Impacts of mammalian herbivores on the *Callitris glaucophylla* - *Eucalyptus albens* woodland of Kosciuszko National Park

by

Jessica Ward-Jones

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Jessica Ward-Jones   Date:

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Abstract

Box Gum Grassy woodlands are classified as a threatened ecological community under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Decline in original extent of Box Gum Grassy woodlands is mostly due to fragmentation and modification for cropping and livestock grazing. The extensive disturbance, erosion, and degradation of the *Callitris glaucophylla – Eucalyptus albens* woodland of Kosciuszko National Park has been well documented up until 1991. Ian Pulsford and The New South Wales National Parks and Wildlife Service assembled a detailed history of the area, describing several waves of environmental disturbance over a period of around 150 years. After the arrival of white settlers in 1834, changes in fire regime, rabbit plagues, and ongoing sheep and cattle grazing resulted in intense degradation of the landscape. Unfortunately the woodland has not had an opportunity to recover, as a new wave of disturbance currently appears to be supressing the ecosystem; horses and deer. Using 33 year old exclosures and paired control plots, soil functionality, and vegetation structure and composition was examined. Soil functionality, understorey and midstorey vegetation were found to be significantly improved in the exclosures. The overstorey did not exhibit any significant improvement by exclusion of mammalian herbivores. However, *Callitris glaucophylla* are slow growing and likely need hundreds of years to change in structure. The native vegetation struggles to cope with the hard hooves and grazing behaviour of pest herbivores in such high population densities. Consequentially, the *C. glaucophylla – E. albens* woodland of Kosciuszko National Park currently appears to be in a stable degraded state.

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List of acronyms and abbreviations

NPWS – National Parks and Wildlife Service

NSW – New South Wales

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Chapter 1: Introduction

Brumby sighting along the Barry Way (Photo Credit: Ian Pulsford, 2017)

Box Gum Grassy woodlands are classified as a threatened ecological community under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Decline in original extent of Box Gum Grassy woodlands is mostly due to fragmentation and modification for cropping and livestock grazing (Prober, 1996, Prober et al., 1998). This research is a case study of the degradation of a unique Box Gum Grassy woodland in Kosciuszko National Park, using long term exclusion of herbivory. The extensive disturbance, erosion, and degradation of the *Callitris glaucophylla – Eucalyptus albens* woodland of Kosciuszko National Park has been well documented up until 1991 (Pulsford, 1991). Any inhibition of recovery over the past 33 years by pest herbivory, following 150 years of ongoing disturbance will be analysed.

The *Callitris glaucophylla - Eucalyptus albens* woodland of Kosciuszko National Park is of high conservation value because it is the only major occurrence of its type east of the Great Dividing Range. The woodland occurs on the steep dry slopes of the Pilot and Byadbo Wilderness areas, divided by the Lower Snowy River. The environmental conditions combined with a history of disturbance in the woodland has resulted in severe erosion of the landscape. In the late 1980's Ian Pulsford and the New South Wales National Parks and Wildlife Service (NSW NPWS) assembled a detailed history of the area, describing several waves of intense environmental disturbance and degradation over a period of around 150 years (Pulsford 1991). Costin (1954) considered that area had the 'most serious erosion damage' in the Monaro region. Previous to white settlers altering the frequency and intensity of the fire regime, rabbit plague invasion, and ongoing sheep and cattle grazing between 1834 and 1972, this woodland was described by early explorers as having "rich black mould to chocolate" soils and was "well grassed" (Robinson, 1941, Stephenson, 1980). Historical structure of the woodland was a wide open woodland with clusters of large wide branching mature *C. glaucophylla* and *E. albens* trees (Pulsford 1991). By 1954 the landscape was completely bare of any understorey or midstorey vegetation, and described as incapable of even supporting the rabbit population by which it was over-run (Costin, 1954, Lacey, 1972). In 1954 Costin called for state intervention and by 1970 the whole woodland area was included in Kosciuszko National Park and all stock grazing was prohibited (Pulsford 1991).

Since inclusion in the National Park, substantial decline in rabbit population, and exclusion of cattle grazing, a new cohort of *C. glaucophylla* trees have established. Much of the woodland is now dominated by substantial areas of dense locked stands of mostly single generation *Callitris glaucophylla* trees, particularly on the exposed north aspect slopes. In many areas the cooler south aspect slopes are dominated by white box *Eucalyptus albens*. This research will investigate whether the soil and lower vegetation structure remains degraded because of lack of opportunity to recover and re-establish. It will also be determined whether any lack of recovery is due to a new wave of threats to the woodland; potentially pest horses and deer. Pest horses have been present in the park since at least 1860 (Worboys and Pulsford, 2013). They are responsible for varying levels of damage according to other land management practises such as sheep and cattle grazing in the Park (which ceased in three stages in 1944, 1958 and 1968). Pest horses have increasingly become an issue for native ecosystems in Kosciuszko National Park since 2003, as their population has grown significantly (Worboys and Pulsford, 2013).

In 1984 Ian Pulsford (the NSW NPWS) erected exclosures and paired control plots to investigate impacts of rabbit plagues in the woodland. These exclosures appear to have since been successful at substantially excluding all forms of mammalian herbivory including horses and deer. The presence of these enclosed areas provide an opportunity to answer the research question:

How are mammalian herbivores inhibiting recovery of the *Callitris glaucophylla - Eucalyptus albens* woodland since its staged inclusion in Kosciuszko National Park (1944 and 1973)?

Bishwokarma et al. (2014) conducted preliminary research in the woodland using the paired exclosures and control plots to investigate any inhibition of recovery using Landscape Function Analysis (LFA). LFA is a means of rapidly assessing patchiness and soil surface conditions at a landscape scale. It was found that soil surface stability, water infiltration rate, and soil nutrient cycling values were significantly lower in the control plots compared to the exclosures. To build on these preliminary findings, this research will use a comprehensive means of assessing recovery of the woodland; the VAST (Vegetation Assets, States and Transitions) system which evaluates changes in structure, composition and function.

This research investigates and quantifies whether there has been a recovery of the condition of the *C. glaucophylla – E. albens* woodland inside the exclosures compared to that observed outside in the controls. Equivalent direct measures of condition variables that were collected and reported by Pulford (1991) and Bishwokarma et al. (2014) are also relevant in evaluating changes in vegetation condition in these same paired plots.

1.1 Research design

Mammal proof exclosures and control plots that Ian Pulsford and the NSW NPWS set up in 1984 were utilised to answer the research question. Five intact exclosures and five paired control plots were used to investigate the environmental impacts of herbivores in the woodland over the past 33 years. Differences were quantified between the exclosures and control plots using the VAST-2 methodological framework – a comprehensive means of assessing change in a landscape. The VAST-2 assessment quantified differences in structure, composition and function between the exclosures which have been herbivore free for 33 years and the control plots which are subject to ongoing herbivory and subsequent risk of erosion. Measurements include soil, invertebrate, and vegetation sampling and surveys.

1.2 Aims

1. To assess woodland structure, composition and function inside the exclosures in comparison to the control plots.
2. To determine if there is suppression of recovery in the woodland by quantifying and comparing the control plots to the exclosures.
3. If recovery is being supressed, to identify the herbivore species primarily responsible for inhibiting recovery of the woodland.
4. To assess the need for feral herbivore control in this relatively poorly researched part of Kosciuszko National Park.

1.3 Hypotheses

Hypotheses:

i. Vegetation structure and composition is more diverse, and landscape functionality is higher inside the exclosures, when compared to the control plots.
ii. Mammalian herbivores are inhibiting the slow recovery of the *Callitris glaucophylla - Eucalyptus albens* woodland in Kosciuszko National Park.

Null hypotheses:

i. There will be no difference in structure, composition, diversity, or functionality inside the exclosures, when compared to the control plots.
ii. Mammalian herbivores are not inhibiting recovery of the *Callitris glaucophylla - Eucalyptus albens* woodland in Kosciuszko National Park; the woodland is in a stable degraded state.

Further hypotheses:

Seventeen indicator assessments were undertaken and specific predictions for each method were included in the methodologies section.

Chapter 2: Literature Review

This chapter describes the extensive history of disturbance and mammalian herbivory in the *Callitris glaucophylla - Eucalyptus albens* woodland in Kosciuszko National Park. It will also describe the significance of the issue of mammalian herbivores in relation to the National Park.

View of Mt Trooper from Site 1 (Photo Credit: Ian Pulsford, 2017)

2.1 Box Gum Grassy woodlands

Box Gum Grassy Woodlands are classified as a threatened ecological community by the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) (Australian Federal Government, 1999). Various species of Box Gum are included in this definition. The focus Box Gum species of this study is White Box (*Eucalyptus albens*). Prior to European settlement, Box Gum Grassy woodlands were extensive and reasonably continuous across south-eastern Australia, covering more than 10 million hectares (Prober, 1996). Clearing and modification for agriculture and livestock grazing is predominantly responsible for the decline in the area covered by the woodlands (Prober et al., 1998). Box Gum Grassy woodlands are considered one of the most poorly conserved vegetation types in Australia, the community is classified as critically endangered (Specht 1981, Florance and Lindenmayer, 2015). McIntyre et al. (2010) states that extensive areas in good condition do not exist. Fragmentation of the woodlands has caused a loss of genetic diversity and further genetic drift and inbreeding within populations is putting remnant stands at increased risk of demise (Frankel and Soule, 1981, Prober et al., 1998). For maintenance and recovery of biodiversity and quality of remnant stands of Box Gum Grassy woodlands, it was recommended that livestock grazing is completely excluded (Prober and Thiele, 1995). Simply excluding livestock grazing from a woodland may not be enough to control excessive herbivory and encourage recovery. Feral mammalian herbivores may now be a significant threat to recovery and conservation of Box Gum Grassy woodlands. This research on the *Callitris glaucophylla - Eucalyptus albens* woodland of Kosciuszko National Park is a case study of the impacts of grazing and pest herbivory on a Box Gum Grassy woodland.

2.1.1 *Callitris glaucophylla - Eucalyptus albens* case study

This *C. glaucophylla – E. albens* woodland of Kosciuszko National Park is a Box Gum Grassy woodland that has been impacted by grazing and pest herbivory. The woodland covers 7084 ha within Kosciuszko National Park and is located on the steep slopes of the Byadbo and Pilot wilderness areas, with the Lower Snowy River running between (Pulsford 1991). The woodland extends further south into VIC but this research will focus on the portion within NSW. A map and detailed description of the area is provided in the Methods section (Figure 2). This *C. glaucophylla – E. albens* alliance is unique, the only occurrence of its type east of the Great Dividing Range (Clayton-Greene, 1981). Due to changes in land management the structure of the woodland has changed from wide open Box Gum Grassy woodland to dense regrowth forest, dominated (particulary on exposed north aspect sites) by even aged stands of *C. glaucophylla*, on eroded soils lacking understorey. Over 150 years of disturbance is responsible for the degradation and structural changes of the woodland (Pulsford, 1991).

2.2 *History of disturbance*

Pulsford (1991) conducted research to create a detailed history of the disturbances to the woodland and consequentially changes in woodland structure. His research focused on changes in land management practices and disturbances over 150 years which included documenting the introduction of pest herbivory and changes in fire regime. Since Pulsfords work in 1984 and present, there has been little research done in the area, this study will contribute to further understanding of the landscape.

2.2.1 Pre European settlement

Prior to European settlement this woodland was occupied by the Ngarigo linguistic group, a sub group of the indigenous Bemeringal people of the southern highlands. Between 1830 and 1856 the indigenous people of the area had “diminished due to persecution, diseases and rapid dispossession of their lands” (Pulsford 1991). The Ngarigo people occupied the area for around 18,000 years before being dispossessed and dissipated in the early 1800’s (Flood, 1973). Reports by early settlers and distribution of still standing dead trees indicate this area was once open woodland with deep soils and lush grasses (Mackaness 1941); this structure may have been a response to land management practices of the Ngarigo people. Pulsford (1991) suggests that occasional low intensity burning of ground cover in the woodland supressed establishment of *C. glaucophylla* seedlings, encouraging a wide open grassy woodland structure with stands of uneven aged *C. glaucophylla* trees maintained.

2.2.2 Use as a stock route

Richard Brooks was the first European to cattle drove and establish a cattle run in the lower Snowy in 1834 and in subsequent years the valley was utilised as a stock route between the Monaro tableland and East Gippsland (Stephenson, 1980). After the establishment of Kosciuszko National Park and the subsequent construction of the Barry way, completed in 1961 the road continued to be utilised infrequently for the movement of stock.

Ongoing sheep and cattle grazing and hard-hooved trampling without allocated recovery time on such steep slopes and unstable soils caused complete loss of midstorey vegetation, understorey vegetation and dense matts of moss and lichen. Loss of shallow rooted vegetation meant there was little organic matter holding the soil profile together. On such steep slopes (20-26 degrees), loss of vegetation caused the almost complete erosion of the A and B soil horizons (Clayton-Greene, 1981). Loss of the deep nutrient rich soil subsequently degraded the ecosystem, its functionality, and ability to recover.

Most of the area is now declared wilderness area however a narrow corridor on the valley floor and Barry way provide access and recreational opportunities for visitors. Currently permitted recreational activities include fishing, camping, canoeing, walking and horse riding along the river and valley floor. Horse riding also occurs on fire trails.

2.2.3 Rabbit plagues

Rabbits were introduced to mainland Australia in 1859 (Rolls, 1977), they escaped from captivity and spread to the *C. glaucophylla – E. albens* woodland of Kosciuszko National Park by around 1900 (Platts, 1989). Rabbit populations fluctuated and occasionally grew to plague proportions (Wakefield, 1970). Presence of rabbits in the woodland inhibited any potential for understory and midstorey recovery. In 1954 Costin described parts of the landscape as "stripped to the subsoil or bedrock and so devoid of grasses it is almost incapable of supporting the rabbit population by which it is over-run." See Figure 1 for photo of rabbit impacts in surrounding area.

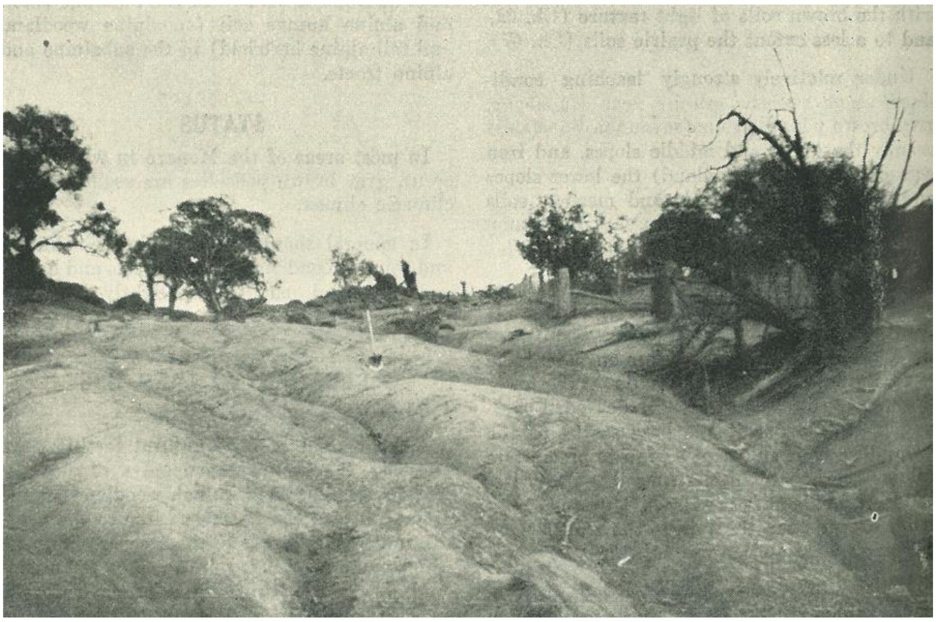


Figure 1. Severe sheet and gully erosion near Jindabyne… due to overgrazing by rabbits and domestic livestock' (adopted from Costin 1954, pg 624)

In response to massive losses of topsoil and ground cover, and some years of above average rainfall, a dense recruitment of *C. glaucophylla* occurred. Between 1885 and 1891 a new cohort of even aged *C. glaucophylla* trees established, referred to as 'wheat field' regeneration (Pulsford, 1991). This new generation of *C. glaucophylla* remain currently as dense locked stands of narrow branching trees. Large old dead *C. glaucophylla* specimens remain that died in response to the previous sequence of disturbance events. Rabbit population fell dramatically in 1952 after the first strain of Myxoma virus was released, but populations grew again to plague proportions by the early 1980's. In 1980 and 1983 the 'Louisiana' strain of Myxoma virus was released simultaneously with the rabbit flea (Pulsford 1991). Rabbit populations have not reached plague propotions since and are not currently considered a major threat to the *C.*

glaucophylla – E. albens woodland of Kosciuszko National Park. The establishment of the new cohort of *C. glaucophylla* trees coincided with rabbit populations being dramatically reduced in 1986; this suggests that rabbit browsing of seedlings was suppressing recruitment in the woodland (Lacey, 1972).

2.2.4 Inclusion in Kosciuszko National Park

In 1944 the area now called the Pilot Wilderness area (to the west of the Snowy River) was reserved as State Park (it was named as the Pilot Wilderness in 1974). In 1967 The Area became Kosciuszko National Park. In 1968 cattle grazing became prohibited by NPWS in the Pilot Wildness, although some illegal grazing may have continued for several years. By 1974 the Byadbo Wilderness area (to the east of the Snowy River) was recognised by management plans and included in Kosciuszko National Park and stock excluded.

2.3 Current pressures

Kosciuszko National Park contains unique scenery and natural phenomena with native animals that are of outstanding conservation and recreational significance and value. The park covers ~670,000 hectares and comprises a diverse range of ecosystems and species. The alpine and sub alpine areas contain many rare and endemic fauna and flora. NPWS invest resources in maintenance of the park with a focus on pest species control. Over the past five years 1844 pigs, 934 deer, 846 goats, 251 cats, 2037 foxes and 1377 wild dogs have been removed from the park (OEH, 2016). Threats to the *C. glaucophylla – E. albens* woodland have changed over time from cattle grazing, rabbits, changed fire regimes and now a new wave of threats are becoming apparent; rising horse and deer populations. Despite removal of cattle grazing since 1967, mammalian herbivores in the woodland have been putting ongoing grazing pressure on the ecosystem. Personal observations of dung, tracks and woodland vegetation condition indicate that horses and deer are the current predominant threat to the slow recovery of the woodland. Adverse effects of pest horses in alpine wetlands and grasslands are well documented (Morgan and Green, 2003, Worboys and Pulsford, 2013, O'Brien et al., 2004) but little is known about their impacts in dry woodlands.

