

The impacts of sambar (*Cervus unicolor*) in the Yarra Ranges National Park

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Abstract

Internationally, the impacts of deer have been widely studied, but little work has been conducted in Australia. Sambar (*Cervus unicolor* Kerr) were introduced to Victoria in the 1860s from Sri Lanka, and have become established throughout eastern Victoria. This study is located in the Yarra Ranges National Park, 100 km north east of Melbourne. The park primarily consists of three protected water catchments that contribute approximately 50% to Melbourne's water supply. This study was conducted from 2005 to 2008 in the Upper Yarra and O'Shannassy catchments. Large open areas covered by forbs and grasses periodically form adjacent to the water body of the Upper Yarra reservoir. Sambar are frequently observed at the largest of these areas known as The Flats. The impacts of sambar at this locality and in other areas of the catchments were investigated.

Faecal pellet transect surveys determined that sambar occupancy and density was greatest on open flats, lower on forest edges adjacent to open flats (< 250 m), and significantly less in other forested areas of the catchment. Observations of The Flats revealed that hinds were the main demographic class represented, with a mean group size of 39 individuals, and up to 70. This is the largest aggregation of sambar ever reported anywhere in the world, and equates to an approximate density of 200 km⁻² at this site.

Selective exclosures effectively differentiated the offtake of forage by sambar from that of native herbivores. Sambar contributed to the majority of offtake at The Flats, and were able to obtain a substantial proportion of their daily food requirements from this source. A culling program began in the Yarra Ranges National Park in May 2008, to reduce the large numbers of deer in the park. The cull reduced the time spent by sambar on The Flats, as determined by faecal pellet accumulation plots, and significantly reduced faecal pellet load and forage offtake.

Sambar significantly decreased relative foliage cover of shiny nematolepis (*Nematolepis wilsonii*), a threatened understorey tree, through their antler rubbing activities. Thrashing of shiny nematolepis saplings also significantly decreased relative foliage cover, with sambar selecting saplings with a larger stem diameter from those available. Rubbed trees

and thrashed saplings experienced damage to, on average, over half the stem circumference.

Selective exclosures allowed differentiation of sambar and native herbivore browsing on forest understoreys. Browsing by sambar in high densities prevented the vertical growth of plants in the understorey, with branches above 60 cm in height most commonly browsed. Plants in the understorey were more frequently and intensely browsed in areas of high sambar density. Three species were browsed to a significantly greater extent by sambar than native herbivores: hazel pomaderris (*Pomaderris aspera*), prickly tea-tree (*Leptospermum continentale*) and prickly bush-pea, (*Pultenaea juniperina*). Sambar significantly reduced plant biomass in forest understoreys where they occur in high densities.

The presence of large, open herb-rich areas drives the high local densities and associated impacts of sambar within the Yarra Ranges National Park. Future areas of research are identified and management recommendations are outlined. A sustained culling program appears to be the only practical option to reduce sambar density and impacts at this locality.

Declaration

This is to certify that

- i) the thesis comprises only my original work towards the PhD except where indicated in the Preface
- ii) due acknowledgement has been made in the text to all other material used
- iii) the thesis is less than 100 000 words in length, exclusive of tables, maps, references and appendices

Signature

Date

Preface

All data presented were collected solely by the author, except observation data presented in Chapter 2, which was collected jointly with Andrea Whelan (Honours student, Department of Zoology, The University of Melbourne, 2005).

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CHAPTER 1

General introduction



*Upper Yarra catchment, Yarra Ranges National Park,
December 2005*

CHAPTER 1

General introduction

Globally, the ecological impacts of deer have been well documented. Figure 1.1 demonstrates the potential pathways through which deer may impact on the environment. Deer are ruminants: this system of digestion allows deer to consume, digest and obtain nutrients from coarse foods including grasses, herbs, shrubs, fallen leaves and fruit. Deer are often classified into grazers, browsers or intermediate feeders according to food preferences, however most deer are generalist herbivores, and utilise food plants depending on availability within their habitat (Geist 1999). The same deer species may therefore select different plants depending on localised food availability (Gebert and Verheyden-Tixier 2001). The ability of deer to alter fundamental elements of forest ecosystems through habitat use has defined deer in some habitats as keystone herbivores or ecosystem engineers (Rooney and Waller 2003; Baiser *et al.* 2008).

Successful introduction and establishment of deer has had major impacts on some ecosystems, for example in New Zealand forests (Coomes *et al.* 2002), where nine deer species were introduced for hunting purposes (Forsyth and Duncan 2001). Similarly, deer were introduced to Australia for recreational hunting (Bentley 1998). While considerable study has investigated the impacts of deer in New Zealand (e.g. Husheer *et al.* 2006), the impacts of deer in Australia have received minimal attention (Dolman and Waber 2008) despite their widespread distribution (Moriarty 2004). Anecdotal evidence suggests that deer populations, in general, are increasing (Moriarty 2004) with deer in Victoria currently managed as a game resource (Hall and Gill 2005). Debate over management practices is largely divided into two arguments. One view is that deer are now a naturalised part of the Australian fauna, and are a resource to be managed for recreational hunting (Hall and Gill 2005). The contrasting argument is that deer are an exotic species that should be managed to protect the natural values of Australia's biodiverse endemic ecosystems (Low 1999; Temby 2007). In resolving this issue, investigation of the impacts of deer is clearly required to increase our understanding and to assist in directing the future management of deer in Victoria, and Australia.



Thesis outline

This thesis investigates one of the four deer species established in Victoria sambar (*Cervus unicolor* Kerr) (Bentley 1998). Sambar are a large tropical deer species, that were introduced primarily from Sri Lanka in the 1860s and are now found throughout eastern Victoria, southern New South Wales and Australian Capital Territory. There are also several isolated populations in Victoria and the Northern Territory. This study addressed four elements, exploring various aspects of sambar ecology and impacts in the Yarra Ranges National Park, a major water catchment in Victoria. Due to a lack of knowledge of the ecology and impacts of deer in Australia (Dolman and Waber 2008), the aspects investigated are near the beginning of potential impact pathways highlighted in Figure 1.1. The links with potential flow-on effects may identify areas that will require further study.

The core chapters of this thesis are written in the style of papers suitable for publication as stand-alone pieces of work. Consequently, some overlap between chapters occurs, particularly with regard to site and species descriptions and elements of the methods. Given the potential management implications for Melbourne's water supply, Chapter 2 investigates the occupancy and density of sambar in the Upper Yarra catchment, with relevance to the large open flats adjacent to the Upper Yarra reservoir. In addition, the demographic structure and group size of sambar are described at this locality. Chapter 3 examines a common concern that introduced species such as sambar impose new threats to endangered native species. This concern is illustrated by the investigation of behavioural rubbing activities by sambar in YRNP on the threatened tree species shiny nematolepis (*Nematolepis wilsonii*). Chapter 4 investigates forage offtake by sambar in a high density locality, to determine the importance of the site as a food resource. The effects of a cull on forage offtake and population density at this site, located adjacent to the Upper Yarra reservoir, were also investigated to aid in directing future management. Chapter 5 explores the browsing impact of sambar on plants in forest understoreys through the use of a selective exclosure experiment, highlighting variation of impact with sambar density. Chapter 6 identifies the management implications of this study and proposes future directions of research that will enhance our understanding of the impacts of this large, exotic herbivore in Victorian ecosystems.

CHAPTER 2

General ecology and distribution of sambar in the Yarra Ranges National Park



*A young sambar hind, Upper Yarra catchment,
Yarra Ranges National Park, July 2006*

CHAPTER 2

General ecology and distribution of sambar in the Yarra Ranges National Park

General ecology of sambar

Sambar (*Cervus unicolor*) is a large-bodied, tropical deer species. There are five recognised subspecies of sambar (Geist 1999), native to Sri Lanka, India, Nepal, Bhutan, southern China, Burma, Taiwan, Thailand, Laos, Cambodia, Indonesia, Malaysia, Celebes and the Philippines (Ngampongsai 1987; Varman and Sukumar 1993; Geist 1999). Sambar have also been introduced to and become established in USA, New Zealand and Australia (Shea *et al.* 1990; Bentley 1998; Forsyth and Duncan 2001).

Sambar generally have a uniform dark brown pelage, although this may vary from almost black through to light brown or reddish brown, with finer and lighter coloured hair on the ventral surface, inner legs, rump and underneath the tail (Bentley 1998; Harrison 1998). In Sri Lanka, Eisenberg and Lockhart (1972) reported that sambar stags were an average size of 150 cm at the shoulder, and weighed up to 216 kg, and hinds were an average of 120 cm and 136 kg, while Santiapillai *et al.* (1981) described minor differences in these measurements in Sri Lanka, with stags measuring 131 cm and 215 kg, and hinds 102 cm and 163 kg.

Sambar occur in tropical and temperate regions at high and low altitudes, and are able to utilise a wide variety of food plants (Schaller 1967; Downes 1983; Ngampongsai 1987; Bentley 1998). Sambar have been variously described as predominantly grazers (Padmalal *et al.* 2003), as intermediate feeders utilising a mixture of browse and herbs (King 1990; Varman and Sukumar 1993; Stafford 1997) and as predominantly browsers (Santiapillai *et al.* 1981; Burke 1982; Ngampongsai 1987; Shea *et al.* 1990; Semiadi *et al.* 1995). Sambar are known to feed on tree seedlings, shrubs, grasses, forbs and ferns (Dinerstein 1987; Ngampongsai 1987; Padmalal *et al.* 2003), and will utilise crops, gardens and fruit trees (Bentley 1998; Mason 2006).

In Thailand, Ngampongsai (1987) found that preferred sambar habitat was a mixture of grassland and forest. Eisenberg and Lockhart (1972) described daily activities of sambar

in Sri Lanka, which entailed browsing in the forest during the morning hours, resting during mid afternoon in a shaded secluded location, followed by more browsing and emerging into the open scrub land for grazing at night. At a landscape level, sambar utilise their habitat in accordance with seasonal food resource availability, forage quality and abundance (Santiapillai *et al.* 1981; Varman and Sukumar 1993; Davies *et al.* 2001). Sambar utilise consistent trails (Eisenberg and Lockhart 1972; Davies *et al.* 2001) to move throughout their habitat.

Varman and Sukumar (1993) proposed that the preference of sambar for dense forest may be a behavioural response to predation. In their native range, the main predator of sambar are tigers (*Panthera tigris*) (Biswas and Sankar 2002; Bagchi *et al.* 2003; O'Brien *et al.* 2003). Karanth and Sunquist (1995) found that tigers in Nagarhole Sanctuary, India preyed on adult sambar, but leopards (*Panthera pardus*) preyed on sambar calves. Approximately half the sambar calves in Wilpattu National Park, Sri Lanka died in their first 2 years from leopard predation, and leopards also took sick adults (Eisenberg and Lockhart 1972). Sambar constituted 15% of the diet of lion (*Panthera leo*) in Gir Lion Sanctuary, India (Khan *et al.* 1996). Dholes (*Cuon alpinus*) hunting in packs may also prey on sambar (Rabinowitz and Walker 1991).

Sambar hinds produce their first calf at approximately 2 years of age (Harrison 1998). Breeding can occur throughout the year (Varman and Sukumar 1993; Semiadi *et al.* 1994; Asher *et al.* 1997). A broad peak in parturition occurs spanning several months, which in their native range roughly coincides with the monsoon (Mishra and Wemmer 1987). Sambar calves exhibit 'hider' behaviour in the first few weeks of life, remaining hidden in thick bushes until they are strong enough to follow the hind (Bentley 1998; Harrison 1998), which is characteristic of species that are likely to be solitary and inhabit dense forests (Caro 2005). Bentley (1998) considers that given the high fecundity and irregular breeding pattern of sambar, it may be possible for a hind to produce two calves within 18 months, although one calf per year is more common (Forsyth *et al.* 2004). Sambar twins are rare (Bentley 1998; Harrison 1998). The age at which sambar calves wean in the wild is not known, although the slightly smaller-bodied red deer (*Cervus elaphus*) wean young at 3 – 4 months of age (Moore *et al.* 1988). Dryden (2002) reported that sambar calves in captivity began consuming forage at 20 days old and ruminating at 35 days, and Semiadi *et al.* (1993) reported captive sambar calves significantly decreased milk intake at

10 weeks. Sambar yearlings are commonly reported as remaining with hinds until two years age (Eisenberg and Lockhart 1972; Forsyth *et al.* 2004), although Shea *et al.* (1990) reported male yearlings remain with their mother for only one year.

Sambar stags produce antlers annually from approximately 2 years age (Bentley 1998). Sambar rub their antlers on trees to remove the velvet once full growth of the antlers has occurred. Sambar also rub their hard antlers on trees to mark their territory in conjunction with scent marking by rubbing their preorbital glands on vegetation. Thrashing is similar to rubbing, but vegetation, such as saplings and shrubs are utilised, and it is often associated with scent marking during the rut (Gill 1992). Preaching is largely carried out by the oldest and largest stags, which scrape the ground beneath an overhanging tree that is generally next to a trail. The tree trunk is rubbed with antlers and scent glands, and the stag stands on the hind legs so that the scent glands are rubbed and antlers crashed into the overhead branches. This behaviour has been interpreted as an advertisement of body size (Geist 1999). Stags also create wallows by scraping with their front hooves and antlers in natural seeps, to which they repeatedly return each year (Bentley 1998). Wallowing by stags increases during the rut. Sambar stags urinate directly on their face and neck and in the wallows (Geist 1999). The urine-soaked mud is spread on the body, in particular on the neck, which is then rubbed on surrounding trees and vegetation as another form of scent marking and sexual display (Bentley 1998; Geist 1999; Mason 2006). Hinds rarely wallow but may do so for cooling during hot weather (Bentley 1998).

Sambar are a shy and secretive species (Bentley 1998; Harrison 1998) and are generally found alone or in small family groups (Table 2.1). Eisenberg (1972) noted that a hind with a yearling and/or a calf comprises the most cohesive social unit, which usually persists for at least two years. While sambar are considered a non-herding species, Eisenberg (1972) reports that groups of sambar can occur, such as at water holes. Varman and Sukumar (1993) reported much more gregarious behaviour at Mudumalai Sanctuary, India with observation of a very large group of 50 individuals (Table 2.1). However, Varman and Sukumar (1993) concluded that the group was not a cohesive unit, but an aggregation of many family groups gathered at an important resource. Although rutting behaviours can occur in these groupings, there is usually no evidence

of territorial behaviour on the part of stags (Eisenberg and Lockhart 1972; Santiapillai *et al.* 1981; Varman and Sukumar 1993; de Silva 1999).

Table 2.1. Mean and maximum group size and density of sambar. Methods used to estimate density: * pellet group density using defecation rate of 12 pellet groups per individual day⁻¹; † dusk/dawn transect survey; ‡ spotlight transect survey.

	Mean group size	Maximum group size	Density estimate (deer km ⁻²)	Source
Sri Lanka				
Ruhuna National Park	5.4	21	-	Santiapillai <i>et al.</i> 1981
Wilpattu National Park	>2	8	-	Eisenberg and Lockhart 1972
Yala Protected Area Complex	2.2	14	-	de Silva 1999
India				
Bhadra Tiger Reserve	1.1	-	0.9 [†]	Jathanna <i>et al.</i> 2003
Gir Lion Sanctuary and National Park	1.7	-	2.1 [†]	Khan <i>et al.</i> 1996
Mudumalai Sanctuary	3.1	50	7.9 [†]	Varman and Sukumar 1993
Nagarahole National Park	1.7	6	3.2 [†]	Karanth and Sunquist 1992
Pench Tiger Reserve	-	-	6.1 [†]	Biswas and Sankar 2002
Ranthambhore Tiger Reserve	3.8	>10	17.1 [†]	Bagchi <i>et al.</i> 2004, Bagchi <i>et al.</i> 2008
Nepal				
Chitwan Valley	1.5	10	-	Seidensticker 1976
Thailand				
Huai Kha Khaeng Wildlife Sanctuary	-	-	1.9 [*] (dry season) 4.2 [*] (wet season)	Srikosamatara 1993
Khao-Yai National Park	-	-	2.3 [†] 13 [‡] 95 [*]	Ngampongsai 1987

Several studies have reported larger groups in the wet season, when sambar tend to utilise open habitats, which include new growth of grasses and herbs (Srikosamatara 1993; Varman and Sukumar 1993; de Silva 1999). Large groups may occur in response to predation risk, a behaviour which is displayed by many open habitat or plains species (Bertram 1978). Large groups are able to persist as the onset of the wet season often coincides with parturition (Mishra and Wemmer 1987), therefore the hinds are not in season, and territorial or rutting behaviours are not being displayed by the stags at this time. Smaller groups are observed in the dry season when grass and herb forage availability has reduced (Srikosamatara 1993; Varman and Sukumar 1993; de Silva 1999), and sambar utilise dense wet forests with high quality browse (Varman and Sukumar 1993).

Sambar in Australia

Australia has six species of introduced free-ranging deer: chital (*Axis axis*), hog deer (*Axis porcinus*), fallow deer (*Dama dama*), red deer (*Cervus elaphus*), rusa (*Cervus timorensis*) and sambar (Bentley 1998). Sambar are often considered the most successful of the deer species introduced to Australia (Bentley 1998). Sambar were introduced in Victoria at Tooradin in 1868 (Bentley 1998), and are most common in eastern Victoria, where they are now widespread, including southern New South Wales and the Australian Capital Territory (Dunn 1985; Moriarty 2004). Isolated populations also occur at Mt Cole in Western Victoria, French Island, Victoria, south eastern South Australia and the Cobourg Peninsula, Northern Territory (Moriarty 2004; Bilney 2008) (Figure 2.1).

Sambar populations in Australia are considered to be derived from the Sri Lankan taxon *Cervus unicolor unicolor* (Bentley 1998). In Australia, average shoulder height and weight respectively of 127 cm and 192 kg for stags and 109 cm and 146kg for hinds have been recorded (Bentley 1995), similar to the measurements reported in their native range (Eisenberg and Lockhart 1972; Santiapillai *et al.* 1981).



Figure 2.1 Distribution of sambar in Australia, adapted from Bilney (2008).

Sambar habitat in Australia appears to correlate strongly with wet sclerophyll forest (Downes 1983; Bentley 1998). Preferred sambar habitat has also been described as forest with 3-4 vegetation strata, including an understorey with mesomorphic (soft) leaves (Downes 1983; Tolhurst 1983). Expert hunter opinion maintains that preferred habitat is forest (Ray and Burgman 2006) in close proximity to water, forest edges or clearings, and gullies (Yamada *et al.* 2003). These preferences were considered to vary with amount of solar radiation relative to ambient temperature, with sambar apparently utilising their habitat to aid in thermoregulation (Yamada *et al.* 2003). Moore (1994) found that high wind and extreme temperatures increased use of cover and the time of day influenced the use of habitat type, while Downes (1983) reported seasonal movement with sambar descending below the snow line (approximately 1000 m a.s.l.) in winter in Australia. Sambar are generally crepuscular to nocturnal. However, during summer they may start feeding earlier and leave open feeding areas well after dawn, then rest during the day in the cover of the forest (Bentley 1998).

Breeding season and associated activities of sambar are as ill-defined in the temperate environment of Australia as in the native tropical habitat, and can occur throughout the year. In Australia, stags are in hard antler for approximately 6 months of the year, with a peak from August to November which coincides with the peak rut, and a peak in calving occurs after 8 months gestation, between May and July (Figure 2.2).



Source: ^a Bentley 1995; ^b Bentley 1998; ^c Menkhorst and Knight 2001

Figure 2.2. Breeding cycle stages of sambar in Australia.

In Australia, dingoes and wild dogs (*Canis familiaris*) (Bentley 1998), and wedge-tailed eagles (*Aquila audax*) (N. Rattray, Melbourne Water pers. comm.) may occasionally take calves, sick or old individuals, but otherwise predation is limited to human hunters (Bentley 1998). Legislation relating to deer and deer hunting in Australia varies according to state (Hall and Gill 2005). In Victoria, sambar are classified as wildlife under the Wildlife Act 1975. Hunting of sambar in Victoria is legal throughout the year but only in specified areas. Sambar may be hunted with the use of a firearm of a specified calibre, or a bow of a specified weight, and with approved breeds of gundogs or scent-trailing hounds, as outlined in the Wildlife (Game) Regulations 2001. Hunting is generally prohibited in national parks, however deer stalking (without the aid of dogs) is permissible for six to nine months of the year in designated sections of Baw Baw National Park, Lake Eildon National Park, Alpine National Park, Avon Wilderness Park and Mitchell River National Park. Sambar were listed in November 2007 as a Potentially Threatening Process under the Victorian Flora and Fauna Guarantee Act 1988. This listing, for the reduction of biodiversity of native vegetation, was primarily due to

sambar rubbing activities on the threatened tree species *Nematolepis wilsonii* (Chapter 3) and *Acronychia oblongifolia* (Scientific Advisory Committee 2007).

Downes (1983) suggests that sambar in Australia are commonly found in groups of two or three, up to seven individuals, but do not form large herds. However Mason (2006) reports temporary aggregations of up to 20 individuals graze at night on crops and pasture in eastern Victoria. Sambar are considered to be distributed across Victoria in low densities (Downes 1983; Bentley 1998; Harrison 1998; Mason 2006). While there have been several attempts to quantify these claims (Lewin 2002; Houston 2003; Whelan 2005), these studies note sampling difficulties as a likely source of error in final estimates.

The majority of the Yarra Ranges National Park is closed to the public because it is a water catchment area. Melbourne Water and Parks Victoria identified the Yarra Ranges National Park as a locality that apparently contained a high density of sambar. In particular large numbers of sambar have been reported adjacent to the Upper Yarra reservoir, which may have significant implications for the management of Melbourne's water supply. Houston's (2003) study was conducted in the Upper Yarra catchment and found a population estimate of 54 km⁻² in forest and 230 km⁻² on open flats adjacent to the Upper Yarra reservoir. However, given the extremely high density estimates obtained compared with other estimates for the species, Houston concludes these estimates are highly unlikely to be representative of the true density. Given that predation of sambar in Australia is minimal and hunting is prohibited in this park, further investigation into the density and potential impacts of sambar in the Yarra Ranges National Park is required.

Study aims

This study aimed to describe the sambar density in the Upper Yarra catchment, Yarra Ranges National Park with reference to distance from the Upper Yarra reservoir and determine how the location of open flats adjacent to the reservoir influence sambar distribution within the catchment. In addition this study aimed to determine the abundance of sambar on The Flats adjacent to the Upper Yarra reservoir and to describe demographic structure and social interactions within the population.

Methods

Yarra Ranges National Park

The Yarra Ranges National Park (YRNP) is located approximately 100 km north east of Melbourne, Victoria (Figure 2.3). The park covers 76 003 ha, encompassing a variety of forest types classified into 14 Ecological Vegetation Classes (EVCs), and provides habitat for 20 threatened plant and 21 threatened animal taxa (Parks Victoria 2002). Within the YRNP there are four designated Reference Areas, which are sites of ecological significance and interest, preserved as botanical and zoological reference sites for comparative purposes (Reference Areas Act 1978). A further 11 areas are recognised as sites of botanical significance at a national, state or regional level (Parks Victoria 2002).

YRNP is jointly managed by Melbourne Water and Parks Victoria, with 84% (64 500 ha) of the park classified as Designated Water Supply Catchment Area. YRNP provides approximately 50% of Melbourne's water supply. Melbourne's catchments have been closed to the public for over 100 years, and the city is one of only five in the world that have protected catchments (Melbourne Water 2007; Melbourne and Metropolitan Board of Works Act 1958). Hunting is prohibited at all times in the YRNP. The park is comprised of three main catchments: Maroondah, O'Shannassy and Upper Yarra. This study was conducted in the Upper Yarra catchment of 33 670 ha (Figure 2.3).

Sambar is the only deer species observed in the YRNP, although fallow deer (*Dama dama*) are known to occur on residential and farm fringe areas nearby. Sambar have become more frequently sighted on the roads in the catchment, with the greatest concentration at the locality known as The Flats, in the Upper Yarra catchment, adjacent to the Upper Yarra reservoir (N. Rattray, Melbourne Water pers. comm.).

Study site

The Flats are approximately 50 ha in area. This open, ephemeral, herb-rich area forms the base of the eastern arm of the Upper Yarra reservoir, at the point where the Yarra River currently enters the water body. The area of The Flats depends on the level of the reservoir (Figure 2.4), which is dictated by rainfall and Melbourne Water operations. The Flats were created during construction of the reservoir, which was completed in 1957 (Melbourne Water 2007). All trees in the valley were felled and their stumps are still present on The Flats (Figure 4.2a). In recent years, maintaining the reservoir at a consistently high level has not been possible, so The Flats have been exposed for much of the time. January 2005 – August 2008, The Flats were submerged on two occasions: November 2005 – March 2006, August 2007 – February 2008.

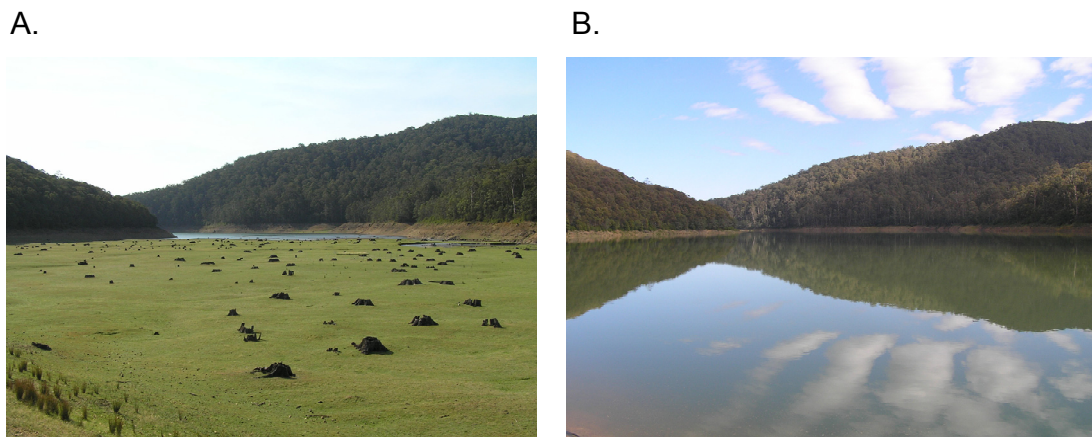


Figure 2.4. The Flats, the large ephemeral area adjacent to the Upper Yarra Reservoir, Yarra Ranges National Park **A.** Exposed October 2007 and **B.** Submerged January 2007.

There are other similar but smaller flats located adjacent to the Upper Yarra reservoir, including Aldermans Creek Flat (southern arm) and Walshs Creek Flat (northern arm) (Figure 2.5). Small patches of forbs and grasses also form at the junction of most small tributaries and the reservoir.

