFRW were least active at night and goats were most active, and at Site 3 where YFRW were most active at night and goats were hardly active at all, aside from a minor peak between 6 am and 9 am. However, even these relationships were not strong enough to indicate that goat activity could be the sole explanation for the observed differences in YFRW activity or behaviour between sites or between treatments. This suggests that, while goat activity might influence YFRW diel activity to some degree, other factors must also be involved. Goat activity was not a reliable predictor of YFRW activity.

Ecosystems operate as a complex system of interactions between interdependent organisms (Wootton 1994; Melzer *et al.* 2009) and the surrounding abiotic environment. The influences of competitors and predators may combine to increase a particular effect on a species (Melzer *et al.* 2009; Woinarski *et al.* 2014) or may mask the effects of the other species. While Sharp (2002a) found YFRW increased in abundance in areas in NSW that were baited for foxes compared to unbaited areas, Hayward *et al.* (2011) reported that fox control was less influential than goat control and sheep removal on YFRW in terms of decreasing their foraging ranges and shifting to more crepuscular activity at a South Australian study site. When goat removal did not halt YFRW decline in New South Wales, Dovey *et al.* (1997) suggested this was because predation was a bigger threat. Rapid immigration was suggested as an explanation in another study, where a 16-year period of goat control in Mootwingee National Park and Coturaundee Nature Reserve in New South Wales did not result in a detectable increase in YFRW populations (Sharp *et al.* 1999). Rainfall and corresponding resource availability have also been reported to strongly influence the abundance and foraging ranges of YFRW, particularly when combined with competition by domestic livestock, sympatric macropods and conspecifics (Lapidge 2001; Sharp

et al. 2006; Lethbridge & Alexander 2008; Sharp & McCallum 2015). These factors were not considered in the scope of this study; nor were vegetation types or extent of vegetation cover. Nevertheless, they are likely to act in combination with the effects of goat activity and/or predation to influence some of the observed differences in YFRW diel activity and behaviour between treatments and between sites in this study.

5.5 Study limitations

The failure of several cameras during periods of the study, and particularly the failure of the only camera at Site 5 during the last few months of the study period, decreased the amount of data collected and the level of confidence in some of the results. However, the standardisation of trends and diel activity and behaviour data as photos/camera/day (or per night) (Engeman 2005) overcame many of the issues of imbalances in number of cameras available at each treatment. More camera-days would have reduced observation error but would not have reduced natural variation already present. In addition, factors such as differences in thermoregulatory demands of habitats (Curtis & Rasmussen 2006; Diete *et al.* 2017), major vegetation types or historical and current land-use of the properties on each side of the fence were not considered due to time and financial constraints on the scope of the study, though these undoubtedly have potential to influence goat and YFRW diel activity. The direction cameras were facing and the side of the hill they were on were not considered for most sites (see Appendix D), despite studies suggesting rock-wallabies utilised different slopes during different seasons and different times of day (e.g. Short 1982; Sharp *et al.* 2006). Vegetation and topographical analyses were outside the scope of this project.

Furthermore, while ages of YFRW were recorded where possible, no comparison was made between activity of different age groups by treatment, site, camera or topographical/vegetation type. In a study of a colony in Idalia NP, Qld, Sharp and McCallum (2010) observed that adult YFRW utilised tree and rock shade during the day while caves and rock piles were mostly used

by juveniles. Neither was YFRW activity compared between sexes (these were recorded where possible), even though the social hierarchy of YFRW can determine the presence or activity of certain individuals in core habitat areas (Lim *et al.* 1992; Blumstein *et al.* 2001; Sharp & McCallum 2010). The use of tagging would have helped identify individuals, compare individual behaviour and activity, determine the relative contributions of each individual to the overall activity index and diel activity patterns, and assess some measure of intraspecific competition. Finally, as YFRW have been observed to travel up to 1.5 km to forage and drink (Sharp 2011), it is possible that the same individuals were present at Sites 2 and 3 (which were positioned within 700 metres of each other); similarly, the complementary levels of activity between the two sites may be because one is a preferred foraging area while the other is a preferred resting area for the same group of individuals. While it is also possible these are distinctly separate colonies along a continuous plateau, we cannot be sure without live trapping and tagging YFRW and seeing if the tagged animals appear in photographs at both sites. This pattern suggests that, in future, sites should be separated by a distance of at least 3 km (twice the distance recorded by Sharp (2011)) to minimise the likelihood of capturing the same individuals at different sites, if that is important to the study objectives. A further limitation on the ability to record predator activity and interaction with prey species, is the inability to record airborne predators such as wedge-tailed eagles, at least while they soar and swoop overhead, which is when they might influence activity and behaviour (Lim *et al.* 1992; Sharp 1997a).

