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Behavioral Differences Among Varyingly-Disturbed Populations of Eastern Grey Kangaroos (Macropus giganteus) in New South Wales, Australia

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Behavioral Differences Among Varyingly-Disturbed Populations of Eastern Grey Kangaroos (*Macropus giganteus*) in New South Wales, Australia

by

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of the requirements for the degree of

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Abstract

Despite their iconic status, kangaroo *spp*. are often treated as pests in Australia due to perceived abundance and extensive grazing behaviors. With growing suburbanization, animals such as kangaroo *spp.*, are forced to inhabit human-dominated areas. Little research has been done examining how different aspects of human-induced disturbance can varyingly affect the behavior of wild animals. Specifically, this study examined how varyingly-disturbed areas affect behaviors such as vigilance, foraging, joey emergence during the in/out stage of pouch emergence, and play in three eastern grey kangaroo (*Macropus giganteus*) populations. Results suggest that acute environmental disturbances (e.g., dogs barking or cars passing by) do alter vigilance behavior. Vigilance behaviors and time spent foraging were significant predictors of disturbance, ($F(5, 289) = 11.05$, $p < 0.000$), with an R^2 of 0.16. Surprisingly, more juveniles were observed out of pouch at the site with more frequent acute disruptions, but there were few counts of play observed. Results suggest that environmental disturbances do alter vigilance and foraging behavior, demonstrating that kangaroos will display more vigilant behavior in locations with more acute disturbances.

Acknowledgments

First of all, I would like to express my sincerest appreciation and gratitude to my advisor, Dr. Liv Baker Van de Graaff. This project would not be what it is today without your continuous support and mentorship. Our countless meetings have been exceptionally valuable throughout my time in the ABC program. Thank you to my second reader, Dr. Diana Reiss for her invaluable advice and guidance. I would also like to thank Dr. Martin Chodorow for his help with the statistics and overall data interpretation for this project.

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Introduction

Behavioral Differences Among Varyingly-Disturbed Populations of Eastern Grey Kangaroos

‘Kangaroo’ is the common name used to distinguish the larger species of Macropodidae, a family indigenous to Australia. Taxonomically, Macropodidae includes about 45 recognized species of kangaroos, wallabies, wallaroos, pademelons, tree-kangaroos, and quokkas. Under the common designation of kangaroo, there are four extant species. *Macropus giganteus* (eastern grey), *M. fuliginosus* (western grey), *M. Osphranter rufus* (red), and *M.O. antilopinus* (antilopine).

The kangaroo is a cultural icon in Australia, having been used, for example, on currency, the coat-of-arms, military emblems, and national logos. Despite their iconic status, kangaroos are often treated as pests in Australia because of perceived abundance and extensive grazing behaviors (Wilson & Croft, 2005). In reality, kangaroos are an important member of grassland and woodland ecosystems, with their grazing habits proving to be a significant contributor in nutrient cycling and habitat formation (Ben-Ami & Mjadwsch, 2018). Currently, the International Union for Conservation of Nature (IUCN) has each of the larger Macropodidae species listed as least concern (LC) (IUCN, 2020), but more recent investigations suggest populations of even those species listed as least concern may be at risk (R. Mjadwesch, macropod ecologist, pers. comm, 2020).

Human expansion has created a disproportionate increase in the development of farmland and pastures for domesticated grazers and reduced the available habitat for many kangaroo *spp.* (Wilson & Croft, 2005). Moreover, the loss of natural predators, such as dingoes and foxes, due to human expansion and hunting has affected kangaroo population dynamics (Green-Barber & Old, 2018; Wilson & Croft, 2005). With fewer natural predators, kangaroos are able to reproduce

at rates that have not been previously seen. Some evidence suggests eastern grey kangaroos (EGK) and farmed animals compete for land during drought years (ACT Government, 2017). Competition with farmed animals is one of the primary justifications for the yearly, nationwide culling of kangaroos (Ben-Ami et al., 2014; Wilson & Croft, 2005), which represents the largest wild animal cull world-wide. In 2010 alone, almost 1.5 million kangaroos were killed commercially (ACT Government, 2019). Kangaroo *spp.* included in the cull are typically *M. giganteus*, *M. fulignosus*, *M. fuliginosus fuliginosus*, *M. rufus*, *M. robustus*, and *M. eugenii* (ACT Government, 2017).

Kangaroos are forced to interact with and inhabit people-dominant areas more than their behavioral preferences indicate due to the loss of habitat (Green-Barber & Old, 2018). As a result of suburbanization and urban sprawl, kangaroos arguably embody the role of a nuisance and pest (Coulson, Cripps, & Wilson, 2014, Favreau et al., 2014; Edwards, Best, Blomberg, & Goldizen, 2013). Some experts argue that kangaroos have historically been instrumentalized for profit more so than viewed as a living animal (Boom, Ben-Ami, Croft, Crushing, & Ramp, 2012; Wilson & Croft, 2005). Citing their abundant numbers, kangaroos have been blamed for much of Australia's environmental degradation (Grigg, 1996; Wilson & Croft, 2005). The concept of killing kangaroos for population control and commercial benefit has been driving mass culling since European colonization in 1788 (Boom, Ben-Ami, Croft, Crushing, & Ramp, 2012). However, numerous studies support the notion that population control by means of a cull are not effective, nor are kangaroos the main contributor to environmental degradation (Ben-Ami et al., 2014; Carter, Pays, & Goldizen, 2009; Dawson, Mctavish, & Ellis, 2004; Favreau, Goldizen, & Pays, 2010; Grigg ,1996). Boom, Ben-Ami, Croft, Cushing, and Ramp. (2012) discuss the history of kangaroos in Australia, how they have become to be known as pests historically, and

how that perceived characteristic has followed them to this day. Authors cite the use of the term 'pest' in the late 19th Century when European landholders conflicted with kangaroos, claiming that the kangaroos were competing with their farmed animals for food (Boom, Ben-Ami, Croft, Crushing, & Ramp, 2012; Grigg, 1996). This is a narrative that persists to this day. Today, kangaroos are often labeled as pests due to perceived damage to rangeland and crops, damage to fences, competition with farmed animals, and the human-incurred damage/injury from vehicular accidents (Pople & Grigg, 1999). In the 1950's the Australian Government implemented laws and policies initiating the mass killing of kangaroos (specifically, *M. giganteus, M. fulignosus,* and *M. rufus*). The first regulation of the commercial industry came into effect in Queensland through the 'Fauna Conservation Act of 1954-1979', which required shooters to be licensed (Pople & Grigg, 1999). It was not until 1970 when the government implemented limits on the number of kangaroos to be killed commercially (Pople & Grigg, 1999). This mindset dates back to European colonization and the commercial market for kangaroo products (Boom, Ben-Ami, Croft, Crushing, & Ramp, 2012; Grigg, 1966).