2.3.1 Pest herbivores

Costin (1954) noted that the woodland is rich in native fauna but most species have been adversely affected by introduced species and changes in land management practices. Goats, rabbits and pigs are also present in Kosciuszko National Park but not evident in *C. glaucophylla – E. albens* woodland of the Lower Snowy. Ungulates are non-native and their hard hooves cause damage to the various delicate ecosystems of Australia. For example, their hard hooves decrease soil stability by churning soil and riparian areas (Bennett, 1999). Lenehan (2010) found that “introduced hoofed grazing animals cause greater mechanical disruption of the soil surface and higher rates of erosion than native macropod species”. Domestic horses were brought to Australia by white settlers in 1788 for agricultural use and transportation. In the 19th century, the industrial revolution rendered horses redundant for work purposes and many were released into the wild (Walter, 2002). In 2001, wild horse population in Kosciuszko National Park was estimated at ~3000 (English, 2006). Aerial surveys in 2014 of the Australian Alps estimate that wild horse populations had significantly increased and could currently be greater than 11,000, spread across more that 1.6 million hectares of wilderness and National Park areas (AANP, 2016). The same aerial surveys estimated up to 1,500 wild deer just in the Byadbo and Pilot Wilderness areas. Macropod populations are somewhat controlled by wild dogs, foxes, dingoes and native raptors. As horses and deer are non-native, they have no natural predator in Kosciuszko National Park. Adult males are too large to be preyed on but female Fallow deer, fawn and foal populations are likely somewhat controlled by dingo and wild dogs (Duarte et al., 2016).

Kosciuszko National Park is unfenced and potential for spread of pest horses and deer into surrounding National Parks and private land is of concern. Public attitudes toward pest horse management are contentious with public opinion on culling often opposing the need for removal of the horses despite pest horse population growing at a concerning rate (between 6 and 17%) (AANP, 2016, Walter, 2002). After culls in Namadji National Park in 1987 and Guy Fawkes National Park in 2000 there was media and public outcry and methods of removal were forced to be reconsidered. In recognition of the community’s views on pest horse population management, the National Park is aiming to work with communities to develop strategies for sustainable management and potentially complete removal of pest horses (O’Brien et al., 2004). In 2016 NSW NPWS released the Draft Wild Horses Management Plan outlining plans for wild horse population control in the Park and invited public debate on the topic. Opinions were diverse and deeply polarised, and consequently the plan was put on hold and a new plan is being drafted.

2.3.2 Damage to ecosystems in Kosciuszko National Park

In 1983 the NSW NPWS carried out a review of the condition of the *C. glaucophylla – E. albens* woodland ecosystem of Kosciuszko National Park and determined that the “condition of the ecosystem posed serious and significant problems for management of the Snowy River catchment” (Pulsford et al., 1996). By trampling and grazing behaviour, horses and deer have been proven to be responsible for damage of various ecosystems in Kosciuszko National Park and the Australian Alps. Morgan and Green (2003) found that exclusion of ungulate grazing promoted greater biodiversity and biomass of native grasses in the Pretty Valley alpine grasslands of the Bogong High Plains. Worboys and Pulsford (2013) found that pest horses had impacted more than 43 km of sub alpine wetlands and streams. Grazing, trampling, compacting and soil pugging disturbance was observed to have exacerbated erosion of stream banks, bogs and fens. Presence of pest horses has negatively affected streamside habitats for native Australian species, water flow regime, water quality, and water yield of catchments. Horse tracks were found to be responsible for draining alpine bogs, further contributing to degradation of ecosystems. Soil nutrient run off can be accounted for by ongoing erosion caused by hard hooved ungulates; this erosion causes increased sediment loads in alpine creeks and streams, altering natural flow (O'Brien et al., 2004). Migrating pest horses can also be responsible for spreading weeds, acting as vectors and carry invasive plant species seeds in their dung (Pickering et al., 2010). The observed presense of horses and deer indicate that the *C. glaucophylla – E. albens* woodland ecosystem of Kosciuszko National Park is likely impacted by pest herbivore ungulates.

2.3.3 Prior assessments of the woodland

Recently (Bishwokarma et al., 2014) found "clear evidence that uncontrolled grazing by growing numbers of introduced herbivores, especially pest horses has become a major threat" to the *C. glaucophylla – E. albens* woodland of Kosciuszko National Park. Bishwokarma (2014) completed a Landscape Function Analysis (LFA), using the same exclosures this research utilises. It was found that indices of soil surface stability, water infiltration rate, and soil nutrient cycling were significantly lower in the control plots where pest horses and deer still currently graze. It was concluded that "pest herbivore activity, particularly grazing and trampling, continues to severely suppress" recovery of the woodland. LFA is predominantly based on indirect (visual) measures, rather than direct quantitative measures, so results of assessment can be variable according to the measurer. To further understand inhibition of recovery in the woodland, additional assessments need to be carried out.

2.4 Argument for pest control

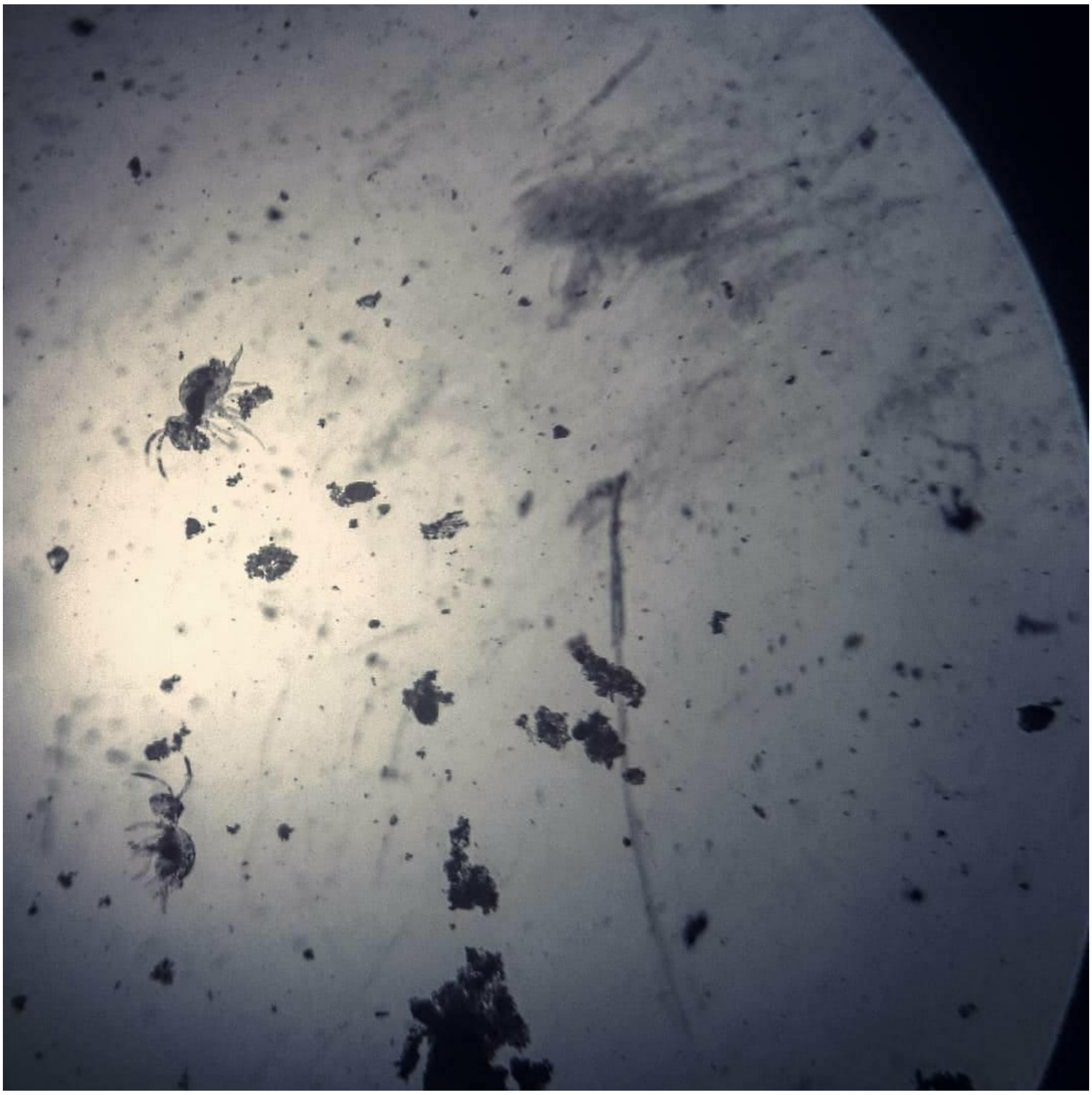
This research will assess the need for pest herbivore control. In comparison to knowledge of grasslands and riparian areas, not much is known about pest herbivory impacts in a dry system. This research will attempt to determine extent of degradation in this dry woodland and what components are still at risk. Attitudes to control of pest herbivores in communities are variable and contentious. There are multiple stakeholders opposing removal of pest herbivores (O'Brien et al., 2004). Control of pest herbivore populations is expensive and controversial, so robust research in required to examine if control is needed, and if so, what species to target.

2.5 Significance

Bishwokarma et al. (2014) determined, using LFA, that functionality of the woodland has been compromised. LFA is a rapid and reasonably accurate, but not a comprehensive means of assessing landscape condition. To further understand differences in condition and advance on Bishwokarmas work, a more direct and comprehensive means of assessment needs to be used. A full census of structure and composition needs to be completed to fully understand any negative impacts of pest ungulates. This research used the VAST system to make this assessment as described below in Chapter 3.

Chapter 3: Methods

The characteristics of study area will be described in depth, site selection and research design explained, methodological approach described, and methods listed.



Collembola under a dissecting microscope

3.1 The study area

The *Callitris glaucophylla – Eucalyptus albens* (White Cypress Pine-White Box) woodland of Kosciuszko National Park inhabit the steep slopes of the Byadbo and Pilot wilderness areas (see Figure 2), adjacent to the Lower Snowy River and cover around 115,500 ha (Pulsford, 1991).

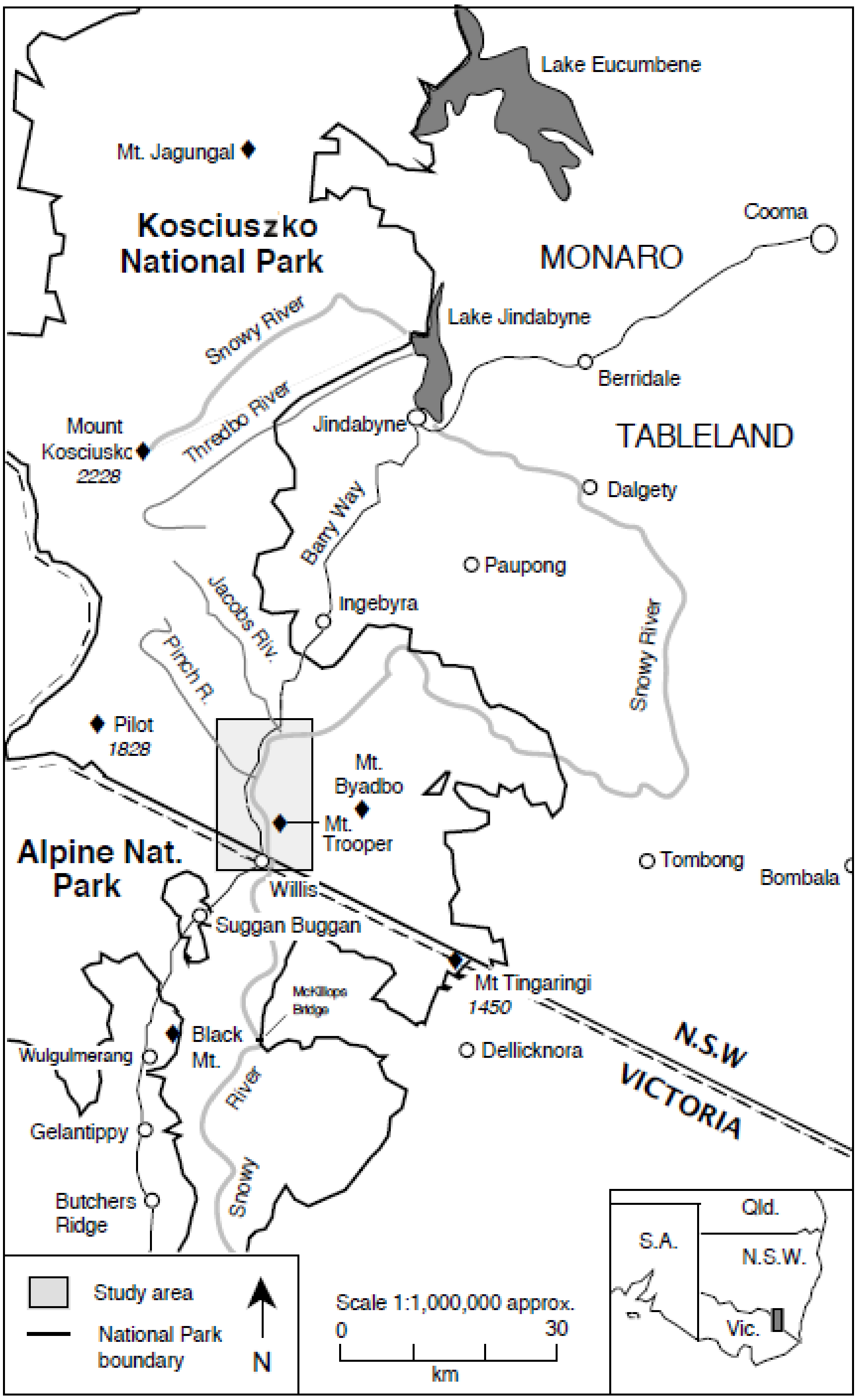


Figure 2. Study area location in context to Kosciuszko National Park (Pulsford 1991)

3.1.1 Soil landscapes

This woodland of *C. glaucophylla – E. albens* trees occurs on granite, gneiss, and metamorphosed sediments which are coarse, and low in fertility (Pulsford et al., 1996) . The soils are lithosolic, including grey brown podsols, brown podsols and colluvial brown earths. These soil types indicate that the landscape is relatively dry, warm, well drained, sandy and infertile (Costin, 1954, Isbell, 1996). Because these soils lose moisture easily, and have low organic matter content, they don't hold together well without vegetation roots providing structure and support (Baranian et al., 2017).

3.1.2 Climate

Temperature and elevation are known to be major drivers of this woodland, and rainfall is also known to influence the ground storey plant diversity (Thompson and Eldridge, 2005). The woodland lies in a rain shadow area and receives relatively low rainfall in comparison to the rest of the National Park (Pulsford 1991). Note that closest Bureau of Meteorology weather station #071017 (Snowy River at Willis) does not collect rainfall or temperature data so more current climate data could not be attained. Average annual rainfall at Tubbut (Station #084039, 26.9km away, 451 m above sea level) is 665.2mm (Bureau of Meteorology, 2017). Compared to other areas in the park, this valley is significantly drier; Thredbo valley receives 1430.3mm on average annually, and the Cabramurra region receives 1165.9mm. There are around 70-100 rainfall days per annum (Costin, 1954). Levels of rainfall also vary by season, December on average receives 66.1 mm whereas May receives just 42.5 mm. Additional to being in a rain shadow, low levels of rainfall can be accounted for by the relatively low elevation of the woodland. The low levels of rainfall received means regrowth and recovery is a slow process. Mean temperatures are mild in the valley, ranging from 7° C during winter, to 24° C during summer (Costin 1954). Maximum summer temperatures can reach up to 40 ° C, exacerbating the effects of the already dry conditions in the valley.

3.1.3 Vegetation structure

Costin (1954) described the woodland assemblage in detail, stating that it is comprised of 148 different flora species. The landscape is dominated by large and medium size perennials, with some herbaceous annuals. The dominant overstorey structuring species are *Callitris glaucophylla* (White Cypress Pine) and *Eucalyptus albens* (White Box). The woodland is currently dominated by an even aged stand of *C. glaucophylla* with narrow crowns, established between 1885 and 1900 (Pulsford et al., 1996). *C. glaucophylla* is very slow growing, the current stand in the woodland is undergoing the very slow process of self-thinning which will take more than 100 years before somewhat resembling the pre disturbed woodland structure. *C. glaucophylla* trees may live to more than 500 years of age (Clayton-Greene, 1981). Large, dead wide-branching *C. glaucophylla* specimens remain, scattered around the woodland with exposed root systems indicating the sheer amount of soil that has been lost (15-30cm (Pulsford 1991)). The old trees are estimated to be 194 to 226 years old (Pulsford 1991). Casuarina specimens scatter the woodland also. The midstorey is now all but non-existent in the woodland with the occasional *Acacia* and *Ericaceae* specimen present (personal observation). The understorey consists of mostly Poa grass and seasonal herbs. The understory and midstorey structure and composition has been severely suppressed by the presence of pest herbivores.

3.1.4 Fauna present

Native

Costin (1954) documented the woodland as supporting the presence of diverse biota: arachnids, reptiles, emus, raptors, echidnas, wombats, koalas, possums, quolls, and members of the suborder Macropodiformes (predominantly eastern grey kangaroos and red necked wallabies).

Non native

Pest species in the woodland have not been well investigated or documented but surrounding areas in Kosciuszko National Park have recorded presence of horses, deer, goats, pigs, rabbits, wild dogs, and foxes (OEH, 2016). Introduced pest predators include wild dogs and foxes. Personal observations confirm the presence of horses and deer in this woodland.