There may be a perceived limitation relating to lack of independence of samples. Non-independence between consecutive image captures was not an issue in this study because the methods used for the general activity index paradigm do not assume independence (Engeman 2005). These data were continuous which were preferred over binary data because the latter are less sensitive to detecting change and continuous data can be more informative (Allen *et al.* 2011).

5.6 Future directions

This study found no difference in YFRW activity between treatments; apparent variation in YFRW diel activity and behaviour between treatments and between sites; and significant but weak relationships between goat diel activity and YFRW diel activity and behaviour. Possible explanations for differences in activity and behaviour are differences in habitat usage by conspecifics, predation threats, topography, vegetation type, extent of vegetation cover and land-use. Tagging of individuals used in combination with camera traps would be a very useful future method to explore how conspecifics can influence the activity and behaviour of one another through social hierarchies and resource depletion. Shooting, poisoning, and trapping of predators could be carried out on the plains near the base of each site, and animals counted and their stomach contents searched for YFRW remains, in a similar manner to Lapidge and Henshall (2001), to explore if predators were more active on the plains at some sites. Another important future step would be to incorporate detailed topographical (including number of caves of varying heights suitable for goats or YFRW, extent of broken rocks and orientation of cliff faces), vegetation, and land-use (such as livestock types and stocking rates used on each property, their history of control of dingoes, goats or other species, and the distance to artificial water sources) factors into multiple regression analyses or mixed models (e.g. Kath *et al.* 2014) to investigate their influence on YFRW activity at each site and treatment.

As there are many unknowns about the potential effects of cluster fences on YFRW populations or their major competitors and predators, it is difficult at this point to confidently predict the ways that YFRW might be affected. If goat activity increases due to reduced predation pressure by dingoes (e.g. Allen *et al.* 2012) because there are fewer dingoes inside the fence due to more effective control, this might in turn place greater competitive pressure on YFRW for space and food and cause a narrowing of temporal activity. This situation is further conflicted by the benefits goats pose to some farmers as source of income during drought (Thompson *et al.* 2002), as well as the potential to stock more sheep in the absence of the dingo (Crothers 2017; Mark

Tully of Ray Station 2017, pers. comm., April), both of which can deplete resources on foraging grounds surrounding YFRW hills (Hayward *et al.* 2011) and damage ecosystem functions and structures (Eldridge *et al.* 2016). However, there may be other landscape factors which have a greater influence on YFRW abundance and activity than goats. In another five or ten years, when differences due to the fence and/or management practices are better established, the experiment should be repeated and compared with the baseline data this study has identified.

This study could be further improved by increasing the number of cameras used to at least three per hill and more cameras for larger hills, to increase the reliability and consistency of sampling methods, along with a more standard way to choose whether to place cameras at the top or bottom of cliffs. Several small and medium-sized mammals have successfully improved in their conservation status through translocation to offshore islands or mainland fenced enclosures (Woinarski *et al.* 2015). The increased use of agricultural fencing has the potential to be used as informal conservation enclosures but any such enclosures rely on ongoing maintenance of fences and control of predators and competitors in order to be successful. To predict the impacts that these fences may have on certain species requires an understanding of the different factors influencing a species' population dynamics and activity. One outcome identified through this dissertation is the importance of planning a robust experimental design that is balanced, informative and reliable and has a great sampling effort which reduces observation error.

Chapter 6: Conclusion

The literature review initially addressed the issues surrounding fences – that fences can restrict species' movements and have the potential to change species' population dynamics and alter interspecific relationships. It also considered the low dispersal tendencies of YFRW and the predators and competitors that may affect YFRW survival and questioned what effect a recently-constructed Quilpie cluster fence might have on the populations inside the fence, particularly when associated with dingo control. From this, a research question was developed (What is the effect of a Quilpie cluster fence on YFRW temporal activity and/or behaviour?) and hypotheses formed (There would be no difference in YFRW activity and/or behaviour between treatments; dingo and goat activity would influence YFRW activity and behaviour). Patterns in diel activity of YFRW, dingoes and goats (and diel behaviour of YFRW) were also explored.

YFRW activity trends and diel activity and behaviour patterns were measured using camera traps. Mean YFRW activity was no different either side of the cluster fence, which supported the null (and experimental) hypothesis. Variations in YFRW diel activity and behaviour were observed between treatments, but these variations were much greater between sites within each treatment than between treatments.

