Bark chewing by the wild horses of Guy Fawkes River National Park, NSW: impacts and causes.

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Bachelor of Science, Honours in Ecology.

Declaration

I certify that the substance of this thesis has not already been submitted for any degree or diploma, and is not currently being submitted for any degree or diploma.

I certify that, to the best of my knowledge, any help received in preparing this thesis and all sources used, have been acknowledged in this thesis.

I certify that this thesis falls within the word limit, 15,000 – 30,000 words, for the text, excluding tables, figures, references and appendices.

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Ainslie Ashton
November, 2005

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In Memory of Lachlan March.

Abstract

Management of the wild horse population in Guy Fawkes River National Park has been controversial and this has led the National Parks and Wildlife Service to find a more acceptable method of management. A trial feed-lure capture program has recently been completed, successfully capturing 157 wild horses. One of the reasons used to justify the removal of the wild horses from the National Park is the damage they cause to eucalypt species by chewing bark. The aim of my project was to examine the bark chewing behaviour by the wild horses of the Red Range Plateau in Guy Fawkes River National Park.

My first aim was to determine the extent and intensity of damage caused by bark chewing. I assessed the distribution of bark chewing, extent of damage, any selection for tree species or tree size, and determined whether there was a correlation between tree health and the degree of bark chewing damage. I also compared the damage at known intensively damaged sites with damage across the rest of the Plateau. Secondly, I aimed to form a hypothesis as to why the wild horses chew bark on the Red Range Plateau, whether the wild horses were responding to a specific cue or reward, such as the nutrient or sugar content of the bark. Assessment of trees at random sites indicated that bark chewing was clumped at the landscape level with chewing more likely to occur in drainage lines. Six sites of known intensive bark chewing damage revealed that 60% of trees in these areas suffered some degree of bark chewing damage, with damage focused upon two species. These results led me to sample twelve random sites located in drainage lines across the Plateau in order to assess the background rate of bark chewing which I measured at 10.9%. Trees with damage had a greater diameter at breast height (DBH) than trees with no damage. There was also a correlation between tree health and the degree of damage inflicted upon the tree. The total starch content of bark indicated that there was an association between trees with higher starch content and the occurrence of bark chewing.

Trees with bark chewing damage are likely to have poorer health than trees with no damage, so over the long-term, bark chewing has the potential to impact upon the species composition and structure of the vegetation along drainage lines on the Red Range Plateau. Although nutrient and sugar analysis was not conclusive, there is much more research to be carried out to increase understanding of the cues and rewards which are involved in the bark chewing behaviour by the wild horses of the Red Range Plateau.

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1.0 General Introduction

1.1 WILD HORSE POPULATIONS

Populations of wild horses (*Equus caballus*) can be found in Canada, America, Australia, New Zealand, Southern France, Mongolia, Namibia, Greece, and even in The Bahamas (wildhorse.com, 2003). The past 25 years has seen an increase in the amount of research being carried out on wild horse behaviour and the environmental impacts caused by wild horse populations. The growing interest in wild horse behaviour and their impacts began with the introduction of the Wild Free-Roaming Horses and Burros Act, 1971 in the United States (BLM, n.d.; Symanski, 1996). Management and understanding of this species became important when the protected wild horse populations in the United States grew to unsustainable levels. Amendments to the 1971 Act allowed removal of the wild horses from the rangelands (Symanski, 1996). Increased understanding of wild horses in Australia has become necessary as the wild horse populations continue to expand, resulting in Australia having the world's largest wild horse population (Dobbie *et al*., 1993; DEH, 2004). The current minimum estimate of wild horses across Australia is 300,000 (DEH, 2004; McLeod, 2004).

Wild horses and their impacts have been studied in central and northern Australia (Berman, 1991; Symanski, 1994; Black, 2000), the Australian Alps National Parks (Dyring, 1990; Walter, 2002) and also in Guy Fawkes River National Park (GFRNP) (Taylor, 1995; Andreoni, 1998; Schott, 2004). As a result of long-term research programs in New Zealand, the population of wild horses in the Kaimanawa Ranges has become one of the most studied horse populations in the world (Rogers, 1991; Linklater *et al*., 1999; Linklater and Cameron, 2002; Linklater *et al*., 2002; Linklater *et al*., 2004). Wild horses have also been studied in the Camargue (Duncan, 1992), southern England (Pratt *et al*., 1986), Iceland (Sigurjonsdottir *et al*., 2003), Argentina (Zalba and Cozzani, 2004), and also on several American islands such as, Cumberland Island (Turner, 1988; Goodloe *et al*., 2000) and Assateague Island (De Stoppelaire *et al*., 2004). The intensity of research around the world is an indication of the growing concerns in regard to the environmental impacts caused by large populations of wild horses and a need to understand their behaviour in order to implement the best possible management strategies.

1.2 WILD HORSE MANAGEMENT

Management of wild horse populations has proven to be a highly contentious issue especially in North America, Australia and New Zealand (Symanski, 1996; Linklater *et al*., 2002; Beever, 2003). Aerial culling of wild horses creates a significant division within the community (G. Ballard, *pers. comm*.), even though this method has been shown to be a humane option (Dobbie *et al*., 1993; English, 2000; English, 2001a). Wild horse management in Australia is closely linked to Australian cultural values. The wild horse, the brumby, is seen as a national icon (English, 2001a) and has been romanticized by movies such as 'The Man from Snowy River' and 'The Silver Brumby'. The degree of protection that should be given to wild horses has been debated for many years because of their perceived heritage value. Both arguments, for and against, have been expressed publicly using highly emotive statements. For example, headlines such as 'Parks Workers Slaughter Australian Brumbies' were used to describe the aerial cull of wild horses in GFRNP in October 2000 (KBR, 2001). Against the protection of wild horses are groups such as 'The Colong Foundation for Wilderness' which advocates the removal of all wild horses from Australian National Parks (The Colong Foundation for Wilderness, 2004).

The problem of humane control methods, which satisfy the requirements demanded by stakeholders, appears to have been managed most successfully by the NSW National Parks and Wildlife Service (NPWS), Dorrigo Plateau Area, with their management of wild horses in Guy Fawkes River National Park. They are currently undertaking a 'feed-lure' trapping method which was trialled in 2004 and for a month in early 2005. So far 157 horses have been captured with the majority of these successfully re-homed (E. Jessup, *pers. comm*.). Feed-luring had previously been used in Coffin Bay National Park, South Australia, where trap yards had been set up around water during summer. Following the dry summer period, when water became freely available, hay bales were placed in the trap yards to lure the remaining horses into the yards (NSW NPWS, 2003). The Guy Fawkes Trial Horse Capture Program won the award for Excellence in Pest Animal Management and Conservation Goals at the 3rd biennial New South Wales Pest Animal Control Conference in July 2005. Feedback on the capture program from the conference was positive (B. Nesbitt, *pers. comm*.), including feedback from the RSPCA and Professor Tony English, who was responsible for investigating wild horse management after the aerial cull of wild horses in GFRNP in 2000 (English, 2000; 2001a; 2001b).

1.3 ENVIRONMENTAL IMPACTS OF WILD HORSES

Wild horses have been shown to have significant impacts upon the environments in which they live. These impacts are exacerbated in the Australian environment due to the lack of native ungulates in the ecosystem. The first ungulates arrived on the First Fleet in 1788, and within seven years Australia had its' first herd of large feral herbivores (Low, 1999). Australia is now home to the world's largest feral populations of camels (*Camelus dromedarius*), donkeys (*Equus asinus*) and horses (*Equus caballus*) (Freeland and Choquenot, 1990; Dobbie *et al*., 1993; Dorges and Heucke, 1995; James *et al*., 1999; DEH, 2004). Approximately 10% of grazing pressure on the Australian environment is due to feral herbivores such as camels, donkeys, rabbits (*Oryctolagus cuniculus*), goats (*Capra hircus*), and horses (Hamblin in Fisher, 2001). Management of these feral herbivores is vitally important for the long-term future of the Australian environment.

Of these species, wild horse management has been the most contentious, causing many debates around the world (Symanski, 1996; Linklater *et al*., 2002; Beever, 2003). The perceptions people have of wild horses, especially in Australia, is made more difficult by the cultural status of wild horses and how they are perceived as a pest species compared with how other introduced vertebrate pests are viewed (English, 2001b). Wild horses impact the environment through overgrazing, forming pads, fouling and depleting waterholes, spreading weeds, soil compaction and erosion (Dyring, 1990; Berman, 1991; English, 2001b; DEH, 2004). The extent and intensity of these impacts is thought to be dependent upon the density of the wild horse population (English, 2001b) but can also be linked to the characteristics of the ecosystem the wild horses inhabit. In this section, I outline impacts on the environment attributed to wild horse populations and explore options for monitoring these impacts.

1.3.1 Wild horse impacts

Grazing damage by wild horses occurs through two different processes. Firstly, overgrazing an area due to drought, population density or competition with other herbivores such as domestic stock and native mammals, can lead to increased erosion, changes to vegetation community composition and structure (Stocker, 1971; Considine, 1985; Duncan, 1992; Smyth and James, 2004), increased weed invasion (Cowan and Tyndale-Biscoe, 1997) and changes to fire frequency and interval (Berman, 1991; Belsky and Blumenthal, 1997). Secondly, wild horses graze selectively, over the short-term impacting vegetation quality and toxicity (Ginane *et al*., 2005) and over the long-term directly impacting upon the floristics of the grazed lands (Bowman, 1985; Ginane *et al*., 2005) and changing the morphology of grasses in these grazed sites (Fahnestock and Detling, 2000).

Wild horse populations also cause damage through overbrowsing. Wild horses strip bark from trees, at times ring-barking the trunk (Duncan, 1992). Damage caused by bark chewing can influence the distribution of tree species (Angelstam *et al*., 2000; Scharf and Hirth, 2000), as total ring-barking of the tree trunk leads to the eventual death of the tree (Forbes and Meyer, 1956). The degree of bark chewing damage is significantly related to the health, that is, vigour, vitality and foliage cover, of the tree (Schott, 2004).

Herbivores are important dispersers of many plant species (Couvreur *et al*., 2004). Dispersal of viable seeds, both native and exotic, is possible through horse manure (Taylor, 1995) and the probability of seed dispersal to isolated areas is high due to the ability of wild horses to travel long distances (Berman, 1991). Grazing ungulates can influence nutrient availability to plants, by excreting nutrients in a form available for uptake, or by changing the amount and quality of litter available for decomposition (Hobbs, 1996).

Trampling by wild horses is a significant environmental impact causing soil compaction, which then leads to structural damage, changing the soil characteristics and increasing the rate of erosion (Weaver and Dale, 1978; Dadkah and Gifford, 1980; Dyring, 1990; Whinam *et al*., 1994; Andreoni, 1998). Wet soils, such as those in sensitive alpine areas and bogs, are particularly susceptible to structural damage from trampling (Dadkah and Gifford, 1980; Taylor and Friend, 1984; Dyring, 1990; Rogers, 1991). Soil compaction also leads to increased run-off (Figure 1.1), reduced infiltration rates and results in changes to the soil hydrology (Braithwaite *et al*., 1984; Fleischner, 1994; Skeat *et al*., 1996; Belsky and Blumenthal, 1997).

Wild horse populations also impact upon water sources and the immediate vicinity around the water source. This is especially the case during times of drought where the populations are concentrated around water sources. In such instances, horses not only deplete and foul the water, but due to the high densities of animals, are also likely to significantly increase damage to the soil and surrounding vegetation (Woinarski *et al*., 2000; DEH, 2004). Water quality will also be affected, through increased turbidity and changes in dissolved oxygen, pH levels, salinity, total nitrogen and total phosphorus (Harnardi and Callaghan, 2004).

Figure 1.1: Run-off along a well used horse pad after heavy rainfall on the Red Range Plateau, GFRNP.

1.3.2 Habitat and Resource Use

The extent of wild horse impacts upon the environment stems from their heterogenous use of the landscape (Beever, 2003). Most ungulates have areas of preference within their range, and areas which they avoid (Duncan, 1983), reacting to the spatial patterns of topography as well as the distribution of feed (Bailey *et al*., 1996). Differential use of the landscape is revealed by wild horse impacts upon the environment occurring through several spatial scales (Beever, 2003). Landscape scale impacts can be seen through horse pads and the resulting terracing on hillsides, erosion damage through overgrazing and trampling, and other visible signs of horses such as stallion piles. Patch dynamics are influenced by the selection of preferred habitats, such as riparian zones and grazing lawns (Crane, 1997; Menard *et al*., 2002), through changes to vegetative community composition caused by selective grazing, overgrazing and overbrowsing. Localised changes to vegetation and soil are then sustained by the microclimate (Dyring, 1990).

Landscape studies have revealed patterns in the distribution of grazing (Bailey *et al*., 1996). Selection of grazing sites is thought to be a combination of information gleaned from smaller scales, for example, by being able to discern different patches available, as well as which plants and sections of plants are palatable (Bailey *et al*., 1996). Locations of preferred sites are usually related to the distance from water and degree of slope (Bailey *et al*., 1996). The grazing preferences of wild horses are reflected by lower vegetation cover and lower species richness in areas near water sources (Beever and Brussard, 2000). Grazing near riparian zones impacts upon water quality, vegetation structure and the abundance of small mammal species (Giuliano and Homyack, 2004). Grazing has also been shown to impact upon small mammal burrows (Beever and Brussard, 2000), levels of egg predation from birds nests (Zalba and Cozzani, 2004) and the numbers and types of shore birds (Levin *et al*., 2002). These responses to grazing disturbance can be used to monitor the degree of grazing disturbance, not only in localised areas, but as indicators over a larger scale (Beever *et al*., 2003). Landscape patches can be modified by selective grazing, as shown in New Zealand, by the threat to the *Chionocholoa pallens* grasslands and the prevention of *Nothofagus* from advancing into the seral grasslands of the Kaimanawa Ranges (Rogers, 1991).

Usage of the spatial and temporal landscape scales impacts upon small scale foraging choices by herbivores (Bailey *et al*., 1996). This is shown by the preferential grazing of short-grass areas (Menard *et al*., 2002). This preference for short-grass areas has led to studies on the repeated grazing of these 'grazing lawns'. Frank and McNaughton (1992) showed that grazers had the potential to alter energy and nutrient fluxes through their use of the landscape, as increasing production of a landscape patch is reflected by increasing consumption. The aim of selective feeding by horses is to maximise intake of high quality food (Duncan, 1983), which occurs through increased productivity as a result of repeated grazing. Repeated grazing of these areas also means that the animals will spend proportionally more time at these productive sites, compared with their usage of less productive sites (Bailey *et al*., 1996).

Not only are changes to productivity a result of repeated grazing but are also a result of nutrient increases due to dung deposition (Frank and McNaughton, 1992). Due to the low nutrient levels in the Australian environment, it only takes 0.2-0.4 days worth of cow manure to raise nutrient levels suitable for supporting native heath, to sustaining most crop and weed species (Low, 1999). Therefore, increases in nutrient levels which assist increasing production of these short-grass areas will also encourage weed invasion in areas where grazing lawns have been established.

Heterogenous use of the landscape is not only a spatial occurrence but also occurs on a temporal scale. Horses use ridge tops and hilly areas disproportionately (Bowman, 1985; references in Beever, 2003) and tend to move to higher areas during summer, and to the lower elevations in winter (Dyring, 1990; Wilson *et al*., 1992; Crane, 1997; Schott, 2004). In alpine areas especially, this seasonal cessation of degradation has the potential to allow recovery of horse pads during the wetter months (Chittick, 1997). Slopes, preferred by wild horses, are also more susceptible to erosion (Andreoni, 1998). Significant soil compaction along horse pads impacts vegetation cover (Dale and Weaver, 1974; Weaver and Dale, 1978), soil nutrient levels (Liddle and Chitty, 1981), water run-off and infiltration rates (Braithwaite *et al*., 1984; Belsky and Blumenthal, 1997), all of which can be used as indicators of disturbance levels.

1.3.3 Monitoring Options

The heterogeneous use of the landscape by wild horses and the potentially large size of their home range (Linklater *et al*., 2000), creates many difficulties in monitoring their impacts as they are spread across a broad range of spatial scales (Beever *et al*., 2003). Many small scale comparison studies of grazing and non-grazing disturbances have been carried out but impacts over broad scales have not yet been fully investigated (Beever *et al*., 2003). Difficulties arise from trying to interpret ecological information across these scales (Bailey *et al*., 1996; Landsberg *et al*., 2002). Monitoring of long-term grazing impacts does not necessarily require direct measurements as shown by Landsberg *et al*. (2003) who used the distance from water as an indicator of disturbance levels. In the rangelands of Australia, changes in abundance of plant species can be used as predictors of disturbance levels (Landsberg *et al*., 2002). It is possible to detect grazing disturbance using a number of response variables which are general enough to be found throughout the disturbed region (Beever *et al*., 2003). Variables such as penetration resistance (soil compaction), size of the small mammal community and numbers of individuals, plant species richness and percent cover of certain species have the potential to provide indications of grazing disturbance across a broad spatial scales (Beever *et al*., 2003).

The degree of environmental impacts caused by wild horse populations upon the landscape varies across spatial scales. Different intensities of impacts are recorded between sites, between landscape patches and at the regional scale (Landsberg *et al*., 2002). This variation between differing scales supports the recommendation by Beever *et al*. (2003) that sampling should be stratified in order to account for natural variation. This includes monitoring variation over space and time to account for seasonal changes and to encourage adaptive management (NRM, 2004).

1.3.4 Conclusion

Impacts upon the environment caused by wild horse populations are closely linked with their usage of the resources and habitats available. Resource use is usually correlated with areas of higher productivity, grazing lawns, preferred plant species as well as proximity to water

(Bailey *et al*., 1996). This will result in these preferred areas receiving greater usage than the less preferred, less productive areas, and the impacts caused by wild horses will be concentrated at these sites. Compaction, erosion, soil hydrology, species composition, plant morphology and water quality are likely to be different in these areas compared with elsewhere within the habitat. Impacts are not restricted to these distinctly preferred areas and this reveals the heterogeneous use of the habitat by wild horse populations.

Monitoring programs can be implemented at a wide scale but understanding the indicators of disturbance and at what degree of disturbance these indicators react is necessary. The type and number of indicators must be adapted for the aims of each monitoring program (Smyth and James, 2004). The use of these indicators as predictors of change due to disturbance, especially grazing disturbance, is an important tool in assessing management options for wild horse populations. The ability to manage impacts on the environment arising from wild horses almost as they occur – adaptive management – will provide a greater opportunity to reduce these impacts. This will occur through understanding how indicator variables respond to changing wild horse density and population size, and will allow population size management to be better regulated. The degree of these density-dependent impacts will gradually be reduced through the introduction of appropriate monitoring programs, using variable environmental indicators to directly manage wild horse populations.

1.4 RESEARCH OUTLINE

Three previous studies on the environmental impact of wild horses in Guy Fawkes River National Park have been carried out (Taylor, 1995; Andreoni, 1998; Schott, 2004). Taylor (1995) demonstrated the potential of wild horses to spread species of weeds through the presence of viable seeds in manure. The study carried out by Andreoni (1998) revealed that extensive erosion on the slopes of GFRNP was linked with movement patterns of the wild horses. Schott (2004) investigated the density, distribution and habitat use by wild horses on the Red Range Plateau. She also studied five areas of intense bark chewing on the Plateau and assessed the impacts of grazing using an exclosure in Bob’s Creek. The extent of bark chewing damage, resulting in the gradual ring-barking of eucalypt species, has been of concern to the NPWS and was one reason that was used to justify the removal of wild horses from GFRNP (E. Jessup, *pers. comm.*; B. Nesbitt *pers. comm.*) (Figure 1.2).

Figure 1.2: Bark chewing damage to *Eucalyptus amplifolia* at Dead Pig Gully, Red Range Plateau, GFRNP. Bark has been removed up to a height of 2.15 metres.

The intention of this research project was to increase the limited knowledge of bark chewing by wild horses on the Red Range Plateau. In order to maximize management options, increased understanding of the distribution and extent of bark chewing damage is required, as is an understanding of why the wild horses chew bark. The aims of this study are specified within each chapter but include:

1. Determining the distribution of bark chewing across the Red Range Plateau. Discussions with the Trial Capture contractors and research by Schott (2004) indicated that bark chewing only took place at the Boban end of the plateau. My first aim was to test this assumption.

2. Assessing whether the bark chewing was distributed randomly or clumped in patches across the landscape. I expected that bark chewing would be clumped as indicated by Schott (2004).

3. Determining whether the wild horses of GFRNP chew bark of certain species. I expected that chewing was limited to selection of three species *Eucalyptus amplifolia*, *E. moluccana* and *E. saligna* and a fourth occasionally preferred species, *E. melliodora* (Schott, 2004).

4. Developing a hypothesis as to why the wild horses chew bark. My expectations were that the bark could act as either a supplement for nutrients lacking from their diet or that the bark provided a food reward, which encouraged repeated visits to the chewed areas.

2.0 Study Site

2.1 GUY FAWKES RIVER NATIONAL PARK

Guy Fawkes River National Park is located approximately 100km north-east of Armidale in northern New South Wales (NSW) (English, 2000; NSW NPWS, 2003). The National Park covers approximately 105,000 hectares (NSW NPWS, 2003), extending from Ebor in the south to as far north as the Old Grafton Road. Prior to being gazetted as a National Park on 30th June 1972, the area was either managed as grazing leases or vacant crown land (Austeco, 1999). The Guy Fawkes Wilderness Area was declared in 1994 (Reid *et al*., 1996) and was increased in 2002 from 34,870 hectares to 49,800 hectares (NSW NPWS, 2004). Historically, clearing, mining and recreation, as well as grazing, have been the primary uses of the Park. Also included within GFRNP are many Aboriginal cultural heritage sites, reflecting historical resource use by local Aborigines (NSW NPWS, 2003).

The steep gorge country surrounding the river system and river flats is a distinguishing feature of GFRNP (Austeco, 1999; NSW NPWS, 2003). The climate within GFRNP is highly variable and localised due to great topographic variation throughout the Park. Elevation throughout GFRNP drops over 1000 metres, from 1380 metres above sea level (asl) at the Chaelundi Mountain area on the eastern boundary of the Park, to 260 metres asl where the Boyd River exits the Park in the north (Austeco, 1999) (Figure 2.1). The many combinations of aspect, elevation and slope strongly influence the rainfall and temperature in GFRNP, evident by the wide range of average annual temperatures in the Park (Australian Bureau of Meteorology, 2004) (Figure 2.3). The highest rainfall is generally recorded towards the end of summer with low, unreliable falls during winter and spring (Austeco, 1999). The area averages 1387.7 mm of rain each year (Australian Bureau of Meteorology, 2004). The annual averages for rainfall and temperature range in GFRNP are shown in Figure 2.2 and Figure 2.3.

Guy Fawkes River National Park is bisected along the Guy Fawkes River by the Demon Fault which originates in Queensland. This Fault separates the Coffs Harbour Block in the east of GFRNP from the Dyamberin Block in the western section of the Park (Austeco,

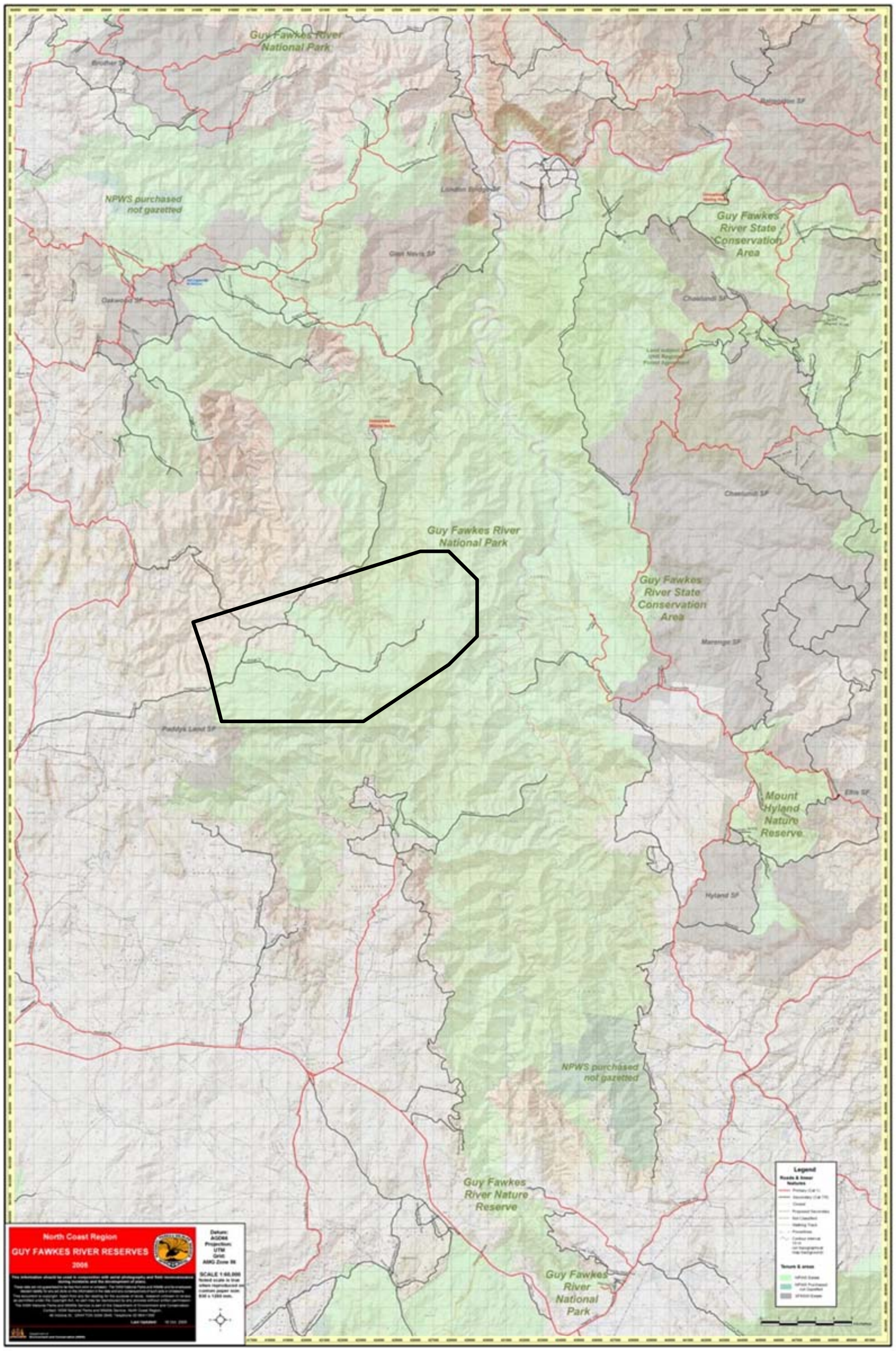

Figure 2.1: Topographic map of Guy Fawkes River National Park. Circled section shows the Red Range Plateau.