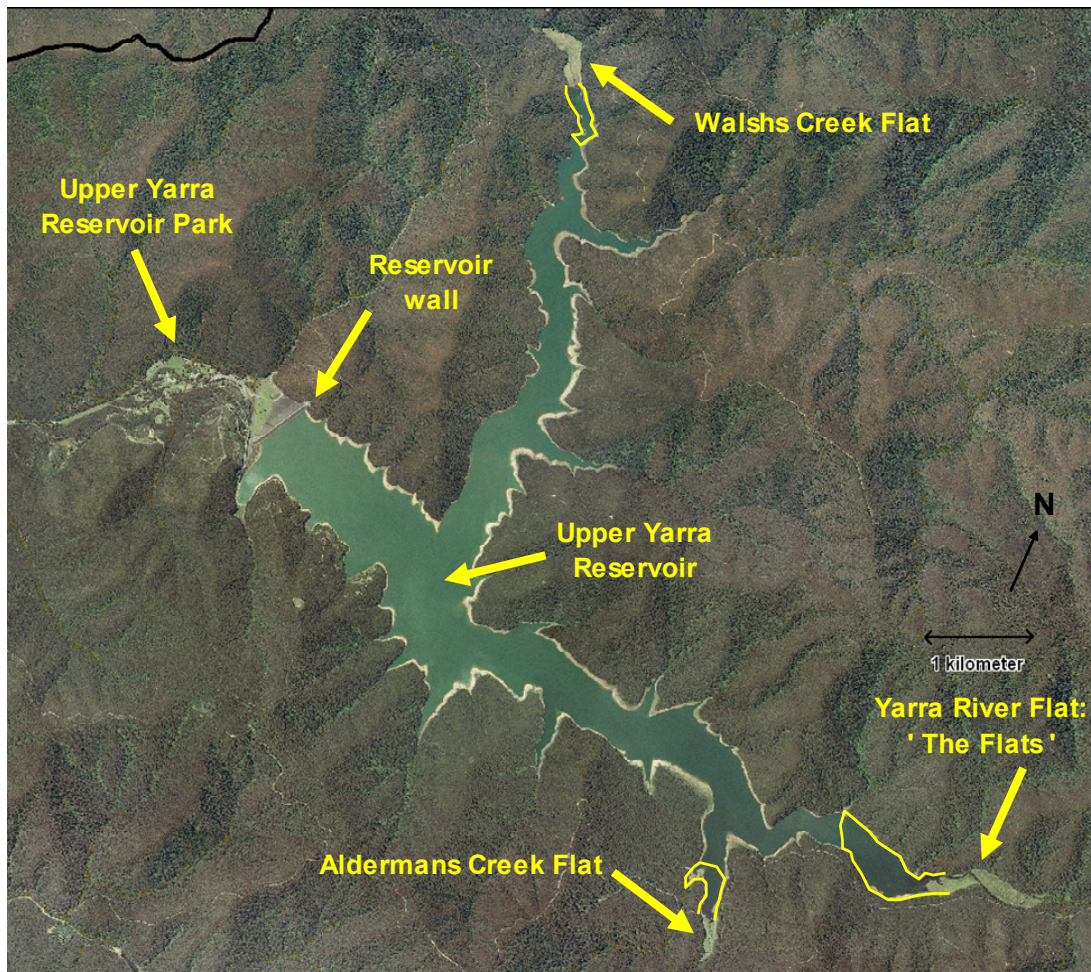


Figure 2.5. Aerial photo of the Upper Yarra reservoir, Yarra Ranges National Park, December 2004, showing the location of Walshs Creek Flat, Aldermans Creek Flat and the Yarra River Flat known as ‘The Flats’. The yellow lines at each of the flats represent the additional area typically exposed during this study when the reservoir is at approximately 50% of capacity. The reservoir wall is at the western end of the reservoir adjacent to the Upper Yarra Reservoir Park.

Much of The Flats is relatively uniform, covered by three forb and two grass species: stinking pennywort (*Hydrocotyle sibthorpioides*), creeping knotweed (*Persicaria prostrata*), hypsela (*Hypsela tridens*), annual meadow grass (*Poa annua*) and blown-grass (*Lachnagrostis* aff. *filiformis*). Of these, hypsela is rare in Victoria, with a limited distribution, and preliminary observations indicate the blown-grass may be a previously undescribed species or sub-species, with taxonomic similarities to common blown-grass (*Lachnagrostis filiformis*) (A. Brown, Department of Primary Industries pers. comm.). Further from the reservoir edge, The Flats experience infrequent flooding and are dominated by green rush (*Juncus gregiflorus*), hollow rush (*Juncus amabilis*) and tall sedge (*Carex appressa*) tussocks, interspersed with a more diverse mixture of grass and forb species (Chapter 4).

In general, the forest to the north of The Flats has a southerly aspect reflected in the EVCs (Ecological Vegetation Class) Wet Forest and Damp Forest. The southern side of The Flats has a northerly aspect with drier forest types dominated by the EVCs Heathy Dry Forest and Shrubby Foothill Forest, and small amounts of Damp Forest in minor tributaries.

Considerable sambar activity is evident on The Flats. While exposed, The Flats are covered in a substantial quantity of sambar faecal pellets (Figure 2.6a). Partially dried faecal pellets float, so when the reservoir rises or water pools in depressions, the wind blows the faecal pellets to the edge of the reservoir or pools. Once the water recedes it is common to observe dense clumps of faecal pellets deposited on The Flats (Figure 2.6b). Following heavy rainfall, surface water run-off from the slope above The Flats washes small stones and sambar faecal pellets down onto The Flats. Sambar also frequently use crossing points on the Yarra River adjacent to The Flats, mainly when the river level is high or fast flowing. The use of these crossings by large numbers of sambar often leads to large muddied areas adjacent to the Yarra River (Figure 2.6c). Temporary wallows also occur on The Flats. These wallows do not persist for extended periods as they dry out and are usually small ($1 - 2 \text{ m}^2$), however on occasion they can be up to 5 m^2 in size (Figure 2.6d).

The Upper Yarra catchment is closed to the public and heavy fines are applicable to trespassers. However occasional trespassing and poaching still occurs, which was evidenced by the presence of empty beer cans and other rubbish in proximity to the three main open flats, and the remains of dismembered sambar carcasses at The Flats.

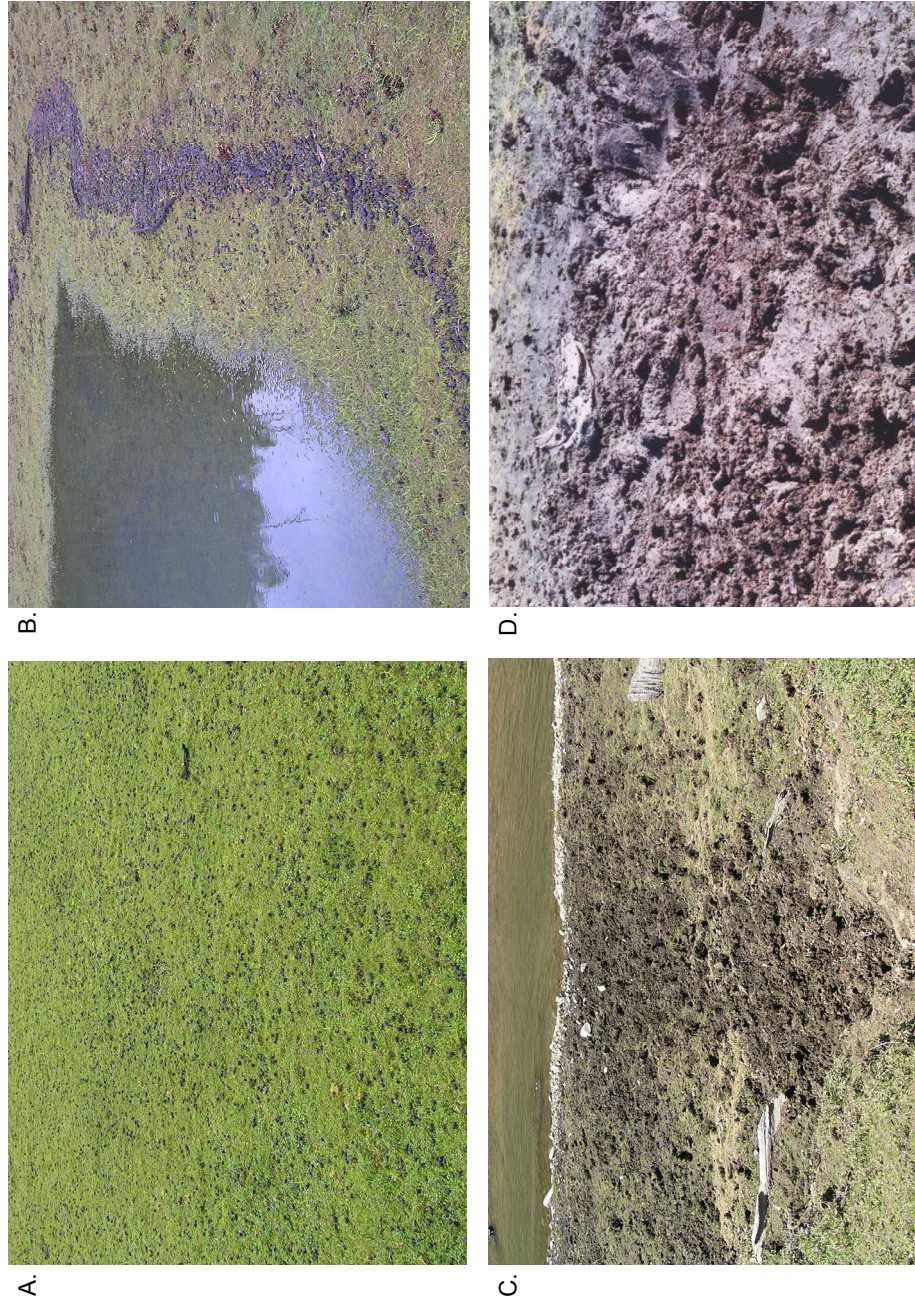


Figure 2.6. Evidence of sambar activity at The Flats, Upper Yarra catchment, Yarra Ranges National Park. **A.** Large quantities of sambar faecal pellets when the area is exposed **B.** Clumps of sambar faecal pellets deposited on The Flats after a pool of water has receded **C.** Sambar trail where it crossed the Yarra River, December 2006 **D.** Large wallow (5 m²) differentiated from a trampled area by smooth patches of mud where a sambar has laid down to cover the body and neck with mud, March 2005.

Vantage point surveys

Vantage point counts are observations of an animal species over 2 to 3 hour periods, usually from an elevated location (Ratcliffe 1987). This method also enables the collection of information such as behavioural observations and demographic elements including sex and age class (Ratcliffe 1987). As observers are stationary in this method, common sources of error inherent in many other direct observational techniques, such as observer movement in transect counts (Focardi *et al.* 2002; Ward *et al.* 2004), are avoided.

Exploratory vantage point observations were conducted on three evenings in February 2005, and indicated that the greatest number of sambar was observed on The Flats with smaller groups frequently observed at Aldermans Creek Flat and Walshs Creek Flat, and that the first individuals appeared several hours before dusk. Two hides were constructed using a combination of star pickets and black shade cloth, which blended well with the many grey and black tree stumps located on each of The Flats (Figure 2.7). One hide was located on the slope above The Flats and the other within a tree stump overlooking Aldermans Creek Flat. No hide was constructed at Walshs Creek Flat, as few individuals were observed at this site.

Vantage point counts were successfully conducted from the hide at The Flats, with apparently minimal disturbance, as indicated by the large groups that remained feeding for several hours. Sambar were easily observed if located at the western end of The Flats, closest to the reservoir, unless they were behind a stump or in a depression. However sambar located at the eastern end of The Flats were more difficult to detect due to the presence of the rush and sedge tussocks, which were tall enough to obscure individuals and were a similar colour to the pelage of sambar. Although The Flats is estimated to cover 50 ha, only about 35 ha could be adequately surveyed for the presence of sambar.

The hide at Aldermans Creek Flat was largely ineffective, often with very few or no individuals appearing, perhaps because the hide was in a more exposed position, although this smaller flat likely attracted less deer. Observation from The Flats hide was much more successful in terms of the number of deer observed and the time they spent there, so the majority of observations were conducted at The Flats. To reduce the

amount of disturbance to the deer, twigs and leaves were raked off an existing trail, approximately 40 m long from the road to the hide. The sound of the running Yarra River also masked most of the noise made by observers.

After confirming the dusk observations were successful, one dawn count was trialled. Two observers arrived at the hide approximately 3 hours before dawn. No sambar were observed in any scans of The Flats at first light, dawn and after sunrise. It is likely the sound of the car at this unusual time scared any deer from The Flats. Camping at the site was not permitted under Melbourne Water regulations, so no further dawn observations were conducted.



Figure 2.7. Observation hide constructed and utilised for vantage point counts of sambar at The Flats, Yarra Ranges National Park from 2005 – 2007. The black shade cloth camouflages with the many black tree stumps located on The Flats.

Evening observations were conducted at The Flats hide between March and September 2005. Observations were on average 2.25 hours duration and were conducted on average 3 times per month. Less frequent observations were conducted during 2006 and 2007, which included three brief observations of ten minutes. Sambar were easiest to count as they appeared on the forest edge and made their way down the slope above The Flats. Using a Kowa TSN-4 Prominar spotting scope, with 30x wide-angle lens or a

20 – 60x zoom lens, the sex and age class of each individual was recorded, which included mature stags and hinds (> 2 years old), yearlings (1 – 2 years old) and calves (< 1 year old). In addition, any behaviours other than feeding on forbs and grasses were recorded.

To determine how many deer remained on The Flats after dusk, a trial was conducted from the hide at The Flats using a spotlight with a red filter, which reduces spotlight glare and disturbance (Dodd and Colwell 1996). However immediately upon exposure of the light after dusk, several loud alarm honks were heard and all that was observed was the eye shine of approximately 10 fleeing deer. After waiting for another hour, it was trialled again with the same effect.

Infrared thermal imagery is another method that has been utilised in the observation of wild animals at night (Naugle *et al.* 1996; Gill *et al.* 1997; Havens and Sharp 1998; Focardi *et al.* 2001). Thermal imaging equipment allows the detection of the long-wave (far infrared) radiant energy emitted by animals (Gill *et al.* 1997). Belant and Seamans (2000) found that forward looking infrared devices were more effective in detecting deer than spotlighting and night vision goggles. The use of an infrared camera during darkness was anticipated to be effective at The Flats because obstacles and vegetation, which reduces the detectability of individuals (Boonstra *et al.* 1994; Gill *et al.* 1997) are minimal, and sambar have a coarse, sparse pelage (Bentley 1998) that may be relatively ineffective in retaining body heat.

A forward looking infrared (FLIR) Agema 570 camera, with an additional Agema lens for a total of 12° field of view, was trialled in darkness from the hide at The Flats, with the camera temperature range set at -2 to 10°C. Given constraints on image storage limit and battery life, filming was conducted on an hourly schedule, recording a series of overlapping still images from the hide in a 180° arc. Each image was subsequently analysed for presence of deer using the program ThermaCAM Explorer 99. Two dusk to dawn surveys were conducted beginning on the evenings of 29 August and 15 September 2005.

Faecal pellet group surveys

Deer generally produce faecal pellets near where they feed (Bennett *et al.* 1940) or after a period of resting and rumination (Collins and Urness 1981; Gunn and Irvine 2003). As such faecal pellets have often been used to describe the density and distribution of cryptic species. This study used faecal pellet counts as an index of abundance. Initial trials followed the method of Forsyth (2005), using a circular plot of 1-m radius, spaced at 5-m intervals along a transect of 150 m. However this protocol was unable to differentiate between low-density areas and areas where sambar were absent. For example a number of FPGs were observed in one transect that did not fall into any plots, giving the same estimate as another survey where no FPGs were seen in the vicinity. Increasing the area surveyed in each transect increases detectability in low-density areas, without adding greatly to the survey time. The plot size was therefore increased to 2-m radius (area 12.57 m²) with an increase in the interval between plots to 10 m to accommodate the larger plots.

In addition, considerable time was also spent between surveys in relocating and finding the next random start point. Several studies have utilised a zig-zag design in transect surveys to decrease down time between surveys. This design has mainly been used for large-scale transect surveys such as by boat or aeroplane (Strindberg and Buckland 2004), and the large scale has allowed each arm of the transect to be treated as an independent survey unit (Marques *et al.* 2001; Strindberg and Buckland 2004). The same principle can be applied to an observer on foot, however on a smaller scale each arm of the zig-zag must be considered dependent on the location of the previous arm, so a complete zig-zag survey is treated as one sample. This design was adopted to investigate the density of sambar in the Upper Yarra catchment.

Twenty one transect surveys were distributed over The Flats, Aldermans Creek Flat and Walshs Creek Flat and the five main EVCs in close proximity to the open areas adjacent to the Upper Yarra reservoir (Figure 2.8). These were Heathy Dry Forest, Shrubby Foothill Forest, Riparian Forest, Damp Forest and Wet Forest. Random GPS coordinates stratified by distance and EVC, and random directions (1 – 360°) were generated using Microsoft Excel®. A Garmin eTrex Legend GPS unit and contour map were utilised to locate the transect start point. A PES Beltchain string was tied off at

nearest tree, and the random direction followed using the compass. The beltchain accurately measured 10-m intervals at which point a peg was placed in the ground as the centre of the survey plot. A 2-m rope was attached to the peg and the plot was systematically searched for intact pellets and pellet groups as defined by Forsyth (2005).

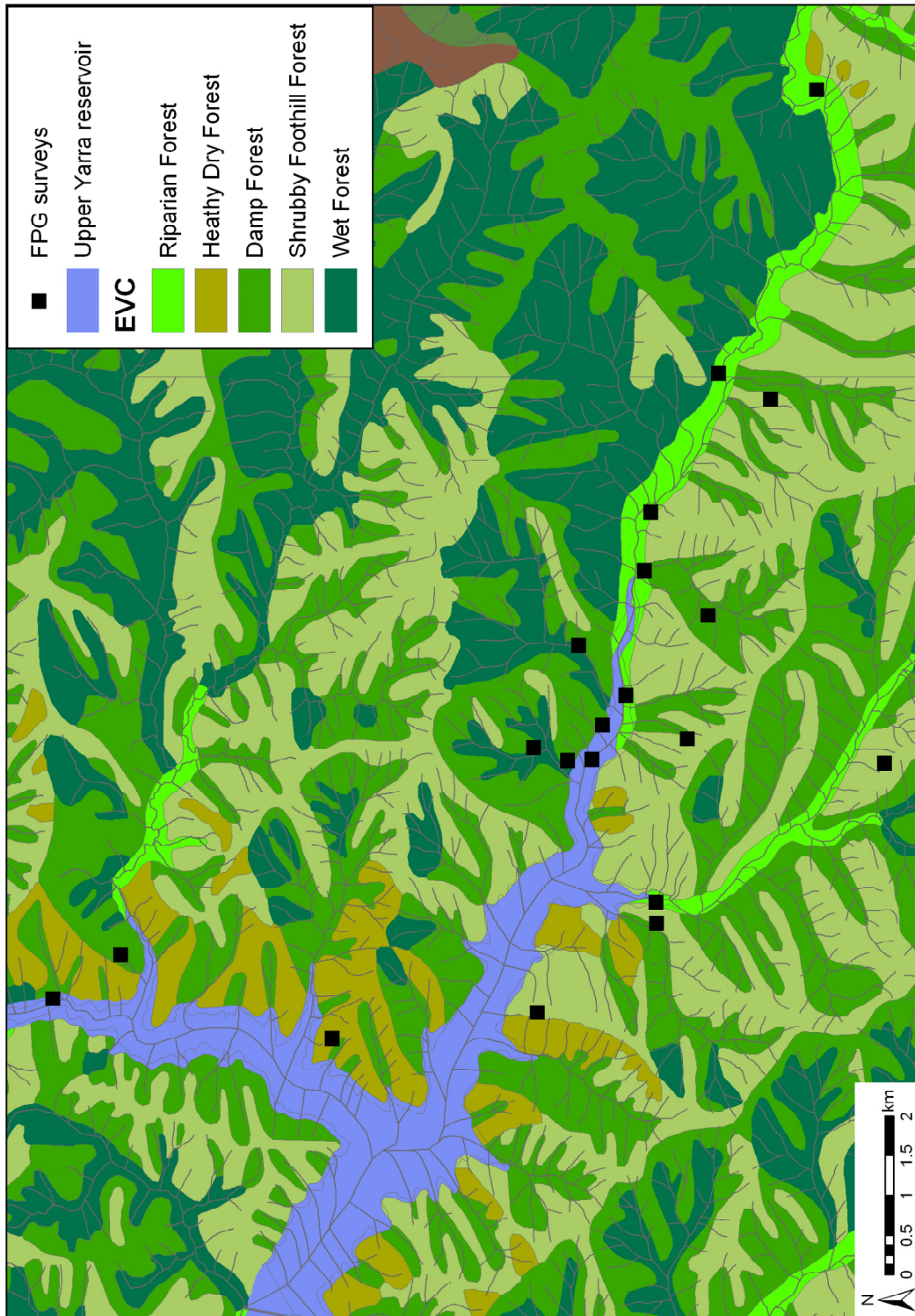


Figure 2.8. Location of faecal pellet group (FPG) surveys located with proximity to the Upper Yarra reservoir, Yarra Ranges National Park, 2005.

An intact pellet has no recognisable loss of material regardless of whether the pellet is cracked, partly broken or trampled. A pellet group contains one or more intact pellets voided in the same defecation, as determined by size, shape and colour of pellets. Vegetation was pushed aside to search the plot, but the leaf litter was not disturbed. After ten plots were surveyed, 120° was added to the compass bearing to set the direction of alternate arms of the transect, until five arms were completed, covering a square area of 1 ha (Figure 2.9).

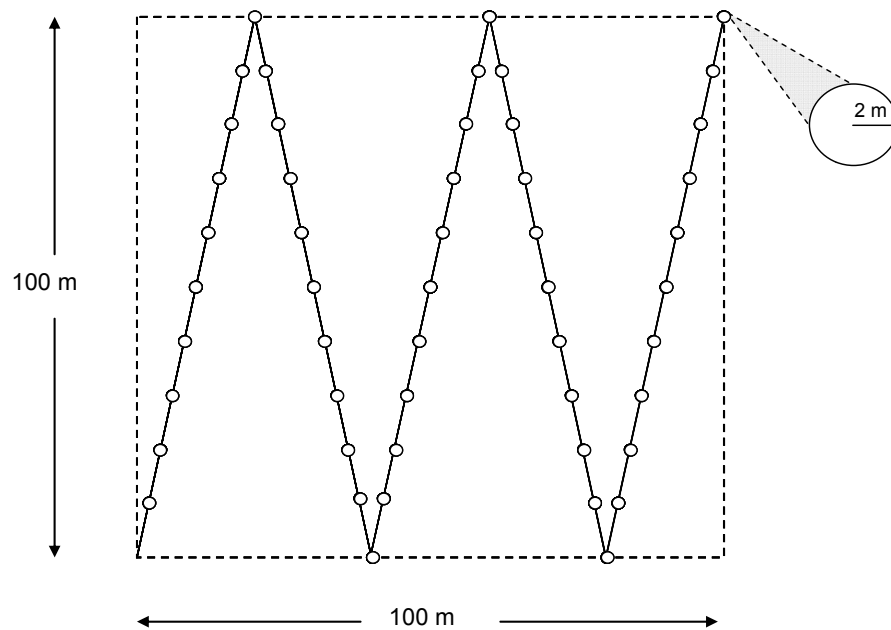


Figure 2.9. Plan view of the Faecal Pellet Group (FPG) transect survey design, conducted in the Yarra Ranges National Park, 2005. Circular plots of $r = 2$ m (area = 12.56 m^2) were surveyed every 10 m in a zig-zag transect pattern covering a total survey area of 1 ha.

Results

Vantage point surveys

Large numbers of sambar were most frequently observed at The Flats at dusk (Figure 2.10), however it was common for several individuals to appear and feed on The Flats during the day. While these aggregations were usually small, 1 – 4 individuals, on several occasions approximately 25 individuals were observed feeding during the day.



Figure 2.10. A group of sambar grazing on The Flats, Yarra Ranges National Park at dusk, (18:30 Eastern Summer Time), February, 2007.

The maximum number of deer observed on each survey varied between 10 and 70 individuals, with an average of 39 individuals. There were 3 – 4 times as many hinds present at each observation than any other sex and age class ($F_{4,155} = 18.34$, $P < 0.001$) (Figure 2.11). Fisher's least significant difference post hoc test revealed no difference in the number of individuals observed among the other sex and age classes. The majority of males observed were relatively young as indicated by their small antlers, with only two large males observed on The Flats throughout the study. The number of deer observed was not influenced by season ($F_{3,28} = 1.12$, $P = 0.357$) (Figure 2.12).

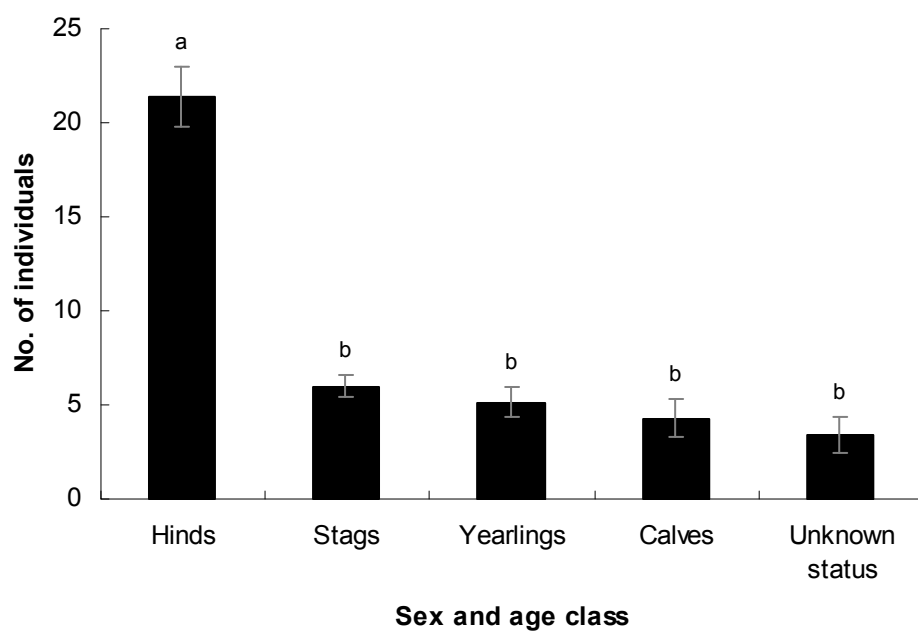


Figure 2.11. Mean number of sambar (\pm standard error) observed at each vantage point survey conducted from the hide at The Flats, Yarra Ranges National Park, between March 2005 and February 2007. Significant differences between sex and age classes, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a and b, where $a > b$.