Secondly, goat activity trends and patterns in diel activity were also measured and compared with YFRW diel activity and behaviour to see if goat activity could explain YFRW activity.

While goat diel activity was found to be significantly related to YFRW diel activity and behaviour within each treatment and at most sites, the hypothesis that goats would influence YFRW activity and behaviour was not supported as the relationship between goats and YFRW could not sufficiently explain the variation observed between treatments or sites. This suggested other factors such as predation, competition with other species or conspecifics, topography, vegetation or land-use history must also be involved. Further research is required in these areas.

In conclusion, the findings of this study indicate that there are many factors which must be considered in determining potential effects of such fences on native species. While these fences may benefit livestock production, the effects on native wildlife are less straightforward due to the complexity of reduced predator impact coupled with potential increased competition with feral and domestic herbivores. As the use of cluster fencing becomes a more prominent management approach in Australian rangelands, the situation of wildlife in those areas requires close monitoring, further research and consideration of appropriate ways to deal with negative impacts. This study has established that YFRW were present inside and outside the Quilpie cluster fence at the time the fence was constructed, at similar levels of activity inside and outside the fence. How this changes in the future as the fence effect and pest control become established will help pinpoint and highlight issues of conservation concern with this and other threatened species on grazing lands.

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Appendix A: Raw camera data

This dataset is electronically available as a supplement.

Appendix B: Summary statistics

Table B1. Summary of statistical analyses of YFRW and goat temporal activity by treatment and camera placement.

Treatment/ Placement	Mean activity by time period					
	Daily	SE	Weekly	SE	Monthly	SE
YFRW						
Inside	1.966	± 0.141	13.481	± 1.359	50.005	± 9.750
Outside	1.590	± 0.180	10.832	± 1.827	39.782	± 7.996
Bottom	2.085	± 0.192	14.313	± 1.932		
Top	1.803	± 0.144	12.358	± 1.439		
Goat						
Inside	15.124	± 2.412	104.761	± 22.602	386.595	± 131.354
Outside	3.853	± 1.649	26.154	± 11.998	95.796	± 49.388
Bottom	7.828	± 2.716	55.247	± 24.539		
Top	15.686	± 2.617	108.054	± 24.811		