Source: NPWS, Dorrigo Plateau Area.

1999). Both igneous and sedimentary rock can be found in GFRNP with the soils of the region derived from the sedimentary rock types of that area. The soils of the surrounding plateaux are Yellow Earths, with Yellow Podzolics occurring in the more unstable areas and the vegetation of these areas typically consists of stringy-barks, New England Blackbutt (*Eucalyptus campanulata*) and tallow wood forest (Austeco, 1999).

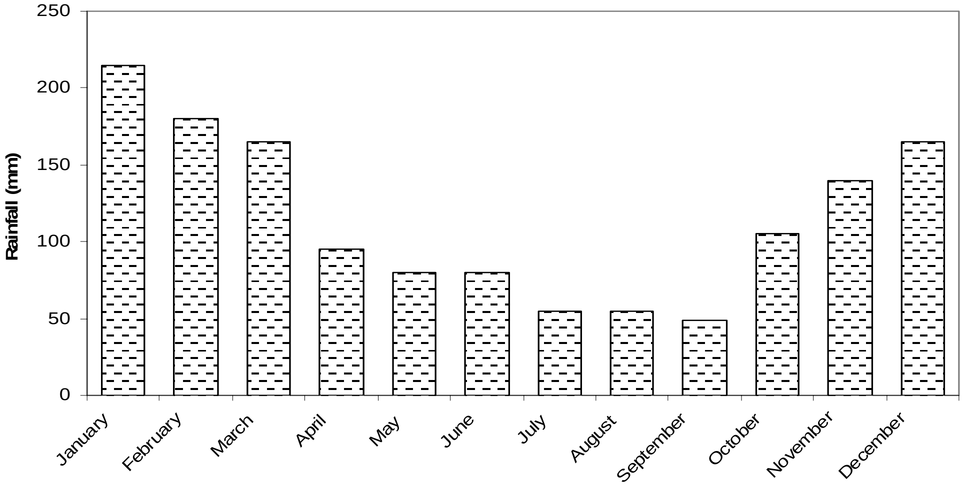

Figure 2.2: Average monthly rainfall (mm) for Guy Fawkes River National Park.

Source: Adapted from NSW NPWS, 2004.

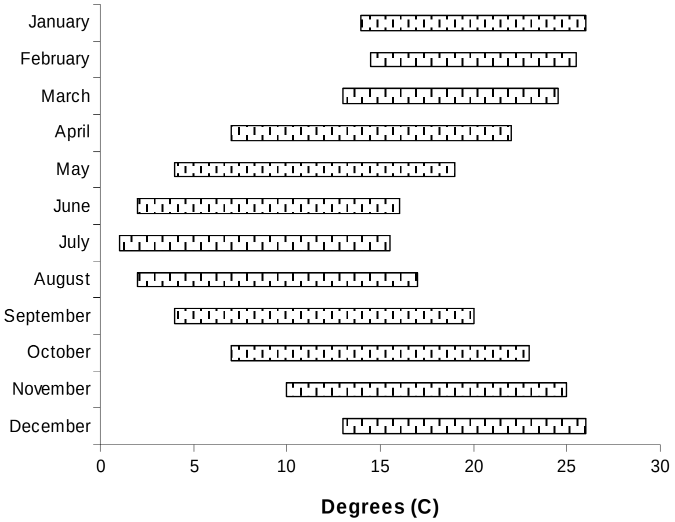

Figure 2.3: Average temperature range for Guy Fawkes River National Park.

Source: Adapted from NSW NPWS, 2004

2.1.1 Flora and Fauna

Guy Fawkes River National Park is regarded as a regional biodiversity hotspot, containing 28 threatened plant species, 24 threatened fauna species and over 40 different vegetation communities (NSW NPWS, 2003). The large number of vegetation communities provides an extremely high level of floristic diversity, and is a direct result of the variation of terrain throughout GFRNP. Vegetation communities range from subtropical, warm temperate and dry rainforest; river and alpine grasslands; wet and dry sclerophyll forests; to heathlands, sedgelands and woodlands (Reid *et al*., 1996). There are also areas of old growth forest in the north-eastern section of the Park (NSW NPWS, 2003).

High faunal diversity is a result of these varied vegetative communities within GFRNP, with 230 different species of vertebrate fauna recorded in the Park so far (NSW NPWS, 2004). One section of old growth forest in the north of the Park contains the highest density of arboreal mammals in NSW (T. Prior, *pers. comm.*). Endangered and vulnerable species (*Threatened Species Conservation Act* 1995) which have been recorded in the Park include the squirrel glider, *Petaurus norfolcensis*, long-nosed bandicoot, *Perameles nasuta*, the powerful owl, *Ninox strenua*, the yellow-bellied glider, *Petaurus australis*, and the stuttering frog, *Mixophyes balbus* (NSW NPWS, 2003). Guy Fawkes River National Park also contains a number of feral mammals. These include wild dogs, foxes, cats, hares, rabbits, pigs, goats and horses (Reid *et al*., 1996). The wild horse population is distributed throughout the catchments of GFRNP as well as on the Red Range Plateau (Schott, 2004).

2.2 RED RANGE PLATEAU

The Red Range Plateau is located in the south western section of GFRNP. The Plateau forms the northern boundary of the Aberfoyle River catchment and the eastern boundary of the Guy Fawkes River catchment. Both the Bob's Creek and Pargo Creek catchments run north to the Sara River, originating from the northern edge of the Plateau. The Red Range Plateau became part of GFRNP when purchased in 2000 by the NSW NPWS (T. Prior, *pers. comm.*). A crown lease of 3,287 hectares and 400 acres of freehold land were purchased from the Maskey family and a 1,671 hectare crown lease was purchased from the Perry family

(T. Prior, *pers. comm.*). The addition of the Red Range Plateau to GFRNP increased the size of the Park by approximately 5,118 hectares. Prior to acquisition by NSW NPWS, this land was used primarily for cattle grazing and the fences used during this period are currently in good condition and are able to contain the movement of livestock and wild horses across the Plateau (*pers. obs.*).

The vegetation report by Austeco (1999) was completed prior to the purchase of the Red Range Plateau, but the southern half of the Plateau, above the Aberfoyle River, was already part of GFRNP and was therefore included in the survey. The results from the surveyed areas surrounding the Plateau can be extrapolated to include the recently purchased land. Austeco (1999) states that two species, a red gum and *Angophora subvelutina*, are considered the dominant species of GFRNP. This is true for the eastern section of the Red Range Plateau, which is dominated by *A. subvelutina* and the red gum, *Eucalyptus amplifolia* (*pers. obs.*). Three of the most common vegetation communities recorded in the southern section of the Plateau include the tall dry sclerophyll forest consisting of *E. campanulata – E. cameronii – Allocasuarina littoralis* (Community 8); medium dry sclerophyll forest consisting of *E. dorrigoensis* (Community 10); and medium dry sclerophyll forest consisting of *E. bridgesiana – E. campanulata – E. caliginosa – E. laevopinea* (Community 12) (Austeco, 1999) (Figure 2.4).

The elevated areas surveyed by Austeco (1999) are equivalent to the Red Range Plateau. The soils are podzols (C. Guppy *pers. comm.*) which is the soil type recorded for the other elevated areas surrounding the gorge system (Austeco, 1999). The elevation of the Plateau ranges from 800m to 1150m and the slope is moderate, 0°-20°, in comparison with the surrounding gorges (Austeco, 1999) (Figure 2.5).

The Red Range Plateau is also home to a range of fauna including koalas, *Phascolarctos cinereus*, spotted-tailed quolls, *Dasyurus maculatus*, dingoes, *Canis lupus*, and glossy black cockatoos, *Calyptorhynchus lathami* (NSW NPWS, 2004; *pers. obs.*) and the brush-tailed rock-wallaby, *Petrogale penicillata*, which inhabits the steep cliffs on the edges of the Plateau (NSW NPWS, 2004). Feral mammals such as wild dogs, cats, hares and horses are also found on the Plateau. Of these, wild horses are of the greatest concern, due to their perceived high density (157 wild horses were removed in 2004/05; E. Jessup, *pers. comm.*), and due to the severe damage they cause to eucalypt trees through stripping bark (Schott, 2004).

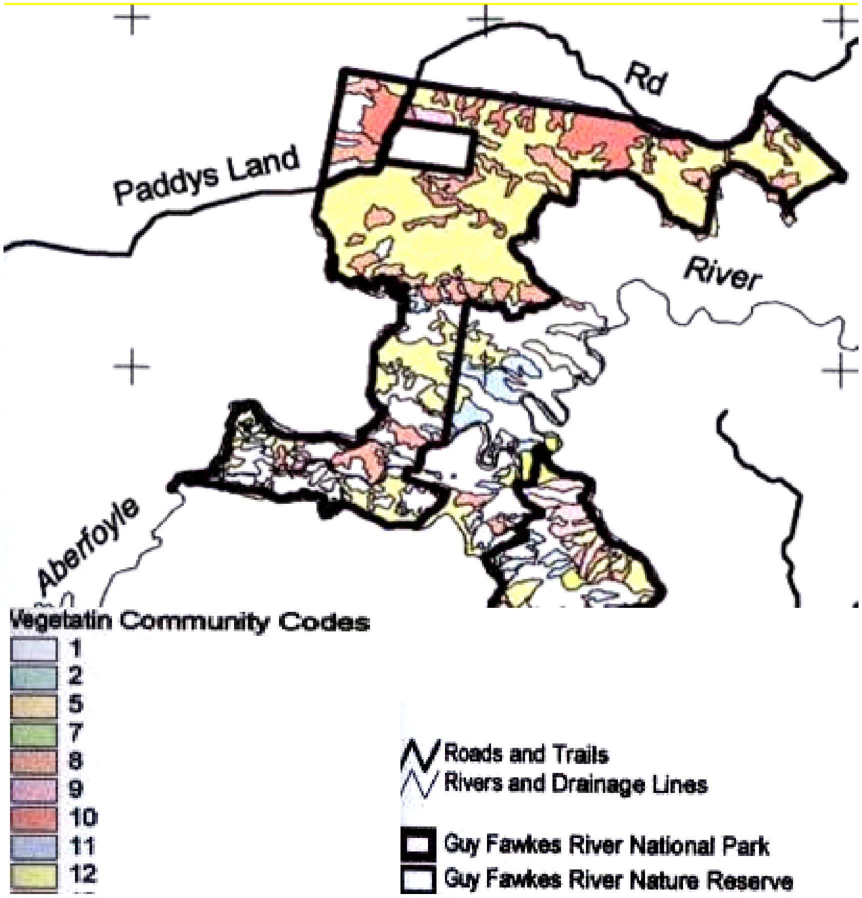

Figure 2.4: Vegetation communities on the Red Range Plateau.

Source: Adapted from Austeco, 1999.

2.2.1 Study Area

This aim of this study was to examine the impact of bark chewing by wild horses across the Red Range Plateau. In certain areas of the Plateau, this occurs at extremely intense levels, ring-barking many of the trees in these areas (Schott, 2004). The wild horses are known only to chew the bark on the Plateau, as there are no reports of bark chewing within the gorges and along the river systems (B. Nesbitt and E. Jessup, *pers. comm.*). It was also thought that bark chewing was restricted to the eastern section of the Plateau, with no chewing sighted at the western end of the Plateau (E. Jessup and G. Baldwin, *pers. comm.*). Therefore, to determine the extent of bark chewing across the Plateau, I divided the Plateau into two sections. The western-most site of known bark chewing (Schott, 2004; E. Jessup, *pers. comm.*) was used to divide the Plateau into two sections - Wonga in the west and Boban in the east. The dividing line is found along the easting 56 J 0420500 (Figure 2.5).

In an attempt to keep the landscape variables similar across the whole plateau, I restricted the extent of the north east area of Boban. The section of Boban north of Spion Kopje was noticeably different from the rest of the Boban and Wonga areas (*pers. obs.*). This is due to the surrounding gorges restricting this area of the Plateau to a narrow point and the likelihood of a limited history of cattle grazing in comparison with the more accessible areas of the Plateau. The change in vegetation included different species and a thicker shrubby understorey beyond Spion Kopje (*pers. obs.*). The first Boban random site, RB1 (Table 1, Appendix), was located approximately two kilometres beyond Spion Kopje, and whilst not showing any bark chewing activity, the walk out to the site revealed a change in vegetation and topography. As this area is close to the edge of the gorge, it has a shrubbier understorey, and included *Xanthorrea* species. This species is commonly found in the steep upper catchments of creeks that drain the Plateau (K. Vernes, *pers. comm.*), and could possibly be used to indicate proximity to the edge of the gorge system as this genus was not seen growing elsewhere on the plateau (*pers. obs.*). Lack of this species on the Plateau may also reflect the history of heavy grazing, as cattle are known to graze this species if the opportunity arises (E. Jessup, *pers. comm.*). To ensure minimal variation of the landscape across the Plateau, Boban was therefore restricted to an area south of Spion Kopje, that is, south of the northing 56 J 6675000 (Figure 2.5).

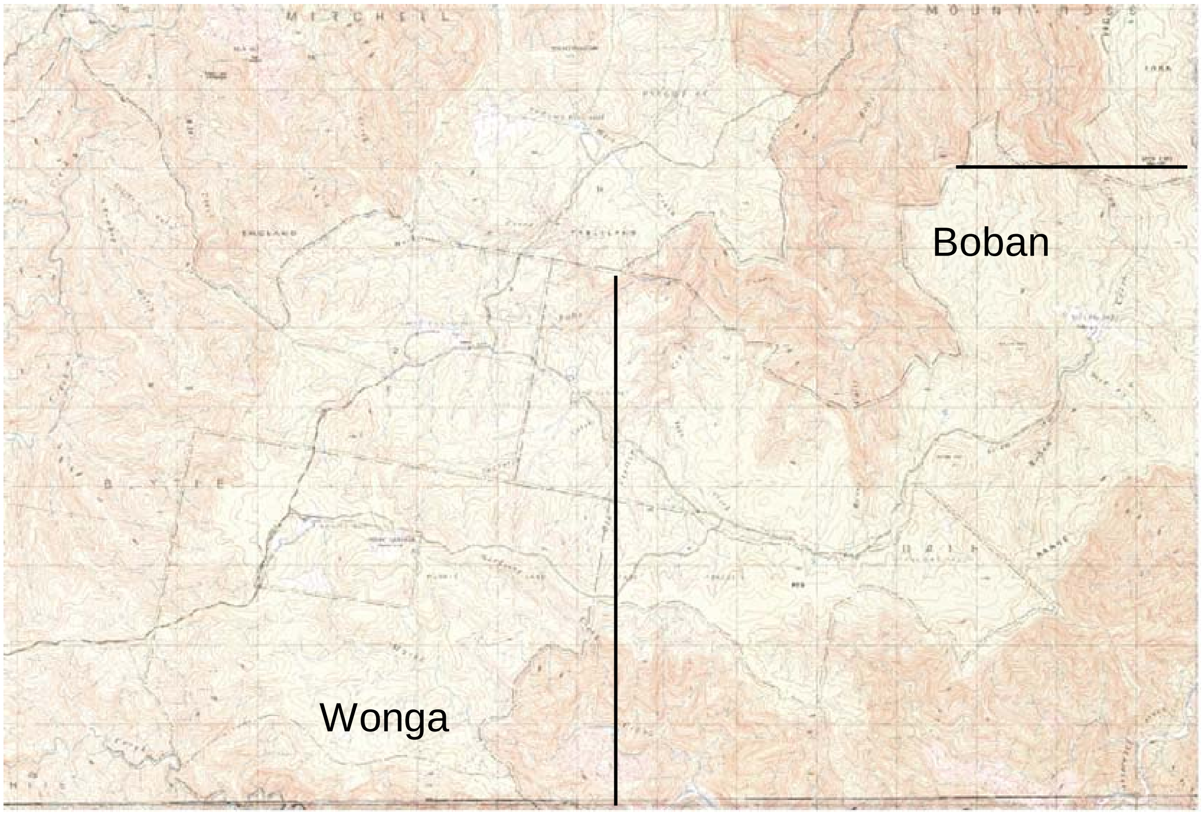

Figure 2.5: Topographic map of the Red Range Plateau, GFRNP, showing the division between Boban and Wonga, and the boundary of the north-eastern extent of Boban.
Source: NSW NPWS, Coffs Harbour.

2.3 HISTORY OF THE WILD HORSE POPULATION OF GUY FAWKES RIVER NATIONAL PARK

It is not known how long GFRNP has been home to wild horses (Andreoni, 1998) but horse breeding began in the area during the 1830's (NSW NPWS, 2003). Cattle also frequently enter GFRNP from neighbouring properties (English, 2000; T. Prior, *pers. comm.*) and were grazed on the Red Range Plateau. Management of the wild horse population did not take place after gazettal of the Park in 1972 until the early 1990's when the growing wild horse population became a cause for concern (NSW NPWS, 2003). One hundred and fifty-six horses were removed from GFRNP between 1992 and 1999 through several mustering and trapping operations (English, 2000; NSW NPWS, 2003). A fire during early September, 2000, burnt 60% of the Park and provided evidence of an extremely large wild horse population which were considered to be in poor condition (English, 2000). An aerial cull was carried out over three days in October, 2000, shooting a total of 606 horses. A recommendation was then made to remove the remaining estimated 80 horses from the Park (English, 2001b). It is thought that the wild horses in GFRNP are concentrated around the Bob's Creek catchment and on the Red Range Plateau (Schott, 2004).

The population estimate provided after the fire has since been revealed to be an underestimate of the size of the remaining wild horse population. The Trial Horse Capture Program, carried out over eight months in 2004 and a month in 2005, removed 157 horses from the Red Range Plateau alone (E. Jessup, *pers. comm.*). Current research by Freeman (2005) indicates that horse density in two catchments within the gorge system of GFRNP could be as high as 5.2 horses/km^2. Freeman (2005) has also estimated the minimum size of the wild horse population in these catchments, estimating that there are a minimum of 163 horses in Bob's Creek catchment and 108 within the Pargo catchment. Competition with other herbivores can also impact upon the distribution of wild horses in GFRNP, especially in times of drought. Competition would be greatest between the wild horses and macropod species found within GFRNP (Table 1.1).

Table 1.1: Macropods recorded in Guy Fawkes River National Park.

Source: NPWS, 2004.

Eastern grey kangaroo	*Macropus giganteus*
Parma wallaby	*Macropus parma*
Whiptail wallaby	*Macropus parryi*
Common wallaroo	*Macropus robustus*
Red-necked wallaby	*Macropus rufogriseus*
Brush-tailed rock wallaby	*Petrogale penicillata*
Red-necked pademelon	*Thylogale thetis*
Swamp wallaby	*Wallabia bicolor*

2.3.1 Wild horses on the Red Range Plateau

The removal of cattle from the Red Range Plateau after purchase of the land by NPWS has allowed the rapid growth of the horse population due to the increase in available resources. The Trial Capture Program revealed that the current annual population increase for the wild horses captured on the Plateau is 32% (E. Jessup, *pers. comm.*). This is well above the maximum population rate increase for wild horses, 21.7% (Linklater *et al.*, 2004), 20%

(Eberhard, 1987) and 18% (Garrott and Taylor, 1990; Garrott *et al*., 1991a). Linklater *et al*. (2004) stated that annual rates of increase above 24% are improbable, though Duncan (1992) indicated that the maximum rate of increase was 30% per year. The high rate of population growth for wild horses in GFRNP is revealed by the fact that 89% of mares older than two years were pregnant (E. Jessup, *pers. comm*.). There were also reports of several yearlings which were pregnant when captured (E. Jessup, *pers. comm*.), not an uncommon occurrence in wild horse populations (Garrott *et al*., 1991b). The high rate of reproduction can be linked to the favourable grazing conditions (Berger, 1986), resulting from the removal of cattle. Compensatory reproduction has also been reported for wild horse populations in response to the removal of unweaned foals (Kirkpatrick and Turner, 1991) or as a response to a large reduction in population size (Garrott and Taylor, 1990), once again, an indication of resource availability.

Impacts caused by the wild horses upon the environment of the Red Range Plateau are severe due to the high population density in this region. In addition to impacts such as erosion, overgrazing and trampling, the wild horses strip bark from the eucalypt species on the Plateau. This behaviour was studied by Schott (2004) who suggested that bark chewing increased from spring to summer and directly impacted upon the health of the tree. As a result of this prior research, my study concentrates upon the impact and distribution of bark chewing across the Red Range Plateau.

3.0 Assessment of bark chewing on the Red Range Plateau

3.1 INTRODUCTION

It is unknown how long wild horses have been living in Guy Fawkes River National Park (GFRNP) but horses have been in the region since the 1830's (NSW NPWS, 2003). The wild horses on the Red Range Plateau in GFRNP are known to have been chewing the bark of eucalypt species for many years (T. Prior, *pers. comm.*). Schott (2004) investigated this behaviour as part of a larger study on the ecology of the wild horses in the northern section of GFRNP. Bark chewing of eucalypt species by domesticated horses was recorded by Keenan (1986) and recently attracted media attention in the Canberra region (Locke, 2005) (Figure 3.1). Duncan (1992) indicated that horses can control the distribution of some tree species and are known to ring-bark large willow and poplar trees. Wood chewing by horses is a well documented phenomenon and has been attributed to a variety of reasons, ranging from boredom to dietary deficiency (Ralston *et al*., 1979).

Horses are not the only mammal known to chew bark. Bark stripping has been recorded for a wide variety of species in both the northern and southern hemispheres. For example, bark stripping damage by elephants, *Loxodonta africana*, has been recorded numerous times (Watson and Bell, 1969; Laws, 1970; Mwalyosi, 1981; Dublin and Douglas-Hamilton, 1987; Mwalyosi, 1987; Dublin *et al*., 1990; Mwalyosi, 1990; Calenge *et al*., 2002; Sheil and Salim, 2004). Elephants have caused severe damage to the *Acacia tortilis* woodland across Africa (northern Tanzania – Mwalyosi, 1981; Dublin and Douglas-Hamilton, 1987; Mwalyosi, 1987; Mwalyosi, 1990; Uganda – Sheil and Salim, 2004) and are thought to influence tree diversity and forest structure (Dublin *et al*., 1990; Sheil and Salim, 2004). Barbary macaques, *Macaca sylvanus*, strip bark from cedar trees in Morocco (Ciani *et al*., 2001) and there are reports of the Samango Monkey, *Cercopithecus albogularis* (Von dem Bussche and Van der Zee, 1985 in Baxter and Hansson, 2001), and the Chacma Baboon, *Papio ursinus* (Bigalke and Van Hensbergen, 1990 in Baxter and Hansson, 2001), also stripping bark.

Figure 3.1: Horses stripping bark from a red stringy-bark on the Hall Common, Canberra.
Source: Locke, 2005.

Packard (1942) originally recorded elk, *Cervus canadensis*, chewing the bark of quaking aspen (*Populus tremuloides*) in the Rocky Mountain National Park, Colorado. Elk eat the bark of mature trees (Romme *et al*., 1995) and it appears to be an important part of the elk diet (Hobbs *et al*., 1981) with nearly all the large aspen trees in Yellowstone National Park showing some signs of damage (Despain, 1990 and Kay, 1990 in Romme *et al*., 1995). Moose, *Alces alces*, in northern North America, eat bark from Mountain Ash (*Sorbus* spp.) and are responsible for a significant increase in mortality of the species (Scharf and Hirth, 2000). Moose are also recorded stripping bark in Sweden (Angelstam *et al*., 2000).

Various species of deer also strip bark. Studies have documented red deer, *Cervus elaphus* (Gebert and Verheyden-Tixier, 2001); sika deer, *Ceruvs nippon* (Putman, 1986 in Gebert and Verheyden-Tixier, 2001; Ueda, 2002); roe deer, *Capreolus capreolus* (Bergman *et al*., 2005); and fallow deer, *Dama dama* (Putman, 1986 in Gebert and Verheyden-Tixier, 2001; Borkowski and Obidzinski, 2003) removing bark from trees. Mountain hares, *Lepus timidus* (Laitinen *et al*., 2004); snowshoe hares, *Lepus americanus* (Reichardt *et al*., 1984); rabbits, *Oryctolagus cuniculus* (Bergman *et al*., 2005); grey and European red squirrels, *Sciurus carolinensis* and *S. vulgaris* (Kenward, 1983); and various other rodents (Baxter and

Hansson, 2001), are also noted for causing damage to trees by either eating or stripping bark.

Black bears, *Ursus americanus*, strip bark to feed on the sapwood of different species of trees and cause significant damage (Radwan, 1969; Peek, 1986). The main food item for beavers, *Caster canadensis*, for 10 months of the year, is bark from willow species, *Salix* sp., poplar, *Populus balsamifera*, and an alder, *Alnus crispa* (Aleksiuk, 1970). Bison, *Bison bison*, damage the bark on trees by rubbing and horning which can lead to the tree being de-barked (Meagher, 1973). Buffalo, *Synceru caffer*, in Africa have also been reported to cause damage to *Acacia* saplings by rubbing the bark off with their horns but the overall impact is not considered significant (Mwalyosi, 1990). Feral water buffalo, *Bubalis bubalis*, in northern Australia are known to strip bark from *Melaleuca* species (Tulloch, 1982; Skeat *et al*., 1996).

Bark stripping results in complete or partial girdling (Radwan, 1969). Girdling (also known as ring-barking) is the removal of a ring of bark from a tree trunk, resulting in death, or the removal of the bark from a branch, which can increase the flowering and fruiting of the tree (Brown, 1993). If the cambium is completely severed and the cuts enter the sapwood, the crown will die but the tree can sprout from below the girdle (Forbes and Meyer, 1956). A slower method of killing the tree occurs by removing two rings of bark and stripping the bark between the rings. This leaves the sapwood intact, the roots then starve and the tree loses the capacity to sprout and will eventually die (Forbes and Meyer, 1956). Starvation occurs as girdling prevents movement of photosynthates through the phloem from the canopy to the roots, but water is still able to move through the xylem (Högberg *et al*., 2001; Li *et al*., 2003; Nordgren *et al*., 2003). Girdling also results in the accumulation of carbohydrates above the girdle (Li *et al*., 2003). The degree of girdling, and the age of the tree, can influence the chances of survival of damaged trees. For Mountain Ash trees which suffered bark stripping by moose in North America, trunks which were 75% ring-barked had higher mortality than otherwise expected (Scharf and Hirth, 2000). As long as the tree was not completely ring-barked, Mwalyosi (1987) reported that the younger trees had a greater chance of recovery.