Throughout Australia *M. giganteus*, *M. fulignosus*, *M. fuliginosus fuliginosus*, *M. O. rufus,* and *M. robustus* are protected under the National Parks and Wildlife Act of 1972. The act states that it is illegal to kill, capture, or sell a protected animal. However, kangaroos are able to be killed and harvested by individuals who hold federal and state licenses to do so (New South Wales Government, 2020). Licenses are granted to commercial harvesters and animal dealers as a requirement for their professions. However, non-commercial licenses are also available, issued by the National Park and Wildlife Service (NPWS) to private landholders (New South Wales Government, 2020). Non-commercial licenses fall under the licensure category of 'Permits to Destroy Wildlife' (ACT, 2019).

Permits and licenses are fairly easy to acquire (R. Mjadwesch, macropod ecologist, Pers. Comm, 2020). To apply for a 'shoot and part-process' (kangaroo harvesting) permit, an individual must be at least 18 years old, complete a firearms safety course and hold a valid firearms license, complete a game meat processing course, have their vehicle inspected to meet the Australian Standard for Hygienic Production of Wild Game Meat for Human Consumption, and have an interview with the Department for Environment and Water (Government of South Australia, 2017). Among the states, there are minimal differences in acquiring a license or permit to kill kangaroos.

Some researchers suggest that kangaroo populations are resilient to population harvests (Grigg ,1996). If so, this brings into question the efficacy of mass culls as means of population control. Drought and poor pasture conditions (due to lack of rainfall) are the two biggest drivers in keeping kangaroo populations low (Grigg, 1996). It has also been documented that farmed animals, such as sheep, significantly damage pastures in a way that is incomparable to kangaroo grazing habits. However, the misconception that kangaroos are the primary reason for land degradation is a main contributor to the continued kangaroo cull. Grigg (1996) goes on to defend the kangaroo harvest, largely for economic gain and not for animal welfare or environmental conservation. Industries that benefit from such harvesting are pet food companies, wild dog and fox control programs, animal skins industry, and other animal trade industries (ACT, 2017; Pople & Grigg, 1999). There is arguably little oversight of culling methods, leaving a large number of kangaroos injured and populations distressed. Many argue that the inhumane treatment of kangaroos needs to be recognized and addressed in order for appropriate regulations to be put in place and enforced.

Little research has been done examining how different aspects of disturbance can affect the behaviors of kangaroos. In addition to direct and indirect effects of culling, at close proximity with humans kangaroo populations contend with a variety of human-induced factors such as needing to navigate fencing, high frequency of injury and death from such fencing, vehicular accidents due to proximity to roads, harassment by dogs, and illegal hunting (Ben-Ami, et al., 2014; Wilson & Croft, 2005). The direct impact of humans, devastating wildfires, and other climate disruption-related changes further jeopardize the lives of kangaroos, in addition to populations of numerous other animals in Australia. As a result, habitats are becoming increasingly fragmented, degraded and disturbed. Much of the research concerning kangaroos has been in service of reducing negative effects of human concerns (Carter, Pays, & Goldizen, 2009; Favreau, Goldizen, & Pays, 2010; Pays, Jarman, Loisel, & Gerard, 2007). Scant research, however, exists to examine the effects humans have on these animals and their respective populations.

Kangaroo Group Structure and Dynamics

Kangaroos live in a fission-fusion social structure; they can break up and join other mobs freely, with few constraints (Jarman, 2014). Jaremovic and Croft (1991) in studying the social organization of kangaroos, specifically looking at their group dynamics and group home ranges, observed that individuals would often congregate in big mixed-sex groups throughout most of the year. During winter males will often form small same-sex groups. The small bachelor groups form a hierarchy, essential for the high variance in reproductive success (Sigg & Goldizen, 2006). Typically, mixed-sex groups (mobs) average more than forty individuals, with subgroups composed of three to seven individuals (Jaremovic & Croft, 1991; Kaufamann, 1975). Clarke,

Jones, and Jarman (1995) observed that changes in group size often occurred in the evening when individuals would break off into smaller groups and re-merge with others.

Notably, only juveniles playing with other juveniles or with their mothers has been documented; play has not been observed among other individuals (Kaufmann, 1975). Vocal communication between young kangaroos and their mothers is documented to be used for identification and localization purposes; as young kangaroos mature the amount of calls declines and is rarely observed between fully mature adults (Baker & Croft, 1993).

Pays, Jarman, Loisel and Gerard (2007) discussed vigilance in kangaroos, defining it as "an adaptive advantage of group living conferring protection against predators". As in other herd species, it is assumed that shared vigilance among the kangaroo groups reduces the need for high vigilance at the individual level. Results support the notion that as group size increases, individual vigilance decreases, and occurs for shorter bouts of time (Jarman, 1987; Pays, Jarman, Loisel, & Gerard, 2007). Scanning the landscape (a type of vigilance behavior) is not synchronous at the group level, but the onset and end of scanning can be synchronous among individuals, producing 'waves' of scanning (Pays Jarman, Loisel, & Gerard, 2007). This would allow individuals within groups to spend more time foraging if there are others in their mob also displaying vigilance activity, increasing the protection of the mob.