3.2 Site selection

The locations of the five exclosures and five paired control plots were selected to represent locations within the woodland most at risk of degradation and inhibition of recovery. A most-at-risk representation was chosen to demonstrate and investigate the worst case scenario. They have been free from all mammalian herbivory for 33 years and have had an opportunity to recover from the 150+ years of various disturbances. Exclosure and control plot location selection was stratified by the following conditions to account for any variation caused by site selection – elevation, aspect, and slope. See Figure 3 for locations and Appendix 1 for GPS coordinates.

In 1984, exclosures were erected by Ian Pulsford and NPWS to investigate impacts of rabbits on the woodland; with a focus on examining erosion and vegetation recovery. These exclosures have since been mostly successful in excluding all forms of mammalian herbivory, therefore are a means of answering the research question: are herbivores inhibiting recovery of *C. glaucophylla – E. albens* woodland of Kosciuszko National Park? One exclosure was deemed unusable as a fallen tree opened up the fence line to herbivory for an unknown period of time. There are five intact exclosures within the woodland and five paired control plots adjacent to them; a total of 10 sites to be measured. The ten sites were chosen to represent the parts of the woodland that are most at risk of degradation. Certain characteristics of the woodland make it more or less vulnerable to erosion and degraded functionality, these characteristics will be discussed in the following sections.

Landscape functionality is a summation of qualities of a landscape that influence the quality and flux of biotic and abiotic resources. Functionality of a landscape is influenced by various abiotic and biotic characteristics including the geology of the site that the ecosystem is located on, climatic influence, vegetation structure and composition, as well as fauna present. The characteristics that influence functionality of the *C. glaucophylla – E. albens* woodland of Kosciuszko National Park follow.

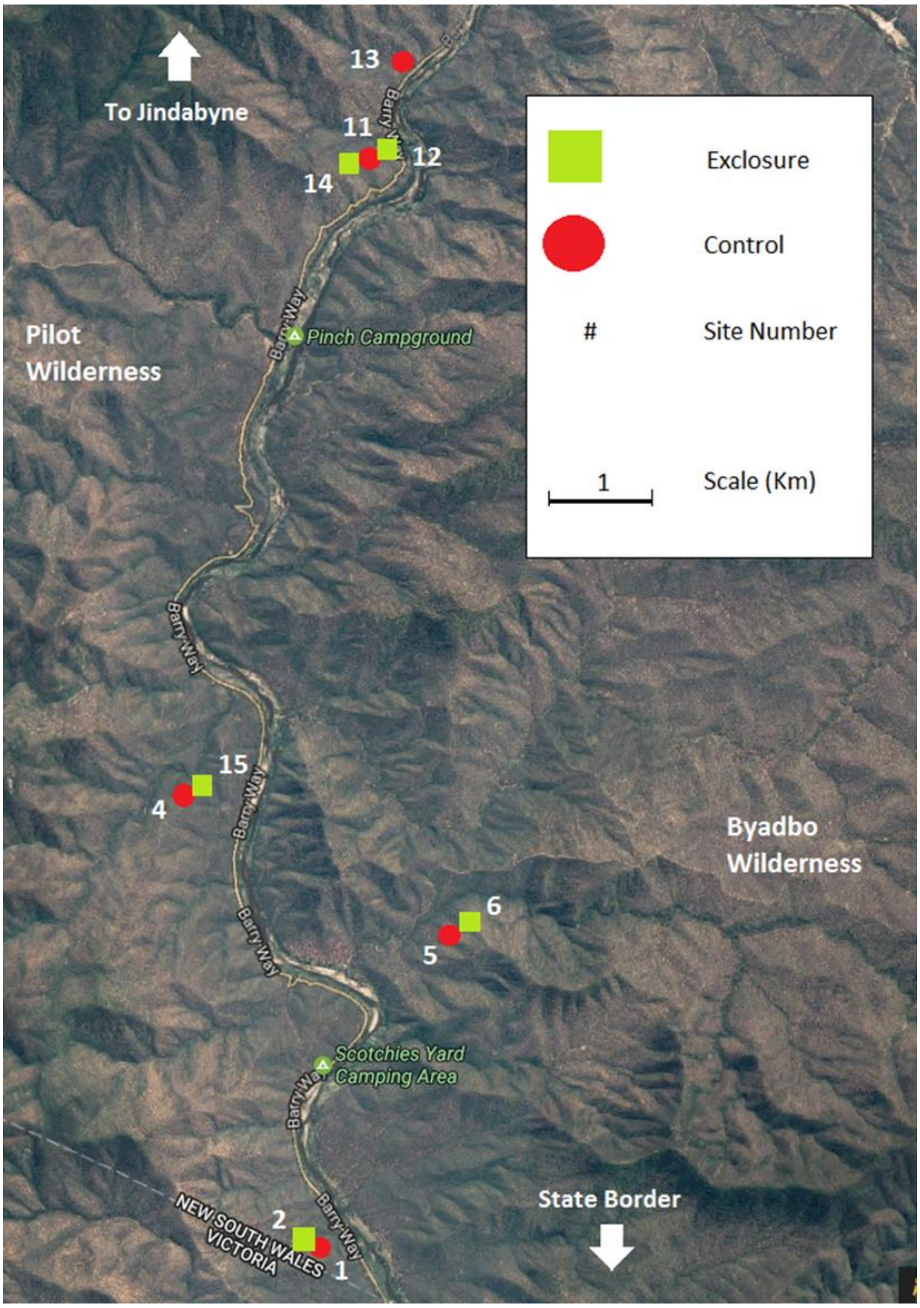


Figure 3. Map indicating the locations of exclosures and plots within the study area

3.2.1 Altitude

The woodland occupies the lowest parts of the valley, significantly lower than the rest of Kosciuszko National Park; occupying slopes between 230m and 500m above sea level. The majority of Kosciuszko National Park is above 900m. This low elevation means the woodland receives relatively low rainfall compared to the rest of Kosciuszko National Park. Rainfall values are specified earlier in the climate description. The exclosures and control plots are located within an altitude range of 350 metres and 400 metres.

3.2.2 Aspect

Northerly aspect slopes receive sunlight at lower angles of incidence which means they are more prone to moisture loss due to solar radiation (Stearns and Carlson, 1960). All the sites occupy a northerly or slightly north-westerly facing aspect slope between 0 and 15 degrees bearing.

3.2.3 Slope

Steeper slopes are more vulnerable to erosion as water is more likely to flow across the surface and downward before pooling or infiltrating into the soil. If the soil is bare and compacted and or there are minimal obstructions to slow flow, the slope will be at risk of sheet erosion. The woodland occupies a valley, steeply divided by the Lower Snowy River, the Byadbo and Pilot wilderness areas on either side. The slopes steeply angle at around 23 degrees. The control plot and exclosure sites are all positioned upon slopes of between 20 and 26 degrees (see Figure 4 for visual representation).

Figure 4. Control Plot 1 exhibiting a steep, 23 degree slope and the loss of the A horizon, noticeable by the exposure of loose rocks on the soil surface

3.3 Study design

Randomised locations of exclosures and control plots were established and environmental variation accounted for. The exclosures and control plots were constructed by contractors in 1984 and physical descriptions follow. The sites are 20 metres x 20 metres square. The exclosures fenced off using star pickets, chicken wire fencing walls at 1.3m high, high tensile wire to maintain shape, and topped with a barbed wire line to deter potential faunal intruders. The control plot corners are marked by short star pickets and have a 30cm tall chicken wire fence along the top edge. The top edge fence was established to account for any rundown edge effects caused by the top fence in the exclosures. Within each exclosure and control plot, two 10 metre long transects were laid across slope and marked by star pickets. The 10 m transects were established by Ian Pulsford to undertake vegetation surveys. The 10 m transects were used again in this study to conduct vegetation surveys.

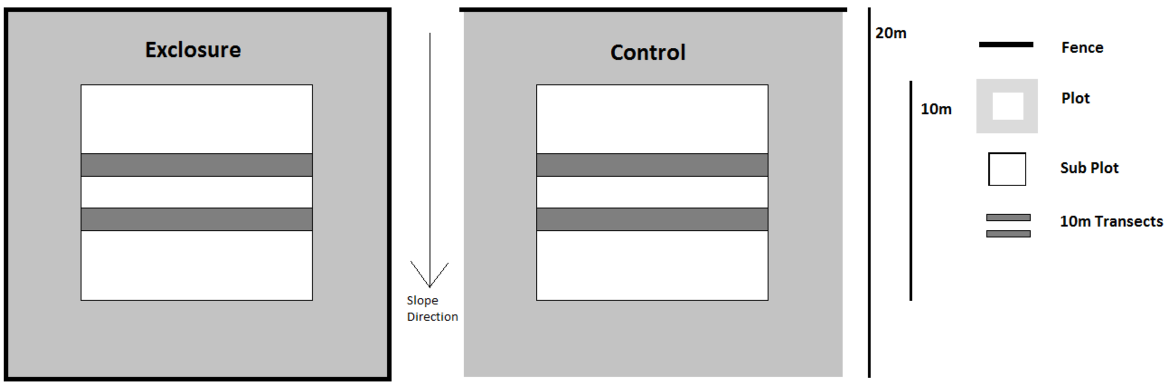


Figure 5. Exclosure and Control Plot design, each encompassing transect locations

See Figure 5 for diagrammatic representation of the exclosure and plot design. The exclosures and control plots were used to answer part one of the research question (are herbivores impacting recovery of the woodland?) The structure, composition and function within the exclosures were directly compared to their paired control plots to quantify and damage that has continued in the woodland and the recovery potential of the woodland without pest herbivores present. The VAST-2 framework for assessing change in a landscape was used to assess differences between the exclosures and control plots as described below.

3.4 Methodological framework: VAST

The Vegetation Assets, States and Transitions (VAST) framework was chosen to assess changes and trends in the condition of plant communities. The VAST framework provides a means of assessing and classifying the degree of vegetation modification caused by anthropogenic drivers (i.e. management regimes). The framework links changes in land management practices and consequential vegetation condition states, as well as contributing to knowledge of resilience (Thackway and Lesslie, 2008). The framework is flexible and applicable to various ecosystem types across Australia, for example, grasslands, forests and tropical vine forests (Thackway and Freudenberger, 2016). The VAST framework is a state transitions model which focuses on assessing three condition components: vegetation structure, composition and landscape function. The framework gathers information on changes over time in vegetation extent, structure, taxonomic composition and functional attributes. As well as data on vegetation, VAST takes into account information on functional or abiotic variables including fire regime, water availability and soil functionality. This woodland landscape falls under the VAST classification of ‘Modified’ (class 2), on a scale of 0-6, ranging from residual or unmodified (class 1) to removed and replaced vegetation (class 6) (Lesslie et al., 2010).

The VAST-2 framework defines 22 response indicators representing function, structure and composition (Thackway 2014). This framework is a methodology, rather than prescribing any one method for collecting or measuring data needed to populate the indictors. For this reason, the framework is flexible and can be applied to any terrestrial plant community. Not all of the 22 VAST indicators are applicable to this woodland and some measurement of those indicators were omitted (Table 1). Additional indicators were added to account for variation in the midstorey. Omitted and additional indicators are listed in the following section. See Table 1 for a full list of the 24 indicators and how they fit within the framework. Methods used in this research project were formulated to be statistically sufficient, efficient and where applicable – to be directly comparable and similar to unpublished data collected by Ian Pulsford in the 1980’s. It was desirable for the results to be comparable to Pulsfords previous work for later comparison of the data sets and further insight.

Table 1. VAST framework outlining indicators (grey boxes indicate omitted indicators) (Thackway, 2014). The buff shading shows the two indicators that were added to the indicator framework to account for midstorey.

indicator #. Description of measurement	Attribute groups	Condition Components	Vegetation Transformation Index
i1. Fire Footprint size	Fire regime	Regenerative capacity	Vegetation Transformation Index
i2. Fire Interval			
i3. Soil surface water availability	Soil hydrology		
i4. Ground water availability			
i5. Depth of A horizon	Soil physical state		
i6. Soil structure			
i7. Nutrient stress (rundown)	Soil nutrient state		
i8. Nutrient stress (toxicity)			
i9. Diversity and abundance of invertebrates responsible for maintaining soil porosity, nutrient recycling	Soil biological state		
i10. Surface organic matter, soil crusts			
i11. Reproductive potential of overstorey structuring species	Reproductive potential		
i12. Reproductive potential of understorey structuring species			
i13. Overstorey top height (mean) of the plant community (DBH)	Overstorey structure	Vegetation structure	
i14. Overstory foliage projective cover (mean) of the plant community			
i15. Overstorey structural diversity (i.e. a diversity of age classes) of the plant community			
i16. Understorey top height (mean) of the plant community	Understorey structure		
i17. Understorey ground cover (mean) of the plant community			
i18. Understorey structural diversity (diversity of age classes) of the plant community			
i23. Midstorey top height (mean) of the plant community	Midstorey structure		
i19. Densities of overstorey species functional groups	Overstorey composition	Species composition	
i20. Relative number of overstorey species (richness) of the plant community			
i21. Densities of understorey species functional groups	Understorey composition		
i22. Relative number of understorey species (richness) of the plant community			
i24. Densities of midstorey species functional groups	Midstorey composition		

3.5 Omitted Indicators

The VAST framework for assessing change is designed to be flexible and applicable to all types of plant communities in varying condition states; because of this, not every indicator is appropriate to measure in this woodland. The following indicators were deemed immeasurable or irrelevant to be included in this study.

3.5.1 Fire regime (i 1&2)

Indicator 1: Area /size of fire footprint and **Indicator 2: Interval between fire starts**

Because the exclosures and paired control plots are spatially adjacent it can be assumed that fire history over the past 33 years (since their establishment) has been very similar if not identical. There are no tangible differences between the exclosures and control plots in regards to Indicators 1 and 2 and so these do not need to be measured.

3.5.2 Ground water availability (i4)

The woodland is situated on steep, rocky, unstable slopes. Ground water availability is associated with ground water dependent ecosystem, for example springs and wetlands. Measuring ground water availability is not relevant on such steep slopes.

3.5.3 Depth of the A horizon (i5)

Due to the extensive domesticated livestock and mammalian herbivore damage, and subsequent erosion described in Chapter 2, the whole of the A horizon has been lost. There is no A horizon present within the exclosures nor control plots and so this indicator could not be measured.

3.5.4 Nutrient stress – excess (toxicity) relative to soil fertility (i8)

Land management practices in the woodland have not included any kind of fertilisation or introduction of nutrients to the soil. Soil toxicity (excess nutrients) will not be present in the exclosures or control plots and does not need to be measured.

3.5.5 Relative number of overstorey species (richness) of the plant community (i20)

The overstorey is a simple assemblage dominated by *C. glaucophylla* and occasional *E. albens* specimens. Both species are present in the control plots and exclosures so overstorey species richness is identical when comparing by treatment.

3.5.6 Relative number of understorey species (richness) of the plant community (i22)

A full census of floristics in the woodland was not possible to carry out as data collection was completed in autumn and winter when ephemeral species were not apparent. A field herbarium provided by Genevieve Wright of NPWS was used to identify the four understorey specimens that were present in the exclosures; *Dichopogon* sp. (Chocolate Lily), *Poa* sp. (Tussock grass), *Xerochrysum* sp. (Everlasting Daisy) and an unidentified forb species. All species but *Xerochrysum* sp. were present in the control plots. Richness was not diverse enough to compare treatments statistically.

3.6 Methods: measurement of the indicators

The remaining VAST indicators (Table 1) not listed in the previous section were deemed relevant and measurable. Additional to these, two more indicators (23 and 24) were added to account for midstorey structure and composition. Seventeen indicators in total were measured. Where possible, fieldwork and unpublished data collected by Ian Pulsford in 1984 was examined and methods tailored to be directly comparable to assist in a potential later analysis. Ian Pulsford laid two 10 m transects across slope within the exclosures and plots, marked by star pickets which remain; these same transect lines were utilised where possible. Some indicators required specific field methods and some indicators could be extrapolated from data collection of other indicators. Some field methods comprised data collection of several indicators, such as vegetation transects (see Figure 5 in section 3.3 for diagrammatic representation of plot and transect design). Field methods for each indicator follow. Predictions for each indicator are shown below.

3.6.1 Soil functionality

3.6.1.1 Soil surface water availability (i3)

Soil surface water availability is important because ephemeral understory species, shallow rooted structuring flora, mosses and cryptogams rely on shallow soil moisture retention to thrive. To measure soil surface water availability, water moisture content was measured using a Delta-T HH2 soil moisture meter probe. Three strata of soil surface were defined as bare soil, colluvium, and patch. For each soil surface strata, ten measurements were taken; for a total of 30 measurements in each plot. Bare soil was defined as the bare soil surface space between understorey vegetation patches, regardless of biological crust or litter cover presence. Colluvium was defined as the accumulated loose sediment that has been deposited by runoff and erosion against an obstruction, the colluvium lacks structure and contains angular sediments (NCST, 2010). Patch was defined as the soil substrate directly beneath an understorey vegetation patch. The 30 replicates were chosen randomly within each plot. Measurements were taken at each replication point by fully inserting the three moisture probe prongs directly into the substrate, held for three seconds to settle, then measured and recorded in a data form. Measurement units were recorded in soil moisture percent.

Predictions:

1. The exclosures will exhibit greater soil surface water availability because there is greater ground cover. Ground cover tends to improve water infiltration (Eldridge and Freudenberger, 2005).
2. Soil surface moisture availability will be lowest in the bare soil
3. Soil surface moisture availability will be greatest in the patches

3.6.1.2 Soil structure (i6)

Slake testing was used to define soil structure. Slake testing measures soil aggregate stability. The slake test was chosen to measure soil structure because it indicates how well soil holds together when exposed to water. This test is relevant to understand how easily the soil surface can be washed away when precipitates fall or run-on. Three strata of soil surface were defined as bare soil, colluvium, and patch (the three soil surface categories are defined in 3.6.1 (i3)). For each soil surface category, 10 measurements were taken; for a total of 30 measurements in each plot. To perform a slake test, a sharp, flat implement was used to sharply incise into the soil surface and gently release a small (~1cm in diameter) aggregate. It is important that the slake test was only performed on dry soil. The aggregate was then gently placed into a petri dish full with fresh water and completely submerged. Structure class (0-4) was then determined using the criteria listed in Table 2. Slake test methods were extrapolated from (Tongway, 2004).