Previous research carried out on the Red Range Plateau provided the background for my study. Schott (2004) determined that there were two eucalypt species, *Eucalyptus saligna* and *E. amplifolia*, that were most often selected for bark chewing on the Red Range Plateau, with *E. moluccana* also a preferred species. The health and damage of 40 trees (20 damaged, 20 undamaged) revealed a significant relationship between bark chewing damage and the overall health of the tree (Schott, 2004). The patches of intensive bark chewing assessed were located in drainage lines, areas which also received the greatest amount of use by wild horses. Schott (2004) also reported that bark chewing appeared to be seasonal, with an increase of chewing from spring to summer.

The aims of this chapter include:

1. Assessing the location of bark chewing on the Red Range Plateau. Surveys by Schott (2004) and the Trial Capture Program contract musterers suggested that bark chewing was thought to only occur at the Boban (eastern) end of the Plateau.

2. Assessing whether bark chewing was clumped on the Red Range Plateau as suggested by Schott (2004), whether trees with chewing damage were clumped within the chewed areas and to determine what landscape variables are related to intensive bark chewing. I expected that trees with chewing damage would be clumped within the chewed areas only if the preferred species had a clumped distribution, as different food types are not randomly distributed across the landscape (Galef and Giraldeau, 2001).

3. Determining which eucalypt species the wild horses damage. Expectations were that only four species would show signs of bark chewing damage (Schott, 2004).

4. Assessing the size of the trees being chewed. Based on Schott's (2004) observations, I expected there would not be any selection of tree size for bark chewing.

5. Testing for a correlation between the level of bark chewing damage by horses and the health of the trees. Given the work by Mwalyosi (1987), Scharf and Hirth (2000) and Schott (2004), I expected there to be a correlation between the degree of damage and the health of the tree.

6. Comparing the degree of chewing in intensively damaged areas with any chewing occurring across the rest of the Plateau, at Boban and Wonga. Due to the descriptions

of these intensively damaged sites from the Trial Capture Program contract musterers and Tony Prior, NPWS Ranger, I expected that the intensively damaged areas would have more intense damage levels and more trees with bark chewing damage, than other areas across the Plateau.

3.2 METHODS

3.2.1 Bark chewing distribution

In order to assess whether bark chewing was distributed non-randomly across the Plateau as indicated by Schott (2004), six random sites were sampled to evaluate the distribution of bark chewing (Figure 3.2). These sites were determined by generating random numbers using Excel to provide UTMs. The first ten combinations which fell within the Boban end of the Plateau and within the GFRNP boundary were marked on the topographic map of the area (Kookabookra, 1:25,000 map sheet), as were the first ten combinations which fell within the Wonga section of the Plateau (see Chapter Two). Any UTM combinations that fell outside of these boundaries were discarded. Three sites to be surveyed at each end of the Plateau were drawn randomly from the sites marked on the map. These points (Table 1, Appendix) were entered into a Garmin Global Positioning System (GPS) unit, which was set to Aus Geod 66. I walked to each site and on arrival measured the diameter at breast height over bark (DBH), type of bark and whether any bark chewing had taken place, from the first sixty trees encountered. If bark chewing was recorded, the age of the chew was also noted.

The age of bark chewing was measured by the colour of the bark and whether the bark had started to heal. I had five categories, fresh (1), new (2), medium (3), old (4) and healed (5). Fresh was distinguished from new chewing by the presence of bark chips at the base of the tree. When bark chewing is fresh, the colour of the bark is a bright orange, and this colour fades as the chew ages. Medium aged chewing was a pale orange colour which was easily distinguished from the colour of undamaged bark. Old chewing had become grey, and healed chewing, showed a clear healing process taking place. These age differences are shown in Figure 3.3.

3.2.2 Intensive Sites

In order to assess sites of bark chewing, discussions with the Trial Capture Program musterers, E. Jessup and G. Baldwin, and National Parks and Wildlife Service (NPWS) Ranger, T. Prior were undertaken. These individuals have covered extensive areas of the Plateau in their roles as part of the Trial Capture Program in 2004/05 and as a NPWS Ranger of the area respectively, and my discussions with them resulted in locating six known sites with intensive bark chewing damage. These six sites provided the opportunity to gather baseline data describing the extent and intensity of damage in known intensively damaged areas and as a comparison with which to compare the rate and intensity of bark chewing across the entire Plateau.

Intensive bark chewing sites were identified by the high density of trees which have experienced severe bark chewing damage. These sites are easily recognised, because when one enters an area where intensive bark chewing has occurred, the majority of trees have some level of bark damage and most have been entirely stripped of their bark, usually from the base to above 1.5 metres in height. All of the six known intensively chewed sites were within the Boban area of the plateau - on the edge of the plateau east of Boban Hut, BC1; Dead Pig Gully, BC2; Top Dam, BC3; Boban dam, BC4; Scrubby dam, BC5; and the 'Super Highway', BC6 (Figure 3.2a; Table 2, Appendix). Intensively chewed areas were mapped by GPS to determine their extent (Figure 1, Appendix).

The boundary of intensively chewed sites was defined with flagging tape prior to being mapped with the GPS. The edge of the intensive bark chewing was defined as the point where I could not see any more chewing damage. An effort was made to ensure that trees were checked around the whole trunk for damage but there was still some potential for the extent of bark chewing to have been underestimated. This is highlighted by BC4, where a drainage line leading away from Boban Dam was later discovered to contain severe bark chewing but had not been included within the original map of the area. The aim of mapping these sites was to sample a representative distribution of bark chewing and to achieve this, I had to decide to discontinue mapping at two sites, BC2 and BC6, where bark chewing extended across a large area.

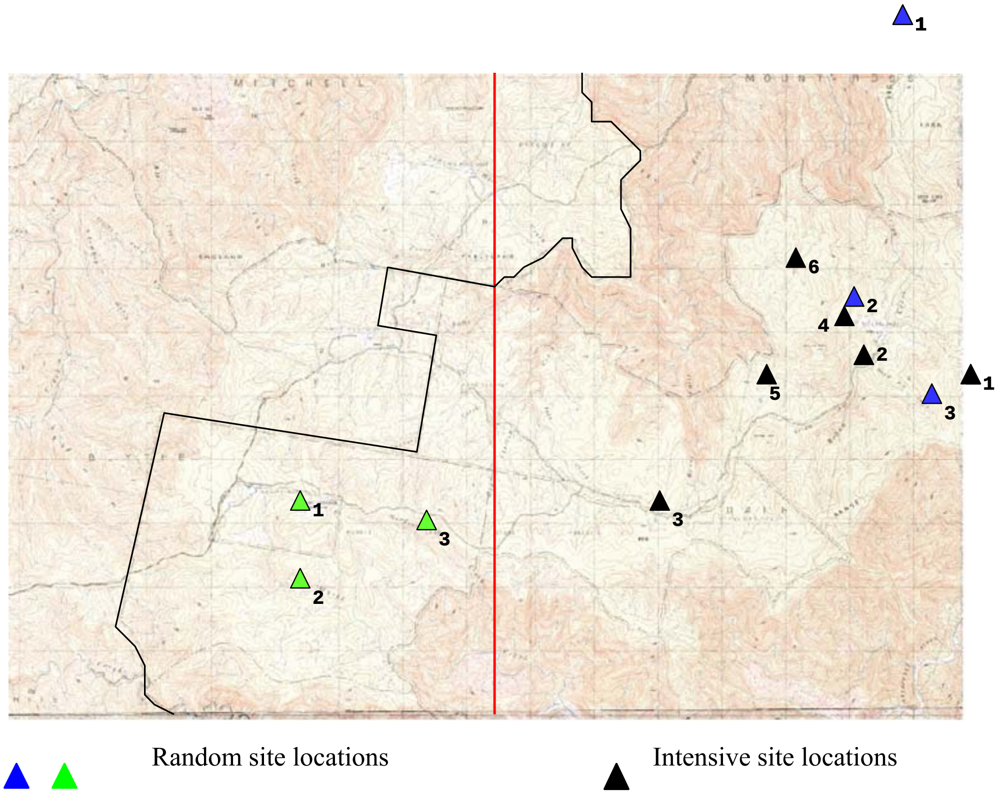

Figure 3.2a: Locations of random sites and intensive sites on the Red Range Plateau, GFNRP.

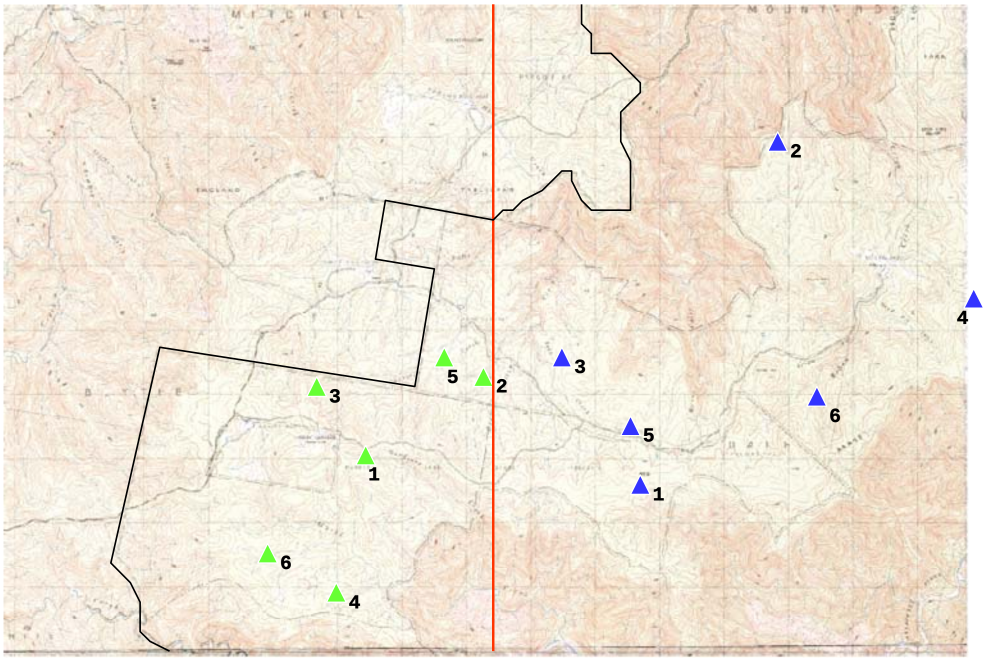

Figure 3.2b: Location of all random drainage line sites on the Red Range Plateau, GFRNP.

Figure 3.2: Locations of all sites on the Red Range Plateau, GFRNP.

Source: NSW NPWS, Coffs Harbour.

Figure 3.3a: New chewing (category 2) over an area which has old chewing (category 4) damage.

Figure 3.3b: The photo on the left shows a healed (category 5) area and the photo on the right shows fresh (category 1) chewing, distinguished from new chewing (category 2) by bark chips on the ground below the damaged sections.

Figure 3.3c: Medium chewing (category 3) on the left, compare with brighter colour of new chewing (category 2) on the right.

Figure 3.3: Categories developed for assessing the age of chewing damage by horses on the Red Range Plateau, GFRNP.

Three random quadrats (20m x 20m) were used to sample the intensively chewed sites. A grid with co-ordinates was placed over the map of the intensive site, with the size of the grid squares equivalent to the size of the quadrats. Ten co-ordinates were drawn from a pool of numbers giving ten potential quadrat sites. To ensure complete randomness, these ten sites were then drawn from another pool of numbers giving the location of the three quadrats to be sampled. I walked to these sites (Table 3, Appendix) by placing the arrow on the corresponding area of the site map on the GPS and laid out the quadrat, marking the corners with flagging tape which allowed revisits during the field work period, if necessary.

Within each quadrat, all tree species present were recorded, as was DBH, chewing activity, age of chewing, level of damage and the health of the tree (Figure 3, Appendix). The health of the tree was assessed using the tree health scale as a guide (J. Duggin, unpublished) (Table 3.1). Modification of the tree health scale (J. Duggin, unpublished) allowed assessment of bark chewing and allowed the depth of chewing and the extent of chewing around the trunk to be taken into account (Table 3.2). Age of chewing was placed into five different categories as for the random sites (see Section 3.2.1). The locations of all trees in each quadrat were mapped as they were sampled. There is a margin for error in the location of each tree within the quadrat but this was minimised by the use of the tape measure around the quadrat to approximate the distance each tree was from the edges of the quadrat. Canopy cover within each quadrat was also measured using a cardboard tube, with a 4.5cm diameter. The tube was divided into quarters and any canopy cover within a quarter was marked, giving an estimated percentage of cover for each point (25%, 50%, 75% or 100%). Twenty points within the quadrat were measured for canopy cover, and an average of these provided the overall canopy cover for the quadrat. The points used to measure cover were randomly selected by using a random walk method. Slope, presence or absence of sedges and elevation were also noted for each quadrat.

Vouchers of each tree species I recorded have been placed in the N.C.W. Beadle Herbarium at the University of New England, Armidale, allowing a redetermination to be made at any time. Species were identified using Harden (2002a; 2002b). Due to the lack of buds and fruits available for identification, it was not possible to identify one of the stringy-bark species, which has therefore been labelled 'Stringy' in the data. Stringy-barks are notoriously difficult to identify (I. Telford, N.C.W. Beadle Herbarium, *pers. comm.*) but as neither this species, nor any other stringy-bark species had bark chewing damage (see Section 3.3), identification of stringy-barks to species was a low priority. Due to the precise mapping of each quadrat, there is the potential to return to any site at a later date, when the species in question may be fruiting, in order to complete identification. Two other species, *Eucalyptus nobilis* and *E. dalrympleana*, are very similar and can only be distinguished using juvenile leaves, though, using vouchers from the N.C.W. Beadle Herbarium and assistance from Mr. Ian Telford, acting curator of the N.C.W. Beadle Herbarium, the species under question was determined to be *E. nobilis*. A fire hazard reduction burn was undertaken at Wonga during September 2005 (T. Prior, *pers. comm.*), which will hopefully give these species an opportunity to germinate. As *E. nobilis* had some chewing damage recorded in one quadrat, and more chewing damage noted in the vicinity, the fire provides the opportunity to clarify the identification of this species.

Table 3.1: Tree health scale (J. Duggin, unpublished).

Score	**Classification**	**Crown condition**
1.0 – 0.9	Healthy.	Full crowns or minor crown thinning (up to 5%) with/without some leaf damage (up to 5%).
0.9 – 0.8	Healthy, with some crown thinning.	Crown thinning evident (up to 10%) with/without some leaf damage (up to 10%). Minor dieback may be evident.
0.8 – 0.7	Slight dieback and minor crown thinning.	Dieback to smallest branches with up to 20% crown thinning with/without some leaf damage (up to 20%).
0.7 – 0.6	Slight dieback and crown thinning.	Dieback to smallest branches with up to 30% crown thinning and/or leaf damage. Crown thinning to 40% without dieback.
0.6 – 0.5	Dieback with crown thinning.	Dieback to minor branches with up to 20% crown thinning and/or leaf damage. Crown thinning to 50% without dieback.
0.5 – 0.4	Dieback with moderate crown thinning.	Dieback to minor branches with up to 30% crown thinning and/or leaf damage. Dieback to smallest branches with crown thinning to 60%.
0.4 – 0.3	Prominent dieback with crown thinning.	Dieback to major branches with up to 20% crown thinning and/or leaf damage. Dieback to minor branches with crown thinning to 50%.
0.3 – 0.2	Prominent dieback with significant crown thinning.	Dieback to major branches with up to 50% crown thinning and/or leaf damage.
0.2 – 0.1	Severe dieback with significant crown thinning.	Dieback to major branches with up to 70% crown thinning and/or leaf damage.
0.1 – 0.0	No crown or dead.	Tree crown absent or all leaves dead or tree dead or apparently so.

Following my first field trip, I realised that a measurement of the height of bark chewing should also be assessed as damage appeared to be concentrated around the base of the damaged trees. From the second field trip, I measured the height of bark chewing which was allocated to one of four height categories, 0-50cm, 50-100cm, 100-150cm and 150cm+.

Table 3.2: Bark chewing damage scale (modified from J. Duggin, unpublished).

Score	**Classification**	**Damage**
1.0	No damage	No visible bites on bark.
0.9	Mild	One or few bites, only top layer of bark removed.
0.8	Mild but more extensive	Top layer removed, larger patch damaged or several patches of damage, <50% of trunk affected.
0.7	Moderate	Damage on surface, all or most of the way around trunk of tree, >50% of trunk affected.
0.6	Moderate with depth	Damage deeper than surface bark, some almost to wood; small area of wood exposed.
0.5	Medium levels with regular depth	Wood exposed in one or more smaller patches; deep chewing over most of trunk.
0.4	Deep with extensive chewing	Wood exposed in several areas, ≤50%.
0.3	Severe	Wood exposed 50% - 75%.
0.2	Extremely Severe	Wood exposed ≥75%.
0.1	Almost ring-barked	Wood exposed most of the way around trunk, >90%.
0.0	Ring-barked	Totally ring-barked, wood exposed all way round trunk.

3.2.3 Random Sampling in Drainage Lines

As a result of the findings from the random sites across the Plateau (see Section 3.3.1) and the locations of the intensively damaged sites, I decided to concentrate on sampling drainage lines (Figure 3.4; Figure 3.5), where bark chewing damage appeared to be concentrated.

Random numbers were again generated as for the random sites (see Section 3.2.1). The first six valid points, falling within the National Park and the Boban and Wonga boundaries, were marked on the map for Boban and a further six were mapped for Wonga. Once again, these points (Table 4, Appendix) were entered into the GPS and I walked to these sites. Upon arrival, if the random point had not fallen within a drainage line, I walked to the drainage line nearest to the random point. The nearest drainage line was assessed by sight as not all drainage lines are marked on the map. The quadrats were placed in the middle of the drainage line if the landscape permitted (some have no trees along the centre of the drainage line), otherwise the quadrats were placed on the side of the drainage line from which I entered, preventing any bias resulting from a decision being made after assessing the site.

A transect with three 20m x 20m quadrats, 50 metres apart, was used to sample bark chewing in the random drainage line sites. The point at which I entered the drainage line marked the centre quadrat to be sampled. The other two quadrats were placed 50 metres from either edge of the central quadrat, along the length of the drainage line (Table 5, Appendix). The trees within the quadrats were sampled for the same criteria as the trees in the intensive quadrats – DBH, chewing, age of chewing, health of the tree and amount of chewing damage. Canopy cover, presence or absence of sedges, slope, and elevation were also recorded, and height of chewing was noted for all but three of the twelve sites.

Figure 3.4: Drainage line below Scrubby Dam, BC5, on the Red Range Plateau, GFRNP.

Figure 3.5: A randomly sampled drainage line, WS4, on the Red Range Plateau, GFRNP.

3.2.4 Statistical Analyses

Prior to analyses, all data were tested for normality. Most data were not normally distributed and could not be transformed and in these instances the appropriate non-parametric statistical test was used. I used *Statistix* (Analytical Software, 2000) to analyse univariate data comparing tree health, damage scores and DBH within and between sites. I undertook chi-squared analyses on the number of damaged and undamaged trees to determine whether tree species were being randomly chewed or whether they were being selected. I used one-way ANOVA, or the non-parametric equivalent, Kruskal-Wallis one-way ANOVA, depending upon normality tests, to assess whether damage levels were different at each site within the intensive, Boban or Wonga treatments. This test was also applied to the health of damaged and undamaged trees at each site. Only the health of live trees was used for this analysis as the inclusion of trees which are already dead could give a false indication of the average health of trees, leading to the assumption that tree health was poorer than it actually was. I used Spearman Rank Correlation to assess whether there was any correlation between the average bark chewing damage to a eucalypt and the health of the tree. This was assessed for the intensive sites, Boban and Wonga as well as an overall assessment of all damaged trees on the Plateau.

Tree DBH data was not normally distributed, due to the skewing of the data when separated into trees with chewing damage and trees with no chewing damage. Therefore, I compared the medians of the DBH of damaged and undamaged trees using a Kruskal-Wallis one-way ANOVA. To determine whether selection for a particular size of tree was occurring, DBH measurements were distributed into six size classes – Class 1 (0.1cm -9.9cm); Class 2 (10.0-19.9cm); Class 3 (20.0cm- 29.9cm); Class 4 (30.0cm- 39.9cm); Class 5 (40.0cm- 59.9cm); and Class 6 (>60.0cm). The proportion of trees being chewed for each size class was analysed using a two-way ANOVA, comparing the proportion of each size class being chewed and whether there was a relationship between this and the sites of bark chewing. Only the intensive sites had normal data, therefore the non-parametric Friedman's test was carried out on the Boban and Wonga data.

Within all quadrats, I drew maps marking the location of all trees (Figure 2, Appendix), providing an approximate distance between each tree. The distance between nearest neighbours for all eucalypts within each quadrat was measured from these maps, as was the distance between the nearest neighbours of chewed trees. This data was entered into the Clarke and Evans Test v.5.1 in *Programs for Ecological Methodology* (Krebs, 2000). This test required a minimum of three trees in order to calculate distribution and therefore, some quadrats with bark chewing were not included in these analyses due to them having fewer than three damaged trees. This test provides information upon the distribution of trees in the quadrats, allowing determination of whether the trees were either, randomly, clumped or regularly distributed. Significant clumping of trees occurs when the resultant z-score is less than -1.96, a significantly regular distribution occurs when $z > 1.96$ and a random distribution occurs when $-1.96 < z < 1.96$ (Krebs, 2000).

PRIMER (Primer, 2002) was used to analyse multivariate data. The variables compared were canopy cover, elevation, slope, percentages of stringy-barks, *E. amplifolia, E.*

moluccana, Acacias and *Allocasuarinas* within each quadrat, the distance to the nearest accessible standing water source, presence or absence of sedges and the percentage of trees in each size class within each quadrat. These were compared for each quadrat and overlaid with the presence or absence of chewing damage.

To calculate the minimum area of the Plateau covered by drainage lines, creek lines with a slope less than 20° were highlighted using the program ArcMap 9.0 (ESRI, 1999-2004). There were only two trees with bark chewing damage recorded in quadrats with a slope of 20°, so any creek lines with a slope greater than this were omitted as the likelihood of the occurrence of bark chewing within these sites was low. A buffer of 10 metres was then placed on either side of the creek lines to approximate the average width of drainage lines where bark chewing had been recorded. This buffer zone provided the area of the Plateau covered by this habitat and the average number of trees per quadrat was used to calculate the number of trees within this habitat. The background rate of bark chewing, which was taken to be the average rate of damage occurring in drainage lines at Boban and Wonga, was then used to determine the minimum number of trees that could be expected to have some level of bark chewing damage.

3.3 Results

3.3.1 Location and rate of bark chewing

Six random sites were used to assess the location of bark chewing on the Red Range Plateau. Out of 360 eucalypt trees randomly sampled across the Red Range Plateau, only three trees had signs of mild bark chewing (Table 3.3). More stringy-barks were sampled at Boban than at Wonga but a similar number of trees with box bark were sampled at both sites. The age of the chewing at Boban was old (category 4) and the two trees at Wonga had chewing that was old (category 4) and healed (category 5). The two trees damaged at Wonga were located near a drainage line and the damaged tree at Boban was on a slope between two drainage lines. Bark chewing damage was observed whilst walking to the random sites and indicated that bark chewing was concentrated in patches across the landscape. The average DBH of the 360 trees sampled was 24.4cm (standard deviation = 20.04), with a range of 2.1cm to 118.3cm.

Table 3.3: Summary of the numbers of trees sampled at the random sites. Chewed trees are in parentheses.

	Boban	Wonga	**2.-1 Total**
Box	96	95 (2)	189
Smooth	15 (1)	32	46
Stringy	68	53	121
Ironbark	1	0	1
3.-1 Total	179	178	**360**

The sites with intensive bark chewing damage were clustered at the Boban end of the Plateau (Figure 3.2a) and the size of these sites did not differ greatly (Table 3.4; Figure 1, Appendix). The random drainage line sites at Boban and Wonga revealed that bark chewing was occurring across the entire Plateau. In total, 60% of the sampled eucalypts in the intensive sites suffered some level of chewing damage. This rate of intensive chewing (60%) is much greater than the background rate of bark chewing (10.9%) recorded in the drainage lines at Boban and Wonga. 12.7% of trees in the drainage lines at Boban and 9.1% of trees in drainage lines at Wonga had bark chewing damage.

Table 3.4: Size of the areas covered by intensive bark chewing sites on the Red Range Plateau, GFRNP.

Site		**Area (Hectares)**
BC1	East Boban	2.64
BC2	Dead Pig Gully	4.66
BC3	Top Dam	1.29
BC4	Boban Dam	2.88
BC5	Scrubby Dam	4.4
BC6	Super Highway	5.39
Average		**3.54**

3.3.2 Selection of tree species, tree size and degree of bark chewing damage

The greatest amount of bark chewing damage was inflicted upon two species, *E. amplifolia* and *E. moluccana* (Figure 3.6). *Eucalyptus saligna* was also damaged and several individual trees of *E. melliodora*, *E. nobilis* and *E. retinens* were mildly damaged. Overall, there were more *E. amplifolia* with bark chewing damage than expected and fewer *E. moluccana* ($p < 0.0001$) (Table 3.5) with the same pattern for the intensive ($p < 0.0002$) (Table 6, Appendix), Wonga ($p < 0.0119$) (Table 7, Appendix) and Boban sites ($p < 0.0002$) (Table 8, Appendix). The drainage lines at Boban also had greater numbers of *E. moluccana* than *E. amplifolia* (Figure 3.6a) compared with the intensive and Wonga sites (Figure 3.6b), which shows that the sites with high *E. amplifolia* density had already been sampled in the intensive sites at Boban. Other species located within the quadrats included *Acacia filicifolia*, *Acacia blakei subspecies diphylla, Allocasuarina torulosa*, *Angophora subvelutina* and *Exocarpos cupressiformis*. These species were also assessed and no bark chewing damage was recorded.

Table 3.5: Chi-squared analysis for the three most commonly damaged eucalypt species on the Red Range Plateau, GFRNP.