When comparing kangaroo populations in developed and more natural landscapes it is seen that populations appear to be denser in developed areas (Green-Barber & Old, 2018). More frequent and longer bouts of vigilance were observed, in these denser populations, reducing the amount of time individuals spent foraging (Green-Barber & Old, 2018; Maguire, Ramp, & Coulson, 2005). As crepuscular animals, kangaroos typically gather in larger mobs to forage around dawn and dusk (Dawson, 1998). However, kangaroos begin foraging in developed areas

much earlier in the day than when in more natural habitats; this is thought to be due in part to light pollution that may disrupt natural circadian activity (Green-Barber & Old, 2018; Maguire, Ramp, & Coulson, 2005). Any observed increase in vigilance could be due to increased predator activity (humans) and other environmental barriers. Higher population density is also positively correlated with an increased amount of resources (Maguire, Ramp, & Coulson, 2005).

Females were found to adjust their vigilance tactics based on the number of other females with young (Favreau, Goldizen, & Pays, 2010). Rieucau et al. (2012) examined how females, with and without young, used different vigilance tactics in mobs. They found that males also adjust their vigilance tactics for this reason. However, males repeatedly have shorter and less frequent bouts of vigilant acts than females (Clarke, Jones, & Jarman, 1995; Carter, Pays, & Goldizen, 2009; Favreau, Goldizen, & Pays, 2010; Pays, Jarman, Loisel, & Gerard, 2007; Rieucau et al., 2012). Data suggest that males who participate in predator detection may negatively affect the safety of females (Rieucau et al., 2012). Studies looking at differences between vigilance in males and females have shown that females tend to be more vigilant than males, with and without a joey present (Rieucau et al., 2012).

Observational studies have been done examining kangaroo grazing habits (Burrell, 2019; Carter, Pays, & Goldizen, 2009; Dawson, 1998; Favreau et al., 20014). For example, EGK have been documented to prefer high protein, green grasses and tend to stay away from tall, browner grasses (Ben-Ami et al., 2014; Taylor, 1984), depending on the sub-species, they can eat a variety of other plants and shrubs (Taylor, 1984). Land used for farmed animals will often have the more desirable food choice.

Although minimal research has been done examining the behavior of groups living in more and less disturbed environments (Green-Barber & Old, 2018), populations in more

disturbed areas are thought to behave in ways that are uncharacteristic in relation to kangaroos in less disturbed areas.

Ecological Impact

There is considerable debate among conservationists, farmers, and the Australian Government on how much kangaroos disrupt the environment. Most of the dispute is focused on how grazing habits may or may not interfere with farmed animal pastures. Ben-Ami, Croft, Ramp, and Boom (2010) conducted an in-depth review on the environmental impact of kangaroos and concluded that there is little chance for competition between kangaroos and farmed animals. According to Ben-Ami et al. (2010), EGK, for example, are expanding into more arid parts of Australia as a result of environmental changes (also see Dawson, McTavish, & Ellis, 2004). This expansion is thought to be on the account of extra watering sites made available for farmed animals, but it is also believed that the extensive grazing of farmed animals displaces kangaroos and forces them into other land areas (Dawson, McTavish, & Ellis, 2004). Foraging strategies remain similar to those in more undisturbed locations, largely taking place at night (Maguire, Ramp, & Coulson, 2006).

Debate exists around the impact of watering holes intended for farmed animals. Kangaroo *spp*. are documented to forage high amounts of arid grasses, and avoid most other vegetation, a behavior some researchers think is due in part to the increased availability of water (Dawson, McTavish, & Ellis, 2004). Contrary to this, other research suggests that waterhole availability does not have a significant influence on kangaroos, but rainfall from the previous year is the main driver of this foraging and movement behavior (Ben-Ami, Croft, Ramp, & Boom, 2010; Ben-Ami & Mjadwesh, 2018).

It was initially believed and rationalized that the mass killing of kangaroos would benefit their welfare during drought, increase commercial revenue, and increase environmental benefits all around (Ben-Ami et al., 2014). Researchers now suggest that current methods of kangaroo population control have more costs than benefits, proposing additional research is needed to determine if killing is justifiable from a welfare perspective (Ben-Ami et al., 2014). Such costs include direct and indirect harm to the young from the killing of adults, inhumane killing of both adults and juveniles, and a disruption of social networks (Ben-Ami et al., 2014). Being an animal with significant grazing practices kangaroos are an important part of Australia's ecosystem, aiding in vegetation control and regrowth.

Study Species: Eastern grey kangaroos (*Macropus giganteus*)

Eastern grey kangaroos (EGK) are marsupial mammals found throughout Eastern Australia, inhabiting grasslands to open woodlands (Burrell, 2019). With human disturbance altering the environment, they are common in urbanized settings. Characterized by their light grey fur, this sexually dimorphic species often sees males grow to more than twice the size of females (Burrell, 2019). Males, on average, weigh between 49-66 kg, while females will typically weigh between 16-41 kg (Joo, 2004). Individuals typically live between 7-10 years in the wild, and up to 20 years in some captive settings (Joo, 2004).

Kangaroos can mate year-round but have higher reproductive trends in the spring and summer months (Stuart-Dick & Jarman, 1988). During the mating season, males fight ("boxing") to assert dominance, which can increase their chance of mating with a female (Joo, 2004). Kaufmann (1975) noted that within mobs only males would participate in ritualized fighting. Females have a remarkably short gestation period of 37 days but young will continue to develop solely in the mothers pouch for two more months (Stuart-Dick & and Jarman, 1988). Joeys will

start to emerge from the pouch for short periods of time at around 9 months (Ben-Ami & Mjadwesch, 2018). Joeys can continue to suckle from their mothers teats until 18 months (Nave, 2002). During these stages of development, joeys can start to forage with their mothers and participate in play with their mothers and other juveniles (Stuart-Dick & Jarman, 1988). Throughout pouch emergence development joeys are at high risk of predation, causing females to be more vigilant (Banks, Newsome, & Dickman, 2000; Favreau, Goldizen, & Pays, 2010)

Goals of this Study

The study was conducted in New South Wales and focused on eastern grey kangaroos (EGK), *Macropus giganteus*. This study examined how varying characteristics of disturbance affect typical kangaroo behavior in three different locations. Dr. Liv Baker (Van de Graaff), Angus McLean (Wesleyan University, ‘16), and Mariel Becker (Wesleyan University, ‘18) previously collected data in 2015 through behavioral observation of mobs and individuals. Vigilance, foraging, play, and pouch emergence for juveniles were chosen behaviors as they have been documented as salient indicators of environmental disturbance. I analyzed the data and hypothesized that these behaviors can predict the level and characterization of disturbance among populations of EGK. Being able to better understand how kangaroos are affected by human-influenced habitat changes can lead to an improved understanding of how humans affect the wellbeing of wild animals with implications for sustainable population health.

