BEHAVIOURAL INVESTIGATIONS AND HABITAT USE BY THE NORTHERN HAIRY-NOSED WOMBAT (LASIORHINUS KREFFTII) AT RICHARD UNDERWOOD NATURE REFUGE

Submitted for Masters of Applied Science,
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Abstract

One of the world's most endangered mammals, the northern hairy-nosed wombat (*Lasiorhinus krefftii*), is geographically restricted to Epping Forest National Park (EFNP) (Johnson, 1991) where a population of approximately 200 wombats resides (Taylor, 2013). However, to secure the species, an insurance population of ten individuals has been established at Richard Underwood Nature Refuge (RUNR) near St George, within the species former range.

The Department of Environment and Heritage Protection (EHP) has an ongoing management program for the northern hairy-nosed wombat at both locations and this study presented an opportunity to explore trapping techniques, habitat utilisation and behavioural investigations of the wombat. The study was based at RUNR, investigating the translocated population. This is the first study to investigate habitat utilisation and behavioural patterns of northern hairy-nosed wombats outside EFNP.

Habitat utilisation of wombats at RUNR was investigated based on vegetation assessments, vegetation mapping of the park and wombat activity in different vegetation communities. Over a sampling period of six months, sightings of wombats were highest in the open woodland vegetation community with wombat activity influenced more by overstorey density than understorey density. Wombat sightings were generally low. The study showed no significant environmental parameters influencing temporal patterns of wombat activity; however, day temperature was the most explanatory factor (P=0.194).

Behaviour was explored using trail cameras deployed by EHP at burrow entrances. Both solitary and social events were recorded; however, social events accounted for only 0.31% of total observations. There was a high use of burrows by multiple wombats; however, rarely at the same time. It is suggested that wombats actively adapt an avoidance strategy at and near burrow entrances as indicated by the very low occurrence of social interaction.

The study showed a general consistency of core habitat structure, and behavioural patterns, with what has previously been observed at EFNP. Wombat activity is focused in specific vegetation structures, which limits the wombat distribution throughout the park.

This study utilised behavioural classifications of northern hairy-nosed wombats, and is only the second study to explore behaviour of the species, and the first to use a non-invasive method that has been demonstrated to be effective and labour efficient. This study explores some of the knowledge gaps in a critically endangered mammal by adaptation of a non-invasive sampling method. It clarifies the importance of known habitat utilisation in terms of establishment of a new population, and interspecific behaviour to accommodate for size, burrow use and species management for a potential second translocation site.

Acknowledgements

I gratefully acknowledge the funding received from The Wombat Foundation through the Department of Environmental and Heritage Protection, which has supported this research.

This research higher degree candidature was supported by a scholarship from the Danish Government. I gratefully acknowledge their support.

Special thanks must be given to all the people who have supported this project. Thank you to the Department of Environment and Heritage Protection for assisting in field work and technical support. Thanks to David Harper, my external supervisor, who helped fund materials and field sessions for this project, to Angela Verner for assisting in field sessions and to Emma Gatehouse for technical support with graphics and fieldwork.

I would like to thank my supervisors, Professor Owen Nevin (CQU) and Dr Alistair Melzer. They continued to support me throughout the project, even when we ran into setbacks. Thank you for your contribution of comments on drafts and methods and for helping me improve my writing style. They have given me a great experience at Central Queensland University, and I could not have pulled through without them.

To Central Queensland University, a big thank you for giving me the opportunity to do my research on a critically endangered animal. All administrative aspects, from purchasing of fieldwork materials to approval of animal ethics was in corporation with Central Queensland University. Animal ethics and a Scientific purpose permit was approved through the Department of Environment and Heritage Protection and Department of Agriculture and Fisheries (DAFF).

Thanks to all the volunteers who have contributed to fieldwork assistance. It couldn't have happened without you. Thanks also to the caretakers at the Richard Underwood Nature Refuge, Jill and Alan Don, and Mary and John Nowill, who all offered their assistance with fieldwork, as we all share the same passion for saving the species.

Professional editor, Dr Leonie Barnett, provided copyediting and proof-reading services, according to the guidelines laid out in the University-endorsed national 'Guidelines for Editing Research Theses'.

To all my friends, in Australia and around the world, thank you. You have always been supportive of me and my decisions and have always been there when I needed it the most. You helped me keep my motivation up, even when things didn't go as planned. And researching an elusive animal never goes to plan. I really appreciate that you have been putting up with me!

And finally a special thanks to my family. Thanks for letting me take the opportunity to move across the world to pursue my passion for conservation biology, and letting me stay for another 2 years, even though I was only supposed to be away for 6 months. Thanks for always believing in me, and putting up with me when things have been hard. I wouldn't have done it if it hadn't been for you. Thanks for always calling me, even if you have to be up in the middle of the night to accommodate for the time difference, and always to encouraging me to follow my dreams. I can now say I truly have!

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Chapter 1: Introduction

1.0 Introduction

The critically endangered northern hairy-nosed wombat (*Lasiorhinus krefftii)* is restricted to one natural population at Epping Forest National Park (EFNP) and one translocated population at the Richard Underwood Nature Refuge (RUNR) near St George. One of the more recent threats faced by these populations is the invasion of the exotic buffel grass (*Cenchrus ciliaris*). This grass is found to be abundant in disturbed areas, especially around burrows where it outcompetes the native grasses found in the parks and this consequently results in loss of species richness in wombat habitat (Jackson, 2005). The physical structure of buffel grass is different from the native grasses, and may cause a barrier for the wombats. It has been speculated that the buffel grass may have an impact on the behaviour of the wombats relating to feeding strategies and ranging behaviour. This project seeks to explore these issues.

2.0 Taxonomic relationships

The northern hairy-nosed wombat is one of three extant species of wombat (Taggart *et al.,* 2003). All wombats belong to the taxonomic family Vombatidae of the order Diprotodontia of the class Mammalia (Phillips and Pratt, 2008). Wombats occur in two genera, *Vombatus* and *Lasiorhinus*, the bare-nosed and hairy-nosed wombats, respectively (Stephenson, 1967; Barboza, 1993). The genus *Vombatus* has only one species, the bare-nosed wombat (also known as the common wombat) *Vombatus ursinus* (Shaw, 1800), while the genus *Lasiorhinus* has two species, the northern hairy-nosed wombat *Lasiorhinus krefftii* (Owen, 1873) and the southern hairy-nosed wombat *Lasiorhinus latifrons* (Owen, 1845). Even though the two genera and three species of wombat are similar in size, they can be told apart from their crania and postcranial skeletons that are quite different from each other (Murray, 1998). Stephenson (1967) found that species of wombat can be distinguished from each other based on characteristics of incisors, cranial bones and the mandible; especially the orientation of the upper incisors, which differs between the two genera, with those in *Vombatus* being obliquely angeled whereas those in *Lasiorhinus* are straight (Stephenson, 1967).

The name *Lasiorhinus* comes from Latin, where *Lasior* means hairy or shaggy and *rhinus* means nose (Van Dyck and Strahan, 2008), whereas for the northern hairy-nosed wombat, *krefftii* refers to the finder (Gerrard Krefft, an Australian curator) (Treby, 2005), and for the southern hairy-nosed wombat, *latrifrons* refers to their wide nose. For the common wombat, *Vombatus* means wombat and *ursinus* means bear-like (Stephenson, 1967).

3.0 The hairy-nosed wombat

Both the southern and northern hairy-nosed wombats have adapted to arid environments characterised by droughts, low rainfall and poor food quality (Wells, 1978a; Evans, 2000; Evans *et al.*, 2003; Hogan *et al.*, 2011). Some similarities or dissimilarities between the hairy-nosed wombats are outlined, in order to understand the underlying biology and ecology of the less studied northern hairy-nosed wombat.

Compared to the southern hairy-nosed wombat, there have been relatively few studies conducted on the northern hairy-nosed wombat. This is partially due to the fact that the population has previously been estimated to be as low as 20–30 animals (Gordon *et al.*, 1985), and invasive research protocols would not have been acceptable at such a vulnerable stage. Although breeding occurs in different seasons for each species, they have a somewhat a similar breeding pattern (Crossman *et al.*, 1994; Gaughwin *et al.*, 1998; Hamilton *et al.*, 2000). Furthermore, both species have female dispersal (this is also the case for the bare-nosed wombat), and this has been investigated for both the southern and northern hairy-nosed wombats (Johnson, 1991a; Johnson and Crossman, 1991; Walker *et al.*, 2008). Finlayson *et al.* (2005) described their home range analysis of the southern hairy-nosed wombat as being smaller than the homerange of the northern hairy-nosed wombat, but similar to other studies of the southern hairy-nosed wombat. When comparing ranging behaviour between hairy-nosed wombats and common wombats, the latter tends to have a smaller home range (Johnson, 1991a; Evans, 2000), which could be due partially to the difference in environmental adaptations.

3.1 Distribution

The northern hairy-nosed wombat has historically only been recorded at three sites in Queensland and New South Wales: Deniliquin in southern New South Wales (Dawson 1983); St George/Moonie River in southern Queensland (De Vis, 1900; Starbridge, 2006) and Epping Forest, central Queensland (Johnson, 1991a; Crossman, Johnson and Horsup, 1994; Gerhardt *et al.*, 2000; Horsup, 2004; Triggs, 2009). Only a few specimens of the northern hairy-nosed wombat have been collected from the two southern sites, and the species is thought to have become extinct from the area in the 1900s (Dawson, 1983). The first northern hairy-nosed wombat specimen from central Queensland was collected in 1937 (Triggs, 2009);

however, the species was recorded from the European settlement in the 1860s (Horsup *et al.*, 2007).

The only natural population remaining of the northern hairy-nosed wombat is at Epping Forest National Park (EFNP), near Clermont, central Queensland, Australia (-22.35656,146.70621) (Johnson, 1991b). A translocated population is located near St George, in southern Queensland (-27.6665, 148.70148), where 15 animals from EFNP were relocated in 2009–2010, following a recovery plan (O'Callaghan, 2007). Since European settlement, the species range has contracted (Smales, 1994; Hoyle *et al.*, *1995*; Woolnough and Johnson, 2000). It is, however, thought that the species was low in abundance before settlement, and this along with a disjunct distribution, made the species particularly sensitive to disturbance (Hoyle *et al.*, 1995; Horsup, 1996; Gerhart *et al.*, 2000), as seen in the southern hairy-nosed wombat (Taylor, 1977). The species decline in range and abundance is thought to have occurred over the past 100 years, and is described as irregular major reductions rather than gradual reduction (Crossman, 1988), with the introduction of high intensity agriculture, competition for food resources with native and introduced grazers, and environmental factors such as wildfires and drought (Horsup, 2004).

The southern hairy-nosed wombat, although considered to be common, has a disjunct distribution throughout semi-arid South Australia with four main occupied regions: Nullabor Plain, Gawler Ranges, northwestern Eyre Peninsula and the Murraylands (Wells, 1978b; Walker, 2004). The two hairy-nosed wombat species occupy habitats often characterised by high drought probabilities, low rainfall, and an environment with low nutrient soils and low quality plants/grasses (Woolnough, 1998) (Figure 1).

Figure 1. Distribution of all three extant wombats. Distribution map borrowed from Evans (2000, p. ?)

The common wombat is found primarily in alpine grasslands throughout south-east Australia, including Tasmania (McIlroy, 1977; Hume, 1999) (Figure 1), occurring in temperate climates, with their main habitats being forest covered.They can also be found in modified habitats including cleared grazing areas and plantation regions (Rishworth *et* al., 1995; Evans *et al.*, 2006).

3.2 Habitat and diet

All three wombat species are grazers, feeding primarily on perennial grasses, sedges and soft new growth of annual grass species, often high in fibre and low in nitrogen content (Barboza and Hume, 1992; Barboza, 1993). Grasses contribute more than 90% to the northern hairy-nosed wombat diet (Hoyle *et al.*, 1995; Woolnough, 1998; Horsup, 2004; Evans, 2008).

In 1988, Crossman investigated the diet of the northern hairy-nosed wombat by analysing faecal pellets. He found that it primarily grazes on native grasses such as purple lovegrass (*Eragrostis lacunaria*), golden beard grass *(Chrysopogon fallax),* black spear grass (*Heteropogon contortus*), sedges (*Fimbristylis* spp.) and wire grass (*Aristida* spp.) (Crossman 1988; Woolnough, 1998). However, studies show that even though buffel grass may be affecting the wombats negatively, the grass may become important during droughts as a food resource (Woolnough and Foley, 2005).

Wombats have several unique features that make them well adapted to their fibrous diet. These include continuously growing teeth, which compensate for feeding on the fibrous material (Barboza and Hume, 1992; Johnson, 1998), a prominent cardiogastric gland in the stomach (Hingston and Milton, 1968) and a large colon (Barboza and Hume, 1992).

Wombat teeth include two upper and two lower incisors, which function to cut off the grass (Crompton *et al.*, 2008; Fowler, 2011), and molars, or cheek teeth, that are used to break down the fibrous and low nutritional grass into smaller digestible sizes (Hume, 1999). Grasses are known for their high silica contents (Sanson *et al.*, 2007; Hummel *et al.*, 2011) that occur as phytoliths, also known as dietary crystals

(Massey *et al.*, 2006; Sanson *et al.*, 2007; Hummel *et al.*, 2011). The teeth of the wombat are exposed to high wear due to this silica content (Massey *et al.*, 2006; Hummel *et al.*, 2011). Wombats have adapted to this by having rootless teeth, known as hypselodonty (Massey *et al.*, 2006; Fraser *et al.*, 2008; Billet *et al.*, 2009). Wombats have a split upper lip which makes them capable of ingesting leaves, roots and sedges, and being able to graze close to the ground when environmental factors, such as drought, prevent the grass from shooting (Barboza and Hume, 1992; Fowler, 2011).

Hypselodonty also allows wombats to live much longer than other similar sized grazing marsupials, such as the eastern grey kangaroo (*Macropus giganteus*) (Wells, 1989), where tooth wear limits life span. Herbivorous mammals depend on fermentation of plant structures by gastrointestinal bacteria (Demment and Van Soest, 1985; Clauss *et al.*, 2003). Herbivores have a large variety of digestive adaptations to consume the fibrous diet (Barboza and Hume, 1992) and generally fit into two groups, based on digestion strategies: foregut fermenters and hindgut fermenters (Hume, 1999).

Wombats belong to the hindgut fermenters, having colonic fermentation as a digestive strategy (Barboza and Hume, 1992; Woolnough, 1998; Evans, 2000). Wombats have a well-developed and voluminous colon, where most microbial fermentation takes place (Hume, 1999). This means that they have highly efficient absorption of the colonic nutrients, and gives them a relatively large digestive capacity. Most colonic fermenters spend large amounts of time feeding. This, however, is not the case for wombats because of their burrowing lifestyle and their intolerance of high temperatures; consequently the wombat is unique in its digestive strategy (Woolnough, 1998).

The cardiogastric gland is a specialised feature found in only 12 other mammal species (Ziolkowska *et al.*, 2014), including the koala (Milton *et al.*, 1968; Krause and Leeson, 1973), the dusky and northern shrew opossums (Richardson *et al.*, 1987) and the European beaver (Ziolkowska *et al.,* 2014). Researchers are unsure of the exact function of the cardiogastric gland (Hume, 1999; Triggs, 2009); however, it contributes a large proportion of gastric secretion. It has been proposed to help digestion by absorbing proteins and lipids from plant cells in the stomach and small intestine instead of in the colon (Barboza and Hume, 1992).

The southern hairy-nosed wombat has been found to graze primarily on perennial grasses, especially *Stipa nitida* (Treby, 2005). Evans (2008) found that the diet of the common wombat varies with seasons, reflecting the seasonal changes in food resources. However, it is possible that the seasonal variation in diet could be related to seasonal selection of feeding ranges (Evans, 2008).

3.2.1 Wombat habitat requirements

The three species of wombat all inhabit different environments; however, the southern hairy-nosed wombat and northern hairy-nosed wombat display some similarities in habitat choice (Johnson, 1998).

The common wombat inhabits more temperate regions (Rishworth *et al.*, 1995; Johnson, 1998; Evans *et al*., 2006) and usually in areas with mountains in south east Australia (Evans *et al*., 2006). Their general habitat is characterised by high forest coverage; however, these do vary, and common wombats also inhabit habitats that include scrub. Common wombats have adjusted to expanding human activity by exploiting modified habitats, such as areas of agriculture, which provide food resources for grazers, including livestock (Evans *et al*., 2006).

The southern hairy-nosed wombat lives in semi-arid areas, characterised by hot weather conditions (Ruykys *et al*., 2009; Whittington-Jones *et al*., 2011). Ideal wombat habitat experiences low rainfall and high drought frequency (Walker, 2004). Key habitat characteristics include stable soil profiles to provide sufficient stability to support a burrow, and perennial grasses essential in the diet of the species (Walker, 2004).

3.2.2 Northern hairy-nosed wombat habitat requirements

The first major investigation of northern hairy-nosed wombat habitat occurred in 1997 (Cox, 1998) and a range of different methods have been used in the search for suitable wombat habitat. In 1998, Cox identified possible wombat habitat by using satellite imagery, Arcview (Esri) and the Atlas of Australian Soils (Isbell *et al*., 1967) to identify potential targets. A total of 44 sites were selected for further assessment of suitability, and nine of these were considered possible wombat habitat; furthermore, five of these sites were considered as key potential habitat, however, only one site was reported to have previously supported populations of the northern hairy-nosed wombat (Cox, 1998). Lees (2002) used regional ecosystem mapping to identify potential wombat habitat. Whilst 20 sites were sampled, the investigation was incomplete and was later revisited by Wormington (2004). Wormington (2004) took up the regional ecosystem method, and identified another nine possible sites with suitable wombat habitat. Wormington (2004) combined the data from both Cox and Lees and narrowed the list of possible sites down to six. Wormington described the sites as either ‘first tier’ or ‘second tier’. First tier locations were locations described as ‘very similar’ to EFNP. Second tier locations were described as ‘similar’ to EFNP.

In 2007, an investigation of northern hairy-nosed wombat habitat was undertaken (Horsup *et al*., 2007). This investigation was designed to explore suitable wombat habitat in Queensland’s southern region for the establishment of a second population (Horsup *et al*., 2007).

Soil characteristics are a main factor for suitable wombat habitat because of the wombat’s fossorial behaviour. The baseline for assessing the suitability of the soil material is based on studies at EFNP. In EFNP, the ideal soil profiles for burrowing showed sands, loamy sands, sandy loams and sandy clay loams (Forster, 2007). The Department of Environment and Heritage Protection (EHP) decided on a minimum depth of 2.5 metres to assess suitable soil, sufficient for burrowing. However, fine grained sands and loamy sands, with low clay content are susceptible to collapse, which has happened to burrows at EFNP (Forster, 2007).

The investigations of soil material at RUNR showed mixes between deep to very deep red sandy and loamy textured soils. Preliminary studies of the soil profiles at RUNR was compared to those of EFNP. The soils found at RUNR belong to the heavier textures, hence there is higher clay content in the soil, which consequently gives the soil a better cohesion. It was suggested that the soils found at RUNR are more suitable for burrowing than those at EFNP, based on depth, clay content and structure of the soil (Forster, 2007).

4.0 Translocation

Translocation is the movement of an organism, by humans, from one area to another for release (IUCN, 2013). Translocation or re-introduction aims to re-establish a species, in a viable population, within its former indigenous range (IUCN, 2013). Translocation is often used to restore native species (Griffith *et al*., 1989). Species today face rapid extinction rates, habitat loss, and a consequence of this is disrupted dispersal and interchange mechanisms (Griffith *et al*., 1989). A translocation is considered successful if it results in a self-sustaining population; however, active management is required (Griffith *et al*., 1989). Griffith *et al*. (1989) suggests that translocations are more successful if the species is released into historical ranges than if the location does not have a historical range recorded for the species. The northern hairy-nosed wombat was the ideal species for translocation, because of the fear of extinction as a result of stochastic events, including wildfire or disease (Lees, 2002).

For optimal translocation of animals, guidelines provided from the International Union for Conservation of Nature (IUCN) (2013) should be followed, which include:

- Re-introductions should only take place where the original causes of extinction have been removed;
- Re-introductions should only take place where the habitat requirements of the species are satisfied; and
- The species should only be re-introduced if measures have been taken to reconstitute the habitat to a state suitable for the species.

Translocation is crucial for an endangered animal, and especially crucial for northern hairy-nosed wombats that are all distributed in the same geographical area. These guidelines help researchers to find a potential third translocation site, which is the longterm goal for the species (to eliminate the possibility of multiple populations being affected by, for example, natural disasters).

The Regional Ecosystem for the RUNR, from the Queensland Government, under the section of biodiversity status and broad vegetation group, is listed as 6.3.17/11.3.2 in a 70/30 split. This means that the bioregions at RUNR are based on mulga lands and the southern brigalow belt (See Appendix B).

The Regional Ecosystem for EFNP, from the Queensland Government, is listed as 11.3.7/11.3.3 in an 80/20 split (See Appendix A).

The criteria used by the EHP to locate suitable wombat habitat, to meet the requirements given by the IUCN, is divided into two categories, primary and secondary criteria. Primary criteria for suitable wombat habitat involve (David Harper, pers. Comm.):

- Soil characteristics such as depth (3 m), texture and structure.
- Pasture species with focus on diversity, dominant species and an estimated coverage.
- Tree species with focus on diversity, dominant species, estimated coverage, and presence of indicator species.
- The size of habitat, preferably 1000 ha or greater, containing potential habitat that should include equal proportions of suitable habitat for burrowing as well as foraging.

The secondary criteria are related to site suitability and include:

- Is the site in an area of potential flooding?
- Recovery requirements, such as pests, weeds and erosion control.

- Surrounding land use; e.g., agriculture, protected area.
- Proximity to EFNP.
- Proximity to regional towns; should preferably be between 50–100 km away.
- Accessibility considering the seasons (sites have experienced floods and droughts before).
- Historic range; has the wombat been present here previously?
- Between 500–600 mm of average rainfall.

All of the listed criteria should preferably be met by a possible translocation site, for it to be suitable for the northern hairy-nosed wombat.

5.0 Ecophysiology and adaption to a burrowing lifestyle

There are energy costs related to digging a burrow, nevertheless, wombats have morphological adaptations to meet the requirements of a herbivorous, burrowing mammal (Johnson, 1998; Finlayson *et al*., 2005; Hogan *et al*., 2011).

Living in arid environments comes with restraints or complications, such as heat or scarce food and water resources, which make up the most stresses of living in extreme environments. However, animals can display either morphological, behavioural or physiological adaptations to these stresses of living in extreme environments, including burrowing (Gaughwin, 1981; Whittington-Jones *et al*., 2011).

The wombat is the largest burrowing herbivore in the world (Table 1) and only a few medium to large mammals adopt the burrowing lifestyle (Shimmin and White, 2002; Horsup, 2004). Along with the wombat are the old world porcupines (*Hystrix* spp.), marmots (*Marmota* spp.), the plains viscacha (*Lagostomus maximus*) and the maras

(*Dolichotis* spp.) (Johnson, 1998). However, size is the key difference between these herbivores and their choice of 'burrow'. Some of the mentioned genera inhabit holes in logs or stone to form their burrow, whereas wombats dig their own burrow.

Burrowing has essential benefits for mammals, providing shelter (Johnson and Crossman, 1990; Whittington-Jones *et al*., 2011), stable temperature and stable humidity (Wells, 1978b; Johnson, 1998; Whittington-Jones *et al*., 2011). Burrowing is considered an adaptation to arid or extreme environments (Johnson, 1998; Gerhardt *et al.*, 2000), reducing water loss and energy costs associated with thermoregulation (Barboza, 1993; Johnson, 1998). Burrows may also provide sanctuary from predators (Nevo, 1999; McGill, 2003).

However, one significant constraint associated with the burrowing lifestyle is the cost of energy, and time spent on digging and maintaining a burrow (Johnson, 1998). It is thought that the burrowing lifestyle is strongly related to diet (Johnson, 1998). Wombats are the only burrowing herbivores. All other burrowing animals present with a high nutrient diet; however, this is not the case for wombats, as grasses in general do not contain lots of nutrients (Johnson, 1998; Woolnough, 1998). Johnson (1998) proposes that the task of digging is explained by the animal's capacity to dig as a function of body surface area. The body surface area will automatically increase with increasing body size, and the costs of digging a burrow are greater in large animals as compared to small animals.

Thus large mammals are less likely to be burrowing mammals, and if they are, they will need to be greatly adapted to digging (Johnson, 1998). The wombat's compact body shape, broad shoulders with an extension of the posterior angle of the scapula, stumpy legs and long claws on both fore and hind legs show a morphological adaptation to burrowing (Wells and Pridmore, 1998; Triggs, 2009).

Table 1. List of burrowing animals, herbivores and carnivores/omnivores. Species are listed according to weight, with wombats being the largest herbivore. Table is modified from Johnson (1998)

Herbivore		Carnivore/Omnivore	
Taxon	**Mass**	**Taxon**	**Mass**
Marmots (*Marmota*)	5 kg	Hog badger (*Arctonyx collaris*)	10 kg
Old–world porcupine (*Hystrix* spp.)	16 kg	*Dhole* (*Cuon alpinus*)	13 kg
Wombat (Vombatidae)	30 kg	European badger (*Meles meles*)	13 kg
		Giant armadillo (*Priodontes maximus*)	28 kg
		Giant pangolin (*Manis gigantean*)	33 kg
		Aardvark (*Orycteropus afer*)	65 kg

6.0 Is the hairy-nosed wombat a social species?

Little is known about the social behaviour of the hairy-nosed wombat, and it presents largely as a solitary animal (Gaughwin, 1981). However, investigating ethograms of individuals will provide a guide on its allocation of energy to social interactions (Gaughwin, 1981). It has previously been speculated that for the southern hairy-nosed wombat, solitary animals display a higher frequency of social interaction based on environmental change and seasonality (Gaughwin, 1981).

6.1 Ranging behaviour

All animals are dependent on having a home range, and this range is influenced by the local landscape or environment where the species can be found (Schai-Braun and Hacklander, 2014). A home range has been described as:

"That area traversed by the individual in its normal activities of food gathering, mating and caring for young. Occasional sallies outside the area, perhaps exploratory in nature should not be considered part of the home range" (Burt, 1943).

Johnson (1991b) investigated the home ranges of the northern hairy-nosed wombat and found that they varied in size with changing seasons, increasing during winter, but with an average home range core area of approximately 6 ha.

Evans (2008) showed that the home range core area for the common wombat was estimated to be an average of 2.9 ha; however, Matthews and Green (2012) showed that common wombats in the Snowy Mountains show plasticity in home range, to adapt to environmental constraints ranging from drought and altitude to scarce food resources. The southern hairy-nosed wombat generally has a smaller home range than the common wombat, where feeding ranges are located adjacent to burrow complexes (Barboza and Hume, 1992).

Activity patterns in animals demonstrate how the individual organises its days, months, or years, depending on the length of the study (Gaughwin, 1981). It is important to note that all activity performed by an animal includes the expenditure of energy (Gaughwin, 1981). Because of this it is thought that the ranging behaviour is strongly related to the energy budget in different strategies (Evans, 2008). This includes adaptations such as long resting times in burrows and alternatively spending a relatively short time above ground to conserve energy (Evans, 2008). This would potentially therefore reflect an energy conservation strategy (energy versus expenditure) in general ranging behaviour, and reflect a small home-range, to limit time above ground (if allowed by the environment) (Evans, 2008). Evans (2008) found that the ranging behaviour in common wombats was quite similar between sexes, and may even overlap between and within sexes. However, because the common wombat has been shown to be a solitary animal (Taylor, 1993; Favreau *et al*., 2009), and individual marking of ranges and burrows does exist, a regular communication mechanism among animals must be present (Evans, 2008). The activity pattern for the common wombat is influenced by a strong diel cycle, with most activity occurring at night (Evans, 2008). With wombats ranging mainly around the area of the burrow/s occupied by the wombat, the home ranges are restricted to these allocated areas, and therefore food resources should ideally be found within the range of the individual (Evans, 2008).

6.2 Antagonistic behaviour

Antagonistic behaviour or intraspecific aggression normally meets certain criteria for species showing this behaviour (Clark *et al*., 1999).

The first criterion is based on the animal's utilisation of a resource that requires defence, such as food, space or shelter (Brown, 1964). For carnivores, prey would be a resource of defence as well; however, they are hard to detect and behaviour such as searching influences the resource. The second criterion is related to morphological behavioural traits that will help the defence of a possible resource (Parker, 1974; Clark *et al*., 1999). These traits include body size and weapons such as teeth and claws. The third criterion is based on the utilisation of a space that includes a resource restricted to a limited space (Clark *et al*., 1999). Gaughwin (1981) described vocalisation as highly related to social interaction in the hairy-nosed wombats. Social interaction in wombats can also be through burrow sharing (Johnson, 1991a).

6.3 Social interactions

Johnson and Crossman (1990) investigated social interactions by direct observation; however, they concluded that observing the species was difficult, and perhaps even impossible to observe directly. Despite that, Stenke (2000) observed social interactions in the northern hairy-nosed wombat. Approximately 1300 observation hours were generated, and only 12 social interactions occurred (approximately covering 2% of observation time) (Stenke, 2000). Gaughwin (1981) recorded 143 social interactions during 1500 observations hours on the southern hairy-nosed wombat.

Gaughwin (1981) found that vocalisation is predominantly used as social interaction in the southern hairy-nosed wombat. However, Stenke (2000) concluded that the level of social interactions displayed by the northern hairy-nosed wombat was relatively low, and suggested that it may be lower than the levels recorded for the southern hairy-nosed wombat (Gaughwin 1981). The social interactions recorded by Stenke (2000) were thought to be of mating purposes, because the interactions would occur between males and females, with seasonal variation.

In the northern hairy-nosed wombat, in general, the individuals show a solitary behaviour, although burrow sharing has been proven in wombats (Johnson, 1991). The author found that the average wombat was alone in a burrow 71% of days, sharing with one other wombat in 27.3% of days and sharing with two wombats in 1.7% of days. The most prominent sharing association was female-female burrow sharing, whereas male-male and male-female interactions occurred less often (Johnson, 1991a). The author furthermore investigated if size of the burrow being shared had an influence on how susceptible wombats were to sharing. The likelihood of wombats sharing burrows was higher in burrows with three or more entrances than all other burrow systems (Johnson, 1991a).

Johnson and Crossman (1991) compared the findings of social organisation in the northern hairy-nosed wombat to those found in the southern hairy-nosed wombat (Gaughwin, 1981). The social organisation of the northern wombat resembles those of the southern; however, burrows were arranged with slight differences (Johnson and Crossman, 1991; Finlayson *et al.*, 2005). The burrows of the northern hairy-nosed wombat were arranged in loose clusters, and not relative to suitable habitat, whereas the burrows of the southern hairy-nosed wombat were arranged into large warrens, relative to their feeding areas (Johnson and Crossman, 1991).

7.0 Options for monitoring wombat behaviour

7.1 Direct observation

Direct observation of an animal is the process of a person, physically present in the field, observing wildlife (Bridges and Noss, 2010). It was the most used approach to obtain behavioural ecology of wildlife before the introduction of radio telemetry (Bridges and Noss, 2010). Today the method is used to investigate reactions of the animal in relation to environmental stimuli, and hence the presence of the researcher is needed (Bridges and Noss, 2010).

Direct observation may be difficult, depending on the choice of study animal (Hewison *et al*., 2007). With regard to wombats, their burrowing lifestyle constrains the use of direct observation (Horsup, 1998; Hogan *et al*., 2009; Keeping and Pelletier, 2014).

There are some complications with the direct observation method (Aguiar and Moro-Rios, 2009). By having an observer following the animal around, there will be disturbance to the animal's natural behaviour and habitat, and therefore the results obtained using direct observation may be biased (Aguiar and Moro-Rios, 2009). This is a clear limitation to the method. However, if used, some considerations can be taken into account before data collection commences (Aguiar and Moro-Rios, 2009). The observer has to find a way to minimise interference with the animal and its behaviour. If the study animal used for this method is in clear view and is easy to approach, habituation can possibly be used (Aguiar and Moro-Rios, 2009).

Additional limitations, including sample size and subjective conclusions based on the researchers own observations, should be considered before using direct observation as the primary method of wildlife behaviour investigations (Bridges and Noss. 2010).

Wells (1978) observed the southern hairy-nosed wombat at the Brookfield Zoo Wombat Reserve, in South Australia, with a focus on behaviour and home range of the species. Direct observation was the chosen method used, and behaviour was observed at both night and day from specific viewpoints by spotlighting, basking counts or marking (Wells, 1978). During days when wombats were not detected, their feeding ranges could be monitored by the areas grazed compared to non-grazed areas (Wells, 1978). The author observed some direct interactions between wombats, especially close to their burrows. Interactions were categorised as vocal defence or scuffling, and could lead to an attempt of bite.

Johnson and Crossman (1991) investigated the dispersal and social organisation of the northern hairy nosed wombat, and made a note that direct observation as a method would be inefficient, due to the nocturnal behaviour of the species.

Hogan *et al.* (2009) recognised the same problem with direct observation, when observing the southern hairy-nosed wombat. Therefore, a facility at the Rockhampton Zoo was established for easy accessibility and to avoid the method of direct observation (Hogan *et al*., 2009). The author instead used video surveillance and radio transmitters to get a detailed picture of their behavioural ecology; however, with the constraints of the animals now being captive animals and no longer providing a wildlife population study (Hogan *et al*., 2009).

7.2 Telemetry technology

From previous data, it is suggested that home ranges of wombats can be up to ten times smaller that of a similar-sized non-burrowing herbivore, such as the eastern grey kangaroo (Wells, 1978; Finlayson *et al*., 2005).

A study was undertaken on the southern hairy-nosed wombat, to investigate the burrow-use and ranging behaviour in South Australia (Finlayson *et al*., 2005). Sixteen animals were fitted with radio-collars, although six animals were lost from the study due to either collar failure or natural mortality (Finlayson *et al*., 2005). Data were obtained during peak activity hours (dusk to dawn). The authors found no evidence of variation in home ranges between either seasons or sexes. The mean core area was estimated to be between 0.81 ha to 4.01 ha. Activity patterns did, however, vary with season, and the data collection had to be flexible hereafter (Finlayson *et al*., 2010).