	Chewed	**Not chewed**	**Total**
E. amplifolia Observed Expected	209 169.52	168 207.48	**377**
E. moluccana Observed Expected	92 130.85	199 160.15	**291**
E. saligna Observed Expected	16 16.64	21 20.36	**37**
Total	**317**	**388**	**705**

$\chi^2 = 37.71$; $p < 0.0001$; df = 2

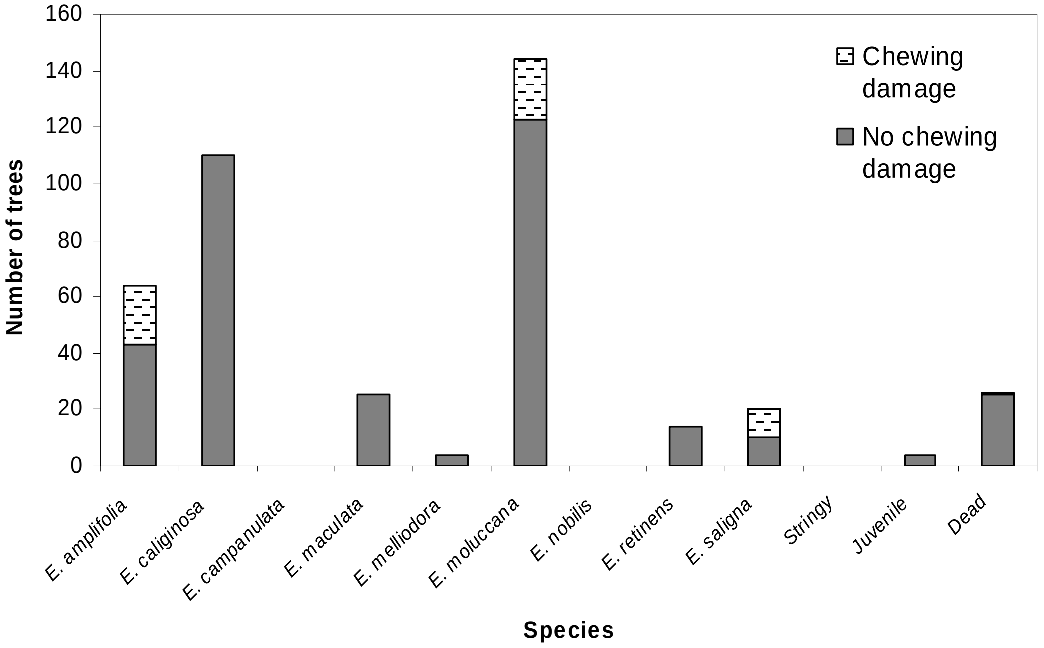

Figure 3.6a: Number and species of trees that were damaged and undamaged at Boban sites on the Red Range Plateau, GFRNP.

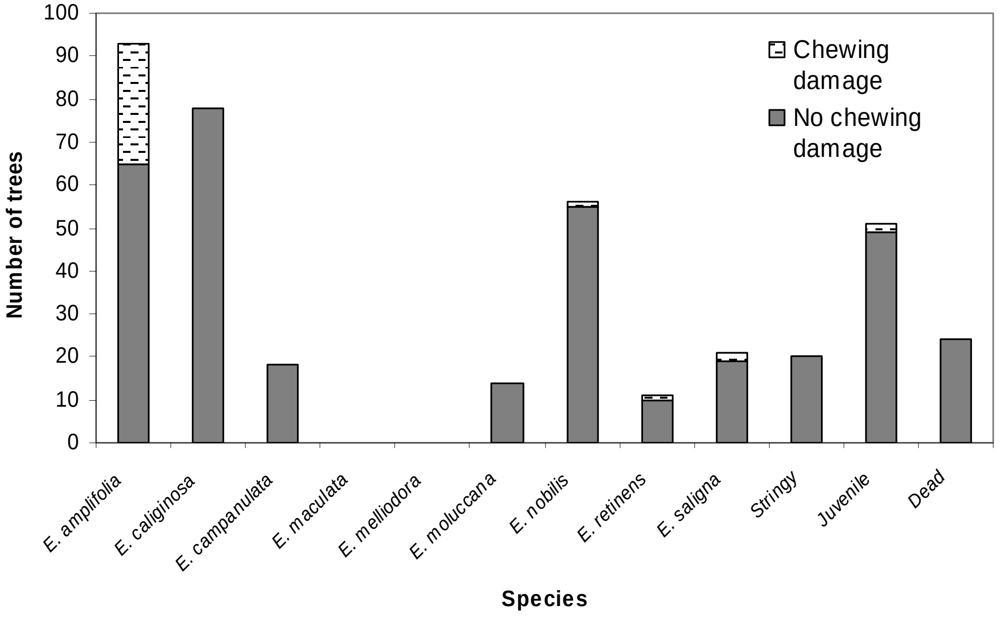

Figure 3.6b: Number and species of trees that were damaged and undamaged at Wonga sites on the Red Range Plateau, GFRNP.

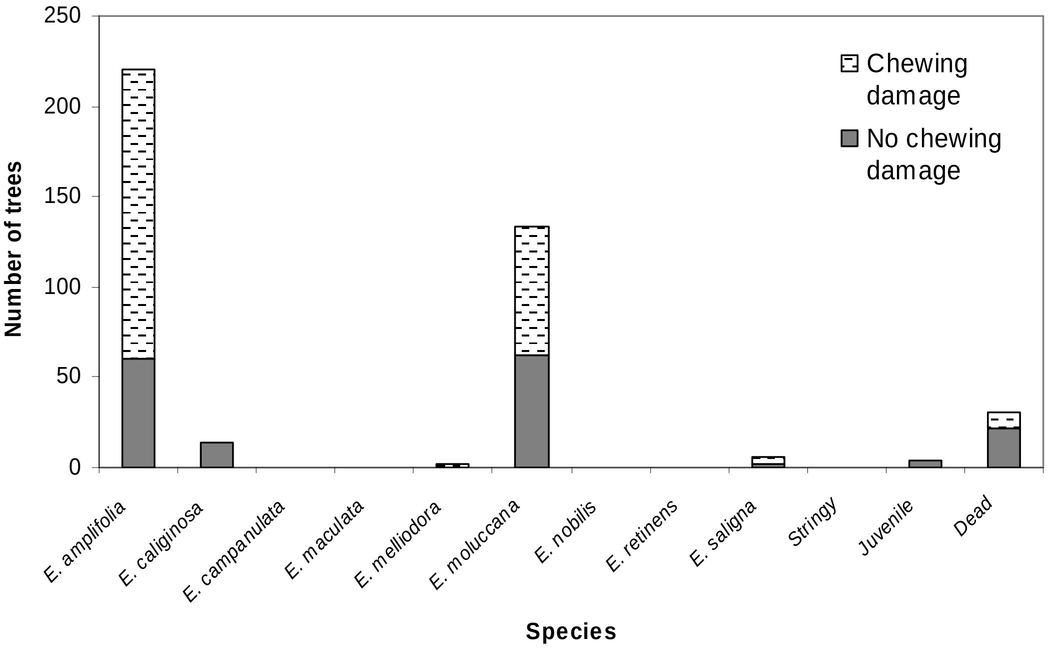

Figure 3.6c: Number and species of trees that were damaged and undamaged at intensive sites on the Red Range Plateau, GFRNP.

Figure 3.6: Number and species of trees that were damaged and undamaged for all treatments on the Red Range Plateau, GFRNP.

The medians of the DBH for all damaged and undamaged trees were significantly different (Kruskal-Wallis statistic = 35.5221; $p < 0.0001$) (Figure 3.7), although this trend was not apparent when data from the Wonga sites were analysed separately (Kruskal-Wallis statistic = 0.0334; $p = 0.8550$). The average DBH of chewed trees had small variation across all sites (20.32cm-23.66cm) (Figure 3.7b). Damaged trees at Boban and within the intensive sites had a significantly larger median DBH than the undamaged trees (Boban: Kruskal-Wallis statistic = 15.0683; $p < 0.0001$; intensive: Kruskal-Wallis statistic = 33.1560; $p < 0.0001$). There was also no difference between the median of the DBH of trees with bark chewing damage between the random drainage line sites and the intensively damaged sites (Kruskal-Wallis statistic = 35.5221; $p < 0.0001$).

A two-way ANOVA revealed that the proportion of trees chewed in each size class did not differ between intensive sites (p = 0.665) but did differ between size classes (p = 0.0407). The Friedman Test showed that at Boban there was no difference between the proportions of trees chewed within each size class (p = 0.6434) but this is most likely a reflection of a large standard error due to the small sample sizes for some of the size classes. There was however, a significant difference between the proportion of trees chewed at each site (p = 0.0027) which reflects the patchiness of bark chewing distribution across the landscape. The Friedman Test was also carried out for the proportion of chewed trees in size classes at Wonga. As with Boban, there were differences between the proportion of each size class chewed at each site (p = 0.0090) but there was no difference between the proportion of trees with chewing damage for each size class (p = 0.3243), once again probably due to the small sample sizes with a large standard error.

The degree of bark chewing damage to trees did not differ between the random drainage line sites and the intensive sites (Kruskal-Wallis statistic = 0.1280; p = 0.7205) (Figure 3.8). Bark chewing damage was recorded in all intensive sites but not at all Boban and Wonga sites. However, bark chewing was shown to occur on the northern, southern and eastern edges of the Plateau as shown by presence of bark chewing at BS2 (northern edge), BC1 (eastern edge) and observations made whilst walking along the southern edge of the Plateau. Sites with bark chewing showed no significant difference in the degree of chewing damage at Boban (Kruskal-Wallis statistic = 8.3070; p = 0.0810) but there was a significant difference between the degree of chewing damage at the Wonga sites (Kruskal – Wallis statistic = 15.5951; p = 0.0014) and each of the intensively damaged sites (Kruskal-Wallis statistic = 29.3266; p < 0.0001). Severe bark chewing occurred when at least 50% of the bark had been removed from the trunk with 14.4% of all damaged trees on the Plateau suffering severe damage. One third of all trees which had been damaged had only slight (0.9) damage (Figure 3.9). The intensive sites had 14.2% of chewed trees with severe bark chewing, compared with the drainage line sites 15.4% (Boban – 13.2%; Wonga – 17.6%).

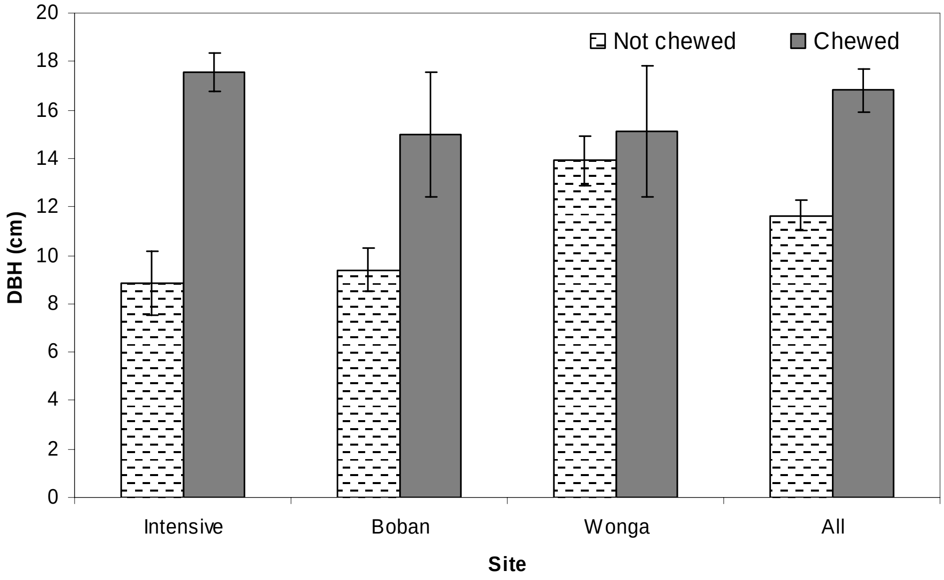

Figure 3.7a: Median of DBH of damaged and undamaged trees (with standard error bars) for all trees at all sites on the Red Range Plateau, GFRNP.

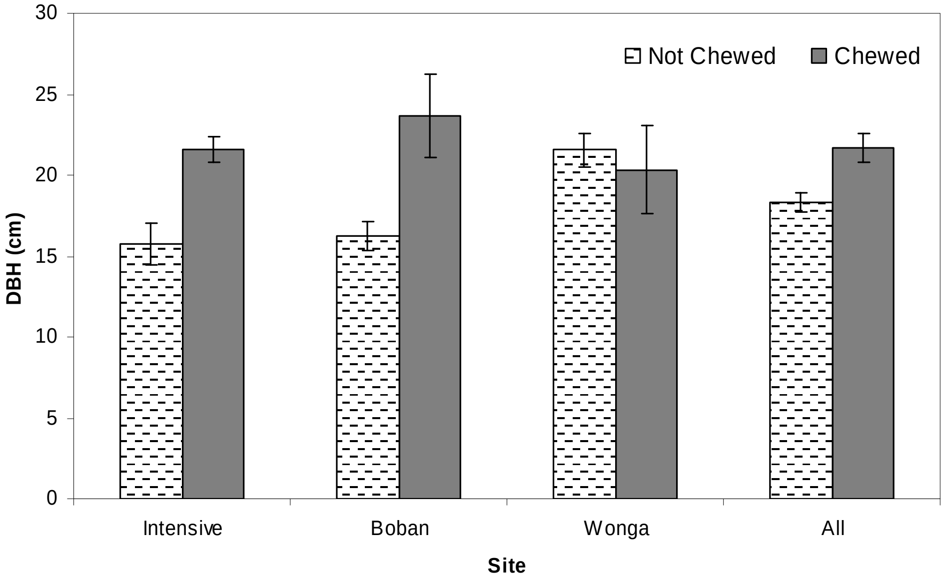

Figure 3.7b: Average DBH of damaged and undamaged trees (with standard error bars) for all trees at all sites on the Red Range Plateau, GFRNP.

Figure 3.7: Comparisons of DBH for damaged and undamaged trees for all sites on the Red Range Plateau, GFRNP.

3.3.3 *Tree health*

Damaged eucalypts in the randomly sampled drainage line sites had an overall poorer median health score than the damaged trees in the intensive sites (Kruskal-Wallis statistic = 8.0348; p = 0.0046). The health of damaged trees within the intensive sites were significantly different (Kruskal-Wallis statistic = 15.8269; p = 0.0074) with damaged trees at Dead Pig Gully (BC2) and Boban Dam (BC4) having poorer health than the damaged trees in Top Dam (BC3) and Eastern Boban (BC1). The health of chewed trees did not differ between sites at Boban (Kruskal-Wallis statistic = 5.6063; p = 0.6257) nor did they differ between sites at Wonga (p = 0.1306).

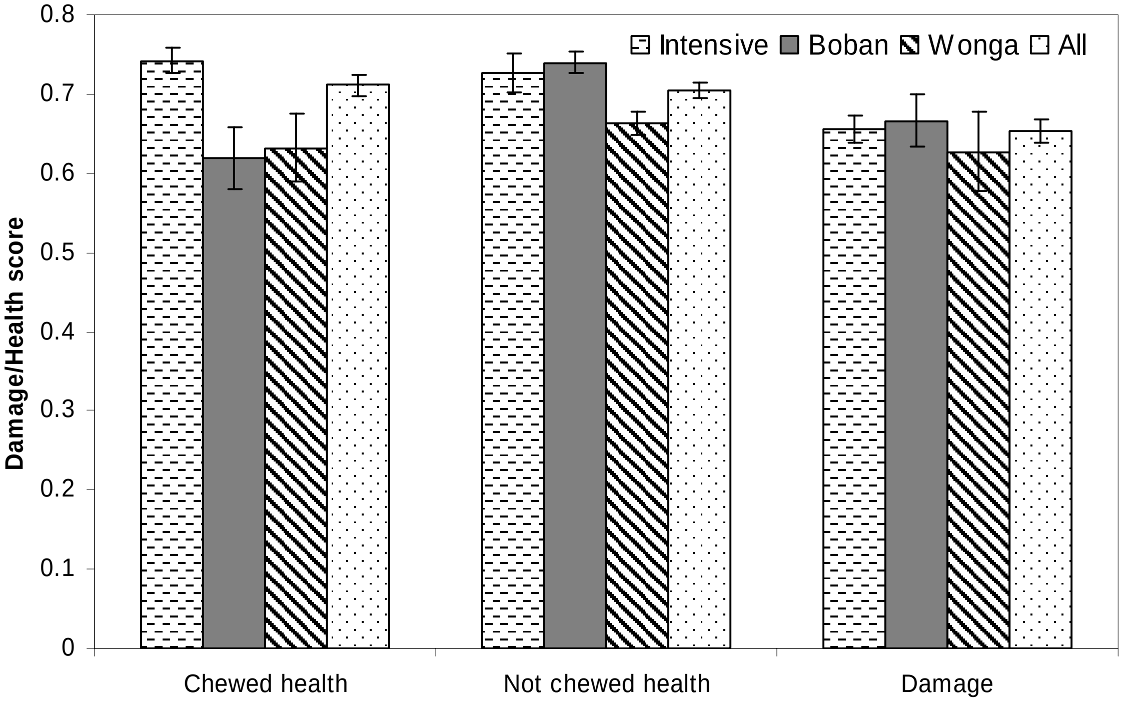

Figure 3.8: Average health for damaged and undamaged trees and average damage scores (with standard error bars) for all chewed trees at all sites on the Red Range Plateau, GFRNP.

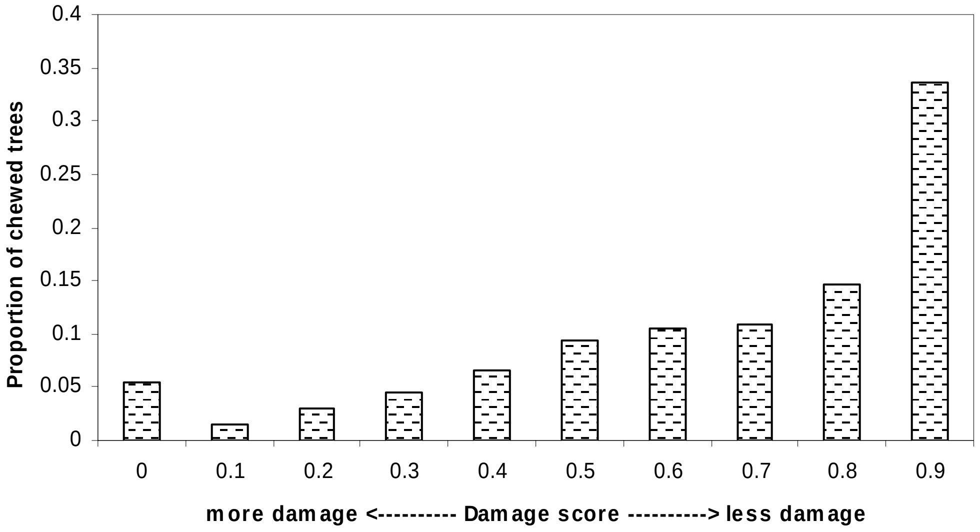

Figure 3.9: Proportion of trees with bark chewing damage for each damage score for all damaged trees sampled on the Red Range Plateau, GFRNP.

Overall, trees on the Red Range Plateau which suffered bark chewing damage had similar levels of health as the trees with no bark chewing damage (Kruskal-Wallis statistic = 0.0567; p = 0.8118). The health of live chewed trees did not differ from the health of the live undamaged trees in the intensively damaged sites (Kruskal-Wallis statistic = 0.1852; p = 0.6670) nor in the Wonga sites (Kruskal-Wallis statistic = 0.6592; p = 0.4169). The level of health did differ in the Boban sites (Kruskal-Wallis statistic = 6.7848; p = 0.0092) with the undamaged trees healthier than the damaged trees (Figure 3.8).

However, among chewed trees, there was a strongly significant negative correlation between the health of damaged trees and the extent of damage (Spearman Rank Correlation = 0.3133; p < 0.0001) (Figure 3.10). The Wonga and intensively damaged sites also showed a strong correlation between tree health and bark chewing damage (Wonga – Spearman Rank Correlation = 0.3873; p = 0.0222; intensive - Spearman Rank Correlation = 0.3598; p < 0.0001) (Figure 3.11). There was no correlation between tree health and damage levels at Boban (Spearman Rank Correlation = 0.0728; p = 0.6065).

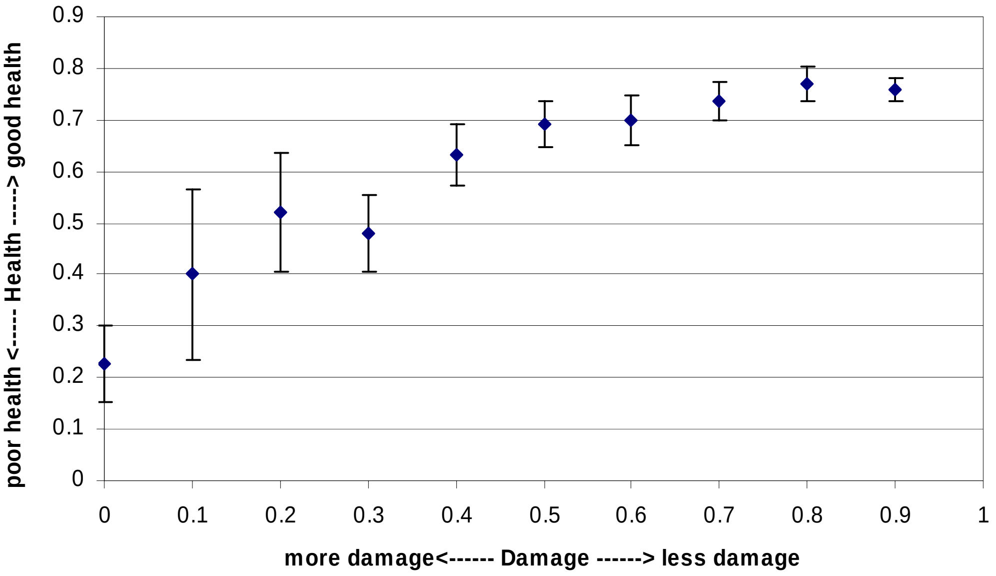

Figure 3.10: Correlation between mean health score and damage score (with standard error bars) for all damaged eucalypts at all sites on the Red Range Plateau, GFRNP.

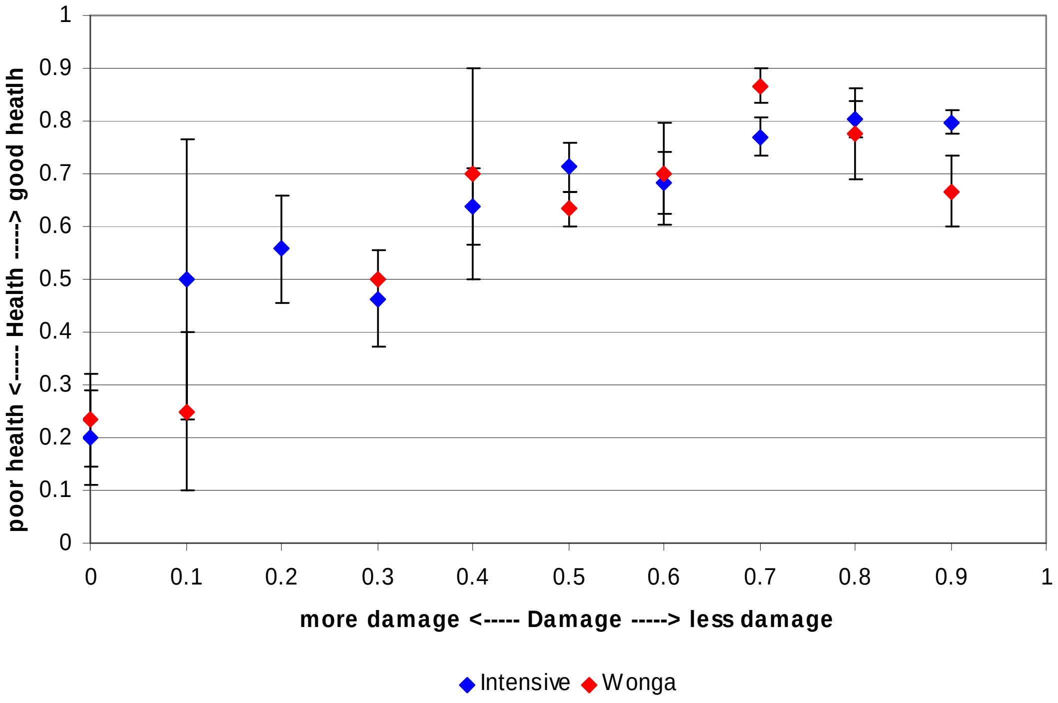

Figure 3.11: Correlation between mean health score and damage score (with standard error bars) for all damaged eucalypts in the Wonga and intensively damaged sites on the Red Range Plateau, GFRNP.

3.3.4 Fine scale pattern of tree damage

Trees were shown to be clumped at the landscape scale through the concentration of chewing within the drainage lines on the Red Range Plateau. The maps of each quadrat provided information which allowed determination of the distribution of the eucalypts in each quadrat. Trees were significantly clumped if the nearest neighbour z-score was less than -1.96 and trees were regularly distributed if $z > 1.96$. If z was close to zero, the trees could be considered randomly distributed through the quadrats. Ignoring whether the trees had suffered bark chewing damage, most quadrats (43/54) showed random tree distribution, with seven quadrats having trees which were significantly clumped and two quadrats at Boban had regular distribution (Figure 3.12). The chewed trees within these quadrats tended to show that the distribution of chewed trees followed the distribution of all trees within the quadrat. Clumping of chewed trees mostly occurred in quadrats which had a clumped tree distribution, although two chewed quadrats at Wonga had a random tree distribution and a clumped chewed tree distribution (Figure 3.12c).

Bark chewing damage by wild horses is concentrated at the base of the eucalypts. Of the 137 trees for which this measure was recorded, 81.8% had chewing damage below 50cm and 77.4% had bark chewing occurring between 50 cm and 100cm (Table 3.6). In total 62.8% of all trees measured had bark chewing damage in both categories below 100cm and 19 trees (13.9%) had bark chewing damage in all four height categories. All categories of bark chewing damage were recorded throughout all field work, with fresh chewing recorded every month, showing that bark chewing occurs throughout the autumn and winter periods.

The mean DBH of chewed trees was 21.7cm and trees which had no bark chewing damage had a mean DBH of 18.3cm. The thickness of bark for trees with bark chewing damage averaged 1.69cm (Figure 4.4). Bark chewing could reach up to 2.15 metres (*pers. obs.*) in an intensively chewed site but this was not common. The average volume of bark removed from a trunk which has been ring-barked to a height of one metre and with a bark thickness of 1.69cm, is 5,536cm^3.

Table 3.6: Percentage of eucalypt trees chewed within each height category of the 137 eucalypts assessed for this criterion on the Red Range Plateau, GFRNP.