Appendix C: Map of Site 2 and 3

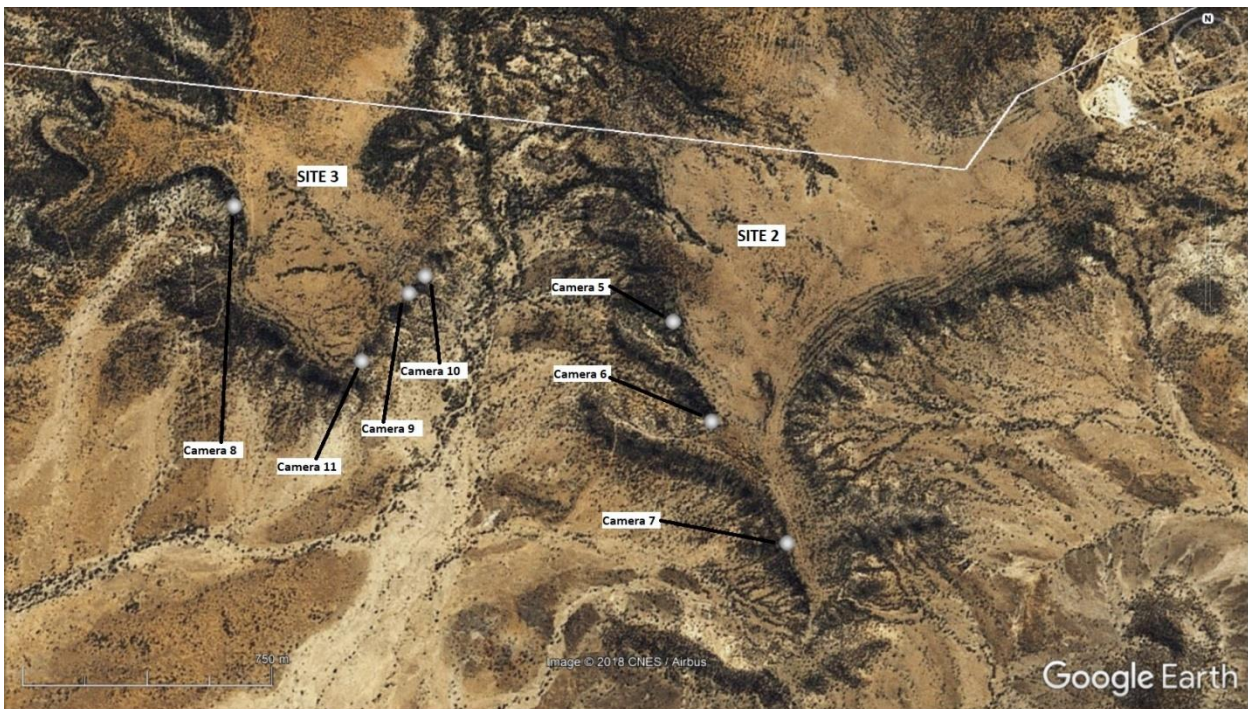


Figure C1. Map of Site 2 and Site 3 on a plateau on Ray Station inside the fence, showing closeness of sites and cliff-face orientation.

Appendix D: Camera site data

Table D1. Aspect data for all camera sites.

Property name	Camera name	Latitude	Longitude	Direction of cliff-face	Distance to fence
Canaway Downs	SITE 1				
	RW001	-26.005834	143.909772	East/South-east	~5 km
	RW002	-26.008535	143.908642	East/South-east	~4.75 km
	RW003	-26.010388	143.910738	East/South-east	~5 km
	RW016	-26.010188	143.900804	West/South-west	~6 km
Ray Station	SITE 2				
	RW005	-26.196326	143.914626	West	~2.5 km
	RW006	-26.199024	143.915782	West	~2.25 km
	RW007	-26.202311	143.918066	West	~2 km
	SITE 3				
	RW008	-26.193195	143.901399	West	~3.75 km
	RW009	-26.195558	143.906662	South-east	~3 km
	RW010	-26.195087	143.907151	South-east	~3 km
	RW011	-26.197392	143.905242	South-east	~3.25 km
Alaric	SITE 4				
	RW013	-26.181789	143.991972	North-west	~5 km
	RW014	-26.183573	143.989640	West	~4.75 km
	SITE 5				
	RW015	-26.163680	143.971412	South-west	~3 km
Fifteen Mile	SITE 6				
	RW017	-26.255180	143.940730	East	~0.5 km
	RW018	-26.251700	143.942030	North	~0.75 km
	RW019	-26.251480	143.944080	South-east	~1 km

Appendix E: Camera site photos



Figure E1. Vegetation and topography directly in front of Camera 1 (Site 1).



Figure E2. Vegetation and topography directly in front of Camera 2 (Site 1).



Figure E3. Vegetation and topography directly in front of Camera 3 (Site 1).



Figure E4. Vegetation and topography directly in front of Camera 16 (Site 1).



Figure E5. Vegetation and topography directly in front of Camera 5 (Site 2).