There has previously been a study of habitat utilisation in the northern hairy-nosed wombat (Johnson, 1991b). The purpose of the project was to explore both habitat utilisation and body condition of the animals related to seasonal variations in quality of the habitat. Fourteen animals were fitted with radiotransmitters; three animals shed collars during the study. Wombat data were obtained by deploying three receiving stations surrounding the study areas. All collar frequencies were scanned every 30 minutes, and scanning of frequencies was only active during activity peak hours for the wombats. Observers had six hour shifts to listen for frequencies and pin point wombat movement (Johnson, 1991b).

The study showed that home range size varied significantly seasonally, with an increase during winter. Winter core areas were averaged at 6.24 ha. Core areas during summer averaged 2.62 ha (with a 70% range use contour).

A similar study has been completed on the common wombat. The common wombat inhabits a different environment to that of the hairy-nosed wombat, and ranging behaviour was proposed to fluctuate more in the common wombat (Matthews and

Green, 2012). Wombats were fitted with Global Positioning System (GPS) datalogging collars; logging in a 60 minute interval in an eight hour cycle. Home range core areas were found to average 14.6 ha (95% Kernel method), the highest estimate of core areas for the three species of wombat. This could be because of the difference in environmental adaptations between the two groups of wombat, where the common wombat has adapted to wetter environments. The activity of wombats is determined by nocturnal temperature, and because common wombats are 'coastal' wombats, temperatures are lower, and hence they are more active (Evans, 2008). Living in arid environments often means living in potentially more extreme weather (especially for temperature). Because of this, wombats who inhabit these areas limit their above ground time opposed to time in their burrows. However, common wombats inhabit environments with more suitable temperatures, and therefore do not need to conserve energy in the same way as other species of wombat. This may result in less time in the burrow to escape heat, and along with a wet environment comes more nutritional food resources, which leads to less digestive time for harsh fibrous grasses (Evans, Year).

A general review of the success rate on the use of GPS collars on Australian mammals was published in 2013 (Matthews *et al*., 2013). The purpose of the review was to explore the success rate of GPS collars, their possible failures and the possibilities of implications to wildlife welfare. The authors used data of 280 deployed GPS collars, where 249 collars were retrieved or data was downloaded successfully remotely. The most common reasons for GPS failure was suggested to be general wear, poor batteries or water ingression. Sixty percent of the collars were retrieved (animals recaptured), and the most common welfare problem for the animal was loss of fur by abrasion.

7.3 Wildlife camera monitoring

To monitor the frequency of occurrence of wombats in a specific habitat, wildlife camera traps can be deployed. Wildlife camera traps combine several methods of observing wildlife but minimise disturbance to research subjects (Bridges and Noss, 2010). However, interpreting the behaviour based on a still picture can be difficult (Bridges and Noss, 2010).

The use of wildlife camera traps in Australia is relatively new, and did not appear in reports until the late 1980s (Meek *et al*., 2015), but the use of wildlife camera trapping is now expanding exponentially. Wildlife camera trapping has been used for different aspects of animal ecology, such as circadian rhythms (Bridges *et al*., 2004b), habitat usage (Augustine, 2004) and social systems (Sequin *et al*., 2003).

Bridges *et al.* (2004) investigated the activity patterns in American black bears (*Ursus americanus*) with the help of remote wildlife cameras. The cameras were used to quantify activity patterns and aimed to look for differences in season, sex and reproductive class (Bridges *et al*., 2004). The authors collected 1533 pictures of black bears from 50 deployed cameras and found that they exhibited a diurnal behaviour during summer and a nocturnal behaviour during fall. The authors suggested that the American black bear was a sensitive species and may become more nocturnal with the increase of human disturbance.

Augustine (2004) explored the habitat use on the Kenyan rangeland by the impala (*Aepyceros melampus*). The author investigated an area ranging over 6,500 km^2 that was previously dominated by grazing cattle, and consequently changing the landscape where the impala can be found (Augustine, 2004). The species in this area were found particularly in *Acacia* communities. However, because of grazing by cattle, the landscape is now dominated by short-grass communities with a lack of woody vegetation (Augustine, 2004). Cameras were set up in these communities to measure seasonal patterns of impala presence. The author found a link between cattle grazing and impala habitat quality, where impala habitat quality was related to cattle management or in areas with former cattle management. These results were obtained by measuring the nutrients in present grasses. These were higher in cattle management areas, due to the enrichment of the soil from cattle faeces and urine.

Sequin *et al.* (2003) explored the social system in coyotes (*Canis latrans)* using wildlife cameras to understand whether or not the status of alpha, beta or non-territorial animals would be more susceptible to photo-capture. The authors held photo sessions over a 6-week period, where cameras were placed in territories that had been individually marked by alpha coyotes in the area (Sequin *et al*., 2003). The authors found that alphas and betas were almost never photo-captured within their own territories, and when captured in pictures, the camera was primarily on the boundaries of other territories. Additionally the non-territorial individuals were exclusively photo-captured on the border of territories, therefore avoiding the territory core (Sequin *et al*., 2003).

A study was generated on the common wombat using camera traps to investigate the use of remnant agricultural habitats by wombats and cattle (Borchard and Wright, 2010). Wildlife camera traps were set up to take pictures 24 hours a day and were set up randomly, according to wombat and cattle use of habitat. The method was used to detect wombat activity patterns and the frequency of occurrence of each animal. It showed that wombats have a lower daylight activity pattern than cattle and determined the most likely activity periods of wombats to be between 7 pm and 1 am, based on wombat detections (Borchard and Wright, 2010).

A similar study was conducted to explore if there was any overlap in activity patterns, or occurrences, of dingos, feral cats and bridled nailtail wallabies (Wang and Fisher, 2012). This was achieved with the use of wildlife camera traps that were placed randomly, but with at least a 500 m gap between cameras. It was shown that dingoes and feral cats occupied the same areas, but with a difference in activity, especially during the wet months. It was found that cats were not excluded in areas with high dingo predation rates, however that there was an overlap between active periods of feral cats and wallabies, which are predated on by the cats.

8.0 Conservation status, and current conservation plan

The northern hairy-nosed wombat is not only one of the rarest mammals in Australia, but also in the world (Banks *et al*., 2003).The first recovery plan was produced in 1991, and was revised in 1994 (Horsup, 1996). The major funders for the recovery program were the Australia Nature Conservation Agency, Queensland Department of Environment and the Australian Research Council (Horsup, 1996). The first recovery program ran initially from 1992 to 1996. The latest recovery plan for the species was generated in 2004, to highlight the top key threats towards the population at EFNP and is ongoing. However, this recovery plan ceased to be in effect from 1 April 2016[1], and there is no current recovery plan for the species.

[1] http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=198

The ability to estimate the population size of endangered animals is crucial for their future survival and for effective conservation actions (Katzner *et al.,* 2011).

In 2013 the population at EFNP was estimated to have approximately 196 individuals, based on a hair census[2]. Adding nine wombats at RUNR, the total estimation is 203 individuals. The report suggested that the population was slightly male biased (EHP Internal, 2014). However, a new baseline estimation was assessed in September 2016, following the hair census studies performed every three years at EFNP. This is an increase from the first estimations when studies began on the species, where Gordon *et al.* (1985) estimated the population to be as low as 20–30 individuals. The limited distribution is one of the main reasons to why the northern hairy-nosed wombat is listed as 'endangered' in Queensland under the Nature Conservation Act 1992[3]. Nationally, it is listed as 'endangered' by the Environment Protection and Biodiversity Conservation Act (EPBC Act, 1999[4]), and listed globally as 'critically endangered' on the IUCN Red List (IUCN, 2008[5]).

8.1 Key threats towards the northern hairy-nosed wombat and its habitat;

Habitat loss

Land clearing is a major factor influencing the loss of suitable wombat habitat (Horsup, 2004), which makes it harder to establish new wild populations via translocation from EFNP. All 'natural' wombats are found in EFNP, which is

[2] For method descriptions see Horsup 2004 and Taylor, 2007.

[3] Link for PDF: https://www.legislation.qld.gov.au/LEGISLTN/CURRENT/N/NatureConA92.pdf

[4] Link for PDF: https://www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl?wanted=fauna#mammals_endangered

[5] Link for PDF: http://www.iucnredlist.org/details/11343/0

completely surrounded by modified pasture land that restricts wombat habitat (Gordon *et al*., 1985; Banks *et al*., 2003a).

Drought

The most important threats to consider with climate change are drought and wildfire. Drought is mostly thought to have had an impact in relation to food competition (Crossman *et al*., 1994; Woolnough and Foley, 2002). More recently the current population has been exposed to droughts and below average rainfalls, but provision of water and protection from predators such as dingos has allowed the population to keep expanding since 2002 (Horsup, 1996).

Resource competition

Before 1981, wombats were competing for food resources with grazing cattle, whereas after the completion of the predator fence in 2002, wombats face increased competition with the park's eastern grey kangaroos (Crossman, Johnson and Horsup, 1994; Woolnough, 2000). Both species have similar diets, so the wombats are competing with the eastern grey kangaroo for food resources, which is a limiting factor for wombat survival (Woolnough and Johnson, 2000).

Habitat invasion by exotic grasses

The biggest concern related to the invasion of buffel grass into EFNP is that it will eventually become a monoculture. This is undesirable and would potentially make it more susceptible to a disease that could affect large areas of the species, thus destroying the wombat's food resource (Tix, 2000). Monocultures also cause loss of dietary diversity for the wombat, making the diet more uniform.

It is unknown if buffel grass is influencing the home range and movement patterns of wombats, in terms of presenting an actual barrier, or if wombats are moving around or through the buffel grass. Since the grass has now taken over approximately 50% of selected transects, and similar is found in wombat habitat (Back, 2013), the wombats have now incorporated buffel grass into their diet, accounting for almost one third of their grass intake (Woolnough and Johnson, 2000).

Wildfire

Wildfires have the potential to impact entire local populations or habitats, such as the population at EFNP. Wildfires may destroy entire food sources and surrounding habitat (Horsup, 2004). Buffel grass contributes to the concern around wildfires within the park. The grass contributes as much as 2–3 times more flammable material than native grasses, and consequently the fire frequency in buffel grass areas has increased (D'Antonio and Vitosek, 1992; Miller *et al*., 2010). Wildfire is beneficial to the grass, because buffel grass growth is facilitated by fire. Buffel grass has a rapid growth rate, compared to native grasses, and hence has the ability to outcompete the native grasses (Franks, 2002).

Invasive grasses

Invasive plants, some thought of as environmental weeds from an environmental perspective, are a globally recognised problem threatening native ecosystems and biodiversity (Ferdinands *et al*., 2005). One of the key invasive families to wombat habitat is grasses (D'Antonio and Vitousek, 1992; Grice *et al*., 2013). Low (1997) highlighted the basis of how invasive grasses are being considered threats, including their contribution of a higher biomass, and therefore a higher fuel load that, when burned, potentially changes habitat conditions. Non-native grasses are prominently featured in agricultural programs as pasture species, in order to increase pastoral productivity (Grice *et al*., 2013).

8.2 Implications of invasive grasses on mammals

Australia has lost a total of 22 mammal species since European settlement (Burbidge *et al*., 2009). This accounts for approximately 50% of the world's mammal loss during the past 200 years (Legge *et al*., 2011). There are several suggestions for these extinctions, including growth in the human population centres, which has caused habitat loss, habitat fragmentation and environmental changes (Woinarski *et al*., 2011). However, species lost during the past 200 years were mainly species found in regions of Australia with low human densities and activity, with little changes to their predominant habitat and less affected environment (Woinarski *et al*., 2011; Cook and Grice, 2013). Hence invasive grasses are considered a cause of changes in biodiversity and species richness, with no need of promotion from human activity.

Martin *et al.* (2006) identified 622 plant species in Australia that can be categorised as non-native naturalised plants, where 25% of these are considered a serious threat to the biodiversity found in Australia. The author mentioned that the most serious weeds, now categorised as environmental weeds, are perennial pasture species such as buffel grass. Only about 30% of the potential distributions of the serious environmental weeds have been mapped on a national scale.

8.3 Strategies for invasive grasses

The Australian government has collected a list of invasive grass species in Australia, and this list includes buffel grass, gamba grass (*Andropogon gayanus*), para grass (*Urochloa mutica*), olive hymenachne (*Hymenachne amplexicaulis*), mission grass (*Pennisetum polystachion*) and annual mission grass (*Pennisetum pedicellatum*). All have been listed as a key threat to ecosystems around Australia (Commonwealth Australia, 2012).

Buffel grass is an exotic, invasive grass in Australia, originally native to northern Africa, Asia and Indonesia (Tjelmeland *et al*., 2008; Smyth *et al*., 2009). It was accidently introduced to Australia in the 1870s with cameleers from the Middle East (Smyth *et al*., 2009; Marshall *et al*., 2012). Later, in the 1920s, it was introduced as a pasture species (Marshall *et al*., 2012), following a series of droughts, and the pastoralists' need for a plant species tolerant to these environmental conditions (Andrew and Robins, 1971; Eyre *et al*., 2009). Later, in the 1990s, the species was recognised as an environmental weed in Australia (Smyth *et al*., 2009; Melzer *et al*., 2014).

Buffel grass is a long-lived perennial grass, occupying tropical and sub-tropical arid environments around Australia (Tix, 2000; Marshall *et al*., 2012; Melzer *et al.*, 2014; Melzer, 2015). The grass is a C4 plant, which has swollen stem bases that function as storage for carbohydrate reserves, especially at the end of the season, and this assists the grass to be highly tolerant to impacts such as grazing or burning (Dixon *et al*., 2002; Franks, 2002; Marshall *et al*., 2012; Melzer, 2015). The storing of carbohydrates is to make up for leaf loss under heavy grazing or fire, so that these conditions are not fatal to grass (Dixon *et al*., 2002).

Gamba grass is native to Africa, and was introduced to Australia in the 1930s as a pasture grass (Flores *et al*., 2005). It is present in three states in Australia: Western Australia, the Northern Territory and Queensland. Gamba grass is similar to buffel grass in structure as it forms large dense swards that can grow up to four metres high (Rossiter *et al*., 2004). Because of its larger biomass compared to native grasses in areas where found, gamba grass increases the total fuel load, with the possibility of more intensive fires (Setterfield *et al*., 2010). This is a concern, because the grass has the potential to out-compete native grass with this fire strategy, and change ecosystems. Gamba grass is still a highly preferred pasture grass, but is not recommended for new plantings, because of the management implications it brings. It is currently listed as a high-risk weed in the Northern Territory, and as a grass with high potential to do damage in areas where cattle are not present in the other two states (Commonwealth Australia, 2012).

Para grass is an invasive grass, native to Africa and South America. It was introduced to Australia in the 1880s where it was used as an erosion control on riverbanks, but was later endorsed as a pasture grass (Douglas and O'Connor, 2004). It is currently found in the Northern Territory and Queensland. Para grass is a perennial grass that forms dense floating mats, of heights up to one metre thick and is found in wetland habitats. Although para grass is not declared as an environmental weed in any state of Australia, it has been shown that the grass has a negative effect on plant communities and biodiversity (Ferdinands *et al*., 2005).

Olive hymenachne originates from central and south America. It was intentionally imported into Australia to investigate the potential as a pasture grass for cattle. It is currently widely represented in the Northern Territory and Queensland, and is found in New South Wales as well (Commonwealth Australia, 2012). Olive hymenachne is a semi-aquatic grass that reaches up to 2.5 metres tall. It is commonly found in shallow freshwater and on riverbanks in coastal areas. It forms dense monocultures in open water, hence reducing plant diversity in freshwater ecosystems. It is declared a weed in all states and territories in Australia, based on the fact that is has the potential to affect primary production, fisheries and water infrastructure (Cobon, 2009).

Buffel grass is one of this suite of introduced exotic grasses, all of which have economic benefits toward communities, while having adverse environmental impacts.

8.3.1 Buffel grass in Australia. An important pasture or environmental weed?

Categorisation of buffel grass is a highly discussed topic; whether or not to categorise it as an environmental weed (environmental perspective) or an essential pasture species (agricultural perspective) (Marshall *et al*., 2012). The grass is a highly valued pasture species due to its remarkable tolerance to fire and grazing (Jackson, 2005; Marshall *et al*., 2012), but has the capacity to invade native ecosystems and alter these, along with a reduction of diversity in both flora and fauna (Butler and Fairfax, 2003; Young and Schlesinger, 2014).

The grass is a highly valued pasture species, with more leaf yield, higher tolerance to fires and grazing and sensitive to rainfall, which means quicker regrowth (Christie, 1975; Martin *et al*., 2015; Melzer, 2015). It is, however, not found acceptable from an environmental perspective, mostly because of its threat to native biodiversity (Arriga *et al*., 2004; Miller *et al*., 2010; Martin *et al*., 2015).

The grass is not only used to improve livestock production, but also to stabilise soils and revegetate eroded areas (Dixon *et al*., 2002; Martin *et al*., 2015). The species germinates readily, propagates quickly and is easy to establish (Dixon *et al*., *2002*). This makes buffel grass the ideal choice for dry communities and for the colonisation of disturbed areas (Bhattarai *et al*., 2008).

The key threats from buffel grass towards natural Australian ecosystems are: (1) altering of fire regimes; (2) apomictic seed production; and (3) remarkable tolerance to fire and grazing (Tix, 2000; Tjelmeland *et al*., 2008; Conner *et al*., 2013).

Apomixis is defined as the asexual reproduction form of a plant (Burson *et al*., 2012; Conner *et al*., 2013), and apomictic reproduction occurs in the tussocks, or vegetatively by rhizomes, although buffel grass does not always show signs of producing rhizomes (Tix, 2000; Dixon *et al*., 2002; Melzer, 2015). Prior to 1958, it was thought that all buffel grass plants were obligate apomicts, but a sexual plant was found in the south of Texas (Burson *et al*., 2012). Reproducing sexually by creating hybrids of the apomictic individuals of buffel grass, the species would successfully bring an outcome of increased leaf yield or an increased tolerance towards grazing (Burson *et al*., 2012).

Seed dispersal mechanisms are either by wind, attachment to animal fur or human clothing, and by vehicles (Melzer, 2015). Because of its aggressive and effective seed dispersal, buffel grass often invades non-targeted ecosystems, close to pasture grass rangelands (Eyre *et al*., 2009).

Buffel grass contributes to the pastoral communities with vast benefits, such as tolerance of grazing and drought, limited effects from fire, and high nutritional values, which helps to improve stock feed (Tix, 2000; Tjelmeland *et al*., 2008). However, the grass is considered one of the most destructive introduced plants (Tix, 2000), primarily because it has a large surface area, and can form large dense swards that alter the fire regimes of an area, further reducing the presence of native grasses not adapted to these fire regimes (Tix 2000; Butler and Fairfax, 2003; Tjelmeland *et al*., 2008). The strategy that buffel grass utilises is that it increases fire frequency and intensity, and ultimately it changes the structure of ecosystems (Melzer *et al*., 2014).

There are several differences between the Australian native grasses and buffel grass. Buffel grass has a higher phosphorus requirement than the natives, and this might influence the spread of the grass (Back, 2013). It also contains a higher proportion of nitrogen, and is therefore more nutritious than native grasses. It can therefore be debated whether or not the introduction of buffel in wombat diet is crucial as a food source during extreme environmental weather conditions (Woolnough and Foley, 2002).

8.3.2 Buffel grass in Queensland

In 2000, buffel grass was estimated to cover approximately around 30–50 million hectares in Queensland (Melzer, 2015), and an estimate of 68% of Australia has been predicted to be viable buffel grass country (Eyre *et al*., 2009; Smyth *et al*., 2009). It was first sown in Cloncurry in 1926, and then later in 1928 sown in the Rockhampton region (Eyre *et al*., 2009). Experimental sowing of buffel grass was common in several Queensland regions by the 1930s (Eyre *et al*., 2009). Buffel grass was not reported as a spreading grass until after heavy rainfall in the 1950s (Tjelmeland *et al*., 2008; Smyth *et al*., 2009).

In a study by the Queensland Department of Primary Industries in EFNP, buffel grass has increased in five transects from an average coverage of 7% in 1987, to 54% in 1994, peaked in 2000 with a coverage of 54.2% and was last recorded as 52.3% in 2013 (Low, 1997; Back, 2013). A similar pattern is seen throughout the park, and is not restricted to the five transects.

8.4 Altered food resources

One of the concerns related to buffel grass as a dominant food resource, is the possibility of osteodystrophia fibrosa, commonly known as ‘big head’. The disease was first recorded in 1974 in horses grazing on subtropical pastures, where buffel is one of the recognised species (Stewart *et al.,* 2010). However, the disease is known as the oldest diagnosed disease in horses (Krook and Lowe, 1964). The disease has been found to be caused by hypocalcaemia, induced by a diet where there is an imbalance between calcium and phosphorus. It may be caused by a ratio of phosphorus to calcium of 3:1 (Krook and Lowe, 1964; Ronen *et al*., 1992). Buffel grass, among other tropical grass species, contains oxalic acid that interferes with calcium utilisation by horses. Pasture grasses need to have more calcium than oxalate, for any calcium to be available for absorption to the horse (Allan *et al*., 2007).

Wombats and horses do not share many common features besides both being herbivores and both being hindgut fermenters. Fermentation occurs in the lower intestinal tract, including the caecum and large intestine. Here bacteria and protozoa break down the fibrous diet of grasses consumed. It is here that the digestion products can be absorbed and used as energy (Barboza and Hume, 1992; Woolnough, 1998; Hume, 1999; Bentz *et al*., 2014).

A diet that contains 1% oxalate reduces the absorption of calcium by 66%, and hereby increases the amount of calcium in faecal excretion (Stewart *et al*., 2010). Certain grasses that are under a rapid growth may even contain 6% oxalate, which is sufficient to bind all the calcium content of the particular grass, leaving no free calcium for the horse to absorb (Stewart *et al*., 2010).

Buffel grass contains a high concentration of oxalates, which bind calcium, and form calcium-oxalate. Horses utilise oxalate as a carbon source by the release of the oxalate in the caecum (Stewart *et al*., 2010).

The compound calcium-oxalate is insoluble in the small intestine of the horse (Allan *et al*., 2007; Stewart *et al*., 2010; Bentz *et al*., 2014). Calcium would normally be absorbed in the upper small intestine of the horse; however, with the compound passing through instead of free calcium, it becomes unavailable. When the compound is being broken down by bacteria in the large intestine, the calcium freed is no longer available to the horse for absorption (Stewart *et al*., 2010).

There are three typical clinical signs in horses of 'big head': (1) lameness, (2) swelling of the mandible and maxilla and nasal bones, and (3) ill-thrift, including nasal discharge and noise changes in the respiratory tract (Stewart *et al*., 2010).

The name 'big head' is related to the swelling of the facial bones (Hintz *et al.*, 1978). This becomes visible in the facial structure, as the horse is unable to absorb any calcium, and the mineral content of the facial bones is changed (Ronen *et al*., 1992). The calcium is replaced with increased quantities of osteoid and fibrous tissue, hence the official name osteodystrophia fibrosa (Krook and Lowe, 1964; Menard *et al*., 1979; Stewart *et al*., 2010).

If the disease is not diagnosed, further incapacities can follow, such as dental pain and chewing problems, which can be noticed as weight loss or poor body condition (Stewart *et al*., 2010).

These are all signs that are recognisable in horses. Horses are normally kept in stables or in a paddock, and can be easily investigated if the assumption of big head arises. However wombats are nocturnal, and this complicates the visual aspects of signs of big head. There is essentially no easily accessible way of acknowledging whether or not a wombat is showing signs of big head or not, until a trapping session is carried out.

8.5 Possible management control of buffel grass, can it be done?

There are in general five types of management control for buffel grass that have been applied in different communities:

1. Letting the native plant community outcompete the buffel grass itself, hence basically no human alteration.
2. Biological control, with the use of fungi. The fungus *Pyricularia grisea* causes leaf lesions in buffel grass, which cause it to wilt.
3. Using chemical control, such as herbicides that contain glyphosate. Some negative aspects of using herbicides can be mentioned. By using a herbicide in an area, especially in grassland communities, native plants may be killed off in the process of managing the buffel, and therefore making it hard for the native grasses to be reintroduced.

4. Burning. This is not effective because of the tolerance buffel has towards fire, and actually promotes regrowth if only burned once. Repeated burning is intended to gradually weaken the grass at a time when buffel grass is translocating nutrients.
5. Slashing or mowing the grass. Slashing transects of buffel grass may be effective, if repeated slashing or mowing is applied. (Tix, 2000; Dixon, Dixon and Barrett, 2002; Tjelmeland, Fulbrigt and Lloyd-Reilley, 2008).

An additional option for management of buffel grass is grazing, often by cattle, but cannot be used under these circumstances in EFNP. Consistent grazing is damaging to buffel at the end of its growing season, when it is storing reserves (Melzer, 2003).

It is possible to combine the general methods for managing buffel grass to achieve a better result; for example, burning and using herbicides for optimal damage to the grass.

Chapter 1 references

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Chapter 2 - Pilot study: Testing trapping techniques for optimal trap response in the northern hairy-nosed wombat

1.0 Introduction

When sampling live specimens for research, a variety of sampling techniques can be used (Thomson and Thomson, 2007), many of which can help provide valuable information during monitoring of species on large spatial and temporal scales (Vernes and Haydon, 2001; De Bondi *et al*., 2010). This can help researchers gain insight into the targeted species and their possible management options (De Bondi *et al*., 2010). Trapping of wildlife is common in research, and using traps is an accepted method for collecting specimens for research (Gannon *et al*., 2007). However, for species-specific surveys, modified trapping techniques and strategies may be implemented to improve capture rates (Thomson and Thomson, 2007). Much research relies on live trapping of specimens, with cage and box trapping being the most widely used method (De Bondi *et al*., 2010).

For wombats there are several trapping methods available (Hoyle *et al*., 1995). Ruykys *et al.* (2009) undertook a project on the southern hairy-nosed wombat using the ‘stunning’ method of Taggert *et al.* (2003); this method requires two people with metal hoop nets, a spotlighter, a shooter and a driver. When a wombat is spotted, a shot will be fired between its ears approximately 10–15 cm above the head of the animal. The catchers will run alongside the animal, and eventually catch the ‘stunned’ animal (Taggart *et al*., 2003). This method has been used on other marsupials, including kangaroos (Robertson and Gepp, 1982). Robertson and Gepp (1982) tested the method on both western grey kangaroos (*Macropus fuliginosus*) and red kangaroos (*M. rufus*). Their results showed a 51.7% success rate in the red kangaroos, and only a 23.9% success rate in the western grey kangaroos. The proposed reason for the success with this method has been suggested to be temporary deafness to the animal as a consequence of a sonic boom from a projectile passing between the animal's ears. This leaves the animal unable to locate sound sources, and while spotlighting an animal at the same time, will leave the animal stunned (Robertson and Gepp, 1982).

A second method used for trapping wombats is hand-held netting. The method is similar to 'stunning', except that no shots are fired. A spotlight is still used, and the main reason for success in trapping is cause by disorientation by shining the spotlight directly at the animal (Finlayson *et al*., 2005; Finlayson *et al*., 2010; Matthews and Green, 2012).

A commonly used method of capture for wombats is the deployment of box or cage traps. Cage traps are widely used in capturing mammals. Because of this the traps may vary in size and material and construction (Powell and Proulx, 2003; Lossa *et al*., 2007). It is suggested that, with these traps, the animal undergoes less stress and injuries than limb-hold traps or nets (Powell and Proulx, 2003). Steel box traps have been used to trap both common wombats and northern hairy-nosed wombats (McIlroy, 1977; Evans *et al*., 2003; Reiss *et al*., 2008; Matthews and Green, 2012). Steel traps, placed in front of the burrow entrance, will only allow movement through the traps if placed in front of a single-entrance burrow (Matthews and Green, 2012). Once a wombat has triggered a trap, a transmitter signal paired to the particular trap is activated. The signal will be received at the research base and will alert the researchers to the capture of an animal.

The northern hairy-nosed wombat has been reported to be difficult to trap (Crossman *et al*., 1994), with re-capture presenting further challenges due to the behaviour of the animals (Johnson and Crossman, 1991; Horsup, 1996). In general, trapping is inefficient because of the constraints that come along with it in terms of labour intensiveness, equipment costs, and habituation periods of traps (Banks *et al*., 2003). When trapping, only a small proportion of burrows can effectively be covered at any one time which allows many animals to avoid being trapped (Banks *et al*., 2003). Both the nocturnal behaviour of the wombat and the animal's tendency to feed among high grasses make direct observation difficult (Johnson and Crossman, 1991). Trapping is the only method to have been successfully applied to date to monitor body condition and health in the northern hairy-nosed wombat (Horsup, 2004).

Trapping of an animal will, to some extent, put stress on that animal. This should be taken into consideration before commencing a trapping session. It has previously been shown that trapping of wombats has a negative effect on their body condition, and that they would lose approximately 0.5 kg of body mass as a consequence of a trapping event (Hoyle *et al*., 1995). This occurred in wombats caught twice within ten trap-nights. Less weight loss was seen in animals caught after the 6^{th} trap-night, and caught again before the 10^{th} trap-night (Hoyle *et al*., 1995).

Burrowing behaviour and trapping behaviour have previously been suggested to be a restricting factor for recapture (Hoyle *et al*., 1995). Wombats can stay in their burrows for up to ten nights without emerging to forage.

The trapping session undertaken at EFNP had multiple objectives, including the test of a new trap design. The rationale for the development of a new trap design was primarily to improve trapping success and reduce the amount of non-target species as well as reducing potential harm to captured animals (Dave Harper, pers. comm.).

In light of this knowledge from the discussion above, the aim and objectives are as follows: the aim of this pilot study was to apply the most appropriate study methods and improve trapping success. The objectives to reach the aim were to: 1) test trapping technique for optimal trapping success, and 2) minimise harm and stress.

2.0 Methodology

2.1 Study design and study sites for the pilot study

The Department of Environment and Heritage Protection had a scheduled trapping session at EFNP (146°42 E, 22°21 S) from the 30th of May 2016 until the 10th of June 2016. A second trapping session was scheduled at RUNR from October 10th to October 19th 2016.

EFNP covers 3300 ha, with approximately 2500 ha fenced by cattle fence and a dingo fence (Evans and Horsup, 1992; Crossman *et al*., 1994; Horsup, 2004). Cattle are thought to be one of the major food resource competitors for wombats (Horsup, 1996). This fenced area (2500 ha) is considered viable wombat habitat; the remaining 800 ha of the park was not considered viable wombat habitat and therefore was not fenced (Horsup, 2004). This is based on the work of Gordon *et al.* (1985), who found that burrows were mainly found in or near a gully (a part of the Belyando River drainage) (Johnson, 1991; Crossman *et al*., 1994). Within the park there are eastern grey kangaroos, swamp wallabies (*Wallabia bicolor*), short-beaked echidnas (*Tachyglossus aculeatus*) and European rabbits (*Oryctolagus cuniculus*), which increases the possibility of catching animals other than wombats when trapping. The park landscape is considered to be of high diversity and is dominated by Moreton Bay ash (*Eucalyptus tessellaris*) in coarse textured soils, Brown's box (*Eucalyptus brownii*) in open woodland, and brigalow (*Acacia harpophylla*) and gidgee (*Acacia cambagei*) on heavier loamy and clay soils (Steinbeck, 1994; Woolnough, 1998).

The RUNR is a 130 ha property surrounded by agricultural land near St George, Queensland ((-27.6665, 148.70148). The park is fenced with a dingo fence around the entire 130 ha. The major vegetation communities found are tussock grasslands, open patchy woodland with species including poplar box (*Eucalyptus populnea*), and dense patchy woodland especially dominated by cypress pine (*Callitris preissii*).

2.1.1 Approvals, trapping techniques and schedules

A Scientific Purpose Permit (*WITK17265216*) and animal ethics approval were obtained in collaboration with the Queensland Department of Environment and Heritage, with animal ethics approved through both the Department of Agriculture and Fisheries (Queensland) and Central Queensland University. The animal ethics approval states a multipurpose trapping trip at EFNP and includes the possible relocation of animals to the RUNR, capture of pouch young for a captive population, and collaring of suitable animals.

A Letter of Approval from the Department of Environment and Heritage Protection (EHP) (Brisbane) was received in order to commence work at the RUNR, directed especially to the scope of this particular project. Animal ethics approval (SA 2016/09/571) was obtained in collaboration with the Queensland Department of Environment and Heritage, with animal ethics approved through both the Department of Agriculture and Fisheries (Queensland) and Central Queensland University. Ethical approval differed in some aspects to that received for the pilot study at EFNP as listed in Table 2.

Table 2. Showing differences in Animal Ethics Applications between Epping Forest National Park and The Richard Underwood Nature Refuge

Description	Epping Forest National Park	Richard Underwood Nature Refuge
Trap-nights for each trap per burrow	10	5
Trapping technique	Majority of old steel traps	Prototype PVC pipe trap
Trapping technique	Permanent trapping fences around burrows	U-shaped evertrench linking trap and burrow together
Weight of animals suitable for collaring (kg)	30	25
Number of animals approved for capture	20	10
Category of wombats captured	Juvenile/ Weaner / Pouch animal / Adults	Adults / Juveniles

The primary trapping method employed closely followed previous trapping methods for the northern hairy-nosed wombat at the study site, and these are thoroughly described by Crossman (1988) and Hoyle *et al.* (1995). Trapping methods have not altered significantly since wombat trapping at EFNP began. Modified cage traps (tunnel traps) were placed at burrow entrances, so that wombat movement could only happen through traps. Where multi-entrance burrows had entrances without a trap, those entrances were blocked and the burrow fenced off with wire mesh, to ensure that movement could only occur through trapped entrances. Each trap was equipped with guillotine doors, which slide down when triggered by an animal. The triggering mechanism consists of nylon line strung across the bottom of the trap. When pulled, doors slide down, simultaneously activating a transmitter sending a signal at a particular frequency allocated to a specific trap. This alerts researchers that a trap has been triggered, and that an animal may have been captured. To prevent the wombats digging between the bars of the traps, a rubber mat was placed underneath each trap. Sand or dirt was then placed across the trap floor to make it more approachable for an animal to walk through. A total of 33 traps with this design were used during the EFNP May–June 2016 trapping session.