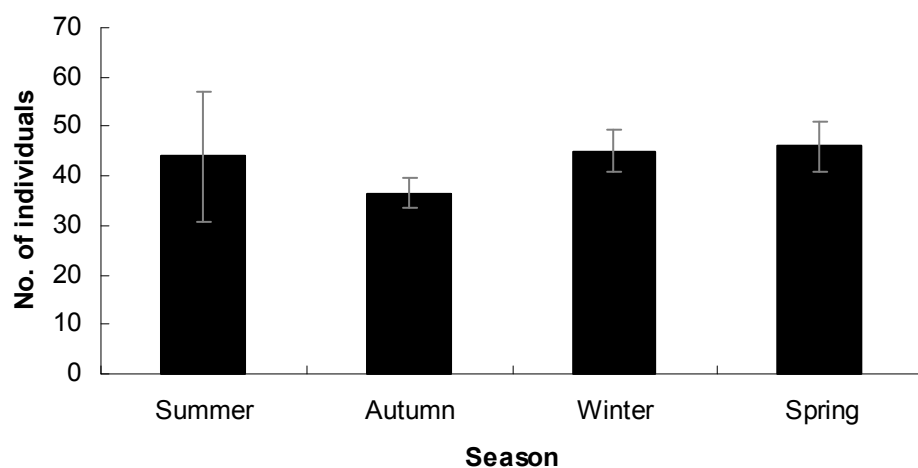


Figure 2.12. Mean number of sambar (\pm standard error) observed during vantage point counts conducted from the hide at The Flats, Yarra Ranges National Park, March 2005 – February 2007, categorised by season: Summer (December – February, $n = 4$), Autumn (March – May, $n = 17$), Winter (June – August, $n = 8$), Spring (September – November, $n = 2$).

If sambar were alarmed they would 'honk' (Harrison 1998) loudly and commonly departed The Flats for forest cover immediately. If this did not occur, an individual honked loudly but remained stationary and alert; head and tail up and ears forward. They would sometimes then slowly lift a foreleg high until it was folded up close to the body, and then stamp it. This behaviour was commonly repeated along with alarm honks for several minutes until they either slowly moved away with high deliberate steps or quickly departed for cover. Occasionally the repeated alarm honks were replaced by a higher pitched, squeaky vocalisation. Young calves that were not eating forbs and grass often played; running between other calves or by themselves, and returned to their mother within a few minutes, and sometimes then resumed play activities.

Sexual behaviours were rarely observed between individuals at The Flats. On these few occasions a stags' behaviour entailed following a hind that was feeding, with the neck stretched out and head held low, and would nuzzle the hindquarters, sometimes dribbling saliva. This momentarily disturbed the hind which moved on to continue feeding nearby.

The images obtained using the infrared camera were effective in identifying sambar on The Flats. If the deer were relatively close, the resulting images were well defined (Figure 2.13a). Sex and age determination, as shown to be successful in other studies when the deer were close to the camera (Gill *et al.* 1997; Focardi *et al.* 2001), could not be evaluated because very few individuals were observed close to the hide. The distant images were much less defined; however they were still effective for total counts (Figure 2.13b).

Comparison between the activity patterns of sambar on The Flats during the two all-night surveys conducted on the evenings beginning 29 August and 15 September 2005, showed they were not significantly different (Kolmogorov-Smirnov test, $\chi^2 = 1.0$, d.f. = 2, $P = 0.607$). Activity on The Flats followed a wave-like pattern (Figure 2.14). Sambar numbers initially rose to a peak at approximately 17:30, fell after dusk until approximately 21:30, increased again between approximately 23:00 and 01:00, decreased from 01:00 to approximately 04:30 and increased again in the pre-dawn light. Following sunrise, numbers decreased again.

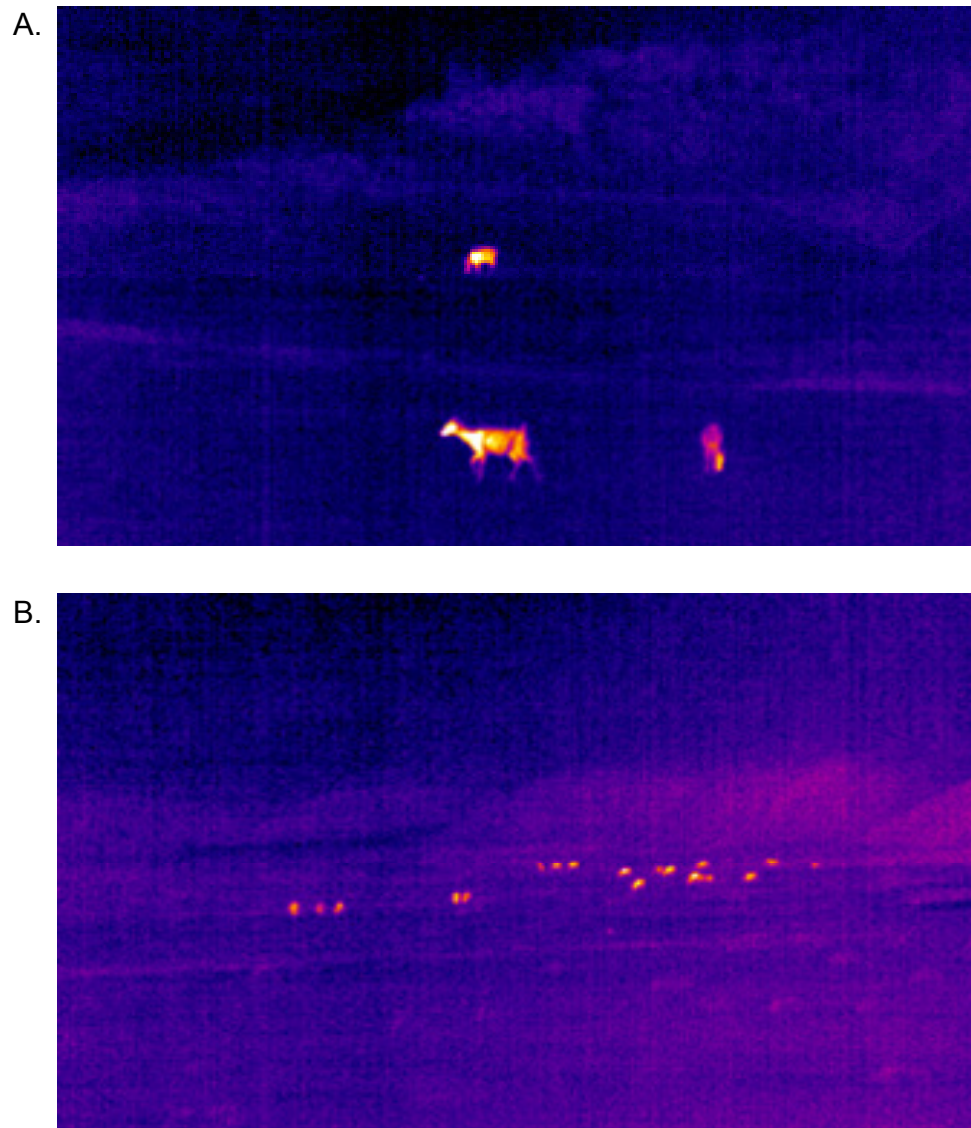


Figure 2.13. Infrared images of sambar on The Flats, Yarra Ranges National Park, at 19:30, 29 August 2005. **A.** Three deer at approximately 50 m and **B.** 18 deer at approximately 500 m.

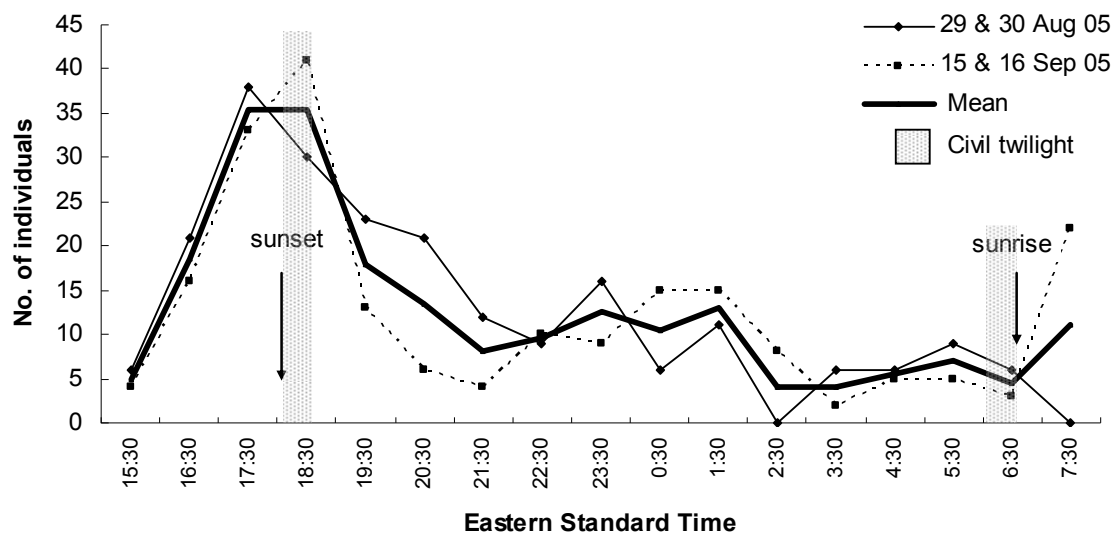


Figure 2.14. Total number of sambar observed at hourly intervals at The Flats, Yarra Ranges National Park, beginning on the evenings of 29 August and 15 September 2005. Data were obtained using a telescope during daylight and civil twilight and infrared camera during darkness. Sunset, sunrise and civil twilight times were obtained from Geoscience Australia, 2007.

Faecal pellet group surveys

The cumulative mean standard error of the number of FPGs recorded on each of the zig-zag survey 'arms' decreased with each additional arm up to the fourth. The addition of the fifth arm did not improve the precision of the FPG count, indicating the hectare was adequately surveyed (Figure 2.15).

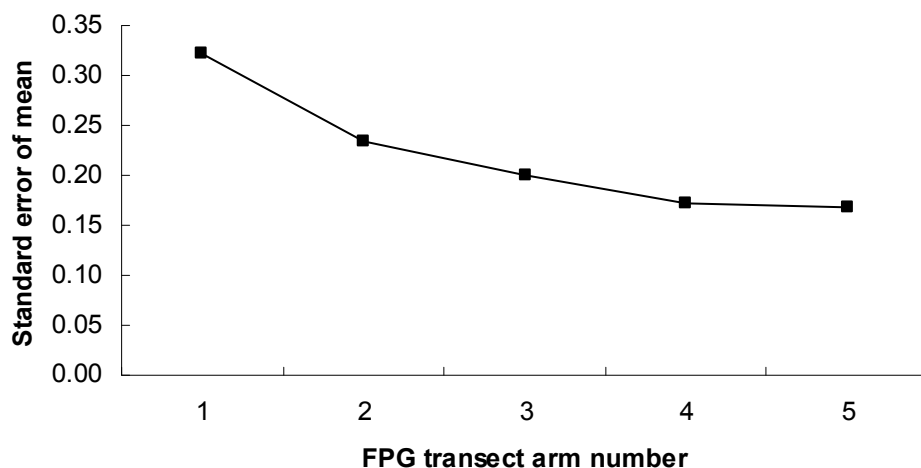


Figure 2.15. Cumulative mean standard error of faecal pellet groups (FPGs) recorded on 1 to 5 transect survey 'arms' conducted in the Upper Yarra catchment, Yarra Ranges National Park, 2005.

To investigate site occupancy by sambar, data were initially considered as presence or absence of FPGs for each survey plot on each complete transect, and expressed as a percentage of the 50 survey plots. Nonlinear regression analysis showed that the occupancy by sambar was explained by distance from any of the three open flats adjacent to the Upper Yarra reservoir ($R^2 = 80.1\%$, $Frequency = -2.13 + (42.73/(1 + 0.0025distance))$). Occupancy on open flats was very high, then sharply decreased with distance until approximately 1000 m, then tailed off in the four survey plots at greater distances ($F_{2,18} = 36.21$, $P < 0.001$) (Figure 2.16).

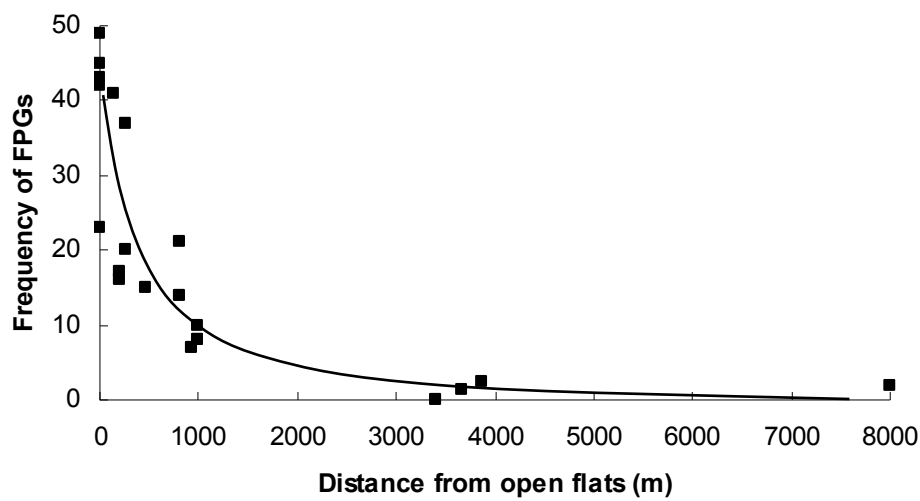


Figure 2.16 Frequency of faecal pellet groups (FPGs) occurring in each survey plot per transect (from a possible 50) with distance from open flats (0 m) adjacent to the Upper Yarra reservoir, Yarra Ranges National Park, 2005.

FPG counts were normalised by a log transformation. Analysis of variance revealed a significant difference in sambar density between the distance categories from open flats ($F_{3,17} = 15.94$, $P < 0.001$). Fisher's least significant difference post hoc test showed that open flats had a significantly higher quantity of FPGs than all other distance categories, followed by the 1 – 250 m category with a significantly higher FPG count than the distance categories over 250 m (Figure 2.17).

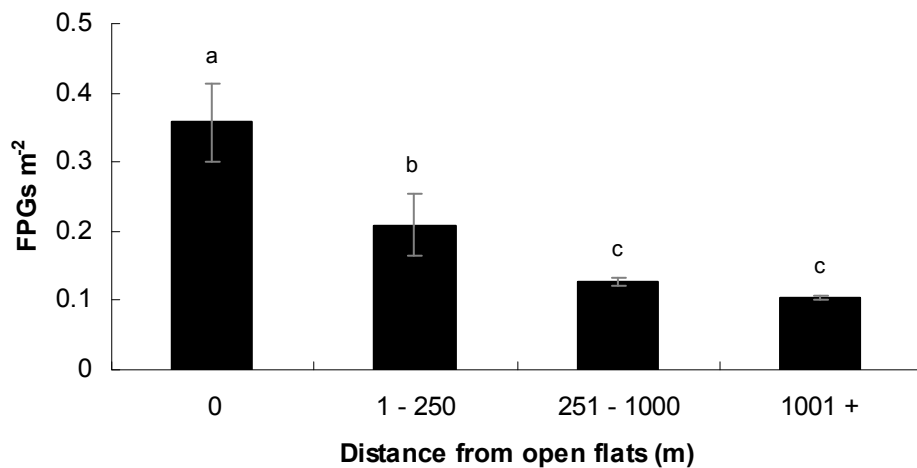


Figure 2.17. Mean number of faecal pellet groups (FPGs) (\pm standard error) categorised by distance from open flats adjacent to the Upper Yarra reservoir, Yarra Ranges National Park, 2005. Significant differences between distance categories, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a – c, where $a > b > c$.

When FPG counts were categorised by vegetation type, open flats had a significantly higher number of FPGs ($F_{5,15} = 6.30$, $P = 0.002$), while Fisher's least significant difference post hoc test showed there was no variation in FPGs among the other EVCs (Figure 2.18). A similar relationship was demonstrated between open and forested areas ($F_{2,18} = 12.76$, $P < 0.001$) when the EVCs were pooled into two broader classifications. Fisher's least significant difference post hoc test showed there was no distinction between 'wet forest types' (encompassing Wet Forest, Damp Forest and Riparian Forest) and 'dry forest types' (encompassing Heathy Dry Forest and Shrubby Foothill Forest) (Figure 2.19).

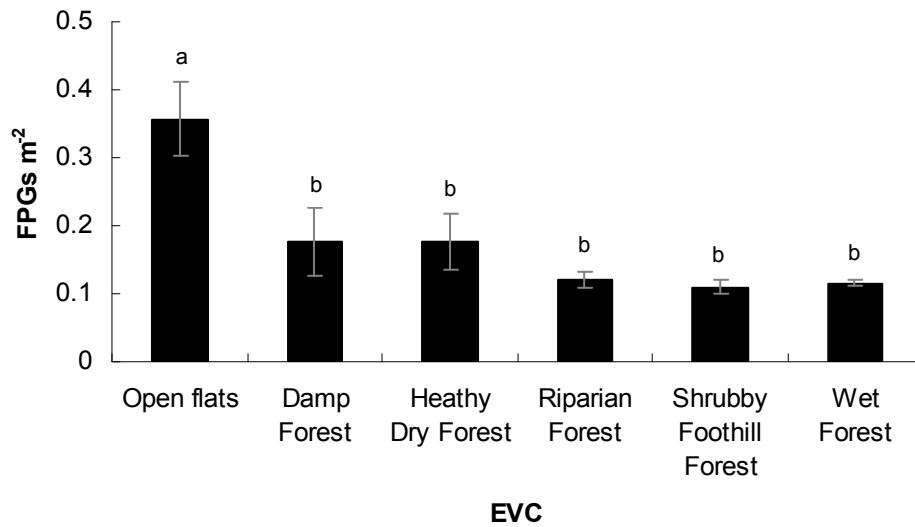


Figure 2.18. Mean number of faecal pellet groups (FPGs) (\pm standard error) in the Yarra Ranges National Park, 2005 categorised by Ecological Vegetation Class (EVC). Significant differences between EVCs, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a and b, where $a > b$.

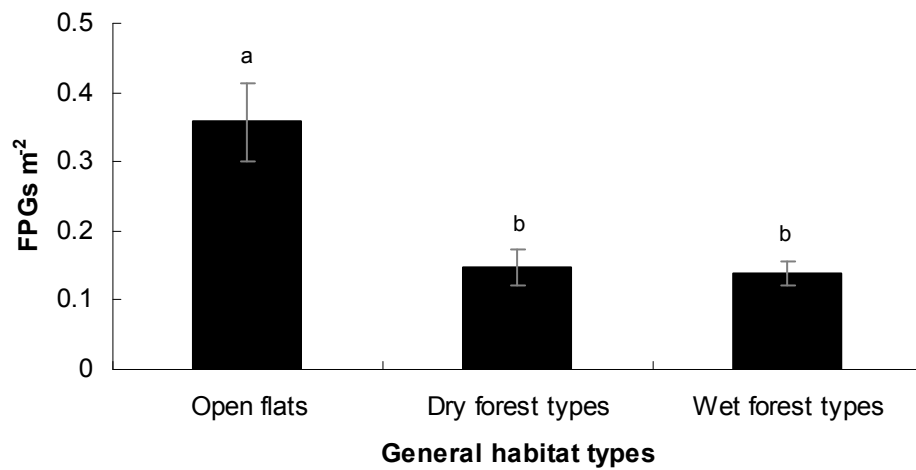


Figure 2.19. Mean number of faecal pellet groups (FPGs) (\pm standard error) in the Yarra Ranges National Park, 2005 categorised by general habitat type. Significant differences between habitat types, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a and b, where $a > b$.

Discussion

Abundance and demographic structure of sambar at The Flats

The largest number of sambar observed on The Flats at one time (70 individuals) equated to an approximate density of 200 km⁻². While it is recognised that a direct comparison cannot be made to studies using different methods over different time frames, Houston's (2003) study of sambar at The Flats yielded a similar estimate of 230 km⁻² in 2003 using faecal pellet accumulation counts. These estimates are considerably higher than all other density estimates for the species (Table 2.1). These aggregations of up to 70 individuals are also the largest reported in Australia and elsewhere throughout the world. The largest group previously reported (50 individuals), was in Mudumalai Sanctuary, India (Varman and Sukumar 1993). The separate appearance of small aggregations (generally 1 – 4 individuals) of sambar on The Flats throughout the evening surveys indicates that the large groups observed on The Flats are not one cohesive unit but an aggregation of many small groups gathered at an important resource. The behaviours observed within these groups were typical for this species (Shea *et al.* 1990; Bentley 1998; Mason 2006). Sexual behaviours were rarely observed, perhaps because the majority of surveys were conducted outside the peak rut (Figure 2.2), but more likely because the majority of stags observed were young and not the dominant stag in the area.

The number of sambar observed was not correlated with season, suggesting The Flats are an important resource to the population of sambar all year round. Hinds were observed in far greater proportion (3 to 4 fold) than any other sex and age class, regardless of season. Some stags without antlers may have been misclassified as hinds, particularly at the furthest point of The Flats. Interaction between stags, such as the presence of a dominant stag may also have deterred subordinate males from utilising The Flats. Other studies have found a female-biased sex ratio in sambar (Flynn *et al.* 1990; Biswas and Sankar 2002; Bagchi *et al.* 2008). In India, stags were more commonly sighted alone (Biswas and Sankar 2002), which may have increased their susceptibility to predation by tigers. However Flynn *et al.* (1990) in Florida, USA, considered predation and poaching to be of minimal influence and were unable to explain the observed female-biased sex ratio. At The Flats, predation by wild dogs and wedge-tailed eagles is

considered to be minimal, and although poaching does occur, and stags in hard antler are likely to be targeted for trophies, the level of poaching seems unlikely to explain the observed sex ratio.

Sexual segregation is another possible explanation for the observed female bias. Partitioning of habitat and resources within a population is a common occurrence within ungulates (Bleich *et al.* 1997; Pérez-Barbería and Gordon 1999; Li and Jiang 2008), including deer species (Beier and McCullough 1990; Koga and Ono 1994; Focardi *et al.* 2003). While this phenomenon is most frequently observed in temperate deer species, it has also been reported in some tropical species (McShea *et al.* 2001). Many hypotheses have been proposed for the evolution of this behaviour, such as differing metabolic and nutritional requirements between the sexes (Illius and Gordon 1987; Beier and McCullough 1990; Barboza and Bowyer 2000) and optimisation of successful reproduction and survival, including minimising predation risk (Kie and Bowyer 1999; Zhigang *et al.* 2000; McShea *et al.* 2001; Main 2008). Focardi *et al.* (2003) suggests that although common, the underlying causes of sexual segregation activities will be highly variable and difficult to predict in different species and populations, and Bleich *et al.* (1997) conclude sexual segregation is likely formed by a varying level of a combination of factors in the environment, including predation risk, forage quality and forage abundance.

Sambar use of The Flats appears to be consistent with the hypothesis of Illius and Gordon (1987), who proposed that females select quality forage over quantity, while the males' primary requirement is a large quantity of forage rather than quality. In addition, the nutritional gain of sambar hinds feeding at The Flats must outweigh the associated predation risk from wedge-tailed eagles, wild dogs or human hunters and the distance travelled to The Flats. The stags observed feeding at The Flats were most commonly young, as indicated by their relatively small antlers, and of a similar size to a mature hind, so their ability to obtain sufficient forage and nutrients from The Flats would thus be comparable. Once stags attain a larger body size, other habitat types and food sources must be utilised to obtain sufficient forage. Although the exact time sambar individuals spent on particular activities at The Flats was not recorded, on the few occasions a large stag was observed, little time was spent feeding, and the sexual behaviours displayed suggests the stags were present to investigate the sexual

receptiveness of hinds, rather than to feed. Future vantage point observations may benefit from further division of the classification of adult stags into young and mature classes and data on the sex ratio of sambar located away from The Flats may further clarify these observations.

The use of a spotlight with a red filter was ineffective for observing sambar after dusk at The Flats. The most likely reason for this is the high intensity of light, since many other studies have utilised a low wattage torch or spotlight with a red filter. However in order to accurately cover the survey area and observe sambar at the farthest point of The Flats (≤ 1 km), the spotlight intensity that was utilised in the trial was necessary. In contrast, the infrared camera provided a useful insight into the activity pattern of sambar at The Flats during darkness. Use of an infrared camera is likely to be most effective on cold nights when the differentiation between ambient air temperature and deer body temperature is greatest, allowing the greatest accuracy in the identification of sambar individuals, particularly at the furthest point of The Flats. The counts obtained are more likely to be underestimates, as individuals captured on the infrared images at the furthest point of The Flats were often identified by only one or two pixels in the resulting image. If two individuals were standing close together or one behind another, there was the potential for the classification of two individuals as one. Individuals may also have been missed from counts if they were located in dense patches of rush and sedge, behind one of the many stumps, or in a depression. While over-estimates have been known to occur when objects absorb and retain heat, such as deer bedding sites, (Boonstra *et al.* 1994), the main activity of sambar on The Flats was grazing, so over-estimates were unlikely. Despite the limited replication, these results show that on both occasions deer were observed feeding on The Flats throughout the night.

Daily activity patterns in deer have been shown to follow a cyclic pattern of foraging-feeding and resting-rumination (Green and Bear 1990; Kamler *et al.* 2007). The wave-like pattern of sambar activity at The Flats throughout the night is likely explained by sambar being observed on The Flats during the feeding phase, which is presumably followed by resting and rumination in the cover of forest. However it is not known whether it was the same individuals repeatedly reappearing on The Flats throughout the night, or different individuals. While animals feeding in groups is often associated with reduced predation risk (Bertram 1978), group cohesion has also been shown to be

highest among individuals of a similar body size, as a result of similarities in activity budgets (Ruckstuhl and Neuhaus 2001). Other factors such as ambient air temperature (Ozoga and Gysel 1972; Oswald 1991; Kamler *et al.* 2007) impact on the activity patterns of deer, including sambar (Moore 1994).

Sambar density and distribution in the Upper Yarra catchment

Determining output and decomposition rates of faecal pellets for wild deer would allow pellet counts to be converted to population estimates (Marques *et al.* 2001). However obtaining sufficient accuracy would be a difficult and costly exercise (Forsyth 2005). The use of a method that determines an index of abundance has been shown here to effectively describe the occupancy and density with distance from open flats adjacent to the Upper Yarra reservoir in the YRNP. Site occupancy represents the likelihood of sambar being found at a given location. The FPG zig-zag transect method showed site occupancy by sambar was extremely high on open flats, which sharply decreased with distance from open flats to 1000 m, followed by a more gradual decline to low levels of occupancy. Density estimates correlate to the amount of time sambar spend at a given location, and were also influenced by distance from open flats. The highest density of sambar is found on open flats, followed by forest immediately adjacent to open flats, with a marked decrease after approximately 250 m.