Height	Number of trees	Percentage chewed
0-50cm	112	81.8%
50-100cm	106	77.4%
100-150cm	76	55.5%
150cm+	21	15.3%

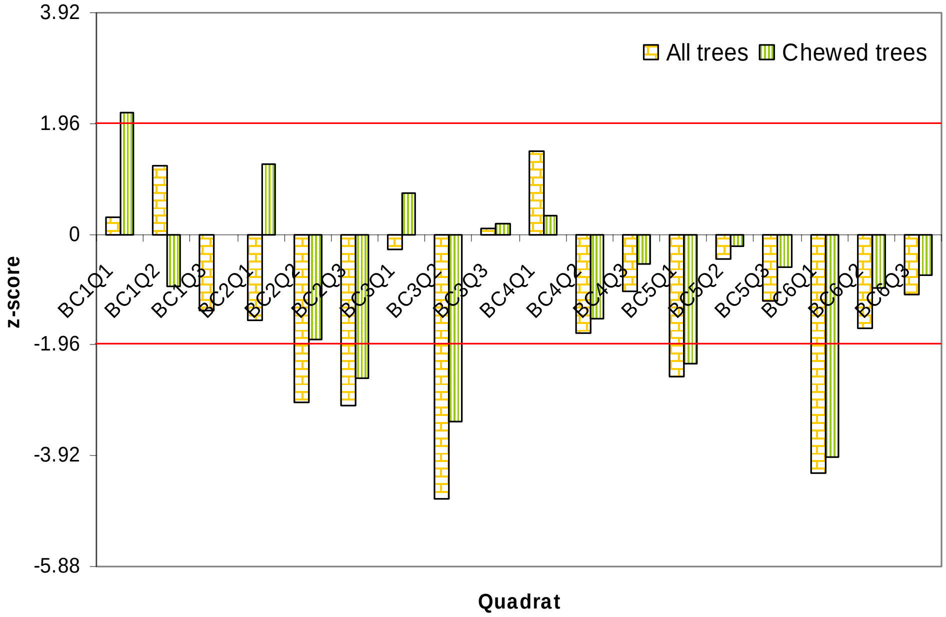

Figure 3.12a: Z-scores for all quadrats within the drainage lines at all intensive sites on the Red Range Plateau, GFRNP.

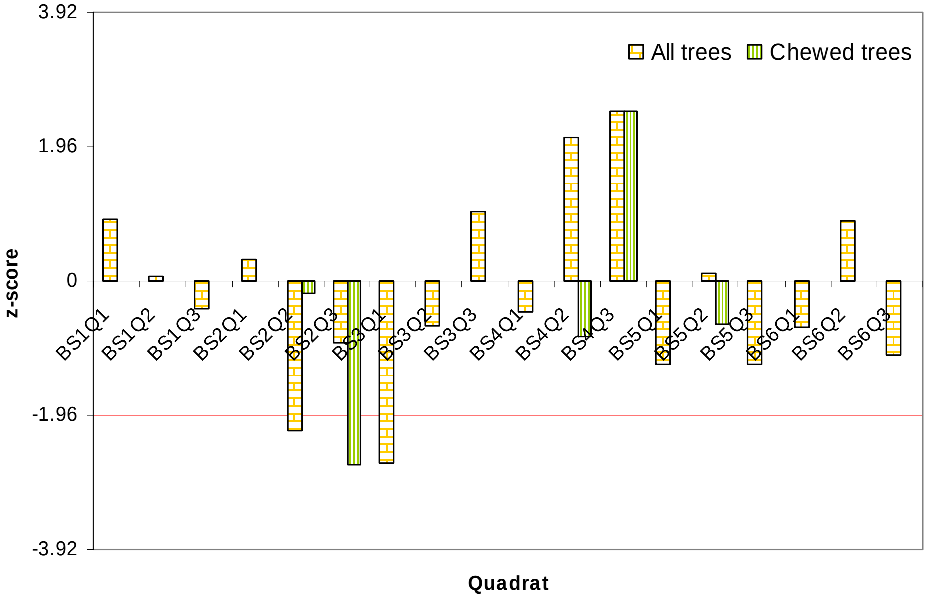

Figure 3.12b: Z-scores for all quadrats within the drainage lines at all Boban sites on the Red Range Plateau, GFRNP.

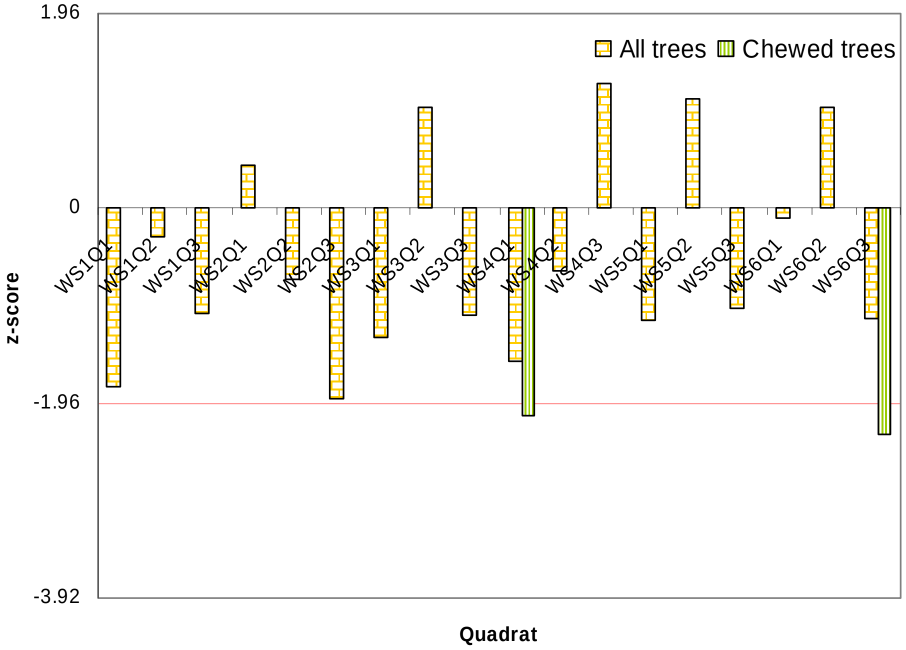

Figure 3.12c: Z-scores for all quadrats within the drainage lines at all Wonga sites on the Red Range Plateau, GFRNP.

Figure 3.12: Z-scores for all quadrats on the Red Range Plateau, GFRNP.

3.3.5 Variables influencing bark chewing sites

Ordination plots revealed that the quadrats which had no recorded bark chewing damage were clumped, in theoretical component space, within the quadrats which had bark chewing damage (Figure 3.12a). This appears to be correlated to the percentage of stringy-barks recorded in these quadrats (Figure 3.12b). Most of the intensively chewed sites are clumped within one region of the plot (Figure 3.12c), and this region has the greatest percentage of *E. amplifolia* (Figure 3.12d). Quadrat BS4Q1 is an outlier most likely due a large number of eucalypts in size class 5 (Figure 4, Appendix). The stress level for this analysis is 0.21 which indicates there is the potential for distortion of the plot by outliers or indicates that another dimension may be required to compare the similarity effectively. Analyses with stress levels below 0.20 are considered to be valid.

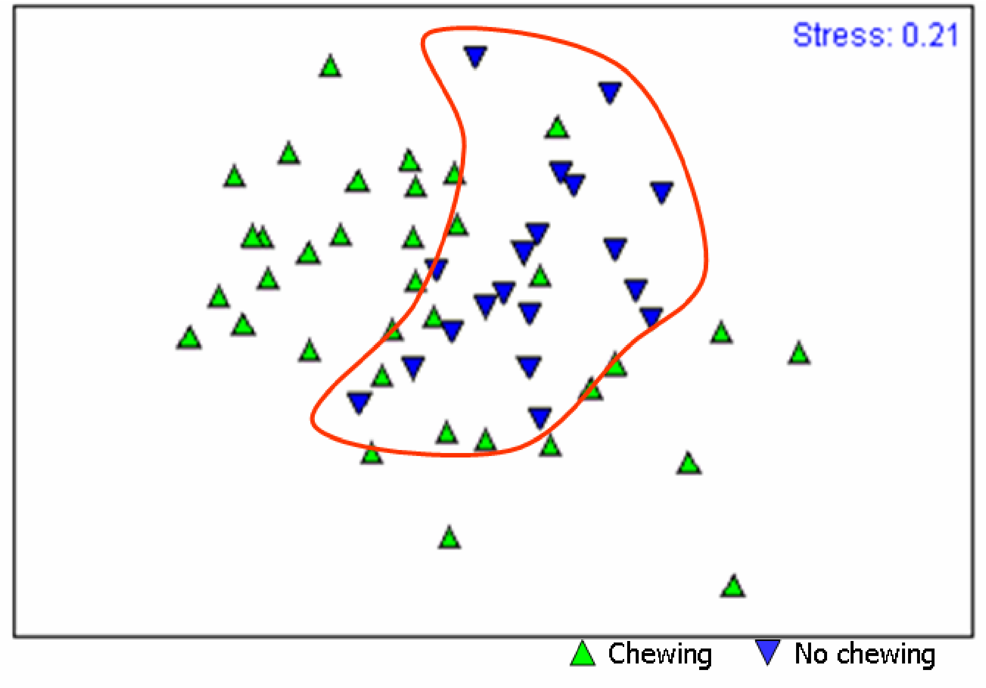

Figure 3.13a: Ordination plot of quadrats sampled with bark chewing damage and no recorded damage on the Red Range Plateau, GFRNP.

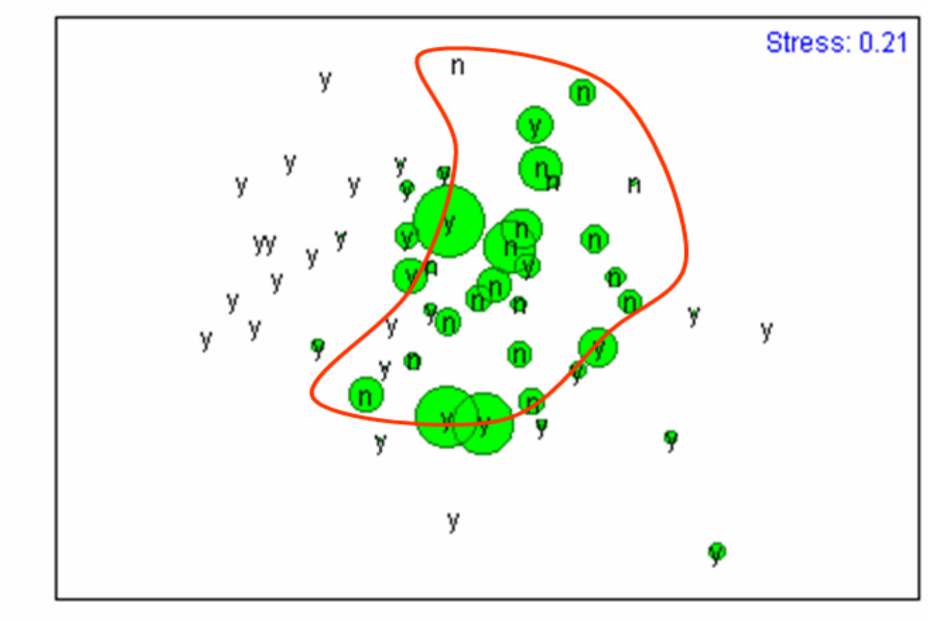

Figure 3.13b: Ordination diagram showing the concentration of quadrats with no chewing damage (n) and quadrats which have high percentages of stringy-barks present. The percentage of stringy-barks are represented by bubbles – the larger the bubble, the greater the percentage of stringy-barks.

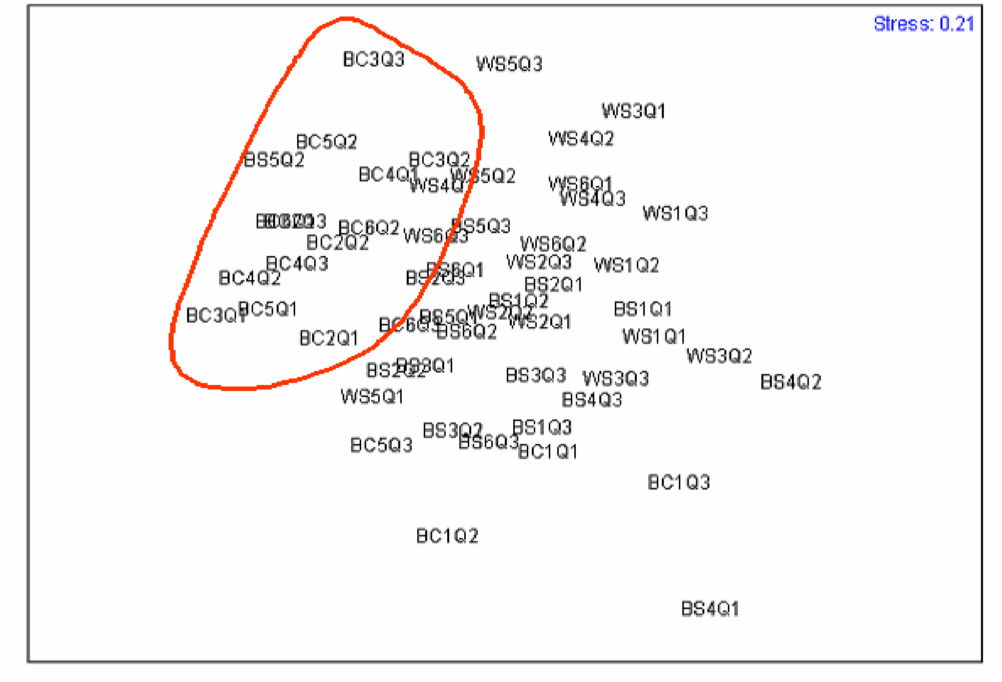

Figure 3.13c: Ordination plot of all quadrats sampled on the Red Range Plateau, GFRNP. BC = intensive sites; WS = Wonga sites, BS = Boban sites.

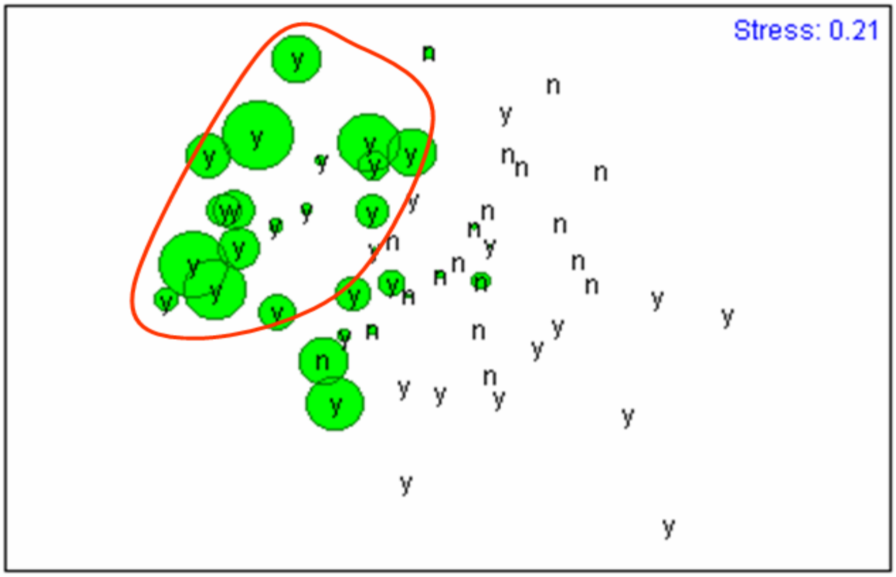

Figure 3.13d: Ordination diagram showing the concentration of quadrats with intensive chewing damage (BC, Figure 3.13c) and quadrats which have high percentages of *Eucalyptus amplifolia* present. The percentage of *E. amplifolia* are represented by bubbles – the larger the bubble, the greater the percentage of *E. amplifolia*.

Figure 3.13: Ordination diagrams of all quadrats on the Red Range Plateau, GFRNP.

3.3.6 Predicted extent of tree damage

The Red Range Plateau has approximately 241.1 hectares of creek lines which do not have a slope of greater than 20° (Figure 3.14). This means that a minimum of 4.7% of the Red Range Plateau is covered by creek lines which have a topography linked with the occurrence of bark chewing. The area covered by these creek lines serves to indicate only the minimum area of land on the Plateau with this topography. Many of the drainage lines where bark chewing was sampled are not marked as creek lines on the map and actually run into marked creek lines (*pers. obs.*) and therefore it is expected that the amount of land covered by this habitat would be greater than the current estimation. Not all of these creek lines form drainage lines similar to the drainage lines sampled due local environmental variation but the presence of unmapped drainage lines prevents the model from over-estimating potential bark chewing habitat. The area covered by creek lines is 116.3 hectares at Wonga and 124.8 hectares at Boban.

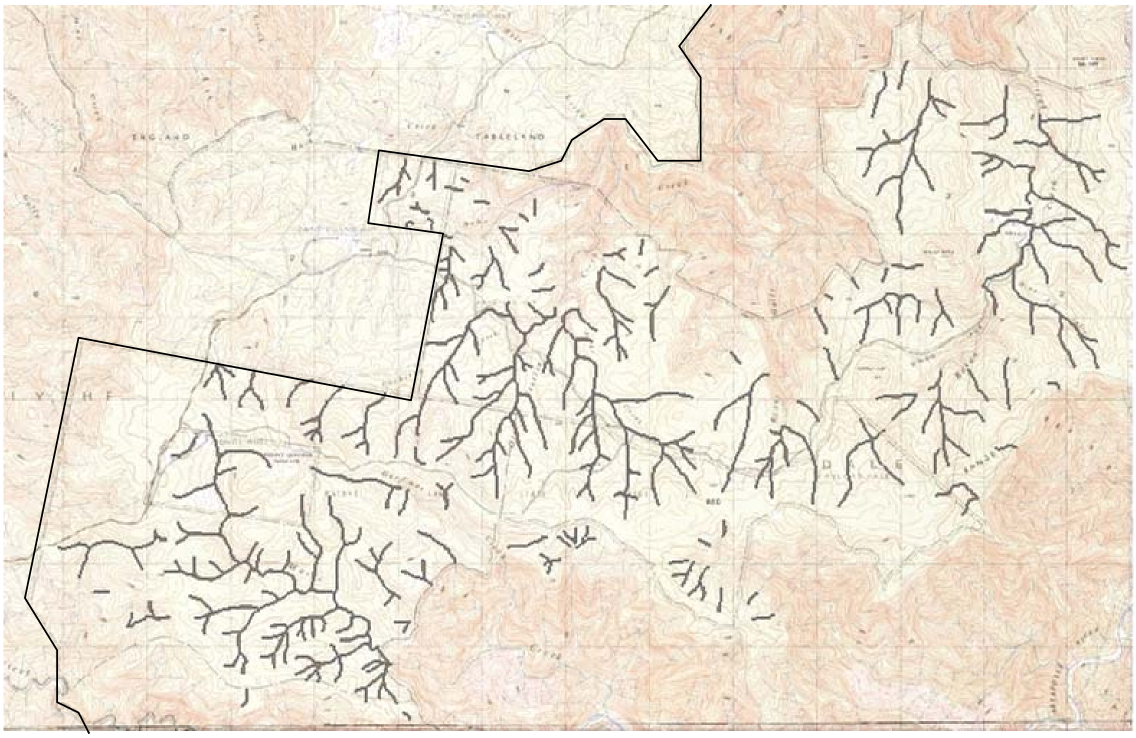

Figure 3.14: The Red Range Plateau, GFRNP, with 20 metre buffer zones over creek lines with less than 20° slope.

Source: Topographic map supplied by NSW NPWS, Coffs Harbour.

I recorded an average of 22.4 eucalypt trees per 400m^2 (one quadrat), which leads to an estimation of 135,014 trees within the 241.1 hectares of creek lines on the Plateau. The numbers of all tree species sampled within the intensive and drainage line sites can be found in Table 9, Appendix. The background rate of bark chewing is 10.9% (excludes intensively chewed sites) which indicates that the minimum number of trees with bark chewing damage on the Red Range Plateau is 14,582 trees. The rate of severe chewing for damaged trees in the random drainage lines is 15.4% (damage levels of 0.3-0.0) and 11.1% of damaged trees have over 75% of the bark removed (damage levels of 0.2-0.0). Therefore, of the 14,582 trees damaged in these areas, 2,246 of these will have severe chewing damage and 1,619 trees will have over 75% of their bark removed. The rates of bark chewing in all drainage lines therefore would be – 10.8% of trees will have some form of chewing, 1.7% will have severe chewing damage and 1.2% of all trees in drainage lines will have been almost ring-barked. Of all trees chewed in the drainage lines, 55.7% of these were *E. amplifolia* and

23.9% were *E. moluccana*. In the intensively chewed sites, the proportion of damaged *E. amplifolia* increases to 65% and *E. moluccana* increases to 28.9%.

3.4 DISCUSSION

3.4.1 Distribution and occurrence of bark chewing

The distribution of bark chewing on the Red Range Plateau is not uniform and is restricted to patches along drainage lines. Bark chewing does occur randomly on slopes and ridges but there were no areas outside of drainage lines where bark chewing occurred in concentrated patches like those seen in the drainage lines (Section 3.3.1; *pers. obs.*). The concentration of bark chewing in drainage lines could be linked to the preferential use of drainage lines by wild horses (Schott, 2004). The distribution of trees with bark damage caused by other large mammals also tends to be clumped and is related to their usage of the available habitat. For example, clumping of trees with bark damage is due to the use of favoured sites within the landscape by bison (Meagher, 1973). Elephant damage to trees is not randomly distributed and is thought to relate to proximity to water (Calenge *et al*., 2002). Bark damage by elk is restricted to their seasonal movement as most damage occurs in their winter range (Packard, 1942) and along the spring and autumn migration routes (Romme *et al*., 1995).

There does not appear to be a distinct seasonal occurrence of bark chewing by the wild horses in GFRNP. Schott (2004) recorded that there was an increase in bark chewing from spring to summer which coincided with migration of wild horses up onto the Red Range Plateau from the gorge system. During my study, fresh bark chewing was observed every month during field trips (March-August), showing that this behaviour is not restricted to the spring and summer seasons. Bark stripping by black bears occurs during spring and is related to the rise of sap (Radwan, 1969) and bark stripping by elephants was concentrated during the rainy season (Douglas-Hamilton, 1972 in Mwalyosi, 1987; Mwalyosi, 1987). There is however, a possibility that bark chewing on the Red Range Plateau is linked with rainfall events. Rain softens the bark, which is otherwise extremely hard, and this would make it easier to strip the bark from the tree. Soil moisture influences the volume of sap within the trees (Eyre and Goldingay, 2003; J. Duggin, *pers. comm.*), therefore rainfall, through increasing soil moisture, could influence the volume of sap as well as moisture in the eucalypts within the drainage lines and this increase could act as a cue for bark chewing.

The lack of consistent clumping of chewed trees within sites could be due to several reasons. Firstly, the pattern of chewing may only reflect the tree distribution within the sites, which are dominated by the preferred species. This means that the wild horses do not need to be selective as there are enough individuals of the preferred species available without having to search out preferred individual species of trees. The other possibility is that social behaviour by the wild horses means that the spacing is related to social pressure (Berger, 1986), the dominant horse would ensure that there is no competition nearby threatening to 'steal' the food source. If this is the case, there would be at least a body length between individuals (to avoid being kicked), but as seen in Figure 3.1, domestic horses at least, are willing to share this resource.

Within drainage lines, there are two categories of bark chewing - background bark chewing, which occurs in most drainage lines on the Plateau and the intensive chewing which occurs at several known sites. During the course of field work, two more sites which have intensive bark chewing were discovered (*pers. obs.*; E. Jessup, *pers. comm.*) and both of these are located within the Boban section of the Plateau. There is no significant difference between the landscape variables of the intensive sites compared with other sites along drainage lines. The only factor which indicates a separation of the intensive sites from other sites with bark chewing damage is the proportion of *E. amplifolia*, which is greatest in intensive sites (3.13d). The clumping of sites with no bark chewing damage (Figure 3.13a) appears to be linked with a higher proportion of stringy-barks (Figure 3.12b).

It appears that the wild horses are therefore selecting areas for bark chewing which have a high density of *E. amplifolia* and a low density of stringy-barks. There are no obvious visual differences between *E. amplifolia* and several other smooth bark species on the Plateau so it is likely that there is a cue, such as a smell or a taste, which stimulates bark chewing rather than density of *E. amplifolia* directly influencing the incidence of bark chewing. Though, similar selection behaviour has been shown by roe deer, which chose to browse patches of trees consisting of preferred species over patches of trees with mixed species (Bergman *et al.*, 2005). The density of cedar trees is also considered a significant predictor for bark stripping by Barbary macaques (Ciani *et al*., 2001) and damage caused by elephants is related to tree height and tree species (Calenge *et al*., 2002).

There were no landscape variables that could be used to predict bark damage by moose (Scharf and Hirth, 2000) and black bears (Radwan, 1969). Radwan (1969) found that there was no difference between sites, or the sugar content of the sapwood, where bark stripping took place and where no damage occurred. It is thought that the choice of tree and amount of damage is related to availability and palatability of other forage, population density and the variation in learnt behaviour (Peek, 1986). Aspect, altitude and tree size did not influence bark chewing distribution by moose (Scharf and Hirth, 2000) and nor do these variables influence bark chewing by wild horses. Moose damage had a similar type of distribution as wild horse damage. Scharf and Hirth (2000) suggest that the moose either browsed casually, leaving little or no damage, or fed heavily at one preferred site, resulting in severe damage. This is also the case for wild horse browsing, highlighted by random mild bark chewing on slopes and the concentration of bark chewing in preferred areas such as the intensively damaged sites within drainage lines.

3.4.2 Selection behaviour

The criteria used by Peek (1986) can also be related to wild horse damage with the likelihood that this is a learnt behaviour being especially important. Bailey *et al*. (1996) state that foraging behaviours are heritable and are probably controlled by multiple genes (Marinier and Alexander, 1991). Horses are thought to cue from each other when choosing their food and Duncan (1992) has shown that the diet of a horse is dependent upon the diet of the herd in which they live. Information provided by the activities of companions are social cues which can influence foraging choice as well as other types of behaviour (Dall *et al*., 2005). Foraging behaviour can be learnt from their mothers or alternatively, selective foraging can be in response to odours, moisture and taste (Provenza *et al*., 2003).

Despite these speculative suggestions, it is doubtful that the origins of bark chewing by wild horses will be easily explained. Bark stripping by Barbary macaques is thought to have begun as a response to a lack of food, nutrients or water, with water availability being the most important variable in relation to bark stripping behaviour (Ciani *et al*., 2001). Water is not an issue on the Red Range Plateau as there is standing water in the form of dams within each paddock so bark chewing is more likely to have started as a response to a lack of feed or as a supplement for low nutrients. If bark chewing is linked with a lack of feed, it is possible that the horses began chewing bark to maintain a high level of gut fill. Horses will suffer a drop in food assimilation if the quantity of digesta in its gastro-intestinal tract declines (Duncan, 1992), so it may be a lack of roughage which leads to an increase in bark chewing (Nadolny, 1983).

Large herbivores must maintain intake rate and can't afford to spend much time selecting bites (Bailey *et al*., 1996). Therefore the bark must provide a benefit for the wild horses without reducing the amount of time spent grazing. Any benefits gained by the horses (see Chapter 4) should be assumed to be significant due to the amount of effort put into stripping and eating the bark. My estimate of the amount of bark that has been removed from a trunk up to a height of one metre is 5,536cm^3. It is quite likely that this level of browsing would require repeated visits over a long period of time to remove this amount of bark, and this is evident from the scars on the trunk and the various ages of chewing damage recorded. Scars from bark chewing can be seen many years later (Scharf and Hirth, 2000). The effort put into chewing bark is revealed by the teeth marks left on the wood where bark has been removed (Figure 3.15).