Hypotheses

Hypothesis 1: *M. giganteus* in locations with fewer acute disturbances will exhibit fewer vigilance behaviors than those in locations with more acute disturbances due to there being fewer perceived threats.

Hypothesis 2: Joeys during the “in-out” period of pouch emergence in areas with fewer acute disturbances will be observed out of their mothers’ pouches more frequently and for longer bouts than those in areas with higher counts of acute disturbances.

Hypothesis 3: *M. giganteus* in areas with fewer acute disturbances will forage more (longer bouts) than those in an area with more acute disturbances.

Methods

Study Sites and Subjects

The study was conducted across three sites in Bathurst, New South Wales, Australia, (see Figure 1.) each with varying characteristics of disturbance. Sites were initially characterized by chronic disturbances that were identified in preliminary observations and will be discussed later on. Sites have been designated A, B, and C (see Figure 2).

Figure 1. Map of Australia. Bathurst is starred on the lower right corner in New South Wales.

Figure 2. Satellite view of Bathurst, NSW, Australia indicating the locations of the three Eastern grey kangaroo mob sites where behavioral observations were conducted.

Data were collected during winter months, June through August 2015 for a total of 31, nonconsecutive days. Observations were taken opportunistically throughout the day, between morning and dusk (approximately 07:00 to 17:00). Subjects were a convenience sample of adult, sub-adult, and juvenile *M. giganteus*.

Additional observations were set to be taken between May-June 2020 at a well-protected site. Due to the COVID-19 outbreak all travel was cancelled.

Data Collection

Researchers, Angus McLean and Mariel Becker (students from Wesleyan University) documented behaviors and additional observations every five minutes in 25-minute sessions, opportunistically throughout the day (see Appendix A for data sheets). All-occurrence sampling and focal sampling methods were used (Altmann, 1974). Each site represented a different EGK

mob. Researchers were dressed in camouflage to minimize detection by kangaroos. Additionally, preceding observations, researchers conducted a 15-minute acclimation period to allow kangaroos to adjust to their presence. Observations were conducted at a distance of 40-400 meters from the mob, using binoculars when needed. Time of day, weather conditions, location, sex, and estimated distance(m) from observer to kangaroos were recorded at the start of each observation period. Key behaviors observed were vigilance, foraging, joeys in/out of pouch, and play (see Table 1). An ethogram developed (courtesy of Dr. Liv Baker Van de Graaff) was used for behavioral recordings. Acute disturbances were documented in counts during each session; they occurred during observations (e.g., dogs barking, gunshots, car horns, construction, and humans walking near mob). Chronic disturbances (to be discussed) were attributes determined for each site, described per site preceding data collection.

Site A, a popular nature reserve, was documented to be heavily populated by humans and dogs (on and off leash) and is located in close proximity to an active gun range. People often let their dogs off leash to let them chase the kangaroos. It is heavily developed on one side, which has a heavy amount of traffic from motor vehicles as well. Site B mob resides in an empty paddock, behind a vineyard, and has been subject to culling in past years. There is a large amount of fencing that often traps the kangaroos, without an easy way out. Additionally, the mob is near a car raceway where international car races are held annually, drawing in large crowds of people and activity. People will often chase the kangaroos out from around the raceway, driving them into town where they become trapped near the vineyard. It is not uncommon for kangaroos to be caught on the racetrack. Site C is the location with the least obvious degree of chronic disturbance among the three locations (R. Mjadwesch and H. Bergen, macropod ecologist, Pers.

Comm, 2020). Although this location is in the middle of a rally car track, it is used only a couple times each year, but the site is known to have many dogs nearby on a regular basis.

Table 1.

Ethogram of Free-Living Eastern Grey Kangaroos (courtesy of Liv Baker)

Category	Behavior	Definition
Body Position		
	Vigilance #1	On all fours with head up
	Vigilance #2	Feet are on the ground, arms are off the ground, back hunched, head up
	Vigilance #3	Body is fully erect
	Lying – Head Up	All four limbs and belly on the ground, head is raised
	Lying- Arms Up	All four limbs and belly on the ground, arms are pushing up the head, neck, and torso
Foraging		
	Eating	On all fours, grazing with head down (for at least five seconds)
	Vigilant Eating	On all fours, chewing, with head up
Cleaning		
	Licking	Tongue moistens arms for at least three seconds
	Grooming	Tongue moistens body for at least three seconds
	Scratching	Claw or paw moves back and forth on fur for at least three seconds
Social		
	Playing	Mom and joey, two juveniles, two sub-adults, hitting, slapping, hanging on one another without noticeable aggression for at least three seconds
	Fighting (agnostic behavior)	Two adult males lean back on their tails and use legs to kick one another, box at one another, or hang on one another's neck for at least three seconds
	Sexual-related activity	Gentle touching or sniffing of the ears, face, or tail of a kangaroo of the opposite sex
	Rejection	Occurs after a female quickly moves away from a male after a failed courting attempt, Male shaking his head horizontally, extending his neck upwards, and standing in Vigilance #3. Then turning to face the ground and digging
Locomotion		
	Walking	Use tails to lift themselves and use arms to land
	Hopping	Bipedal movement, using feet/hindlegs to propel body forward

Data Analysis

To perform statistical analyses, counts of each behavior indicated above (see Table 1.) were sampled every five minutes in 25-minute observation sessions. Behaviors observed that were not accounted for in Table 1. were reported in the notes section of the data collection sheets. Each 25- minute session accounted for the entirety of the mob that was within sight. All start and end times were recorded, as well as weather conditions, noises, and estimated distance from researchers to kangaroos (see Appendix A).