A prototype for a new trap design was developed for this pilot study. These prototype traps were round tunnel traps (450 mm x 1500–1800 mm) constructed from polyvinyl chloride (PVC) pipes, and based on the design of Tasmanian devil (*Sarcophilus harrisii*) traps. Doors are rounded, and rotate to close, instead of guillotine doors, and are triggered by disruption of infrared beams across the inside of the trap. When an infrared beam is disrupted, a transmitter will signal on a frequency paired to a single trap to alert the researcher. Two hatches are placed on the side of the pipe in order to enable viewing of trapped animals as well as to sedate an animal without the risk of injury to trapped wombats. To improve chances of capturing wombats, PVC pipe was used to connect the trap to the entrance of the burrow. This allows the burrow to be free of additional fencing and only gates to block alternative entrances at multi-entrance burrows are needed. A total of three traps of this design were deployed at EFNP during the May–June trapping session.

Both trap designs had the possibility of capturing non targeted species (by-catch) such as wallabies or echidnas.

The trapping at EFNP ran for nine nights (30th of May to 9th of June 2016) and represented 258 trap-nights. Previous trapping sessions have lasted between 2–12 consecutive nights (Gordon *et al*., 1985; Hoyle *et al*., 1995). Traps were set from 6 pm until 7 am, approximately, and were locked open during the day in order not to catch animals during the heat of the day, which may put more stress on animals. All traps were opened and locked manually by a trap checking team each morning and set manually each night.

Only traps of the new trialled design were used for the trapping session at RUNR. Four traps had been modified with new electronics, after trialling them at the EFNP session, and two traps with the old trialled electronics. According to the approved animal ethics application, traps were only allowed to be set at a given burrow for a maximum of five consecutive nights. This was decided upon by the EHP, to minimise stress related issues for the animals.

The trapping session went for nine nights (10th of October to 19th of October, 2016). Traps were set from 6 pm to 7 am and were locked open during the day.

Captured wombats were sedated in the trap by an authorised vet with Zoletil (Zolazepam Tiletamine) (Evans *et al*., 1998; Pitt *et al.*, 2006), at a dosage rate of 3–5 mg/kg, until the animal was unconscious. Zoletil is good for field conditions because it accommodates an estimated dosage and not a fixed dosage, which makes the usage of it safe (Pitt *et al*., 2006), and has been proven adequate for preliminary sedation of wombats (Evans *et al*., 1998; Holz, 2014). The drug was administered intra-muscularly, and isoflurane was given to maintain anaesthesia (Lamont and Grimm, 2014) while processing the wombat. Isoflurane safely kept the animal lightly sedated and it is easy to adjust the concentration of the drug (Heath *et al.*, 1997; Masamoto *et al.*, 2009). Isoflurane is a gas, and is therefore not metabolised by the animal, but rather exhaled when treatment is stopped (Derelanko and Auletta, 2014; Lamont and Grimm, 2014). The animal was transferred from the trap to a processing table for processing. All captured wombats were weighed, and various body measurements were taken (total length; head length; head width; neck girth; chest girth; tibia length; tail length; ear length; foot length). In addition, captured animals were given an ear tattoo with a unique number for identification. A general body condition score was given to the animal based on established criteria (see Appendix C). It should be noted that there are different condition scoring criteria for assessing females versus males because of the possibility of young.

After processing, sedated animals were held in a recovery crate until the Zoletil had been metabolised sufficiently to allow recovery of consciousness, and were not released to return to their burrow until they were fully capable of walking and orientating within the recovery crate. The condition of sedated animals was monitored using a pulse oximeter which measures oxygen levels, heartrate and temperature of the animal (Matthews *et al.*, 2003) and is normally attached to the pouch of a female or the scrotum of a male.

3.0 Pilot Results

Thirty-three original steel traps were deployed on a total of 25 burrows at EFNP (see Appendix D). The steel traps were deployed over the first four days of trapping, with 17 traps out on the first night of trapping, 26 on the third night, and 33 on the fourth night. The three PVC pipe traps were all set on night 5 and onwards. This delivered 273 trap-nights of capture effort (258 trap-nights with original steel traps; 15 trap-nights with prototype PVC pipe traps). A total of 24 target and non-target animals were captured with capture events by species recorded in Table 3.

Table 3. Species caught during 273 trapping nights with both trap designs

Species	Number
Northern hairy-nosed wombat	6
Swamp wallaby	9
Echidna	8
Spectacled hare-wallaby	1

Six wombats were caught during 273 trap-nights for an average trapping success of 0.022 captures per trap-night. With one capture from 15 trap-nights (0.066 captures per trap-night) the prototype PVC pipe traps appear to outperform steel traps (0.019 captures per trap-night based on 5 captures in 258 trap-nights). One animal was collared with a VHF-collar before being translocated to RUNR. In addition to actual capture events there were 49 other occasions (Table 4) when traps inaccurately signalled captures.

Table 4. Total sum of either false transmitter signals, misfires or traps closed to continuous failing.

Summary of failed trapping technology	Number of events
Number of false transmitter signals checked	32
Number of traps closed for operation on a night due to repeat false signals	5
Number of trap 'misfires'	12

Four modified pipe traps and two original pipe traps were deployed on a total of 13 burrows at RUNR (see Appendix E). The six traps were deployed over two days, with two traps out the first night of trapping and six on the second night of trapping.

During 52 trapping nights, no animals were caught, giving a trap response of 0.0 for the duration of the trapping session.

During the nine trapping nights, the following results were obtained on the traps (Table 5). The total sum of triggered traps was 16.

Table 5. Total sum of fires on pipe traps used at the second trapping trip.

Summary of failed trapping technology	Number of events
Number of triggered traps without successful catch	16
Number of traps closed for operation on a night due to repeat false signals	0
Number of false transmitter signals checked	3

4.0 Pilot Study Discussion

Some clear issues were identified arising from the application of the established (steel trap and fence) trapping protocol. First, fencing and gating large multi-entrance burrows demands significant human resource investment. Secondly, there was a high incidence of failure within the system, with a total of 49 misfires or failed transmitter signals recorded.

Trapping success from previous trapping sessions at EFNP have resulted in a trapping success (measured in captures per trap-night) of 0.06 in 1988 (Crossman, 1988), 0.016 in a trapping session undertaken in 1993 (Horsup, 1996), 0.016 in 1999 (EHP, internal) and a trapping success of 0.020 during the trapping session designed for the relocation of animals to the RUNR in 2009–2010 (EHP, internal).

Testing of the new trap design at EFNP was successful in that it was demonstrated to have the capacity to capture a wombat. One wombat was caught and tracks of wombats were found in another trap; however, the trap had not been set and did therefore not catch any animals. The new design was also shown to be easier for handling and setting up, with no need for fencing multi-entrance burrows; this greatly reduced preparation time. On two separate occasions a pipe trap was triggered but without catching anything. There were no obvious marks to determine what had triggered the trap on the first misfire, but animal prints were observed after the second misfire although the doors did not fully close. Nevertheless, a few hours after a misfire, the same trap caught the now translocated male.

The new trap design was modified before the RUNR trapping session was commenced. Revisions to the electronic detection system used in the traps were implemented to more efficiently capture target animals. This revision was achieved by replacing the single-beam infrared detector with a dual-beam system as proposed after the trialled work at EFNP, so that any given animal walking through the trap would have to be big enough to interfere with both beams instead of one to trigger the trap. This should ultimately give a higher discrimination towards the capture of wombats. No hardware design was altered between the trapping sessions. The RUNR trapping session did show improvement in relation to trap function in the new traps; however, despite that, no animals of any species were trapped. Table 6 explores other reasons for not trapping any animals.

Improvements can be made to the new trap design with some technology development, and possibly hardware upgrades before being deployed in future trapping sessions.

It has previously been found that environmental factors may influence trap responses (Perry *et al.*, 1977). These factors, including weather conditions and habitat, not only affect trap responses but also in the distribution and behaviour of animals (Stokes *et al.*, 2001). Behavioural changes can be displayed as different activity patterns, social behaviour or foraging behaviour in relation to changing weather conditions, including moon light, wind or rain. Rain has been suggested to inhibit the olfactory senses in predators of rodents, leaving possible prey animals likely to have a higher activity pattern when it rains (Vickery and Bider, 1981). Brown *et al.* (1988) suggested that moonlight influences foraging behaviour in rodents, with least activity when the moon is full. Stokes *et al.* (2001) captured cotton rats (*Sigmodon hispidus*) in different seasons, to investigate if the species capture rate was influenced by temperature. Most cotton rats were captured on warmer nights during autumn, suggesting that the species may prefer warmer nights.

During the EFNP trip, it rained heavily (24 mm) over the first two days of the trapping, which resulted in no traps being deployed on the second day/night, and causing failure with the transmitter system. Given the literature, it would be expected that there may be an increase in wombat activity after the rain. However, this was not the case. The rain may have had an effect on the willingness of the wombats to come through the traps, along with the noise from traps failing or closing because of transmitter failure.

Ethics approvals constrained trapping at RUNR to no more than five consecutive nights. Wildlife cameras were set up on all burrows to monitor wombat activity. It was noted that, at burrows where traps were installed, wombats moved in and out of the burrows after the traps were removed. This could imply that the wombats actively avoided the traps. However it is known from research at EFNP that wombats may stay in their burrows for up to ten days. So, the return of wombat activity to burrow after the removal of the traps may coincidently represent the wombat re-emergence after a slightly extended stay under ground. Whatever the reason, the decision to restrict traps to 50% of the usual trapping duration precludes meaningful interpretation of the results. Future trapping should (a) extend trap-nights to the usual to allow comparison with trapping sessions at EFNP; and (b) employ a design to test for trap avoidance by the wombats.

The trapping programs provided by the EHP gave me the opportunity to test the feasibility of trapping wombats. In the case of trapped wombats during the RUNR trip, opportunistic collaring of wombats would have happened. However, trapping of wombats was not shown to be efficient, and a non-invasive method was chosen to explore the behaviour, habitat utilisation and extent of range of the population at RUNR.

Table 6. Outlining possible reasons for unsuccessful trapping at the second trapping session.

Possible cause for unsuccessful trapping	Consequences
Animals being trap shy	Considering that all wombats are translocated from EFNP to RUNR, which means they have all been trapped before in 2009/2010, this could make the animals trap shy during a trapping session.
Faulty setup of traps	Faulty setup of traps could mean wombats could either escape or walk through traps without being trapped. Traps were set up according to setup procedure from EFNP, where trapping of wombats was successful.
Weather conditions	From the first trapping session, it was clear that wombats were less active outside of their burrow when there were extreme weather conditions such as heat, cold or rain. During this trapping session, it rained for two days. This could have inhibited our trapping.
Animals' sensitivity to disturbance	Setting up of traps is a disturbance to the wombats' environment. Furthermore, the disturbance in case of a triggered trap could disturb the wombats enough to cause them to not come out of their burrow.

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Chapter 3 – Habitat utilisation at Richard Underwood Nature Refuge by the northern hairy-nosed wombat

Understanding the population status of any endangered species is essential for management and recovery of that species (Linkie *et al.,* 2007; Sollman *et al.,* 2013; Zero *et al.,* 2013). Furthermore, the ability to estimate ecological relationships of a target species and its habitat is crucial for the future management of the species (Bridgness and Noss, 2010; Katzner *et al.,* 2011). A species' utilisation of habitat is a necessary part of understanding how endangered animals will recover or whether or not manipulation of habitat or animals is required for species survival (Johnson, 1991a). However, researching terrestrial mammals can be challenging, specifically if they display cryptic and secretive behaviour (Carbone *et al.,* 2001; Linkie *et al.,* 2007; Zero *et al.,* 2013). This is the case in the study of the northern hairy-nosed wombat (Evans and Horsup, 1992; Hoyle *et al.,* 1995; Banks *et al.,* 2003). Habitat selected by the animal contains vital environmental components such as food resource and shelter from potential predators (Cahill and Matthysen, 2007; Chalfoun and Martin, 2007). Consequently, understanding habitat choices, utilisation and preferences in mammals is critical for effective management and conservation planning, especially for endangered species (Chalfoun and Martin, 2007; Banks *et al.,* 2003). The study of habitats will increase the understanding of the potential risk of loss of these environmental components. Furthermore, it may improve success rates of potential future re-introductions of endangered species (Cahill and Matthysen, 2007; Banks *et al.,* 2003). The northern hairy-nosed wombat is listed as critically endangered on the IUCN Red List, and is one of the world's rarest mammals (Johnson, 1991b; Banks *et al.,* 2003). The species critical conservation status and highly restricted geographical distribution have presented substantial management difficulties (Johnson, 1991b). The contemporary natural distribution of the northern hairy-nosed wombat is restricted to EFNP in central Queensland (Van Dyck and Strahan, 2008); however, a major translocation program was commenced in 2009–2010 and successfully translocated 15 individuals to the RUNR, within the historic range of the species, near St George in southern Queensland (Johnson, 1991b; Dinwoodie, 2012). This population, however, functions as an insurance population, and has not contributed to a range extension for the species.

The northern hairy-nosed wombat is a nocturnal, semi-fossorial species (Woolnough and Johnson, 2000), which restricts researchers' capacity to monitor the species (Woolnough and Johnson, 2000; Banks *et al.,* 2003; Reiss *et al.,* 2008). Direct observation and trapping methods have previously been used in monitoring programs for northern hairy-nosed wombats. These methods are, however, challenging, costly, and require extensive investment of time (Johnson and Crossman, 1991; Crossman *et al.,* 1994; Banks *et al.,* 2003). Live trapping of animals will inevitably add stress to the trapped animal, and hence it may alter its behaviour (Hoyle *et al.,* 1995). Trapping of the northern hairy-nosed wombat has apparent negative effects on the animals, including weight loss (Hoyle *et al.,* 1995); consequently, a less invasive method has been adopted (Banks *et al.,* 2003). Among the various monitoring methods available, camera trapping provides a minimum interference method, and data collection can be obtained remotely (Rowcliffe *et al.,* 2008; Rowcliffe *et al.,* 2011; Meek *et al.,* 2015). Camera trapping has become an important method for observing animals when other methods fail to obtain data, and can: (1) be applied in most environments (Carbone *et al.,* 2001; Rowcliffe *et al.,* 2008; De Bondi *et al.,* 2010), and (2) provide multiple results, including density and occupancy (Karanth and Nichols, 1998; Rovero *et al.,* 2013), behaviour and social systems (Sequin *et al.,* 2003; Bridges *et al.,* 2004), as well as habitat usage and distribution (Augustine, 2004; Burton *et al.,* 2015). The use of camera traps in Australia goes back to the 1950s and1960s where the first attempts at recording animals via camera traps were pursued (Meek *et al.,* 2015). The first Australian-made camera (Fauna Tech 4000 VHS camera) was tested in the 1980s and 1990s on the northern hairy-nosed wombat at EFNP (Meek *et al.,* 2015). Camera trapping is often combined with another non-invasive method of species detection, track and scat detection (Kawanishi and Sunquist, 2004). Tracks and scat surveys can be broadly applied, and give an indication of a broad distribution of a target species, as well as being a low interference, low cost method of animal detection (Kendall *et al.,* 1992; Karanth *et al.,* 2003; Heinemeyer *et al.,* 2008).

It has previously been suggested that translocation is more successful if the targeted species is re-introduced into its former historic ranges (Griffith *et al.,* 1989; IUCN, 2013). The northern hairy-nosed wombat was an ideal candidate species for translocation because of the fear of extinction due to stochastic events impacting on the remaining population at EFNP (Lees, 2002). Prior to translocation of the species, the EHP commenced an extensive search for suitable wombat habitat as potential translocation sites (Cox, 1998; Lees, 2002; Wormington, 2004; Forster, 2007; Horsup *et al.,* 2007). Soil type is an important ecological variable for wombat habitat (Walker *et al.,* 2007) because wombats are obligate burrow users (Evans, 2008). A paleo-channel, associated with the Belyando river system, runs through EFNP and provides the essential areas of burrowing substrate (McGill, 2003; Horsup, 2004). Johnson (1991a) investigated the utilisation of habitat of the northern hairy-nosed wombat in EFNP. The author found that mean core areas of habitat preferences were in open bloodwood/Moreton Bay ash (*Corymbia* spp.) woodlands or open grasslands, near the paleo-channel, where the burrows were found. It was suggested that this could be linked to the higher level of moisture because of lateral drainage in this area (Johnson, 1991a).

The habitat at the RUNR has been broadly described in terms of regional ecosystems and a general soil profile (Lees, 2002; Forester, 2007). However, there has been no detailed assessment of habitat structure and composition, as well as no investigation of how the translocated animals may be using the habitat for feeding or for burrowing.

In the light of the gap in understanding of how the species utilise the habitat at its relocation site, this study aims to understand wombat utilisation of the vegetation at RUNR, and to better define core habitat. The key objects are to: (1) describe and map the plant communities, (2) map wombat activity in relation to the mapped communities, (3) describe core wombat activity, and (4) explore the influence of environmental factors on wombat activity and habitat utilisation. Given that the population at the RUNR is likely to be more sensitive than the population at EFNP because they are: (a) in a relative new habitat, and (b) a small population (ten individuals) with a highly skewed sex ratio (female (8); male (2)), I decided to: (a) do a full vegetation assessment of RUNR based on methods applied by the Queensland Department of Science, Information Technology, Innovation and the Arts, (b) adopt a camera trap technique, as well as (c) do surveys of tracks and scats within belt transects, to improve the understanding and extent of ranging within the Nature Refuge, of the northern hairy-nosed wombat and the association of wombat activity relative to plant communities and structures in the RUNR.

1.0 Methods and materials

Study site

The RUNR is a 130 ha property surrounded by agricultural land near St George, Queensland ((-27.6665, 148.70148), and is managed by the EHP, Queensland. The park is fenced with a dingo fence around the entire 130 ha and contains ten translocated northern hairy-nosed wombats. The major vegetation communities found are tussock grasslands, open patchy woodland with species including poplar box and dense patchy woodland especially dominated by cypress pine (Lees, 2002; Naske, Horsup and Cook, 2007).

Vegetation assessment

The methodology followed Department of Science, Information Technology, Innovation and the Arts (2012) for vegetation surveys. A preliminary desk-top assessment was undertaken using Google Earth Imagery to define provisional map units. These were refined/confirmed by on-site ground truthing. Within the final map units, data were collected on plant community structure and composition, with data derived from three 50 x 4 m belt transects (Figure 2) located within each map unit, in conjunction with a broad walk around. Species identification is being confirmed by the Queensland Herbarium.

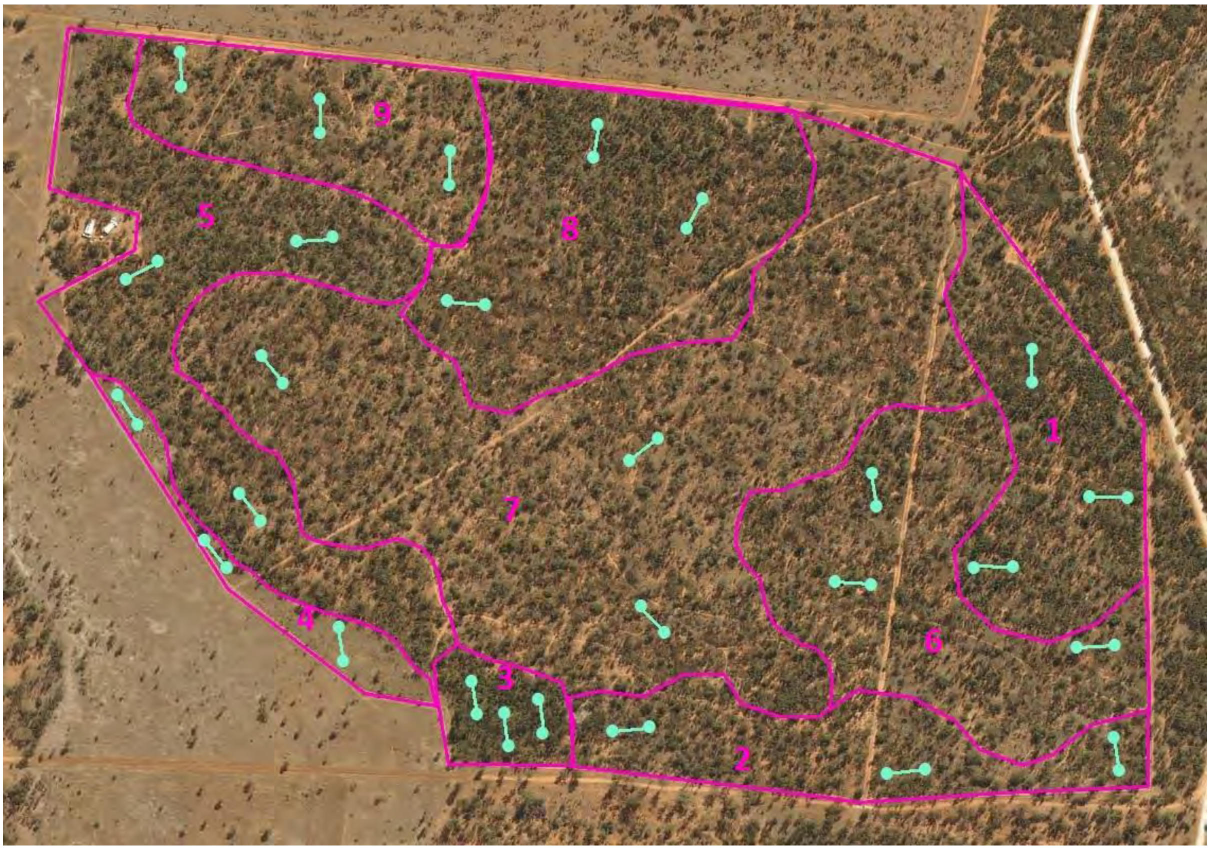

Figure 2. RUNR (Sound East Queensland) divided into 9 vegetation units, each containing 3 vegetation assessment plots.

A species list for each vegetation unit was generated (Appendix F) based on the individual vegetation plots. Soil texture, colour (Munsell) and pH were recorded from each vegetation unit (Appendix G). A refuge-wide plant species list was created by combining plot lists and compared to the current species list for the Refuge.

2.0 Wombat habitat utilisation

Tracks and scats survey

Wombat activity across the entire property was initially assessed by mapping the distribution of wombat traces (scats and tracks). Fourteen belt transects were established 100 m apart across the park. Transects were mapped in ArcGIS 10.3.1. Wombat scats and tracks were recorded within a 50 m belt of the transect. All records were mapped with GPS coordinates. Scats were categorised as single or cluster, and presence of tracks was recorded. All tracks and scats were recorded in November 2016. Only fresh and semi-fresh (still soft scat, but not squishy) tracks and scats were recorded in January 2017.

Camera trapping

To further gauge the extent of ranging and frequency of use, twenty-nine wildlife cameras were deployed in an even grid throughout the park on a 200 m x 200 m grid, with the camera placed in the centre of each cell. The camera grid was mapped in ArcGIS 10.3.1 (Figure 3), and specific camera position was located with GPS (Figure 4). Positioning of camera direction was randomised between North, South, East and West. Five additional cameras were deployed in grid corners known to have confirmed wombat activity (Dave Harper, pers. comm.); hence, five grid points had two cameras. The positioning of the five additional cameras was randomised between the corners of the grid and positioning was randomised between North, South, East and West. Cameras were set to take still pictures with a low sensitivity to avoid false triggering.

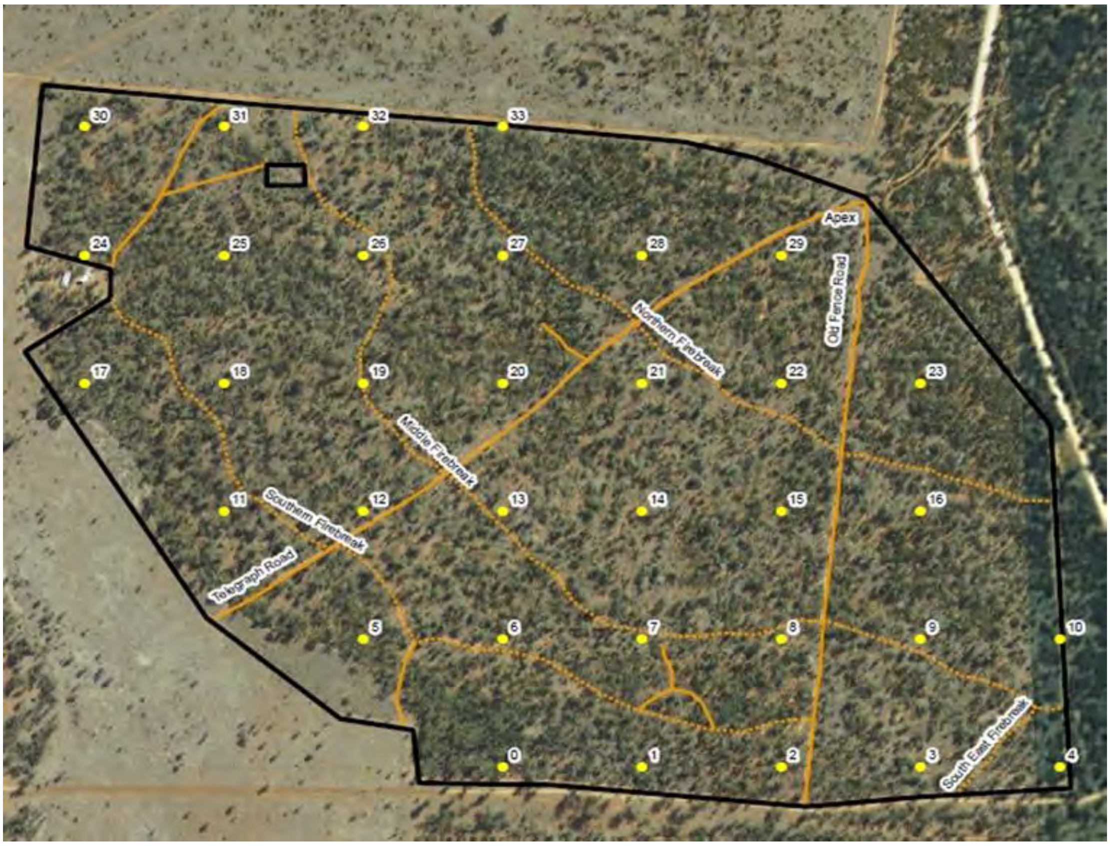

Figure 3. RUNR with fence line. Yellow dots form a 200 m x 200 m camera grid.

Figure 4. Camera positioning for the first 105 days of the experiment.

Cameras were set for 105 days in their respective grid, in order to confirm wombat activity throughout the refuge. Data were scored up (wombat presence/absence), and cameras in cells with 105 days of no activity and records in the track and scat sign survey were moved to a high intensity wombat activity pattern in a re-structured experimental design (Figure 5). Eight cameras were moved from no activity to high activity areas and distributed randomly on all high activity grid points, and data collection of all cameras continued for a further 84 days.

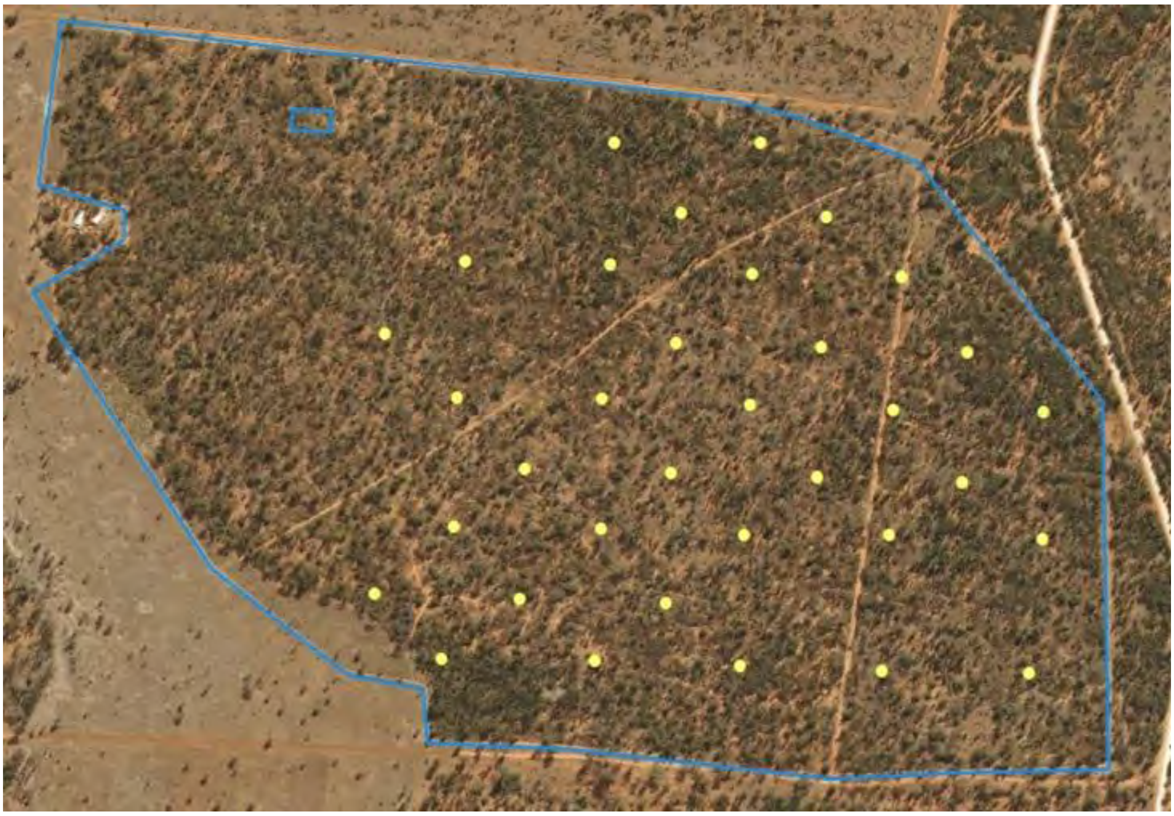

Figure 5. Camera positioning for the remaining 84 days of the study.

Environmental influences

Weather data were extracted from the St George Airport weather station (*ID* 043109), located approximately 45 km from RUNR, as provided by the Bureau of Meteorology. For the duration of the study (15/11/2016 to 22/05/2017), environmental factors including average daily temperature (Celsius), maximum daily temperature (Celsius), minimum daily temperature (Celsius), daily dew point (Celsius), moon phase and daily average wind speed (km/h) to relate to environmental factors influencing wombat activity.

3.0 Data analysis of camera data

Catch per unit effort (CPUE) was calculated for the following: (1) total park area, (2) each camera grid (1–3 months versus 3–6 months), and (3) each major vegetation unit.

Number of wombat events was determined under the definition: wombat within three minutes of first sighting was the same wombat. Wombat sighting after three minutes was an independent wombat event.

Environmental data was related to wombat presence/absence by backwards elimination regression, using SigmaPlot 13.0. This was done using CPUE as the dependent value. Regression was performed per day over the duration of the project (189 days).

Heat maps were generated in ArcGIS 10.3.1 for the following; wombat CPUE (Total, 1–3 months, 3–6 months). Transect maps were generated showing found scats and tracks for both November 2016 and January 2017.

Graphs were generated for CPUE in each major vegetation unit, using Excel.

4.0 Results

Vegetation assessments

The initial vegetation plots, combined with their respective soil pH and texture throughout the park, based on vegetation assessments, are listed in table 7.

Table 7. Each vegetation unit with its average pH and identified soil textures. S= sand, SL= Sandy Loam, LS=Loamy sand.

Vegetation unit	Average pH	Soil textures identified
1	5.6	S, SL, LS
2	6.0	S
3	6.0	
4	6.0	LS
5	6.5	S, LS
6	6.3	SL
7	5.8	LS
8	5.1	SL
9	5.6	LS

There were six steps in relation to a full vegetation assessment;

(1) Each vegetation unit was described in terms of the vegetation field sites and from here a single floristic description was derived (Table 8).

(2) A re-classification of vegetation units based on floristic categories was generated (Table 9), to further identify vegetation communities throughout RUNR.

Following re-classification of RUNR, a new vegetation map was generated numbered with Map Units (Figure 6):

Table 8. Each vegetation unit with their respective floristic description.

Vegetation unit	**Description**
1	Low *Callitris glaucophylla* forest/dense shrubland with a sparse to open shrub layering of *Acacia* spp., *Geijera parviflora* and *Eremophila mitchellii*, over an open tussock native grassland with patches of enclosed *Cenchrus ciliaris* grass tussock.
2	Open woodland of *Eucalyptus populnea* +/- *Eucalyptus melanophloia* and *Callitris glaucophylla* with a low open shrubland dominated by *Geijera parviflora* +/- *Eremophila mitchellii* and *Hakea lorea* over a native tussock grass land including A*ristida* spp. and *Enteropogon ramosus*.
3	Low *Allocasuarina luehmannii*/*Geijera parviflora* forest with a tall open shrublayer of *Eremophila mitchellii* over a sparse ground cover of *Cenchrus ciliaris* and *Tripogon loliiformis*.
4	Closed *Cenchrus ciliaris* tussock grassland with isolated *Eremophila mitchellii* shrubland.
5	Open *Eucalyptus populnea* with an open shrubland over an open *Cenchrus ciliaris* tussock grassland with a few native species.
6	Low open woodland of *Acacia* spp. and *Callitris glaucophylla* with an open *Hakea lorea* and *Eremophila mitchellii* shrublayer over a closed *Cenchrus ciliaris* tussock grassland.
7	*Acacia* spp. woodland +/- *Callitris glaucophylla* with emergent *Eucalyptus populnea*, with an *Eremophila mitchellii* and *Geijera parviflora* shrubland over a dense *Cenchrus ciliaris* grassland including *Aristida* spp.
8	*Callitris glaucophylla* and *Angophora melanoxylon* forest including a small tree layer of *Geijera parviflora* and a sparse *Eremophila mitchellii* shrub layer over a sparse native tussock grassland +/- *Cenchrus ciliaris*
9	*Eucalyptus populnea* tall open woodland with an open shrub layer of *Eremophila mitchellii*, *Acacia* spp. +/- *Geijera parviflora* over a sparse tussock grassland dominated by C*enchrus ciliaris* +/- *Aristida* spp.