Overall, wild horses preferred to chew the bark of *E. amplifolia* compared with the bark of other species which experienced bark chewing damage. Preference for a food type is the result of a selective response in choosing that forage over another (Peek, 1986) and it is the preferred forage which will be depleted first (Petrides, 1975). The horses on the Red Range Plateau were choosing *E. amplifolia* over other available species at all sites, even at Boban where *E. moluccana* dominated the drainage lines, *E. amplifolia* was being preferred. The presence of the intensive sites within the Boban section of the Plateau meant that the habitat dominated by *E. amplifolia* had already been selected as the prime sites for bark chewing. Selection of tree species is important, influencing the distribution of bark chewing, with two species being preferred by wild horses. As well as *E. amplifolia*, *E. moluccana* is preferred for chewing over any other species found within the drainage lines, as shown by the low numbers of *E. saligna*, *E. melliodora*, *E. nobilis* and *E. retinens* with bark chewing damage.

Figure 3.15: Scars of teeth marks on the wood, where bark has been removed from *Eucalyptus amplifolia* on the Red Range Plateau, GFRNP. The highest teeth marks are two metres above the ground.

3.4.3 Damage to trees and impacts upon tree health

Most bark chewing occurs at the base of the eucalypts between 0cm and 50cm from the ground (Table 3.6). Basal injuries are also common when black bears strip bark (Radwan, 1969). Beavers remove bark from the base of firs but remove bark from twigs rather than the basal section of aspens (Hall, 1960). This indicates that there is a component of the basal bark of firs which attracts the beavers to this section of trunk compared with the basal bark of aspen (Hall, 1960). The location on the tree of damage caused by the wild horses also indicates that this behaviour probably does not occur due to boredom as the horses have to make an effort to reach down to the site rather than taking opportunistic bites at head height (G. Hinch, *pers. comm.*). Many trees with only mild damage had bites taken from low down on the trunk (Figure 3.16) and others had bites taken at head height. Bites at head height appeared to be the position on the trunk of bark chewing more often on the randomly chewed trees on slopes and ridges than basal damage.

The damage to individual trees from ring-barking can eventually lead to death. Trees do not die immediately when damaged, so a low mortality rate is not surprising (Scharf and Hirth, 2000) but health of eucalypts was significantly linked with the amount of bark chewing damage (Figure 3.10). Removal of bark can also increase the chance of invasion by pathogens and the chance of cankers occurring (Scharf and Hirth, 2000). Girdling can potentially lead to an increased rate of decomposition of starved roots and their symbionts which can lead to a temporary increase in the rate of soil respiration (Högberg *et al*., 2001). This increase in soil respiration is due to the metabolism of stored sugars and starch (Nordgren *et al*., 2003). Girdling can also cause an increase in the senescence of fine roots and these will not be replaced when the current root crop decomposes (Nordgren *et al*., 2003). Girdling does not only lead to physical changes of the affected trees but it is thought to also result in extensive changes to gene expression (Li *et al*., 2003).

Figure 3.16: Three bites at the base of *Eucalyptus saligna* on the Red Range Plateau, GFRNP.

Even when debarked, some eucalypt species have the potential to re-sprout from buds forming from epicormic strands (Burrows, 2002). Some eucalypt species have the ability to regenerate phloem and bark tissue after being debarked over a large area (Chudnoff, 1971 in Burrows, 2002). Dormant buds have the capability of surviving progressive killing of the bark and phloem and even occasionally surviving the death of the cambium (McArthur, 1968 in Burrows, 2002). Therefore, even with mild to severe bark chewing damage, eucalypts have the capacity to survive due to the ability to re-sprout after being damaged.

3.4.4 Predicted extent of bark chewing damage on the Red Range Plateau, GFRNP

Bark chewing damage to eucalypt trees on the Red Range Plateau by wild horses is widespread. The severity of damage is revealed by the prediction that if a tree has over 75% of the bark removed from its trunk, the probability of mortality increases (Scharf and Hirth, 2000). Within the creek lines on the Plateau up to 14,582 trees may have bark chewing damage with more trees in drainage lines which were not able to be mapped. It is possible that over 1,600 trees on the Red Range Plateau are likely to die in the future and a further 627 will have an elevated chance of mortality as they have over 50% of bark removed from their trunks. The mortality rate of these damaged trees is likely to be above the average mortality rates for eucalypts within this landscape, due to ring-barking, especially if repeated bark chewing targets these trees. These estimations should be taken as the minimum number of trees impacted by bark chewing as there are many drainage lines on the Plateau which are not indicated on available maps. It is acknowledged that not all of the creek lines on the Plateau which were mapped (Figure 3.13) will contain a high proportion of *E. amplifolia* and low proportion of stringy-barks, aspects which appear to be linked with the occurrence of bark chewing, but the unmapped drainage lines are likely to prevent any over-estimation by this method.

The increased chance of mortality of so many trees, focusing upon two particular species, *E. amplifolia* and *E. moluccana*, has the potential to change species composition in these drainage lines. It is possible that the death of a large number of trees in the future in these specific areas can lead to an increase in the width of the drainage lines, reducing canopy cover, potentially providing a chance for seedlings to become established. This has been shown to occur with the widespread damage caused by elephants in Africa where they are known to influence tree diversity and forest structure (Sheil and Salim, 2004). Even with the severe effects on the woodlands in the Serengeti and the Mara, elephants were not able to reduce recruitment rates below adult mortality rates (Dublin *et al*., 1990), but have changed the landscape from a woodland to a grassland (Laws, 1970). It is thought that elk help to sustain a sharp ecotone between forest and open meadows (Patten, 1963 in Meagher, 1973).

Depending upon the rate of mortality due to bark chewing and the germination rates of affected species, there is the potential that the clearings along the drainage lines will be at least either maintained, or increased, by bark chewing. Bark chewing can also impact the form of the eucalypt, as girdling can result in the death of the crown of the tree, but the tree can sprout from below the girdle (Forbes and Meyer, 1956) from buds within the bark (Burrows, 2002). Continuation of bark chewing damage on the Red Range Plateau has the potential to increase the size of areas affected and over the long term, impact upon species composition, tree form and vegetation structure along the drainage lines.

4.0 Nutrient and Sugar Analysis

4.1 INTRODUCTION

Mammalian herbivores make foraging decisions on several scales, from where to feed in the landscape, through to determining which plant species and plant parts to consume (Bailey *et al*., 1996). Forage choice is influenced by factors including prior experience, odour, allelomimetic behaviour, plant protein content, energy content, and moisture content (Peek, 1986). Herbivores have been shown to select diets which are high in nutrients and low in toxins (Provenza and Balph, 1990 in Ginane *et al*., 2005; Provenza, 1995) indicating that pre-ingestive cues, such as the odour of the plant, must relate to the post-ingestive consequences (Provenza, 1995; Ginane *et al*., 2005), such as increasing the physiological well-being of the animal (Peek, 1986). The link between olfaction and memory allows associations between odours and metabolic reactions to result in learnt behaviours (Pain *et al*., 2005). Success in choosing the right food sources impacts upon the overall fitness of the animal (Ginane *et al*., 2005).

The realisation that herbivores have the ability to select food in order to maximise nutrient intake has led to increasing interest in the chemical and nutrient composition of differing food types. Browsing of different tree species, and especially browsing of bark, has been the subject of research due to the potential impact on the landscape by influencing the distribution of tree species (Duncan, 1992; Angelstam *et* al., 2000; Scharf and Hirth, 2000) and impacts upon forestry operations (Angelstam *et al*., 2000; Baxter and Hansson, 2001). Research has been carried out on the bark chemistry of birch species (*Betula* sp.) and how it impacts upon hare herbivory (Laitinen *et al*., 2004). For example, papyriferic acid in Alaskan white birch (*Betula resinifera*) was thought to act as a browsing deterrent for snowshoe hares (Reichardt *et al*., 1984) and platyphylloside, a phenolic glycoside, was also thought to affect browsing (Sunnerheim *et al*., 1988). The level of papyriferic acid also appears to be correlated with moose herbivory as birch trees not browsed by moose had a higher papyriferic acid content than browsed birch trees (Reichardt *et al*., 1984). Condensed tannins are also thought to affect the palatability of plant material (Waterman, 1988 in Laitinen *et al*., 2004; Marsh *et al*., 2003).

The damage to trees caused by black bears stripping bark in order to reach the sapwood appeared to be linked with the high sugar content of the trees (Radwan, 1969). The tree species selected by the bears vary throughout different locations and not all of the trees with similar sugar levels are targeted (Radwan, 1969; Peek, 1986). This indicates that more than just a chemical analysis is required to determine why the bears choose particular tree species, and individual trees within those species, for browsing (Peek, 1986). Laitinen *et al*. (2004) determined that there was a high variation in bark chemistry between clones, which implied that the localised environment may have a direct influence upon bark chemistry. Variation in environmental resources was also reported by O'Reilly-Wapstra *et al*. (2005) as impacting upon herbivore response by altering plant secondary metabolite concentrations.

The environment not only impacts upon bark chemistry but also impacts nutrient levels, depending on the ability of the plant to take up available nutrients. The diversity in nutrient uptake and acquisition means that different species of trees can have different micronutrient concentrations even when growing in the same soils (Hagen-Thorn and Stjernquist, 2005). Different eucalypt species have significantly different nutrient concentrations in their leaves and bark (McColl and Humphreys, 1967 in McColl, 1969). Nutrient levels of eucalypts in a plantation revealed that calcium and magnesium accumulated more in the bark whilst nitrogen, potassium and phosphorus were found to be concentrated in the wood (Zaia and Gama-Rodrigues, 2004). Kramer and Kozlowski (1960 in McColl, 1969) also found that calcium is concentrated in the bark and wood of trees.

Bark chewing of eucalypt species by horses was recorded by Keenan (1986) as an activity which had previously occurred irregularly, but during one season it became a significant problem at the Queensland Agricultural College, Lawes. The intense bark chewing took place when the horses were placed on irrigated pasture which contained half the fibre of the natural pasture. The chewing declined once the horses were returned to natural pasture. The eucalypts being intensively chewed were stringy-barks, *Eucaylptus microcorys* (yellow tallow wood), *E. robusta* (swamp mahogany) and *E. tessellaris* (Moreton Bay Ash) with *E. tereticornis* (blue gum) and *E. melliodora* (yellow box) having mild chewing damage. This is in contrast to my findings (see Chapter 3) and those of Schott (2004), who recorded only smooth and box-barked eucalypts being chewed.

Nutrient deficiency, for example, possibly phosphorus (Heusner, 1995; Kohnke, 2000), has been postulated as a reason why horses chew bark (Ralston *et al*., 1979). Kohnke (2000) and Heusner (1995) both agree that lack of fibre is a potential reason for bark chewing, especially during late winter and early spring in cold, wet weather when the grass has low fibre content, as demonstrated by Keenan (1986). Two other suggestions as reasons for bark chewing include a lack of protein, or taking advantage of flowing sap (Kohnke, 2000). Bark chewing may also occur during cold, wet weather in an attempt to keep the body temperature of the horse at normal levels, as consumption of bark may increase fermentation and heat production in the horse (Heusner, 1995). Debarking of *Acacia tortilis* by elephants in Tanzania was thought to have been in response to a shortage of protein in their diet (Mwalyosi, 1990).

The aim of this chapter was to determine a hypothesis as to why the wild horses chew bark. The first section aims to assess whether the trees with bark chewing damage significantly accumulate nutrients and therefore satisfy a nutrient deficiency in the diet of the wild horses. This would be shown by the nutrient levels in bark being greater than the amount of nutrients in the soil which are available to be taken up by the trees, and a difference between the nutrient levels of damaged and undamaged trees. The second aim was to assess the sugar and starch content in the bark to determine whether these could act as either cues or rewards for bark chewing. My aim of this work was to provide an indication of what cues or rewards may be influencing the occurrence of bark chewing so as to provide a focus point for further research.

4.2 METHODS

4.2.1 Bark tissue nutrient analysis

Bark samples to be used for nutrient analyses were taken from Dead Pig Gully, BC2. Approximately 4cm x 10cm of bark was removed from seven eucalypt trees. Samples of the outer and inner layers of bark were taken from five *Eucalyptus amplifolia* and two *E. moluccana* (Table 4.1). These trees had differing levels of bark damage, from being repeatedly chewed through to no chewing damage and five of the trees were within the intensively chewed site and two of the trees were outside of the intensively chewed area.

Table 4.1: Description of bark samples taken for nutrient analysis from trees in Dead Pig Gully, BC2, Red Range Plateau, GFRNP.

Sample	Site	Species	DBH (cm)	Chewing and damage category (Figure 3.2)	Comments
1	In BC2	*E. amplifolia*	59.9	Repeated chewing, wood exposed, 0.1.	Bark taken from chewed area, height approx. 1.3m.
2	In BC2	*E. amplifolia*	45.2	Repeatedly chewed, 0.2.	Bark taken from chewed area, height approx. 1.5m.
3	In BC2	*E. amplifolia*	53	Only one bite at base of tree, 0.9.	Outside layer of bark taken, height approx. 1.5m.
4	In BC2	*E. amplifolia*	53	Same tree as sample 3.	Inside layer of bark taken, height approx. 1.5m.
5	In BC2	*E. amplifolia*	53	Same tree as sample 3 and 4.	Bark taken from area of chew at base of tree.
6	In BC2	*E. moluccana*	55	New and old chewing taken place, 0.7.	Bark taken from outer layer.
7	In BC2	*E. moluccana*	55	Same tree as sample 6.	Inner layer of bark.
8	In BC2	*E. amplifolia*	56	No chewing damage, 1.0.	Outer layer of bark.
9	In BC2	*E. amplifolia*	56	Same tree as sample 8.	Inner layer of bark.
10	Out of BC2	*E. amplifolia*	25	No chewing damage, 1.0.	Tree on slope above BC2, outer layer of bark.
11	Out of BC2	*E. amplifolia*	25	Same tree as sample 10.	Inner layer of bark.
12	Out of BC2	*E. moluccana*	23.1	No chewing damage, 1.0.	Tree on slope above BC2, next sample 10. Outer layer of bark.
13	Out of BC2	*E. moluccana*	23.1	Same tree as sample 12.	Inner layer of bark.

The bark samples were dried in an oven at 70° for a week before being ground to a homogenate with fragments less than 2mm. The bark samples were then analysed using a modified variation on the Milestone Application Note 031 and uses the Ethos Plus High Performance Microwave Labstation (Milestone Application Note 031, 2000) which is the same method as the microwave digestion technique for Aqua Regia digestion for soil samples. The ground bark was weighed and 0.18g was measured into a teflon TFM vessel. For all 13 samples, plus the control, 9ml of hydrochloric acid (36%) and 3ml of nitric acid (70%) was added to the ground material in the fume hood. The solution was swirled to homogenize it and the vessel was closed. The vessel was then placed in the rotor segment which was then tightened using a torque wrench. The segments were then placed in the microwave and attached to the temperature sensor. The microwave program (Table 4.2) was then completed and the rotor cooled to room temperature. The liquid was transferred to a 25ml volumetric flask and the solution was made up to 25ml using deionised water. Nutrient analysis was then carried out using the Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). Elements measured were aluminum, arsenic, cadmium, cobalt, chromium, copper, iron, phosphorus, magnesium, manganese, sodium, lead, antimony, selenium and zinc.

Table 4.2: Microwave program for Aqua Regia digest of bark samples for the analysis of bark nutrient content.

Step	Time (minutes)	Temperature (°C)	Microwave power
1	5	100	Up to 1000 Watt
2	10	175	Up to 1000 Watt
3	10	175	Up to 1000 Watt
4	15	Vent	

4.2.2 Soil copper analysis

Three soil samples were collected from one intensively chewed site, Dead Pig Gully, BC2. Samples were taken from the middle of the intensively chewed area (defined in Chapter 3), outside the chewed area along the drainage line and from the slope above the chewed area. Soil samples at two depths was able to be taken for the first two samples, 0-10cm and 30-40cm, but only 0-5cm was taken for the third sample due the shallow depth of the soil at that location.

Due to the results from the bark tissue nutrient analysis (Section 4.3.1), the soil from Dead Pig Gully was then tested for copper content. The soil was extracted for 16 hours with 0.01M $CaCl_2$. The solution was then filtered and analysed by the ICP-OES for exchangeable copper.

4.2.3 Sugar and starch analyses

Samples of bark were taken from 30 *E. amplifolia* trees at two different intensively chewed sites. Fifteen samples were taken from Dead Pig Gully, BC2, and another 15 samples from Scrubby Dam, BC5. At each site, the samples were taken from five trees with bark chewing, five trees with no damage within the intensively chewed site and five trees outside of the mapped sites. These samples were approximately 6cm x 10cm in size and bark was removed in a single section, where possible, down to the wood. The thickness of the bark was measured, to the nearest millimetre, for all 30 of these samples. Eleven samples from Dead Pig Gully were used for starch and sugar content analysis. Once again the bark was dried and ground as above. All analyses were undertaken by the Animal Science Nutrition Laboratory of the University of New England.

4.2.4 Statistical analyses

Statistix (Analytical Software, 2000) was used to analyse nutrient, starch and sugar data. Normality for all data was tested prior to performing any statistical analysis. A one-way ANOVA was used to compare the bark nutrient content between damaged and undamaged trees and the nutrient content in the outside and inside layers of bark. Data which were not normally distributed and could not be transformed were analysed using Kruskal-Wallis one-way ANOVA. One-way ANOVAs were also used to assess the total starch in the bark. The depth of the bark from damaged and undamaged trees was analysed using a one-way ANOVA, as was the depth of bark of trees within and outside the intensively chewed areas for Scrubby Dam. A Kruskal-Wallis one-way ANOVA was used to compare the medians for the same criteria at Dead Pig Gully and for a combination of all samples taken. A Spearman Rank Correlation was also used to test whether there was any correlation between the depth of the bark and total starch content.

4.3 RESULTS

4.3.1 Bark nutrient analysis

The chewed and undamaged trees had similar levels of nutrients within the bark tissue (Table 4.3). Copper, iron, magnesium and sodium content were tested for any difference between all samples for damaged and undamaged trees. Only copper (Kruskal-Wallis statistic = 7.3876; p = 0.0066) and iron (p = 0.0239) showed that chewed trees (samples 1-7) had significantly higher levels of these nutrients than the undamaged trees (samples 8-13). Potassium and magnesium levels are higher in *Eucalyptus moluccana* whereas manganese and sodium are higher in *E. amplifolia*, but these differences may be only due to the low number of *E. moluccana* sampled.

Table 4.3: Nutrient content of bark tissue for two species of eucalypts at Dead Pig Gully, Red Range Plateau, GFRNP.

Element	**Average overall (ug/g)**	**Average for *E. amplifolia* (ug/g)**	**Average for *E. moluccana* (ug/g)**	**Av. for chewed (ug/g)**	**Av. for not chewed (ug/g)**
4.2 Al	30.32	30.98	28.83	34.36	24.68
As	0.51	0.66	0.19	0.14	0.77
Cd	0.00	0.00	0.00	0.00	0.00
Co	0.17	0.16	0.19	0.07	0.29
Cr	0.24	0.22	0.29	0.48	0.00
Cu	1.76	1.80	1.67	2.98	0.38
Fe	16.34	17.91	12.82	19.02	10.95
K	1963.24	1481.84	3046.40	2417.79	2102.43
Mg	2034.53	1930.85	2267.84	1897.69	2354.83
Mn	692.43	785.16	483.77	757.77	482.68
Na	769.24	961.88	335.81	779.02	469.07
Ni	0.00	0.00	0.00	0.00	0.00
Pb	0.10	0.14	0.00	0.13	0.00
Sb	0.00	0.00	0.00	0.00	0.00
Se	3.43	4.56	0.87	3.01	2.46
Zn	7.68	6.65	10.00	8.79	7.78

The samples also reveal that each tree has different nutrient levels depending upon where the bark was removed. For example, samples 3-5 come from the same tree, with sample 3 from the outside layer of bark, 4 from the inside layer of bark and sample 5 from the base of the tree, with copper levels highest in the basal bark (Figure 4.1). The highest level of copper was found in the outside layer of the *E. moluccana* within the intensively damaged site (Sample 6, Figure 4.1). Iron (Kruskal-Wallis statistic = 4.5000; p = 0.0339) and copper (Kruskal-Wallis statistic = 4.5818; p = 0.0323) levels were also significantly higher in the outside layer of bark than the inside layer. Magnesium and sodium levels were not significantly different for the inner and outer layers of bark, though the outer layer of bark contained higher levels of these nutrients for the trees within the bark chewing site (Table 4.4). Iron levels were significantly different as Samples 1 and 2 had much higher levels of iron than any other sample, therefore strongly influencing the statistical analysis carried out (Figure 4.2).

Table 4.4: Magnesium and sodium content for two eucalypt species at Dead Pig Gully, GFRNP. (* outside layer of bark; $^{\wedge}$ inner layer of bark).

Sample	Bark Damage	Species	Mg ug/g	Na ug/g
1$^{*\wedge}$	Bark chewing damage	*E. amplifolia*	1162.33	2280.42
2$^{*\wedge}$		*E. amplifolia*	1521.24	1402.71
3*		*E. amplifolia*	2466.48	1420.01
4$^{\wedge}$		*E. amplifolia*	1179.03	729.45
5		*E. amplifolia*	1171.38	960.52
6*		*E. moluccana*	3344.81	236.64
7$^{\wedge}$		*E. moluccana*	1245.79	162.19
8*	No bark chewing damage	*E. amplifolia*	2327.29	948.87
9$^{\wedge}$		*E. amplifolia*	1472.19	203.72
10*		*E. amplifolia*	2948.91	258.48
11$^{\wedge}$		*E. amplifolia*	3128.76	452.72
12*		*E. moluccana*	1747.07	536.98
13$^{\wedge}$		*E. moluccana*	2733.67	407.42

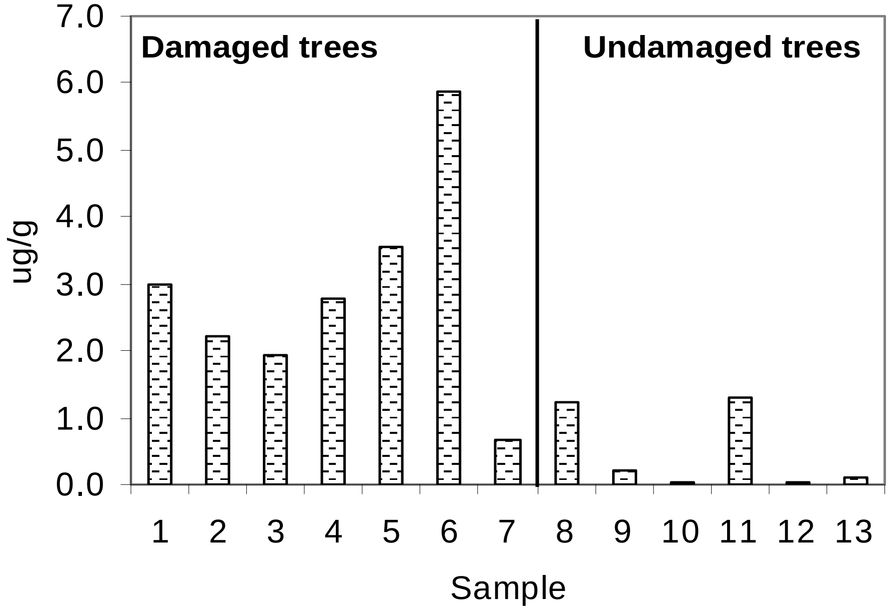

Figure 4.1: Copper content of bark samples from eucalypt trees in Dead Pig Gully, Red Range Plateau, GFRNP.

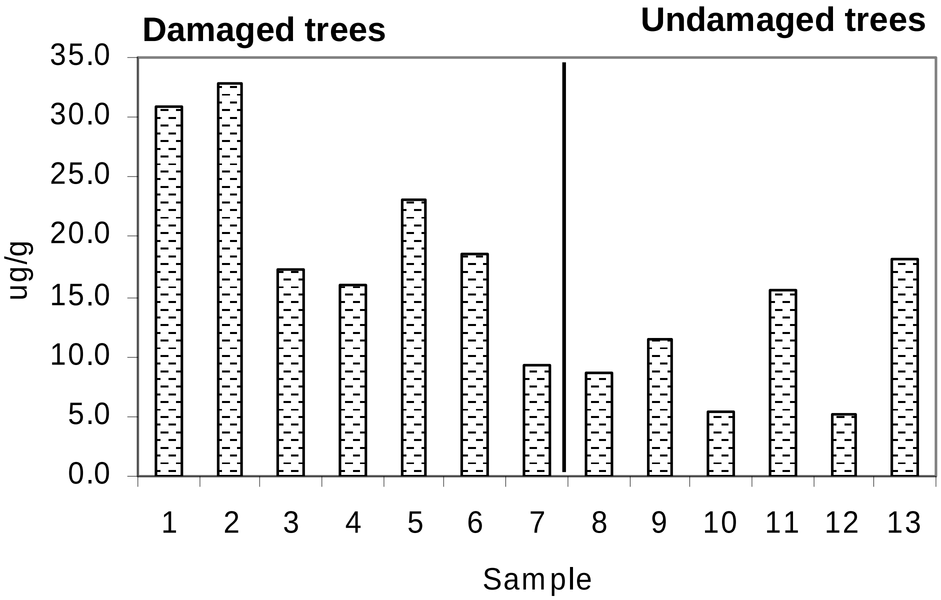

Figure 4.2: Iron content of bark samples from eucalypt trees in Dead Pig Gully, Red Range Plateau, GFRNP.

4.3.2 Soil copper analysis

The copper measured in the bark tissue reflected the available copper within the soil. The samples within the drainage line have a higher copper content compared with the sample taken from the slope above Dead Pig Gully, reflecting the leaching patterns at the site.

Table 4.5: Copper content of soil samples taken from Dead Pig Gully, Red Range Plateau, GFRNP.

Sample	Location	Depth	Cu (ug/g)
1	In BC2	0-5	0.115
2	In BC2	40-45	0.168
3	Out of BC2, on hill	0-5	0.087
4	Out of BC2, along drainage line	0-5	0.112
5	Out of BC2, along drainage line	40-45	0.158

4.3.3 Bark thickness and starch analysis

Analysis of starch levels in the bark samples revealed a low level of starch in the bark of eucalypts (S. Song, *pers. comm.*). The statistical analysis of the average starch levels of damaged and undamaged trees indicates that there is potentially a difference between the total starch content of trees with and without bark chewing damage (p = 0.0584) (Figure 4.3). There was no significant difference between the starch levels of trees within the intensively chewed areas and the trees outside this area (p = 0.1416). It was noted during analysis that three samples, 7, 8 and 10, had a strong odour (S. Song, *pers. comm.*). These samples also had the lowest starch content, 1.32%, 1.58% and 2.08% and were taken from undamaged trees (Table 4.6).