There was no difference of sambar density among the forest types, either by EVC or when clumped into the more generalised habitats of ‘wet forest types’ and ‘dry forest types’. It is likely that the high density of sambar located in forest adjacent to the open flats masked any preferences for forest habitat. The Flats and other open flats appear to be a major attractant as a food resource. Therefore it is likely the forest in close proximity to The Flats primarily provides cover and a safe resting place before emerging to feed and perhaps also between feeding times, rather than being selected for food plants.

While the high FPG counts obtained on open flats were consistent with the large numbers of sambar that were frequently observed on The Flats, these results may have been biased towards larger numbers for three reasons. Firstly, detectability of FPGs differed between open flats and forested sites. FPGs on the open flats were easily detected because they contrasted with the bright green of the short forbs and grasses. In

comparison, FPGs located in forested sites were initially more difficult to detect because the similar coloured FPGs blended with leaf litter, and FPGs may also have fallen through or become covered by plant debris, and were therefore omitted from the count. Secondly, factors such as temperature, rainfall and leaf litter (Neff 1968; Wigley and Johnson 1981; Lehmkuhl *et al.* 1994) affect the decomposition rate of faecal pellets. FPGs located on the open flats do not break down as fast as those in a forested environment (Houston 2003; Whelan 2005), most likely because FPGs on the open flats are more quickly desiccated, increasing their persistence rate compared with pellets in a forested environment. Thirdly, FPGs on The Flats were more likely to be scattered further due to the large numbers of deer on The Flats, and because there were no barriers such as plant debris, to stop pellets being distributed further from the original deposition point. Therefore some FPGs located on open flats may have been split into more than one FPG, falsely inflating the final count.

The Riparian Forest EVC was the most difficult forest type to survey in terms of FPG detection. This particular EVC is characterised by a minimal understorey shrub layer replaced by a dense fern layer under which there is a deep layer of plant debris such as leaves, sticks, branches and logs. Although ferns can be brushed aside in the search for FPGs, the procedure does not allow the leaf litter to be disturbed. FPGs are likely to have fallen through these dense layers on deposition and were therefore less likely to be recorded. This survey method and other methods that use faecal pellets to provide an index of abundance may be unsuitable for measuring sambar density in vegetation types with a similar ground cover.

CHAPTER 3

The impacts of sambar on the threatened shiny nematolepis



*Shiny nematolepis tree with rubbing damage, O'Shannassy catchment,
Yarra Ranges National Park, November 2007*

CHAPTER 3

The impacts of sambar on the threatened shiny nematolepis

Introduction

A major concern of introduced species such as sambar is that through the use of their habitat they impose new threats to endangered native species. This concern is highlighted by the potential impact of sambar in YRNP on the threatened tree species shiny nematolepis (*Nematolepis wilsonii*).

Shiny nematolepis is a small understorey tree endemic to Victoria. This species is listed as a threatened taxon in Victoria under the Flora and Fauna Guarantee Act 1988 and as vulnerable under Commonwealth's Environment Protection and Biodiversity Conservation Act 1999. This status reflects the species' limited distribution and low abundance, as the sole known population of less than 500 mature individuals is found within a small (approximately 4 ha) area, in the O'Shannassy catchment, Yarra Ranges National Park (YRNP). It has been proposed that sambar (*Cervus unicolor*) have detrimental impacts on this population through thrashing and rubbing activities (Murphy *et al.* 2006). The reduction in biodiversity of native vegetation by sambar was recently listed (gazetted November 2007) under the Flora and Fauna Guarantee Act 1988 as a potentially threatening process. Shiny nematolepis was one of the species noted as being at risk from this process (Scientific Advisory Committee 2007).

Shiny nematolepis is classified in the Rutaceae family, most members of which are characterised by having many translucent oil glands in the leaves and often possessing a distinct fragrance (Costermans 1983). The leaves of shiny nematolepis are, as the common name suggests, very shiny, glossy and dark green on the upper surface, with oil glands clearly visible (Figure 3.1a). The stems and branchlets of saplings (young trees) are glandular-verrucose (warty) textured (Figure 3.1a), with a distinct and at times quite strong fragrance. Mature trees are characteristically spindly (Figure 3.1b) and grow to approximately 10 m. Flowering occurs in October – November (Walsh and Entwisle 1999), and seeds have been collected in January – February (N. Walsh, Royal Botanic Gardens Melbourne pers. comm.)

A.



B.



Figure 3.1. Shiny nematolepis in the Yarra Ranges National Park **A.** Sapling in flower showing glandular leaves and stems and **B.** Spindly form of mature tree (at left) in flower with abundant saplings located beneath (lower right), November 2006.

In 2003 the presence of large scars on the trunks of some mature individuals was first observed, and it was proposed the most likely cause was antler rubbing by sambar (Murphy *et al.* 2003). The effect of rubbing on flora may range from a small loss of growth to deaths of individuals due to complete ring-barking (Welch *et al.* 1988; Motta and Nola 1996), while wounding of stems creates a potential access point for wood boring insects and fungal infections (Elliot *et al.* 1998; Stewart 2001). Although it is probable this activity had been occurring for some years, it had not previously been recognised as a potential threat to the population (White 1999; Murphy *et al.* 2003). In an endeavour to obtain baseline information, the population of shiny nematolepis in YRNP was surveyed by Lorimer and Lorimer (2005), who recorded sambar antler rubbing damage on 27% ($n = 281$) of individuals in May 2005. It was estimated that the population then consisted of approximately 1000 saplings and 400 mature trees. Damage to shiny nematolepis caused by insect borers, and subsequently by yellow-tailed black cockatoos (*Calyptorhynchus funereus*) seeking the wood-boring larvae, was also recorded. Exposure to sunlight and soil disturbance were noted as the most likely factors influencing successful seedling recruitment in this species (Lorimer and Lorimer 2005).

Sambar have been present in the YRNP for approximately 100 years (Bentley 1998). Sambar stags use elements of their habitat essentially as signposts for marking territory, which may include preaching trees, scapes, rub trees and wallows (Chapter 2). Sambar stags have antlers from approximately 2 years of age, and rub their antlers on trees to remove the velvet. Dominant stags also rub their antlers to mark territory (Bentley 1998). In addition, deer may thrash vegetation, usually associated with scent marking during the rut (Gill 1992). Many deer species actively select particular species to rub according to tree morphology (Kile and Marchinton 1977; Benner and Bowyer 1988; Massei and Bowyer 1999), stem diameter (Benner and Bowyer 1988; Johansson *et al.* 1995; Ramos *et al.* 2006) and aromatic properties (Kile and Marchinton 1977; Johansson *et al.* 1995), which may enhance the use of the tree as an olfactory marker.

This study investigates whether sambar cause rubbing damage to trees and thrashing damage to saplings of shiny nematolepis, and aims to determine if these behaviours impact on the health of shiny nematolepis. Other forms of damage to the population are also investigated.

Methods

Site description

The O'Shannassy catchment, encompassing 11,900 ha, has been classified a designated water supply catchment area since 1908 (Fleming et al. 1979) and is listed as a site of regional, state and national significance (Parks Victoria 2002). This is in part due to the large area of continuous, mature Wet Forest (Gullan et al. 1979), an Ecological Vegetation Class (EVC) which covers the majority of the catchment. While this EVC is not rare, large continuous areas of mature Wet Forest in Victoria are not common (Gullan et al. 1979).

The sole known shiny nematolepis population is found adjacent to Deep Creek in Cool Temperate Mixed Forest, the ecotone between Wet Forest dominated by mountain ash (*Eucalyptus regnans*) and Cool Temperate Rainforest dominated by myrtle beech (*Nothofagus cunninghamii*). The shiny nematolepis population is located just outside the Deep Creek Reference Area, but within the associated buffer strip that surrounds and protects the reference area boundary from other land uses and management regimes (Figure 3.2). This is one of four reference areas within the YRNP, which are retained as sites of ecological interest and significance to be preserved in perpetuity as a botanical and zoological reference for comparative purposes (Reference Areas Act 1978).

The site is bisected by an access road known as Road 5. This section of road has been closed since February 2001 due to damage to the bridge over Deep Creek, and standard catchment road management practices of clearing roads and slashing of road verges had ceased. Subsequently approximately 1000 shiny nematolepis saplings have germinated in dense patches along the road verge at this site in addition to the mature trees, which are mainly located in the forest (Figure 3.3) (Lorimer and Lorimer 2005).

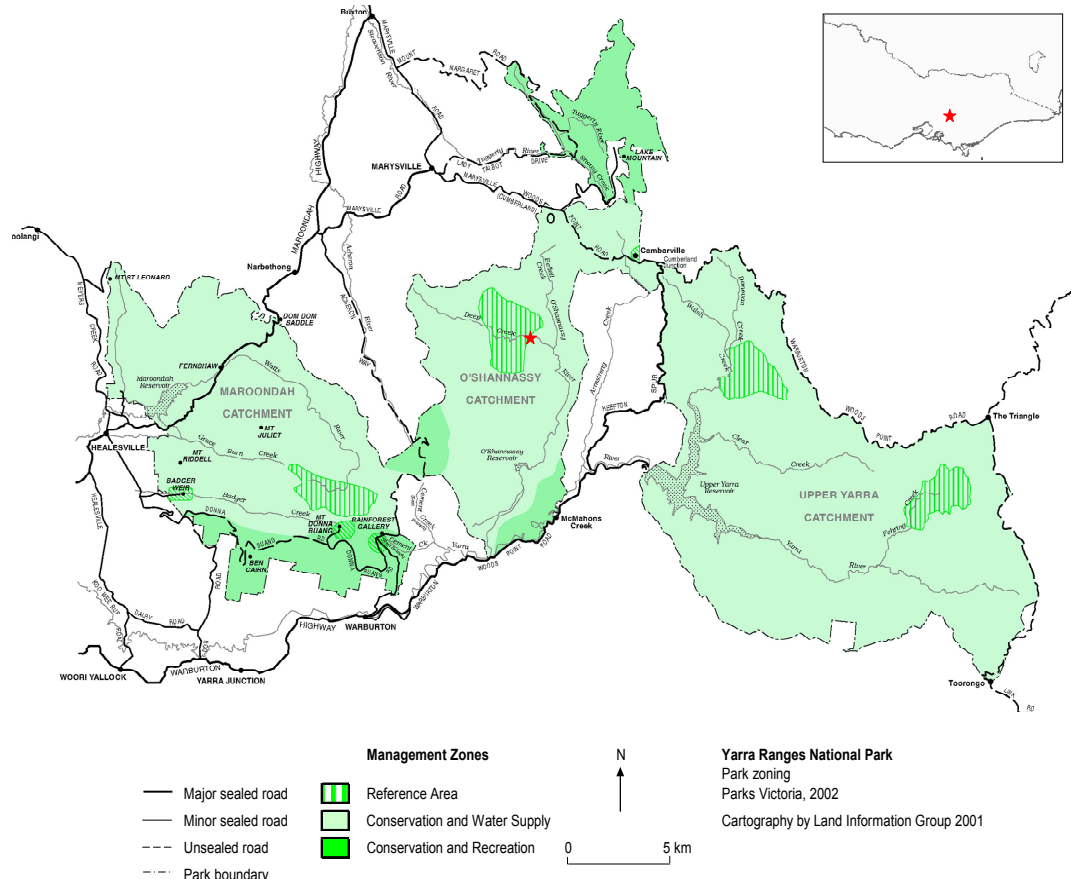


Figure 3.2. The Yarra Ranges National Park, Victoria encompassing three water catchments: Maroondah, O'Shannassy and Upper Yarra. The shiny nematolepis site is located adjacent to the Deep creek reference area in the O'Shannassy catchment (centre). For enlarged map see Figure 2.3.

Paired exclusion plots

Four paired-plot exclusions (10 x 10 m) (Figure 3.3) were constructed in October 2006 and March 2007 for this study. Each pair or 'unit' consisted of a fenced and an open plot, which was a modification of the exclusion plot method outlined in Bennett and Coulson (2008) (Appendix 1). Units 1 and 2 contained mature trees and Units 3 and 4 contained predominantly saplings. Mature trees possessed a woody stem while saplings (young trees) had a softer, more flexible stem and were < 5 m in height. The majority of the mature shiny nematolepis trees had previously been labelled with a metal identification tag by Lorimer and Lorimer (2005).

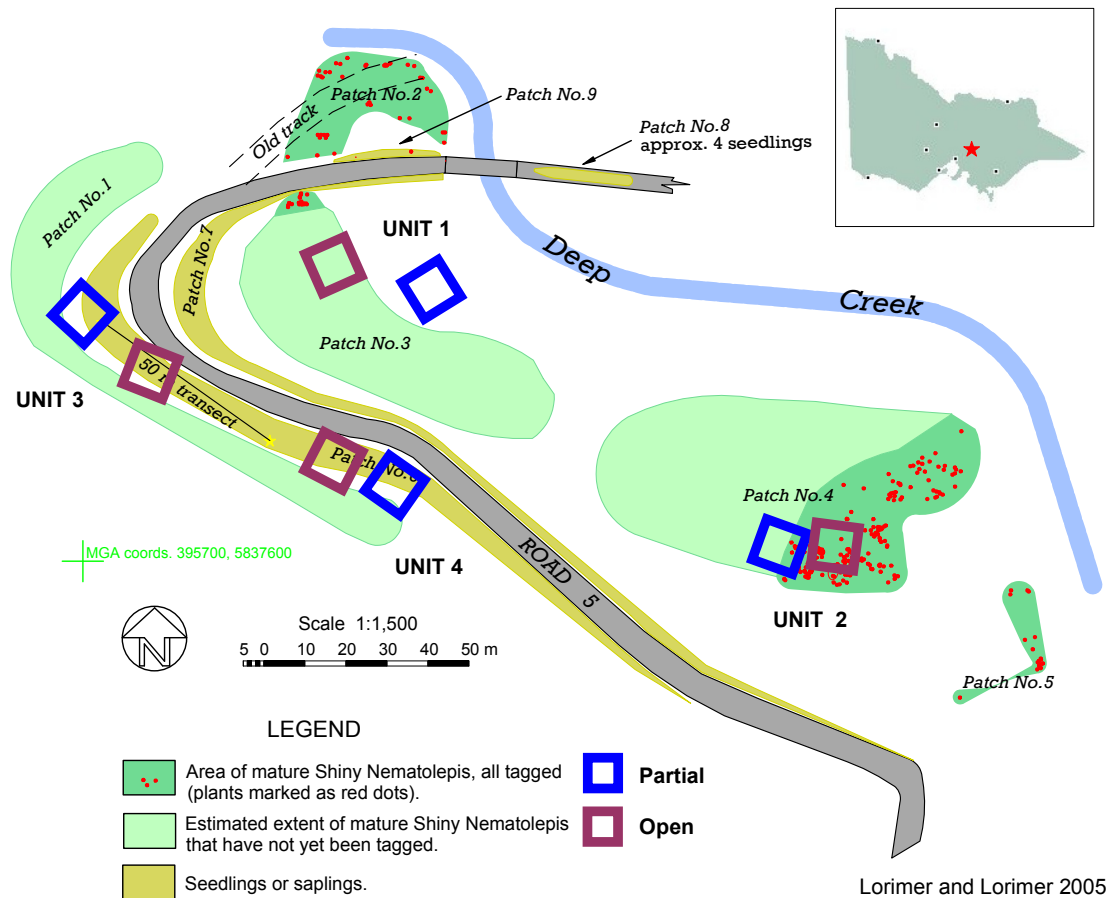


Figure 3.3. Schematic map of the shiny nematolepis site by Lorimer and Lorimer (2005), adapted to show approximate locations of exclusion units 1 and 2 in the forest and units 3 and 4 on the road verge, with each unit comprised of a partial and an open plot. Exclusion units were constructed in October 2006 and March 2007. Patch numbers and 50 m transect were not utilised in this study.

A further 45 mature individuals were tagged in the plots so that all individuals within a plot were surveyed, and a total of 124 saplings (23 - 40 / plot) were tagged for this study. As it had previously been suggested that soil disturbance by vertebrates including superb lyrebird (*Menura novaehollandiae*) and common wombat (*Vombatus ursinus*) were potentially an important factor in seedling recruitment (Walsh and Albrecht 1988; Ashton and Bassett 1997), it was deemed important to allow these species access to the plots whilst excluding sambar. Therefore the fenced exclosures, termed partial exclusion plots, were constructed to a height of 1700-mm high using fencing mesh and steel star pickets, with a 500-mm gap at the base to allow access to the plots by native species (Figure 3.4).

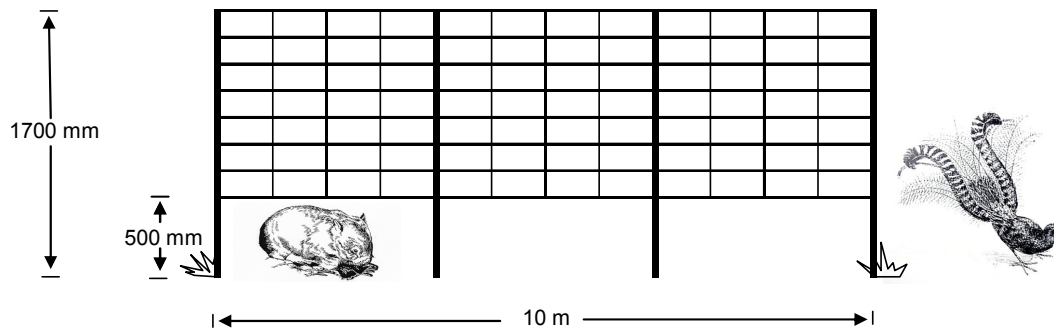


Figure 3.4. Partial exclusion plot design adapted from Bennett and Coulson (2008) that excludes sambar but allows access by native species such as common wombats and superb lyrebirds. Exclusion plots were used to determine the impacts of sambar on shiny nematolepis at the Deep Creek population, O'Shannassy catchment, Yarra Ranges National Park. Exclusion plots were surveyed in May and November, 2007.

During May 2007, the DBH (diameter at breast height, 1.3 m above the ground) was measured using a diameter tape, and rubbing damage (presence/absence) attributed to sambar (Figure 3.5a) were recorded for each mature tree located in the paired plots. In addition the frass scars created by borers, trunk damage caused by cockatoos searching for borers and broken limbs from storm damage were recorded, together with a visual health assessment. The survey was repeated in November 2007. As exclusion units were constructed after much of the damage had occurred, damage recorded in exclusion units during the first survey in May 2007 was classified as pre-existing, while all subsequent damage recorded in the second survey in November 2007 was known to have occurred after construction of exclusion units. All trees exhibiting cockatoo damage were assumed to also have borer damage. The health assessment was an estimation of relative percentage foliage cover present on the individual, visually estimated in comparison to an individual of optimum health (100%), illustrated by Lorimer and Lorimer (2005). To reduce error, all health assessments were conducted by one observer. The height, stem diameter taken from 10 cm above the ground using digital callipers, thrashing damage (rubbing of stems and breakage of branches) attributed to sambar (Figure 3.5b) and a health assessment of relative foliage cover present were recorded for all tagged saplings, in addition to signs of borers. A 1-ha faecal pellet group (FPG) survey (Chapter 2) was conducted to determine sambar presence. Data were analysed using Genstat 9.1. Two tailed t-tests and analysis of variance were utilised to investigate the impact of sambar rubbing and thrashing activities.

A.



B.



Figure 3.5. Shiny nematolepis in the Yarra Ranges National Park **A.** Mature tree with rubbing damage, October 2006 **B.** Saplings that have been thrashed, November 2007.

Results

A total of 156 mature trees and 124 saplings were surveyed in the paired plots, with a variety of forms of damage recorded. No deer sign or new damage was observed in the partial exclusion plots following construction. Signs of superb lyrebird activity, distinguished by large patches of freshly turned earth, were observed at the site including inside partial plots. Common wombat activity was also evident, with fresh scats observed inside one partial plot and a newly dug burrow in the vicinity. A severe wind storm had occurred in Spring 2007, between the May and November surveys, as evidenced by many fallen trees and branches at the site.

Sambar activity

No sambar pellets were recorded on the FPG surveys in May and November 2007. A wallow was situated approximately 50 m from the shiny nematolepis site beside Road 5. It had been used by sambar in November, but it was not large and mud rubs and splatters on surrounding vegetation were not extensive.

Shiny nematolepis saplings

Shiny nematolepis saplings on average increased in height by 10.5 cm ($t = -3.46$, d.f. = 116, $P < 0.001$) and stem diameter by 1.16 mm ($t = -7.45$, d.f. = 116, $P < 0.001$) from May to November, although relative foliage cover did not change ($t = 0.15$, d.f. = 116, $P < 0.885$). A few shiny nematolepis individuals had thrashing damage (10 individuals in May, 12 individuals in November). While most of the thrashed individuals were located on the edge of the dense sapling patches closest to the road, one individual was located adjacent to an animal trail within a dense patch of shiny nematolepis saplings. Mean percentage (\pm standard error) of stem circumference damaged on thrashed saplings was $48.9 \pm 9.2\%$ in May, similar to November with $49.0 \pm 7.9\%$ ($t = -0.64$, d.f. = 116, $P = 0.525$), while the mean length of damage on thrashed saplings was 45.1 ± 6.4 cm in May and 53.9 ± 7.9 cm in November ($t = -0.64$, d.f. = 9, $P = 0.538$).

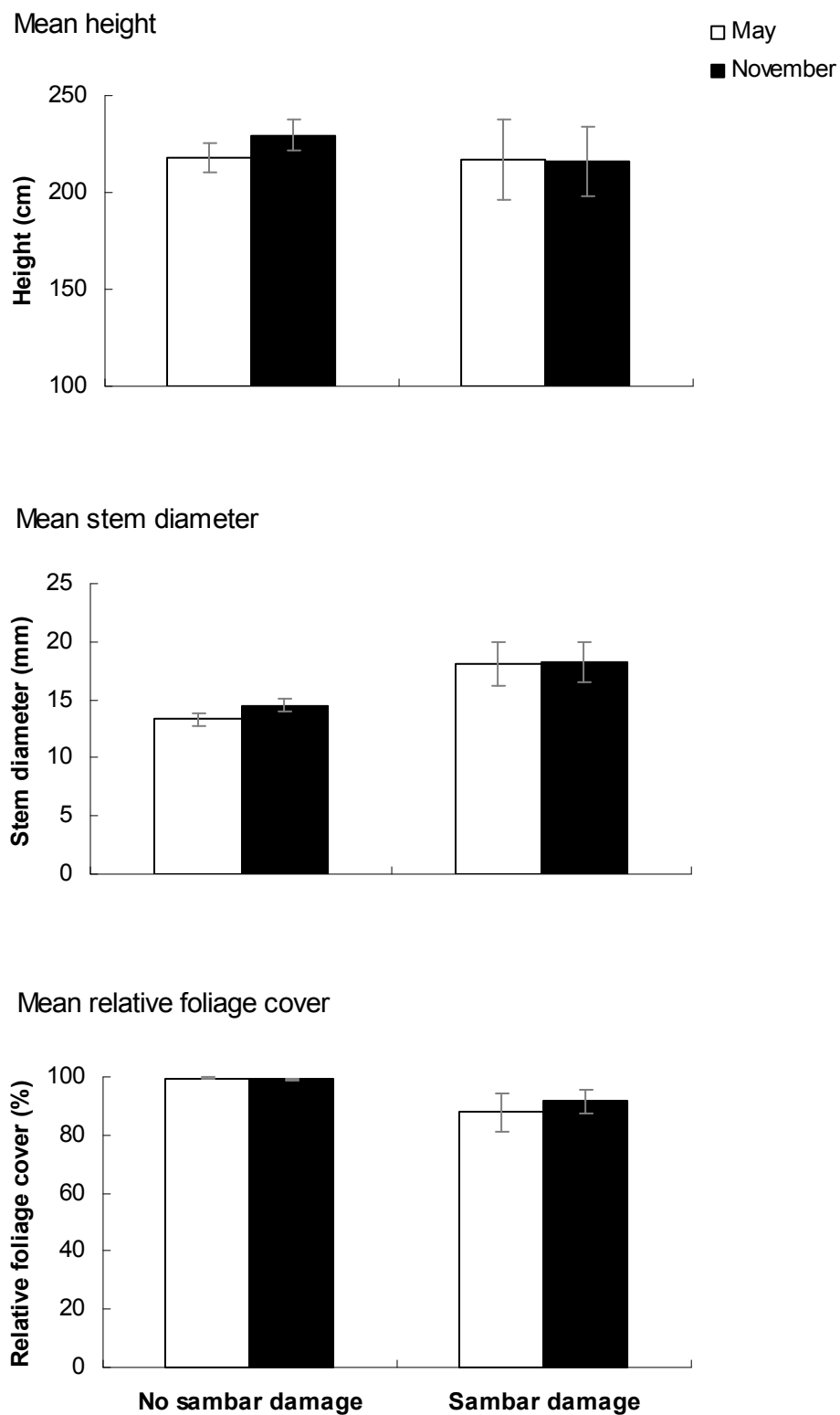


Figure 3.6. Mean height, mean stem diameter and mean relative foliage cover (\pm standard error) of shiny nematolepis saplings in Yarra Ranges National Park during May and November 2007.

In May the mean stem diameter of thrashed saplings was 4.8 mm greater than non-thrashed saplings ($F_{1,122} = 6.99$, $P = 0.009$) and thrashed saplings had 11% less relative foliage cover than non-thrashed individuals ($F_{1,122} = 27.71$, $P < 0.001$). There was no difference in height between non-thrashed and thrashed saplings ($F_{1,122} = 0.01$, $P = 0.930$). During November this pattern was repeated, with the stem diameter of thrashed saplings 3.7 mm greater than non-thrashed saplings ($F_{1,122} = 4.93$, $P = 0.028$), and thrashed saplings having 7% less relative foliage cover than non-thrashed individuals ($F_{1,122} = 6.15$, $P < 0.015$). Again there was no difference in height between non-thrashed and thrashed saplings ($F_{1,122} = 0.00$, $P = 0.978$) (Figure 3.6).

No new thrashing damage was recorded in the partial plots during the November 2007 survey (Figures 3.7 and 3.8). Following observations of thrashed saplings occurring immediately adjacent to the road, selection of saplings according to proximity to the road was tested. In each of the sapling-dominated plots (units 3 and 4), eight saplings were classified as ‘edge’ and the remaining saplings in the plot classified as ‘centre’ (Figures 3.7 and 3.8). Individuals termed ‘edge’ saplings were located adjacent to a vacant space of > 1 m on at least one side. The ‘centre’ saplings were surrounded (< 0.3 m) by other plants or obstacles such as logs. There was no difference in stem diameter ($F_{1,115} = 1.45$, $P = 0.231$) or relative foliage cover ($F_{1,115} = 2.54$, $P = 0.114$) of saplings between the different locations, but the edge saplings were shorter by an average of 37.5 cm ($F_{1,115} = 5.47$, $P = 0.021$) and had a 25% higher incidence of thrashing than centre saplings ($F_{1,113} = 4.47$, $P = 0.037$). Analysis within the edge saplings showed that on average the stem diameter was 4.6 mm greater for thrashed individuals than non-thrashed individuals ($F_{1,30} = 5.39$, $P = 0.027$).