Data were input and analyzed in SPSS (version 26.0) and Microsoft Excel. Independent samples *t*-tests were performed to compare acute disturbances across the three sites and to compare global vigilance across the three sites. A correlation matrix was calculated to determine the relationship between site location, acute disturbances, vigilance, time spent foraging, joeys in/out of pouch, and joeys playing. A multiple linear regression was calculated to predict disturbance based on vigilance, foraging time, joeys in/out of their mothers' pouch, joeys playing, and acute disturbances.

Results

A total of 296 all-occurrence samples were taken over 31 days (between June 29, 2015-August 8, 2015) (N=296) at three different site locations A (n=106), B (n=101), and C (n=83). Of the samples taken data indicate that site A had the highest recorded number of acute disturbances (107) followed closely by site C (103), while site B had fewer counts of acute disturbances (86) (See Figure 5). Observed acute disturbances were primarily documented to be gun shots, human interference, dogs, noise from motor vehicles, construction, other (e.g., birds, noises from nearby recycling center) and 'unknown', as documented in initial data collection sheets.

Independent samples *t*-tests were run to compare the differences between number of acute disturbances among the three sites. There was no significant difference in number of total acute disturbances for site A (M= 15.29, SD= 13.17) and site B (M= 12.29, SD= 10.50); *t* (6) = 0.47, *p*= 0.65. There was no significant difference in acute disturbances for site A (M= 15.29, SD= 13.17) and site C (M= 14.71, SD= 18.50); *t* (6) = 0.07, *p*= 0.95. There was no significant difference in number of acute disturbances for site B (M= 12.29, SD= 10.50) and site C (M= 14.71, SD= 18.50); *t* (6) = -0.07, *p*= 0.77.

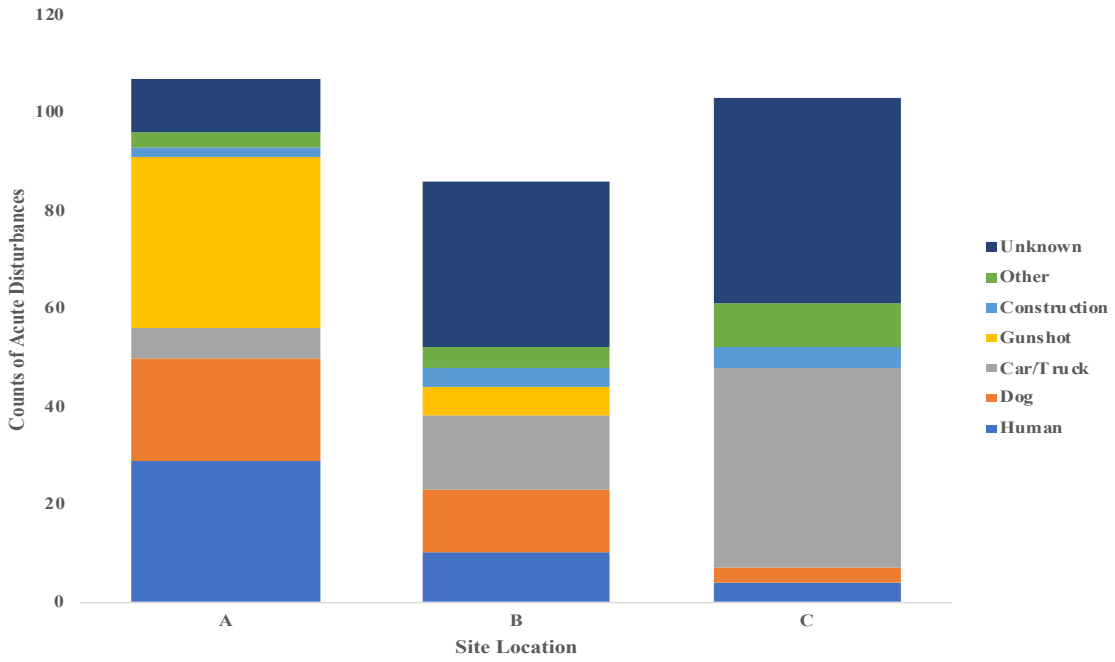

Figure 3. Observed acute disturbances (counts) of *Macropus giganteus* at sites A, B, and C in Bathurst, NSW, Australia.

Populations spent a majority of their time eating/foraging (see Figure 4). With increased counts of acute disturbances joeys were observed out of their mothers pouch more frequently, but had very few play behaviors across locations. (see Figure 4).