Figure 4.3: Average total starch content (with standard error bars) of damaged and undamaged trees at Dead Pig Gully, Red Range Plateau, GFRNP.

Table 4.6: Total starch content of bark tissue of *Eucalyptus amplifolia* at Dead Pig Gully, Red Range Plateau, GFRNP.

Sample	Site/chewed	Total starch (%)	Depth of Bark (cm)
1	Chewed in BC2	4.92	1.5
2	Chewed in BC2	3.16	2.2
3	Chewed in BC2	3.64	1.6
4	Chewed in BC2	2.33	1.5
5	Chewed in BC2	2.85	1.9
6	Not chewed, out BC2	3.11	1.1
7	Not chewed, out BC2	1.32	1.0
8	Not chewed, out BC2	1.58	1.2
9	Not chewed, in BC2	3.19	0.9
10	Not chewed, in BC2	2.08	1.1
11	Not chewed, in BC2	2.13	1.1

The thickness of bark from chewed and undamaged trees was not significantly different at Scrubby Dam ($p = 0.1333$) but was significant at Dead Pig Gully (Kruskal-Wallis statistic = 6.4301; $p = 0.0112$) and strongly significant for a combination of both sites (Kruskal-Wallis statistic = 8.1482; $p = 0.0043$) (Figure 4.4). The average thickness of bark for the trees with bark chewing damage at Dead Pig Gully is 1.74cm and the average bark thickness for undamaged trees is 1.18cm (Figure 4.4). There was no significant difference between the medians of bark thickness within the intensively chewed site and outside of the site at Dead Pig Gully (Kruskal-Wallis statistic = 0.3825; $p = 0.5363$) but bark thickness was significantly different at Scrubby Dam ($p = 0.0088$) and for a combination of both sites (Kruskal-Wallis statistic = 5.5016; $p = 0.0190$) (Figure 4.5). For both sites, there was no significant difference between the mean bark thickness for undamaged trees within and outside of the intensively damaged areas ($p = 0.3911$). There was also no correlation between the depth of the bark and the total starch content (Spearman Rank Correlation = 0.4322; $p = 0.1825$).

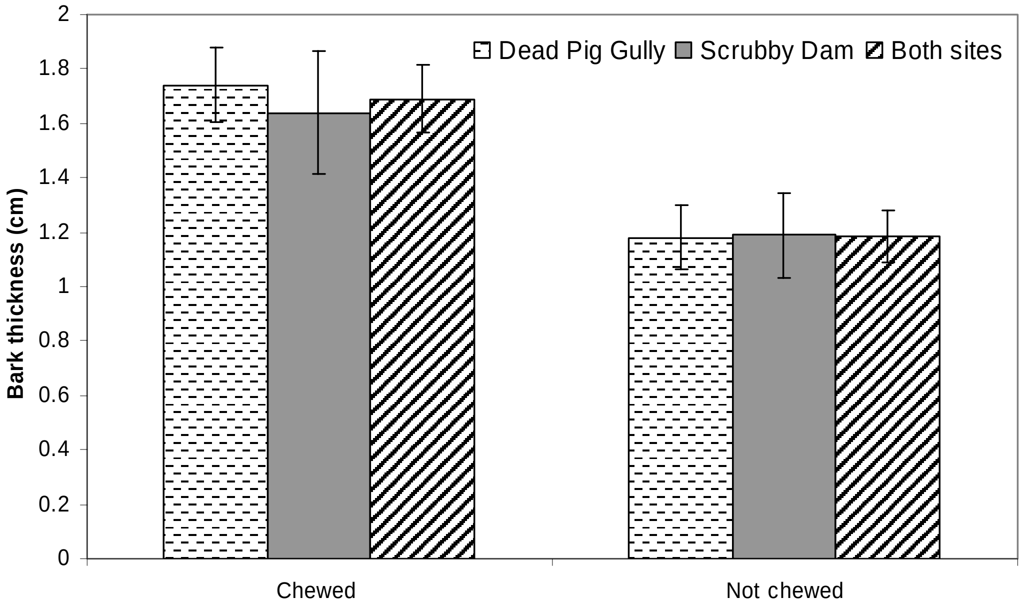

Figure 4.4: Average bark thickness (with standard error bars) of *Eucalyptus amplifolia* with and without chewing damage for the intensively damaged sites, Dead Pig Gully and Scrubby Dam, and both sites combined, on the Red Range Plateau, GFRNP.

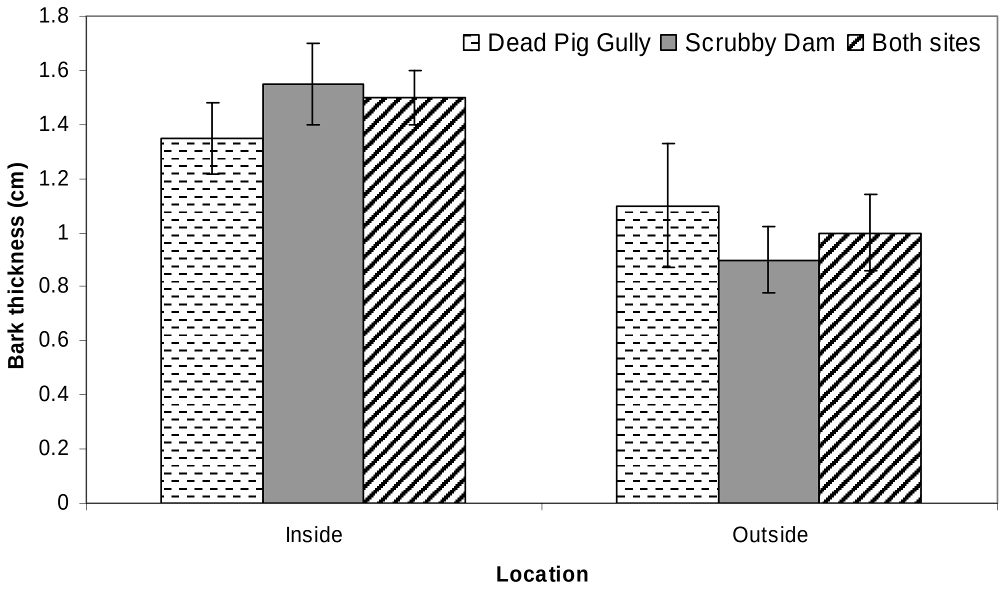

Figure 4.5: Median bark thickness (with standard error bars) of *Eucalyptus amplifolia* located inside and outside of the intensively damaged sites, Dead Pig Gully and Scrubby Dam and both sites combined, on the Red Range Plateau, GFRNP.

4.3.4 Bark sugar analysis

Sugar analyses did not reveal any selection by the wild horses for any type of sugar. Eight different sugars were sampled within the non-starch polysaccharides and the free sugars, none of which showed any significant difference between trees with bark chewing damage and trees with no damage (Table 10, Appendix). Total non-starch polysaccharides which indicate the fibre available in the bark, did not show any difference for trees with and without bark chewing damage ($p = 0.6479$), nor was there any difference between trees within the intensively damaged area and trees outside of this area ($p = 0.1515$). Total free sugars were also assessed and also revealed no significant difference between these categories (damaged trees compared with undamaged trees, $p = 0.1157$; trees located within the intensively damaged area compared with trees outside of the area, $p = 0.7441$).

4.4 DISCUSSION

4.4.1 Bark nutrients and influence upon selectivity

None of the nutrients I analysed for showed a significant accumulation in the eucalypts with bark chewing damage compared with the eucalypts with no bark chewing damage. Soil nutrient levels have been shown to be reflected within the levels of nutrients in the leaves and bark of the dominant tree species in eucalypt woodlands (McColl, 1969). For Dead Pig Gully, the copper content of bark was a direct reflection of the copper content of the soil at that site – trees with low copper levels were located on the hill where the soil was shallow and low in copper. Much more work is required before eliminating a relationship between bark chewing and nutrient content of eucalypts, especially as calcium was not assessed for these analyses, and also as a nutrient/bark chewing relationship has been recorded for other species. Correlations between bark stripping and the seasonal presence of nutrients have been recorded for Barbary macaques (Menard and Vallet, 1993 in Ciani *et al*., 2001). Rodents have also been recorded choosing some nutrients and avoiding others (Baxter and Hansson, 2001). Minerals such as chlorine, phosphorus and potassium show no patterns linking them with the occurrence of bark chewing (Baxter and Hansson, 2001) and nitrogen also appeared to be of little importance (Hjältén and Palo, 1992). Low phenolic levels (Roy and Bergeron, 1990) and the quantity of secondary defence compounds (Hjältén and Palo, 1992) have been hypothesized as also influencing rodent food choice whereas toxins in *Eucalyptus* such as diformylphloroglucinol compounds (DFPs) are thought to influence feeding by arboreal marsupials (Lawler *et al*., 1998; Lawler *et al*., 1999; Lawler *et al*., 2000).

Nutrient content of the plant depends upon the available nutrients in the soil (Bryant *et al*., 1983), with nutrient levels varying between plants and between different plant parts (Hagen-Thorn and Stjernquist, 2005). Some plant species are known to concentrate certain nutrients, for example aspens and hazels have concentrated calcium levels and aquatic plants are known to have concentrated sodium levels (Peek, 1986). Different sections of plants can also have different nutrient levels, as indicated by the nutrient variation in the leaves and bark of eucalypts (McColl and Humphreys, 1967 in McColl, 1969). This is reflected by the significantly different copper levels between the inside and outer layers of bark (Kruskal-Wallis statistic = 4.5818; p = 0.0323). The soil magnesium content is correlated with the phosphorus levels in eucalypt leaves and the calcium content in the bark (McColl, 1969) and Zaia and Gama-Rodrigues (2004) indicated that calcium and magnesium accumulated more in the bark than in the wood of eucalypts. McColl (1969) also indicated that the sodium concentration of eucalypts varies between species and is more dependent on atmospheric sources rather than the soil content.

The carbon-nutrient status of plants affects their nutrient and secondary metabolite content, impacting upon their palatability and resistance to herbivores (Bryant *et al*., 1983). Palatability of a plant is influenced by micro- and macro-nutrient content (Provenza *et al*., 2003). The feedback from nutrient content, preference or avoidance, allows herbivores to differentiate between different foods (Villalba *et al*., 2002; Provenza *et al*., 2003) in order to optimize their intake of nutrients and toxins (Provenza *et al*., 2003). The outside layer of bark is the first indicator of palatability the wild horses would encounter when chewing bark on the Red Range Plateau. The first few bites taken from the bark appear to indicate palatability, shown by some trees having only had a few bites taken but no further bark chewing has occurred (Figure 3.16) compared with other trees where more severe (Figure 3.15) and repeated damage has occurred (Figure 3.2a). The higher magnesium and sodium content in the outside bark layer of chewed trees provides an indication that there may be other nutrients, for example calcium, following a similar pattern and these might have the potential to influence bark palatability and therefore, the occurrence of bark chewing.

4.4.2 Influences of bark thickness, starch and sugar content

The eucalypts located within the drainage lines had significantly thicker bark than the eucalypts outside of the drainage lines (Figure 4.5). This can perhaps be explained by the higher soil moisture content within the drainage lines as compared with the soil outside of the drainage line. As drainage lines are being selected for bark chewing (see Chapter 3), it can therefore be expected that the trees being chewed have thicker bark than the trees with no bark chewing damage. There was a significant difference between the bark thickness for trees with and without bark chewing damage (Figure 4.5). However, the eucalypts with no damage situated within the drainage line did not have significantly different bark thicknesses from the trees with no damage outside of the drainage line. As soil moisture can influence plant growth and therefore bark thickness, and is known to influence the volume of sap within the bark (Eyre and Goldingay, 2003; J. Duggin, *pers. comm.*), this may then indicate a greater potential for these trees to accumulate nutrients or chemicals which influence food selectivity. The thicker bark may also have a better capability to transport water or nutrients as well as sap and therefore may contain stronger cues which may trigger the occurrence of bark chewing. Therefore, bark thickness is worthy of further research as it appears to be significantly associated with the occurrence of bark chewing damage.

The analysis for starch was indicative of a difference for the total starch content of eucalypts with and without bark chewing damage. Starch provides positive post-ingestive feedback for herbivores (Villalba and Provenza, 2000) and therefore has the potential to act as a cue for bark chewing. Little is known of the influence water and nutrients have on the ability of woody plants to store non-structural carbohydrates (Knox and Clarke, 2005) but carbohydrates are known to accumulate above the site of the girdle (Li *et al.*, 2003). Starch is considered to form part of the rapidly fermentable carbohydrates and the level of starch intake can impact upon the digestion and fermentation of hydrolysable carbohydrates (Hoffman *et al.*, 2001) which may be why Kohnke (2000) suggests that bark chewing is a result of horses seeking fibre to compensate for the high soluble starch content of pasture during spring.

Although the samples showed no differing sugar content for eucalypts with and without bark chewing damage, sugar has been found to influence bark damage by other species and should not be eliminated from additional research without further examination. Sap flow varies locally and annually, and was shown to be the most important influence on bark damage caused by squirrels (Kenward, 1983). Sugar was a major component of sapwood and was considered to be the major factor influencing tree selection (Radwan, 1969), though sugar content is not the only characteristic which influences bark damage by black bears (Peek, 1986). In Australia, sap is an important component of the diet of yellow-bellied gliders, *Petaurus australis* (Eyre and Goldingay, 2003) and squirrel gliders, *Petaurus norfolcensis* (Sharpe and Goldingay, 1998). Sap is most important for squirrel gliders during autumn and winter, though this pattern is most likely related to the availability of exudates, which are scarce during the wet autumn periods (Sharpe and Goldingay, 1998). Rainfall can influence the rates of sap flow through affecting the soil moisture content (Eyre and Goldingay, 2003) though variation of the sap flow appeared to be independent of soil moisture content and may be linked with individual genetics of the eucalypts (Goldingay, 1987).

4.4.3 Selection behaviour and indicators for further research

Girdling not only impacts tree health but also impacts the movement and accumulation of carbohydrates and nutrients. Carbohydrates accumulate above the site of the girdle (Li *et al*., 2003), which, if sugar or starch are significant bark chewing cues or rewards, may encourage repeated visits to particular trees for further bark chewing. Following girdling, a short-term increase of starch in the root system increases soil respiration but over the long-term, the starch reserves in the roots will be depleted as the roots starve and senesce (Högberg *et al*., 2001; Nordgren *et al*., 2003).

Food selection is a complex process which involves relationships between the post-ingestive effects and the flavour of the food (Provenza, 1995; Pain *et al*., 2005). Once feedback and flavour associations have been learned, herbivores use visual and olfactory cues for recognition of the food source (Launchbaugh and Provenza, 1993; Pain *et al*., 2005). The actual diet of the horse is dependent upon the diet of the herd in which they live as they are thought to obtain cues from each other (Duncan, 1992), but work with domestic horses has shown that individual horses differ in their grazing ability (Marinier and Alexander, 1991), even though foraging behaviours are thought to be heritable (Marinier and Alexander, 1991; Bailey *et al*., 1996). Horses have been shown to select their food by using chemoreception (Waring, 1983) with learnt behaviours based on odour and metabolic reactions (Pain *et al*., 2005). Due to the ability to associate nutritional consequences with particular food items, herbivores are able to assess temporal changes in the quality and toxin concentration of forage available (Bailey *et al*., 1996).

Chemical defence against herbivory comes in many different forms and is a complex process. The levels of toxins, plant secondary metabolites, phenols and tannins all appear to influence the degree of herbivory as well as limiting the number of mammal species which are able to browse the plant (Reichardt *et al*., 1984; Sunnerheim *et al*., 1988; Bailey *et al*., 1996; Marsh *et al*., 2003; O'Reilly-Wapstra *et al*., 2005). The concentrations of the chemical and nutrient components of plants vary temporally, as well as in response to environmental variables (Chapin III *et al*., 1980; Bailey *et al*., 1996; O'Reilly-Wapstra *et al*., 2005). Sunnerheim *et al*. (1988) suggest that it is likely that a specific substance is linked with deterrence against herbivory by vertebrate mammals rather than groups of compounds.

Temporal variation impacts forage quality but environmental and individual tree variation also impacts upon the nutrient and chemical concentration of forage. The chemical composition within each tree species can differ and influence the degree of herbivory (Marsh *et al*., 2003) as environmental resources can alter plant secondary metabolite concentration which then impacts the browsing responses by herbivores (Sunnerheim *et al*., 1988; O'Reilly-Wapstra *et al*., 2005). Tannin-binding salivary proteins are thought to affect feeding by eutherian mammals and this affects the ability of the mammal to counter the tannins within the food source (Marsh *et al*., 2003).

Although my work indicated some links between physical and chemical characteristics of the bark and the damage to the bark by wild horses, there is much further research to be carried out on the nutrient and chemical composition of eucalypt bark, especially comparing preferred eucalypt species with the eucalypt species which do not experience bark chewing. Assessments of phenols, tannins, plant secondary metabolites, toxins, protein content as well as further studies on nutrient contents will be necessary to gain further understanding of what cues may be influencing the occurrence of bark chewing.

5.0 Synthesis and conclusion

5.1 BARK CHEWING ON THE RED RANGE PLATEAU

Bark chewing by the wild horses on the Red Range Plateau causes widespread and in some areas, intense, damage to eucalypt species. Two species of eucalypts, *Eucalyptus amplifolia* and *E. moluccana* are chewed by wild horses at higher rates than expected with *E. amplifolia* seeming to be the preferred species. There were also four other eucalypt species on the Red Range Plateau which had some bark chewing damage recorded. The intensity of chewing damage has the potential to change species composition and structure within the impacted sites, pushing the tree line back up the slopes away from the drainage lines. It is doubtful though, that chewing-related tree mortality at these sites will exceed the recruitment rate, as even elephant damage at its most extreme did not increase tree mortality above the recruitment rate (Dublin *et al*., 1990).

Bark chewing can impact upon trees in a variety of ways other than increasing the chance of mortality but there is a lack of information on the physiological effects of girdling (Li *et al*., 2003). Known effects from girdling include the accumulation of assimilates above the girdle (Li *et al*., 2003) and depletion of root starch reserves (Högberg *et al*., 2001), which can then lead to a temporary increase in soil respiration (Nordgren *et al*., 2003). Individual tree response to bark chewing could allow re-sprouting from buds located within the eucalypt bark (Burrows, 2002). The opportunity for sprouting from below the girdled site would provide the tree with a higher chance of survival, but as bark chewing is concentrated below a height of 50cm, these sprouting opportunities would be minimised. The accumulation of assimilates, such as starch, above the girdled site (Li *et al*., 2003) could increase the chances of revisits to trees, resulting in greater bark damage and impacting upon the long-term health of the tree.

Bark chewing in different localities is due to different species seeking different rewards (Baxter and Hansson, 2001), such as sugar, nutrients or protein. Therefore, bark chewing by other species can act as an indicator for why the wild horses chew bark, but the precise explanation for why bark chewing takes place on the Red Range Plateau is likely to be unique. Bark consumption in the southern hemisphere appears to be linked with rainfall, with chewing increasing during drought (Atkinson, 1993 in Baxter and Hansson, 2001). Rainfall can influence the volume of sap within the bark by increasing soil moisture (Eyre and Goldingay, 2003) and could possibly impact the transport or accumulation of nutrients, starch or other chemical compounds found within the bark. The thicker bark on the trees with bark chewing damage may also influence the composition of chemicals and nutrients within the bark, potentially increasing the strength of the cues that trigger bark chewing.

There is a potential link between bark chewing and the starch content of the bark. Although the results did not show a significant difference between the starch content of damaged and undamaged trees, there is an indication that starch may be involved in the choices of trees being chewed. This is also highlighted by the presence of an odour during analysis (S. Song, *pers. comm.*) for the samples with the lowest starch content. Further sampling with greater sample sizes as well as comparisons between total starch content of different species, including stringy-barks, will reveal whether total starch content is an indicator for bark chewing by the wild horses. Total starch was not correlated with the depth of the bark but once again, further sampling is required to determine if there is a correlation, especially as there was a significant difference between the depth of the bark of trees with chewing damage and trees with no chewing damage.

Trees with no chewing damage had no difference between bark thickness for those trees located within and outside of drainage lines. This indicates that there may be some selection for trees with thicker bark, which is likely to be a result of the strength of the cues or rewards correlated with thicker bark. However, this reveals selection for individual trees as opposed to selection for tree species, showing that intraspecific variation is as strong as that found between species (Lawler *et al.*, 1998; Lawler *et al.*, 2000). Chemical compounds such as DFPs vary significantly between individual trees within species (Lawler *et al.*, 1998) as does sap flow (Goldingay, 1987), which increases the difficulty in locating precise triggers for bark chewing because instead of concentrating upon differences between tree species, differences between individuals may have important influences.

The wild horses at GFRNP show significant selection for smooth and box-barked eucalypts and selection against stringy-bark species. Preference for trees with smooth and box bark indicates that there is either a strong cue triggering bark chewing in the preferred eucalypts or a strong deterrent within the stringy-barks. The trees which suffer bark chewing damage are all part of the subgenus *Symphyomyrtus* whereas the stringy-bark *E. caliginosa* and other stringy-barks recorded within the vegetation report of GFRNP (Austeco, 1999) fall within the subgenus *Eucalyptus*. Marsh *et al*. (2003) found that the high tannin concentrations within the subgenus *Eucalyptus* cause brush-tail possums, *Trichosurus vulpecula*, to avoid some species within this subgenus which ringtail possums, *Pseudocheirus peregrinus*, willingly eat. Tannin-binding salivary proteins are thought to impact the ability of mammals to counter the tannins within the food source (Marsh *et al*., 2003). Eucalypt resistance to herbivory of foliage occurs through variations of the chemical composition in the foliage, for example, plant secondary metabolites, condensed tannins and essential oils (Lawler *et al*., 1998; O'Reilly-Wapstra *et al*., 2005), therefore combinations of these chemicals within the bark may also act as deterrents to bark chewing.

5.2 FURTHER RESEARCH AND MANAGEMENT

There are a great variety of options which could be pursued to increase further understanding of the bark chewing behaviour by the wild horses on the Red Range Plateau. The distribution of bark chewing is clear, though there is a high probability that there are other intensively chewed areas than the eight sites that my work revealed. Further investigation should involve assessing whether *E. nobilis, E. melliodora* and *E. retinens* are chewed as intensively as the three species known to be preferred or whether bark chewing of these species occurs randomly, similar to bark chewing on slopes and ridges. Monitoring of the mortality rate of eucalypts with severe bark chewing damage is recommended, as this is currently unknown, yet will provide an indication of the overall mortality rate of damaged trees and the impacts this will have on species composition and vegetation structure of the drainage lines where bark chewing occurs. The location of the drainage lines reflects the geological structure of the Plateau. Due to the clumping of bark chewing within drainage lines, further work should also include assessing the variation of trace metals within the soil along these drainage lines. Any variation of trace metals could provide important information regarding site selection for bark chewing, especially the locations of the intensively damaged sites.

Further research should ideally focus on trying to provide an understanding of why the wild horses chew the bark of certain species. Seasonal patterns of bark chewing, when and where, should be monitored more closely, as should the occurrence of bark chewing in relation to rainfall. Sap flow in eucalypts should be measured in response rainfall and also assessed when new bark chewing is recorded. Nutrient content should also be investigated further though it is more likely to be an immediate food reward, such as the positive post-ingestive feedback associated with starch (Villalba and Provenza, 2000), which prompts bark chewing.

Bark nutrient and chemical content should be tested at different heights of the trunk, due to the basal concentration of bark chewing. Temporal variation of these components is also likely to be detectable and may be important, therefore monitoring the temporal variation of nutrient and chemical content of individual trees with damage and correlating this variation with any further occurrence of bark chewing on those particular trees. The bark above the girdle site should be tested in order to determine whether there is any accumulation of carbohydrates (Li *et al*., 2003) or other components above the girdle which encourages repeat visits to trees. Crude protein could also be assessed as this was thought to be the reason for bark stripping by elephants (Mwalyosi, 1990) and browse such as fallen leaves and stems contain high levels of crude protein (Hobbs *et al*., 1981).

The number of samples required to gain a wider understanding of bark chewing means that the cost of sampling becomes extremely expensive (McIlwee *et al*., 2001). Once a greater understanding of bark content such as protein, fibre and chemical composition is reached, the use of near-infrared reflectance spectroscopy (NIRS) has the potential to carry out multiple analyses (W.J. Foley, *pers. comm*.). The NIRS reflects the chemical bonds that make up the different nutrients and plant secondary metabolites (McIlwee *et al*., 2001) and as these components appear to be important factors related to the occurrence of bark chewing, this method has the potential to ease the cost of the intensive sampling required to further knowledge of bark chewing cues and rewards. This method has been shown to be successful at predicting the behaviour of herbivores which select forage types due to the chemical composition of the food (McIlwee *et al*., 2001).

Management of the wild horses in GFRNP currently involves a feed-lure capture program which proved to be successful during the trial period. If bark chewing is a learnt behaviour, the removal of the current population of the wild horses from the Red Range Plateau is likely to reduce the occurrence of bark chewing, therefore reducing further damage. It is possible though that the horses which will migrate to the Plateau to fill the empty niche will also chew bark, as they will probably respond to the cues initiating bark chewing by the current wild horse population. The most severe damage has already occurred on the Red Range Plateau, further damage of this intensity is unlikely to occur whilst active management of the wild horse population continues.

The extent of the damage resulting from bark chewing damage will be revealed in the future as the trees which have been severely ring-barked gradually die. As the density of the wild horse population is reduced by the capture program, the occurrence of bark chewing should decline. Although sugar content appears not to be an important indicator for bark chewing, if sugar is a bark chewing cue or reward, the provision of molasses which occurs as part of the capture program should reduce the incidence of chewing, however, some new bark chewing on the Plateau still occurs when molasses is freely available. Therefore, until an understanding of what rewards are gained by the wild horses through chewing bark and what cues are driving this behaviour, it is not possible to provide an alternative source of this resource to reduce the occurrence of bark chewing.

5.3 CONCLUSION

Continued active management of the wild horse population on the Red Range Plateau is recommended to prevent any further increase of the extent of bark chewing damage. Bark chewing is distributed across the entire Red Range Plateau and is clumped within the drainage lines. The current levels of damage have been shown to be severe but the long-term health of damaged eucalypts will be revealed by the gradual mortality of trees which have been ring-barked. Over the long-term, the mortality of a large number of trees due to bark chewing damage is likely to impact upon the vegetative composition and structure of drainage lines on the Red Range Plateau.

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Appendix

Table 1: Random site locations on the Red Range Plateau, GFRNP.