Table 2. Slake score descriptors (Tongway, 2004)

Observed Behaviour	Class	Interpretation
Not Applicable	0	No Coherent fragments available e.g. sand
Very unstable	1	Fragment collapses in less then 5 seconds
Unstable	2	Fragment substantially collapses 5-10 seconds; a thin surface crust remains. >50% of the sub-crust material slumps
Moderately stable	3	Surface crust remains intact with some slumping of the sub-crust but less then 50%
Very stable	4	Whole fragment remains intact with no swelling

Predictions:

4. The exclosures will exhibit greater soil structure compared to the control plots because of slightly higher presence of organic material, causing higher aggregate stability.
5. Soil structure will be least stable in the colluvium.
6. Soil structure will be most stable in the patch.

3.6.1.3 Nutrient stress – rundown (deficiency) relative to soil fertility (i7)

Most nutrients are found in the top 5 cm of a soil profile (Kriedemann et al., 1999). Nutrient deficiency was identified as a potential issue as a large amount of topsoil has been lost to sheet erosion. Nutrient deficiency was measured by taking soil samples from the field then analysing them in a lab using a Leco machine to test for levels of total Carbon and Nitrogen. Three strata of soil surface were defined as bare soil, colluvium, and patch. The three soil surface categories are defined in 3.6.1 (i3). For each soil surface category, three measurements were taken; for a total of nine measurements in each plot. To take a soil core sample, a 100 mL steel ring was pressed into the soil until the top of the ring was level with the soil surface. The surrounding soil was then excavated using a sharp trowel, being careful not to disturb the soil core sample within the steel ring. The steel ring enclosing the dirt sample was then unearthed by hand, a thin piece of stocking immediately placed on the lower end to retain the soil (kept in place by an elastic band), and then two flexible plastic lids placed on either end to retain all qualities of the soil sample within the ring. The samples were labelled and then transported carefully to the lab to be analysed. Each sample was dried, ground and sieved then a subsample analysed by the Leco machine. The Leco machine then calculated and output C and N percent content for each sample.

Predictions:

7. The exclosures will exhibit higher levels of C and N compared to the control plots because of slightly higher presence of organic material.
8. C and N levels will be lowest in the bare soil.
9. C and N levels will be highest in the patches.

3.6.1.4 Diversity and abundance of invertebrates responsible for maintaining soil porosity, nutrient recycling (i9)

Terrestrial fauna are responsible for maintaining soil porosity and nutrient recycling. Historically, small marsupials such as bettongs and wombats would have been somewhat responsible for this (refer to section 3.1.4). The current fauna primarily responsible for maintaining soil porosity and nutrient recycling are invertebrates. Bioturbating invertebrates in the woodland were identified into the lowest taxonomic rank possible using efficient diagnosing characters. Taxonomic orders identified as present in the woodland include Blattodea, Coleoptera, Collembola, Diptera, Orthoptera, Hymenopterans, Isopoda, and Lycosids. Two classes also present were Acari and Diplopoda. To measure presence of these terrestrial invertebrates, pit fall traps were used. Nine pit fall traps were placed randomly within each site. Pit fall traps were 40 mL specimen jars, dug into the soil with the rim of the jar level with the soil surface so invertebrates passively fell in. The befallen specimens were preserved in saline solution, dish washing detergent was added to break the surface tension of the solution. The traps were laid for 48 hours and the paired sites were measured simultaneously to account for climatic variance. The specimen jars were then carefully removed and taken to be examined under a dissecting microscope. Invertebrates were defined by taxonomic group. Total abundance of individuals, sorted by taxonomic richness was recorded according to treatment.

Predictions:

10. The exclosures will exhibit greater presence of invertebrates responsible for maintaining soil porosity and nutrient recycling because there is more organic matter available for invertebrate herbivory and shelter where grazing has been excluded.

3.6.1.5 *Surface organic matter, soil crusts (i10)*

Presence of soil surface organic matter is important for functionality of an ecosystem; increased breakdown of organic matter encourages soil profile development and nutrient availability. Organic matter also provides invertebrates with cover; this is beneficial as invertebrates are responsible for bioturbation and porosity. Presence of rocks with lichen can be used as indicators of disturbance; when a rock is left in situ - lichen develops on the upper surface. Constant turning over by large biota inhibits lichen development.

Two 10 metre long transects were established across slope using the previously erected (Pulsford, 1991) star pickets for location guidance (refer to 3.3, Figure 5 for visual representation). The methods following refer to one single transect, but both were assessed for a total of two understorey assessment transects for each site. A measuring tape was overlaid on the transect location. Point intercept method was used. Measurements and observations were taken at 20 cm intervals for a total of 50 measurement points along each transect. Observations were recorded in the field on a data form. Presence of the following surface organic matter types was recorded: cryptogam, moss, litter, and rock with lichen. Surface inorganic matter was defined as bare soil, colluvium and rock. If the point intercepted with vegetation patch, the point was recorded as surface organic matter also.

Predictions:

11. Overall surface organic matter will be greater in the exclosures as there is more vegetation present, dropping biomass.
12. 'Rock' cover will be greater than 'rock with lichen' cover in the control plots as there is increased disturbance turning over rocks and less opportunity for lichen to establish.

3.6.2 Understorey state

3.6.2.1 *Understorey composition and structure (i12, i16, i17, i18, i21)*

Understorey composition and structure was surveyed using point intercept method and the two 10 m transects described in 3.6.5. The transect was walked along, and several variables concerning understorey structure, composition and function were noted on a data form. These variables concern six VAST indicators listed below. Measurements and observations were taken at 20 cm intervals for a total of 50 measurement points along each transect. Observations were recorded in the field on a data form. Four understorey functional groups were identified as *Dichopogon* sp. (Chocolate Lily), *Poa* sp. (Tussock grass), *Xerochrysum* sp. (Everlasting Daisy) and an unidentified forb species.

Reproductive potential of understorey structuring species (i12)

At each point intercept, if an understorey specimen was present, the plant was examined for absence of presence of seed heads (flowers included). Presence or absence of seed heads was noted on a data form. Percent of seed heads by total vegetation proportion was calculated.

Understorey top height (mean) of the plant community (i16)

At each point intercept, if an understorey specimen was present, the functional type and height (in cm) of the tallest part of the plant was measured using a tape measure. Recorded height was noted on a data form. Mean understory top height by functional type was calculated for each site.

Understorey ground cover (mean) of the plant community (i17)

Ground cover density was measured by recording presence or absence of an understorey specimen at each 20cm point intercept. Percent cover was then calculated with the data collected.

Understorey structural diversity of the plant community (i18)

Structural diversity was measured as diversity of age classes by functional group. The range of understorey heights was extrapolated using data collected for indicator 16.

Densities of understorey species functional groups (i21)

At each point intercept, if an understorey species was present, the functional type was observed and recorded. Functional types are classified above. Functional group proportional density was then calculated.

Predictions:

13. The exclosures will exhibit greater reproductive potential
14. Understorery mean top height will be greater in the exclosures.
15. There will be greater percent ground cover in the exclosures.
16. Understorey structural diversity will be greater in the exclosures.
17. The exclosures will exhibit a more diverse range of functional groups

3.6.3 Midstorey state

3.6.3.1 Midstorey composition and structure (i23, i24)

Two indicators concerning midstorey structure and composition were noted on a data form concurrently. These variables concern two VAST indicators listed below. A full census of midstorey specimens was done - to ensure that no specimen was unintentionally overlooked, the 20x20m site was divided into four 5x20m sections using measuring tapes laid on the ground, and the four sections were walked along lengthways. A full census count of all midstorey shrubs was done (including dead specimens) by observing and noting all occurrences and variables on a data form. Midstorey was defined as all vegetation growing between the vertical lacunas of the grass dominated understory and the *C. glaucophylla – E. albens* overstorey.

Midstorey top height (mean) of the plant community (i23)

For every occurrence of a live midstorey plant, height was measured along with functional type (see next indictor description). Mean top heights across treatments were calculated for each functional type.

Densities of midstorey species functional groups (i24)

For each understorey specimen present, the functional type was observed and recorded. Functional groups were defined as *Acacia amoema*, *Epacris sp*., Bipinnate *Acacia sp*. and dead shrubs. Functional group proportional density was then calculated per treatment.

Predictions:

18. Mean midstorey top height will be higher in the exclosures
19. The exclosures will exhibit a more diverse range of functional groups

3.6.4 Overstorey state

3.6.4.1 Reproductive potential of overstorey structuring species (i11)

Reproductive potential of the overstorey structuring species was measured by counting all current regeneration of the overstorey structuring species. Regeneration was defined as a live specimen of an overstorey structuring species (*C. glaucophylla, E. albens* or Casuarina) less than 2 metres high. To ensure that no regeneration was unintentionally overlooked, the 20x20m site was divided into four 5x20m sections using measuring tapes laid on the ground, and the four sections were walked along lengthways. A full census count of all overstorey regeneration was done by observing and tallying all occurrences on a data form.

Predictions:

20. Counts of regenerating plants will be higher in the exclosures as they have not been exposed to trampling, and increased ground cover means less runoff and seedlings have a greater chance of establishing themselves.

3.6.4.2 Overstorey composition and structure (i13, i15, i19)

Several indicators concerning overstorey structure, composition and function were noted on a data form concurrently. These variables concern four VAST indicators listed below. A full census of overstorey species was completed - to ensure that no tree was unintentionally overlooked, the 20x20m site was divided into four 5x20m sections using measuring tapes laid on the ground, and the four sections were walked along lengthways. A full census count of all overstorey trees (including dead specimens) was carried out by observing and noting all occurrences and variables on a data form.

Overstorey top height (mean) of the plant community (i13)

Due to the steep slope the woodland occurs on, and high density of the stand, it was determined that height was too difficult to measure efficiently. Diameter at Breast Height (DBH) was measured as a surrogate instead of height. DBH was measured using a DBH measuring tape at breast height (1.3m) on all specimens. Mean DBH was calculated for each site.

Overstorey structural diversity (i.e. a diversity of age classes) of the plant community (i15)

The structural diversity was measured by calculating range of DBHs using the data collected for indicator 13. This was done for each species present.

Densities of overstorey species functional groups (i19)

For each tree, while measuring DBH, the functional type was also noted. Functional types were defined as live *Callitris*, dead *Callitris*, live *Eucayptus*, and dead *Eucalyptus*.

Predictions:

21. Mean DBH will be greater in the exclosures.
22. Structural diversity will be greater in the exclosures.
23. The exclosures will exhibit a more diverse range of functional groups

3.6.4.3 Overstory foliage projective cover (mean) of the plant community (i14)

Overstorey Projected Foliage Cover was calculated using the two 10 m transects described in 3.6. A point intercept method was used, resembling methods described in 3.6.5 and 3.6.7. Using a denisometer, at every 20 cm interval, presence or absence of foliage cover was noted on a data form. Percent Projected Foliage Cover was then calculated for each transect.

Predictions:

24. Percent Projected Foliage Cover will be higher in the exclosures because there is more moisture and nutrient availability to encourage growth.

3.7 Identifying the mammalian herbivores

Identifying the mammalian herbivore species present compliments this landscape assessment and has potential to assist with future management. By identifying the species responsible there can be recommendations for potential pest control specific to what animals are responsible. Personal observations and camera trapping was used to determine species present.

3.7.1 Camera trapping

Two camera traps were established for each exclosure and control plot. The camera traps were installed for one week. The first trap was attached to a tree just above the middle of the uphill perimeter of each site, facing down into the exclosure or plot. Traps were faced into the exclosures to confirm there was no herbivore entry and to learn which herbivores passed by (that would otherwise have passed through the exclosure area). The second camera was placed on a tree facing onto a clearly used track within 10 metres of the downhill perimeter of each exclosure or control plot. A third trap was laid on a clear thoroughfare downhill of each exclosure/plot pair. Species and abundance was noted.

3.8 Data analysis

Microsoft Excel for Mac version 14.5.6 was used to collate and check the field data and investigate the patterns in the data using histograms. IBM SPSS Statistics version 24 and RStudio version 1.0.143 were used to run analyses and create box plots. Various statistical tests were used to compare means depending on the number of condition levels. A significant result was defined as producing a p value of 0.05 or less. Independent samples T-tests, One-way Analyses of Variance (ANOVAs), two-way ANOVAs and Pearson's Chi squared analyses were used to compare exclosure to control plot mean values. Some interactions between levels of conditions were also examined.

Independent samples T-tests were used to compare the means of two unrelated groups on the same continuous variables. One-way ANOVAs were used to compare the means of three or more groups of one independent variable. Two-way ANOVAs were used to compare the means of two or more groups on two independent variables. Pearson's Chi squared analyses were used to examine differences in frequency between two categorical variables.

Results were presented in box plots (and some frequency histograms) generated in R studio. An example plot is included following, describing the presentation of values.

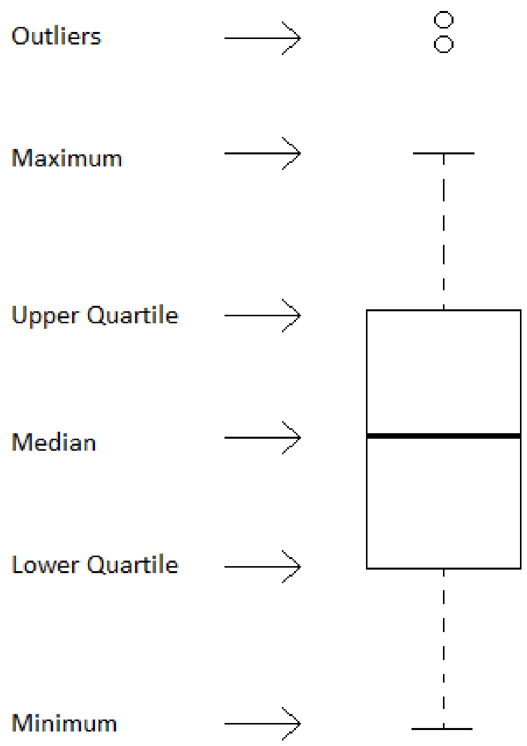


Figure 6. Box plot explanation

3.9 GIS analysis

ESRI ArcGIS was used to model woodland extent and to quantify the proportion of the forest represented by this research. To do so, parameters chosen by Ian Pulsford (1984) to select study sites were elaborated on. Parameters were widened to attain a better understanding of woodland extent. The exclosures were chosen in 1984 to fall within the following parameter restrictions: aspect between 0° and 15°, slope 20°-26° and 350-400 metres above sea level. This modelling extends the aspect parameter 15°east and west to between 345° and 30°, as direct sunlight falls here. The altitude parameter was set to a maximum of 500m metres above sea level as that is the highest extent of the woodland, and below, to the lowest point at river level. The slope (gradient) parameter was widened from 8° to 71. Kinnell (2000) found that below an 8° gradient soil loss was not concurrent with gradient. GIS analysis found that 71° is the steepest slope present in this landscape within the altitude and aspect parameters. A second modelled extent was calculated using the same slope and altitude parameters but expanded the aspect parameter to the winter solstice day length as this aspect range is applicable all year round. This widened second aspect parameter was 299° to 61°. The first analysis was a representation of woodland very closely represented by the exclosures. The second analysis was a more comprehensive indication of north-facing woodland extent. A 25m Digital Elevation Model, " New South Wales DTDB Landform Theme 50 k x 50 k Digital Elevation Model" was obtained from Land and Property Information-NSW and used as the source data for slope, aspect and altitude analysis using the Slope, Aspect and Map Algebra functions in ESRI ArcGIS 10.3. The analysis was only undertaken on the NSW portion of the woodland as there was an incomplete data set for Victoria. Hectare extent of each analysis was calculated from the pixel count within each modelled woodland extent.

Chapter 4: Results

This chapter presents the results of the field research carried out between April and September in 2017.

Fence line contrast of Sites 5 and 6 (exclosure on the right) (Photo Credit: Ian Pulsford 2017)

4.1 Mammalian herbivores present

Firstly, the pest herbivores identified as present in the woodland are identified. These herbivores can be considered responsible for the following impacts as they are excluded from the treatment areas (the exclosures).

Camera trapping indicated presence of several pest herbivore species. Horses (*Equus caballus*), Sambar deer (*Rusa unicolor*), and Fallow deer (*Dama dama*) were the dominant camera trap triggers. Other native herbivores also included Common Brushtail Possums (*Trichosurus vulpecula*), Eastern Grey Kangaroos (*Macropus giganteus*) and Swamp Wallabies (*Wallabia bicolor*).

Table 3. Summary of camera trap herbivore triggers. See following page for trap images of each species in the same order.

Species	Camera trigger count
Dama dama	48
Rusa unicolor	7
Macropus giganteus	6
Wallabia bicolor	3
Equus caballus	2
Trichosurus vulpecula	2

Personal observation indicated a large population of pest horses (*Equus caballus*) were present in the woodland. Frequent evidence of pest horses included sightings of animals on access roads into the research sites, dung piles, hoof prints and numerous wide tracks across slopes. See page 47 for images.

The following sections document the response indicators associated with the environmental impacts of these herbivores. The control plots represent the woodland as is, where the herbivores occur. The exclosures represent the condition of the woodland if these herbivores had not been present since erection of the exclosures in 1984. The ecological differences between treatments describe the impacts of these herbivores.

Selected camera trap images in order from top left: Fallow Deer, Sambar Deer, Eastern Grey Kangaroo, Swamp Wallaby, Horse, and Common Brushtail Possum.

Personal observations of horses in the woodland: frequent sightings, dung piles and tracks.