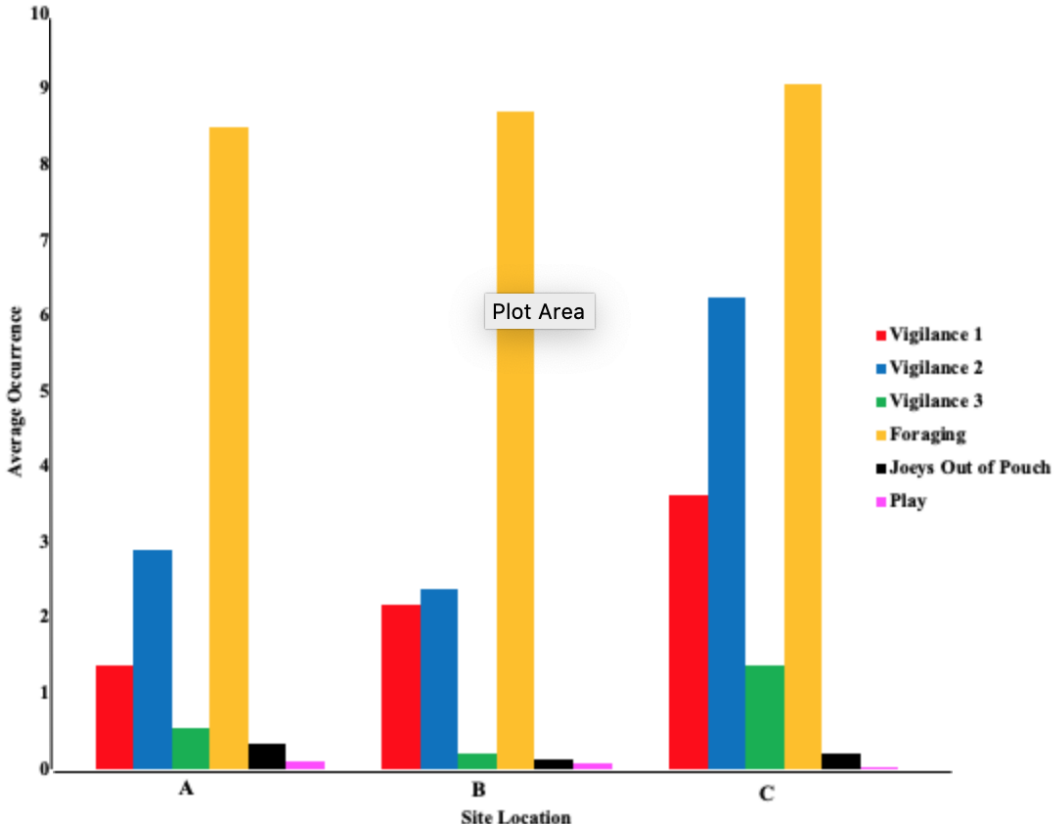

Figure 4. Averages of observed behaviors of *Macropus giganteus* at sites A, B, and C in Bathurst, NSW, Australia.

On average, there was a large difference in occurrence of global vigilance between site C and sites A and B. However, independent samples t-tests were run to compare the differences between global vigilance among the three sites. There was no significant difference in global vigilance between site A (M=171.48, SD= 127.37) and site B (M= 136.37, SD= 102.80); t (2) = 0.37, p= 0.73. There was no significant difference in global vigilance between site A (M=171.48, SD= 127.37) and site C (M=385.25, SD= 250.73); t (2) = -1.32, p= 0.26. There was no significant difference in global vigilance between site B (M= 136.37, SD= 102.80) and site C (M=385.25, SD= 250.73); t (2) = -1.59, p= 0.19.

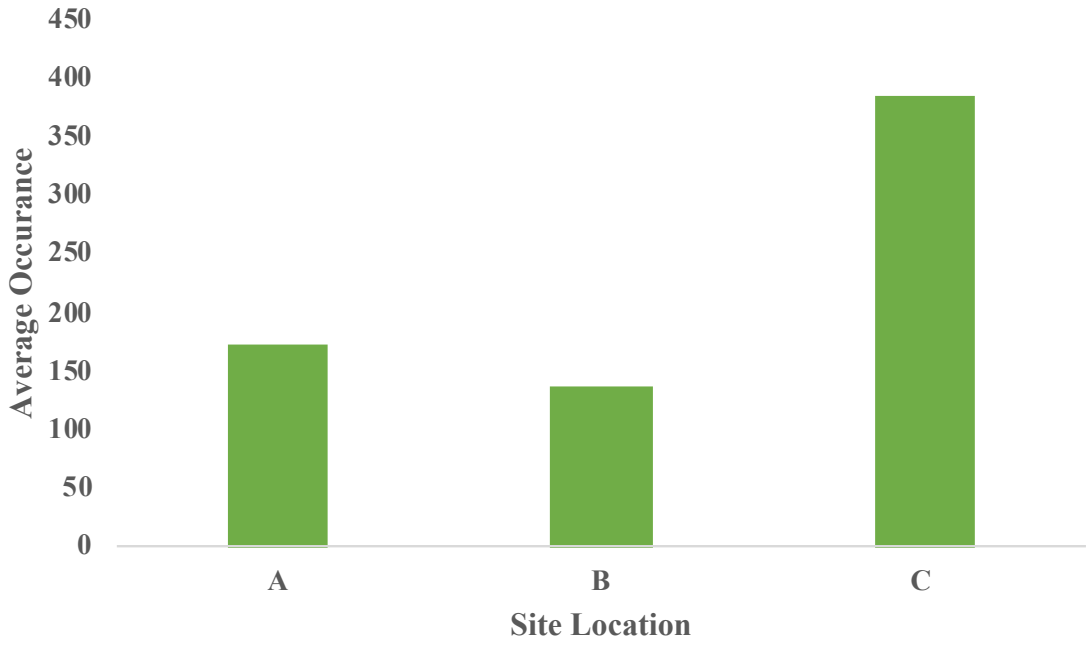

Figure 5. Average global vigilance of *Macropus giganteus* at sites A, B, and C in Bathurst, NSW, Australia.

A correlation matrix was calculated to determine the relationship between site location, acute disturbances, vigilance, time spent foraging, joeys in/out of pouch, and joeys playing. Highly significant correlations were found between site location and vigilance 1, 2, and 3; between vigilance 1, vigilance 2, and time spent foraging; and between time spent foraging and joeys in/out of pouch (see Table 2.). Significant correlations were found between site location and vigilance 3; and vigilance 3 and joeys playing (see Table 2.). Negative correlations were found between site location and joey in/out of pouch and joeys playing; between vigilance 2 and joeys playing and acute disturbances; between vigilance 2 and acute disturbances; between vigilance 3 and joey in/out of pouch and acute disturbances; between time spent foraging and acute disturbances; and between joey in/out of pouch and joeys playing and acute disturbances (see Table 2.).

Table 2.