Site	UTM
RB1	56 J 0426736, 6677063
RB2	56 J 0425942, 6673441
RB3	56 J 0427137, 6672110
RW1	56 J 0417656, 6670268
RW2	56 J 0417380, 6669116
RW3	56 J 0419297, 6670107

Table 2: Intensive site locations on the Red Range Plateau, GFRNP.

Site		UTM
BC1	Eastern Boban	56 J 0427994, 6672670
BC2	Dead Pig Gully	56 J 0426466, 6672754
BC3	Top Dam	56 J 0422963, 6670160
BC4	Boban Dam	56 J 0426101, 6673160
BC5	Scrubby Dam	56 J 0424615, 6671907
BC6	Super Highway	56 J 0425150, 6674000

Table 3: Locations of all quadrats within the intensively damaged sites on the Red Range Plateau, GFRNP.

Site and Quadrat	UTM	Elevation (m)
BC1 Q1	56 J 0427957, 6672785	965
BC1 Q2	56 J 0427931, 6672758	955
BC1 Q3	56 J 0427973, 6672629	935
BC2 Q1	56 J 0426378, 6672822	860
BC2 Q2	56 J 0426433, 6672796	868
BC2 Q3	56 J 0426609, 6672611	862
BC3 Q1	56 J 0422984, 6670205	981
BC3 Q2	56 J 0423042, 6670189	991
BC3 Q3	56 J 0423080, 6670396	1011
BC4 Q1	56 J 0426246, 6673080	855
BC4 Q2	56 J 0426234, 6673129	862
BC4 Q3	56 J 0426219, 6673192	860
BC5 Q1	56 J 0424616, 6672026	940
BC5 Q2	56 J 0424642, 6672029	947
BC5 Q3	56 J 0424582, 6672108	953
BC6 Q1	56 J 0425190, 6673916	893
BC6 Q2	56 J 0425240, 6673851	902
BC6 Q3	56 J 0425337, 6673682	918

Table 4: Sites for random drainage lines on the Red Range Plateau, GFRNP.

BS1	56 J 0422831, 6669472
BS2	56 J 0424797, 6674677
BS3	56 J 0421529, 6671449
BS4	56 J 0427816, 6672394
BS5	56 J 0422342, 6670404
BS6	56 J 0425468, 6670908
WS1	56 J 0418242, 6670013
WS2	56 J 0420468, 6671110
WS3	56 J 0417598, 6670920
WS4	56 J 0417849, 6667893
WS5	56 J 0419852, 6671545
WS6	56 J 0416909, 6668640

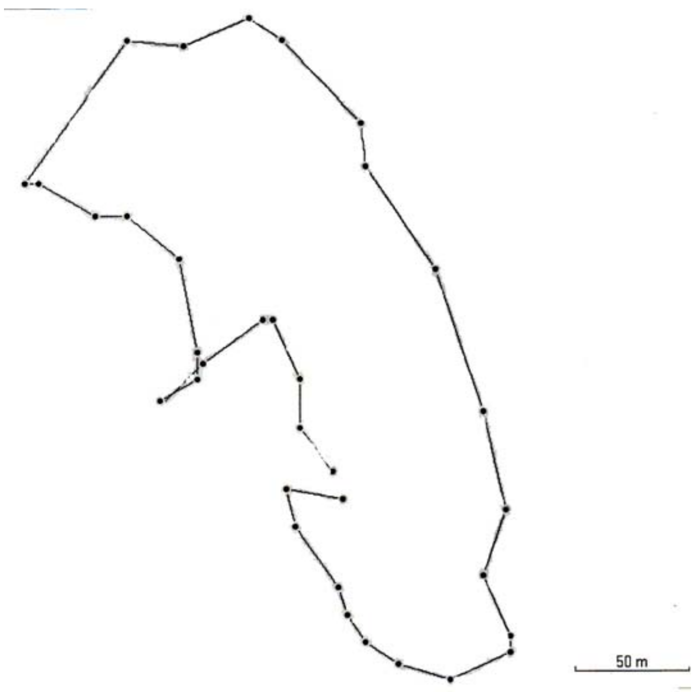

Figure 1a: Map of the extent of bark chewing damage at the intensively damaged site Eastern Boban, BC1, on the Red Range Plateau, GFRNP.

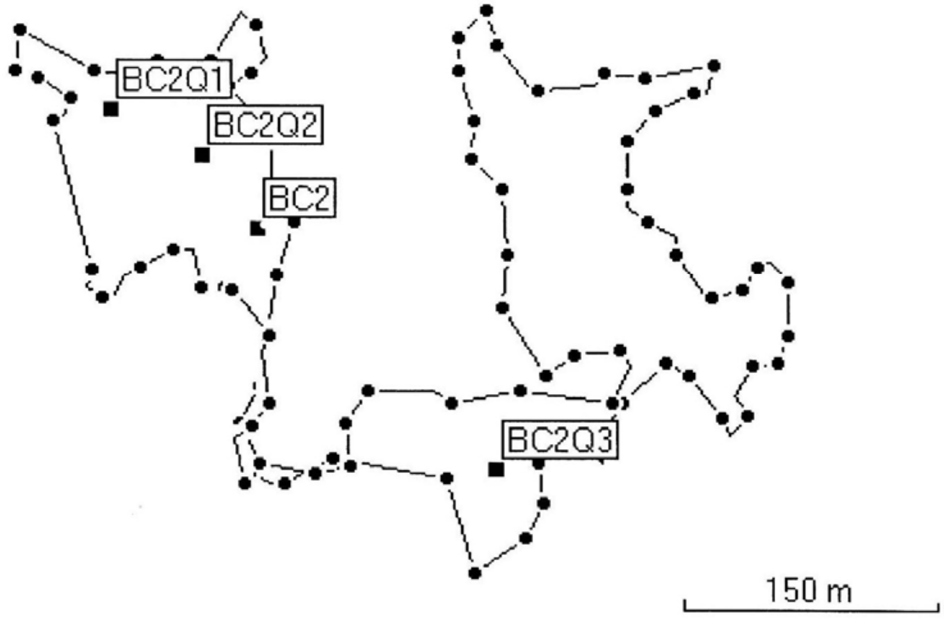

Figure 1b: Map of the extent of bark chewing damage and random quadrat locations for the intensively damaged site Dead Pig Gully, BC2, on the Red Range Plateau, GFRNP.

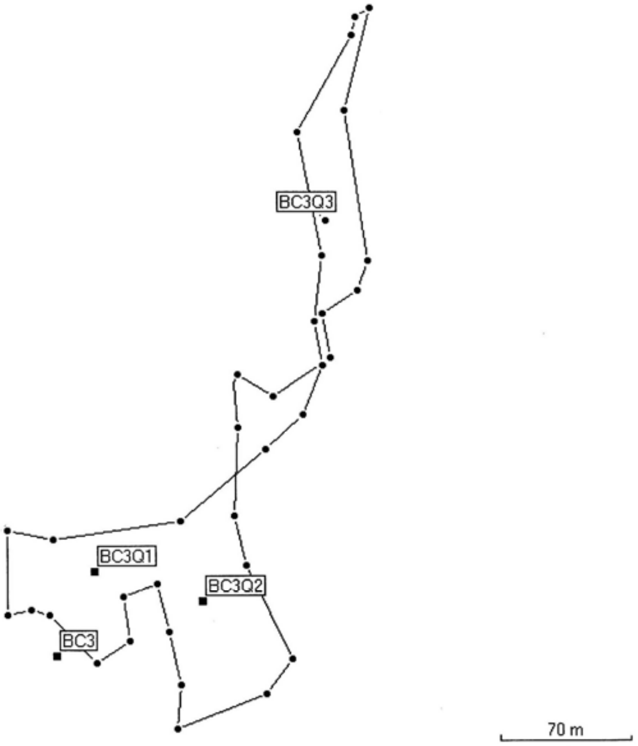

Figure 1c: Map of the extent of bark chewing damage and the locations of random quadrats, within the intensively damaged site Top Dam, BC3, on the Red Range Plateau, GFRNP.

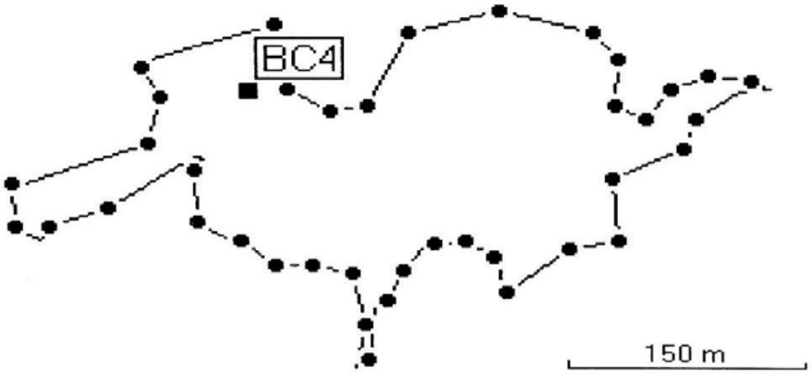

Figure 1d: Map of the extent of bark chewing damage at the intensively damaged site Boban Dam, BC4, on the Red Range Plateau, GFRNP.

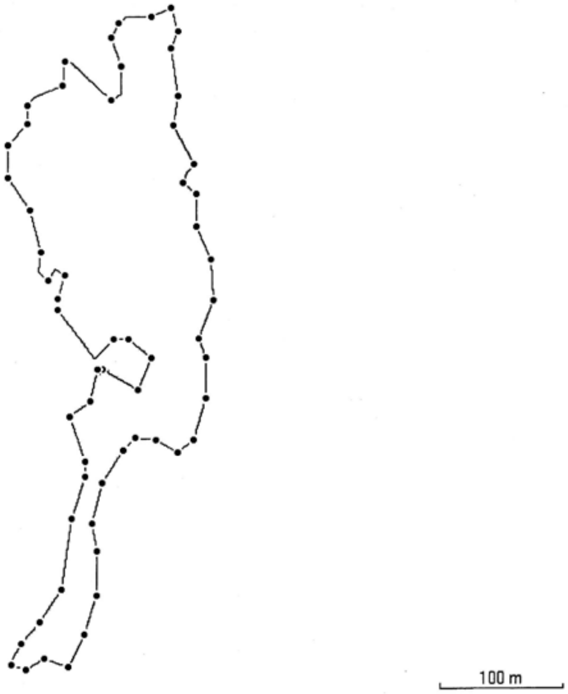

Figure 1e: Map of the extent of bark chewing damage at the intensively damaged site Scrubby Dam, BC5, on the Red Range Plateau, GFRNP.

Figure 1f: Map of the extent of bark chewing damage at the intensively damaged site, Super Highway, BC6, on the Red Range Plateau, GFRNP.

Figure 1: Maps of the extent of bark chewing of the intensive sites on the Red Range Plateau, GFRNP.

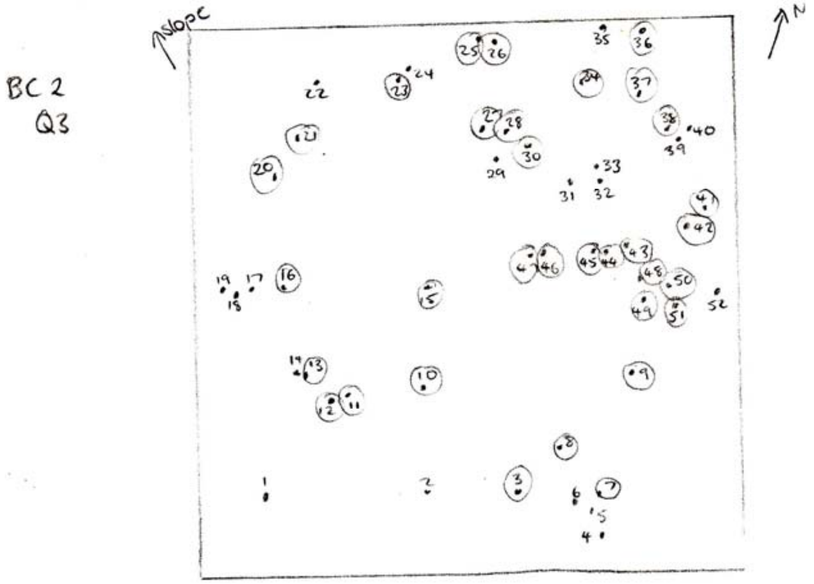

Figure 2a: Location of all tree species within quadrat three within the intensively damaged site, Dead Pig Gully, on the Red Range Plateau, GFNRP. Circled trees show the location of trees with bark chewing damage.

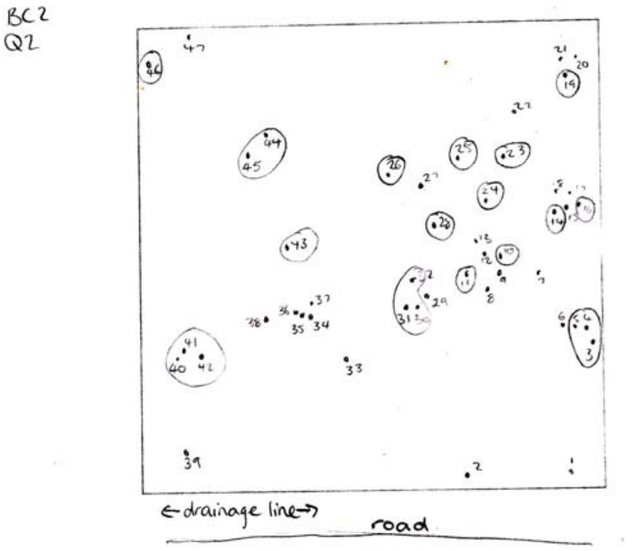

Figure 2b: Location of all tree species within quadrat two within the intensively damaged site, Dead Pig Gully, on the Red Range Plateau, GFNRP. Circled trees show the location of trees with bark chewing damage.

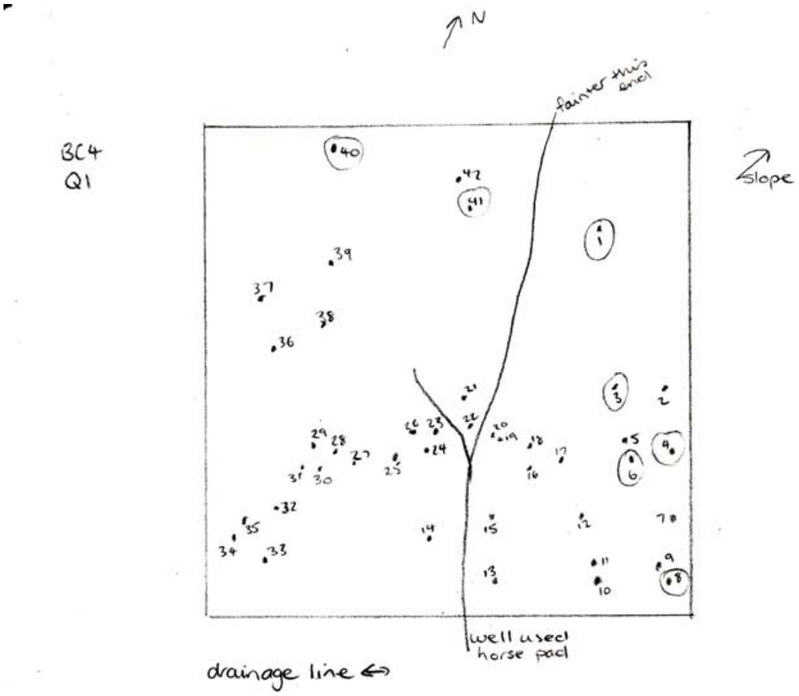

Figure 2c: Location of all tree species within quadrat three within the intensively damaged site, Boban Dam, on the Red Range Plateau, GFNRP. Circled trees show the location of trees with bark chewing damage.

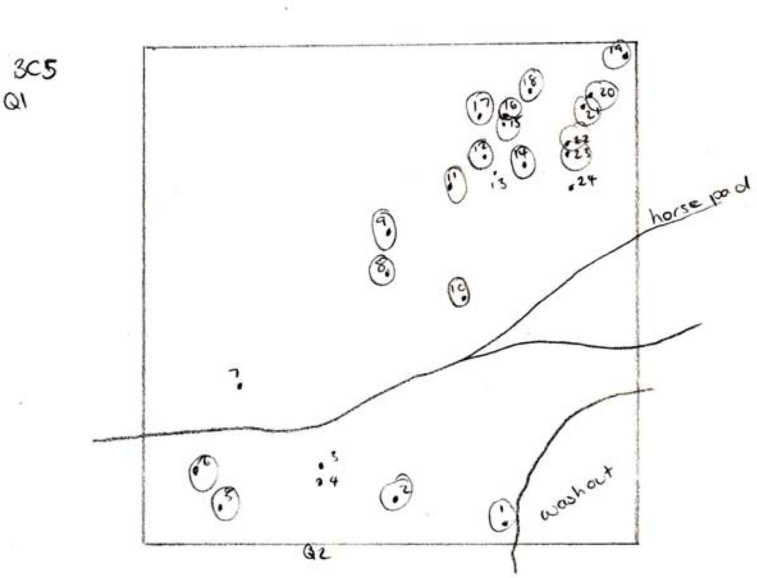

Figure 2d: Location of all tree species within quadrat three within the intensively damaged site, Scrubby Dam, on the Red Range Plateau, GFNRP. Circled trees show the location of trees with bark chewing damage.

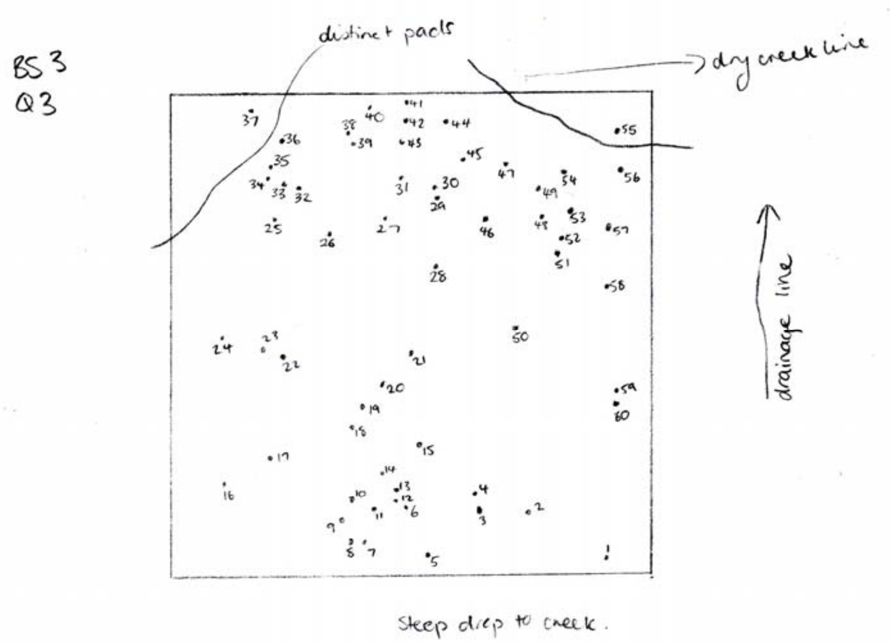

Figure 2e: Location of all tree species within quadrat three within a random drainage line site, BS3, on the Red Range Plateau, GFNRP.

Figure 2: Examples of quadrat maps showing the distribution of trees within each quadrat. The circled trees are those with bark chewing damage and each quadrat is 20m x 20m.

Bark Chewing

Transect:__________ Quadrat:______________ Intensive / Random

GPS:_____________ Aspect:______________.

Site description:____.

____.

Species	DBH	Chewed	Damage	Age	Health	Comments

Figure 3: Example of the work sheet used for field work.

Table 5: Locations and elevation of all random drainage line quadrats on the Red Range Plateau, GFRNP.

Site and quadrat	**UTM**	**Elevation (m)**
BS1 Q1	56 J 0422723, 6669530	999
BS1 Q2	56 J 0422770, 6669562	1001
BS1 Q3	56 J 0422814, 6669521	1028
BS2 Q1	56 J 0424743, 6674613	931
BS2 Q2	56 J 0424773, 6674681	887
BS2 Q3	56 J 0424810, 6674729	912
BS3 Q1	56 J 0421506, 6671444	954
BS3 Q2	56 J 0421422, 6671465	940
BS3 Q3	56 J 0421380, 6671421	934
BS4 Q1	56 J 0427743, 6672383	974
BS4 Q2	56 J 0427792, 6672340	967
BS4 Q3	56 J 0427842, 6672291	925
BS5 Q1	56 J 0422407, 6670428	962
BS5 Q2	56 J 0422387, 6670461	978
BS5 Q3	56 J 0422313, 6670501	944
BS6 Q1	56 J 0425310, 6670596	980
BS6 Q2	56 J 0425344, 6670650	973
BS6 Q3	56 J 0425356, 6670737	955
WS1 Q1	56 J 0418094, 6670090	1094
WS1 Q2	56 J 0418124, 6670072	1054
WS1 Q3	56 J 0418213, 6670046	1090
WS2 Q1	56 J 0420411, 6671068	893
WS2 Q2	56 J 0420433; 6671125	931
WS2 Q3	56 J 0420438, 6671170	908
WS3 Q1	56 J 0417668, 6670956	1084
WS3 Q2	56 J 0417682, 6671009	1071
WS3 Q3	56 J 0417729, 6671092	1075
WS4 Q1	56 J 0417777, 6667873	1049
WS4 Q2	56 J 0417849, 6667887	1010
WS4 Q3	56 J 0417911, 6667861	1016
WS5 Q1	56 J 0419703, 6671530	930
WS5 Q2	56 J 0419715, 6671560	941
WS5 Q3	56 J 0419704, 6671623	975
WS6 Q1	56 J 0146759, 6668407	967
WS6 Q2	56 J 0416825, 6668466	963
WS6 Q3	56 J 0416892, 6668457	1022

Table 6: Chi-squared analysis of chewing damage to *E. amplifolia* and *E. moluccana* for all intensively damaged sites on the Red Range Plateau, GFRNP.

	Chewed	Not chewed	**Total**
E. amplifolia Observed Expected	160 144.01	60 75.99	**220**
E. moluccana Observed Expected	71 87.06	62 45.97	**133**
E. saligna Observed Expected	4 3.93	2 2.07	**6**
Total	**231**	**122**	**353**

$\chi^2 = 13.72$; $p < 0.0001$; df = 1

Table 7: Chi-squared analysis for bark chewing damage to three eucalypt species for all Boban sites on the Red Range Plateau, GFRNP.

	Chewed	Not chewed	**Total**
E. amplifolia Observed Expected	43 49.4	21 14.6	**64**
E. moluccana Observed Expected	21 32.84	123 111.16	**144**
E. saligna Observed Expected	10 15.44	10 4.56	**20**
Total	**52**	**176**	**228**

$\chi^2 = 17.57$; $p < 0.0002$; df = 2

Table 8: Chi-squared analysis for bark chewing damage to three eucalypt species for all Wonga sites on the Red Range Plateau, GFRNP.

	Chewed	Not chewed	**Total**
E. amplifolia Observed Expected	28 21.8	65 71.2	**93**
E. moluccana Observed Expected	0 3.28	14 10.72	**14**
E. saligna Observed Expected	2 4.92	19 16.08	**19**
Total	**30**	**98**	**128**

$\chi^2 = 8.86; p < 0.0119; df = 2$

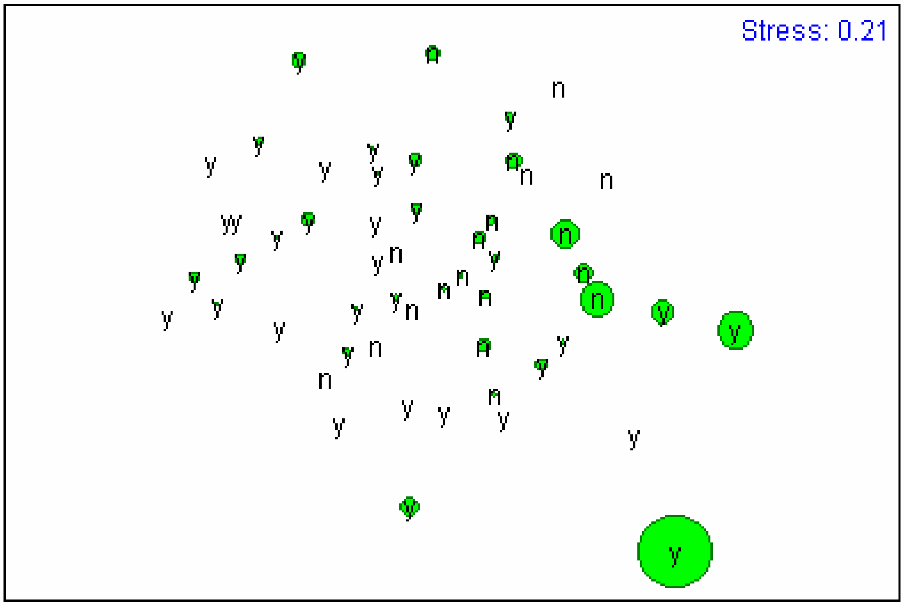

Figure 4: Ordination diagram of sampled quadrats showing the link between percentage of stringy-barks and the quadrat BS4 Q1.

Table 9: Number of species sampled at intensively damaged sites and the random drainage line sites.

Species	**Intensive**	**Boban**	**Wonga**	**Total**
E. amplifolia	220	64	93	**377**
E. moluccana	133	144	14	**291**
E. saligna	6	20	21	**47**
E. nobilis	0	0	56	**56**
E. caliginosa	14	110	78	**202**
E. retinens	0	14	11	**25**
E. campanulata	0	0	18	**18**
E. melliodora	2	4	0	**6**
E. maculata	0	25	0	**25**
Acacia filicifolia	41	35	179	**255**
Acacia blakei subsp. diphylla	0	16	0	**16**
Allocasuarina torulosa	144	174	83	**401**
Angophora subvelutina	23	42	0	**65**
Exocarpos cupressiformis	34	2	2	**38**
Stringy	0	0	20	**20**
Dead	31	26	24	**81**
Juvenile	4	4	51	**59**
Total	**652**	**680**	**650**	**1982**

Table 10: P-values for comparisons of sugar content for trees with bark chewing damage and no bark chewing damage at Dead Pig Gully on the Red Range Plateau, GFRNP. (NSP = Non-starch polysaccharide)

	Rhamnose	**Fucose**	**Ribose**	**Arabinose**	**Xylose**	**Mannose**	**Galactose**	**Glucose**	**Total NSP**	**Total Free Sugars**
NSP	0.4961	0.6102	0.0924	0.2993	0.3944	0.8137	0.3504	0.6479	0.6479	-
Free Sugars	0.6449	-	-	0.3880	0.6449	0.4383	0.6479	0.1250	-	0.1157