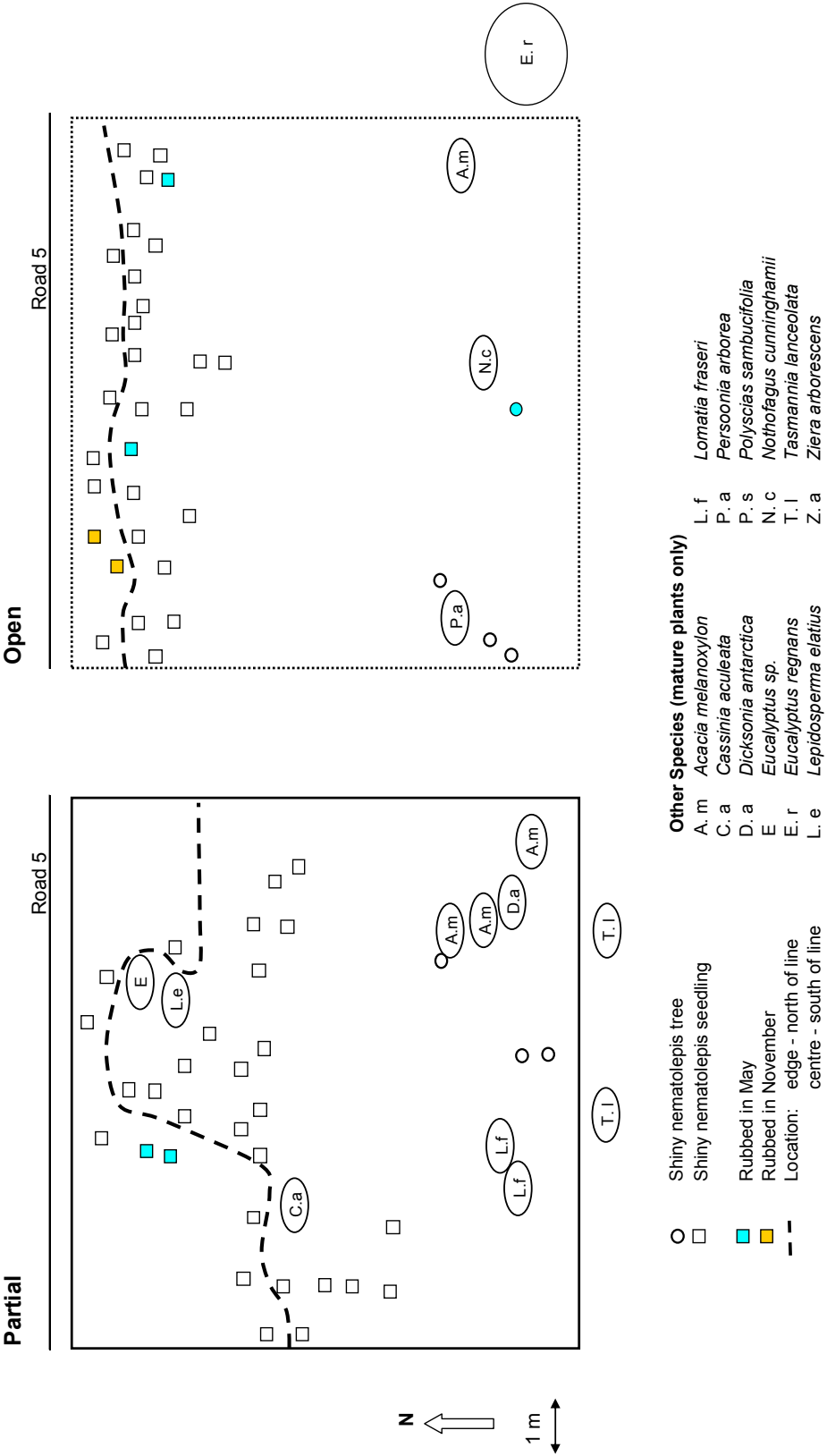


Figure 3.7. Schematic diagram of Unit 3 in the Yarra Ranges National Park showing the location of shiny nematolepis saplings and the classification of 'edge' saplings north of the dashed line and 'centre' saplings located south of the dashed line during May and November 2007.

Unit 4

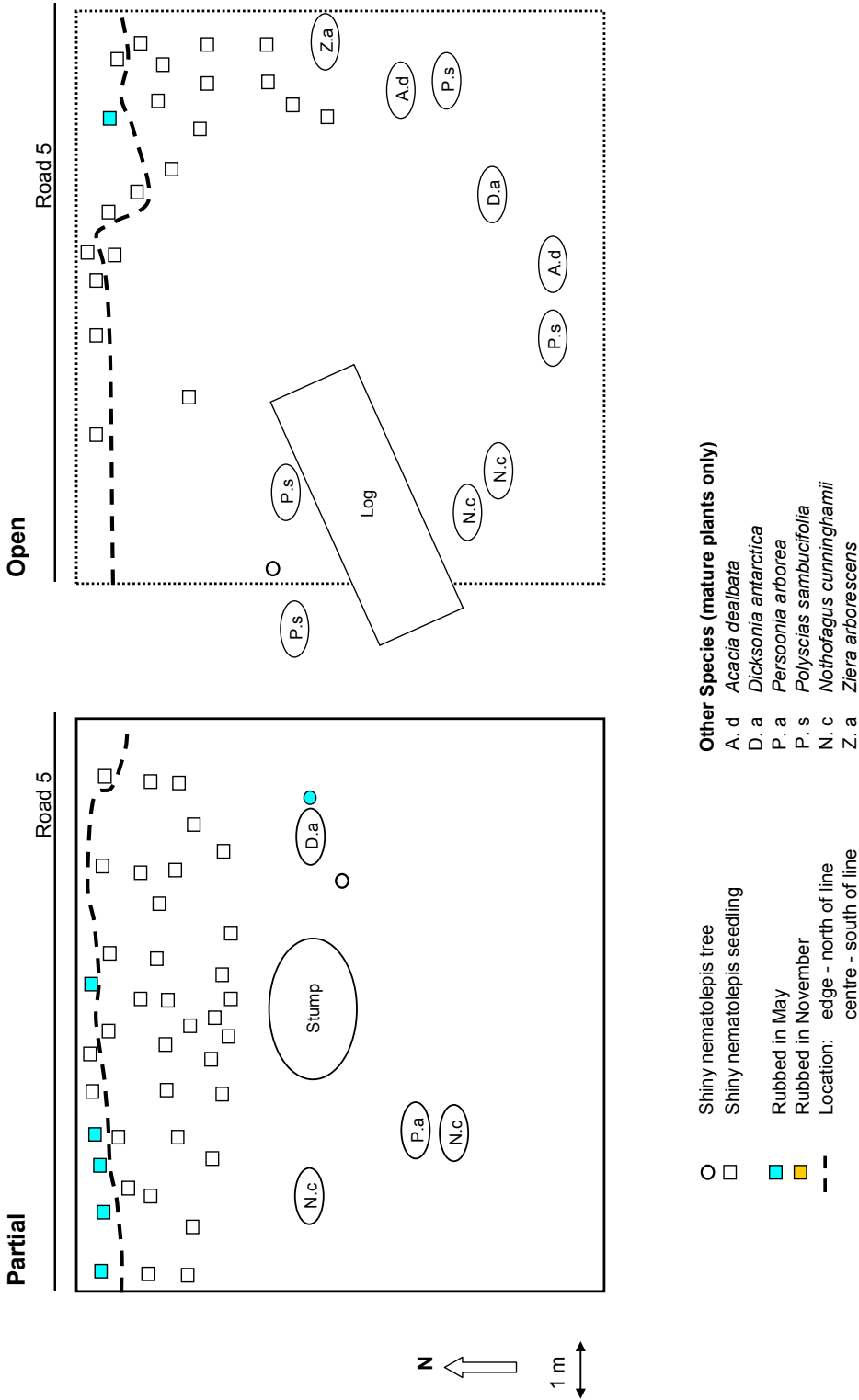


Figure 3.8. Schematic diagram of Unit 4 in the Yarra Ranges National Park showing the location of shiny nematolepis saplings and the classification of 'edge' saplings north of the dashed line and 'centre' saplings located south of the dashed line during May and November 2007.

Shiny nematolepis trees

During May, 64 trees ($n = 156$) were surveyed with rubbing damaged, while in November 10 of these trees were re-rubbed and a further three were newly rubbed. No new rubbing damage was recorded in the partial plots during the November 2007 survey (Figures 3.9 and 3.10). The mean DBH of mature trees was 6.2 ± 0.3 cm and did not change over the 6 months between surveys ($t = 0.73$, d.f. = 257, $P < 0.467$). Rubbing damage covered a range of tree sizes from 2.6 to 17.4 cm DBH; the mean DBH of rubbed trees 5.9 ± 0.4 cm. There were 19 individuals surveyed over 10.0 cm DBH, and 5 of these (26.3%) had experienced rubbing damage. Mean percentage of circumference damaged on rubbed trees was $51.3 \pm 3.1\%$ in May and $53.2 \pm 3.4\%$ in November ($t = -0.23$, d.f. = 255, $P < 0.817$).

Individuals that had sustained storm damage were omitted from analyses because the measure of health used, relative foliage cover, was generally very low on these individuals, potentially confounding the effect of rubbing damage. Of the 156 trees surveyed, 12 were omitted from the May survey and 41 from the November survey due to storm damage. Due to this large discrepancy, each survey was analysed separately using analysis of variance.

In May, 73.5% ($n = 144$) individuals showed rubbing damage. These individuals were in significantly poorer condition than non-rubbed individuals with an average of 19.3% less relative foliage cover ($F_{1,142} = 11.36$, $P < 0.001$). In November this pattern was repeated with 72.4% ($n = 115$) of individuals rubbed, and an average of 19.2% less relative foliage cover ($F_{1,113} = 8.11$, $P = 0.005$) (Figure 3.11).

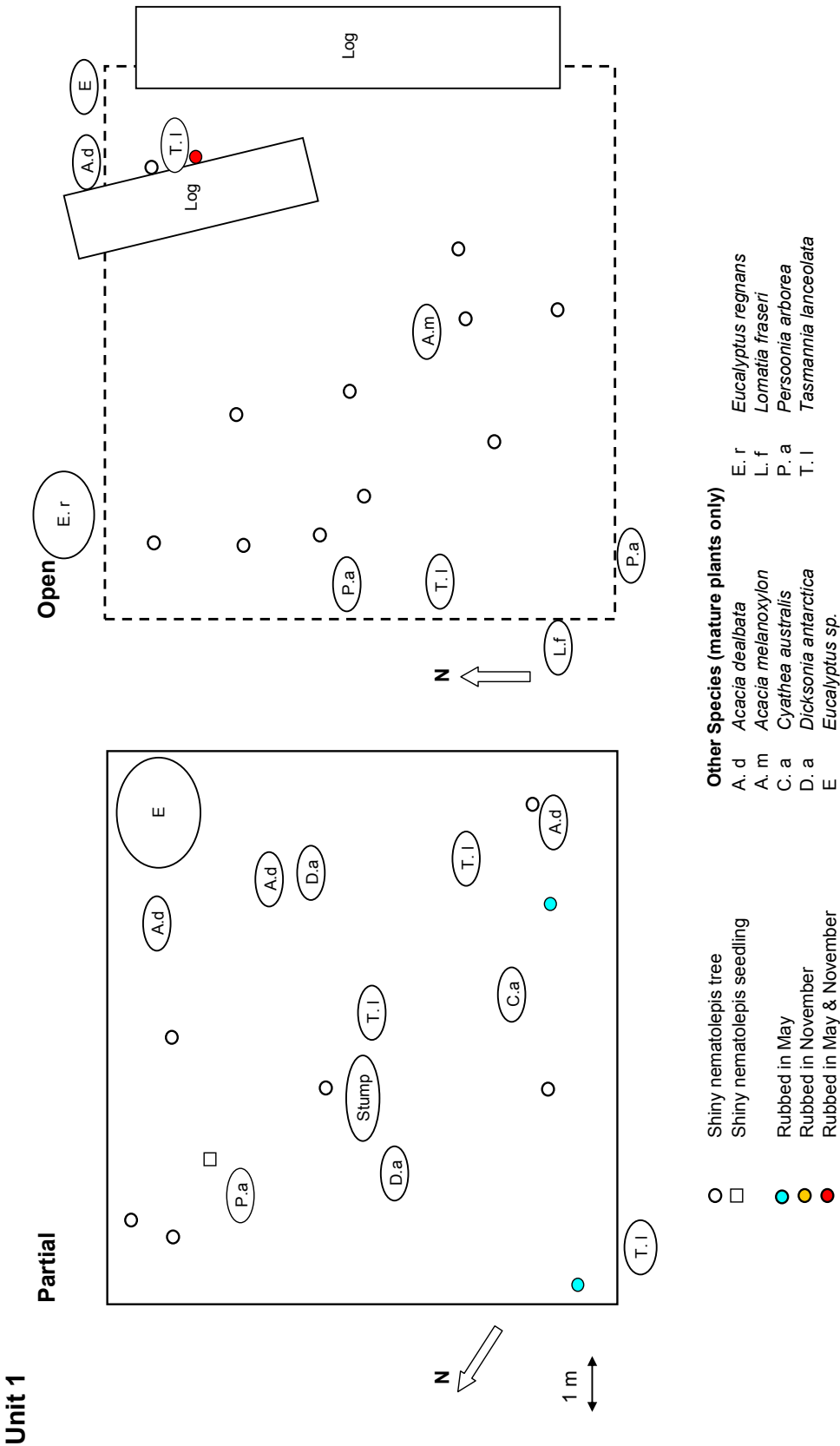


Figure 3.9. Schematic diagram of Unit 1 in the Yarra Ranges National Park showing the location and rub status of shiny nematolepis trees during May and November 2007.

Unit 2

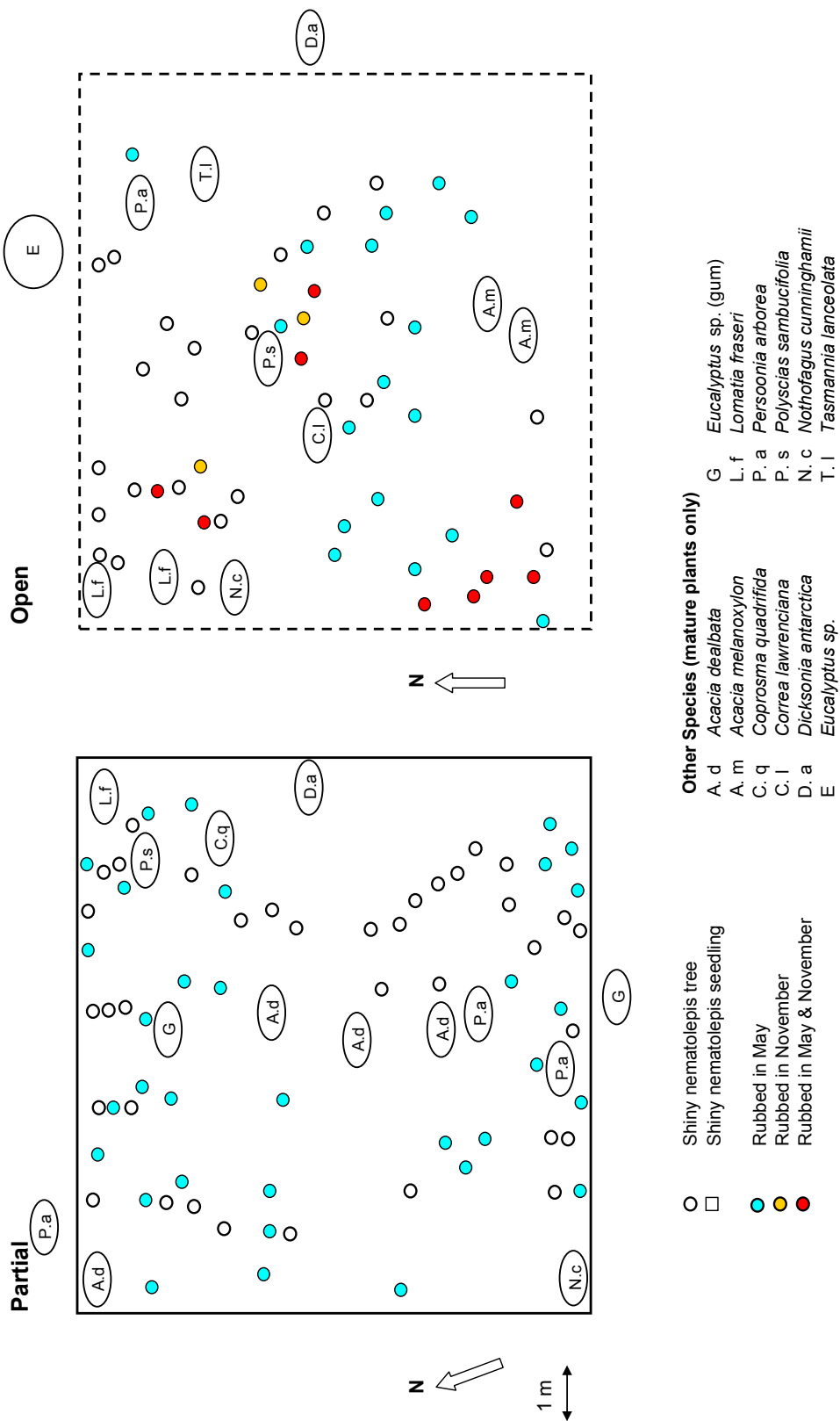


Figure 3.10. Schematic diagram of Unit 2 in the Yarra Ranges National Park showing the location and rub status of shiny nematolepis trees during May and November 2007.

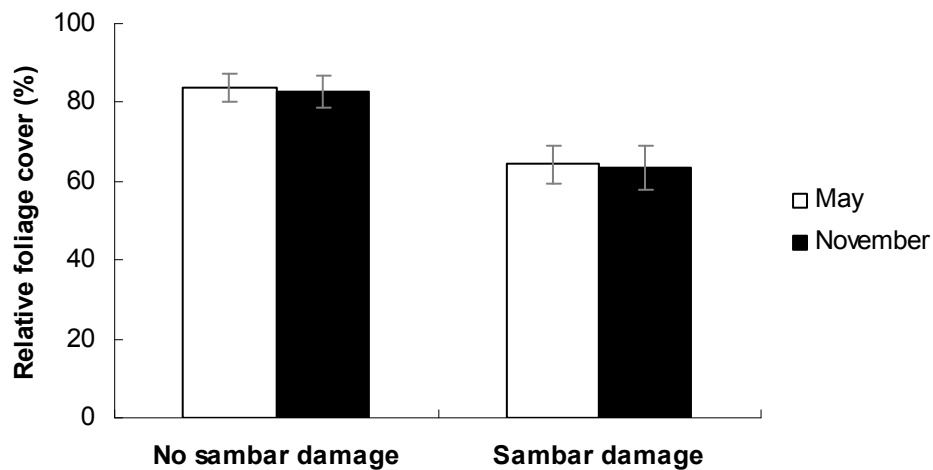


Figure 3.11. Health assessment of mature shiny nematolepis trees, Yarra Ranges National Park, based on relative foliage cover (\pm standard error), categorised by presence or absence of sambar rubbing damage during May and November 2007.

The average length of rub scars in May was 72.9 ± 3.0 cm and in November was 76.3 ± 3.6 cm. The mean height at which rubbing damage occurred on trees during November was 74.3 ± 2.0 cm with a mean lower limit at 36.1 ± 2.0 cm and a mean upper limit 121.8 ± 3.9 cm (Figure 3.12).

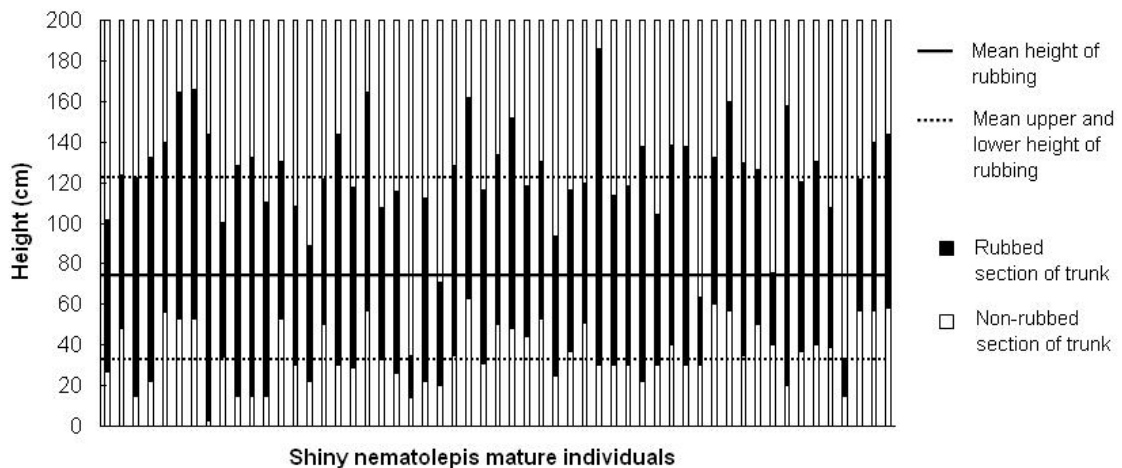


Figure 3.12. Shiny nematolepis mature trees in the Yarra Ranges National Park that had been rubbed showing rubbed and non-rubbed areas of the trunk up to 200 cm, November 2007. The mean rub height is shown as a solid line and the mean upper and lower limits as a dashed line.

Other forms of damage

Borer and cockatoo activity

Some shiny nematolepis saplings exhibited signs of borer damage evidenced by the presence of a swollen frass scar: 1.6% of saplings (2 individuals) in May and 4.8% (6 individuals) in November. However the majority of borer damage, determined by the presence of cockatoo damage, was observed on mature trees. The yellow-tailed black cockatoo rips bark and wood away on mature trees in search of the larvae (McInnes and Carne 1978), and this form of damage was in many instances quite severe (Figure 3.13).



Figure 3.13. Shiny nematolepis tree in Yarra Ranges National Park that has sustained severe cockatoo damage, November 2007.

During the May survey, 80.0%, ($n = 144$) trees had cockatoo damage, and 66.7% ($n = 115$) trees had damage in November. In May, individuals with cockatoo damage were in significantly better condition than individuals without cockatoo damage with an average of 16.7% more relative foliage cover ($F_{1,142} = 8.31$, $P = 0.005$). In November this pattern was repeated with cockatoo damaged individuals in significantly better health with an

average of 16.0% more relative foliage cover ($F_{1,113} = 5.53$, $P = 0.020$). There was no interaction between cockatoo and sambar rubbing damage in May ($F_{1,140} = 0.22$, $P = 0.641$) or November ($F_{1,111} = 0.094$, $P = 0.762$). The worst condition was observed for trees with rubbing damage, while individuals with cockatoo damage were in better condition within each of these categories (Figure 3.14).

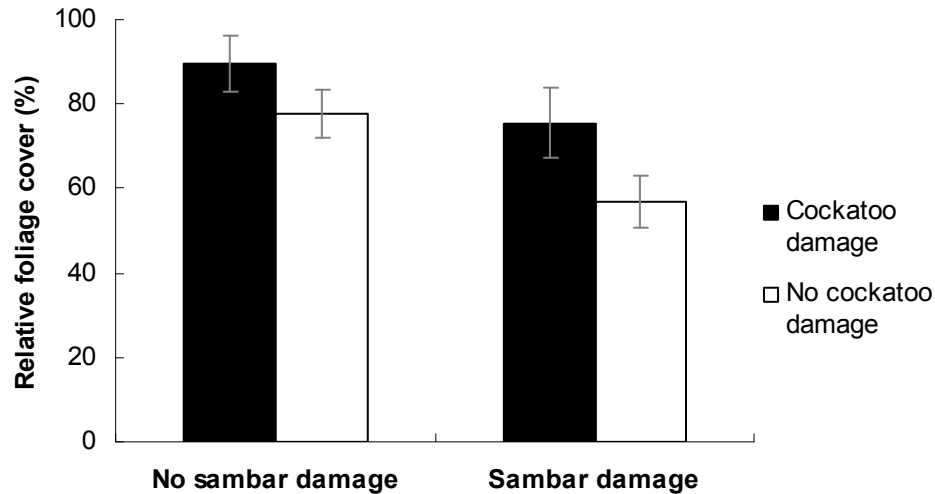


Figure 3.14. Mean relative foliage cover for shiny nematolepis trees (\pm standard error) categorised by the presence and absence of sambar rubbing damage and cockatoo damage in Yarra Ranges National Park, November 2007.

Storm damage

Storm damage was observed on 12 (7.7%, $n = 156$) trees in May compared with 41 (26.9%) trees in November. Of the storm damaged trees in November, 18 had fallen over, 10 had lost all foliage-bearing branches although the trunk remained standing, and 13 had some to most of their branches broken off, leaving between 30 and 90% foliage cover remaining. Trees with no foliage-bearing branches were classified as dead as it was presumed they would die, evidenced by other individuals that were dead with no top branches. Analysis of the individuals that were dead from storm damage included trees that had fallen or had lost all foliage-bearing branches combined. Three individuals that had lost all foliage-bearing branches due to overstorey tree fall were omitted from analysis. There were significantly more dead shiny nematolepis caused by the storm among individuals with sambar rubbing damage ($F_{1,152} = 8.75$, $P = 0.004$) and cockatoo damage ($F_{1,152} = 7.22$, $P = 0.008$) (Figure 3.15). Although there were approximately

equal proportions of sambar and cockatoo damaged individuals that had been storm damaged, there was no interaction between sambar and cockatoo damage ($F_{1,152} = 1.53$, $P = 0.218$).

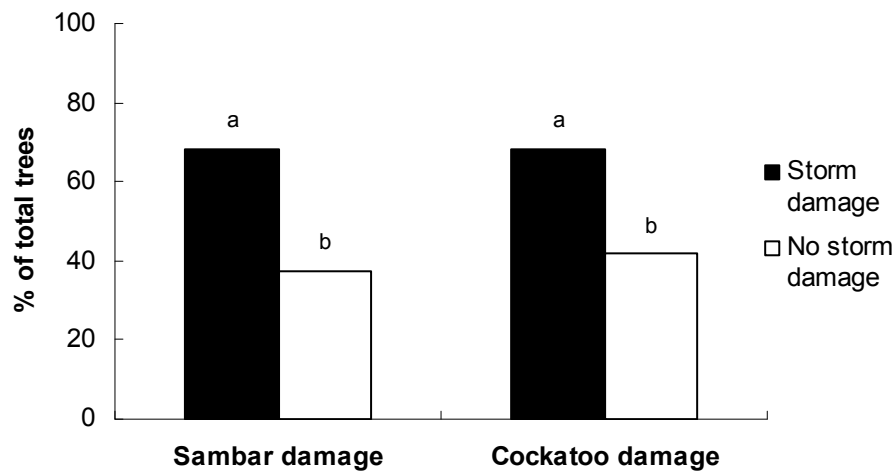


Figure 3.15. The percentage of shiny nematolepis trees surveyed with sambar damage and cockatoo damage, categorised by presence or absence of storm damage in the Yarra Ranges National Park, November 2007. Significant differences with and without storm damage, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a and b, where $a > b$.