Table 9. The floristic category, vegetation units, map unit, sub map unit (if applicable) and map unit vegetation description.

Floristic Category	Vegetation units	Map unit	Sub map unit		Map Unit Vegetation description
Tussock grassland	4	1	N/A		Closed *Cenchrus ciliaris* tussock grassland with isolated *Eremophila mitchellii* shrubland.
Allocasuarina forest	3	2	N/A		Low *Allocasuarina luehmannii*/*Geijera parviflora* forest with a tall open shrublayer of *Eremophila mitchellii* over a sparse ground cover of *Cenchrus ciliaris* and *Tripogon loliiformis*.
Callitris	1, 8	3	3a: 1	3b: 8	*Callitris glaucophylla* forest with a *Geijera* parviflora, *Acacia* spp., *Eremophila mitchellii*, +/- *Hakea lorea* shrub layer over an open native tussock grassland +/- C*enchrus ciliaris* patches.
Poplar box	2, 5, 9	4	4a: 2	4b: 5, 9	Open *Eucalyptus populnea* woodland, with an open *Eremophila mitchellii* and acacia shrub layer over a sparse tussock grassland dominated by C*enchrus ciliaris* and *Aristida* spp.
Acacia	6, 7	5	5a: 6	5b: 7	*Acacia* low open woodland, +/- *Callitris glaucophylla*, with an open *Eremophila mitchellii* and *Hakea lorea* shrub layer over a dense C*enchrus ciliaris* tussock grassland.

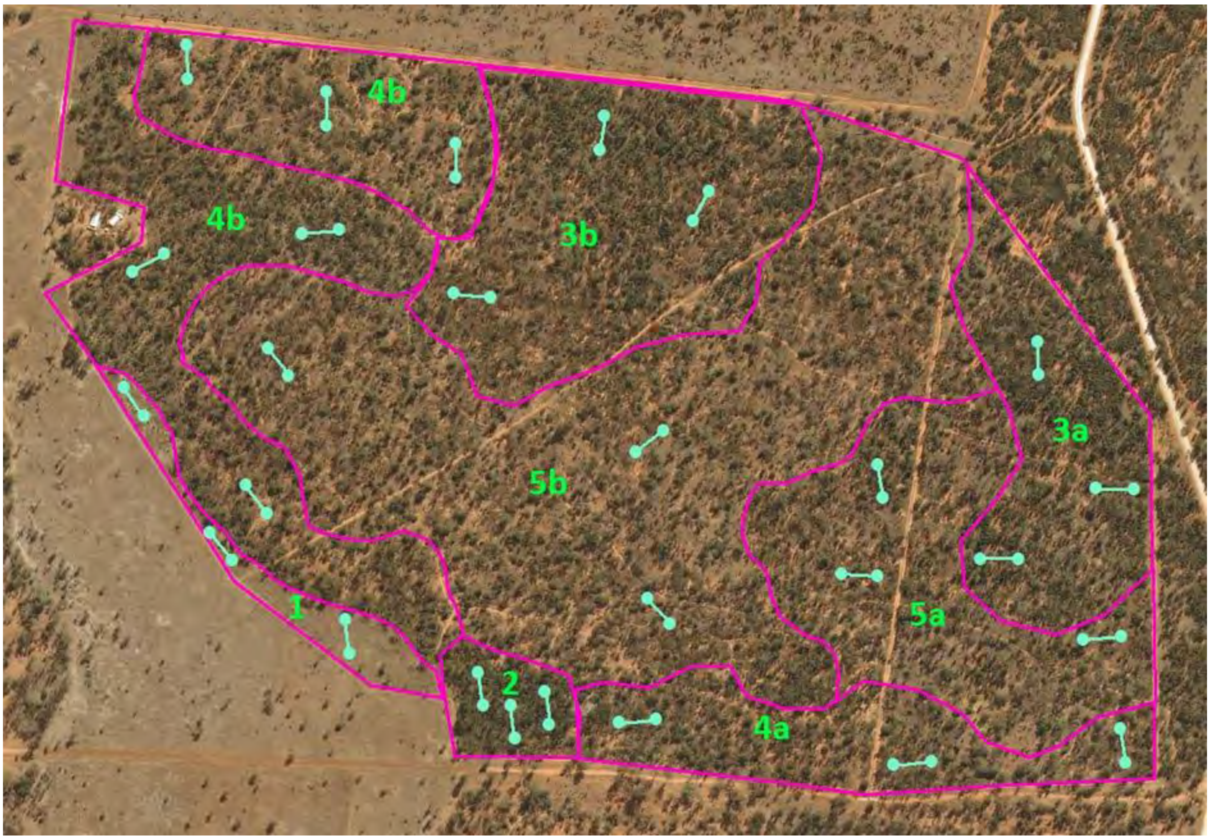

Figure 6. Vegetation communities re-classified into Map Units.

(3) Density was determined based on overstorey, shrub layer and ground story, following the map unit vegetation descriptions (Table 10).

Overall, 37.5% of RUNR was categorised as forest, 37.5% as open woodland, 12.5% as woodland and 12.5% as tussock grassland.

(4) Relating wombat activity to vegetation structure and composition, CPUE values were related to Map Unit categories (Table 11).

CPUE was calculated as:

$$\text{CPUE} = \frac{\textit{Wombats}}{\textit{Trap-nights}}$$

Table 10. Map units (and sub units), and their respective density category based on floristic vegetation descriptions.

Map unit	Overstorey density	Shrub density	Ground density
1	N/A	N/A	Closed
2	Forest	Open	Open
3a	Forest	Sparse	Open
3b	Forest	Sparse	Sparse
4a	Open	Open	Open
4b	Open	Open	Sparse
5a	Open	Open	Closed
5b	Woodland	Open	Closed

Table 11. Wombat activity calculated as CPUE values in relation to Map Unit scores.

Map unit	1	2	3a	3b	4a	4b	5a	5b
# Cameras	0	1	4	5	0	7	7	18
CPUE	0	0.00529	0.01190	0.0119	0	0	0.14285	0.26132

Appendix F and G show the individual species list for each vegetation unit, as well as each vegetation assessment on all vegetation plots.

The open woodland/ woodland community was the most utilised by wombats. No activity was recorded in the tussock grassland community. Figure 7 shows total wombat CPUE per camera in its corresponding vegetation unit. Figure 8 shows wombat CPUE month 1–3 per camera in its corresponding vegetation unit. Figure 9 shows wombat CPUE month 3–6 per camera in its corresponding vegetation unit.

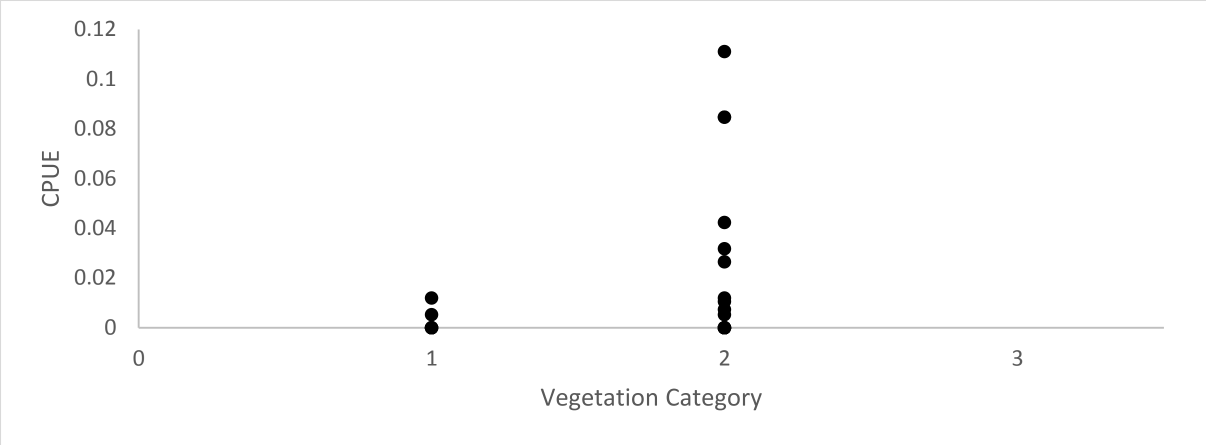

Figure 7. Graph showing total wombat CPUE per camera in its corresponding vegetation unit (1: Forest, 2: Open woodland/woodland, 3: Tussock grassland).

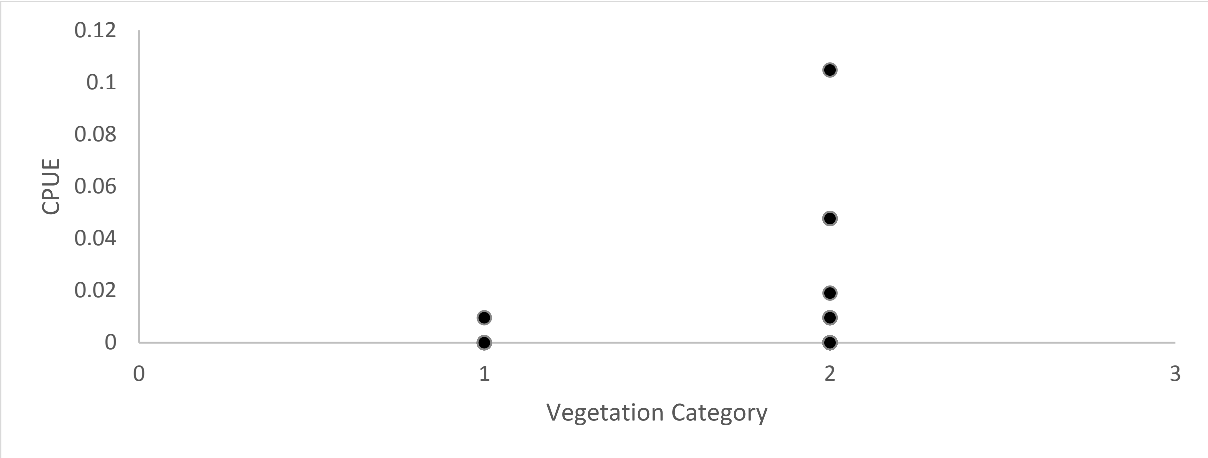

Figure 8. Graph showing wombat CPUE month 1-3 per camera in its corresponding vegetation unit (1: Forest, 2: Open woodland/woodland, 3: Tussock grassland).

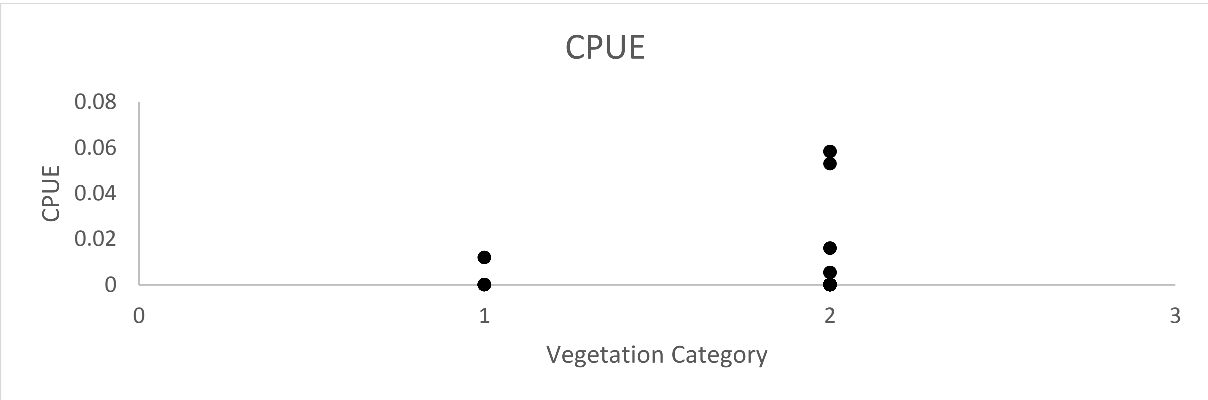

Figure 9. Graph showing wombat CPUE month 3-6 per camera in its corresponding vegetation unit (1: Forest, 2: Open woodland/woodland, 3: Tussock grassland).

In relation to CPUE values, this showed that wombat core habitat could be described as; open woodland/ woodland mainly dominated by *Acacia* spp. with isolated *E. populnea* in the tree layers, with *Eremophila mitchellii*, *Hakea lorea* and *Geijera parviflora* as an open shrublayer, over an open to dense tussock grass cover dominated by *C. ciliaris* and a few represented native grasses, including *Aristida* spp.

Tracks and scats survey

The tracks and scats survey in November 2016 yielded a lot of recorded scats. When visualised on ArcGIS map with the belt transects, it shows the majority of recorded scats were old, and only a few tracks on main roads were recorded (Figure 10).

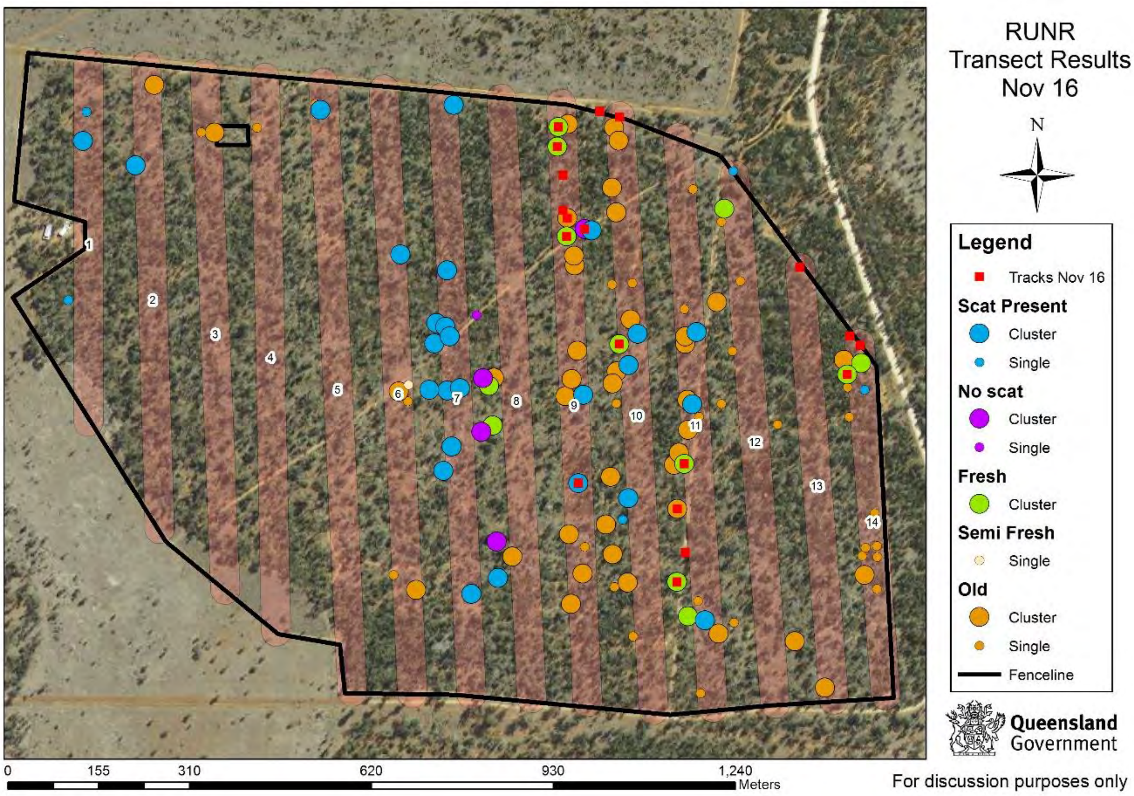

Figure 10. Transect data from November 2016 survey. Majority of scats were recorded as old and only a fraction as fresh or semi-fresh.

The tracks and scats survey in January 2017 recorded semi-fresh scats in high activity areas with no current wombat activity in the first 1/3 of the park (transect 1–5) (Figure 11).

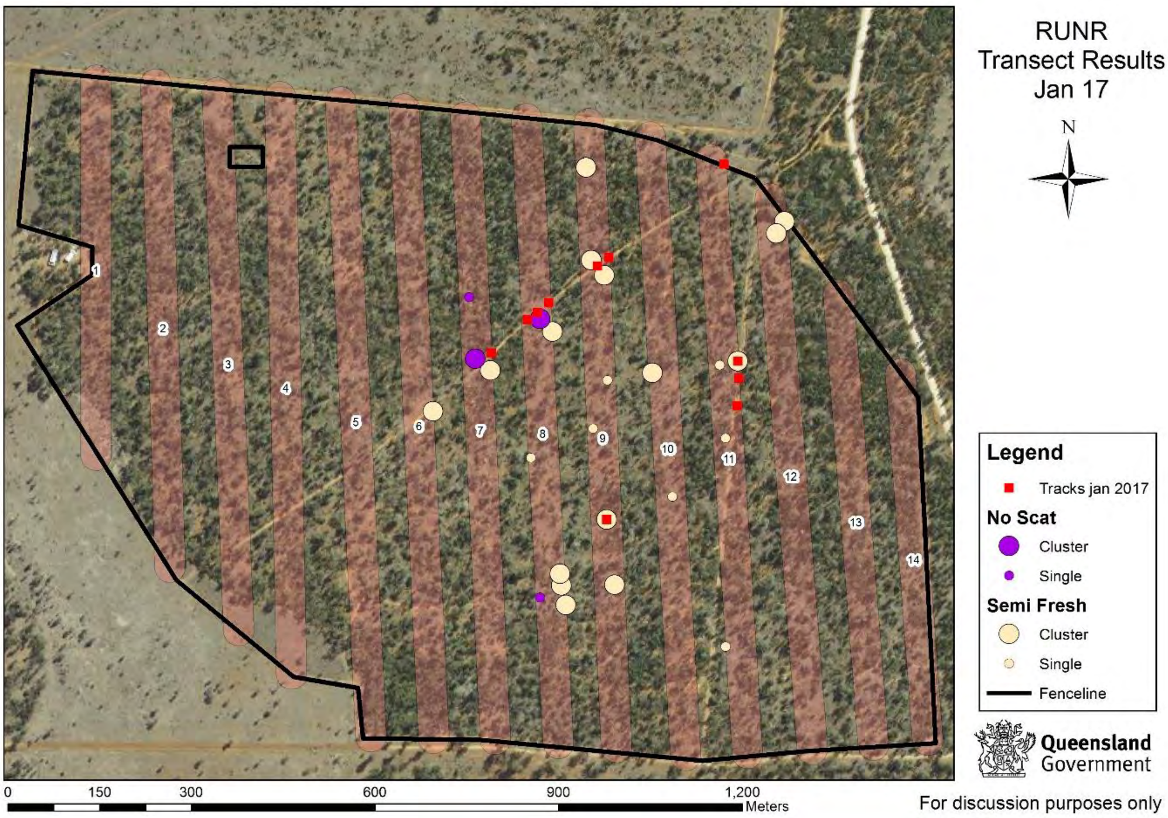

Figure 11. Transect data from January 2017. Only semi-fresh scats were recorded along with tracks. All tracks and scats were recorded in high activity areas surrounded by the majority of burrows.

Camera trapping

Wombat presence/absence was recorded for 189 days, with 105 days covering the entire 130 ha, and 84 days in high activity areas.

CPUE values were generally low, ranging 0–0.1 over the duration of the experiment. Figure 12 shows presence/absence of wombat sightings, based on CPUE values, for the total duration of the project. Figure 13 shows presence/absence of wombat sightings, based on CPUE values, for month 1–3 of the project. Figure 14 shows presence/absence of wombat sightings, based on CPUE values, for month 3–6 of the project.

The heat maps show high frequency of wombat sightings in the middle of the park. Over the total duration of the project, they show no wombat activity in approximately 1/3 of the park.

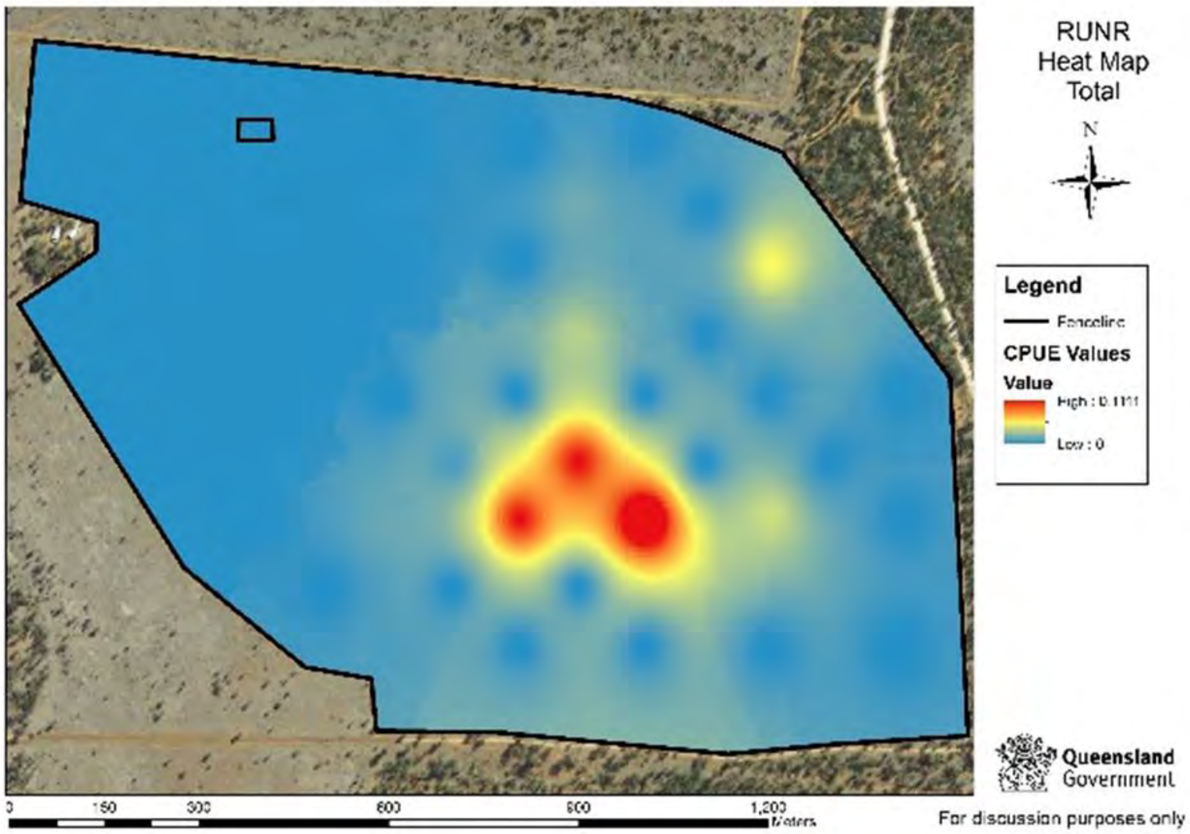

Figure 12. Heat map showing wombat sightings over a duration of 189 days.

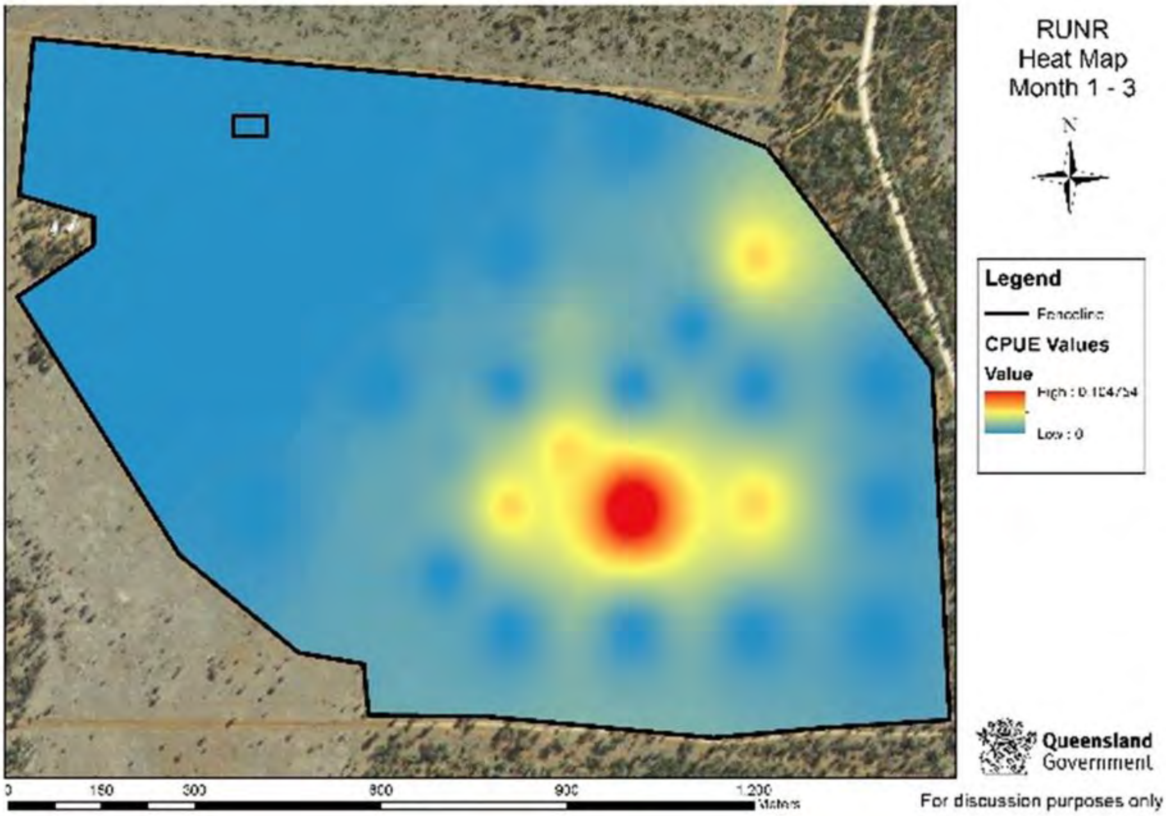

Figure 13. Heat map showing wombat sightings over a duration of 105 days.

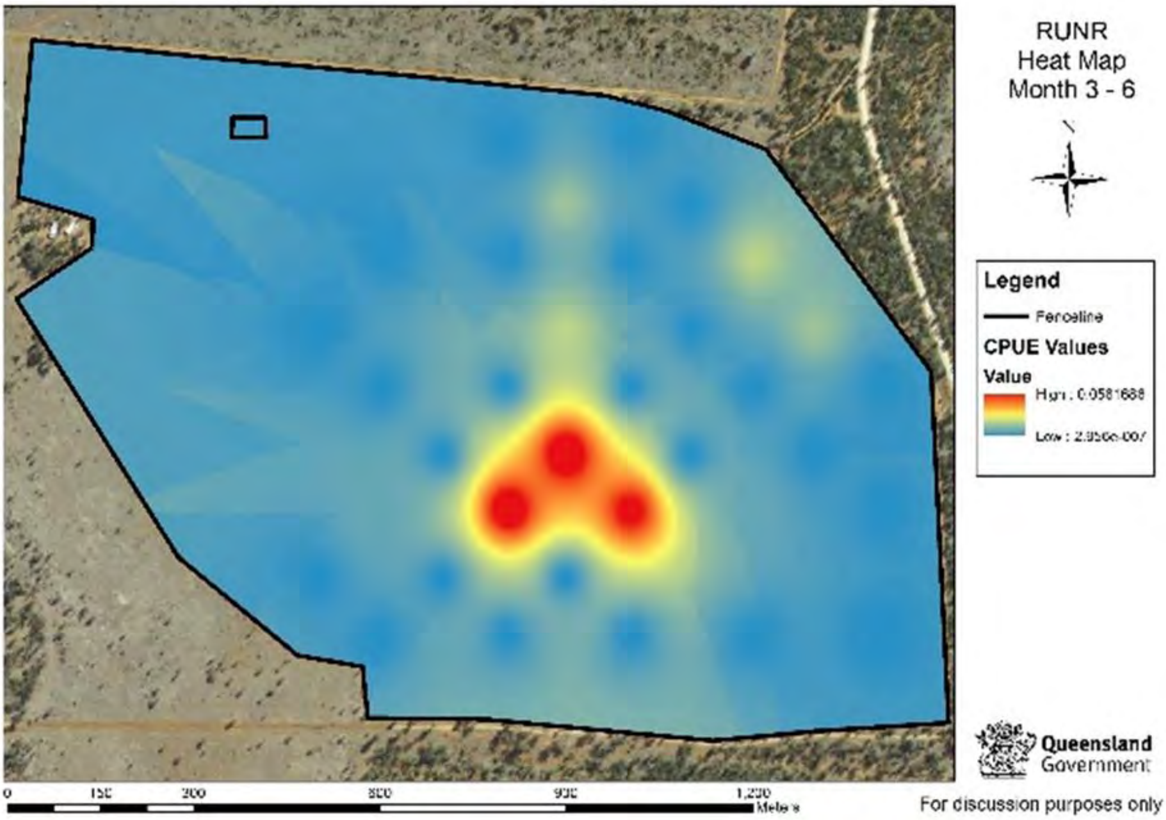

Figure 14. Heat map showing wombat sightings for 84 days.

Environmental variables influencing wombat activity

Backwards elimination regression was conducted with the following variables: (1) moon phase; (2) dewpoint; (3) average wind speed; (4) night temperatures[6]; (5) day temperatures[7]; (6) maximum temperature; and (7) minimum temperature.

Environmental data showed no significance between wombat activity and environmental factors; however, with Day temperature being the most explanatory factor for wombat activity (Table 12).

Table 12. Environmental factors and their p-values. None are significant in explaining wombat activity, however, with PM temperature being the most explanatory factor.

Environmental variable	p-value
Day temperature	0.194
Maximum temperature	0.202
Average wind speed	0.294
Minimum temperature	0.372
Dewpoint	0.449
Moon phase	0.459
Night temperature	0.899

The first factor to be excluded is Night temperature. The second and third are Moon phase and Dewpoint. The fourth and fifth are Minimum temperature and Average wind speed. Lastly, Maximum temperature, with similar p-value to the explanatory factor, Day temperature (*p= 0.194, p= 0.202)*.

[6] Average measured from 6 pm – 6 am.

[7] Average measured from 6 am – 6 pm.

5.0 Discussion

This study is the first to investigate habitat utilisation in the northern hairy-nosed wombat at a translocation site. Furthermore, this study explores the preferred vegetation communities utilised by the wombat, as well as incorporating environmental factors that could influence wombat activity.

Three major vegetation communities were identified as (1) Forest, (2) Open woodland/ woodland and (3) Tussock grassland. The results showed a higher use of vegetation communities categorised as open woodland/woodland. It was found that buffel grass was present in all nine vegetation units; however, it was most prevalent in tussock grassland vegetation. Buffel grass has been suggested to influence wombat ranging behaviour and no wombat activity was found in tussock grassland, which could suggest that wombats avoid dense patches of buffel grass.

Gordon *et al.* (1985) were the first researchers to investigate habitat use in the northern hairy-nosed wombat at EFNP. Their results were based on wombat dropping density, and showed that the density of wombat droppings were greater in vegetation communities with dense grass than in open grasslands. They also showed a positive association of wombat dropping density with higher density of shrubs and trees (overstorey) compared to open areas.

Horsup, Naske and Healy (2007) stated (based on studies from Steinbeck, 1994) that preferred habitat for the northern hairy-nosed wombat is sandy alluvial soils with a decent grass cover and, to some extent, tree and shrub cover. Grasses, including *Aristida* spp*., Enneapogon* spp., and *C. ciliaris*, are the dominating species for wombat diet when analysed at EFNP (Woolnough, 1998; Lees, 2002; Horsup, 2004).

This study revealed a similarity of broad structural vegetation descriptions, utilised as core habitats, between RUNR and ENFP. By reclassifying vegetation units into map units, it was possible to derive a density category for each of these. The results showed a high association between overstorey density and wombat activity rather than understorey. This correlates with the findings of Gordon *et al.* (1985) for EFNP findings.

Johnson (1991) explored habitat utilisation of the species at EFNP. He showed that preferred core areas of the wombats related to two major vegetation units found at EFNP; bloodwood/Moreton Bay ash woodland and poplar box woodland, with burrowing preference along an old paleo-channel running through the park, creating ideal soil for burrowing.

Burrows at RUNR, are situated along main dirt roads through out the park (Figure 15), allowing wombats to create burrows in ‘banks’ along the roads.

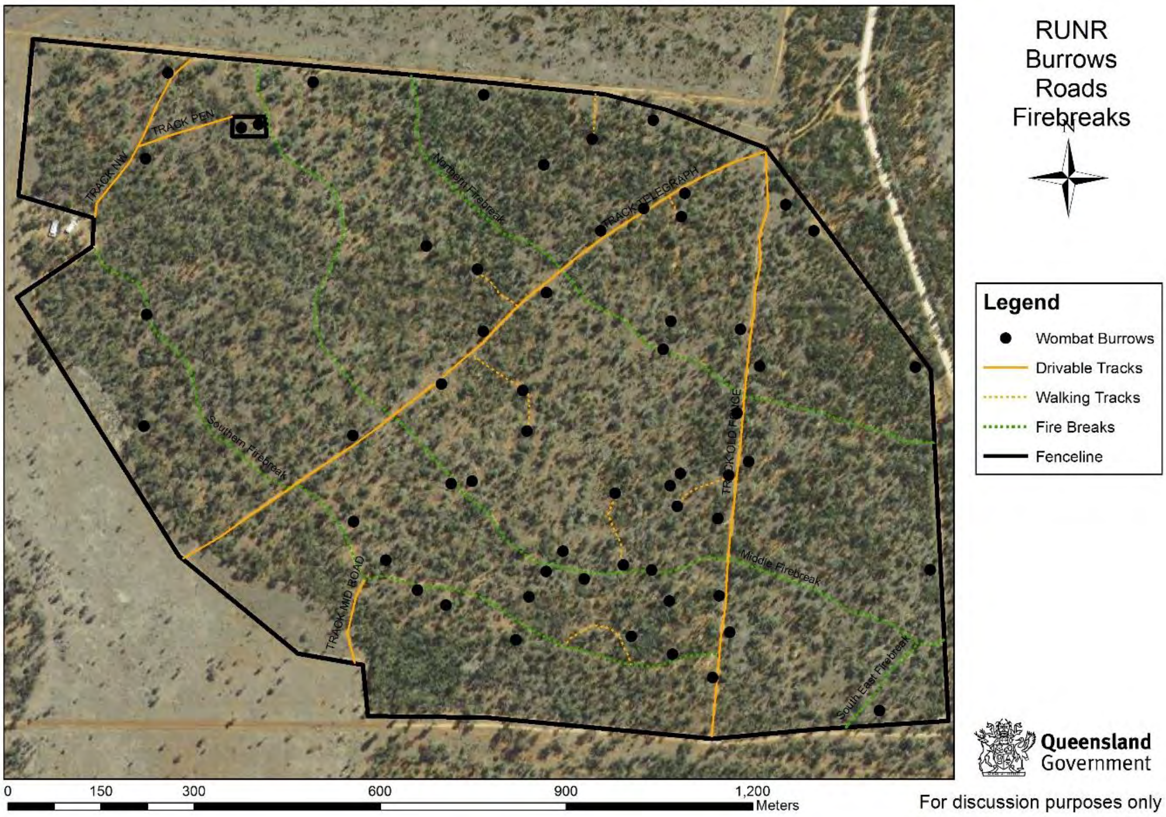

Figure 15. Map showing: yellow, main roads; Green, fire breaks and Black, burrow points.