4.2 Modelled woodland extent

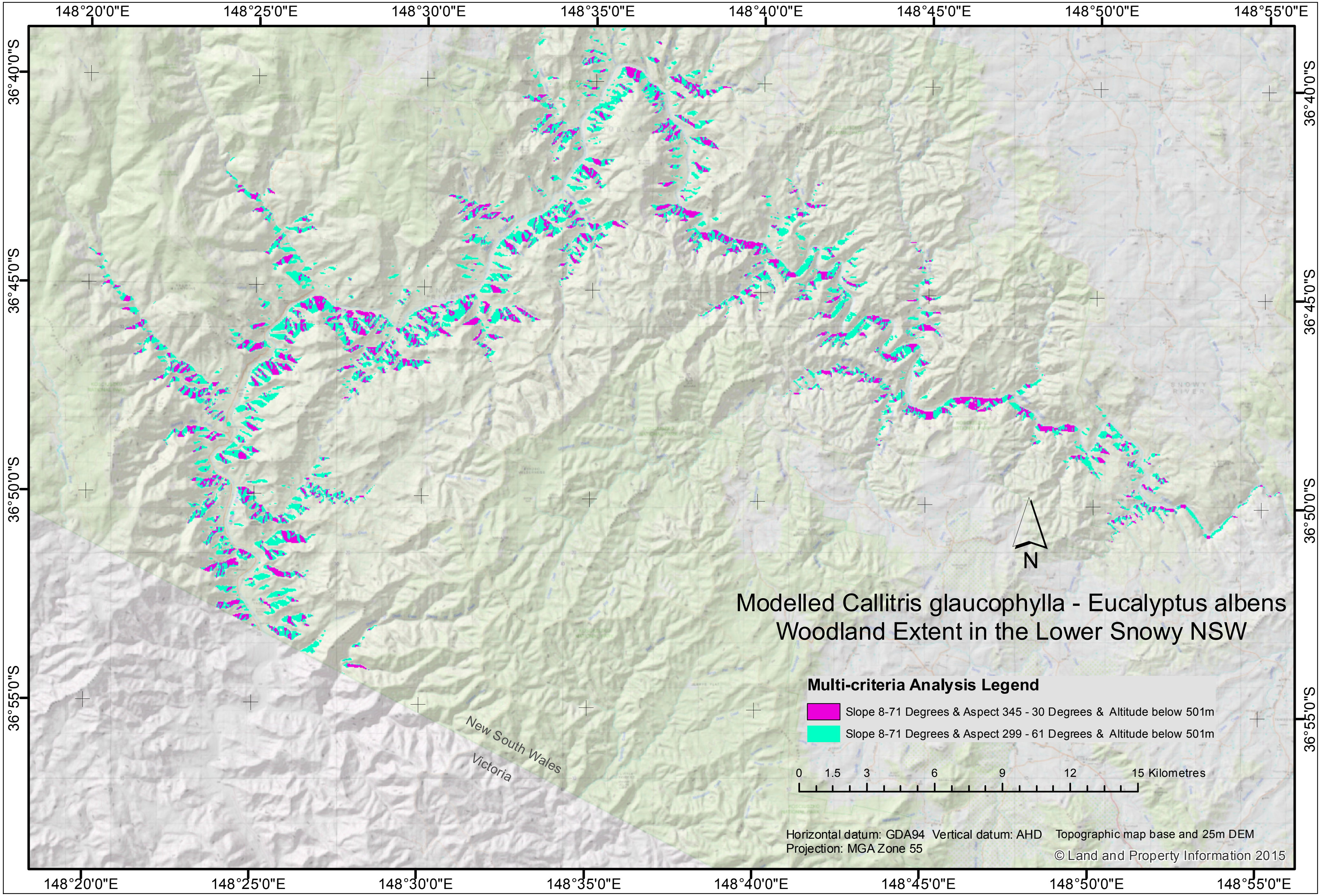
See following page for map of modelled woodland extent (Figure 7) and Table 4 for summary of area each analysis represents.

Table 4. GIS parameters and extent calculations

	Elevation (m)	Aspect (degrees)	Slope (degrees)	Hectares (^{2})
Analysis 1 (Pink)	Below 500	345 - 30	8 - 71	84.46
Analysis 2 (Green)	Below 500	299 - 61	8 - 71	249.11
Total woodland area	Below 500	0 - 360	0 - 71	829.12

Following page:

Figure 7. Modelled extent of north facing *Callitris glaucophylla – Eucalyptus albens* woodland



148°20'0"E
148°25'0"E
148°30'0"E
148°35'0"E
148°40'0"E
148°45'0"E
148°50'0"E
148°55'0"E
36°40'0"S
36°45'0"S
36°50'0"S
36°55'0"S
N
Modelled Callitris glaucophylla - Eucalyptus albens Woodland Extent in the Lower Snowy NSW
Multi-criteria Analysis Legend
Slope 8-71 Degrees & Aspect 345 - 30 Degrees & Altitude below 501m
Slope 8-71 Degrees & Aspect 299 - 61 Degrees & Altitude below 501m
0 1.5 3 6 9 12 15 Kilometres
New South Wales
Victoria
Horizontal datum: GDA94 Vertical datum: AHD
Projection: MGA Zone 55
Topographic map base and 25m DEM
© Land and Property Information 2015

4.3 Soil functionality

This section presents the measurements of soils state variables, comparing the means of the control plots and the exclosures. Table 5 summarises these comparisons and highlights the indicators that were found to be influenced by treatment. The following sections break down each of these findings into more detail and suggests ecological reasons for differences.

Table 5. Soil state means, standard deviations and significance values for each treatment by indicator (i9 results are total count, not mean, SD is irrelevant)

Indicator Number	Measure	Control Mean	SD	Exclosure Mean	SD	P value
i3	Soil surface moisture (%)	10.19	5.19	9.18	4.58	0.07
i6	Soil structure (slake score)	0.91	0.83	1.07	0.92	**0.05**
i7	Soil Carbon (%)	2.68	1.00	2.80	0.88	0.53
i7	Soil Nitrogen (%)	0.15	0.03	0.17	0.05	0.18
i9	Total invertebrate abundance (n = 80 traps)	510		742		**0.01**
i10	Ground biological cover (%)	27.20	6.61	62.60	17.04	**<0.01**

4.3.1 Soil surface water availability (i3)

A one-way ANOVA determined that soil surface water availability was not influenced by treatment. There was no significant difference in soil surface moisture percent when comparing the exclosures and control plots (p=0.08), see Figure 8. This may be due to the large range in soil surface moisture percent across the sites. Unaccounted for spatial and meteorological variation may be influencing this result as the sites are up to 6km apart and measurements were taken on separate days.

Soil surface moisture percent was significantly different across soil surface cover categories (p=0.04), see Figure 9. The mean soil moisture percent for bare soil was 8.67 (SD = 4.78), significantly lower than patch (10.19, SD=4.60), and colluvium (10.21, SD=5.23

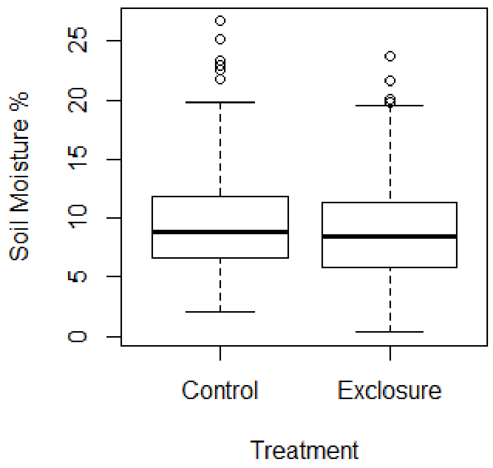


Figure 8. Mean soil surface moisture percent by treatment

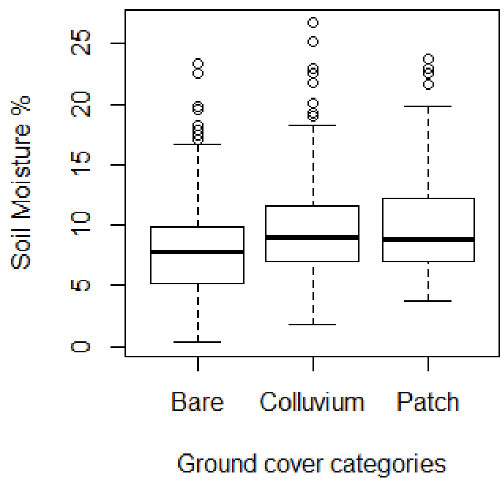


Figure 9. Mean soil surface moisture percent by soil surface cover category

4.3.2 Soil structure (i6)

A two-way ANOVA determined that soils structure and stability was significantly higher in the exclosures when comparing to the control plots (p=0.05) (see Figure 10). The controls plots on average scored within class 0 of Tongways slake scoring system (0.91), this is defined as not applicable and having no coherent fragments available. The exclosures on average scored within class 1 of Tongways slake scoring system (1.07), classified as very unstable and the fragments collapsing within 5 seconds. Mean slake scores were also significantly different between cover categories (p= <0.05) (See Figure 11). Patch (1.72, SD=0.84), was significantly more stable than bare (0.47, SD =0.54), colluvium (0.79, SD=0.70).

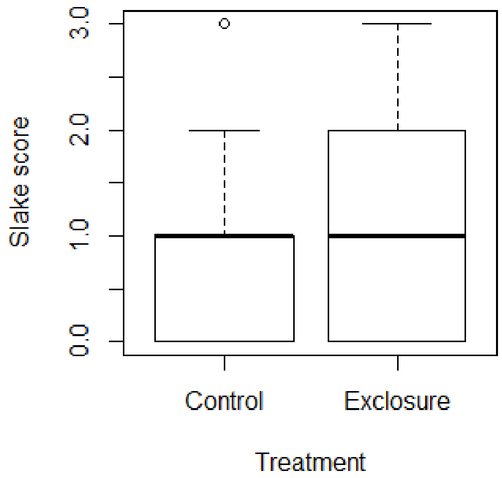


Figure 10. Mean slake score by treatment

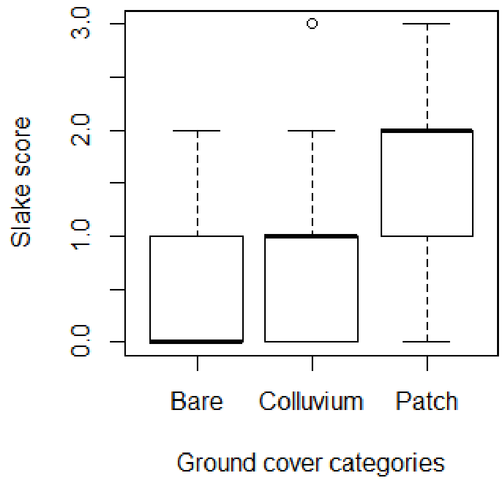


Figure 11. Mean slake score by cover category

4.3.3 Nutrient stress – rundown (deficiency) relative to soil fertility (i7)

A one-way ANOVA determined that there was no significant difference in soil Carbon or Nitrogen content when comparing the control plots to exclosures, p=0.53 and p=0.21 respectively (see Figures 12 and 13) (see Table 5 for means). There was no significant difference in percent Carbon and Nitrogen content when comparing the cover categories (bare, patch and colluvium, p= 0.18 (Nitrogen) and p= 0.14 (Carbon). Although there was a greater range of nutrient percent content in the patches (see Figures 14 and 15).

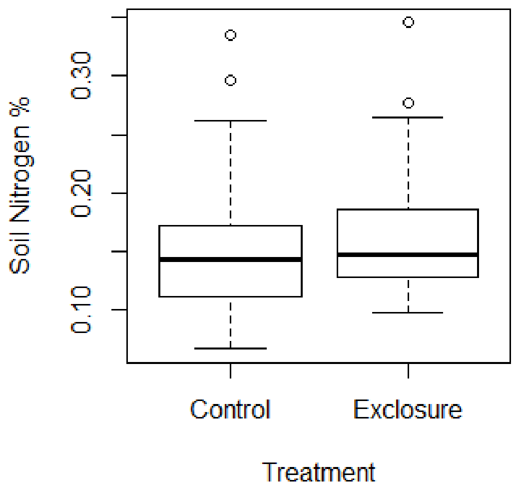


Figure 12 Mean soil Nitrogen percent by treatment

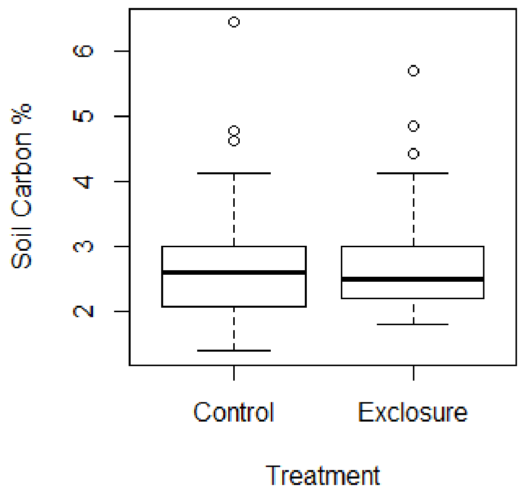


Figure 13. Mean soil Carbon percent by treatment

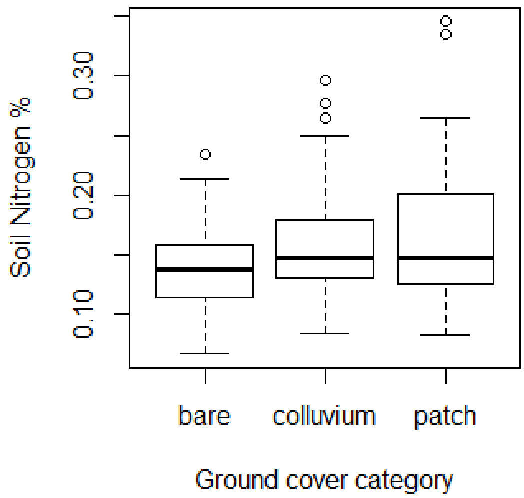


Figure 14. Mean soil Nitrogen percent by cover category

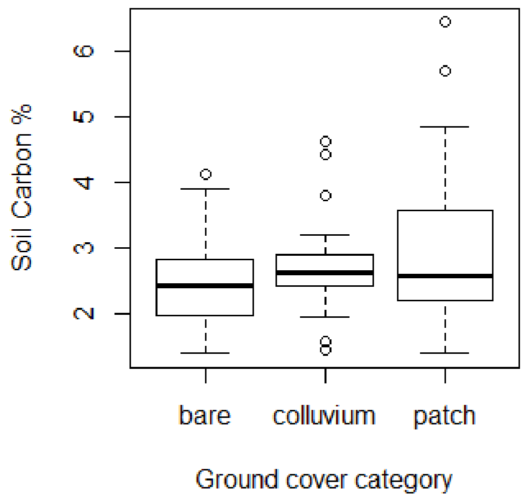


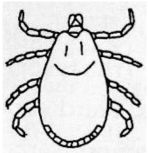
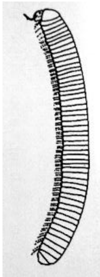
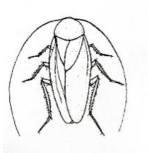
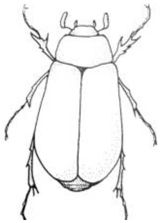
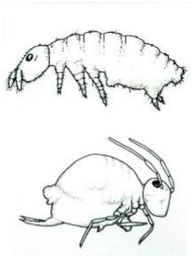
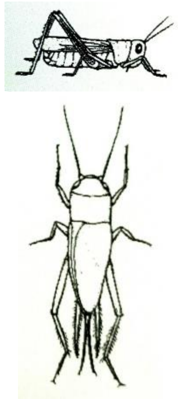
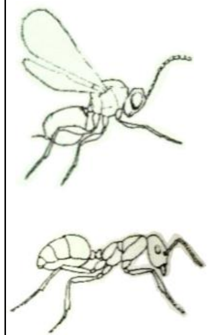
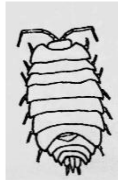
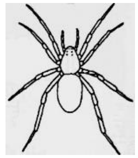
Figure 15. Mean soil Carbon percent by cover category

4.3.4 Diversity and abundance of invertebrates responsible for maintaining soil porosity, nutrient recycling (i9)

A Pearson's Chi-squared analysis determined that treatment had a significant effect on abundance of invertebrates when examined by taxonomic order (X^2 =21.31, p=<0.01). Although diversity of taxonomic orders was largely the same inside and outside the exclosures, with the exception of lack of presence of Blattodea and Isopoda in the control plots (See Table 6 on the following page for summary). Invertebrate abundance was dominanted by Collembolans, pioneer soil dwelling omnivorous microorganisms.

Following page:

Table 6. Total count of diversity and abundance of invertebrates by treatment (n = 40 exclosure traps, 40 control plot traps). Illustrations adopted from (Zborowski and Storey, 2010).

	Order (total abundance)										Total
	Acari (Class) 	Diplopoda (Class) 	Blattodea (Order) 	Coleoptera (Order) 	Collembola (Order) 	Diptera (Order) 	Orthoptera (Order) 	Hymenoptera (Order) 	Isopoda (Order) 	Araneae (Order) 	
Controls	12	2	0	1	382	37	1	71	0	4	510
Exclosures	2	3	2	1	523	56	2	143	3	7	742
Total	14	5	2	2	905	93	3	214	3	11	1252

4.3.5 Surface organic matter, soil crusts (i10)

And independent T-test determined that there was a significant difference in biological ground cover between the control plots and exclosures (p=<0.01) (Figure 16), see Table 5 for means. An independent T-test determined that leaf litter cover was not dependent on treatment, p=0.11 (Figure 17). See Figure 18 for observable differences in surface organic matter when comparing a control plot to an exclosure.

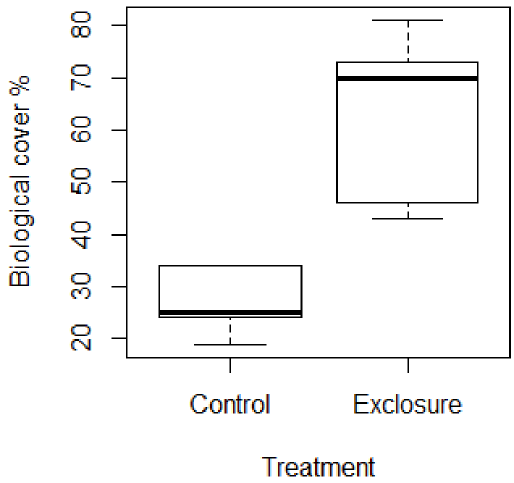


Figure 16. Biological cover (%) by treatment

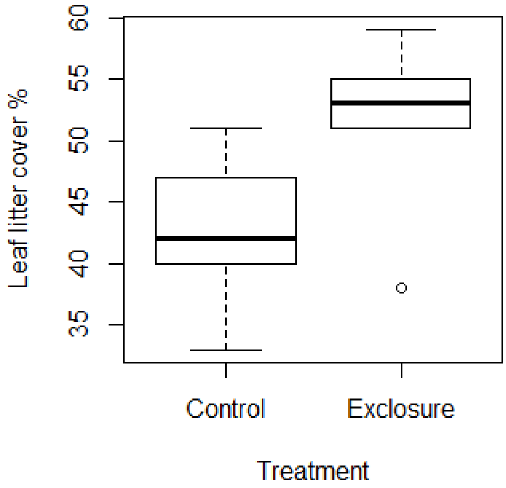


Figure 17. Leaf litter cover (%) by treatment

Figure 18. Fence line contrast of surface organic matter. Left side is inside exclosure 6, right side is subject to mammalian herbivory (Ian Pulsford 2017).