Summary of Correlations between Site Location and Vigilance, Foraging Time, Joeys In/Out of Pouch, Joeys Playing, and Acute Disturbances

		1	2	3	4	5	6	7
1	**Site Location**							
2	**Vigilance 1**	.32**						
3	**Vigilance 2**	.32**	.54**					
4	**Vigilance 3**	.13*	.23**	.25**				
5	**Time Spent Foraging**	.05	.24**	.32**	.09			
6	**Joey In/Out of Pouch**	-.14	.03	.09	-.07	.37**		
7	**Joeys Playing**	-.10	-.03	.16**	.12*	.04	-.03	
8	**Acute Disturbances**	.03	-.04	-.06	-.02	-.06	-.01	.06

*Note. * p< .05; ** p < .01*

A multiple linear regression was calculated to predict disturbance based on vigilance, foraging time, joeys in/out of their mothers pouch, joeys playing, and acute disturbances. A significant regression equation was found ($F(5, 289) = 11.05$, $p< 0.000$), with an R^2 of 0.16. Predicted disturbance is equal to 0.83 + 0.06 (Vigilance 1) + 0.05 (Vigilance 2) + 0.01 (Vigilance 3) -0.002 (time spent foraging) - 0.01 (Joeys in/out pouch), where vigilance and joeys in/out of pouch are measured in counts and time spent foraging was measured in minutes. Vigilance 1, vigilance 2, and time spent foraging were significant predictors of (acute) disturbance.

Discussion

The purpose of this research study was to investigate the relationship between salient eastern grey kangaroo behaviors and disturbance characteristics at different population sites. Each of the three sites chosen suffered from numerous and varied acute and chronic disturbances. Individual and group behaviors can be indicators of abnormalities in the environment. With growing (sub)urbanization many animals are forced to adapt different lifestyles than they typically would without such disturbances. By being able to analyze EGK

behavior in severely disturbed environments we can apply a behavioral interpretation to how human expansion and culling play a role in those behaviors in comparison to EGK in locations with fewer disturbances.

Of the three locations, site A had the highest occurrence of acute disturbances followed by C, with site B having lowest occurrence of recorded acute disturbances. Vigilance behaviors (V1 and V2) and time spent foraging were significant predictors of disturbance, which support hypotheses 1 and 3 (*M. giganteus* in locations with fewer acute disturbances will exhibit fewer vigilance behaviors than those in locations with more acute disturbances due to there being less perceived threats; *M. giganteus* in areas with fewer acute disturbances will forage more (longer bouts) than those in an area with more acute disturbances). Hypothesis 2, which predicted joeys during the "in-out" period of pouch emergence in areas with fewer acute disturbances will be observed out of their mothers' pouches more frequently and for longer bouts than those in areas with higher counts of acute disturbances, was not supported. Rather, a negative correlation was found between joeys in/out of pouch and number of acute disturbances. Joeys out of pouch during the in/out period of pouch emergence also could not be used as a predictor for disturbance and had a negative correlation with site location (disturbance).

Joeys during the in/out period of pouch emergence and V3, which indicated heightened alertness were not significant predictors of disturbance. As expected, significant correlations were found between vigilance behaviors (V1, V2, and V3) and site location. No correlation was found between site location and time spent foraging. The significant, negative correlation between site location and joeys in and out of the pouch could be due in part to the characteristic of disturbances in each location, regardless of documented counts of acute disturbances during observations. Specifically, in site B, which was subject to periodic culling, a negative correlation

could indicate the ability to distinguish between type and severity of threats that are present at a current moment (e.g., threatening or nonthreatening human behavior) (Austin & Ramp, 2019). Anecdotal evidence provided by R. Mjadwesch, a macropod ecologist, (pers. comm, 2020) found unique EGK behavior in a protected area. The site was described as a 'joey nursery', wherein joeys were readily observed out of their mother's pouches and engaged in exploratory and play behavior. To the degree described, this has not been seen in other EGK mobs. According to R. Mjadwesch this may suggest that there are significant, broad impacts of human-induced disturbance on EGK populations. Although anecdotal at this time, the disparity of joey behavior observed at sites A, B, C and that at the (more) protected site may also suggest that the low level of joey exploration and play at sites A, B, and C was not merely due to baseline behavior of a prey species, but due more specifically to the anthropogenic nature of the disturbances. In a study examining how red fox population density affects population growth rate in EGK, higher predation rates resulted in fewer occurrences of joeys observed out of the pouch and an increase of vigilance behaviors (Banks, Newsome, & Dickman, 2000).

Results for hypotheses 1 and 3 are consistent with previous studies, indicating that kangaroos will spend less time foraging in areas with more acute disturbances (Green-Barber & Old, 2018; Hume, Brunton, & Burnett, 2019; Maguire et al., 2005; Riceucau et al., 2012). As suggested by the hypotheses, significant correlations between types of vigilance behaviors and site location were expected to rely on the number of disturbances documented during observations because animals are affected by and adapt to changing environments. Results also correspond with previous studies in that kangaroos in more disturbed areas will be more vigilant than those in a lesser disturbed environment (Edwards et al., 2013; Favreau et al., 2014). Overall, results suggest that environmental disturbances do alter vigilance and foraging behavior.

Kangaroos, specifically EGK, are highly sensitive to predatory threats and other disturbances; they have to be comfortable in an area in order to carry out relaxed, naturalistic behavior (R. Mjadwesch, macropod ecologist, pers. comm, 2020). Even if there are no perceived immediate threats, EGK can still display vigilance behaviors as if there were a perceived threat, especially if threats have been experienced in that area in the past. Winnie and Creel (2006) investigated behavioral responses of individual and herds of elk, another large grazing prey animal, in response to wolf presence. Similar to EGK, female elk tended to display more vigilance behaviors than males, and consequently spent shorter amounts of time foraging even when not in imminent danger.

However, it is possible that the types of disturbances documented during our observations influenced behavior. For example, site B, which had the lowest recorded number of acute disturbances was also the site known to be subjected to periodic culling. Although this study may not have been able to discern the more nuanced impact of different disturbances, we know the quality of disturbances can varyingly alter behavior and should be studied further. For example, sounds from a construction site likely elicit different behavioral reactions than would dogs, as dogs may be perceived as a direct threat rather than a regularly occurring loud noise that has no history of causing harm. Austin and Ramp (2019) observed that EGK can respond to the frequency and intent of human disturbances, suggesting that kangaroos can distinguish between categories of disturbance.