Burrowing is strongly related to soil profiles. Soil profile testing has previously been done for EFNP, showing that the ideal burrowing soils are sand, loamy sand, sandy loam or sandy clay in texture, with a coherence and firmness adding to burrow architecture (Forester, 2007). Fine grained sands are more likely to collapse when in burrows, whereas loamy sand or sandy clay add to the coherence of a burrow, and are particular suitable for burrowing (Forester, 2007).

Similar soil profiles were found at RUNR (Forester, 2007), with uniform soils of either loamy sands, sandy loam or sandy clay and clay loam. It was stated that RUNR soil profiles in general were suitable burrowing soils. It was also stated that the presence of rough-barked apple, bloodwood and silver-leaved iron bark were a good association for burrowing soil (based on baseline studies at EFNP).

Wombat activity patterns are potentially influenced by several environmental factors. Wells (1978) explored temperature as an environmental influence on wombat activity on southern hairy-nosed wombats. It was discovered that wombats altered behaviour in relation to temperature, and thus activity is only displayed when the wombat can physiologically cope. However, wombat activity in free ranging wombats was recorded in extreme temperatures (-3.0 to 27.0 degrees Celsius).

Finalyson *et al.* (2005) investigated activity patterns in the southern hairy-nosed wombat in relation to environmental factors, specifically temperature, and found that activity patterns were significantly influenced by ambient temperature, with individuals emerging at a mean temperature of 12.9 degrees Celsius. It was suggested that southern hairy-nosed wombats were more likely to be above ground when night length increased.

Johnson (1991b) studied activity patterns of northern hairy-nosed wombats and found seasonal variation between activity patterns as well as a significant variation in activity patterns with ambient temperature. Activity was shown to be low with lower temperatures (in winter) and low with high temperatures (in summer).

This study did not show any significant environmental variables on wombat activity patterns. However, temperature had the most explanatory factor for wombat activity patterns during monitoring.

Wombat activity in this study was explored with the use of a non-invasive method, wildlife camera trapping. This showed to be a successful method for monitoring wombat activity in different areas of their habitat. With 34 cameras available, this study managed to cover the range of the park, as well as re-strategising capture efforts into high activity areas with a smaller layout. Activity has been studied in other wombat species, predominantly using GPS-collaring for an optimised and more detailed picture of activity schedules (Finlayson, 2003; Finlayson *et al.,* 2005; Evans, 2008; Hogan *et al.*, 2009).

Environmental factors influencing behaviour such as activity and home range size have been studied in other endangered marsupials (Fisher, 2000). Fisher (2000) investigated optimal habitat preferences for the bridled nailtail wallaby in relation to ranging behaviour, available habitat and moon phases. It was mentioned that home range size is an indicator of habitat quality.

To further investigate a detailed picture of activity and home ranges in relation to vegetation communities, it is recommended to explore GPS-collaring methods. This will provide a detailed picture of time spent above and under ground, and exact locations in vegetation communities. By investigating home ranges in both EFNP and RUNR, a more optimised picture of habitat preferences and quality may be generated, and could potentially further assist in determining vegetation quality and structure for a third translocation site.

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Chapter 4 – An investigation of the behaviour of the northern hairy-nosed wombat in a translocated population

1.0 Introduction

The northern hairy-nosed wombat is a large, herbivorous marsupial that displays nocturnal behaviour and a semi-fossorial nature (Shimmin and White, 2002; Horsup, 2004; Hogan *et al.,* 2009). The species' only known natural population is found at EFNP, Queensland (Johnson, 1991b); however, a translocated population has been established within the former historic range at St George, Queensland (Johnson, 1991b; Dinwoodie, 2012) within the RUNR.

The behaviour of the northern hairy-nosed wombat (*Lasiorhinus krefftii*) is not a commonly explored area, due to the nocturnal behaviour of the species (Johnson and Crossman, 1990; Hogan *et al*., 2009). The investigation of behaviour in the species can provide important information about time use, potential social behaviour and activity patterns. It could provide baseline information for further conservation of the species. Behavioural studies were first started in 1991 by Johnson, although Stenke (2000) was the first author to describe structure and behavioural definitions of the species. However, neither incorporated a non-invasive observation method. Until now, behavioural patterns are still not well understood in the species.

Although wombats are generally known for displaying solitary behaviour (Johnson, 1991a), Stenke (2000) observed social interactions between individuals at EFNP using direct observation. However, during 1300 observation hours only 12 social interaction observations (intraspecific) were made. The author based observations of social interaction on the presence of vocalisation (social) or absence of vocalisation (solitary). Behaviours were described in detail and were categorised as foraging behaviour, environment check, social interactions, locomotion and other (Stenke, 2000). Evidence of social interaction can also include burrow sharing, and Johnson (1991a) found that burrow sharing does occur in this species.

Hogan *et al.* (2009) investigated the daily behavioural pattern of captive southern hairy-nosed wombats at the Rockhampton Zoo. Behaviours were categorised as active behaviour (mating, digging, exploring, feeding, grooming, handling, foraging and stereotypy), inactive behaviour (sunbasking, lying resting and sitting behaviour) and sleeping (sleep only). A total of 12 animals (also equipped with GPS-collars) were studied, and showed that on average wombats spent 69.9% of total time sleeping as the main behavioural activity, and 0.1% mating.

Behavioural studies on Vombatidae are, in general, sparse; however, a few additional studies have been performed, including wild and captive individuals (of all wombat species) as well as the use of various methods (Finlayson *et al.,* 2005; Hogan *et al.,* 2009). Most studies focus on active versus inactive periods of time. Finlayson (2003) found that wild southern hairy-nosed wombats were, on average, active 25% of the day. This was investigated with the use of GPS-collaring of one case-study animal. Activity of wild common wombats has been reported to be 33% of daily activity (McIlroy, 1973).

Behavioural time budgets have been studied on captive southern hairy-nosed wombats (Hogan *et al.,* 2009) and on captive common wombats (Hogan, 2004), using remote camera observations and on northern hairy-nosed wombats (Stenke, 2000), using direct observation. A modification of present ethograms has been adopted to fit this current study.

Direct observation has been used for behavioural studies in both the southern hairy-nosed wombat and the common wombat (Wells, 1978), and was previously the only method of observing animals (Bridges and Noss, 2010). However, since the introduction of wildlife cameras as a method for remote-monitoring of animal behaviour this has become a highly utilised methods of behavioural observations. For example, to investigate spatial distribution or animals with an elusive nature, such as tigers (*Panthera tigris*) (Karanth *et al.,* 2003), black bears (Bridges *et al.,* 2004), snow leopards (*Uncia uncia*) (Jackson *et al.,* 2006), southern hairy-nosed wombats (Hogan *et al.,* 2009) and common wombats (Hogan and Tribe, 2007), direct observation is a less chosen method for observation of animal behaviour.

Using a non-invasive methodology, such as remote-monitoring wildlife cameras, offers a method of exploring the behaviour of wombats without the interference of the observer (Hogan *et al.,* 2009), as well as recording real-time behavioural events, and hence the ability to document behaviour accurately (Hogan and Tribe, 2007; Hogan *et al.,* 2009). The above mentioned authors proved the method to be successful for captive wombats. It has, however, not been trialled for wild wombats. It does provide a stable baseline for trialling it on wild wombats, as there are no captive northern hairy-nosed wombats.

The use of remote-monitoring methods are fairly new to the species. The first studies of northern hairy-nosed wombat behaviour were performed by direct observation by the researcher (Johnson, 1991b; Stenke, 2000). Direct observation has proven to be a difficulty, due to the constraints of the nocturnal behaviour and semi-fossorial nature (Johnson and Crossman, 1990; Johnson, 1991a; Horsup, 1998; Hogan *et al.,* 2009). Not only does direct observation have the possibility to influence animal behaviour (Horsup, 1998; Hogan *et al.,* 2009; Keeping and Pelletier, 2014), it is also limited on a spatial level, as the researcher cannot cover an extended research area at all times.

The EHP has an ongoing species monitoring program at the RUNR that involves the use of 32 camera traps (Trophy Cam HD 119466/119467 and Trail Aggressor Cam HD 119776C) and four microchip loggers (ANT-C600 Circular Antenna 600 mm and ANT-SQR300 Square Frame Antenna 500 mm x 500 mm with LID-665 decoders). This program provided the opportunity to explore solitary versus social behaviour using a non-invasive methodology, and to provide recommendations on future study design. In this study, wild individuals from the translocated population at the RUNR were used to explore the nature of solitary and social behaviour in the species using a remote-monitoring method.

Therefore, in order to successfully obtain behavioural data free from observer-influence across the study site, a method of camera sampling was adopted. The sampling protocol drew on established methods, including those mentioned above. Improvements from using direct observation to remote-monitoring cameras was: (a) minimising stress related issues; (b) avoiding observer-based influence on animal behaviour; and (c) recording real-time behavioural events.

The aim of the project was to gain further insight into northern hairy-nosed wombat behaviour. The primary objectives of the study were to (a) describe solitary and social behavioural patterns of wild northern hairy-nosed wombats; (b) identify the efficiency of using remote camera traps for behavioural studies; and (c) investigate burrow use and burrow sharing by using a remote-monitoring method.

2.0 Materials and methods

2.1 Study site

The RUNR is a 130 ha property surrounded by agricultural land near St George, Queensland, and is managed by the EHP, Queensland. The 130 ha park is bounded by a dingo fence; enclosing ten translocated northern hairy-nosed wombats. The major vegetation communities found are tussock grassland mainly dominated by buffel grass, open patchy woodland with species including poplar box, and dense patchy woodland especially dominated by cypress pine (see Chapter 3 for a detailed description of the plant communities on the reserve). There are a total of 61 burrows at RUNR, occupied by ten wombats. Within these, 20 are categorised as 'dead' burrows, 14 as 'dormant' burrows, 7 as 'MISC' burrows and 20 as 'primary' burrows by EHP staff managing the site (see Figure 16). Eighteen burrows are equipped with one or more cameras deployed by EHP.

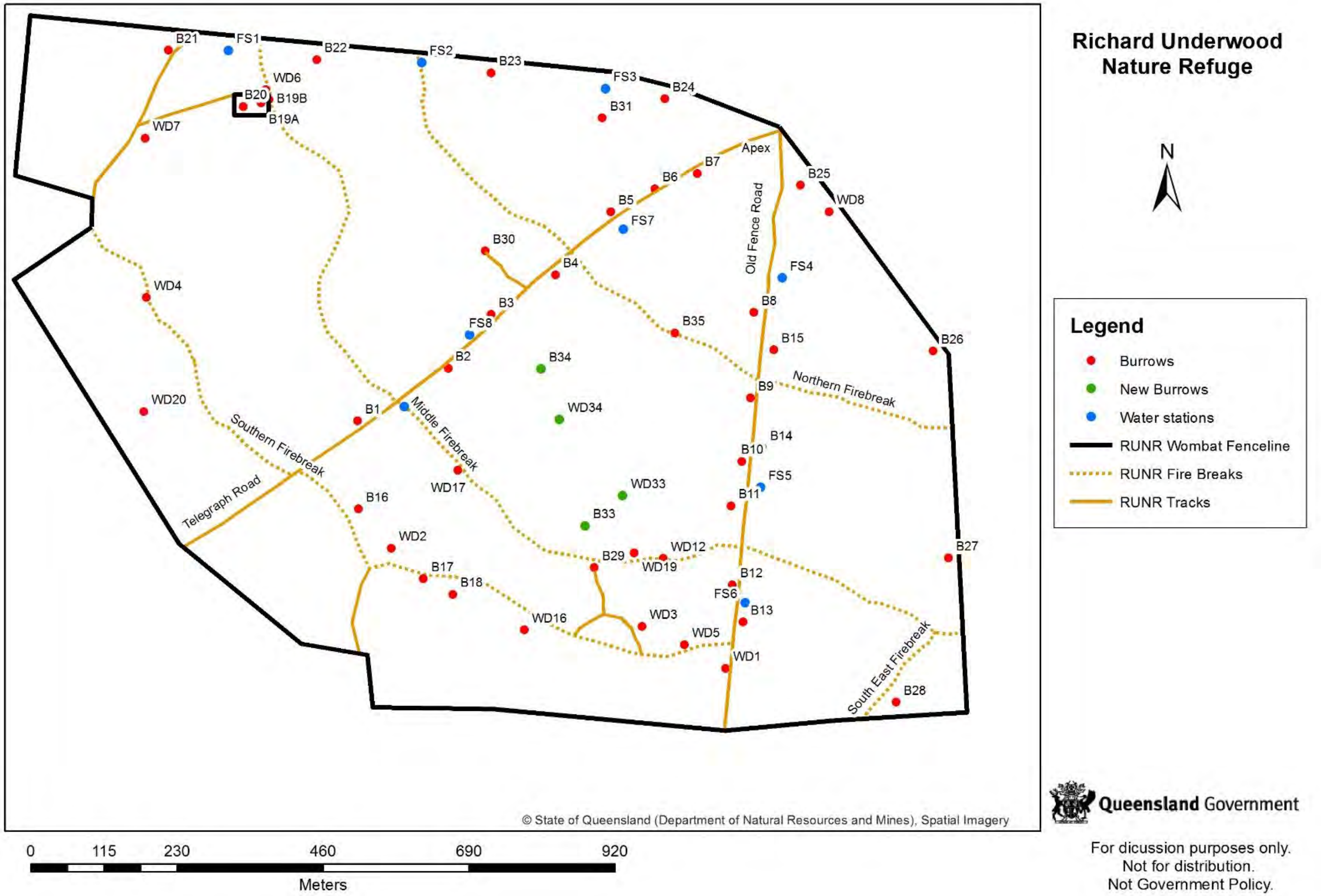

Figure 16. Richard Underwood Nature Refuge, marked burrows.

3.0 Behavioural observations

Solitary behaviour was defined as a single wombat recorded in the display range of a camera. Social behaviour was defined as two or more wombats recorded in the same display range of a camera. These definitions follow the methods used by Stenke (2000) to observe behaviour in the northern hairy-nosed wombat.

All videos with social behaviour were identified and included in analyses with the exception of videos displaying the same site from a different angle (in the case of the burrows with multiple cameras at the same site) to avoid -replication. An equal number of videos of solitary behaviour stratified by date were selected. To match social behaviour, solitary recordings were randomly selected, independent of burrow numbers. This balanced sample increases robustness of statistical analysis.

Thirty two wildlife cameras were deployed across the burrow field, and were situated at the entrance of the burrow. Some burrows had multiple cameras associated with them. Data were collected each month for a six month period (December 2016–May 2017). Camera SD cards were collected every two days, and videos with wombats were archived for later analysis. All cameras were set for 30 second videos. They were mounted on solar panel tripods (SLIK F153) to maintain battery charge. Videos collected were initially screened by on-site caretakers to identify those with wombats versus other fauna present. Wombats were assumed to be habituated to the cameras, and not to display any altered behaviour on recordings.

Videos were treated as focal animal samples (Altman, 1974) and scored using an ethogram developed specifically for this study (Table 13). Behavioural descriptions were modified from those of wombat studies, as well as other fauna studies (Stenke, 2000; Hogan, 2004; Hogan *et al.*, 2009; Nevin and Gilbert, 2005).

Table 13. Ethogram coding structure and behavioural definitions used during monitoring of the northern hairy-nosed wombat at the Richard Underwood Nature Refuge. Table adapted from Nevin and Gilbert (2005) and Hogan et al. (2009).

Coarse	Fine	Description
00 Unobservable		Off video but with sound
10 Locomotion	11 Walking	At normal pace
	12 Running	Rapid movement
	13 Stopping	Stopping of movement
	14 Lying down	Lying down flat on stomach or side
	15 Sitting	Sitting position with hind legs tucked under the body. Front legs still stretched.
	16 Digging	Digging around or at burrow entrance
	17 Standing	Standing on all four feet
20 Grooming	21 Scratching	Using either of four legs to scratch, usually in a sitting position
	22 Dusting	Lying down on side, flicking dirt with front leg on abdomen region
30 Alertness	31 Looking	Passively looking around, no tension observed
	32 Listening/ staring	Ears forward or towards side, tension in body composure
40 Foraging	41 Grazing	Chewing on grass
50 Social behaviour	51 Passive	Sitting or standing participants without vocalisation* or movement
	52 Active	One or both participants walking or running past each other, vocalisation can be present
	53 Aggressive	Chasing of participants with strong vocalisation
60 Scent communication	61 Urinating	At burrow entrance
	62 Defecating	At burrow entrance
	63 Sniffing	Nose towards ground, either slow movement or cease of movement
70 Other		

Burrow sharing and use was explored using data collected by microchip loggers that had previously been deployed by EHP. A total of four microchip loggers were deployed on four burrows (B4, B5, B25, B36), representing 6.55% of all burrows. These four are thought by EHP staff working on-site to be high activity burrows (Dave Harper, pers. comm.). All wombats at the RUNR are microchipped with Trovan ID100 (FDX-A) microchips (as a part of translocation processing), and consequently any wombat entering or leaving any of the four burrows should be logged. Microchip loggers are either circular or box shaped, and are installed at the entrance of the burrow and connected to solar-charged batteries. Data were collected once a month for a six month period (December 2016–May 2017).

4.0 Data presentation and statistical analysis

Solitary and social behaviour was visualised using Excel (2013) and Sigmaplot 13.0. All behaviour was scored up in percentage of time spent on a particular behaviour in relation to the duration of the video (30 s). Behaviour was illustrated in three ways: (1) coarse behaviour, (2) fine behaviour, and (3) 'social' (this was enhanced to show underlying behaviour).

Chi-square (Goodness of fit) test was used to test significance between time spent on solitary and social coarse behavioural structures. It was furthermore used to test for significance between solitary coarse behaviour, and 'social' coarse behaviour. Chi-square test was used to show the association between burrows.

5.0 Results

Of 6607 video captures, 0.31% (21 videos) represented social events, with two wombats present, and 99.72% (6586 videos) represented solitary events during the six month data collection period. There were no more than two wombats observed in any video capturing social events. Of the solitary animals, main behavioural displays were locomotion (walking and lying down), grooming (scratching) and scent marking (defecating) (see Figure 17 for examples). In cases where two animals occurred together, interaction occurred. This included chasing (in aggressive instances), vocalising and alertness. In all instances the vocalising animal appeared to be the sub-ordinate animal (in cases where the second animal appears in camera range, it was the already visual animal expressing vocalisation).

A time budget was developed across the six months observation period from 15/11/2016 to 30/05/2017 for both solitary wombats and social interactions; these are presented at both coarse (Figure 18) and fine (Figure 19) behavioural scales as defined in the ethogram (Table 13). Data was investigated to test for differences in behaviour between social and solitary events in the species. Data did not pass a normality test.

The time budget only explains time recorded in front of the burrow entrance, hence only a fraction of the entire activity period of an animal.

Figure 17. Showing example of (A) Wombat lying down. *(B) Wombat scratching.*

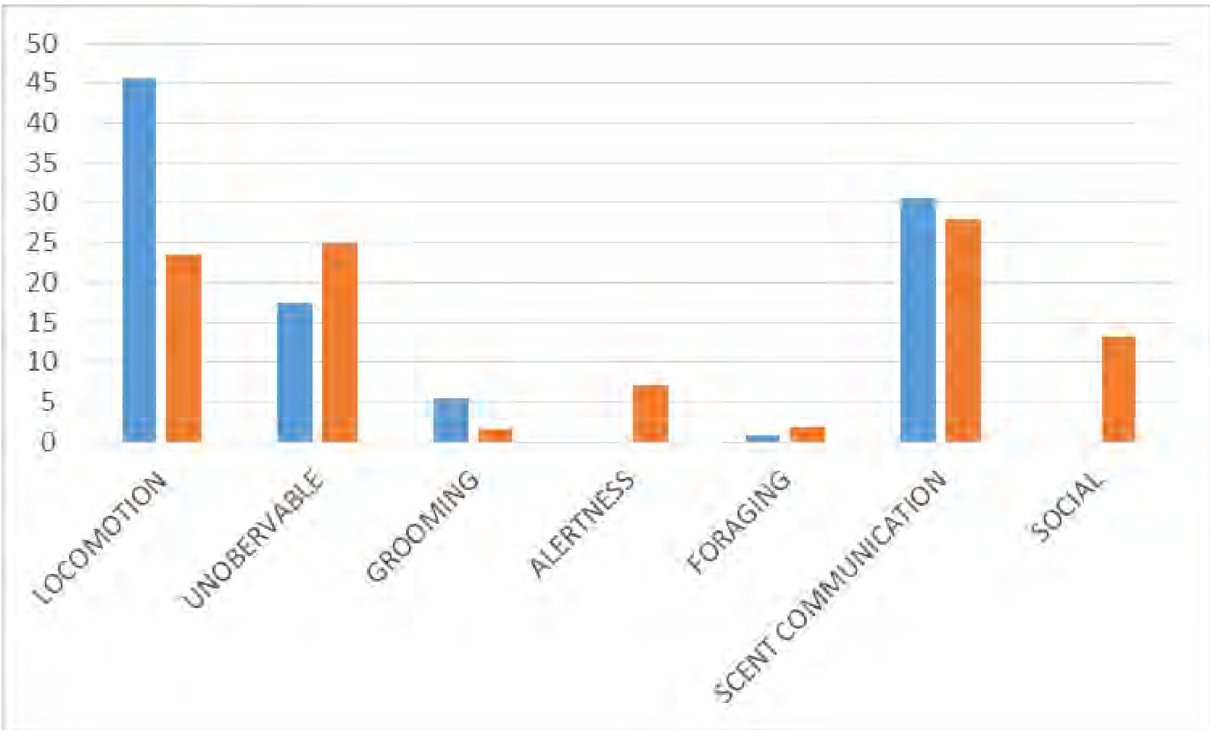

Figure 18. Time budget (coarse behaviour) for solitary (Blue) and social (Orange) wombats.

It was found that locomotion decreases in social events, by approximately 50%, and alertness, as well as social behaviour, was not recorded for solitary events. Chi square test showed significant difference ($p=9.56E^{-10}$) between solitary and social coarse behaviour events, with locomotion being the main driver for this result (Table 14).

Table 14. Chi square, error and p-value for coarse behaviour.

Chi^2	53.43
X^2 (0.05, 6)	12.59
P	9.59E^{-10}

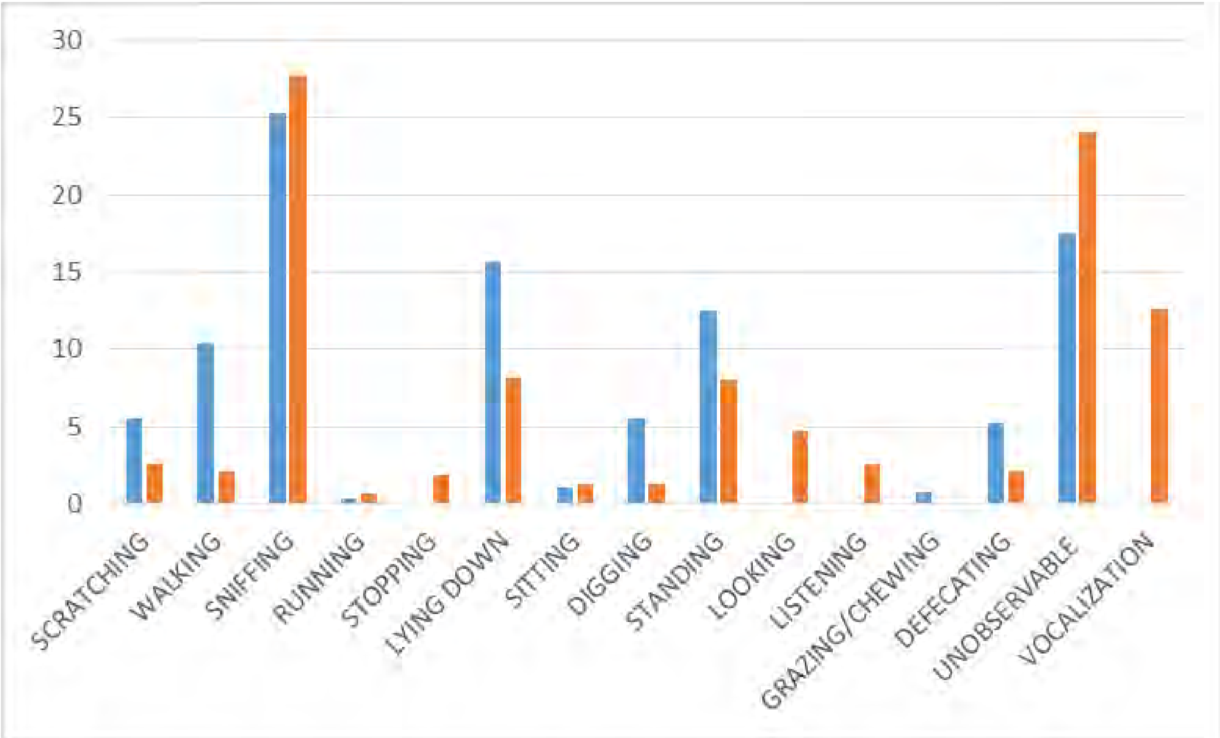

Figure 19. Time budget (fine behaviour) for solitary (Blue) and social (Orange) wombats.

It was found that all behaviours present in both events decrease in social events, except for sniffing, running, sitting and unobservable. Four behaviours were only recorded in social events (stopping, looking, listening, and vocalisation). Chi square test showed significant difference ($p=4.05E^{-14}$) between solitary and social fine behaviour events, with walking being the main driver for this result (Table 15).

Table 15. Chi square, error and p-value for fine behaviour.

Chi^2	95.12
X^2 (0.05, 14)	23.68
p	$4.05E^{-14}$

A time budget was developed across the six months observation period from 15/11/2016 to 30/05/2017 for both solitary wombats and social interactions, outlining the basic behaviour of vocalisation, compared to the correlating solitary behaviour. This is presented for both solitary behaviour (Figure 20), and vocalisation (Figure 21). Chi square test showed a significant difference ($p=4.14E^{-22}$) between the underlying basic behaviour of vocalisation and the solitary behaviour, with an increase of walking, and a decrease of being unobservable (23.07%) in the underlying behaviour of social vocalisation as the main driver for this result (Table 16).

Table 16. Chi square, error and p-value for vocalisation behaviour.

Chi^2	106.45
X^2 (0.05, 6)	9.48
p	$4.14E^{-22}$

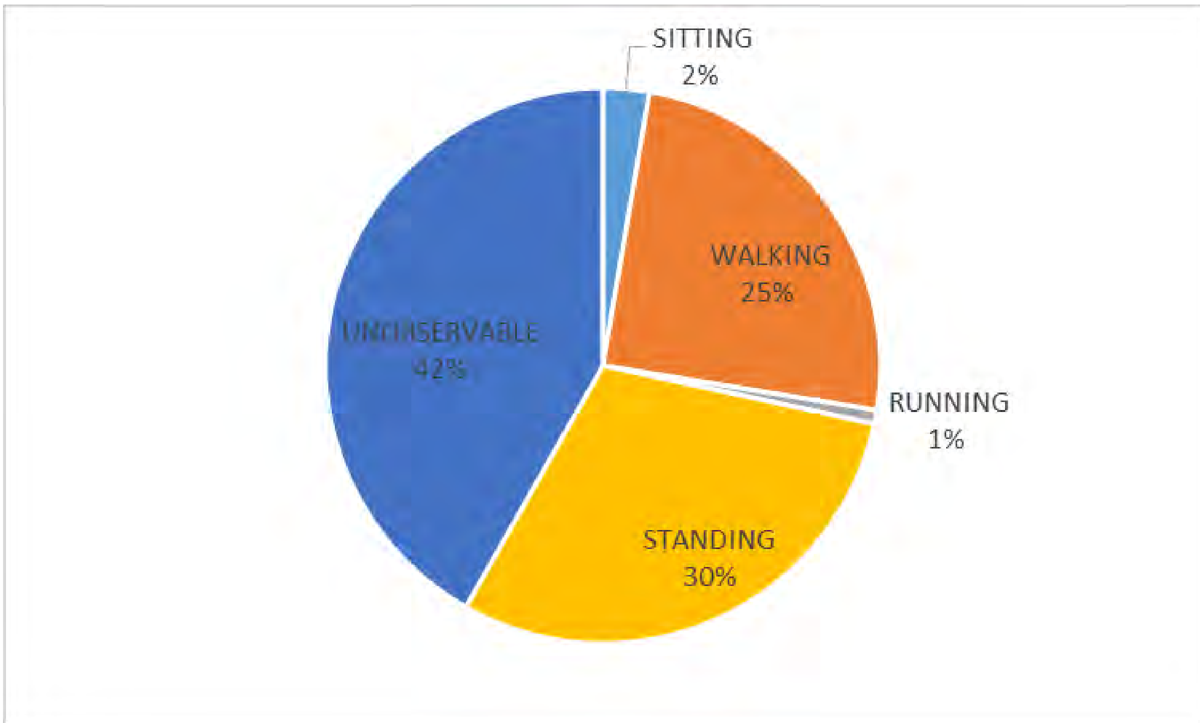

Figure 20. Time budget of solitary behaviour.

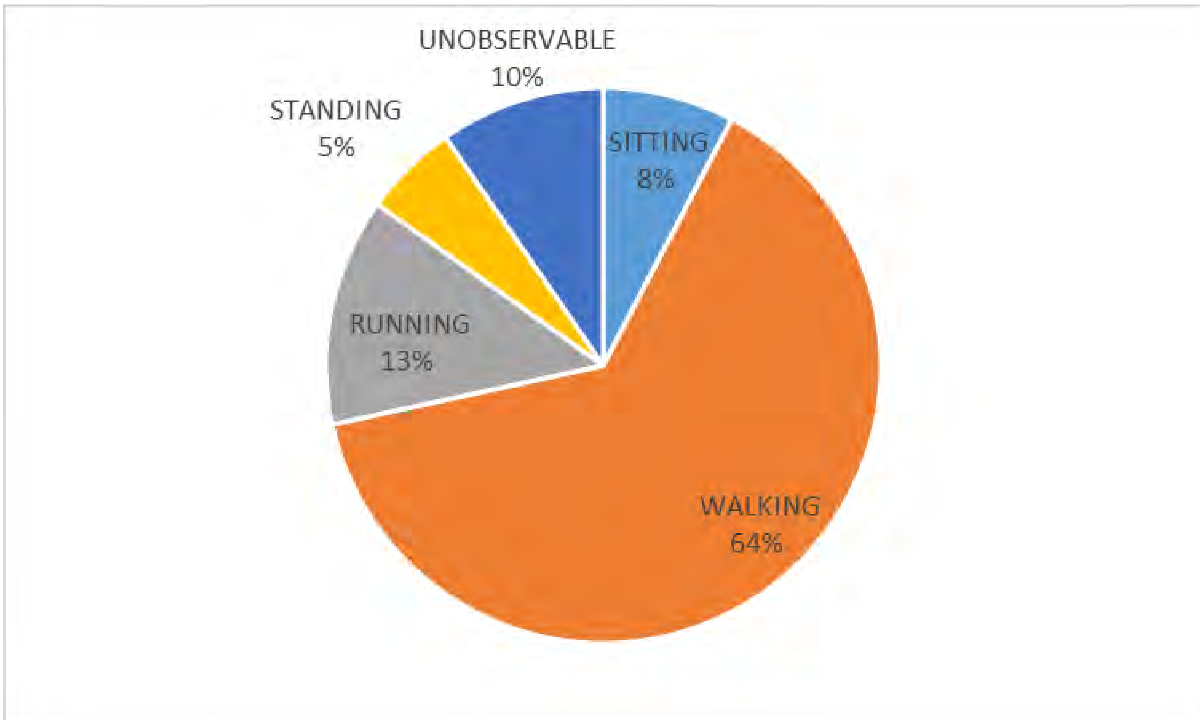

Figure 21. Time budget of behaviour in vocalising animals.

Burrow share and use

In the duration of a six month period, each logger logged a total number of entries (Table 17) along with total number of wombats visited, and total percentage of population visited.

Table 17. Total entries, numbers of wombats visited each burrow and total percentage representation of the population for a six month period.

Burrow number	**B4**	**B5**	**B25**	**B36**
Total log of entries	55	179	62	28
# wombats visited	6	4	2	7
% of total population	60	40	20	70

The most used burrow equipped with a microchip logger was burrow 36. Seven different wombats (of ten) visited the burrow. More than 50% of the population has used burrow 36 and burrow 4.