Discussion

The partial fences proved successful in excluding sambar from patches containing shiny nematolepis, and in allowing access to the exclusion plots by native species such as superb lyrebird and common wombat, which through soil disturbance may aid in seedling recruitment. While there is some cost in fence construction and on-going maintenance, it is a relatively simple and effective way to protect shiny nematolepis from sambar.

The FPG survey did not detect any pellets in May or November 2007, indicating a very low abundance of sambar, since deer faecal pellet group numbers are approximately linearly associated with deer density (Forsyth *et al.* 2007). However the shiny nematolepis site has a deep layer of leaf litter and other plant debris, along with a dense ground cover of hard water fern (*Blechnum wattsii*), which is likely to decrease the accuracy of the survey. Pellets are likely to be missed if they fall through the dense ground covering, as the survey method allows fern fronds to be pushed aside in search of pellet groups but does not include searching through leaf litter and other plant debris (Chapter 2). As found in the Riparian Forest EVC (Chapter 2), this method and other survey methods that utilise faecal pellets to provide density estimates may be unsuitable for measuring sambar density at the Deep Creek site due to the nature of the ground cover. There is also a low representation of understorey shrub species, and therefore few food plants (Chapter 5) available at the shiny nematolepis site. This may also explain the absence of faecal pellets in the FPG survey because deer, including sambar (Mason 2006), produce faecal pellets near where they feed (Bennett *et al.* 1940) or after a period of resting and rumination (Collins and Urness 1981; Gunn and Irvine 2003). However the rubbing, thrashing and use of the wallow, demonstrates that there are some sambar present at the site.

The relative foliage cover estimate used to measure the health of shiny nematolepis individuals was subject to inevitable observer error, however visual estimates of foliage cover are a commonly used method to rapidly assess tree health, and error was minimised by the use of one observer.

Thrashing occurred mostly on saplings located on road side verges. Massei and Bowyer (1999) found that fallow deer (*Dama dama*) also preferred to rub trees near roads. It is

likely that sambar are using the roads to move through their range, and thrashing vegetation on the verges may allow them to advertise their presence in the area. Following a tree fall during the storm prior to the November 2007 survey, the last section of Road 5 was impassable by vehicle, so approximately 1 km of the road was walked to reach the site. During this walk a moderate amount of sambar thrashing was evident on eucalypt (*Eucalyptus* spp.) and silver wattle (*Acacia dealbata*) saplings beside the track. These observations suggest that sambar may not select saplings according to species. Shiny nematolepis saplings may have been thrashed simply because it is the dominant species of sapling on the road verges at this site. This is supported by the recording of minimal thrashing on other tagged understorey shrub species located in forested areas of the nearby Upper Yarra catchment (Chapter 5). Sambar thrashed shiny nematolepis saplings with a larger stem diameter from the available saplings located on the edge of the sapling patches on road verges at the site. Body size is correlated to antler size (Geist 1999) and antler morphology, which is related to selectivity of stem diameter size for rubbing (Ramos et al. 2006). This is likely because saplings with a larger stem diameter are more robust and provide greater resistance when thrashed, providing a solid substrate for signposting. Thrashed saplings had almost half their stem circumference damaged, which is likely to decrease the health of individuals by interrupting the flow of water and nutrients throughout the plant due to damage to the vascular tissue. Although all the thrashed saplings were still alive, in some instances thrashed stems had died and new stems had coppiced. This was also reflected in thrashed individuals having significantly less relative foliage cover than non-thrashed individuals, although saplings that had been thrashed in May 2007 appeared to recover somewhat and had increased foliage cover by November 2007.

Mature shiny nematolepis trees appear to be susceptible to rubbing damage by sambar, although there were few other similar-sized trees at this site for comparison. As in this study, Shea *et al.* (1990) found that sambar in Florida, USA, rubbed a range of tree diameter sizes. However the mean length of sambar rub scars was 37 cm greater and mean upper limit 34 cm greater than the rubbing damage on shiny nematolepis in YRNP. The mean lower limit however was similar, perhaps indicating rubbing at the shiny nematolepis site was conducted by individuals that were on average smaller than those in the Florida study. Rubbing damage for the purpose of marking territory increases when a mature stag is defending territory from another stag or subordinate

male (Bentley 1998). A similar concentration of rubbing has not been reported or observed elsewhere in YRNP. The high concentration of rubbing damage on shiny nematolepis at this site therefore appears unusual. Further surveys are required to determine if shiny nematolepis are preferentially selected by sambar for rubbing. Surveys should consider tree characteristics such as tree morphology (Kile and Marchinton 1977; Benner and Bowyer 1988; Massei and Bowyer 1999), stem diameter (Benner and Bowyer 1988; Johansson *et al.* 1995; Ramos *et al.* 2006) and aromatic properties (Kile and Marchinton 1977; Johansson *et al.* 1995), as well as frequency and distribution. This information will aid in identifying species vulnerable to sambar rubbing activities.

As with damage to saplings, sambar rubbing damage to trees, on average, removed over half the circumference of bark down to the tree cambium. Sambar rubbing activities, likely to be caused over several years of repeated rubbing, may ringbark shiny nematolepis individuals and cause death, which was noted as the apparent cause of death for several individuals in 2005 (Lorimer and Lorimer 2005) and for seven dead individuals in this study, which all had 100% of circumference rubbed. Sambar rubbing activities have been noted to cause tree death in Florida, USA (Shea *et al.* 1990).

It is unknown which properties of shiny nematolepis attract sambar. An appropriate stem diameter size for the function of removing velvet and marking territory, the relatively straight trunk with few low branches, and the strong fragrance of the trees could be involved in attraction. Yellow-wood (*Acronychia oblongifolia*) has recently been listed as threatened in Victoria (Flora and Fauna Guarantee Act 1988) primarily due to rubbing damage caused by sambar. This species is also an aromatic member of the Rutaceae, and may function as an olfactory marker.

Based on the high level of cockatoo damage, shiny nematolepis also appears susceptible to borer damage. A number of moth, beetle and wasp species have larval stages commonly referred to as borers that feed on stems, branches and shoots of living trees. In particular several moth genera (*Xyleutes*, *Endoxyla* and *Aenetus*) can cause structural weakness within living trees as their larvae feed and create tunnels or galleries in the heartwood (McInnes and Carne 1978; Elliot *et al.* 1998). Trees may be more susceptible to borers if they are stressed, for example through poor nutrition, damage by other insects, or lack of water (Plant Disease Diagnostic Unit 2007).

Yellow-tailed black cockatoos methodically search tree trunks for signs of frass ejection holes or the swollen spongy frass scars, and use their powerful beaks to gouge and strip bark and wood from the tree in search of the larvae (McInnes and Carne 1978), leaving characteristic and at times severe damage to shiny nematolepis trees. Despite the destructive appearance of cockatoo damage, results from the visual health assessment suggest that cockatoo predation of larvae is beneficial to shiny nematolepis, and that once larvae are extracted from the tree by cockatoos, individuals improve in health. This result was unexpected given that cockatoo damage may expose the trees to fungal infection and potentially attract more insects to lay eggs on the tree due to the release of volatile compounds from the wounds (Elliot *et al.* 1998; Stewart 2001). However this study was not specifically designed to test the impact of larval predation by cockatoos on shiny nematolepis. The measure of relative foliage cover as an assessment of health may not have been appropriate for measuring the physical effects of cockatoo damage to shiny nematolepis.

Storm damage at the site demonstrated that a single natural event can kill numerous trees. Shiny nematolepis inhabits the mid structural stratum of forest, and foliage is generally found only on the top branches, presumably in a response to light availability. While severe storms do not appear to be common, these foliage-bearing branches are susceptible to storm damage through falling branches from surrounding overstorey trees that either break shiny nematolepis branches or tear bark off when the falling branches slide down the trunks of shiny nematolepis. Strong wind may also break branches off or knock shiny nematolepis trees over. The actions of yellow-tailed black cockatoos in search of larvae has been shown to structurally weaken trees to the extent they are unable to withstand strong wind (McInnes and Carne 1978). This study indicates that the presence of damage by both cockatoos and sambar each independently increased the susceptibility of mature trees to death by storm damage.

CHAPTER 4

Biomass off-take by sambar at high densities on The Flats



*Sambar grazing on The Flats, Upper Yarra catchment,
Yarra Ranges National Park, January 2007*

CHAPTER 4

Biomass off-take by sambar at high densities on The Flats

Introduction

Deer select habitats that provide both food and cover (Borkowski and Ukalska 2008). As a result, deer often show a habitat preference for forest edges (Williamson and Hirth 1985; Licoppe 2006), with forested habitats and the associated cover it provides commonly utilised during the day, and open habitats that provide ample forage utilised between dusk and dawn (Beier and McCullough 1990; Ager *et al.* 2003). Densities of deer are often higher (Alverson *et al.* 1988; Polisar *et al.* 2008), and home ranges smaller (Kie *et al.* 2002) at forest edges, which has been associated with the higher abundance and nutrient content of forage in this ecotone (Miyashita *et al.* 2007). Group sizes tend to be high along these ecotones: group size is correlated with population density (Hirth 1977; Borkowski 2000; Pépin and Gerard 2008), and larger groups form in more open habitats (Molvar and Bowyer 1994).

Sambar (*Cervus unicolor*) is a large, tropical deer species found throughout many parts of Asia and introduced to Australia in the 1860s (Bentley 1998) (Chapter 2). Sambar are known to utilise their habitat depending on seasonal food resource availability, forage quality and abundance (Santiapillai *et al.* 1981; Varman and Sukumar 1993; Davies *et al.* 2001). In Thailand, Ngampongsai (1987) found that preferred habitat was a mixture of grassland and forest, and in Sri Lanka, Eisenberg and Lockhart (1972) described daily habitat use as covering a mosaic of habitat types from dense forest through to open scrubland. Sambar are often described as shy and secretive, and are solitary or found in small family groups (Bentley 1998; Harrison 1998). However aggregations of up to 50 sambar individuals were reported by Varman and Sukumar (1993) in India, while in Australia, Mason (2006) reported aggregations of up to 20 on crops and pastures at night.

There has been only limited research on the energy requirements of sambar in captivity (Semiadi *et al.* 1998) and the daily forage intake of sambar in the wild has not been investigated. However, Owen-Smith (2002) concluded that there was an approximately linear relationship between daily food intake and body mass for a number of ungulate

species. Medium-sized ruminants, such as cattle and antelope, had a forage (dry weight) intake of approximately 2% of their total body mass. Assuming that sambar intake fits this relationship, and given the average body weight of mature sambar in Australia was recorded at 192 kg for stags and 146 kg for hinds (Bentley 1998), sambar stags would consume approximately 3800 g and hinds 2900 g biomass dry weight day⁻¹. In comparison, swamp wallabies (*Wallabia bicolor*) and common wombats (*Vombatus ursinus*), two common, native herbivores at this site, have significantly lower daily food requirements. Swamp wallabies weigh up to 25 kg (Di Stefano *et al.* 2005), although commonly average around 15 kg (Troy and Coulson 1993). Average-sized swamp wallabies consume 398 g biomass dry weight day⁻¹ (Nagy *et al.* 1990). Common wombats weigh approximately 35 kg (Triggs 1988), and have a seasonally variable intake of 694 – 1450 g biomass dry weight day⁻¹ (Evans *et al.* 2003).

The population of sambar in the Upper Yarra catchment, Yarra Ranges National Park is at high density on open, ephemeral flats adjacent to the Upper Yarra reservoir and in the edge of the forest (< 250 m) adjacent to these open areas (Chapter 2). The most frequent sightings of sambar are on the largest of these open areas known as The Flats, where aggregations of up to 70 individuals have been observed feeding on herbs, including forbs and grasses (Chapter 2). In response to the large numbers of sambar observed at The Flats and throughout the Yarra Ranges National Park, Melbourne Water and Parks Victoria conducted a cull that began in May 2008.

This study aims to estimate the biomass offtake by sambar at high densities on The Flats to determine the importance of this resource to the population within the YRNP. In addition this study aims to investigate the influence of a cull on population density and biomass offtake on The Flats.

Methods

The study site

The Yarra Ranges National Park (YRNP) is located 100 km north east of Melbourne. The majority of the YRNP (84%) is closed to the public, protected as Designated Water Supply Catchment Area, which provides approximately 50% of Melbourne's water supply (Melbourne Water 2007). The Upper Yarra catchment (33 670 ha) is the largest of three water catchments in the YRNP. Located in this catchment adjacent to the Upper Yarra reservoir is a large, open, ephemeral area known locally as 'The Flats'. This area of approximately 50 ha forms the base of the eastern arm of the Upper Yarra reservoir, and is periodically flooded depending on the level of the reservoir (Chapter 2). During this study, between October 2005 and August 2008, The Flats were exposed for approximately two thirds of the time, when the reservoir was commonly at about 50% of capacity. During these times, a dense sward of forbs and grasses establish which are utilised as a food source by a number of herbivore species. The Flats are surrounded by a variety of forest types, with an access road running approximately parallel to the southern boundary of The Flats.

The Flats, while distinct in the context of the Upper Yarra catchment, is an artificial environment and unclassified within the Ecological Vegetation Class (EVC) system. The eastern end of The Flats is flooded infrequently, and is dominated by rush and sedge tussocks, which are unpalatable to the suite of herbivores found at The Flats. Therefore, to determine the area of available forage at The Flats, the site was divided into three floristic zones: Open Herb-rich Zone, Grassy Rush Zone and Rush-sedge Zone (Figure 4.1). The Open Herb-rich Zone was the largest of the three areas, covering approximately 34 ha, and was the most prone to flooding. This zone was mostly comprised of three forb species, stinking pennywort (*Hydrocotyle sibthorpioides*), hypsela (*Hypsela tridens*) and creeping knotweed (*Persicaria prostrata*), and two grass species, blown-grass (*Lachnagrostis* aff. *filiformis*) and annual meadow grass (*Poa annua*). The Rush-sedge Zone, covering 13 ha, was densely covered (70 – 90%) with green rush (*Juncus gregiflorus*), hollow rush (*Juncus amabilis*) and tall sedge (*Carex appressa*), with a diverse mixture of forb and grass species between the tussocks. The Grassy Rush Zone was a transitional zone between the two areas, covering 4 ha, and had approximately 20% coverage of green

rush and hollow rush tussocks, interspersed with a mixture of primarily grass species (Table 4.1).

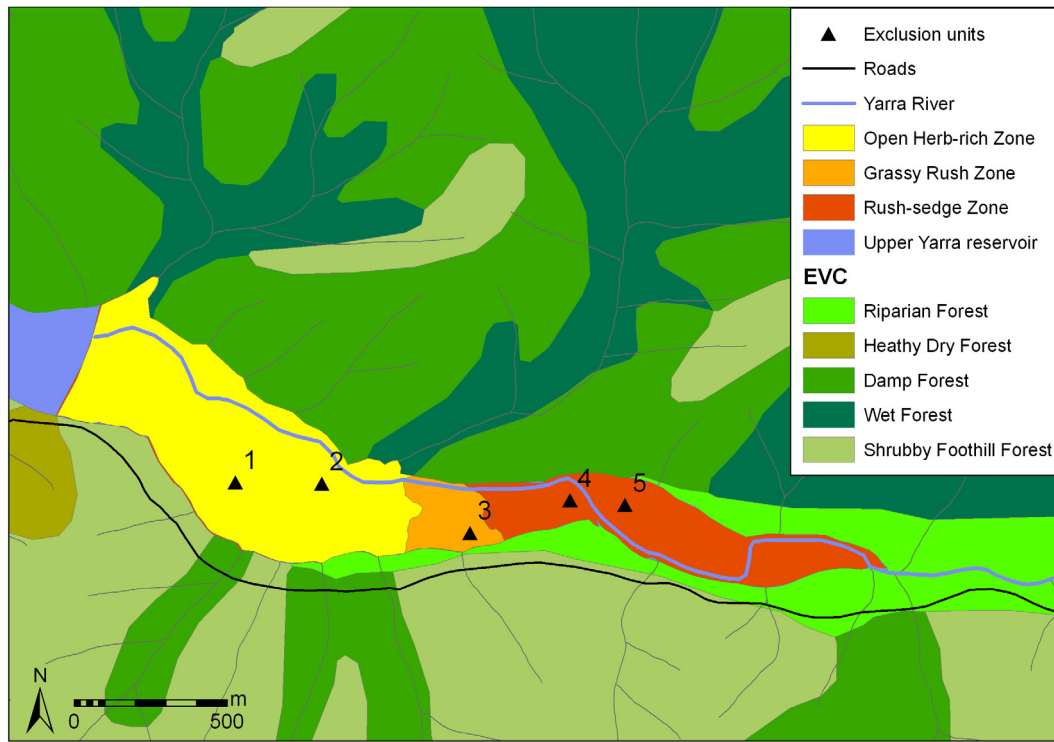


Figure 4.1. Location of exclusion units 1 – 5 on The Flats, Upper Yarra catchment, Yarra Ranges National Park, constructed in October and December 2005 and March 2006.

In response to the large numbers of sambar observed in the park, a cull was conducted in 2008 throughout the Yarra Ranges National Park (authority number 13272748), in a jointly managed project by Melbourne Water and Parks Victoria. As part of this program, shooting at The Flats began 12 May 2008 and was conducted at The Flats for a month, ceased on 9 June for a month and then resumed on 7 July until 4 August. Shooting was conducted at The Flats on 12 nights during darkness with the aid of a spotlight and 21 sambar were culled on or in the vicinity (< 100 m) of The Flats.

Table 4.1 Attributes of exclusion units located on The Flats, Yarra Ranges National Park. All species are grazed except *Carex appressa*, *Juncus amabilis* and *Juncus greigiflorus*.

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Construction date	16 March 2006	28 March 2006	4 October 2005	29 October 2005	11 December 2005
Flood frequency	Frequent	Frequent	Occasionally	Infrequent	Infrequent
Biomass production	Poor	High	Medium	Medium	High
Floristic zone	Open Herb-rich Flats	Open Herb-rich Flats	Grassy Rush Flats	Rush-dominated Flats	Rush-dominated Flats
Main species	<i>Hydrocotyle sibthorpioides</i> Sinking pennywort <i>Hypselia tridens</i> Hypselia <i>Lachnagrostis</i> aff. <i>filiformis</i> Undescribed blown-grass <i>Pericaria prostrata</i> Creeping knotweed <i>Poa annua</i> Annual meadow grass	<i>Hydrocotyle sibthorpioides</i> Sinking pennywort <i>Hypselia tridens</i> Hypselia <i>Lachnagrostis</i> aff. <i>filiformis</i> Undescribed blown-grass <i>Pericaria prostrata</i> Creeping knotweed <i>Poa annua</i> Annual meadow grass	<i>Carex appressa</i> Tail sedge <i>Cyperus eragrostis</i> Drain sedge <i>Eragrostis brownii</i> Common love-grass <i>Hydrocotyle sibthorpioides</i> Sinking pennywort <i>Hypochaeris radicata</i> L. Common catsear <i>Juncus amabilis</i> Hollow rush <i>Juncus greigiflorus</i> Green rush <i>Microlaena stipoides</i> Weeping grass <i>Pericaria prostrata</i> Creeping knotweed <i>Trifolium dubium</i> L. Clover	<i>Anthoxanthum odoratum</i> Sweet vernal grass <i>Brachyhectium rutabulum</i> Rough-stalked Feather-moss <i>Carex appressa</i> Tail sedge <i>Cirsium vulgare</i> Spear thistle <i>Cyperus eragrostis</i> Drain sedge <i>Eragrostis brownii</i> Common love-grass <i>Holcus lanatus</i> Yorkshire fog grass <i>Hydrocotyle sibthorpioides</i> Sinking pennywort <i>Hypochaeris radicata</i> L. Common catsear <i>Juncus amabilis</i> Hollow rush <i>Juncus greigiflorus</i> Green rush <i>Microlaena stipoides</i> Weeping grass <i>Poa annua</i> Annual meadow grass <i>Prunella vulgaris</i> L. Self-heal <i>Trifolium dubium</i> L. Clover	<i>Anthoxanthum odoratum</i> Sweet vernal grass <i>Brachyhectium rutabulum</i> Rough-stalked Feather-moss <i>Carex appressa</i> Tail sedge <i>Cirsium vulgare</i> Spear thistle <i>Cyperus eragrostis</i> Drain sedge <i>Holcus lanatus</i> Yorkshire fog grass <i>Hydrocotyle sibthorpioides</i> Sinking pennywort <i>Hypochaeris radicata</i> L. Common catsear <i>Juncus amabilis</i> Hollow rush <i>Juncus greigiflorus</i> Green rush <i>Microlaena stipoides</i> Weeping grass <i>Poa annua</i> Annual meadow grass <i>Prunella vulgaris</i> L. Self-heal <i>Trifolium dubium</i> L. Clover

Temperature and rainfall at The Flats

Temperature data was obtained from Bureau of Meteorology observation station 85277 located at Noojee, approximately 7 km south of The Flats. During the study period, May 2006 – June 2007, mean daily maximum temperatures were on average 1.1 °C higher than the long-term average from 1981 to 2005. Although May 2006 was 1.4 °C cooler, February 2007 was 3.3 °C warmer than the long-term average (Figure 4.2). The mean daily minimum temperature for the study period fluctuated around the long-term mean; on average 0.2 °C cooler than the mean minimum temperature. June 2006 experienced the coldest nights at 2.0 °C below average and May 2007 the warmest, with temperatures on average 2.4 °C above the long term mean daily minimum (Figure 4.2).

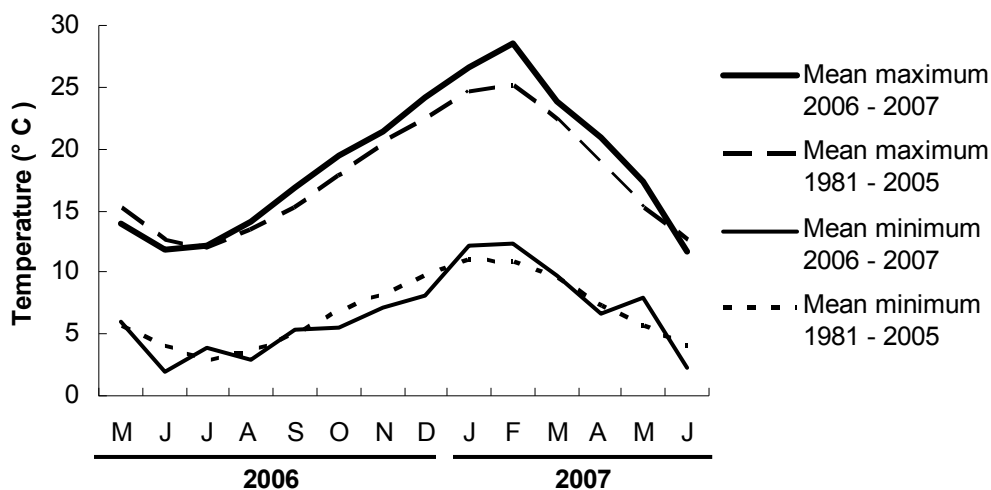


Figure 4.2. Mean monthly maximum and minimum temperature (°C) recorded at Bureau of Meteorology Noojee weather station (85277) during biomass survey period May 2006 – June 2007, and compared with mean monthly maximum and minimum temperatures 1981 – 2005.

The rainfall recording station operated by Melbourne Water is located at the Upper Yarra reservoir wall, approximately 7 km west of The Flats. During the sampling period, The Flats received below average rainfall with two substantial rainfall events in March and June 2007 (Figure 4.3).

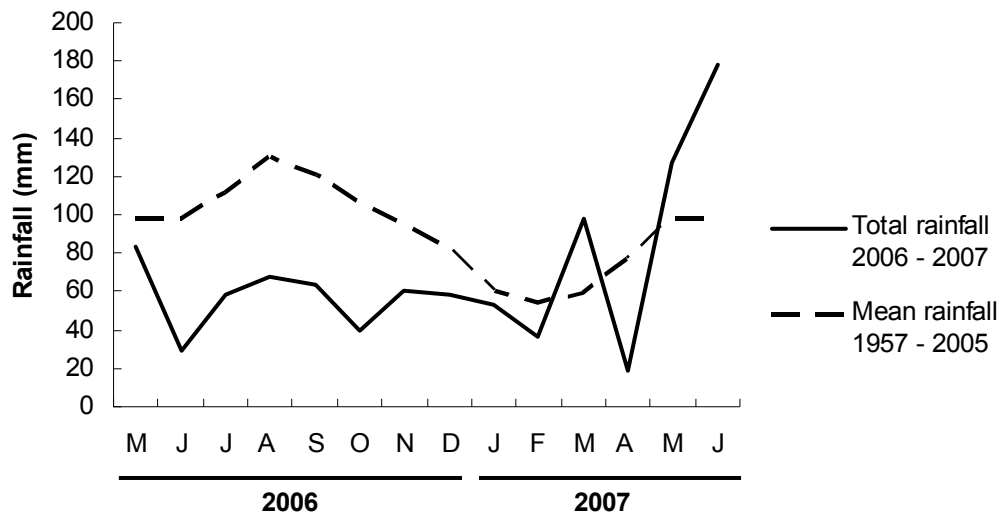


Figure 4.3. Total monthly rainfall recorded by Melbourne Water from the Upper Yarra reservoir wall during biomass survey period May 2006 – June 2007, and compared with mean monthly rainfall 1957 – 2005.

Exclusion plot design

Selective exclusion plots were used to differentiate biomass offtake by sambar from that by other herbivores at the site. Herbivores present at The Flats, in addition to sambar, included common wombat, swamp wallaby, swamp rat (*Rattus lutreolus*), wood duck (*Chenonetta jubata*) and the introduced rabbit (*Oryctolagus cuniculus*). Swamp wallabies are considered to be predominantly browsers (Hollis *et al.* 1986; Jarman and Phillips 1989), although commonly consume grasses, forbs, ferns and sedges (Osawa 1990). Wombats are grazers feeding almost exclusively on grasses (Evans *et al.* 2006), although may also consume sedges, matrushes, and the roots of shrubs and trees (McIlroy 1983). Swamp rats feed on basal stems and rhizomes of sedges and grasses (Watts and Braithwaite 1978; Cheal 1987) but also include a small proportion of insects in their diet (Watts 1977). Wood ducks are generalist grazers, which feed almost exclusively on terrestrial grasses and forbs (Kingsford 1989). Rabbits consume a wide variety of plant species but will select forbs and grasses where available (Martin *et al.* 2007). Sambar consume a wide variety of plants including tree seedlings, shrubs, grasses, forbs and ferns (Dinerstein 1987; Ngampongsai 1987; Padmalal *et al.* 2003). It was expected that the main contributors to biomass offtake other than sambar would be common wombats and swamp wallabies, as wood duck activity appeared to be restricted to the edges of The

Flats in close proximity to the reservoir. Sightings, scats or signs of habitat use by swamp rats and rabbits were rarely observed.