4.4 Understorey state

This section will present the measurements of understorey state variables, comparing the means of the control plots and the exclosures. Table 7 summarises these comparisons. The following sections break down each of these findings into more detail. Overall, analyses indicated significant impacts on structure and composition of the understorey by pest herbivores present in the control plots.

Table 7. Understorey state means, standard deviations and significance values for each treatment by indicator

Indicator Number	Measure	Control Mean	SD	Exclosure Mean	SD	P value
i17	Understorey cover (%)	14.40	4.78	24.49	4.83	**<0.01**
i16	Understorey height (cm)	16.52	6.05	24.49	3.43	**0.04**
i21	Understorey functional group density (average abundance per site)					**<0.01**
	Daisy	2.20	2.28	2.40	2.07	
	Forb	0.20	0.44	5.20	6.91	
	Lily	0.20	0.45	0.40	0.89	
	Poa	12.00	6.12	21.60	5.89	
i18	Understorey structural diversity (average height)					**<0.01**
	Daisy	27.75	13.94	27.81	17.16	
	Forb	10	n/a	20.88	7.05	
	Lily	1	n/a	10	2.82	
	Poa	10.81	11.32	39.20	21.48	
i12	Understorey seed head (abundance)	11		90		**<0.01**

4.4.1 Understorey ground cover (mean) of the plant community (i17)

A one-way ANOVA determined that overall, understorey ground cover density was significantly higher in the exclosures compared to the control plots, p= <0.01 (Figure 19), see Table 7 for means.

4.4.2 Understorey top height (mean) of the plant community (i16)

A Two way ANOVA determined that across all understorey plants, the effect of treatment on height was significant, p=<0.01 (see Figure 20), see Table 7 for means. It was also found that mean height of each functional group when comparing treatments was significant (see Figure 21), p=<0.01. Daisy mean height was unaffected by treatment, suggesting herbivores prefer not to eat them. In contrast, Forbs, Lilys and Poa grasses were significantly shorter in the control plots, suggesting they are being eaten by mammalian herbivores.

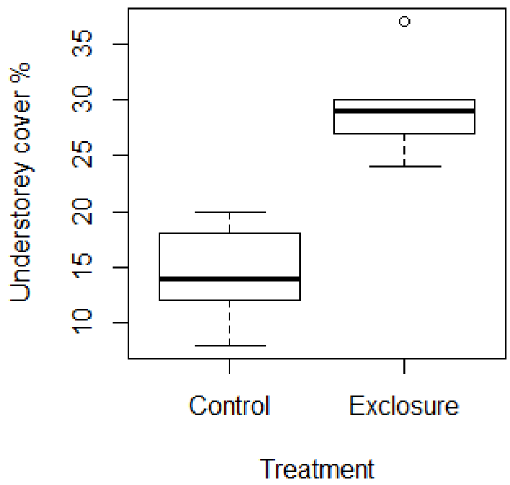


Figure 19. Understorey ground cover by treatment

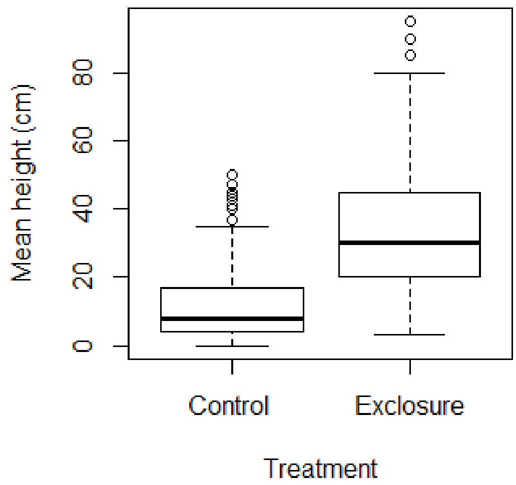


Figure 20. Mean height of understorey plants by treatment

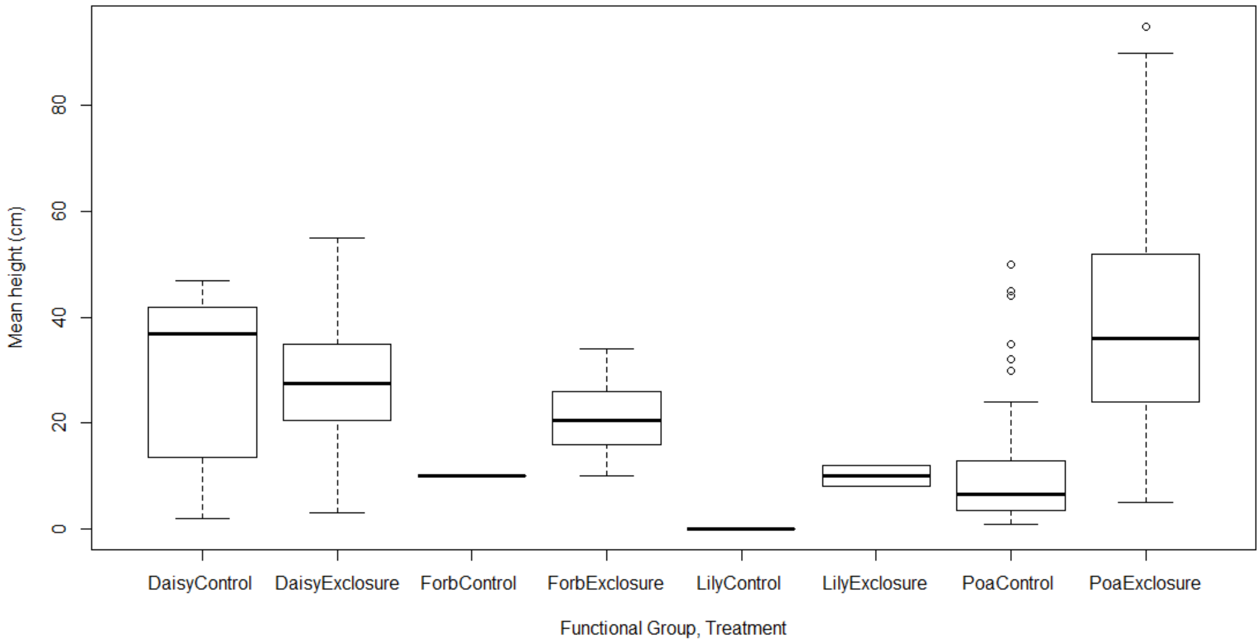


Figure 21. Mean plant height of understorey functional groups by treatment

4.4.3 Densities of understorey species functional groups (i21)

A two-way ANOVA was used to determine that treatment had a significant effect on densities of understorey plant functional groups, p=<0.01, see Figure 22. The trends here reflect findings of Figure 21 (i16).

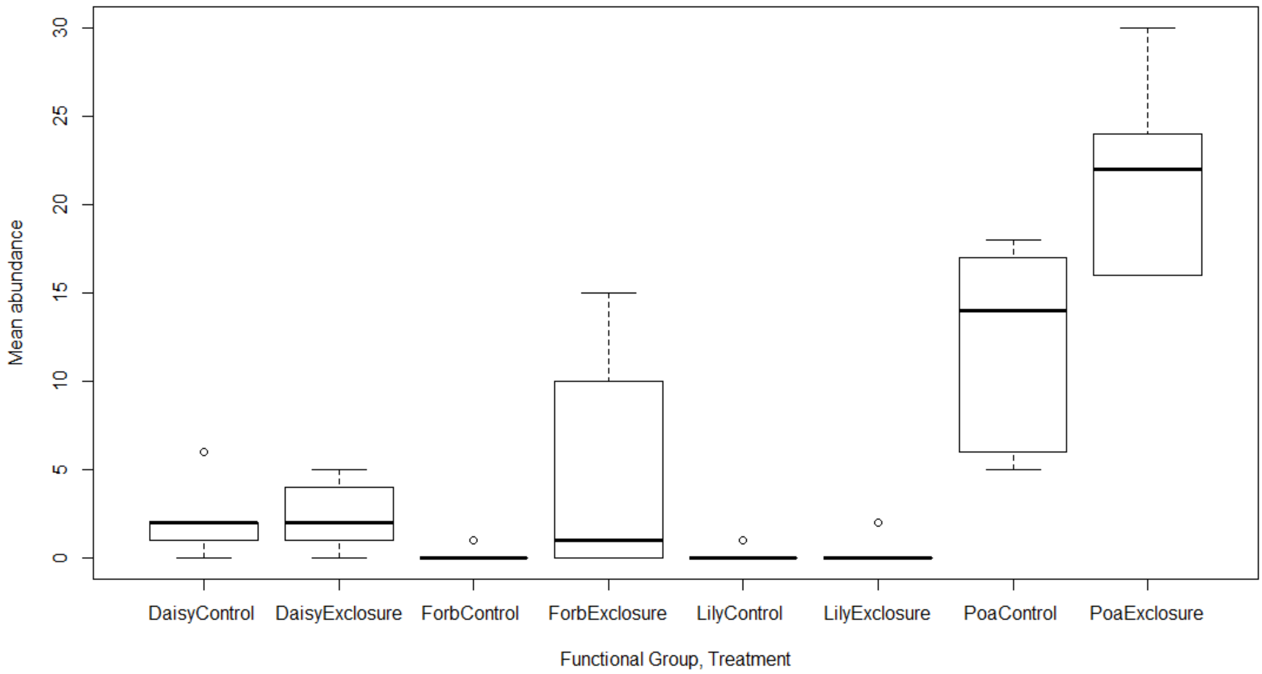


Figure 22. Mean abundance (count/site) of understorey functional groups by treatment

4.4.4 Understorey structural diversity of the plant community (i18)

Understorey structural diversity was significantly different between treatments, p = <0.01. Abundance of plants was separated into 10 cm bins and treatments compared, see Figure 23. Exclosure structural abundance distribution was more normal that the control plots which were skewed toward the lower height bins.

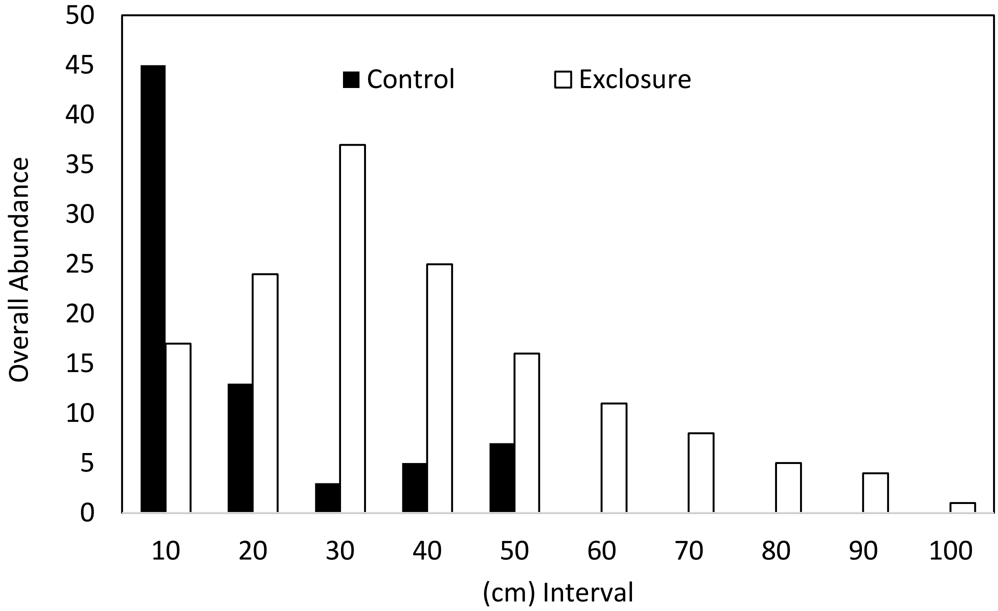


Figure 23. Understorey structural diversity (overall count/10cm interval bin) by treatment

4.4.5 Reproductive potential of understorey structuring species (i12)

A Pearson's Chi-squared analysis determined that there was a significant difference in seed head presence when comparing the control plots to exclosures (χ^2 = 39.31, p=<0.01). See Figure 24 for diagrammatic representation. Abundance of plants without seed heads was similar inside and outside the exclosures. In contrast, significantly more plants with seed heads were present in the exclosures than the control plots.

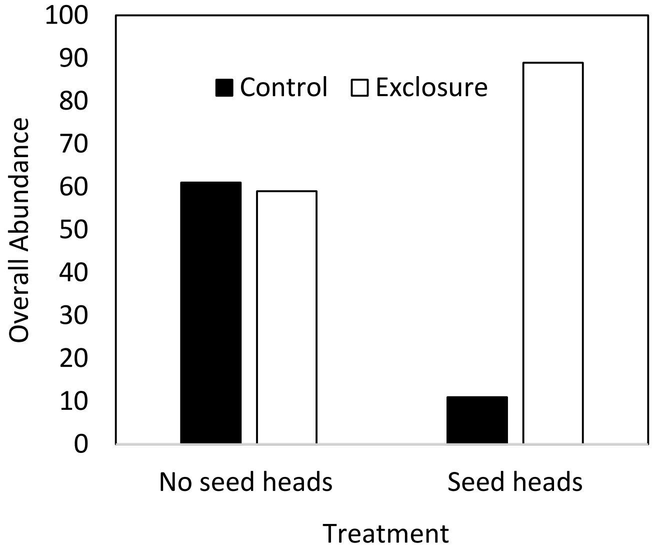


Figure 24. Abundance (overall count/treatment) of understorey plants with and without seed heads by treatment

4.5 Midstorey state

This section will present the measurements of understorey state variables, comparing the means of the control plots and the exclosures. Table 8 summarises these comparisons, noting that these means are across functional groups. Both midstorey indicators were found to be influenced by treatment. The following sections break down each of these findings into more detail.

Table 8. Midstorey state means, standard deviations and significance values for each treatment by indicator

Indicator Number	Measure	Control Mean	SD	Exclosure Mean	SD	P value
i23	Midstorey height (cm)	67.03	38.73	87.64	42.34	**<0.01**
i24	Midstorey functional group density (mean count/treatment)	8.45	8.36	20.25	19.14	**0.01**

4.5.1 Midstorey top height (mean) of the plant community (i23)

A two-way ANOVA determined that treatment had a significant effect on midstorey top height across functional groups, p=<0.01, see Table 8 for overall means. See Figure 25 for diagrammatic representation. *Acacia amoema* and *Epacris sp*. exhibited higher top height on average but the bipinnate *Acacia sp*. did not reflect this trend, this may be because of the comparably small sample size (See Figure 25 caption for N).

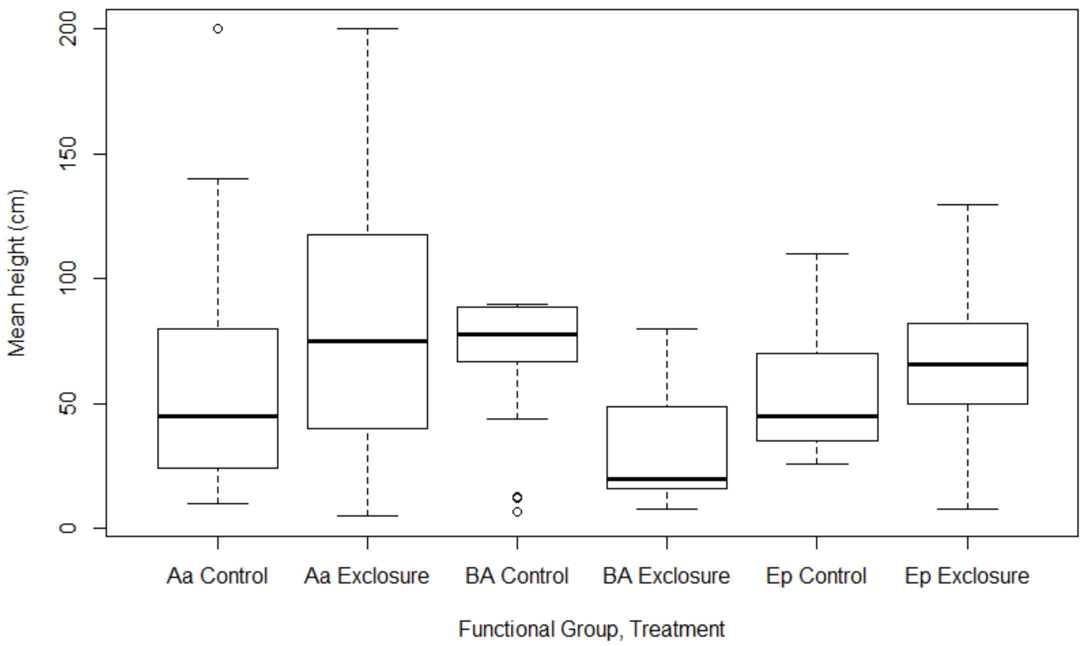


Figure 25. Mean top height of each midstorey functional group by treatment (Aa = *Acacia amoema*, N= 319, BA = bipinnate *Acacia* sp., N=28, Ep = *Epacris* sp., N=47).

4.5.2 Densities of midstorey species functional groups (i24)

A two-way ANOVA determined that treatment had a significant effect on densities of midstorey functional groups, $p = 0.01$ (see Figure 26). See following page for Figures 27 and 28 showing mistorey contrast of paired sites.