6.0 Discussion

This is only the second study to identify complex behaviour in the northern hairy-nosed wombat. Together with Stenke (2000), results suggest a large investment in relative interactions (based on the few social observations), presumably to facilitate low metabolic activity and digestion of relatively low quality food (Woolnough, 1998). However social interactions were recorded at the burrow entrances, and usually with apparent antagonistic behaviour displays including alertness, vocalisation, and avoidance or chasing.

The use of digital video recording systems for monitoring the behaviour of the northern hairy-nosed wombat was shown to be successful. Data collection was limited to the immediate vicinity of the burrow entrances due to the placement of the cameras and, as such, time budgets presented herein have limited application beyond this range. Using this method, however, comes with constraints such as physical labour in changing SD cards every second day and testing solar panels. Remote monitoring by using wildlife cameras has been used to monitor the behaviour of captive southern hairy-nosed wombats as well as common wombats, and worked well as a non-invasive methods to minimise stress and altered behaviour (Hogan, 2004; Hogan *et al.,* 2009). Wombats do use the tripod setup as scratching posts, which resulted in a few cameras being turned upside down. However, when checked, this was easily fixed.

Of 6607 videos recorded in total, only 0.31% were of social interaction. Similar results were found by Stenke (2000), where of 1300 observation hours, only 12 incidents of social behaviour were recorded. This suggests that the northern hairy-nosed wombat primarily lives as a solitary individual. Johnson and Crossman (1991) found similar results, where both solitary and communal behaviour were recorded in the species. Communal behaviour was referred to an overlap of burrow use. In this study, I found that solitary behaviour and social behavioural time budgets were significantly different. However no vocalisations were found to occur when solitary behaviour was observed, suggesting a purely social behaviour feature.

Comparison of the underlying behaviour of vocalising animals with the behaviour of solitary animals showed them to be significantly different. It showed an increase in walking and running when animals were in social events.

The behavioural classification, adapted here, incorporated all expected behaviour, including vocalisation. However, modifications could be applied for further studies. Behaviours such as lying down and stopping could be categorised as resting behaviours. The classification followed the principles of those of Stenke (2000), and Hogan (2004, 2009); however, with slight modifications to specifically fit the study. Other behavioural patterns have primarily focused on active versus inactive, mainly because of the use of radio-collars (Finlayson 2005; Evans, 2008).

The results of vocalisation being used as a warning call in social interactions are the same results that Stenke (2000) found in 1997–1998 when he performed a behavioural study on the northern hairy-nosed wombat at EFNP using direct observation. The author concluded that vocalisation was used solely in social interactions, and not when the wombat was solitary.

Similar results have been shown with the other wombat species. Gaughwin (1981) found that in the southern hairy-nosed wombat, 40–62% of all social encounters were observed with vocalisation as an alarm or distress call.

The limited microchip data revealed a high rate of burrow use by multiple wombats (70% of the total population at high activity), but unfortunately the technological limitations meant that data on possible communal use or strictly solitary use of burrows could not be provided. However, for strictly solitary use, spatial and temporal avoidance to some extent would be expected.

The microchip loggers were not consistent in their logging ability of microchips, resulting in either no logs, or a large number of logs that reflected a single event. One of the limitations to the method relates to the microchip. The microchip itself has to face a certain way when going through the microchip logger, otherwise the possibility of it not being detected is relatively high.

The four microchip loggers were not equipped with directional sensors, which limited the results to burrow use, as it was not possible to determine if two or more wombats were present at the same time for potential burrow sharing. The extensive use of burrows by different individuals indicates regular movement between burrows and that individuals are not restricted to certain burrows. Burrow sharing has, however, been shown to exist in the species. Johnson (1991a) showed that northern hairy-nosed wombats at EFNP in 71% of instances will be in a burrow alone, 27.3% will share with one other wombat, and 1.7% will share with two wombats. These results indicate that burrow sharing is a possibility, as the burrows were used by multiple wombats. Burrow use by multiple wombats has shown to exist in the two other wombat species. Finlayson *et al.,* (2005) had 16 radio-collared animals (of both sexes), and showed that 65% of burrows occupied by one collared animal would also be used by at least one other radio-collared individual. Evans (2008), using radio-collared animals, found that common wombats have multiple wombats using the same burrow; however, most of the recordings were not at the same time. On average, 2.2 individuals would use the same burrow. Based on the size of the RUNR and distribution of burrows, this could be a factor influencing the increased number of different wombats visiting the same burrows. With data providing information on other wombat species and their relation to burrow sharing, it should be expected that burrow sharing would occur at RUNR, although the large number of burrows (61 for ten wombats) leaves the animals with ample opportunity for a solitary burrow.

This study is the first to investigate behaviour of translocated northern hairy-nosed wombats, as well as investigating behaviour in the species using a non-invasive method. It represents a successful method for monitoring and assessing the behaviour of northern hairy-nosed wombats at occupied burrows. The investigation of burrow sharing and use can be improved by adding directional sensors to the microchip loggers. Microchip logging did however successfully show the overall number of different wombats utilising high activity burrows. Further investigation of behaviour can be accomplished by GPS-collaring, for investigation of ranging behaviour and burrow sharing. Social behaviour can furthermore be explored by adding proximity loggers to collars. This has been used in cattle (Patison *et al.,* 2010) to determine interaction between individuals, and would potentially give an additional perspective in social behaviour of the northern hairy-nosed wombat.

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Chapter 5 – Summary, conclusion and recommendations

This study took place at the RUNR, investigating behaviour and habitat utilisation of the northern hairy-nosed wombat in a translocated population. This study is the first to address the subject of analysing wombat activity patterns in relation to complex vegetation structure and composition at a relocation site. The study explored wombat behavioural patterns with a non-invasive method, which has not been trialled on this species previously. The aim of this project was to gain insight on behavioural patterns and habitat utilisation of the northern hairy-nosed wombat. This was achieved through the following approaches: (a) utilising previously deployed EHP cameras on burrow entrances for monitoring of behaviour; (b) conducting a full vegetation assessment of RUNR; leading to a (c) vegetation map of plant communities at RUNR; (d) deploying wildlife cameras at RUNR to monitor presence/absence of wombat in plant communities; and (e) assessing wombat activity based on sign surveys and environmental influences.

1.0 Trapping techniques and trialling of a trap design

An initial trapping session, managed by the EHP and held at EFNP, allowed this project to trial a new trap design, based on designs from Tasmanian devil trapping. The trialling of this new trap design was incorporated into the trapping session, to explore optimisation of trapping effort, minimisation of risk of injury to captured animals, minimisation of by-catch, and minimisation of manual labour when trapping northern hairy-nosed wombats. The new trap design was shown to be capable of capturing wombats, with one wombat captured over a 15-night trapping session. The trigger system of the trap revealed some limitations during this session, with animals ranging from spiders to wombats able to trigger the infrared beam.

To further test the new trap design, a second trapping session was held at RUNR. Modifications to the traps were made to overcome for limitations revealed by the first trapping session; by installing two infrared beams, the size insensitivity was addressed. This trapping session was unsuccessful as no wombats were caught.

2.0 Recommendations:

Trapping sessions are an invasive method of investigation. However, they are the only possible method for getting body condition scores and general health scores for the species. A new trap design was shown to be effective in minimising the amount of labour associated with trapping, as well as minimising possible by-catch, by making a trap design that primarily targets wombats, but cannot be triggered by common by-catch including swamp wallabies and echidnas. The fact that this trap design captured a wombat, suggests that a similar trap design could be optimised to increase capture effort.

An updated version of the current trapping protocol should be considered, allowing for new trap designs to be trialled that meet the requirements of decreased labour, reduced potential by-catch and reduced damage to captured individuals. The new trap design did show the ability to trap wombats; however, technological aspects of the trap need improvement. The trap should be used alongside already approved traps, for trialling purposes and optimisation of wombat capture effort.

3.0 Habitat utilisation

This study was the first to explore habitat utilisation by the translocated northern hairy-nosed wombat using a non-invasive method. Plant communities within RUNR were mapped and described and wombat activity in relation to these mapped communities was explored.

Complex vegetation assessments have not previously been conducted in relation to northern hairy-nosed wombat activity patterns; however, previous researchers have broadly described wombat core habitat at EFNP (Johnson, 1991a).

Wombat sightings were in general low with CPUE ranging from 0–0.1 wombat captures per camera trap night for the duration of the project (189 days). Both wombat CPUE, and a tracks and scats survey determined that approximately 1/3 of the park was not being utilised by wombats. Burrows were mainly situated close to main dirt roads, simulating ‘banks’ (perhaps analogous to the paleo-channel at EFNP).

This study is the first to map vegetation in structure and composition in relation to wombat activity. A full vegetation assessment for RUNR was generated, and showed that wombat activity was associated with overstorey density rather than understorey density.

In relation to CPUE values, it showed that wombat core habitat could be described as open woodland/ woodland mainly dominated by *Acacia* spp. with isolated *E. populnea* in the tree layers, with *E. mitchellii*, *H. lorea* and *G. parviflora* as an open shrublayer, over an open to dense tussock grass cover dominated by *C. ciliaris* and a few represented native grasses including *Aristida* spp.

Furthermore, the study investigated the influence of environmental variables on wombat activity and revealed no significant relationship to wombat activity. However, Day temperature (average temperature from 6 am to 6 pm) showed the strongest explanatory relationship, but was not statistically significant (P=0.194).

Environmental parameters do potentially play an important roles in wombat activity. It has been shown in previous studies that activity patterns do alter in all species of wombat in response to environmental variables. It is, however, more likely to be an array of explanatory parameters and not just a single parameter that affects activity patterns. This could not be effectively investigated in a study with a small data set, as in this study.

Anecdotal accounts have previously suggested that moon phase may affect wombat activity. However, this study found no association between moon phase and wombat activity over the duration of 189 days of observation.

4.0 Behaviour and burrow use

This study is the second study to investigate behaviour in free-ranging northern hairy-nosed wombats, after that of Stenke (2000). However, this is the first study to use a non-invasive method for observation. The non-invasive method was chosen to minimise observer influence on animals when observed. The previously deployed EHP cameras provided this study with records of behaviour at the entrance of multiple burrow systems covering a large area of RUNR.

A total of 6607 30-second videos of wombat activity were recorded during the study. Of these only 0.31% represented social events, with two wombats present in the camera view.

The record revealed a surprising degree of solitary behaviour (99.7%) compared to social events. It is generally assumed that the species is solitary; however, this study proves that even in very confined spaces, wombats still actively avoid social interactions. In cases of social events, animals displayed a high level of contact calling. However, individuals did not alter their underlying behaviour. Social events were predominantly of a non-aggressive nature, with most animals being passive towards one another. Vocalisation has previously been categorised as a social occurrence only (Stenke, 2000) and predominantly used as a warning call.

Deployed microchip loggers showed that there was a large amount of burrow use by multiple wombats, although rarely at the same time. Burrow 36 was the most used, with seven different wombats visiting it over a six month period. This accounts for 70% of the population at this site. Burrow use by multiple wombats indicates that there was an overlap in home ranges among animals. However, with the lack of technology it was not possible to state if burrow sharing occurred. It is nevertheless a possibility, especially based on overlapping burrow use in the species. Given the apparent rarity of animal-animal encounters at the burrow entrance, and the relatively high rates of shared burrow usage, it is suggested that animals may adopt spatial and temporal avoidance strategies. A note of caution, however, as this study can make no comment on behaviour and social interaction within the burrow or elsewhere in the species’ range on RUNR.

The results of this study revealed a consistency in terms of the structural characteristics of core habitat (Johnson, 1991a), the association of ranging and burrowing (Johnson, 1991a) and the broad spectrum of observed behaviour in the species (Stenke, 2000).

5.0 Recommendations:

Digital video recordings captured using stand-alone wildlife cameras were shown to be a successful method for monitoring the northern hairy-nosed wombat at burrow entrances, as well as for a broad presence/absence study across the park. While cameras were effective in recording activity in proximity to burrow entrances they did not provide a good record of wombats coming in or out of the burrow, and while microchip loggers provided evidence of burrow sharing, this research was unable to confirm temporal overlap in burrow use in the translocated population. This could potentially be corrected, simply by adjusting positioning of cameras, for example, changing sensitity on the camera settings to obtain a higher capture rate.

A digital recording method creates a good baseline of behavioural data that can be further improved. By applying this method from burrow to the general habitat, feeding behaviour and other behavioural strategies could possibly be detected. For further movement recording, GPS-collaring can be recommended. GPS-collaring has previously been used in both the southern hairy-nosed wombat and the common wombat. GPS-collaring provides a detailed view of animal movement. The GPS-tracking device will however not be tracked once a wombat is in its burrow underground; however, this would provide data on activity schedules of the individual animal. Further details could be obtained including:

(a) detailed movement in habitat
(b) home ranging behaviour (potentially identifying differences between sexes, if both are collared)
(c) activity schedules of individual animals
(d) burrow use (and potential sharing)

Alterations or improvements of microchip loggers will help track movements of individuals of the population. If we can monitor the whole population in this way, it will provide an insight into population structure and dynamics, which is crucial for the species when translocating.

Microchip loggers did log wombats' use of the particular burrows. However, only a small sample was available as there were only four burrows equipped with microchip loggers. This gives a total of 6.55% of the total number of burrows. Microchip loggers on several burrow systems would provide a bigger sample of general burrow use across the RUNR. Further development strategies for microchip loggers should be taken. It is recommended that:

(a) General testing of detection rate of the individual microchip logger devices should be performed. This will provide a measure of instrument specific detection probability.
(b) Directional devices should be added to the logging devices. Detection of direction of a wombat could provide information of burrow sharing, activity schedule of a specific individual and general burrow use.

The logging devices should not be able to log a microchip, if held steady underneath the device, as they are designed to log a moving pattern of a chip. However data showed that loggers do log data points for a stationary chip.

6.0 Relevance of findings

The results from this study can:

- assist in optimising trapping techniques for the northern hairy-nosed wombat
- assist in background knowledge of habitat utilisation, and specific vegetation communities preferred by northern hairy-nosed wombats
- provide background knowledge for selecting a suitable third translocation site
- assist in understanding the behaviour of the northern hairy-nosed wombat to be able to accommodate for:
    - size and animal capacity of a third selection site
    - site location of potential release burrows
    - behavioural patterns/strategies in northern hairy-nosed wombats
- provide video recordings for educational purposes

7.0 Conclusions

The translocated population of northern hairy-nosed wombats showed a consistency of core habitat area and behavioural patterns previously observed at EFNP. Behaviour of the animals was consistent with a solitary animal. Wombat activity was focused in a specific vegetation community, which limits wombat distribution across the park.

Wombat core habitat includes an open woodland/ woodland mainly dominated by *Acacia* spp. with isolated *E. populnea* in the tree layers, with *E. mitchellii*, *H. lorea* and *G. parviflora* as an open shrublayer, over an open to dense tussock grass cover dominated by *C. ciliaris* and a few native grasses including *Aristida* spp.

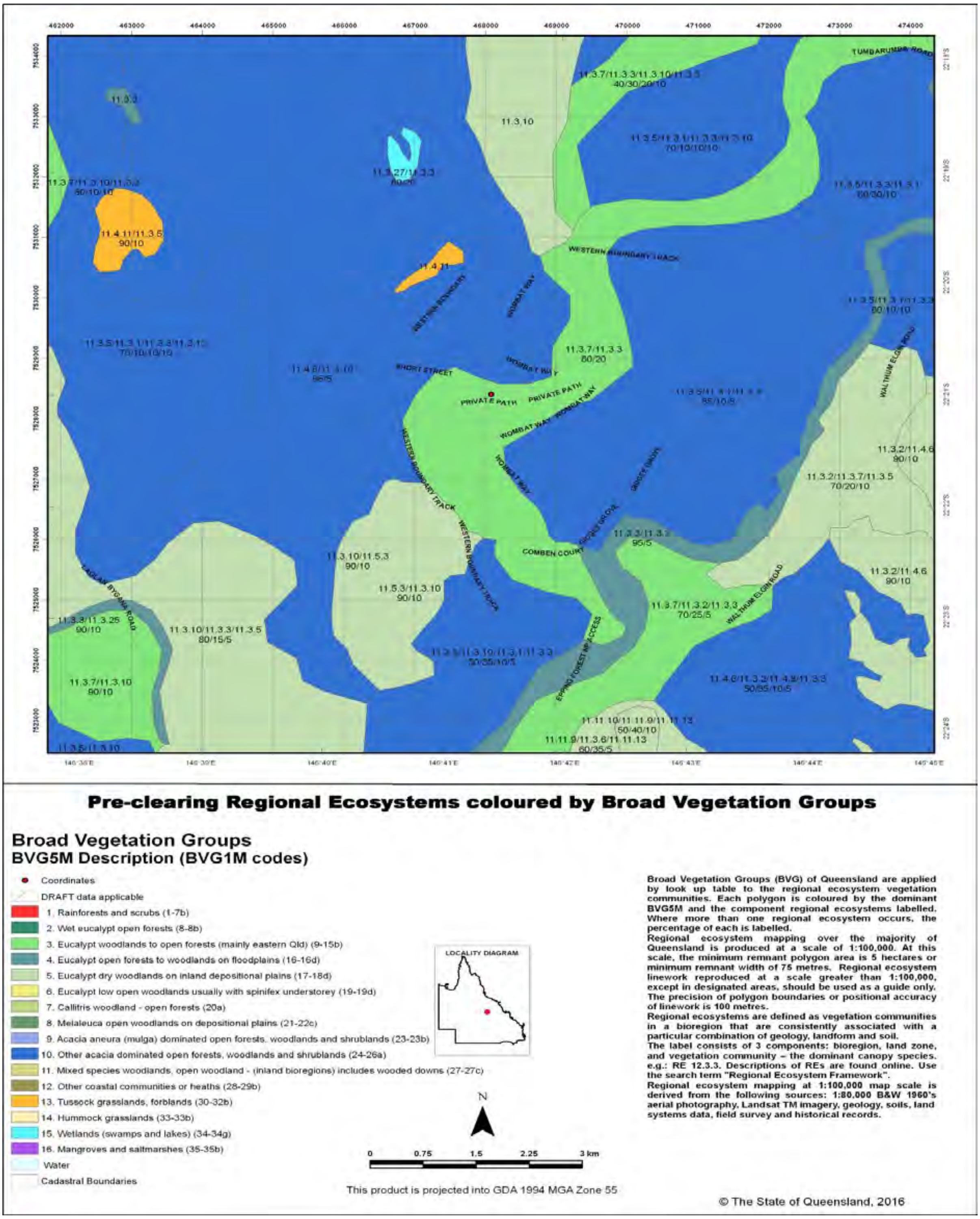
The wombats at RUNR may have adapted an avoidance strategy incorporating spatial and temporal elements limiting encounters at or near burrow entrances. Even though the animals display a solitary behavioural pattern, social events do occur.

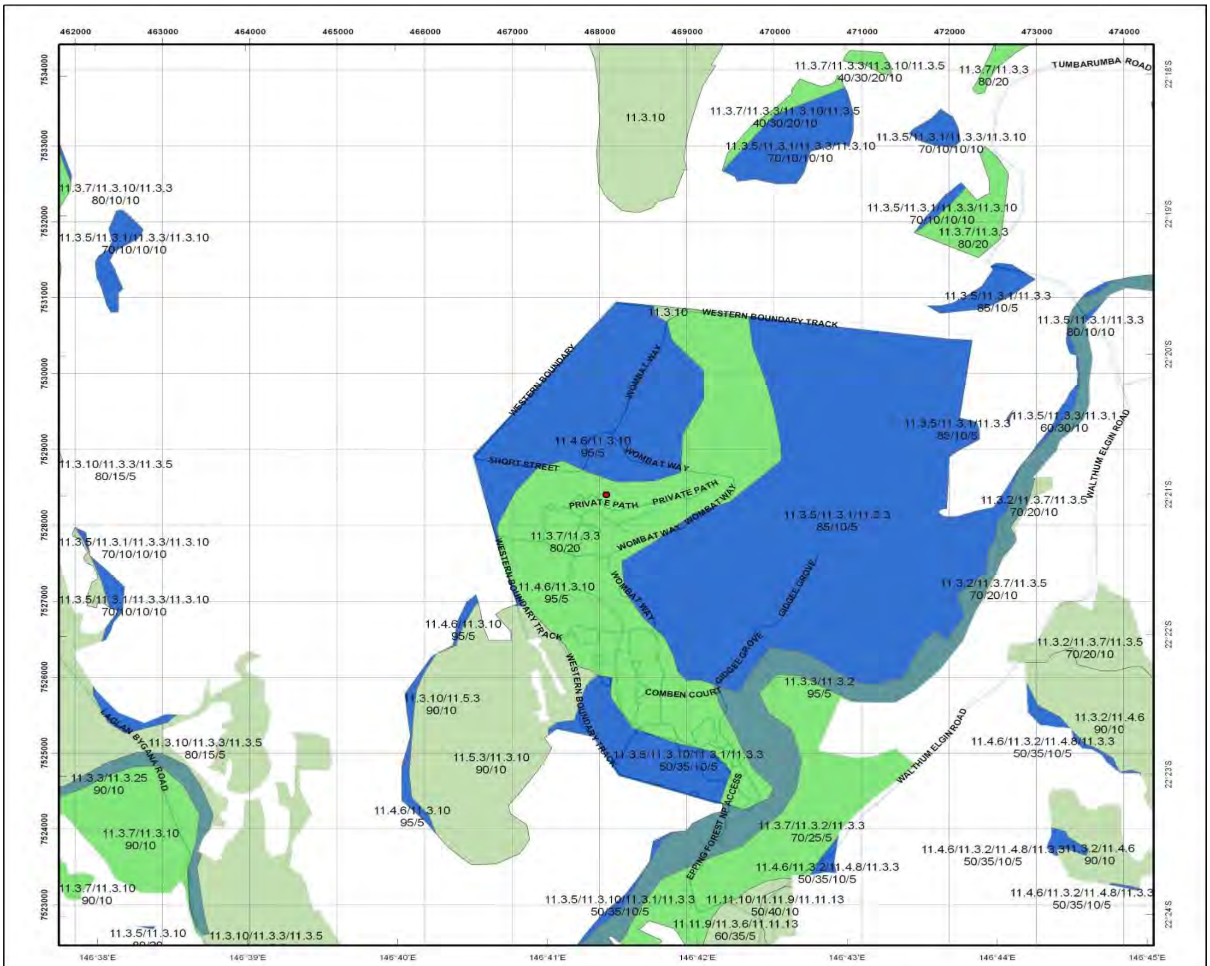
Compared to the natural EFNP population, wombats at RUNR had similar habitat preferences, when compared to the more broadly described vegetation preferences at that site, and displayed broadly similar behavioural patterns to those occurring naturally at EFNP.

8.0 Further studies

- GPS collaring and proximity logging of northern hairy-nosed wombats at both EFNP and RUNR for ranging behaviour, potential burrow sharing, and social interaction amongst individuals. This will show ranging behaviour between sexes (if both are collared), potential sharing, and activity patterns of the species.
- Social behavioural studies with the use of proximity loggers. They can additionally be attached to collars and will investigate the range at which wombats interact, who they interact with and for how long.
- Applying habitat assessments accompanied by GPS collaring in *C. ciliaris* treatments. This would measure the impact of buffel grass on wombats pre and post treatment in the form of ranging behaviour and possibly feeding behaviour.
- Investigation of behavioural patterns inside their burrow as well in their ranging habitat. Does this observed solitary behaviour continue throughout, or is it adapted for burrow ranging?

APPENDIX A – REGIONAL ECOSYSTEMS EFNP





Remnant 2013 Regional Ecosystems coloured by Broad Vegetation Groups

Broad Vegetation Groups

BVG5M Description (BVG1M codes)

- Coordinates
- DRAFT data applicable
- 1. Rainforests and scrubs (1-7b)
- 2. Wet eucalypt open forests (8-8b)
- 3. Eucalypt woodlands to open forests (mainly eastern Qld) (9-15b)
- 4. Eucalypt open forests to woodlands on floodplains (16-16d)
- 5. Eucalypt dry woodlands on inland depositional plains (17-18d)
- 6. Eucalypt low open woodlands usually with spinifex understorey (19-19d)
- 7. Callitris woodland - open forests (20a)
- 8. Melaleuca open woodlands on depositional plains (21-22c)
- 9. Acacia aneura (mulga) dominated open forests, woodlands and shrublands (23-23b)
- 10. Other acacia dominated open forests, woodlands and shrublands (24-26a)
- 11. Mixed species woodlands, open woodland - (inland bioregions) includes wooded downs (27-27c)
- 12. Other coastal communities or heaths (28-29b)
- 13. Tussock grasslands, forblands (30-32b)
- 14. Hummock grasslands (33-33b)
- 15. Wetlands (swamps and lakes) (34-34g)
- 16. Mangroves and saltmarshes (35-35b)
- Non-remnant vegetation, cultivated or built environment
- Water
- Cadastral Boundaries

N

0 0.75 1.5 2.25 3 km

This product is projected into GDA 1994 MGA Zone 55

Broad Vegetation Groups (BVG) of Queensland are applied by look up table to the regional ecosystem vegetation communities. Each polygon is coloured by the dominant BVG5M and the component regional ecosystems labelled. Where more than one regional ecosystem occurs, the percentage of each is labelled.

Regional ecosystem mapping over the majority of Queensland is produced at a scale of 1:100,000. At this scale, the minimum remnant polygon area is 5 hectares or minimum remnant width of 75 metres. Regional ecosystem linework reproduced at a scale greater than 1:100,000, except in designated areas, should be used as a guide only. The precision of polygon boundaries or positional accuracy of linework is 100 metres.

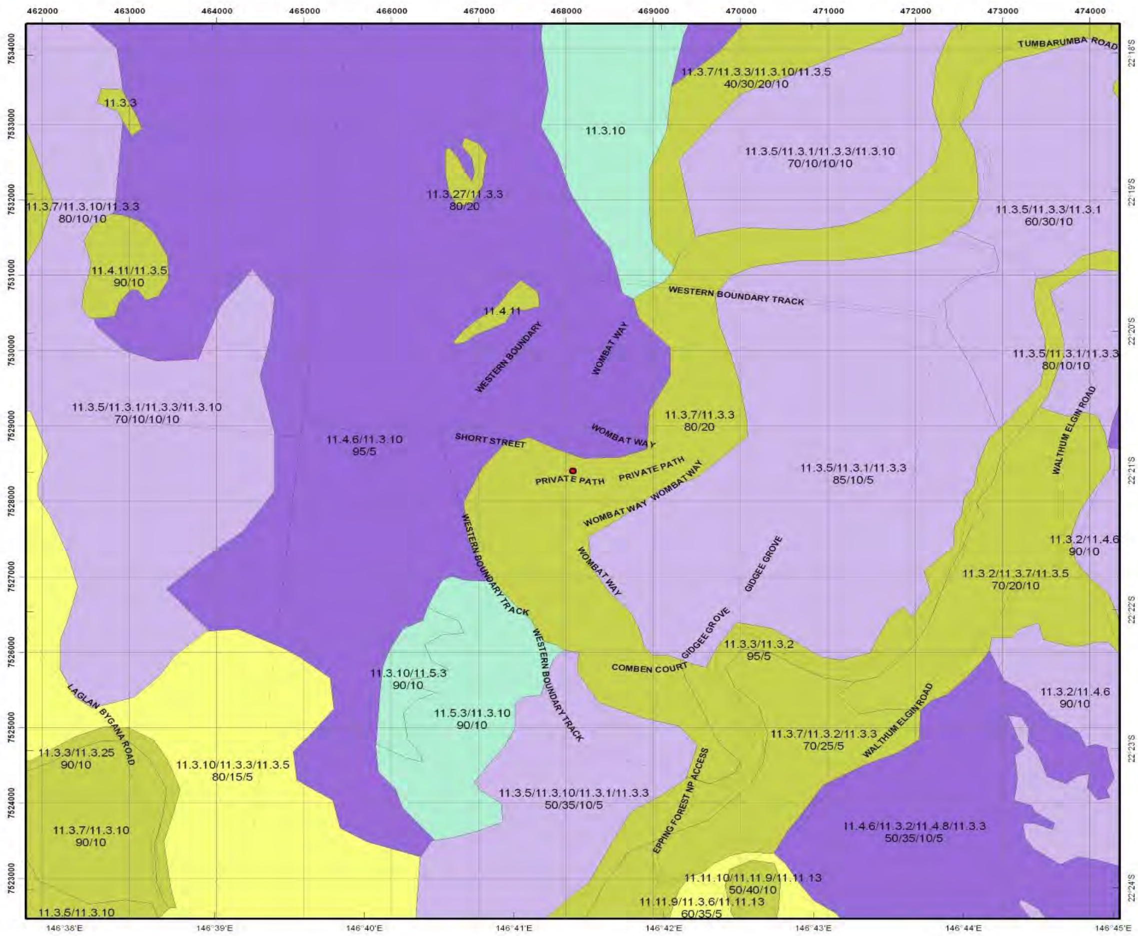
Regional ecosystems are defined as vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil.

The label consists of 3 components: bioregion, land zone, and vegetation community – the dominant canopy species. e.g.: RE 12.3.3. Descriptions of REs are found online. Use the search term "Regional Ecosystem Framework".

Regional ecosystem mapping at 1:100,000 map scale is derived from the following sources: 1:80,000 B&W 1960's aerial photography, Landsat TM imagery, geology, soils, land systems data, field survey and historical records.

Remnant woody vegetation is defined as vegetation that has not been cleared or vegetation that has been cleared but where the dominant canopy has >70% of the height and >50% of the cover relative to the undisturbed height and cover of that stratum and is dominated by species characteristic of the vegetation's undisturbed canopy.

Non-remnant vegetation includes regrowth and disturbed native vegetation.