Exclusion plots have often been used to investigate the offtake and impacts of herbivores (Lenzi-Grillini *et al.* 1996; Nomiya *et al.* 2002; Tsujino and Yumoto 2004; Webster *et al.* 2005; Stroh *et al.* 2008). However in many ecosystems, separating the effects of habitat use by a particular species from other non-target species can prove challenging. Selective exclosures have been shown to effectively differentiate the offtake and subsequent impacts of co-existing herbivores, primarily by exploiting the variation in body size between the species (Bowers 1993; Allcock and Hik 2004; Olofsson *et al.* 2004).

Five exclusion units were constructed on The Flats between October 2005 – March 2006, with each unit consisting of a total, a partial and an open plot (Bennett and Coulson 2008) (Appendix 1). Exclusion plots (10 x 10 m) were randomly positioned with Units 1 and 2 located in the Open Herb-rich Zone, Unit 3 located in the Grassy Rush Zone and Units 4 and 5 located in the Rush-sedge Zone (Figure 4.1).

The three plot treatment types were utilised to determine the quantity of biomass offtake by sambar through a process of deduction. All herbivores had access to the open plot, while the partial plot permitted access to all herbivores except sambar, and the total exclusion plot excludes all herbivores. Therefore the quantity of biomass offtake by sambar and other herbivores present at The Flats may be obtained by:

$$\begin{aligned} \text{Partial standing crop} - \text{Open standing crop} &= \text{offtake by sambar} \\ \text{Total standing crop} - \text{Partial standing crop} &= \text{offtake by other herbivores} \end{aligned}$$

Effectiveness of exclusion units

It was considered unlikely the large-bodied sambar would enter the small enclosures via the 500-mm gap at the base of the partial plots. However on several occasions during July 2006, small sambar faecal pellets, presumably produced by yearlings, were observed in the partial plots. Wood duck, a herbivore previously considered to utilise only a small amount of The Flats adjacent to the reservoir, were occasionally observed in the total plots. The wood ducks were small enough to fit through the mesh squares and entered

the plots from the ground, but did not appear to fly in and out of the plots. The partial plots were modified to a 300-mm gap by the addition of a band of chicken mesh to exclude sambar. The total plots were modified to include a band of chicken mesh over the existing mesh to prevent access to the wood ducks. (Bennett and Coulson 2008) (Appendix 1). This alteration also excluded rabbits, which were not observed at the site until after initial plot construction. These modifications proved effective in excluding wood ducks and rabbits from the total plots and sambar from the partial plots, since no faeces were subsequently observed inside plots. The effectiveness of the modifications was also demonstrated by the appearance of a browse line in several of the partial plots, where sambar had reached their head and neck under the gap to feed along the inside edges of the partial plots.

While The Flats are a relatively level area, there are rises and depressions, generally of less than 500 mm but up to 1000 mm in height, created by currents in the Yarra River when The Flats are submerged. During the survey period it was evident that plants located on the rises in the Open Herb-rich Zone were in poor health, with brown patches, while those located in the depressions were greener and in apparently better health (Figure 4.4). This effect did not occur in the other floristic zones of The Flats.

Unit 1 had little vegetation cover throughout the study (Figure 4.5). The total and partial exclusion plots in this unit were positioned on rises and the open plot was in a slight depression. Despite the different plot treatments, the open plot yielded a higher biomass quantity for five of the 14 monthly surveys than did the total and partial plots. In comparison, the total plot of Unit 2 was highly productive throughout the study period and showed a dramatic change over time (Figure 4.6). Biomass production and offtake in Unit 3 was consistent with treatment type but yielded comparatively lower biomass standing crop measurements. Units 4 and 5 received fewer hours of direct sunlight in winter months due to a steep hill situated to the north of the units. Approximately 6 months after construction, the total and partial plot of Unit 4 and, to a lesser extent, the total plot of Unit 5 were occupied by swamp rats, determined by the presence of their distinctive runways. On several occasions the diggings of swamp rats covered a sub-plot, which was then omitted from the monthly survey.



Figure 4.4. The Flats, Yarra Ranges National Park during a period of below average rainfall. Topographical rises were visible as brown patches, while plants in topographical depressions were in apparent better health shown by green areas, February 2007.



Figure 4.5. Unit 1, total exclusion plot, Yarra Ranges National Park, nine months after construction, December 2006. Biomass production was poor throughout the study period reflected in data and demonstrated by a lack of visual differentiation between the inside and outside of the treatment plot.

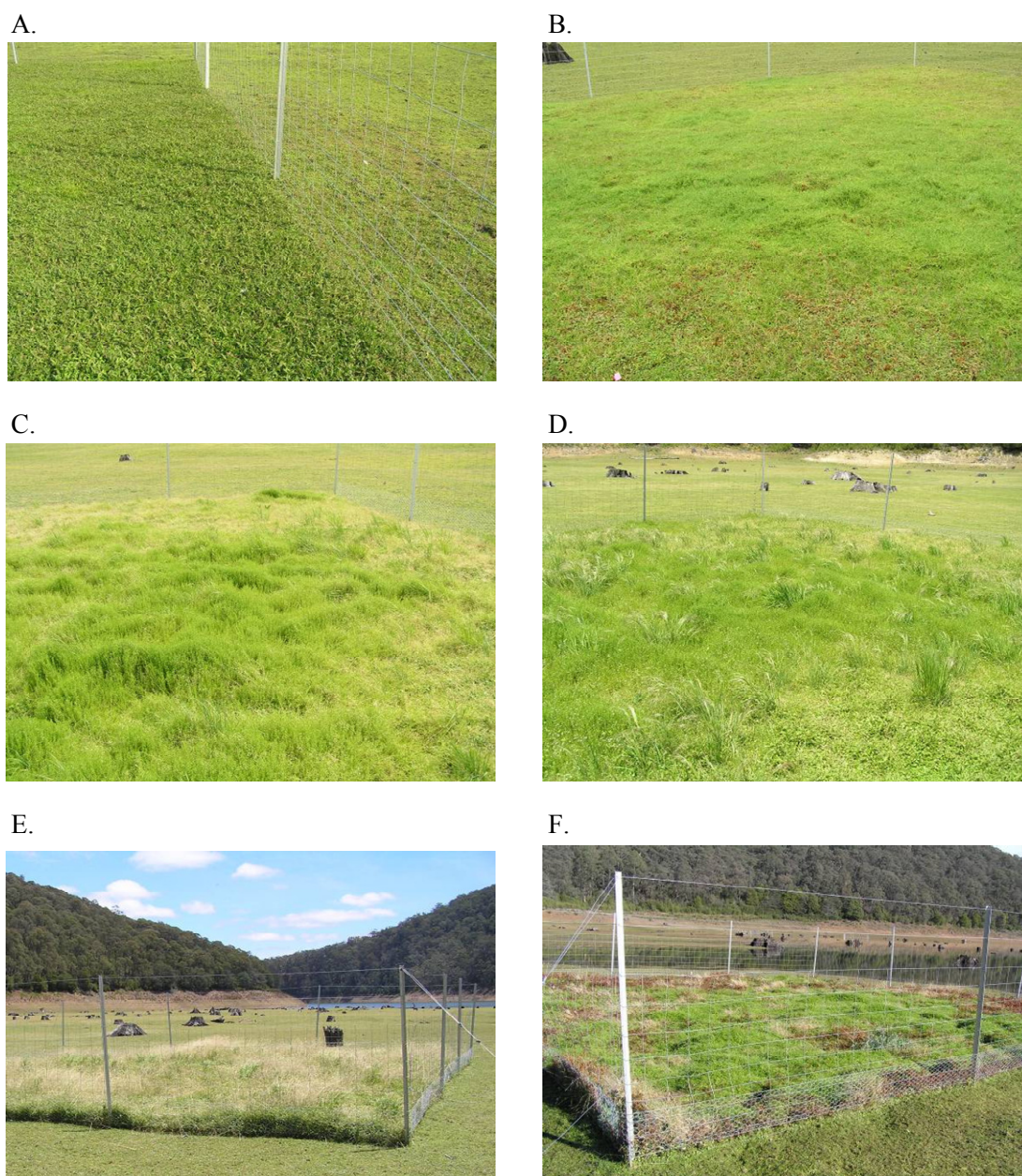


Figure 4.6. Unit 2, total plot change over time at The Flats, Yarra Ranges National Park **A.** One month after construction dominated by creeping knotweed (*Persicaria prostrata*) **B.** Four months after construction patches of hypsela (*Hypsela tridens*, bright green patches) have increased **C.** Six months after construction the plot is now densely covered with large patches of hypsela **D.** Seven months after construction patches of stinking pennywort (*Hydrocotyle sibthorpioides* – bottom right) in amongst hypsela and the taller blown-grass (*Lachnagrostis* aff. *filiformis*). **E.** Eight months after construction the blown-grass has dried off with the forb species still present underneath **F.** Fifteen months after construction, two days before it was submerged. The large green patches are hypsela that have persisted since winter 2006 and the dark brown patches are creeping knotweed that have browned off.

Herbivore use of exclusion units

The use of exclusion units by herbivores was determined by scat presence at each of the five units located on The Flats and is summarised in Figure 4.7. Sambar were the only deer species present in the YRNP and large numbers were sighted and their faecal pellets observed in proximity to all units throughout the study (Figure 4.8). Wood duck faeces were also observed in proximity to Unit 1 and 2, but no faecal matter from any other herbivore was observed near these units during the study period. Wood duck faeces were occasionally observed near Unit 3. Swamp wallaby faeces were frequently observed near Unit 4, and there were five sightings of swamp wallabies nearby. Common wombat faeces were frequently present at Unit 5, along with swamp wallaby and rabbit faeces. There was an existing wombat burrow in the vicinity of the total plot, and a new wombat burrow was dug inside the partial plot approximately 9 months after construction.

Habitat type	Open Herb-rich Zone		Grassy Rush Zone	Rush-sedge Zone	
Unit	1	2	3	4	5
Sambar					
Common wombat					
Rabbit					
Swamp rat					
Swamp wallaby					
Wood duck					

☐ Not observed
☒ Occasionally (1 - 5 observations)
☒ Frequently (>10 observations)

Figure 4.7. Frequency of herbivore scats observed in or in close proximity (< 10 m) to exclusion units over 14 monthly surveys at The Flats, Yarra Ranges National Park, May 2006 – June 2007.



Figure 4.8. Large aggregation of sambar (32 individuals) grazing in proximity to an exclusion unit located in the Open Herb-rich Zone at The Flats, Yarra Ranges National Park, January 2007.

Sambar density

Surveys of deer faecal pellet groups are commonly used to provide density estimates and are often used to determine management needs (Marques *et al.* 2001). Faecal pellet accumulation plots were established in the Open Herb-rich Zone, where the majority of sambar activity was observed, to measure changes in faecal pellet load during the course of the cull conducted in 2008. This method utilises established plots that are cleared of all faecal pellets, and at set time intervals are repeatedly surveyed for pellets and re-cleared. Randomly-generated plot locations would have been difficult to locate on subsequent counts at this site without elaborate and obvious marking, which can deter use of plots (Fraser 1998). Instead six transects, 100 m apart on a north-south axis, were established across the Open Herb-rich Zone of The Flats. The start of each transect was permanently marked on the southern edge of The Flats using a star peg and flagging tape, and a total of 20 plots were located at a random number of paces along the transect lines, generated using Microsoft Excel®.

Circular sample plots with an area of 40 m² were established on 28 April 2008. Permanent pegs marked with flagging tape located along the transect line identified the centre of each plot. Pegs were pushed into the ground with only a small piece of flagging tape able to be seen, to minimise visibility to the deer. To survey the plots, a rope measuring 3.57 m was anchored on the peg and each plot was systematically searched within this radius. The number of Faecal Pellet Groups (FPGs) and the number of pellets within each FPG were recorded. While most studies count only FPGs, Forysth *et al.* (2007) suggested the number of pellets may in some cases be more sensitive to changes in deer abundance. A FPG was classified as a group of pellets containing ≥ 1 pellet, voided in the same defecation, as determined by size, colour and shape. Following the FPG and pellet counts, all pellets located in the plot were removed. Plots were re-surveyed every 14 days on seven occasions between 12 May and 4 August 2008, and ceased when plots were submerged by a rise in the reservoir level.

Biomass offtake

In each of the five exclusion units, eight square sub-plots (25 x 25 cm) were established in each plot. The 120 sub-plots were permanently marked out with metal pegs and flagging tape, and were positioned within each plot to ensure coverage of the main species present. Rush and sedge species were not included in any of the sub-plots because they were not utilised as a food source. All sub-plots were located > 1 m from the edges of the fenced plots to minimise edge effects from the presence of the fence itself, such as altered levels of wind, sunlight and moisture or grazing by sambar from the outside. Between May 2006 and June 2007, each sub-plot was surveyed monthly for biomass production by placing a square wooden template, 4 mm in thickness, over the sub-plot to ensure uniform plot size. The biomass was then cut to 'grazing height' using grass clippers. This height was uniformly achieved by cutting the grass as low as the template edges would permit. The biomass harvested from each sub-plot was collected in a paper bag, and subsequently oven dried for 3 days at 60 °C to remove moisture, and then weighed using an electronic balance. To determine the effect of the cull on biomass offtake, a new set of eight sub-plots was established in the existing partial and open plots in May 2008 and surveyed in June and July until the exclusion plots were submerged by a rise in the reservoir level. Biomass offtake by sambar in June occurred

when there was no shooting and compared with biomass offtake by sambar in July 2008, when shooting was conducted.

To determine the quantity of biomass available to sambar and other herbivores at The Flats, the area of each floristic zone was calculated and then adjusted to approximate the area of available forage. A 5% reduction in area was applied to the Open Herb-rich Zone to account for the area occupied by the Yarra River. A 20% reduction in the Grassy Rush Zone and an 80% reduction in area to the Rush-sedge Zone was applied, as this was the approximate area covered by the rush and sedge tussocks, which were not utilised as a food source. The area of The Flats with available forage was thus estimated at 38 ha (Table 4.2).

Table 4.2. Area of The Flats, Yarra Ranges National Park in each floristic zone, adjusted to the area with available forage.

	Total Area (ha)	Area with available forage (%)	Adjusted Area (ha)
Open Herb-rich Zone	34.4	95	32.7
Grassy Rush Zone	3.6	80	2.9
Rush-sedge Zone	12.7	20	2.5
TOTAL	50.7		38.1

Results

Biomass production and offtake at The Flats

Data were log transformed and a regression analysis was employed to examine the relationships between biomass production with temperature and rainfall between May 2006 and June 2007. Biomass harvested from total plots only were used in this analysis, as variation with grazing pressure in the partial and open treatment plots could impact on observed relationships. Biomass production was strongly correlated with both mean monthly maximum and minimum temperature, while a lower level of correlation was observed between biomass production and rainfall (Table 4.3).

Table 4.3. Correlation of mean monthly maximum and minimum temperature and rainfall with biomass production (dry weight, g) obtained from total plots at The Flats, Yarra Ranges National Park, May 2006 – June 2007. All values showed significance except where values are approaching significance indicated by * or are not significant, indicated by **. † data was obtained from Bureau of Meteorology Noojee weather station (85277), approximately 7 km south of The Flats. ‡ data was obtained from Melbourne Water, rainfall gauge located at Upper Yarra reservoir wall approximately 7 km west of The Flats.

Unit	Mean maximum temperature (°C) [†]		Mean minimum temperature (°C) [†]		Rainfall (mm) [‡]	
	Correlation	<i>P</i> value	Correlation	<i>P</i> value	Correlation	<i>P</i> value
1	0.870	< 0.001	0.744	< 0.001	0.663	< 0.001
2	0.847	< 0.001	0.867	< 0.001	0.441	0.019
3	0.672	< 0.001	0.673	< 0.001	0.31	0.109 **
4	0.459	0.014	0.367	0.055 *	0.184	0.349 **
5	0.759	< 0.001	0.705	< 0.001	0.287	0.196 **

To determine the effect of plot treatment on biomass standing crop, the mean of the eight sub-plots for each plot per month was utilised. Within-unit one-way analysis of variance between plot treatments revealed that the exclusion units generally performed as intended. All treatments were statistically different within each unit except Unit 1, which showed no variation with treatment due to minimal growth in all treatment plots, and Unit 4, with no difference found between the total and partial plots (Table 4.4).

Table 4.4. Comparison of mean standing crop (\pm standard error) between exclusion units at The Flats, Yarra Ranges National Park, May 2006 – June 2007. Significant differences between plot treatments within each unit, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a – c, where $a > b > c$. Overall, the within-unit plot treatments are all statistically significant except Unit 1 as indicated by **.

Unit	Mean biomass dry weight g m ⁻²			Degrees of freedom	Variance	P value
	Total	Partial	Open			
1	1.10 \pm 0.10 ^a	0.98 \pm 0.11 ^a	1.04 \pm 0.08 ^a	357	0.61	0.543 **
2	23.94 \pm 1.91 ^a	3.86 \pm 0.49 ^b	1.46 \pm 0.12 ^c	357	133.46	<0.001
3	5.71 \pm 0.53 ^a	3.19 \pm 0.28 ^b	1.59 \pm 0.12 ^c	381	17.20	<0.001
4	7.17 \pm 1.06 ^a	8.04 \pm 0.72 ^a	2.66 \pm 0.21 ^b	402	12.74	<0.001
5	15.52 \pm 1.37 ^a	5.46 \pm 0.61 ^b	1.67 \pm 0.20 ^c	301	101.63	<0.001

Repeated measures analysis of variance was utilised to determine the influence by plot treatment on standing crop. Between May and August 2006, standing crop was quite similar. However, after modification of plots with chicken mesh in September 2006, differentiation between plot treatments increased and at times showed large variation (Figure 4.9).

Subsequent statistical analysis utilised measurements only after the mesh was added, October 2006 – June 2007. Data was log transformed followed by repeated measures analysis of variance, using a first order autoregressive model. This model recognises biomass measurements obtained from consecutive months are related, demonstrated by a high level of correlation between data taken at successive times ($\Phi = 0.909 \pm 0.028$, $P < 0.001$). The month with the greatest standing crop was November 2006, and the lowest June 2007. The large decrease in standing crop in December 2006 appears exceptional but reflects variation in production between units, in particular large growth in Unit 2 during January. Biomass standing crop was significantly different between treatments ($Wald_2 = 3.14$, $P = 0.043$), while there was no significant interaction between time and treatment. The mean biomass standing crop in the total plots was greater than the partial plots, and the mean partial plot biomass standing crop was greater than that in the open plots for all months surveyed (Figure 4.9). Fisher's least significant difference post hoc test showed however, that while the total and open plots were significantly different throughout the study period, biomass standing crop in the partial plots was not statistically different from either the total or open plots in any month.

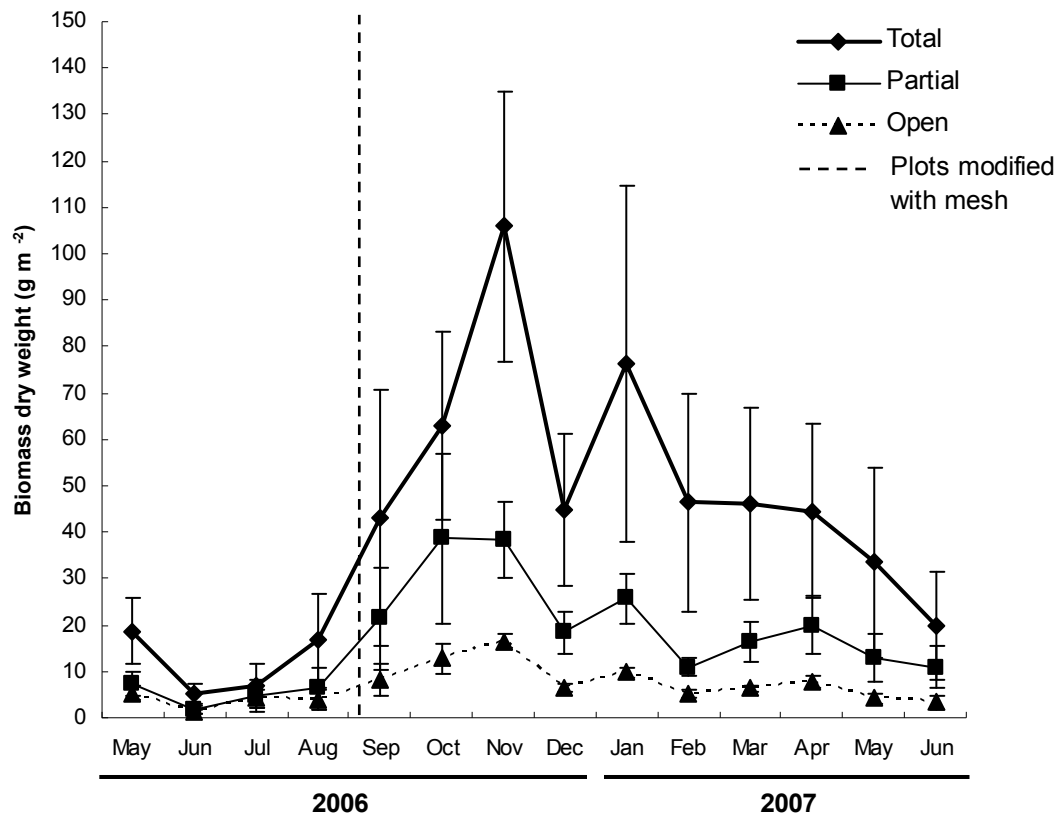


Figure 4.9. Mean monthly standing crop for Units 1 – 5 (\pm standard error) located at The Flats, Yarra Ranges National Park, May 2006 – June 2007. The additional chicken mesh was added to the total and partial plots on 4 and 14 September 2006.

The biomass standing crop measured in the different plot treatments in conjunction with the estimated area each of the herbivores utilised at The Flats based on the scat data, was used to extrapolate the total quantity of biomass offtake by sambar and other herbivores at The Flats (Figure 4.10). These results showed that sambar consume almost all available forage at The Flats, while other herbivores consumed a minor proportion primarily due to the large Open Herb-rich Zone not being utilised.

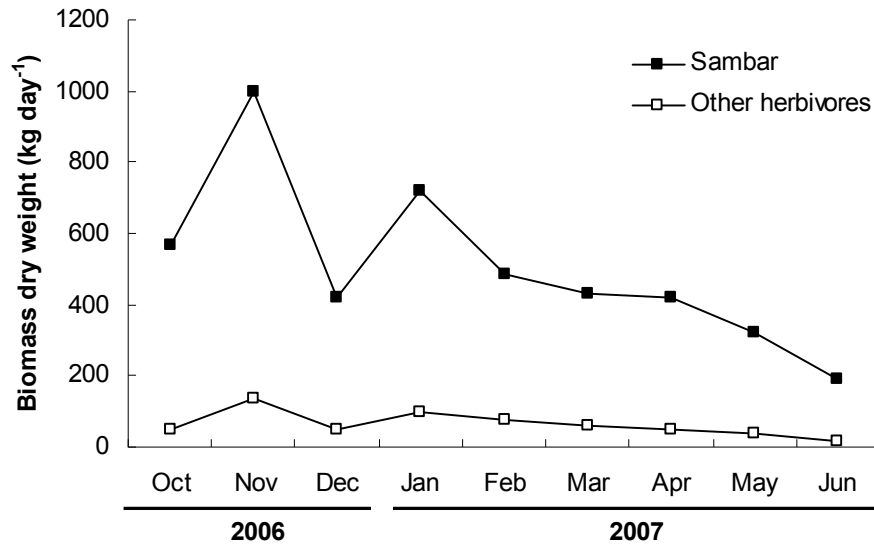


Figure 4.10. Estimation of biomass offtake by sambar and other herbivores across The Flats, Yarra Ranges National Park, October 2006 – June 2007.

Effect of cull on biomass offtake and density

Offtake by sambar in June 2008 when no shooting occurred was 14.7 g m⁻² (dry weight) compared with 3.7 g m⁻² in July 2008 when shooting was conducted (Figure 4.11). Repeated measures analysis of variance showed that overall, treatments were significantly different ($F_{1,4} = 8.19$, $P = 0.046$), while the Fisher's least significant difference post hoc test revealed that partial and open treatments were significantly different in June only.

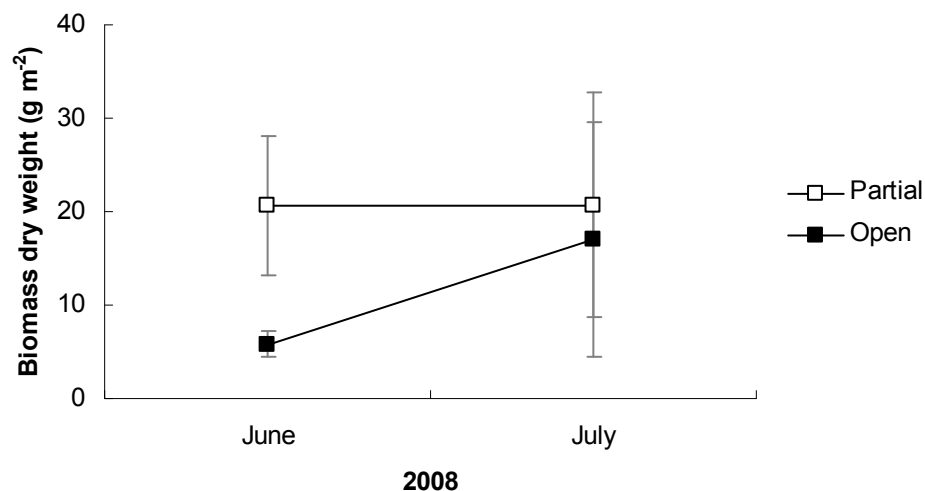


Figure 4.11. Mean standing crop (\pm standard error) at The Flats, Yarra Ranges National Park, June (no cull) – July (cull) 2008.

The number of FPGs was not significantly effected by the cull on The Flats ($F_{1,5} = 0.02$, $P = 0.90$). However the number of pellets was significantly lower during times at which culling was conducted ($F_{1,5} = 8.91$, $P = 0.03$). During the first period of culling, FPGs stayed constant while pellet numbers declined, however in the following period of no shooting both FPGs and pellets increased. In the second period of culling, FPGs again became relatively constant while the number of pellets declined (Figure 4.12). The magnitude of density change, as measured by FPGs, was generally smaller in comparison to the magnitude of change observed by the number of pellets (Figure 4.12).