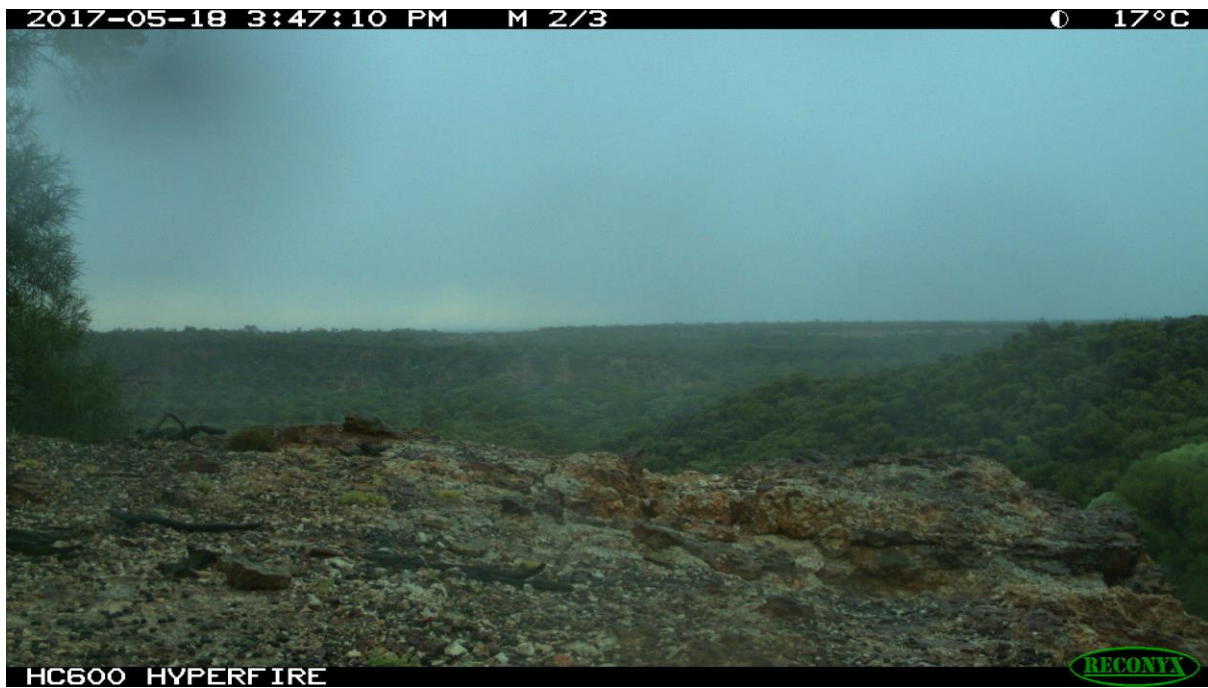


Figure E6. Vegetation and topography directly in front of Camera 6 (Site 2).



Figure E7. Vegetation and topography directly in front of Camera 7 (Site 2).



Figure E8. Vegetation and topography directly in front of Camera 8 (Site 3).



Figure E9. Vegetation and topography directly in front of Camera 9 (Site 3).

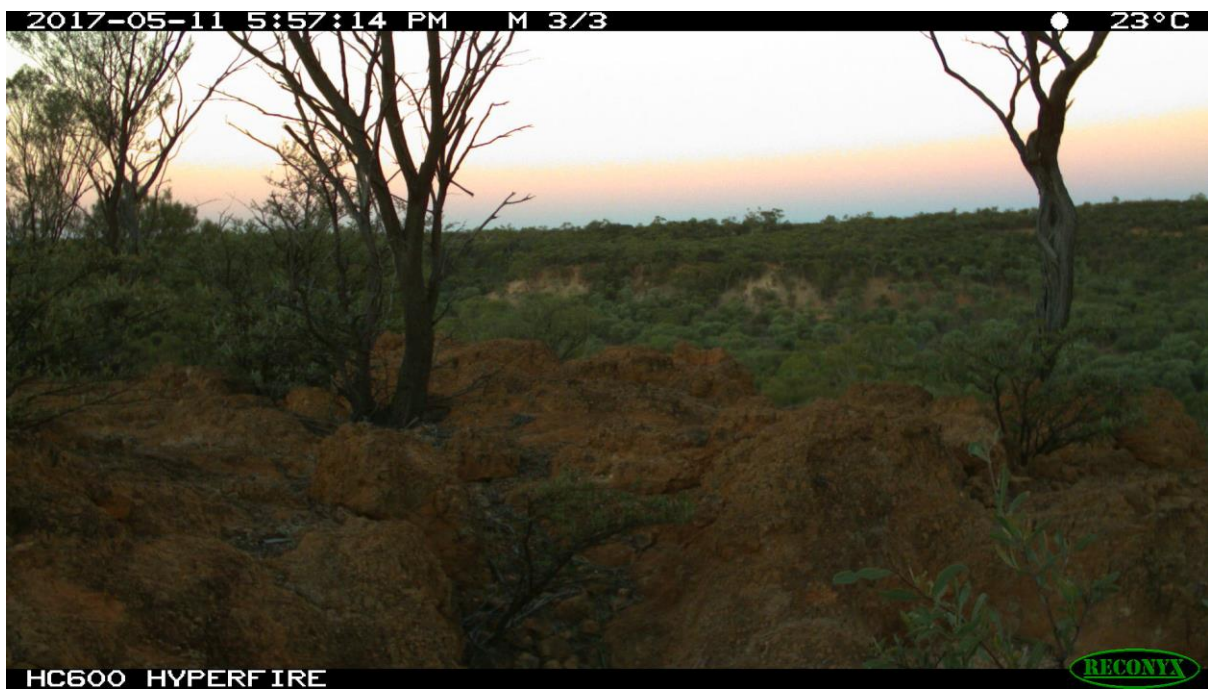


Figure E10. Vegetation and topography directly in front of Camera 10 (Site 3).



Figure E11. Vegetation and topography directly in front of Camera 11 (Site 3).



Figure E12. Vegetation and topography directly in front of Camera 13 (Site 4).



Figure E13. Vegetation and topography directly in front of Camera 14 (Site 4).



Figure E14. Vegetation and topography directly in front of Camera 15 (Site 5).



Figure E15. Vegetation and topography directly in front of Camera 17 (Site 6).



Figure E16. Vegetation and topography directly in front of Camera 18 (Site 6).



Figure E17. Vegetation and topography directly in front of Camera 19 (Site 6).