Pre-clearing Regional Ecosystems

Biodiversity Status

- Coordinates
- No data areas
- Endangered - Dominant vegetation
- Endangered - Sub-dominant
- Of Concern - Dominant
- Of Concern - Sub-dominant
- No concern at present
- Water
- Cadastral Boundaries

N

0 0.75 1.5 2.25 3 km

This product is projected into GDA 1994 MGA Zone 55

Regional ecosystem mapping over the majority of Queensland is produced at a scale of 1:100,000. At this scale, the minimum remnant polygon area is 5 hectares or minimum remnant width of 75 metres. Regional ecosystem linework reproduced at a scale greater than 1:100,000, except in designated areas, should be used as a guide only. The precision of polygon boundaries or positional accuracy of linework is 100 metres.
Regional ecosystems are defined as vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil.
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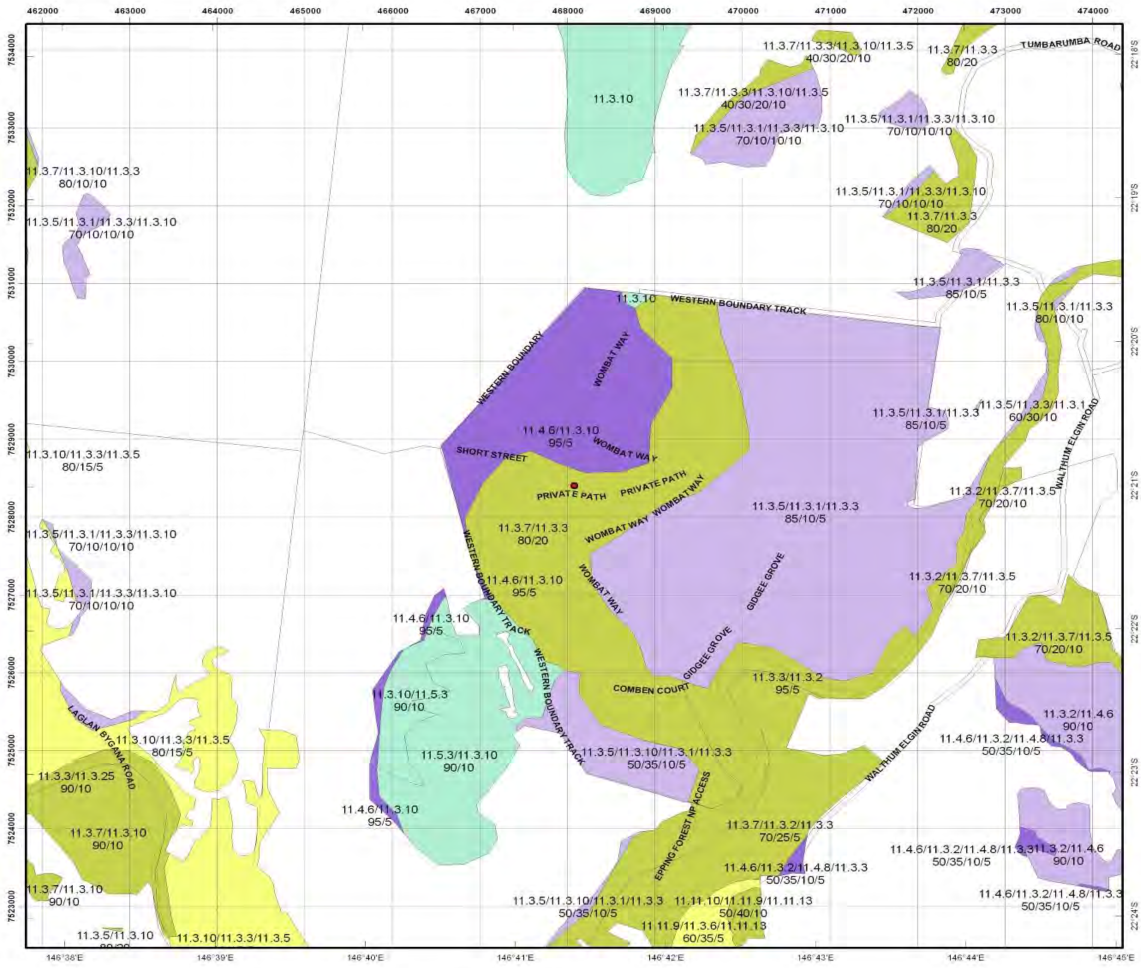

Remnant 2013 Regional Ecosystems

Biodiversity Status

- Coordinates
- No data areas
- Endangered - Dominant vegetation
- Endangered - Sub-dominant
- Of Concern - Dominant
- Of Concern - Sub-dominant
- No concern at present
- Non-remnant vegetation, cultivated or built environment
- Plantation
- Water
- Cadastral Boundaries

N

0 0.75 1.5 2.25 3 km

This product is projected into GDA 1994 MGA Zone 55

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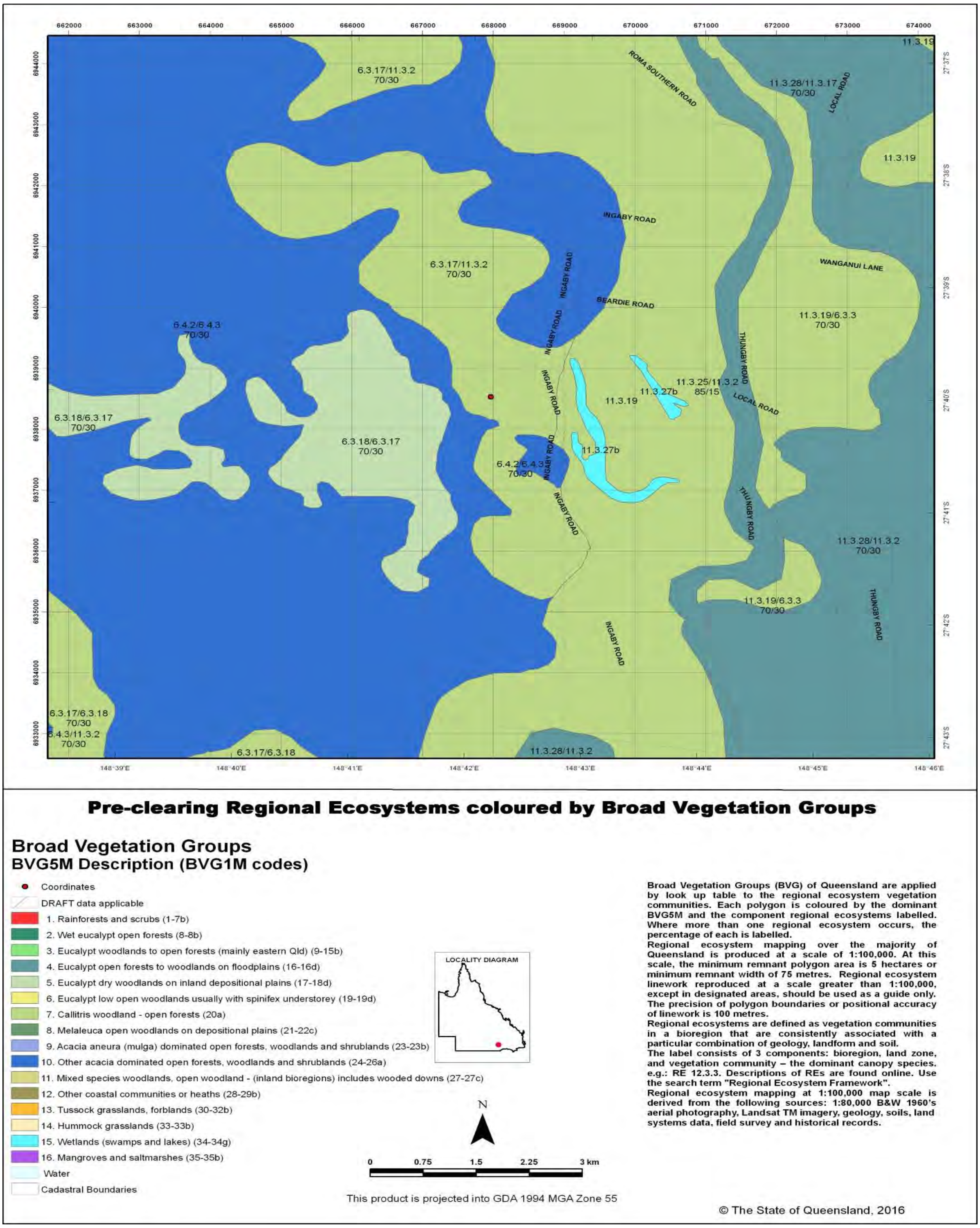
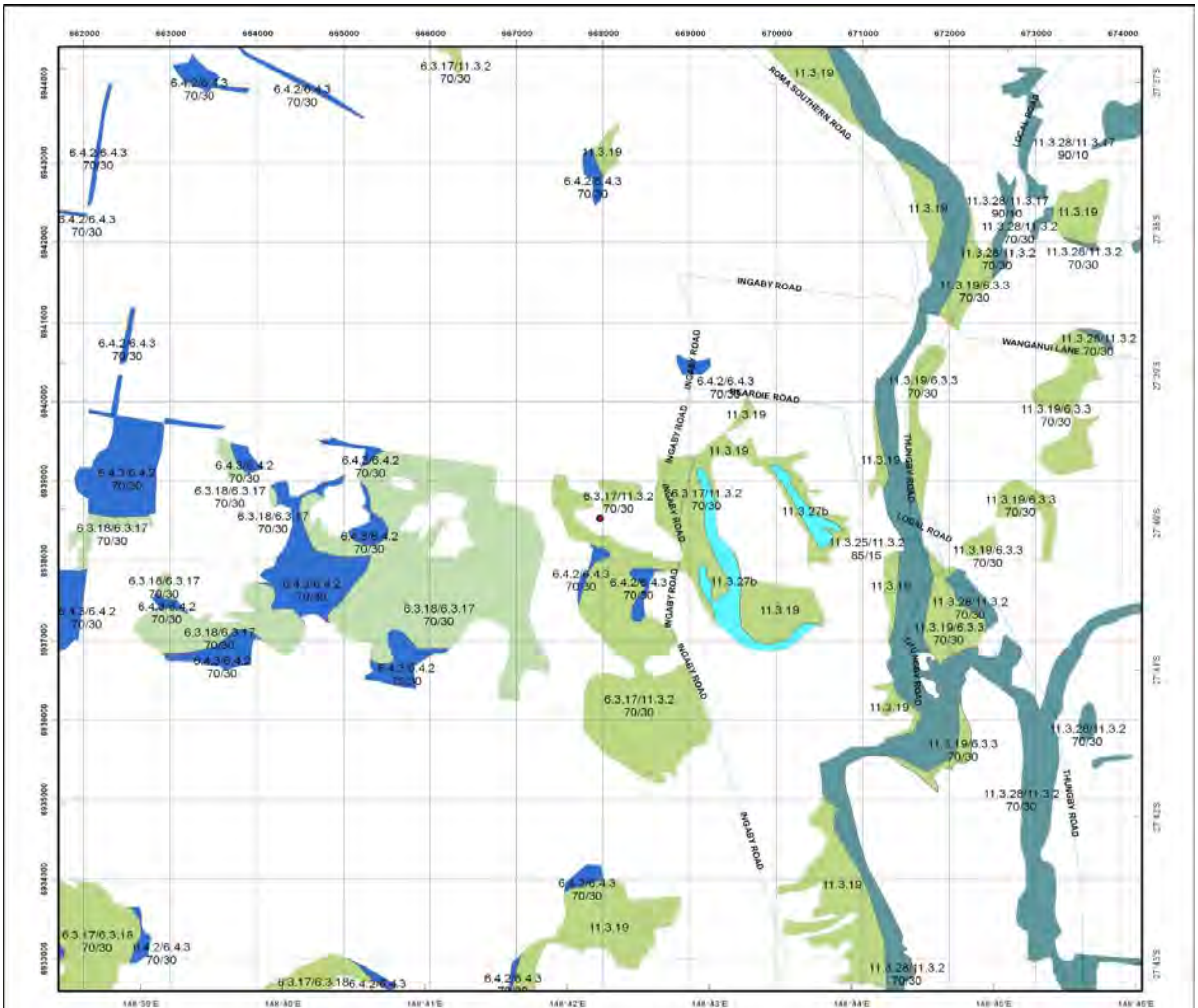
Non-remnant vegetation includes regrowth and disturbed native vegetation.

APPENDIX B – REGIONAL ECOSYSTEMS RUNR





Remnant 2013 Regional Ecosystems coloured by Broad Vegetation Groups

Broad Vegetation Groups

BVG5M Description (BVG1M codes)

- Coordinates
- DRAFT data applicable
- 1. Rainforests and scrubs (1-7b)
- 2. Wet eucalypt open forests (8-8b)
- 3. Eucalypt woodlands to open forests (mainly eastern Qld) (9-15b)
- 4. Eucalypt open forests to woodlands on floodplains (16-16d)
- 5. Eucalypt dry woodlands on inland depositional plains (17-18d)
- 6. Eucalypt low open woodlands usually with spinifex understorey (19-19d)
- 7. Callitris woodland - open forests (20a)
- 8. Metaleuca open woodlands on depositional plains (21-22c)
- 9. Acacia aneura (mulga) dominated open forests, woodlands and shrublands (23-23b)
- 10. Other acacia dominated open forests, woodlands and shrublands (24-26a)
- 11. Mixed species woodlands, open woodland - (inland bioregions) includes wooded downs (27-27c)
- 12. Other coastal communities or heaths (28-29b)
- 13. Tussock grasslands, forblands (30-32b)
- 14. Hummock grasslands (33-33b)
- 15. Wetlands (swamps and lakes) (34-34g)
- 16. Mangroves and saltmarshes (35-35b)
- Non-remnant vegetation, cultivated or built environment
- Water
- Cadastral Boundaries

N

0 0.75 1.5 2.25 3 km

This product is projected into GDA 1994 MGA Zone 55

Broad Vegetation Groups (BVG) of Queensland are applied by look up table to the regional ecosystem vegetation communities. Each polygon is coloured by the dominant BVG5M and the component regional ecosystems labelled. Where more than one regional ecosystem occurs, the percentage of each is labelled.
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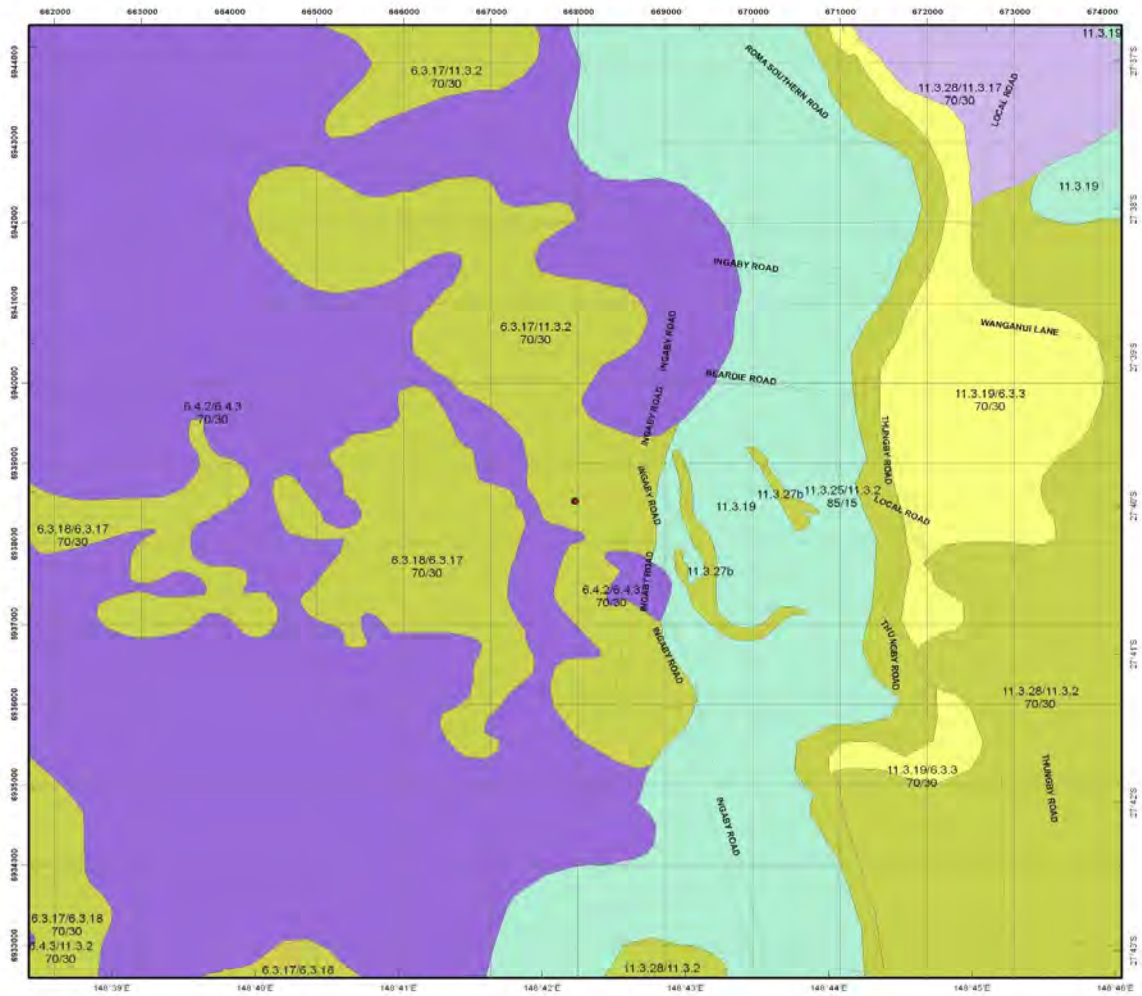

Pre-clearing Regional Ecosystems

Biodiversity Status

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- Endangered - Sub-dominant
- Of Concern - Dominant
- Of Concern - Sub-dominant
- No concern at present
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N

0 0.75 1.5 2.25 3 km

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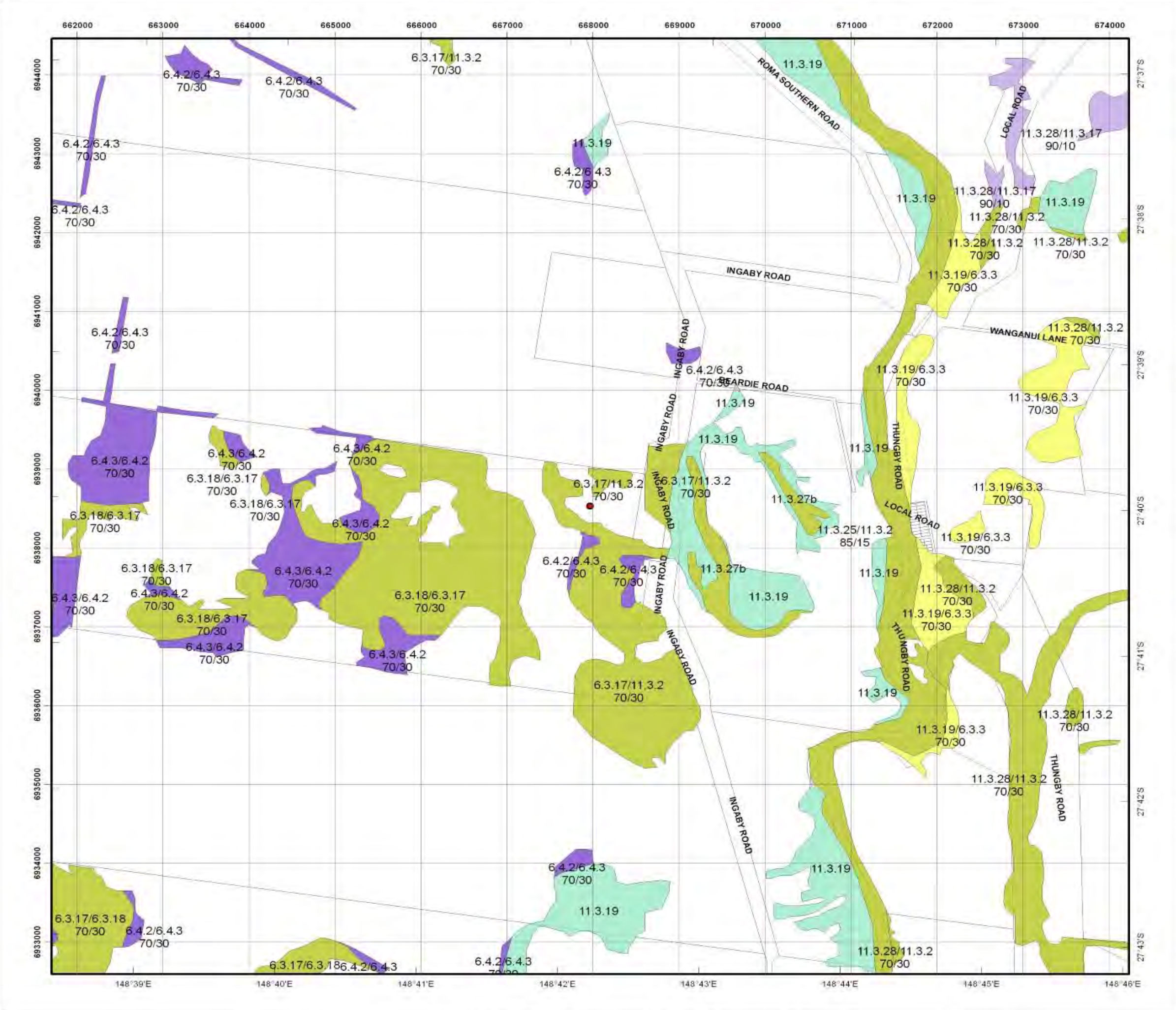

Remnant 2013 Regional Ecosystems

Biodiversity Status

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APPENDIX C – NORTHERN HAIRY-NOSED WOMBAT CONDITION SCORE (EHP)

SCORE	DESCRIPTION	CONDITION
1.0	• Ribs and pelvis sticking out. • Barely any muscle mass.	EMACIATED
2.0	• Ribs covered, not sticking out, but easily felt. • Vertebrae sharp, obvious laterally, can feel sides. • Easy to clasp around pelvis (esp. the wings). • Sunken rump.	POOR
3.0	• Ribs, pelvis and vertebrae well covered. • Good muscle mass	GOOD
4.0	• Ribs and pelvis very well covered • Vertebrae difficult to feel.	VERY GOOD
5.0	• Overweight	OBESE

1) Coat condition

- scraggly coat often indicates poor overall condition

2) Prominence of ribs

- can you see or feel them?

3) Prominence of vertebrae

- can you feel around them or just on top?

4) Prominence of pelvis

- are the edges sharp or rounded?
- can you easily feel the boney wings of the pelvis?

5) Rear plate

- is it flat, sunken or rounded?

Parasite Load

Low	0-10 parasites
Medium	10-50 parasites
High	> 50 parasites

FEMALE NORTHERN HAIRY-NOSED WOMBAT

Date		Weight	kg	Tattoo	
Time processed		Condition		Burrow No.	
Time caught (est.)		PIT tag		Burrow entrance	

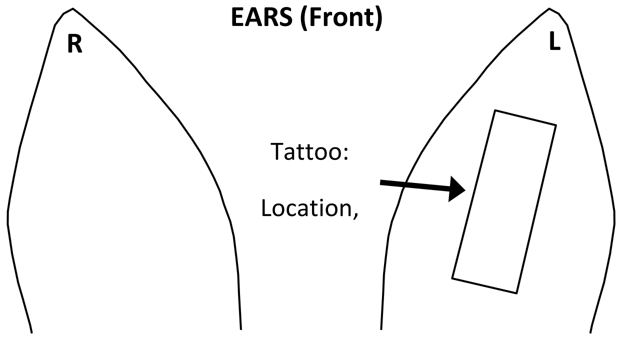
Body length		mm
Head length		mm
Head width		mm
Neck girth		mm
Chest girth		mm
Tail length		mm

	L	R	
Hind pes length			mm
Tibia length			mm
Ear length			mm

SAMPLES

	Volume / For which org ?	
Blood 1		
Blood 2		
Tissue		
Faeces		
Hair		
Other		

EARS (Front)



POUCH

Moisture	Dry	Intermed.	Moist	Very	Wet
Depth	Shallow	Intermed.	Deep	Very	Distended
Colour	Skin	Bright	Dark	Faeces	
Secretions	Clean	Intermediate	Dirty		
Lactating?	Yes	No			

Teat length at	L	R	mm
	Latitude	Longitude	
Mammary			mm

POUCH YOUNG

Sex			Tibia length		mm
Weight		kg	Pes length		mm
Body length		mm	Tail length		mm
Head length		mm			
Head width		mm	PIT tag		

	Folded	Unfolded	
Ear length			mm
Eyes	Open	Closed	

Ear biopsy

BELLY ECTOPARASITES (LOW / MED / HI)

Ticks	Lice	Fleas	Stick-fast Fleas	Mites

ANAESTHETIC

Drug

	mg	Time
First dose		
Second dose		

COMMENTS

RADIO-COLLAR

Frequency

Pattern

RECAP TATTOO

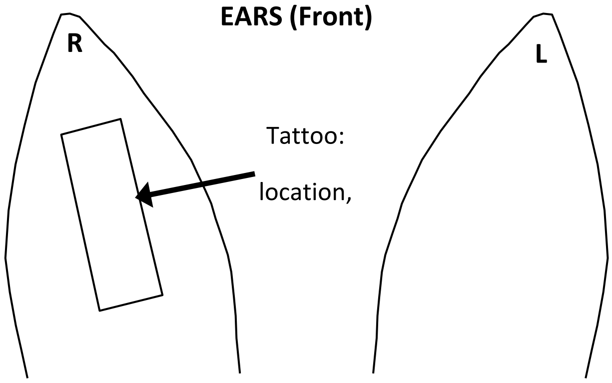
MALE NORTHERN HAIRY-NOSED WOMBAT

Date		Weight		Tattoo	
Time processed		Condition		Burrow No.	
Time caught (est.)		PIT tag		Burrow entrance	

Body length		mm
Head length		mm
Head width		mm
Neck girth		mm
Chest girth		mm
Tail length		mm

	L	R	
Hind pes length			mm
Tibia length			mm
Ear length			mm

EARS (Front)



TESTES

	L	R	
Length			mm
Width			mm
Depth			mm
Scrotal width			

	Latitude	Longitude	
Accessory Gland			mm

SAMPLES

Volume / For which org ?

Blood 1		
Blood 2		
Tissue		
Faeces		
Hair		
Other		

BELLY ECTOPARASITES (LOW / MED / HI)

Ticks	Lice	Fleas	Stick-fast Fleas	Mites

RADIO-COLLAR

Frequency	
Pattern	

ANAESTHETIC

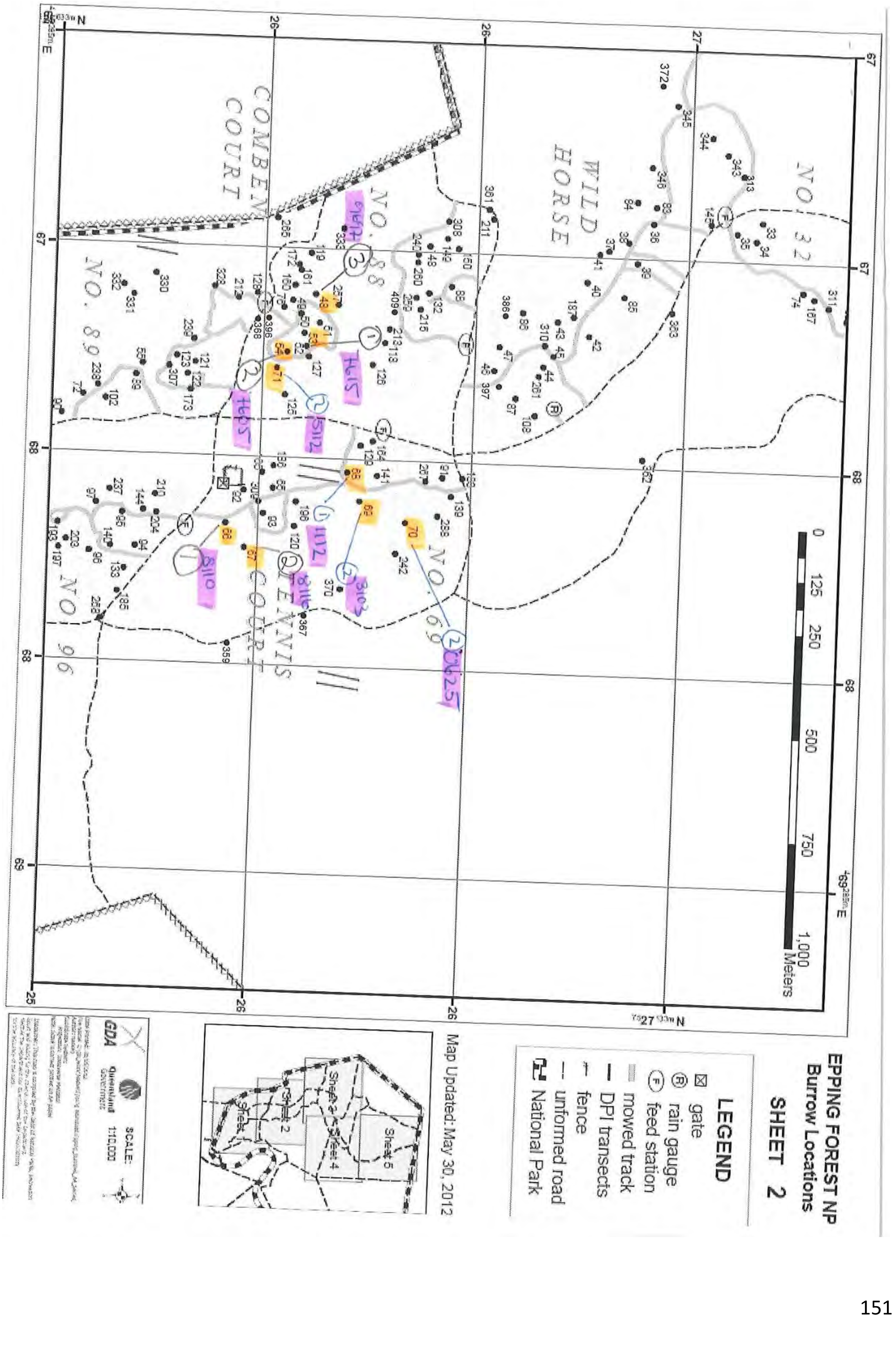
Drug	

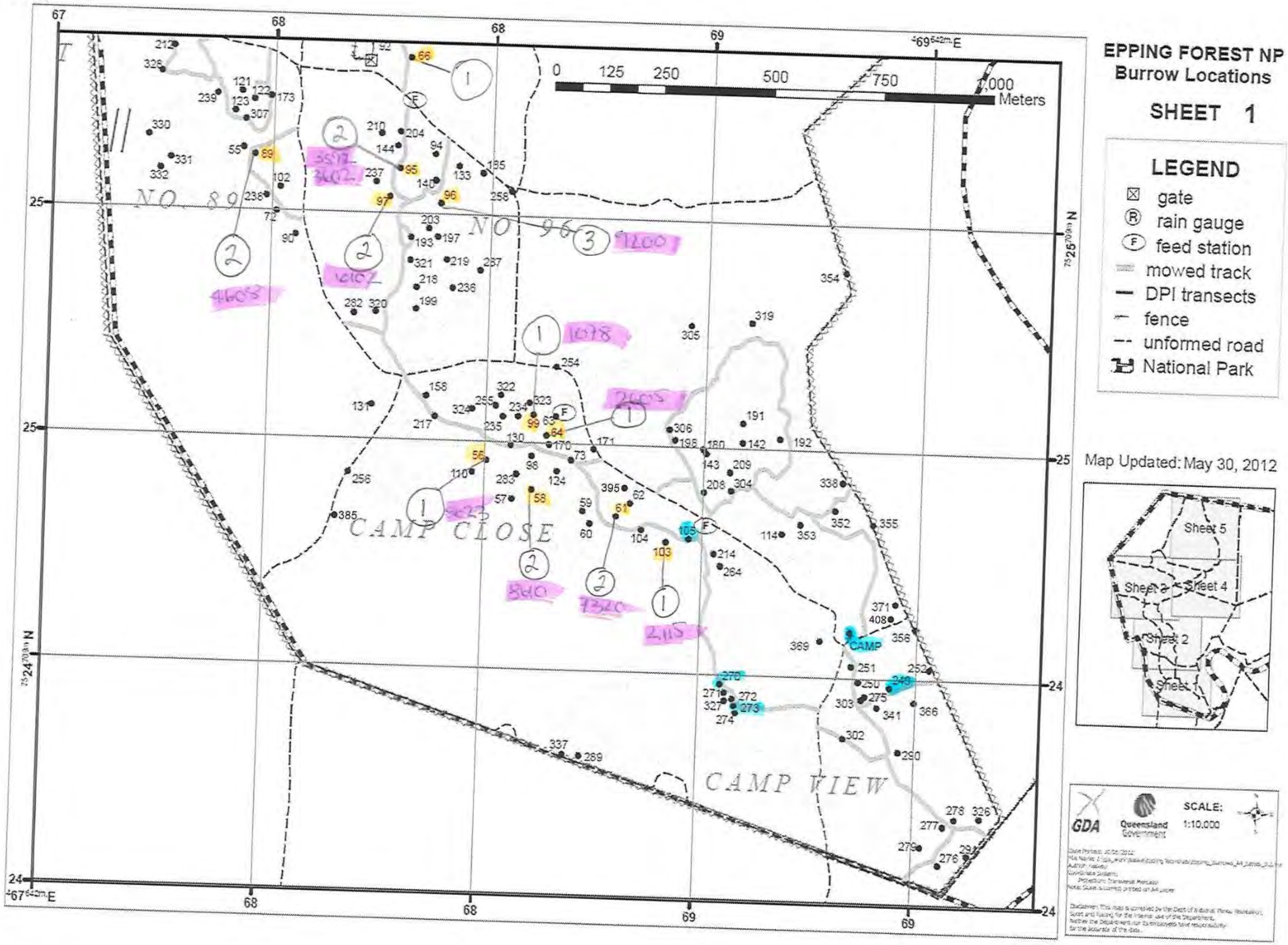
	mg	Time
First dose		
Second dose		

COMMENTS

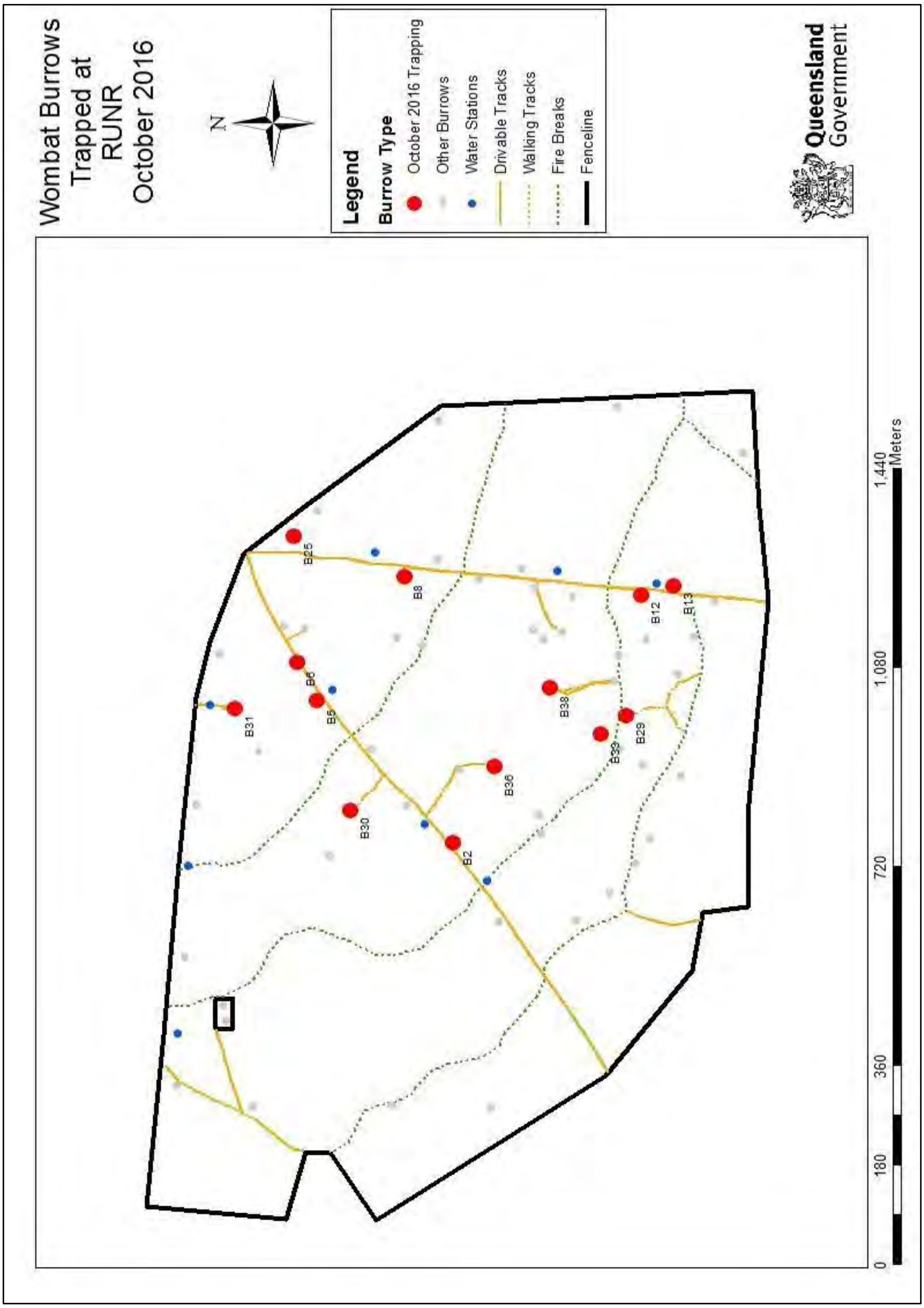
RECAP TATTOO

APPENDIX D – TRAPPED BURROWS AT EFNP (EHP)




EPPING FOREST NP
Burrow Locations
SHEET 1
LEGEND
gate
rain gauge
feed station
mowed track
DPI transects
fence
unformed road
National Park
Map Updated: May 30, 2012
0 125 250 500 750 1,000 Meters
NO. 89
NO. 96
CAMP CLOSE
CAMP VIEW
CAMP
Sheet 5
Sheet 4
Sheet 3
Sheet 2
Sheet 1
GDA
Queensland Government
SCALE: 1:10,000

APPENDIX E – BURROWS TRAPPED AT RUNR (EHP)



APPENDIX F – VEGETATION UNIT SPECIES LIST

VEGETATION UNIT	FAMILY NAME	SCIENTIFIC NAME	COMMON NAME
1	Cupressaceae	*Callitris glaucophylla*	White cypress pine
1	Cactaceae	*Opuntia tomentosa*	Velvet tree pear
1	Mimosaceae	*Acacia* sp.	
1	Myoporaceae	*Eremophila mitchellii*	False sandelwood
1	Poaceae	*Aristida* sp.	Three-awns
1	Poaceae	*Cenchrus ciliaris*	Buffel grass
1	Poaceae	*Digitaria brownii*	Cotton panic grass
1	Poaceae	*Enneapogon pallidus*	Conetop nineawn
1	Poaceae	*Poaceae* sp. 4	Possibly barb wire grass
1	Poaceae	*Paspalidium* sp.	
1	Poaceae	*Poaceae* sp.	
1	Poaceae	*Poaceae* sp. 2	
1	Poaceae	*Sporobolus caroli*	Fairy grass
1	Poaceae	*Tripogon loliiformis*	Rye beetle grass
1	Rutaceae	*Geijera parviflora*	Wilga/Native willow

VEGETATION UNIT	FAMILY NAME	SCIENTIFIC NAME	COMMON NAME
2	Cactaceae	*Opuntia tomentosa*	Velvet tree pear
2	Cupressaceae	*Callitris glaucophylla*	White cypress pine
2	Cyperaceae	*Cyperus* sp. 2	
2	Mimosaceae	*Acacia excelsa*	Iron wood
2	Myoporaceae	*Eremophila mitchellii*	False sandalwood
2	Myrtaceae	*Eucalyptus melanophloia*	Silver-leaf iron bark
2	Myrtaceae	*Eucalyptus populnea*	Poplar box
2	Poaceae	*Aristida* sp.	Three-awns
2	Poaceae	*Cenchrus ciliaris*	Buffel grass
2	Poaceae	*Enteropogon ramosus*	Windmill grass
2	Poaceae	*Paspalidium* sp.	
2	Poaceae	*Tripogon loliiformis*	Rye beetle grass
2	Proteaceae	*Hakea lorea*	Bootlace oak
2	Rutaceae	*Geijera parviflora*	Wilga/Native willow

VEGETATION UNIT	FAMILY NAME	SCIENTIFIC NAME	COMMON NAME
3	Apocynaceae	*Parsonsia eucalyptophylla*	Gargaloo
3	Cactaceae	*Opuntia tomentosa*	Velvet tree pear
3	Casuarinaceae	*Allocasuarina luehmannii*	Bulloak
3	Cyperaccae	*Cyperus* sp. 1	
3	Myoporaceae	*Eremophila mitchellii*	False sandalwood
3	Rutaceae	*Geijera parviflora*	Wilga/Native willow
3	Poaceae	*Cenchrus ciliaris*	Buffel grass
3	Poaceae	*Chloris* sp.	
3	Poaceae	*Enteropogon acicularis*	Curly windmill grass
3	Poaceae	*Enteropogon ramosus*	Windmill grass
3	Poaceae	*Paspalidum* sp.	