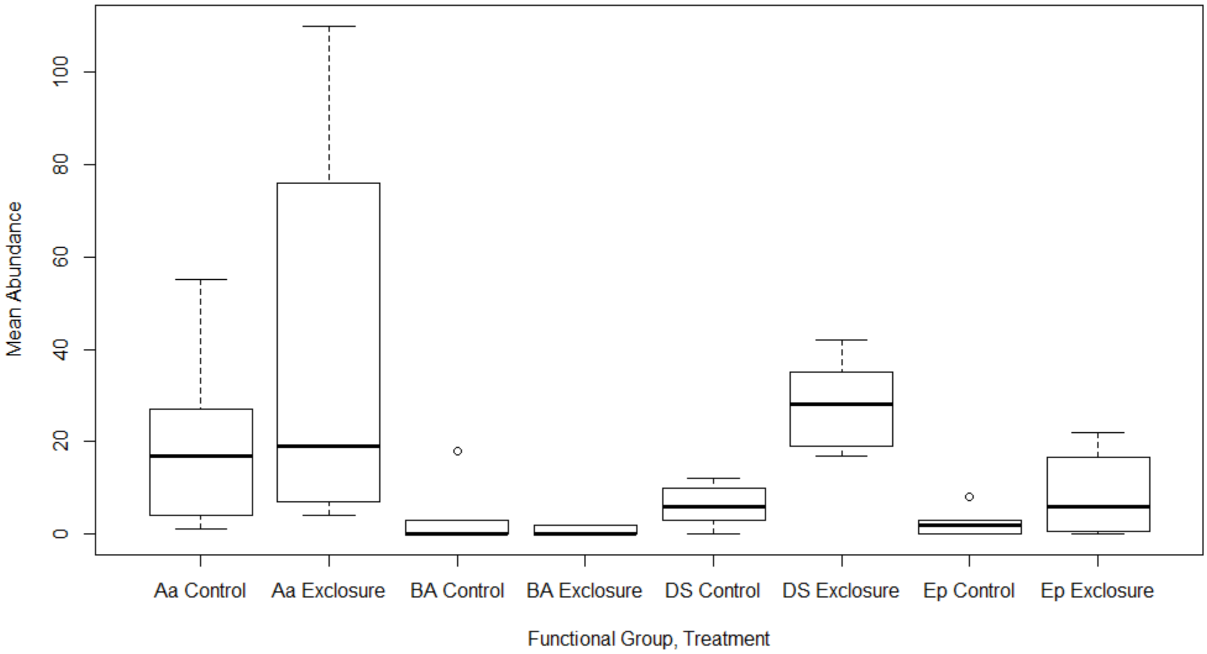


Figure 26. Mean abundance (count/site) of midstorey functional groups by treatment (Aa = *Acacia amoema*, BA = bipinnate *Acacia* sp., DS = dead shrub, Ep = *Epacris* sp.).

Figure 27. Site 1 (Control plot)

Figure 28. Site 2 (Exclosure)

4.6 Overstorey state

This section presents the measurements of overstory state variables, comparing the means of the control plots and the exclosures. Table 9 summarises these comparisons. The following sections break down each of these findings into more detail. Overall, analyses indicated no significant impacts on structure and composition of the overstorey when comparing the exclosures to the control plots.

Table 9. Overstorey state means, standard deviations and significance values for each treatment by indicator

Indicator Number	Measure	Control Mean	SD	Exclosure Mean	SD	P value
i19	Overstorey functional group density (overall abundance per site)	69.10	29.86	66.20	42.68	0.12
i13	Overstorey Diameter at Breast Height (cm)	9.79	4.64	9.35	4.88	0.08
i14	Overstorey Projected Foliage Cover (%)	24.20	3.11	40.2	20.41	0.12
i15	Overstorey structural diversity					0.93
	Live *C. glaucophylla (mode cm bin)*	12	n/a	9	n/a	
	Dead *C. glaucophylla (mode cm bin)*	6	n/a	6	n/a	
i11	*E. albens* regeneration abundance (mean count/treatment)	1.60	2.61	2.40	2.51	0.63

4.6.1 Densities of overstorey species (i19)

A two way ANOVA determined that treatment had no significant effect on abundance of live and dead *Eucalyptus albens* trees, p = 0.12 (see Figure 29) Treatment also had no strong significant effect on abundance of live or dead *Callitris glaucophylla* trees, p = 0.08 (see Figure 30).

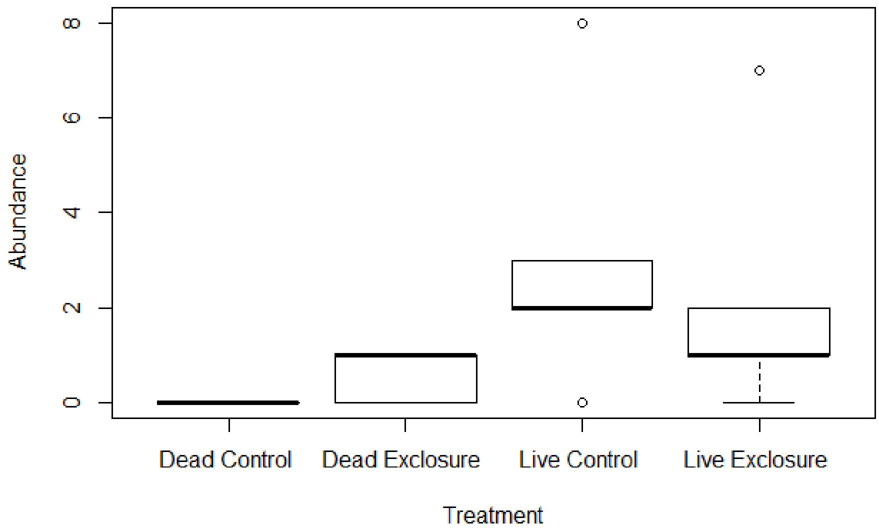


Figure 29. *Eucalyptus albens* abundance (mean count/site) by treatment

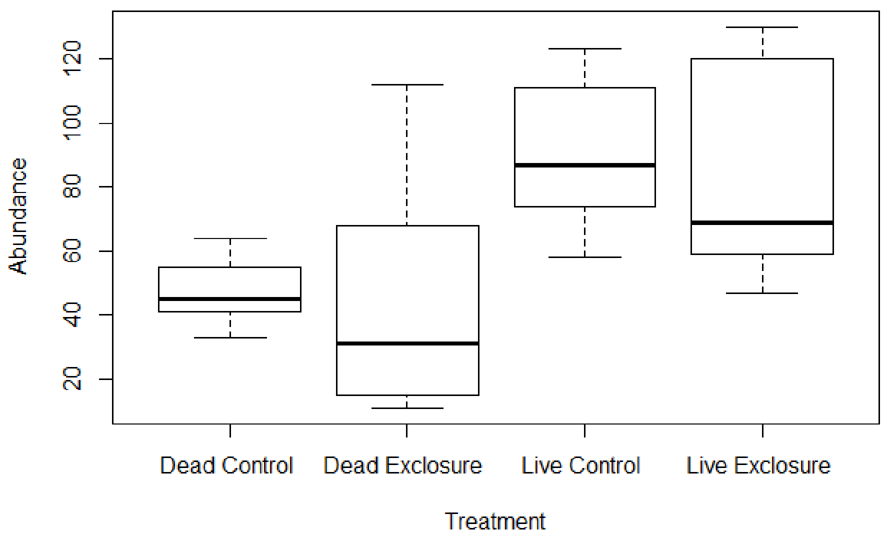


Figure 30. *Callitris glaucophylla* abundance (mean count/site) by treatment

4.6.2 Overstorey top height (mean) of the plant community (i13)

Note that Diameter at Breast Height (DBH) was used as a surrogate for top height. A two-way ANOVA determined that there was no strong significant difference between DBHs of live *Callitris glaucophylla* trees when comparing the controls and exclosures, p= 0.08, N=878. See Figures 31 and 32 for comparison of live and dead *Callitris glaucophylla* specimen DBHs by treatment. An insufficient amount of *Eucalyptus albens* specimens were measured to conduct a meaningful statistical analysis (26 live and 3 dead in total).

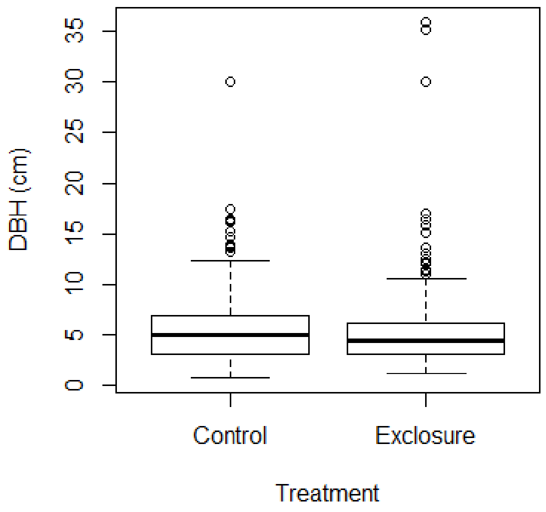


Figure 31. Dead *Callitris glaucophylla* DBH by treatment

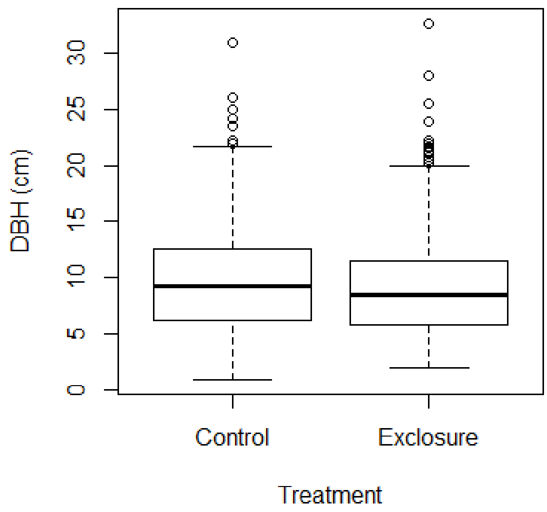


Figure 32. Live *Callitris glaucophylla* DBH by treatment

4.6.3 Overstory foliage projective cover (mean) of the plant community (i14)

A one-way ANOVA determined that there was no significant difference between mean Projected Foliage Cover percent when comparing control plots to exclosures, p=0.12 (See Figure 33). The mean Projected Foliage Cover was noticeable different between treatments but the variation of Projected Foliage Cover measurements was not consistent.

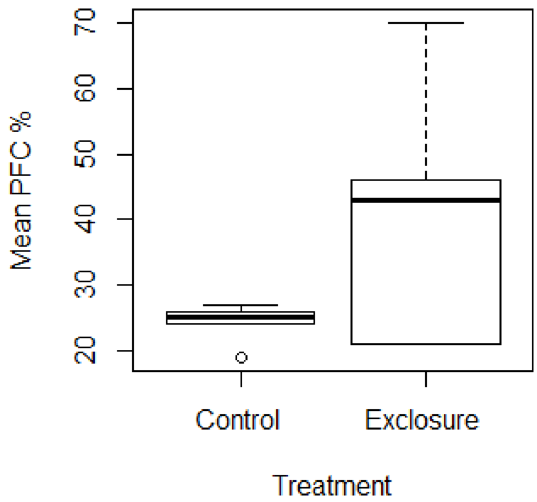


Figure 33. Overstorey mean Projected Foliage Cover (%) by treatment

4.6.4 Overstorey structural diversity (i.e. a diversity of age classes) of the plant community (i15)

A two-way ANOVA determined that treatment had no effect on structural diversity of dead *Callitris glaucophylla*, p = 0.98 (see Figure 34). Treatment also had no effect on structural diversity of live *Callitris glaucophylla*, p = 0.88 (see Figure 35). Bin intervals were chosen to clearly represent the range of each data set.

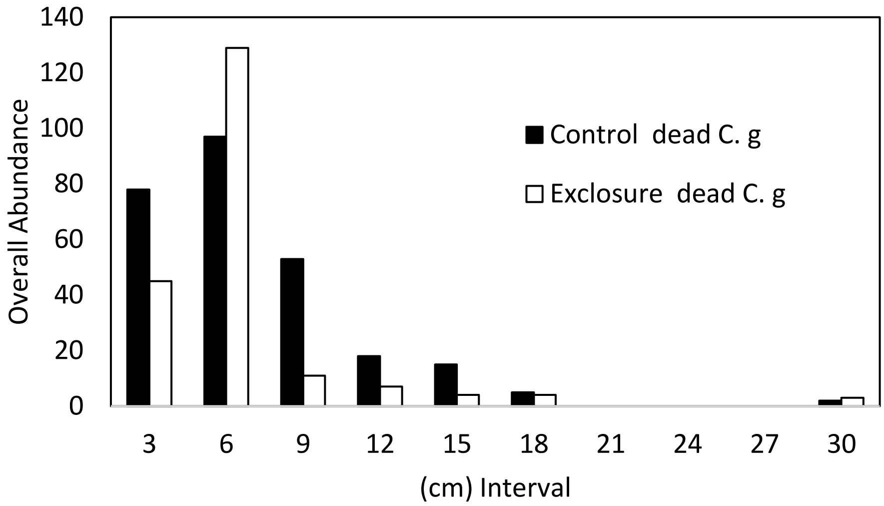


Figure 34. Dead *Callitris glaucophylla* structural diversity by treatment (overall count/ 3cm interval bins)

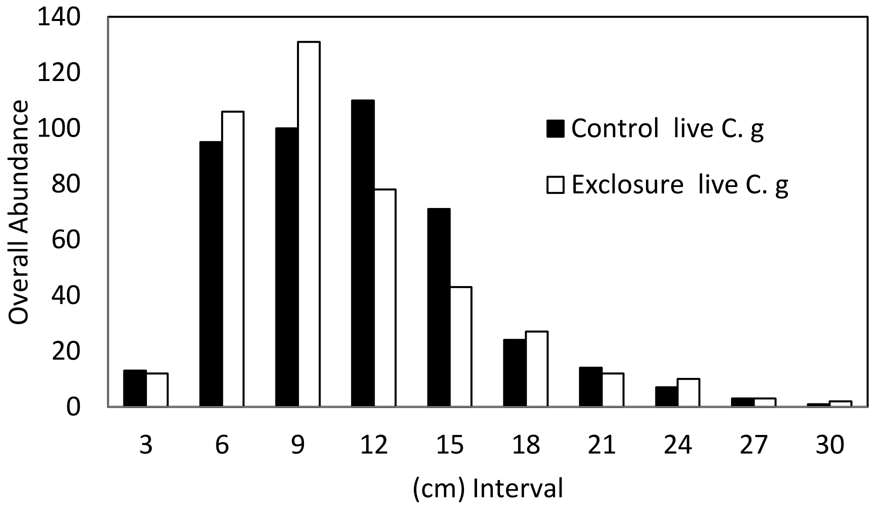


Figure 35. Live *Callitris glaucophylla* structural diversity by treatment (overall count/3cm interval bins)

4.6.5 Reproductive potential of overstorey structuring species (i11)

A one-way ANOVA determined that there was no significant difference in mean *Eucalyptus albens* regeneration abundance per treatment ($p=0.63$), see Table 9 for means. An insufficient amount of *Callitris glaucophylla* seedlings were counted to statistically compare treatments (5 total across all control plots and exclosures).

Chapter 5: Discussion

This chapter describes and interprets the results of this research. By examining results, both hypotheses stated in Chapter 1 can be accepted:

i. Vegetation structure and is more diverse, and landscape functionality is higher inside the exclosures, when compared to the control plots.
ii. Mammalian herbivores are inhibiting the slow recovery of the *Callitris glaucophylla - Eucalyptus albens* woodland in Kosciuszko National Park.

Note that it was undetermined if vegetation composition is significantly different when comparing treatments It was not possible to complete a full floristics survey as fieldwork was carried out during winter months. The following sections address these in more detail as well as approach broader issues this study contributes to.

5.1 Mammalian herbivores present

Camera trapping and personal observations confirmed that mammalian herbivores are present and responsible for inhibiting recovery of the *Callitris glaucophylla - Eucalyptus albens* woodland in Kosciuszko National Park, as hypothesised in Section 1.3. Results of camera trapping and conclusions of personal observations were indicative but not quantitative as sample sizes were small. Horses (*Equus caballus*), Sambar deer (*Rusa unicolor*), Fallow Deer (*Dama dama*), Common Brushtail Possums (*Trichosurus vulpecula*), Eastern Grey Kangaroos (*Macropus giganteus*) and Swamp Wallabies (*Wallabia bicolor*) were identified as the mammalian herbivores present on these slopes. Personal observations indicated an overwhelming abundance of pest horses. Whereas camera trapping suggested deer species were more prevalent. Population densities and proportional affects of each species cannot be determined without further camera trapping, dung surveys and other observations.

Depending on the herbivore species, impacts are likely variable. Deer are grazers and browsers and likely impact vegetation from ground level to ~2m. Horses eat mainly understorey grass and forbs (Mayes and Duncan, 1986). Further research to determine mammalian herbivore population densities is important if targeted pest herbivore population control is to be undertaken.

In contrast to observations by Pulsford (1991), there was little evidence of Rabbits in this woodland. Decreased rabbit population is likely due to the effectiveness of Myxoma and Calici viruses.

5.2 Impact of 33 years of exclosures

This section will summarise impacts of mammalian herbivores in the woodland. Predictions made in Chapter 3 will be addressed and ecological interactions discussed.

5.2.1 Soil functionality

Predictions from Chapter 3 in relation to soil functionality are restated here for convenience, either confirmed or rejected, and discussed in relation to the results. As expected, soil functionality was found to be higher within the exclosures, primarily due to lack of soil surface disturbance by mammalian herbivores.