Fear ecology has been extensively studied in non-human animal relationships (Brown, Laundré, & Gurung, 1999; Laundré, Hernandez, & Ripple, 2010; Parsons & Blumstein, 2010) and it has not been until recent years that studies have considered humans in this framework (Austin & Ramp, 2019; Ben-Ami & Mjadwesch, 2018; Gaynor et al., 2020; Støen et al., 2015).

Humans are viewed as novel threats to EGK (Austin & Ramp, 2019), therefore eliciting a high fear response. Due to this, with high occurrences of human activity, it is likely that EGK will respond with an increase in vigilance behaviors, as may have been observed in our study.

Parsons and Blumstein (2010) studied the olfactory response of western grey kangaroos to predatory scents (dingo urine) over repeated exposure. Researchers initially found that only after repeated exposure would kangaroos respond with an alarm state, or increased vigilance. From that, habituation may be falsely interpreted since mobs that were exposed to coyote urine (a novel scent) did not (initially) produce alarm responses. It is possible that in our study the acclimation period prior to data collection to show that the researchers were not a threat to the mobs being observed, may have been a confounding variable. Further research should be done examining how repeated human (scent) exposure affects kangaroo behavior. Additionally, camera traps and audio recordings could be used to minimize the possibility of unintentional disturbances produced by human researchers and observers. Speaking to kangaroo awareness of humans, a recent study suggests that kangaroos may be more cognitively aware than previously thought. To test human-directed kangaroo communication, Dr. Alan McElligott (see Blake; 2020) tested a small sample of captive kangaroos (N=11) with treat-filled, un-openable puzzle boxes. During the tests, kangaroos would often stare or scratch at researchers to elicit help, communication that is seen in domesticated animals when presented with the same scenario. This study is one of the first to highlight human-directed kangaroo communication.

Prior to this study, the effect of varying environmental disturbances on free-ranging kangaroo behavior had been minimally studied but recent results suggest that it does affect behavior (Austin & Ramp, 2019; Green-Barber et al., 2018; Hume et al., 2019; Laundré, Hernandez, & Ripple, 2010). Environmental factors have a major role in kangaroo behavior, but

the specificities of disturbance have not been adequately investigated. Due to each of the study sites having significant acute and chronic disturbances it is likely that minimal relaxed behavior was observed, such as joeys out of pouch and play. It should be mentioned that it is becoming increasingly difficult to find populations that have minimal disturbances in their environment as natural disasters and human-caused disturbances take over much of the environment. For example, the site A population resided within a nature preserve but was still exposed to a number of acute disturbances, that included gunshots, and direct presence of dogs and people. Due to this it is not surprising that few counts of joeys out of pouch and play behavior were observed.

It is important to note the limitations of this study. We initially set out to see if different disturbances elicited different behavioral responses from the kangaroos, but the data collected were not sensitive enough to isolate the effects, if any, of specific disturbances. Also, we were not able to observe a population in a minimally disturbed area thus we lacked a control group for comparison. Thus, we cannot say that the behaviors observed were due to any specific type of disturbance. Additionally, different amounts of observations were taken at each site as opportunistic sampling methods were utilized. While this difference was not significant, it may be helpful to have equal sample sizes in future studies, when possible. Since this study was conducted during summer months it should not be generalized to the entire year as there may be hormonal changes during mating season.

In conclusion, each site had varying levels and types of disturbance. Our results suggest that kangaroos will display increased vigilance behaviors in locations with more acute disturbances, which is consistent with past reports. Such findings can be used to further understand how eastern grey kangaroo behavior can be affected by various disturbances. I want to highlight the idea that different types of disturbances may elicit different behaviors from

kangaroos. Further research should be done examining the effect of different types of disturbances on kangaroo behavior and how it may affect joeys during the in/out phase of pouch emergence to better understand the species in all stages of life. The data presented in this study provide insights into understanding how human-induced disturbances affect free-roaming EGK behavior, provides additional support of past findings, and will hopefully inspire future research in this area.

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Appendix A

EGK Behavioral Observations

General Information

Location :
Date (m/d/y) :
Observation day (Day 1, 2, 3, etc.):
Start time (24 h clock):
Weather Conditions:

GPS Coordinates	Temperature	Time	Demographic Information
			Total Total sex ratio: F M Adult: (F) (M) Subadult: (F) (M) Possible Mothers Juveniles
			Total Total sex ratio: F M Adult: (F) (M) Subadult: (F) (M) Possible Mothers Juveniles
			Total Total sex ratio: F M Adult: (F) (M) Subadult: (F) (M) Possible Mothers Juveniles
			Total Total sex ratio: F M Adult: (F) (M) Subadult: (F) (M) Possible Mothers Juveniles
			Total Total sex ratio: F M Adult: (F) (M) Subadult: (F) (M) Possible Mothers Juveniles

EGK Behavioral Observation Collection Sheet: Demographics

EGK Behavioral Observations- FOCAL

Location: Date (m/d/y) :
Observation day (Day 1, 2, 3, etc.) : Start time (24 h clock):
Observer: Estimated distance to kangaroos:
Kangaroo information: Weather/ Visibility:

25- Minute Focal Observations

	0-5	5-10	10-15	15-20	20-25
Body Position (V1, V2, V3, Laying [HU/HA], eating, vigilant eating [in frequency])					
Cleaning (licking, grooming, scratching)					
Social Interaction (playing, fighting, sexual activity)					
Locomotion (walking/ hopping)					
Notes					

EGK Behavioral Observation Collection Sheet: Focal Sampling

EGK Behavioral Observations- ALL OCCURRENCE

Location: Date (m/d/y) :
Observation day (Day 1, 2, 3, etc.) : Start time (24 h clock):
Observer: Estimated distance to kangaroos:
Kangaroo information: Weather/ Visibility:

25- Minute All Occurrence Sampling

	0-5	5-10	10-15	15-20	20-25	At 25
VI						
V2						
V3						
Lying						
Lying HU						
Eating						
Licking						
Grooming						
Scratching						
Playing						
Fighting						
Sexual Activity						
Head Shaking						
Mothers						
Joeys Out of Pouch						
Total Mob Count						

EGK Behavioral Observation Collection Sheet: All-Occurrence Sampling