VEGETATION UNIT	FAMILY NAME	SCIENTIFIC NAME	COMMON NAME
4	Apocynaceae	*Parsonsia eucalytophylla*	Gargaloo
4	Cactaceae	*Opuntia tomentosa*	Velvet tree pear
4	Capparaceae	*Capparis lasiantha*	Nipan
4	Mimosaceae	*Acacia oswaldii*	Nelia
4	Myoporaceae	*Eremophila mitchellii*	False sandalwood
4	Myrtaceae	*Eucalyptus populnea*	Poplar box
4	Oleaceae	*Notelaea microcarpa*	Native olive
4	Poaceae	*Aristida* sp.	Three-awns
4	Poaceae	*Cenchrus ciliaris*	Buffel grass
4	Poaceae	*Chloris* sp.	
4	Poaceae	*Digitaria brownii*	Cotton panic grass
4	Poaceae	*Digitaria cuenicola*	
4	Poaceae	*Enneapogon* sp. 2	
4	Poaceae	*Enteropogen acicularis*	Curly windmill grass
4	Poaceae	*Enteropogon ramosus*	Windmill grass
4	Poaceae	*Poaceae* sp. 3	
4	Poaceae	*Tripogon loliiformis*	Rye beetle grass

VEGETATION UNIT	FAMILY NAME	SCIENTIFIC NAME	COMMON NAME
5	Acanthaceae	*Acanthaceae* sp. 1	
5	Cactaceae	*Opuntia Tomentosa*	Velvet tree pear
5	Cupressaceae	*Callitris glaucophylla*	White cypress pine
5	Mimosaceae	*Acacia* sp	
5	Myoporaceae	*Eremophila mitchellii*	False sandalwood
5	Myrtaceae	*Eucalyptus populnea*	Poplar box
5	Oleaceae	*Notelaea microcarpa*	Native olive
5	Poaceae	*Ancistrachne uncinalata*	Hookey grass
5	Poaceae	*Aristida* sp.	Three-awns
5	Poaceae	*Aristida* sp. 2	Three-awns
5	Poaceae	*Cenchrus ciliaris*	Buffel grass
5	Poaceae	*Enteropogon ramosus*	Windmill grass
5	Poaceae	*Panicum effusum*	Hairy panic
5	Poaceae	*Poaceae* sp.	
5	Poaceae	*Poaceae* sp. 2	
5	Poaceae	*Sporobolus caroli*	Fairy grass
5	Poaceae	*Tripogon loliiformis*	Rye beetle grass
5	Proteaceae	*Hakea lorea*	Corkwood
5	Rutaceae	*Geijera parviflora*	Wilga/Native willow

VEGETATION UNIT	FAMILY NAME	SCIENTIFIC NAME	COMMON NAME
6	Cupressaceae	*Callitris glaucophylla*	White cypress pine
6	Mimosaceae	*Acacia* sp.	
6	Myoporaceae	*Eremophila mitchellii*	False sandalwood
6	Myrtaceae	*Angophora melanoxylon*	Black-wood apple
6	Poaceae	*Aristida* sp.	Three-awns
6	Poaceae	*Cenchrus ciliaris*	Buffel grass
6	Poaceae	*Paspalidium* sp.	
6	Poaceae	*Poaceae* sp.	
6	Proteaceae	*Hakea lorea*	Corkwood
6	Rutaceae	*Geijera parviflora*	Wilga

VEGETATION UNIT	FAMILY NAME	SCIENTIFIC NAME	COMMON NAME
7	Mimosaceae	*Acacia* sp.	
7	Myoporaceae	*Eremophila mitchellii*	False sandalwood
7	Myrtaceae	*Eucalyptus populnea*	Poplar box
7	Oleaceae	*Notelaea microcarpa*	Native olive
7	Poaceae	*Aristida* sp.	Three-awns
7	Poaceae	*Cenchrus ciliaris*	Buffel grass
7	Poaceae	*Poaceae* sp. 4	Possibly barb wire grass
7	Poaceae	*Paspalidium* sp.	
7	Poaceae	*Poaceae* sp. 2	
7	Poaceae	*Sporobolus caroli*	Fairy grass
7	Rutaceae	*Geijera parviflora*	Wilga/Native willow
7	Sapindaceae	*Atalya hemiglauca*	Western whitewood

VEGETATION UNIT	FAMILY NAME	SCIENTIFIC NAME	COMMON NAME
8	Cactaceae	*Optunia tomentosa*	Velvet tree pear
8	Cupressaceae	*Callitris glaucophylla*	White cypress pine
8	Mimosaceae	*Acacia* sp.	
8	Myoporaceae	*Eremophila mitchellii*	False sandalwood
8	Myrtaceae	*Anogophora melanoxylon*	Black-wood apple
8	Oleaceae	*Jasminum didymum*	Narrow-leaved jasmine
8	Oleaceae	*Notelaea microcarpa*	Native olive
8	Poaceae	*Aristida* sp.	Three-awns
8	Poaceae	*Aristida* sp. 1	Three-awns
8	Poaceae	*Cenchrus ciliaris*	Buffel grass
8	Poaceae	*Enneapogon pallidus*	Conetop nineawn
8	Poaceae	*Enteropogon ramosus*	Windmill grass
8	Poaceae	*Panicum effusum*	Hairy panic
8	Poaceae	*Poaceae* sp.	
8	Poaceae	*Poaceae* sp. 2	
8	Poaceae	*Sporobolus caroli*	Fairy grass
8	Proteaceae	*Hakea lorea*	Corkwood
8	Rutaceae	*Geijera parviflora*	Wilga/Native willow

VEGETATION UNIT	FAMILY NAME	SCIENTIFIC NAME	COMMON NAME
9	Cactaceae	*Opuntia tomentosa*	Velvet tree pear
9	Cupressaceae	*Callitris glaucophylla*	White cypress pine
9	Mimosaceae	*Acacia* sp.	
9	Mimosaceae	*Acacia* sp. 2	
9	Myoporaceae	*Eremophila mitchellii*	False sandalwood
9	Myrtaceae	*Angophora melanoxylon*	Black-wood apple
9	Myrtaceae	*Eucalyptus populnea*	Poplar box
9	Oleaceae	*Notelaea microcarpa*	Native olive
9	Poaceae	*Aristida* sp.	Three-awns
9	Poaceae	*Cenchrus ciliaris*	Buffel grass
9	Poaceae	*Enneapogon pallidus*	Conetop nineawn
9	Poaceae	*Paspalidium* sp.	
9	Poaceae	*Poaceae* sp.	
9	Poaceae	*Sporobolus caroli*	Fairy grass
9	Poaceae	*Tripogon loliiformis*	Rye beetle grass
9	Proteaceae	*Hakea lorea*	Corkwood
9	Rutaceae	*Geijera parviflora*	Wilga/Native willow

APPENDIX G – VEGETATION PLOT SHEETS

Mid	**12/04/2017**	**Kristina Jorgensen, John Nowill**	**1**

Site location: The Richard Underwood Nature Refuge – vegetation unit 1

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: S **Colour**: **Munsell (circle wet/dry)**: Strong Brown **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Low *Callitris glaucophylla* forest/dense shrubland with a sparse to open shrub layering, of, *Acacia* spp., *Geijera parviflora* and *Eremophila mitchellii*, over an open tussock native grassland with patches of enclosed *Cenchrus ciliaris* grass tussock.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Callitris glaucophylla					x		
Cenchrus ciliaris							x
Geijera parviflora						x	

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Geijera parviflora					x	
Sporobolus caroli						x
Poaceae sp. 2						x
Aristida sp.						x
Callitris glaucophylla			x			
Acacia sp.					x	
Paspalidium sp.						x
Opuntia tomentosa						x
Digitaria brownii						x
Tripogon loliiformis						x

Mid	**12/04/2017**	**Kristina Jorgensen, John Nowill**	**2**

Site location: The Richard Underwood Nature Refuge – vegetation unit 1

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: Z	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: SL **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 5

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Low *Callitris glaucophylla* forest/dense shrubland with a sparse to open shrub layering, of, *Acacia* spp., *Geijera parviflora* and *Eremophila mitchellii*, over an open tussock native grassland with patches of enclosed *Cenchrus ciliaris* grass tussock.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Callitris glaucophylla			x				
Cenchrus ciliaris	*C. ciliaris*						x
Eremophila mitchellii						x	

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Callitris glaucophylla			x			
Tripogon loliiformis						x
Poaceae sp.						x
Aristida sp.						x
Eremophila mitchellii					x	
Digitaria brownii						x
Sporobolus caroli						x
Geijera parviflora					x	
Acacia sp.					x	

Mid	**11/04/2017**	**Kristina Jorgensen, John Nowill**	**3**

Site location: The Richard Underwood Nature Refuge – vegetation unit 1

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: LS **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Low *Callitris glaucophylla* forest/dense shrubland with a sparse to open shrub layering, of, *Acacia* spp., *Geijera parviflora* and *Eremophila mitchellii*, over an open tussock native grassland with patches of enclosed *Cenchrus ciliaris* grass tussock.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Callitris glaucophylla					x		
Aristida spp.							x
Eremophila mitchellii						x	

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Sporobolus caroli						x
Aristida sp.						x
Tripogon loliiformis						x
Callitris glaucophylla				x		
Eremophila mitchellii					x	
Poaceae sp.						x
Digitaria brownii						x
Cenchrus ciliaris						x
Paspalidium sp.						x
Enneapogon pallidus						x

Long	11/04/2017	Kristina Jorgensen, John Nowill	1

Site location: The Richard Underwood Nature Refuge – vegetation unit 2

Landform Pattern	Landform Element	Land Surface
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: S **Colour**: **Munsell (circle wet/dry)**: Brown **pH**: 6

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Open woodland of *Eucalyptus populnea* +/- *Eucalyptus melanophloia* and *Callitris glaucophylla* with a low open shrubland dominated by *Geijera parviflora* +/- *Eremophila mitchellii* and *Hakea lorea* over a native tussock grass land including A*ristida* spp. and *Enteropogon ramosus*.

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Enteropogon ramosus							x
Geijera parviflora						x	
Eucalyptus populnea			x				

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Enteropogon ramosus						x
Geijera parviflora					x	
Aristida sp.						x
Eucalyptus populnea		x				
Cyperus sp. 2						x
Acacia excelsa				x		
Eremophila mitchellii					x	

Long	**11/04/2017**	**Kristina Jorgensen, John Nowill**	**2**

Site location: The Richard Underwood Nature Refuge – vegetation unit 2

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: Z	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: **Colour**: **Munsell (circle wet/dry)**: **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Open woodland of *Eucalyptus populnea* +/- *Eucalyptus melanophloia* and *Callitris glaucophylla* with a low open shrubland dominated by *Geijera parviflora* +/- *Eremophila mitchellii* and *Hakea lorea* over a native tussock grass land including A*ristida* spp. and *Enteropogon ramosus*.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Enteropogon ramosus							x
Geijerva parviflora						x	
Eucalyptus populnea			x				

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Eremophila mitchellii					x	
Geijera parviflora					x	
Opuntia tomentosa						x
Hakea lorea					x	
Acacia excelsa			x			
Opuntia aurantiaca						x
Tripogon loliiformis						x
Enneapogon ramosus						x
Eucalyptus populnea		x				

Long	11/04/2017	Kristina Jorgensen, John Nowill	3

Site location: The Richard Underwood Nature Refuge – vegetation unit 2

Landform Pattern	Landform Element	Land Surface
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: **Colour**: **Munsell (circle wet/dry)**: **pH**: 6

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Open woodland of *Eucalyptus populnea* +/- *Eucalyptus melanophloia* and *Callitris glaucophylla* with a low open shrubland dominated by *Geijera parviflora* +/- *Eremophila mitchellii* and *Hakea lorea* over a native tussock grass land including A*ristida* spp. and *Enteropogon ramosus*.

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Enteropogon ramosus							x
Geijera parviflora						x	
Eucalyptus melanophloia		x					

Species	**Presence and abundance**					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Acacia excelsa		x				
Geijera parviflora					x	
Eremophila mitchellii					x	
Acacia sp.			x			
Eucaluptus melanophloia		x				
Callitris glaucophylla		x				
Opuntia tomentosa						x

Corner	11/04/2017	Kristina Jorgensen, John Nowill	1

Site location: The Richard Underwood Nature Refuge – vegetation unit 3

Landform Pattern	Landform Element	Land Surface
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: **Colour**: **Munsell (circle wet/dry)**: **pH**: 6

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Low *Allocasuarina luehmannii*/ *Geijera* parviflora forest with a tall open shrublayer of *Eremophila mitchellii* over a sparse ground cover of *Cenchrus ciliaris* and *Tripogon loliiformis*.

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Eremophila mitchellii			x				
Allocasuarina luehmannii		x					
Cenchrus ciliaris							x
Tripogon loliiformis							x
Geijera parviflora					x		

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Allocasuarina luehmannii		x				
Eremophila mitchellii			x			
Tripogon loliiformis						x
Opuntia tomentosa						x
Paspalidium sp.						x
Cenchrus ciliaris						x
Geijera parviflora		x				
Enteropogon ramosus						x
Opuntia aurantiaca						x

Corner	**11/04/2017**	**Kristina Jorgensen, John Nowill**	**2**

Site location: The Richard Underwood Nature Refuge – vegetation unit 3

Landform Pattern	**Landform Element**	**Land Surface**
Name: Gilgei	**Name**: Z	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** V	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: **Colour**: **Munsell (circle wet/dry)**: **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Low *Allocasuarina luehmannii/ Geijera parviflora* forest with a tall open shrublayer of *Eremophila mitchellii* over a sparse ground cover of *Cenchrus ciliaris* and *Tripogon loliiformis*.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Eremophila mitchellii			x				
Allocasuarina luehmannii		x					
Cenchrus ciliaris							x
Tripogon loliiformis							x

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Allocasuarina luehmannii		x				
Eremophila mitchellii			x			
Tripogon loliiformis						x
Opuntia tomentosa						x
Paspalidium sp.						x
Cenchrus ciliaris						x

Corner	11/04/2017	Kristina Jorgensen, John Nowill	3

Site location: The Richard Underwood Nature Refuge – vegetation unit 3

Landform Pattern	**Landform Element**	**Land Surface**
Name: Gilgei	**Name**: Z	**Microrelief type**: BV
Relief class: R	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** V	**Fragment Size**: O
Relief/Modal Slope Class: GR		**Rock Outcrop**: O

Soil Type: **Texture**: **Colour**: **Munsell (circle wet/dry)**: **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Low *Allocasuarina luehmannii*/ *Geijera parviflora* forest with a tall open shrublayer of *Eremophila mitchellii* over a sparse ground cover of *Cenchrus ciliaris* and *Tripogon loliiformis*. **Dominant/characteristic species**:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Eremophila mitchellii			x				
Allocasuarina luehmannii		x					
Cenchrus ciliaris							x
Tripogon loliiformis							x
Geijera parviflora					x		

Species	**Presence and abundance**					
	Emerg	T1	T2	S1	S2	Ground
Allocasuarina luehmannii		x				
Eremophila mitchellii			x			
Tripogon loliiformis						x
Opuntia tomentosa						x
Cyperus sp. 1						x
Cenchrus ciliaris						x
Geijera parviflora			x			
Parsonsia eucalyptophylla				x		

Buffel	**11/04/2017**	**Kristina Jorgensen, John Nowill**	**1**

Site location: The Richard Underwood Nature Refuge – vegetation unit 4

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: LS **Colour**: **Munsell (circle wet/dry)**: Reddish Brown **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Closed *Cenchrus ciliaris* tussock grassland with isolated *Eremophila mitchellii* shrubland.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Eremophila mitchellii			x				
Cenchrus ciliaris							x

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Enteropogon acicularis						x
Capparis cosiantha					x	
Opuntia tomentosa						x
Eremophila mitchellii				x		
Digitaria brownii						x
Enneapogon sp. 2						x

Buffel	**11/04/2017**	**Kristina Jorgensen, John Nowill**	**2**

Site location: The Richard Underwood Nature Refuge – vegetation unit 4

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: Z	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: LS **Colour**: **Munsell (circle wet/dry)**: Reddish Brown **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Closed *Cenchrus ciliaris* tussock grassland with isolated *Eremophila mitchellii* shrubland.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Eremophila mitchellii					x		
Cenchrus ciliaris							x

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Acacia oswaldii			x			
Eremophila mitchellii				x		
Eucalyptus populnea		x				
Aristida sp. 2						x
Poaceae sp. 3						x
Digitaria coenicola						x
Enneapogon sp. 2						x
Enteropogon acicularis						x
Tripogon loliiformis						x
Chloris sp.						x

Buffel	**11/04/2017**	**Kristina Jorgensen, John Nowill**	**3**

Site location: The Richard Underwood Nature Refuge – vegetation unit 4

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LE		**Rock Outcrop**: O

Soil Type: Texture: LS **Colour**: **Munsell (circle wet/dry)**: Reddish Brown **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Closed *Cenchrus ciliaris* tussock grassland with isolated *Eremophila mitchellii* shrubland.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Eremophila mitchellii					x		
Cenchrus ciliaris							x

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Eremophila mitchellii				x		
Notelaea microcarpa				x		
Opuntia tomentosa						x
Geijera parviflora				x		

Top mid	11/04/2017	Kristina Jorgensen, John Nowill	1

Site location: The Richard Underwood Nature Refuge – vegetation unit 5

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: **Colour**: **Munsell (circle wet/dry)**: Brown **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Open *Eucalyptus populnea* with an open shrubland over an open *Cenchrus ciliaris* tussock grassland with a few native species.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Cenchrus ciliaris							x
Eucalyptus populnea			x				
Hakea lorea						x	

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Acacia sp.						x
Eremophila mitchellii				x		
Opuntia tomentosa						x
Aristida sp. 2						x
Geijera parviflora						x
Poaceae sp. 2						x
Anistrachne uncinulata						x
Callitris glaucophylla				x		
Hakea lorea					x	

Top mid	**11/04/2017**	**Kristina Jorgensen, John Nowill**	**2**

Site location: The Richard Underwood Nature Refuge – vegetation unit 5

Landform Pattern	Landform Element	Land Surface
Name: PLA	**Name**: Z	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: Texture: S **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 6 ½

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Open *Eucalyptus populnea* with an open shrubland over an open *Cenchrus ciliaris* tussock grassland with a few native species.

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Cenchrus ciliaris							x
Eremophila mitchellii						x	

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Sporobolus caroli						x
Poaceae sp. 2						x
Aristida sp. 2						x
Geijera parviflora						x
Opuntia tomentosa						x
Enteropogon ramosus						x
Eremophila mitchellii					x	
Acanthaceae sp. 1						x
Hakea lorea						x

Top mid	**11/04/2017**	**Kristina Jorgensen, John Nowill**	**3**

Site location: The Richard Underwood Nature Refuge – vegetation unit 5

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: Texture: LS **Colour**: **Munsell (circle wet/dry)**: Yellowish Brown **pH**: 7

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Open *Eucalyptus populnea* with an open shrubland over an open *Cenchrus ciliaris* tussock grassland with a few native species.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Cenchrus ciliaris							x
Acacia spp.		x					
Geijera parviflora					x		

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Sporobolus caroli						x
Aristida sp.						x
Tripogon loliiformis						x
Cenchrus ciliaris						x
Eremophila mitchellii				x		
Eucalyptus populnea		x				
Geijera parviflora			x			
Callitris glaucophylla				x		
Panicum effusum						x
Acacia sp.		x				
Notelaea microcarpa						x

Mid	**12/04/2017**	**Kristina Jorgensen, John Nowill**	**1**

Site location: The Richard Underwood Nature Refuge – vegetation unit 6

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 6 ½

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Low open woodland of *Acacia* spp. and *Callitris glaucophylla* with an open *Hakea lorea* and *Eremophila mitchellii* shrublayer over a closed *Cenchrus ciliaris* tussock grassland.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Callitris glaucophylla					x		
Acacia spp.					x		
Cenchrus ciliaris							x
Hakea lorea						x	

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Paspalidium sp.						x
Poaceae sp.						x
Eremophila mitchellii					x	
Callitris glaucophylla				x		
Acacia sp.				x		
Hakea lorea				x		
Aristida sp.						x

Mid	**12/04/2017**	**Kristina Jorgensen, John Nowill**	**2**

Site location: The Richard Underwood Nature Refuge – vegetation unit 6

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: Z	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: SL **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Low open woodland of *Acacia* spp. and *Callitris glaucophylla* with an open *Hakea lorea* and *Eremophila mitchellii* shrublayer over a closed *Cenchrus ciliaris* tussock grassland.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Eremophila mitchellii						x	
Acacia spp.			x				
Cenchrus ciliaris							x

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Eremophila mitchellii				x		
Aristida sp.						x
Geijera parviflora			x		x	
Acacia sp.			x			

Mid	12/04/2017	Kristina Jorgensen, John Nowill	3

Site location: The Richard Underwood Nature Refuge – vegetation unit 6

Landform Pattern	Landform Element	Land Surface
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: LS **Colour**: **Munsell (circle wet/dry)**: Brown **pH**: 6 ½

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: Low open woodland of *Acacia* spp. and *Callitris glaucophylla* with an open *Hakea lorea* and *Eremophila mitchellii* shrublayer over a closed *Cenchrus ciliaris* tussock grassland.

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Cenchrus ciliaris							x
Angophora melanoxylon		x					

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Angophora melanoxylon		x				x

Mid	12/04/2017	Kristina Jorgensen, John Nowill	1

Site location: The Richard Underwood Nature Refuge – vegetation unit 7

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: LS **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 7

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: *Acacia* spp. woodland +/- *Callitris glaucophylla* with emergent *Eucalyptus populnea*, with an *Eremophila mitchellii* and *Geijera parviflora* shrubland over a dense *Cenchrus ciliaris* grassland including *Aristida* spp.

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Cenchrus ciliaris							x
Eremophila mitchellii					x		
Acacia sp.			x				

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Geijera parviflora						x
Aristida sp.						x
Eremophila mitchellii				x		
Sporobolus caroli						x
Acacia sp.		x				
Paspalidium sp.						x

Mid	**12/04/2017**	**Kristina Jorgensen, John Nowill**	**2**

Site location: The Richard Underwood Nature Refuge – vegetation unit 7

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: Z	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: Texture: LS **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 5 ½

Disturbance:

Type	**Severity**	**Notes**
5	**2**	**Grazing Macropods**
V	2	Human Wombat Management

Structural and floristic description: *Acacia* spp. woodland +/- *Callitris glaucophylla* with emergent *Eucalyptus populnea*, with an *Eremophila mitchellii* and *Geijera parviflora* shrubland over a dense *Cenchrus ciliaris* grassland including *Aristida* spp.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Cenchrus ciliaris	*C. ciliaris*						x
Eremophila mitchellii							

Species	**Presence and abundance**					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Aristida sp.						x
Eremophila mitchellii					x	
Atalaya hemiglacia					x	
Geijera parviflora		x				

Mid	**12/04/2017**	**Kristina Jorgensen, John Nowill**	**3**

Site location: The Richard Underwood Nature Refuge – vegetation unit 7

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: LS **Colour**: **Munsell (circle wet/dry)**: Yellowish red **pH**: 5

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: *Acacia* spp. woodland +/- *Callitris glaucophylla* with emergent *Eucalyptus populnea*, with an *Eremophila mitchellii* and *Geijera parviflora* shrubland over a dense *Cenchrus ciliaris* grassland including *Aristida* spp.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Eucalyptus populnea	x						
Acacia sp.					x		
Cenchrus ciliaris							x

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Acacia sp.				x		
Poaceae sp. 2						x
Sporobolus caroli						x
Paspalidium sp.						x
Cenchrus ciliaris						x
Aristida sp.						x
Eremophila mitchellii					x	
Eucalyptus populnea		x				
Notelea microcarpa					x	

Top	11/04/2017	Kristina Jorgensen, John Nowill	1

Site location: The Richard Underwood Nature Refuge – vegetation unit 8

Landform Pattern	Landform Element	Land Surface
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: Texture: SL **Colour**: **Munsell (circle wet/dry)**: Strong brown **pH**: 4 ½

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: *Callitris glaucophylla* and *Angophora melanoxylon* forest including a small tree layer of *Geijera parviflora* and a sparse *Eremophila mitchellii* shrub layer over a sparse native tussock grassland +/- *Cenchrus ciliaris*

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Cenchrus ciliaris							x
Eremophila mitchellii					x		
Callitris glaucophylla			x				

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Eremophila mitchellii				x		
Poaceae sp.						x
Aristida sp.						x
Callitris glaucophylla			x			
Acacia sp.					x	
Sporobolus caroli						x
Notelaea microcarpa						x
Poaceae sp. 2						x
Opuntia aurantiaca						x

Top	11/04/2017	Kristina Jorgensen, John Nowill	2

Site location: The Richard Underwood Nature Refuge – vegetation unit 8

Landform Pattern	Landform Element	Land Surface
Name: PLA	**Name**: Z	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: Texture: SL **Colour**: **Munsell (circle wet/dry)**: Yellowish Brown **pH**: 6

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: *Callitris glaucophylla* and *Angophora melanoxylon* forest including a small tree layer of *Geijera parviflora* and a sparse *Eremophila mitchellii* shrub layer over a sparse native tussock grassland +/- *Cenchrus ciliaris*.

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Cenchus ciliaris							x
Angophora melanoxylon		x					
Eremophila mitchellii					x		

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Aristida sp.						x
Eremophila mitchellii				x		
Angophora melanoxylon		x				
Callitris glaucophylla				x		
Notelaea microcarpa						x
Poaceae sp. 2						x
Enteropogon ramosus						x
Aristida sp. 1						x
Acacia sp.					x	
Enneapogon pallidus						x
Eremophila mitchellii				x		
Hakea lorea				x		
Sporobolus caroli						x
Panicum effsum						x

Top	**11/04/2017**	**Kristina Jorgensen, John Nowill**	**3**

Site location: The Richard Underwood Nature Refuge – vegetation unit 8

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: SL **Colour**: **Munsell (circle wet/dry)**: Yellowish red **pH**: 5

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: *Callitris glaucophylla* and *Angophora melanoxylon* forest including a small tree layer of *Geijera parviflora* and a sparse *Eremophila mitchellii* shrub layer over a sparse native tussock grassland +/- *Cenchrus ciliaris*

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Cenchrus ciliaris							x
Eremophila mitchellii					x		
Geijera parviflora			x				

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Enteropogon ramosus						x
Aristida sp.						x
Poaceae sp. 2						x
Sporobolus caroli						x
Eremophila mitchellii				x		
Enneapogon pallidus						x
Geijera parviflora			x			
Jasminum didymum					x	

Top Left	11/04/2017	Kristina Jorgensen, John Nowill	1

Site location: The Richard Underwood Nature Refuge – vegetation unit 9

Landform Pattern	Landform Element	Land Surface
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: Texture: LS **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 6

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: *Eucalyptus populnea* tall open woodland with an open shrub layer of *Eremophila mitchellii*, *Acacia* spp. +/- *Geijera parviflora* over a sparse tussock grassland dominated by C*enchrus ciliaris* +/- *Aristida* spp.

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Cenchrus ciliaris							x
Eremophila mitchellii					x		
Acacia spp.			x				

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Eremophila mitchellii				x		
Acacia sp.			x			
Hakea lorea				x		
Notelaea microcarpa			x			
Acacia sp. 2					x	
Aristida sp.						x

Top Left	11/04/2017	Kristina Jorgensen, John Nowill	2

Site location: The Richard Underwood Nature Refuge – vegetation unit 9

Landform Pattern	Landform Element	Land Surface
Name: PLA	**Name**: Z	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: Texture: LS **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 5

Disturbance:

Type	Severity	Notes
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: *Eucalyptus populnea* tall open woodland with an open shrub layer of *Eremophila mitchellii*, *Acacia* spp. +/- *Geijera parviflora* over a sparse tussock grassland dominated by C*enchrus ciliaris* +/- *Aristida* spp.

Dominant/characteristic species:

Species	Emergents	T1	T2	T3	S1	S2	Ground
Cenchrus ciliaris							x
Eucalyptus populnea		x					
Geijera parviflora			x				

Species	Presence and abundance					
	Emerg	T1	T2	S1	S2	Ground
Cenchrus ciliaris						x
Paspalidium sp.						x
Acacia sp.					x	
Hakea lorea					x	
Opuntia tomentosa					x	
Eremophila mitchellii					x	
Poaceae sp.						x
Aristida sp.						x
Callitris glaucophylla					x	
Eucalyptus populnea		x				
Geijera parviflora			x			

Top Left	11/04/2017	Kristina Jorgensen, John Nowill	3

Site location: The Richard Underwood Nature Refuge – vegetation unit 9

Landform Pattern	**Landform Element**	**Land Surface**
Name: PLA	**Name**: PLA	**Microrelief type**: BV
Relief class: P	**Slope Value or Class**: LE	**Fragment Abundance**: O
Model Slope Class: LE	**Morphological Type:** F	**Fragment Size**: O
Relief/Modal Slope Class: LP		**Rock Outcrop**: O

Soil Type: **Texture**: LS **Colour**: **Munsell (circle wet/dry)**: Yellowish Red **pH**: 6

Disturbance:

Type	**Severity**	**Notes**
5	2	Grazing Macropods
V	2	Human Wombat Management

Structural and floristic description: *Eucalyptus populnea* tall open woodland with an open shrub layer of *Eremophila mitchellii*, *Acacia* spp. +/- *Geijera parviflora* over a sparse tussock grassland dominated by C*enchrus ciliaris* +/- *Aristida* spp.

Dominant/characteristic species:

Species	**Emergents**	**T1**	**T2**	**T3**	**S1**	**S2**	**Ground**
Cenchrus ciliaris							x
Eremophila mitchellii					x		
Acacia spp.			x				x

<table>
<tr><th rowspan="2">Species</th><th colspan="6">Presence and abundance</th></tr>
<tr><td>Emerg</td><td>T1</td><td>T2</td><td>S1</td><td>S2</td><td>Ground</td></tr>
<tr><td>Cenchrus ciliaris</td><td></td><td></td><td></td><td></td><td></td><td>x</td></tr>
<tr><td>Poaceae sp.</td><td></td><td></td><td></td><td></td><td></td><td>x</td></tr>
<tr><td>Geijera parviflora</td><td></td><td></td><td></td><td></td><td></td><td>x</td></tr>
<tr><td>Aristida sp.</td><td></td><td></td><td></td><td></td><td></td><td>x</td></tr>
<tr><td>Enneapogon pallidus</td><td></td><td></td><td></td><td></td><td></td><td>x</td></tr>
<tr><td>Angophora melanoxylon</td><td></td><td></td><td></td><td>x</td><td></td><td></td></tr>
<tr><td>Tripogon loliiformis</td><td></td><td></td><td></td><td></td><td></td><td>x</td></tr>
<tr><td>Eremophila mitchellii</td><td></td><td></td><td></td><td></td><td>x</td><td></td></tr>
<tr><td>Acacia sp.</td><td></td><td></td><td colspan="2">x</td><td></td><td></td></tr>
<tr><td>Sporobolus caroli</td><td></td><td></td><td></td><td></td><td></td><td>x</td></tr>
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