Table 10. Restatement of predictions for indicators concerning soil functionality

#	Prediction	
1	The exclosures will exhibit greater soil surface water availability because there is greater ground cover. Ground cover tends to improve water infiltration.	**Confirmed**
2	Soil surface moisture availability will be lowest in the bare soil.	**Confirmed**
3	Soil surface moisture availability will be greatest in the patches.	**Rejected**
4	The exclosures will exhibit greater soil structure compared to the control plots because of slightly higher presence of organic material, causing higher aggregate stability.	**Confirmed**
5	Soil structure will be least stable in the colluvium.	**Rejected**
6	Soil structure will be most stable in the patch.	**Confirmed**
7	The exclosures will exhibit higher levels of Carbon and Nitrogen compared to the control plots because of slightly higher presence of organic material.	**Rejected**
8	Carbon and Nitrogen levels will be lowest in the bare soil.	**Rejected**
9	Carbon and Nitrogen levels will be highest in the patches.	**Rejected**
10	The exclosures will exhibit greater presence of invertebrates responsible for maintaining soil porosity and nutrient recycling because there is more organic matter available for invertebrate herbivory and shelter where grazing has been excluded.	**Confirmed**
11	Overall surface organic matter will be greater in the exclosures as there is more vegetation present.	**Confirmed**
12	'Rock' cover will be greater than 'rock with lichen' cover in the control plots as there is increased mechanical disturbance turning over rocks and less opportunity for lichen to establish.	**Confirmed**

The exclosures on average did not exhibit greater soil surface water availability. But bare soil was found to be significantly less moist than colluvium and patch. Soil surface moisture in the colluvium and patches was similar. Although, results from Indicator 17 (Figure 19) show that there is more patch cover in the exclosures. Consequently it can be inferred that there is more ground cover that is moist in the exclosures and soil surface moisture availability is higher in the exclosures. This is consistent with the findings of Eldridge and Freudenberger (2005) who state that ground cover tends to improve water infiltration. Greater available soil moisture in the exclosures provides greater potential for shallow rooted understorey plants to grow, and a more hospitable environment for bioturbating organisms to habituate.

Exclusion of heavy hooved herbivores mechanically disturbing the soil surface has resulted in slightly more stable soil in the exclosures, although still very unstable. The more stable soil is a result of greater organic cover (see Figure 19) being allowed to regenerate and provide structure in the soil profile. Increased biological cover of understorey, moss and cryptogams are important for protecting and binding the soils surface, reducing erosion and runoff. Tongway (2004) describes biological crusts as early colonisers that recover soil surfaces. They 'indicate soil surface stability and elevated levels of available nutrients in the surface layers of soil and are known to exchange minerals and water with vascular plants in return for carbohydrates.

Soil Carbon and Nitrogen soil content was found to be unaffected by treatment or cover type. Soil nutrient content is dependent on organic matter recycling and soil deposition. *C. glaucophylla* trees do not shed their bark, branches or leaves purposely, after 3-5 years each leaf becomes incorporated into the bark (Clayton-Greene, 1981). Most excess understorey matter is consumed by herbivores that occupy the forest. Any remaining litter does not have the opportunity to accumulate and decompose as there so little understorey and biological cover to obstruct runoff. 33 years has not been long enough for Carbon and Nitrogen accumulation or soil deposition to occur, even within the exclosures.

Invertebrate diversity was independent of treatment, invertebrates are mobile and opportunist so will disperse according to resource availability. Abundance was influenced by treatment, overall there were more invertebrates present in the exclosures. Small soft bodied invertebrates prefer moist and sheltered habitats to avoid desiccation and predation. More available patch area and subsequent increased available moisture is likely preferable habitat. The overall count was proportionally dominated by herbivores indicating a small population, unable to support a diverse predator prey system (Lycosid Arachnids are the only predators present). Abundance and diversity of invertebrates is a good indicator of ecosystem diversity. Dorrough et al. (2006) found that ground dwelling fauna are highly responsive to the state of the herbaceous ground layer.

Surface organic material was significantly higher in the exclosures. Small delicate biological cover such as moss, lichen and cryptogams are slow growing and easily trampled. Presence of large, hooved animals moving through account for decreased presence of biological cover.

These results were consistent with findings of Bishwokarma (2014), who found that water infiltration, nutrient cycling and soil surface stability indices were significantly less outside the exclosures.

5.2.2 Understorey state

Predictions from Chapter 3 in relation to understorey state are restated here for convenience, either confirmed or rejected and discussed in relation to the results following. Overall understorey state was found to be significantly improved within the exclosures. Due to mammalian grazing, the cover and functional diversity outside the exclosures was much reduced.

Table 11. Restatement of predictions for indicators concerning understorey state

#	Prediction	
13	The exclosures will exhibit greater reproductive potential	**Confirmed**
14	Understorery mean top height will be greater in the exclosures.	**Confirmed**
15	There will be greater percent ground cover in the exclosures.	**Confirmed**
16	Understorey structural diversity will be greater in the exclosures.	**Confirmed**
17	The exclosures will exhibit a more diverse range of functional groups	**Confirmed**

The exclosures on average exhibited 24.49% ground cover, almost double that of the control plots (Figure 4.12), this is a clear difference but still sparse. This increased cover was also on average significantly taller (Figure 4.13). The majority of understorey cover in the control plots was less than 20 cm tall, and 50 cm at maximum height. Understorey plants in the exclosures exhibited a normal distribution with the most frequent heights being ~30 cm, and ranged up to 100 cm tall (Figure 4.16). A diverse understorey structure is preferable and important habitat for small reptiles and mammals to seek shelter (Garden et al., 2007). Presence of mammalian herbivores grazing tall plant parts is likely the reason for proportionally increased abundance of shorter plants in the control plots.

Seed heads were always found on the extremities of the plant specimens. Proportionally, there were more plants with seed heads in the exclosures (Figure 4.17). It can be inferred that herbivores in the forest are eating the extremities and seed heads of understorey plants in the control plots. This reduces reproductive potential in the immediate area but may also provide dispersal of seeds into other parts of the woodland.

Examining mean height and abundance by functional groups revealed that grazing herbivores prefer some plants over others (Figures 4.14 and 4.15). *Poa* grass, Forbs, and Lily species were shorter and less abundant in the control plots. Daisy abundance and height was independent of treatment, indicating herbivores avoid eating them. Functional group diversity and abundance is likely dependent on season. It can be assumed this examination was not comprehensive as it was carried out in winter when ephemerals are not apparent.

5.2.3 Midstorey state

Predictions from Chapter 3 in relation to midstorey state are restated here for convenience, either confirmed or denied and discussed in relation to the results following. Overall midstorey state was found to be significantly improved within the exclosures.

Table 12. Restatement of predictions for indicators concerning midstorey state

#	Prediction	
18	Mean midstorey top height will be higher in the exclosures	**Confirmed**
19	The exclosures will exhibit a more diverse range of functional groups	**Confirmed**

Midstorey top height was found to be significantly higher in the exclosures. This trend was apparent in the *Acacia amoema* and *Epacris* sp. plants but not reflected by the Bipinnate *Acacia* sp. (Figure 4.18). This is likely because sample size for the Bipinnate *Acacia* sp. was only 28. Denisties of all midstorey functional groups was significantly higher in the exclosures. There were particularly more dead shrubs in the exclosures. Decreased presence of midstorey structuring species in the control plots is likely due to large mammalian herbivores moving through and damaging regeneration and standing specimens. Lack of stable soils as discussed previous may also be inhibiting the plants ability to regenerate. Midstorey structure is a valuable asset to a well-functioning system as it provides shelter and roosts for birds and small mammals (Montague-Drake et al., 2009). Despite the increased presence of *Acacia* sp. as a Nitrogen fixing plant in the exclosures, there was no significant increase in soil Nitrogen (discussed in Section 5.2.1). This further suggests that the system is either very slowly recovering or in stable degraded state.

5.2.4 Overstorey state

Predictions from Chapter 3 in relation to overstorey state are restated here for convenience, either confirmed or denied and discussed in relation to the results following. Overall overstorey state was found to be similar between control plots and exclosures.

Table 13. Restatement of predictions for indicators concerning overstorey state

#	Prediction	
20	Counts of regenerating plants will be higher in the exclosures as they have not been exposed to trampling, and increased ground cover means less runoff and seedlings have a greater chance of establishing themselves.	**Rejected**
21	Mean Diameter at Breast Height will be greater in the exclosures.	**Rejected**
22	Structural diversity will be greater in the exclosures.	**Rejected**
23	The exclosures will exhibit a more diverse range of functional groups	**Rejected**
24	Percent Projected Foliage Cover will be higher in the exclosures because there is more moisture and nutrient availability to encourage growth.	**Rejected**

Contrary to my predictions and despite substrate functionality being improved within the exclosures, density, structural diversity, and DBH of *Callitris glaucophylla* specimens were found to be independent of treatment. Thompson and Eldridge (2005) found that *Callitris glaucophylla* stands lack a self-thinning mechanism and can reach a period where the trees occupy almost all available space. Negligible growth occurs in this 'locked up' state. It is also reported that this dense state can reduce understorey growth and increase erosion risk but the extent of which is dependent on grazing (Eldridge et al., 2003). It may be that the stand is so dense, and resource availability so low that there is no opportunity for physical changes and the vegetation structure is stagnant. Projected Foliage Cover was also found to be independent of treatment. This may be concurrent with the previous assumption that the woodland is in a stagnant structure or this result may be reflective of the small sample size. One large tree in a plot could have biased the means. Regeneration of both overstorey species was very low. The current locked stand provides limited resources or opportunity for *Callitris glaucophylla* trees to regenerate, further exacerbating the effects of this stagnant single aged stand. *Eucalyptus albens* density was very low and regeneration abundance reflected this.

5.3 Slow recovery in the absence of herbivores

Overall there is evidence that total grazing pressure by native and feral herbivores is suppressing the slow recovery of the woodland. There were significant but relatively small differences in structure, composition and function between the control plots and exclosures. It is likely that the woodland system in stable degraded state.

Overall the soil functionality was greater in the exclosures. Understorey and midstorey condition was significantly degraded outside of the exclosures and significantly supressed by mammalian herbivory and trampling.

Overstory composition and structure was unaffected by treatment, this is likely due to the fact that this *Callitris glaucophylla* stand is locked up and very slow growing. This stand will require much longer than 33 years to benefit from mammalian herbivory exclusion.

By examining results we can accept both Hypotheses stated in Chapter 1. Vegetation structure and is more diverse, and landscape functionality is higher inside the exclosures. Unmanaged mammalian herbivores grazing and trampling are inhibiting the slow recovery of the *Callitris glaucophylla - Eucalyptus albens* woodland in Kosciuszko National Park. Ongoing grazing by pest horses and deer may not further degrade the ecosystem, as it appears to be in a stable degraded state. But this research has confirmed that the woodland is not in an irreversibly degraded state. Presence and examination of the exclosures has shown that the woodland is capable of recovery (albeit very slow).

5.4 Implications

Presence of large mammalian herbivores is inhibiting recovery of the woodland from previous disturbance of cattle, sheep and rabbits (Pulsford, 1991). Ongoing presence of these herbivores would likely result in a continually stable degraded woodland state. In contrast, population control or complete exclusion of mammalian herbivores would result in a slow recovery of the woodland. Understorey and Midstorey recovery would be most rapid, then soil functionality. Changes in overstorey structure and composition would likely take 100s of years as *Callitris glaucophylla* are very slow growing. The landscape is unlikely to return to a predominantly *Eucalyptus albens* woodland as the dense *Callitris glaucophylla* stand now dominates.

Options for horse population control as listed in the Draft Wild Horses Management Plan (2016) include trapping and removal from park for domestication or transport to knackery or abattoir, trapping and culling on site, aerial and/or ground mustering, yarding and removal from park for domestication or transport to knackery or abattoir, aerial and/or ground mustering, yarding and culling on site, ground shooting, fencing, and fertility control. All options are time and cost intensive and must take into account animal ethics and stakeholder interests.

5.5 Proportion of forest under the same threat

The woodland extent modelled in ArcGIS (Figure 7) is an indication of what proportion of the woodland is under the same threats as the control plots. This map provides evidence to extrapolate conclusions beyond the paired sites and across the woodland extent. Analysis 2 represents all north facing sites that receive sunlight every day of the year and calculated extent to be 30% of the whole woodland area. This is a large portion of the woodland undergoing significant impacts of unmanaged grazing pressure.

5.6 Limitations

The predominant limitation of this study was small sample size. The exclosures and paired control plots were essential for research design but limiting. Despite further replication within plots, having only five paired sites may not account for spatial variation or provide completely accurate insight into trends of composition, structure and function.

Time restrictions meant detailed mammalian herbivore identification and density estimations could not be carried out. Camera trapping was indicative but not rigorous enough to infer on population densities.

Comprehensive floristics could not be carried out as research was conducted in winter months when ephemeral species are not apparent. Understorey plants are also slow growing in colder conditions and structure and composition would likely vary seasonally.

5.7 Further research

5.7.1 Estimating mammalian herbivore densities

My research of the impaired condition of this woodland is sufficient enough to conclude that mammalian herbivores are indeed inhibiting recovery of the system, confirming Hypothesis 2. Brief camera trapping and personal observations were adequate to suggest that the dominant herbivores in the woodland include feral species (horses and deer). Further research to estimate densities of each mammalian herbivore would complement the condition assessments and be valuable for future recommendations of management. More extensive camera trapping and dung transects should be used to estimate mammalian herbivore density. Dung transect methods should replicate Ian Pulsfords unpublished methods of 1984. Directly comparable data can provide insight into changing herbivore densities. In addition to conducting dung transects, extensive camera trapping should be done to increase sample size and integrity. Camera traps should be placed for a substantial period of time and spread across diverse locations within the woodland.

The establishment of more exclosures representing different parts of the woodland would provide further insight into inhibition pf recovery. Exclosures set up on south facing slopes may exhibit more dramatic differences as they receive less direct sunlight and therefore would be moister. Exclsoures set up on flat parts of the woodland, in valleys for example, may also exhibit greater difference as there is likely a deeper soil horizon there and consequently greater soil functionality.

It is also integral to future understanding of the woodland that the current exclosures continue to be maintained. I commend NSW NPWS for doing so for the past 33 years and am pleased to see that funding was put toward strengthening and heightening them in the latter part of this year.

5.7.2 Potential for VAST-2 chronology

The VAST system is designed to create landscape condition chronologies. This framework was chosen to assess the woodland as it is a comprehensive system and has potential to be directly comparable to historical data. Unpublished and published data from Ian Pulsfords work in 1984 should be examined and fit into the VAST framework. With the two data sets directly comparable, a comprehensive assessment of changes in condition since exclosure erection (33 years of recovery) can be completed. In addition to landscape condition from 1984, historical records compiled by Pulsford (1984) should be examined to estimate pre European settlement condition. These three VAST landscape assessments can provide a timeline of condition and be examined against influencing factors to estimate magnitude of external disturbance in this unique woodland.

Chapter 6: Conclusion

Several waves of disturbance over ~150 years has caused severe vegetation damage, erosion, and structural change to the Callitris glaucophylla – Eucalyptus albens woodlands of Kosciuszko National Park. Despite exclusion of cattle and sheep, and eradication of rabbits, the woodland has not had an opportunity to recover as a new wave of mammalian herbivory is suppressing growth. Pest horses and deer are introduced species whose populations are growing considerably in the Park. The native vegetation struggles to cope with the hard hooves and grazing behaviour of pest herbivores in such high population densities. By examining exclosures free from mammalian herbivory for the past 33 years, conclusions can be made on the ecological impacts of mammalian herbivory in the woodland. Soil functionality, and understorey and midstorey structure greatly benefit from herbivory exclusion. Overstorey structure did not respond to mammalian herbivory exclusion, this is likely because the stand is in a single generation stagnant state. The *C. glaucophylla – E. albens* woodland of Kosciuszko National Park is currently in a stable degraded state and appears incapable of recovery while mammalian herbivores are present in high densities in the Park.

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Appendix 1: GPS coordinates for site locations

Pair	Site #	Corner	Datum: WGS84	
			Latitude	Longitude
A	1 (Control)	1	-36° 52' 56.7"	148° 24' 36.6"
		2	-36° 52' 57.3"	148° 24' 36.6"
		3	-36° 52' 57.4"	148° 24' 35.7"
		4	-36° 52' 56.8"	148° 24' 35.8"
	2 (Exclosure)	1	-36° 52' 56.4"	148° 24' 34.4"
		2	-36° 52' 56.9"	148° 24' 34.6"
		3	-36° 52' 57.0"	148° 24' 33.8"
		4	-36° 52' 56.4"	148° 24' 34.0"
B	4 (Control)	1	-36° 50' 17.4"	148° 23' 45.1"
		2	-36° 50' 18.0"	148° 23' 45.1"
		3	-36° 50' 18.1"	148° 23' 44.4"
		4	-36° 50' 17.5"	148° 23' 44.5"
	15 (Exclosure)	1	-36° 50' 17.2"	148° 23' 46.0"
		2	-36° 50' 17.7"	148° 23' 46.0"
		3	-36° 50' 17.9"	148° 23' 45.4"
		4	-36° 50' 17.2"	148° 23' 45.1"
C	5 (Control)	1	-36° 51' 5.8"	148° 25' 44.1"
		2	-36° 51' 6.4"	148° 25' 44.2"
		3	-36° 51' 6.6"	148° 25' 43.4"
		4	-36° 51' 5.9"	148° 25' 43.6"
	6 (Exclosure)	1	-36° 51' 5.5"	148° 25' 43.0"
		2	-36° 51' 6.0"	148° 25' 43.1"
		3	-36° 51' 6.0"	148° 25' 42.4"
		4	-36° 51' 5.5"	148° 25' 42.4"
D	11 (Control)	1	-36° 46' 29.8"	148° 25' 12.3"
		2	-36° 46' 30.2"	148° 25' 12.7"
		3	-36° 46' 30.5"	148° 25' 11.9"
		4	-36° 46' 30.0"	148° 25' 11.6"
	12 (Exclosure)	1	-36° 46' 28.7"	148° 25' 13.2"
		2	-36° 46' 29.2"	148° 25' 13.4"
		3	-36° 46' 29.4"	148° 25' 12.6"
		4	-36° 46' 28.7"	148° 25' 12.5"
E	13 (Control)	1	-36° 45' 59.7"	148° 25' 16.1"
		2	-36° 46' 0.1"	148° 25' 15.6"
		3	-36° 45' 59.9"	148° 25' 15.0"
		4	-36° 45' 59.4"	148° 25' 15.3"
	14 (Exclosure)	1	-36° 46' 30.0"	148° 25' 11.6"
		2	-36° 46' 30.5"	148° 25' 11.9"
		3	-36° 46' 30.8"	148° 25' 11.3"
		4	-36° 46' 30.3"	148° 25' 11.0"