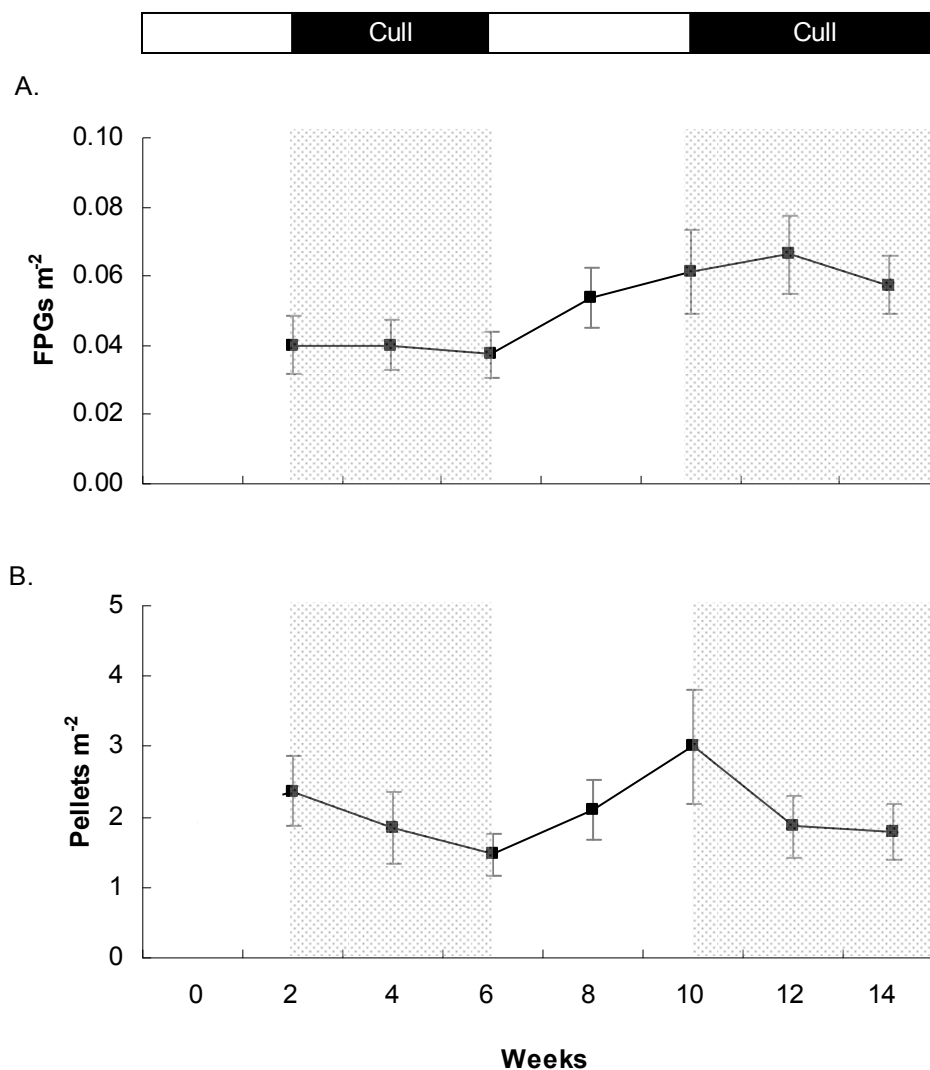


Figure 4.12. The mean number of **A.** Faecal pellet groups (FPGs) and **B.** Pellets (\pm standard error) observed in faecal accumulation plots on The Flats, Yarra Ranges National Park, April – August 2008. Initial plot clearance occurred at week 0 on 28 April 2008 followed by plot surveys at 14 day intervals 12 May – 4 August 2008. Grey shading indicates periods of culling.

Discussion

Following plot modifications, the exclusion plot design successfully differentiated the quantity of biomass offtake by sambar from the suite of herbivores at The Flats. It was unexpected that a deer measuring 120 cm at the shoulder could crawl under the 500 mm gap at the base of the partial plots. However the amount of effort required to gain access to the plots perhaps demonstrates that forage on The Flats is an important food source for the population of sambar at this site. While the yearlings are almost as tall as a mature sambar, they are smaller-bodied, likely making it easier for them to crawl under fences with a 500-mm gap. Following the modification of the total and partial plots, targeted herbivores were effectively excluded: sambar were excluded from the total and partial plots while common wombats, swamp wallabies, rabbits and wood ducks were excluded from the total plots. The only herbivore that could not be excluded from the total plots with this design was swamp rats, which could burrow under the mesh. The presence of the swamp rats in exclusion plots located in the Rush-sedge Zone may have decreased the maximum potential of biomass growth. The comparatively heavy use of Unit 4 total plot by swamp rats may explain the overall lower biomass yield compared with Unit 4 partial treatment, although plant species variation between sub-plots and plots may also have contributed to this result.

Mean daily maximum temperature was generally higher and most closely correlated with biomass weight, while the mean daily minimum fluctuated around the long term average. The amount of rainfall experienced by the area during the study period was considerably below the long term average. Surprisingly, rainfall was not as closely correlated as temperature, but this result may have occurred because there was not sufficient rainfall to show a strong relationship. Several studies have shown that rainfall and biomass growth is positively correlated and rainfall is the driving factor in determining grass biomass production (Silvertown *et al.* 1994; du Plessis 2001; Kettlewell *et al.* 2006). Soil moisture, particularly during summer has also been shown to effect grass growth (Kettlewell *et al.* 2006). Although the effects of reduced rainfall on the growth of the specific herb species at The Flats was not investigated, the observed browning-off of plants in the Open Herb-rich Zone, may have been caused by a combination of low rainfall and subsequent reduced soil moisture on the topographic rises. The browning-off effect did not occur in the Grassy Rush Zone or Rush-sedge

Zone, perhaps because the presence of the rush and sedge tussocks reduced the hours of direct sunlight and wind exposure, thereby reducing the moisture loss of plants located in these zones. There was also considerable variation in productivity between the exclusion units (Units 1 – 5). The combination of these factors; variation in species representation, the associated species-specific growth rates and topographical location of plots on The Flats, regardless of treatment type, appears to have influenced biomass productivity. However the influence of these factors was overcome by utilising the mean biomass standing crop for each treatment type to represent biomass offtake over the whole of The Flats.

During the periods of culling, FPGs stayed relatively constant while pellet numbers declined, in comparison to the period of no shooting when both FPGs and pellets increased (Figure 4.12). The decrease of the number of pellets in FPGs during periods of culling suggests a behavioural change in the population of sambar at The Flats induced by shooting pressure. The magnitude of change as measured by FPGs throughout the cull period was much less than when measured by pellets. The number of pellets therefore appears to be a more sensitive measure of sambar density on The Flats. The number of sambar culled at The Flats totalled 21 individuals, which is likely to represent only a small proportion of the population at The Flats. The rapid increase to pre-cull levels of faecal matter after the period of no shooting at week 10, indicates the cull had not noticeably impacted on the sambar population density; rather the presence of the shooters had deterred the use and reduced the time spent on The Flats by sambar.

Herbivores other than sambar did not utilise the Open Herb-rich Zone, perhaps due to lack of cover from predators. While the Open Herb-rich Zone was dominated by different and less diverse species than the Grassy Rush Zone and Rush-sedge Zone, these herbivores are all generalists and could have utilised the plant species in the Open Herb-rich Zone as a food source. Wood ducks utilised areas of the Open Herb-rich Zone only in close proximity (> 30 m) to the reservoir or the Yarra River, where the water may have provided a refuge from ground predators. The predatory species sighted at The Flats include wild dog (*Canis familiaris*), fox (*Vulpes vulpes*) and wedge-tailed eagle (*Aquila audax*), all of which pose a minor threat to sambar (Bentley 1998). The physical

presence of the large-bodied sambar at high density in the Open Herb-rich Zone may have also deterred the use of this area by other smaller herbivore species.

The Open Herb-rich Zone encompassed the greatest proportion (86%) of available forage area at The Flats and was utilised almost exclusively by sambar, while other herbivores only utilised the Grassy Rush Zone and Rush-sedge Zone, which combined, encompassed a minor proportion (14%) of available forage area. It may be argued that the partial plots in the Grassy Rush Zone and Rush-sedge Zone, where units 3 – 5 were situated, existed as ‘islands’ of habitat, that were probably utilised by other herbivores to a greater extent than the open plots, and elsewhere on The Flats outside the plots, because there was such an abundance of forage available due to the exclusion of sambar. Therefore offtake attributed to herbivores other than sambar when extrapolated across The Flats, could have been overestimated.

This study has shown sambar consume the majority of forage at The Flats, and the population of sambar daily consumed between 193 kg in June 2007 and 999 kg in November 2006. Given that sambar approximately consume 3 – 4 kg forage dry weight day⁻¹ equates to a seasonally variable carrying capacity at The Flats of 55 - 285 sambar. The largest number of sambar observed at the site at the same time was 70 individuals in January 2007 (Chapter 2), which indicates that sambar are able to obtain a significant proportion of their daily food requirements from The Flats. The reduced use of The Flats by sambar during the cull in 2008, significantly reduced the offtake by sambar in July 2008 when shooting was being conducted. The quantity of biomass offtake in the partial plots in June and July 2008 did not vary, indicating the other herbivores at the site were minimally or unaffected by shooting at The Flats. Further data collection on the effects of the cull on density and biomass offtake by sambar was not possible due to submersion of The Flats in August 2008. However these results indicate that the culling program reduced the offtake and time spent on The Flats by sambar, mostly through the deterrent effects of shooting.

CHAPTER 5

The impacts of sambar on forest understoreys



*Forest understorey adjacent to The Flats, Upper Yarra catchment,
Yarra Ranges National Park, October 2007*

CHAPTER 5

The impacts of sambar on forest understoreys

Introduction

High deer densities can impact on ecosystems through a range of mechanisms. For example selective browsing can decrease plant biodiversity (Webster *et al.* 2005; Holmes *et al.* 2008) and seedling recruitment (Husheer *et al.* 2006; Stroh *et al.* 2008), trampling by deer can increase seedling mortality (Tsujino and Yumoto 2004), while physical effects of browsing and trampling can cause structural changes and a loss of habitat for other fauna species (Flowerdew and Ellwood 2001; Allombert *et al.* 2005; Gill and Fuller 2007). Thrashing and rubbing damage may reduce the growth of plants and in some instances result in death due to ring-barking (Welch *et al.* 1988; Motta and Nola 1996). Extensive and prolonged deer browsing has resulted in suppression of forest regeneration and changes in species composition through removal of tree seedlings in the understorey (Allen and Allan 1997; Husheer *et al.* 2006).

Selective browsing by deer causes an increase in abundance of fast-growing and less palatable species, at the expense of highly selected species (Cooke and Farrell 2001; Kirby 2001; Morecroft *et al.* 2001; McGraw and Furedi 2005; Barret and Stiling 2006), and overall seedling density may decline (Opperman and Merenlender 2000; Husheer and Robertson 2005). Other species have shown a decrease in reproduction due to browsing of inflorescences (Cooke and Farrell 2001), and a decrease in growth rates (Opperman and Merenlender 2000; Vila *et al.* 2003). Browsing may induce physiological and phenological responses by plants, such as increases of leaf size (Focardi and Tinelli 2005), number of inflorescence produced (Paige 1999) and plant defences. These may include an increase of structural deterrents such as spines and prickles (Takada *et al.* 2001; Kato *et al.* 2008) or chemical defences, such as an increase of the concentration of tannins (Barroso *et al.* 2003).

The impacts of browsing herbivores are commonly determined through the use of exclusion plots (Lenzi-Grillini *et al.* 1996; Nomiya *et al.* 2002; Tsujino and Yumoto 2004; Webster *et al.* 2005; Stroh *et al.* 2008). However in many ecosystems, it is difficult to differentiate browsing impacts from other non-target species. Selective exclosures have

been shown to effectively overcome this by utilising the variation in body size between the species. The effects of a suite of herbivores on plant species community composition was demonstrated in Australia by Allcock and Hik (2004) for sheep (*Ovis aries*), eastern grey kangaroos (*Macropus giganteus*) and rabbits (*Oryctolagus cuniculus*). Similar studies have been conducted internationally by Bowers (1993), USA, investigating the effects of white-tailed deer (*Odocoileus virginianus*), woodchucks (*Marmota monax*), rabbits (*Sylvilagus floridanus*) and a number of rodent species, and by Olofsson *et al.* (1994) in Scandinavia, investigating the effects of reindeer (*Rangifer tarandus*), lemmings (*Lemmus lemmus*) and voles (*Clethrionomys rufocanus*).

Through the use of selective exclosures, this study aimed to investigate the browsing impacts of sambar on forest understoreys in the Upper Yarra catchment, Yarra Ranges National Park. The frequency and magnitude of browsing with exclosure treatment was investigated, in addition to the frequency and magnitude of browsing with flora species and the height at which browsing occurred. The extent of browsing with sambar density was also examined.

Methods

The study site

The Yarra Ranges National Park (YRNP) is located north east of Melbourne, and is largely comprised (84%) of protected water catchments that are closed to the public. The YRNP contains three catchments: Maroondah, O'Shannassy and Upper Yarra. The majority of this study was conducted in the Upper Yarra catchment of 33 670 ha and to a lesser extent in the O'Shannassy catchment of 11 900 ha. This study was conducted in four forest types that occur throughout the park and were selected to investigate the impacts of sambar on forest understoreys because they are located adjacent to The Flats, where there is a high sambar density (Chapter 2). The Flats is a large (approximately 50 ha), open, ephemeral, grass and forb-rich area located adjacent to the Upper Yarra reservoir and forms an important food resource to the sambar population (Chapter 4).

Native vegetation

In Victoria, native vegetation is classified into Ecological Vegetation Classes (EVCs). These are categorisations of floristic communities based on species composition, proportional coverage of plant life forms and a range of other inferred environmental attributes such as annual rainfall, aspect and soil type (Department of Sustainability and Environment 2008). YRNP is represented by 14 EVCs, with this study conducted in four of these: Shrubby Foothill Forest, Damp Forest, Wet Forest and Riparian Forest. All EVCs in which this study was conducted have a Bioregional Conservation Status rating of Least Concern (Department of Sustainability and Environment 2008). The plant species present in exclusion plots located in the four study EVCs, were surveyed April – August 2006, and are listed in Table 5.1.

Table 5.1. Flora species observed in exclusion plots located in the four Ecological Vegetation Classes in which this study is conducted, Yarra Ranges National Park, 2006 – 2007. ● indicates the presence of a species.

Scientific Name	Common Name	Shrubby Foothill Forest	Damp Forest	Wet Forest	Riparian Forest
Shrubs					
<i>Bursaria spinosa</i>	Sweet bursaria	●			
<i>Cassinia aculeata</i>	Common cassinia			●	
<i>Coprosma quadrifida</i>	Prickly current bush	●	●	●	
<i>Correa lawrenciana</i>	Mountain correa			●	
<i>Daviesia ulicifolia</i>	Gorse bitter-pea	●			
<i>Dillwynia phyllicoides</i>	Parrot pea	●			
<i>Epacris impressa</i>	Common heath	●			
<i>Goodenia ovata</i>	Hop goodenia		●	●	
<i>Kunzea ericoides</i>	Burgan	●	●	●	●
<i>Leptospermum continentale</i>	Prickly tea-tree	●			
<i>Olearia lirata</i>	Snowy daisy-bush		●	●	
<i>Olearia phlogopappa</i>	Dusty daisy-bush		●	●	
<i>Pimelea axiflora</i>	Bootlace bush		●	●	
<i>Platylobium formosum</i>	Handsome flat-pea	●	●	●	
<i>Pultenaea juniperina</i>	Prickly bush-pea	●			
<i>Pultenaea muelleri</i>	Mueller's bush-pea	●			
<i>Pultenaea daphnoides</i>	Large-leaf bush-pea	●			
<i>Sambucus gaudichaudiana</i>	White elderberry				●
<i>Senecio linearifolius</i>	Fireweed groundsel				●
<i>Tasmannia lanceolata</i>	Mountain pepper		●	●	
Ferns					
<i>Blechnum cartilagineum</i>	Gristle fern				●
<i>Blechnum nudum</i>	Fishbone water fern		●	●	●
<i>Blechnum wattsii</i>	Hard water fern			●	●
<i>Culcita dubia</i>	False bracken		●	●	●
<i>Cyathea australis</i>	Rough tree-fern		●	●	●
<i>Dicksonia antarctica</i>	Smooth tree-fern		●	●	●
<i>Histiopteris incisa</i>	Bats wing fern			●	●
<i>Polystichum proliferum</i>	Mother shield fern		●	●	●
<i>Pteridium esculentum</i>	Common bracken	●	●	●	
Sedges, herbs and lianes					
<i>Billardiera longiflora</i>	Purple appleberry		●	●	
<i>Clematis aristata</i>	Mountain clematis		●	●	●
<i>Dianella tasmanica</i>	Tasman flax-lily		●	●	
<i>Gahnia</i> sp.		●			
<i>Geranium</i> sp.			●	●	●
<i>Gonocarpus humilis</i>	Shade raspwort		●	●	
<i>Lepidosperma elatus</i>			●		
<i>Stellaria flaccida</i>	Forest starwort		●	●	●
<i>Tetrarrhena juncea</i>	Forest wire-grass	●	●	●	●
<i>Tetratheca</i> sp.		●			
<i>Viola hederacea</i>	Ivy-leaf violet	●	●	●	●
Trees					
<i>Acacia dealbata</i>	Silver wattle		●	●	●
<i>Acacia melanoxylon</i>	Blackwood wattle		●	●	
<i>Acacia mucronata</i>	Narrow-leaf wattle	●	●		
<i>Banksia spinulosa</i>	Hairpin banksia	●			
<i>Bedfordia arborescens</i>	Blanket-leaf		●	●	
<i>Daviesia mimosoides</i> var. <i>laxiflora</i>	Mountain bitter-pea	●		●	
<i>Eucalyptus</i> spp.		●	●	●	●
<i>Exocarpos cupressiformis</i>	Cherry ballart	●			
<i>Hakea sericea</i>	Bushy needlewood	●			
<i>Hedycarya angustifolia</i>	Austral mulberry	●		●	
<i>Hovea rosamarinifolia</i>	Mountain beauty		●	●	
<i>Lomatia fraseri</i>	Tree lomatia		●	●	
<i>Notelea ligustrina</i>	Privet mock-olive		●	●	
<i>Olearia argophylla</i>	Musk daisy-bush		●	●	
<i>Polyscias sambucifolia</i>	Elderberry panax		●	●	
<i>Pomaderris aspera</i>	Hazel pomaderris		●	●	●
<i>Prostanthera lasianthos</i>	Victorian Christmas bush		●	●	
<i>Ziera arborescens</i>	Stinkwood		●	●	

Native fauna

The most common terrestrial, medium-sized herbivores at these sites are the common wombat (*Vombatus ursinus*) and swamp wallaby (*Wallabia bicolor*). Common wombats are predominantly grazers, consuming almost exclusively grasses (Rishworth *et al.* 1995; Evans *et al.* 2006), but also feed on sedges, matrushes and roots of shrubs and trees (McIlroy 1983). Common wombats weigh up to 35 kg, reaching 25 cm at the shoulder (Triggs 1988). Swamp wallabies are predominantly browsers, consuming a wide variety of shrubs (Hollis *et al.* 1986; Jarman and Phillips 1989), but also commonly feed on grasses, forbs and sedges (Osawa 1990). Given their food preferences, swamp wallabies are perhaps the most functionally similar herbivore present to that of sambar (Chapter 2). Swamp wallabies weigh up to 25 kg (Di Stefano *et al.* 2005) although more commonly weigh around 15 kg (Troy and Coulson 1993) and are up to 40 cm high at the back when crouched (pers. obs.).

While a number of arboreal herbivore species are present, excluding these species with a roof over forested exclosures was not possible, due to the presence of trees and the likely damage from falling branches and trees (Bennett and Coulson 2008) (Appendix 1). The mountain brushtail possum or bobuck (*Trichosurus cunninghamii*) is likely to be one of the most common arboreal species present in YRNP. This species not only utilises the forest canopy but also spends a large amount of time foraging on the ground (Martin *et al.* 2004), with the main food sources for this species are silver wattle (*Acacia dealbata*) and fungi (Seebeck *et al.* 1984; Martin *et al.* 2004). Although several tree-fern and understorey shrub species found in the YRNP were also found to be consumed in minor amounts by bobucks (Seebeck *et al.* 1984), bobuck browsing was considered unlikely to form a significant proportion of observed browsing in the exclusion plots.

Exclusion unit distribution

A total of 41 exclusion units (123 plots) were established between October and December 2005: 35 were located in the Upper Yarra catchment and six in the O'Shannassy catchment. The exclusion units were evenly distributed over the four main EVCs in close proximity to The Flats: Wet Forest, Damp Forest, Shrubby Foothill Forest and Riparian Forest (Figure 5.1). The six units located in the O'Shannassy catchment were established to ascertain if the impacts in the Upper Yarra were unique

to the region. These units were located in Wet Forest and Riparian Forest, two dominant forest types in this catchment (Figure 5.2). The specific location details of each unit are listed in Appendix 2. Another EVC, Heathy Dry Forest also found in proximity to The Flats was not sampled because it was represented by only a small area.

Exclusion units were located by generating random coordinates in Microsoft Excel®, stratified by EVC, distance to The Flats and elevation. These coordinates were entered into a Garmin eTrex Legend GPS unit and subsequently located on foot. There were five exclusion units constructed in each of the four forested EVCs within close proximity (< 1 km) to The Flats. These units were situated between 400 – 700 m elevation and were termed ‘high sambar density’, as they were located in the area that had previously been identified as a high use area for sambar (Chapter 2). To differentiate and compare the impacts of sambar with varying density, a further 15 exclusion units, termed ‘low sambar density’, were constructed > 5 km from The Flats, encompassing Wet Forest, Damp Forest and Shrubby Foothill Forest. Riparian Forest was not replicated because it was minimally represented in the catchment > 5 km from The Flats. The elevation of low sambar density exclusion units was < 700 m, replicating this element of the high sambar density exclusion units as sambar are thought to descend to lower elevations during winter (Downes 1983).

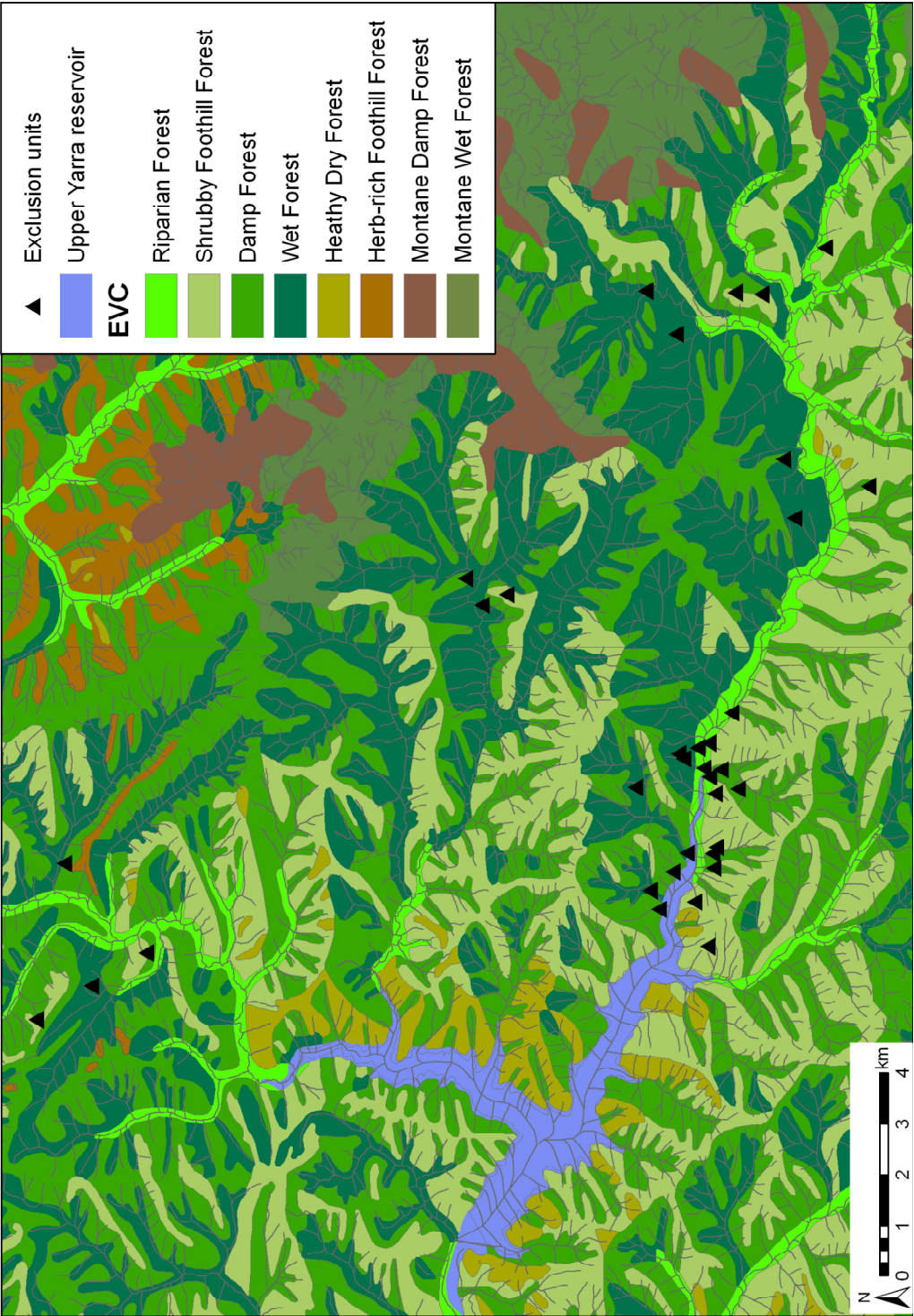


Figure 5.1. The distribution of exclusion units in the Upper Yarra catchment, Yarra Ranges National Park. Five exclusion units were located in each of the four major Ecological Vegetation Classes in close proximity to The Flats: Shrubby Foothill Forest, Damp Forest, Riparian Forest and Wet Forest, with a further five units replicated in each of three of these EVCs, Shrubby Foothill Forest, Damp Forest and Wet Forest at > 5 km from The Flats.



Figure 5.2. The distribution of exclusion units in the O'Shannassy catchment, Yarra Ranges National Park. Exclusion units were located in Wet Forest and Riparian Forest.

Exclusion unit design

Selective exclosures were designed for this study (Bennett and Coulson 2008) (Appendix 1). Exclusion plots (10 x 10 m) were arranged in units consisting of three plot treatments: total, partial and open (Figure 5.3).

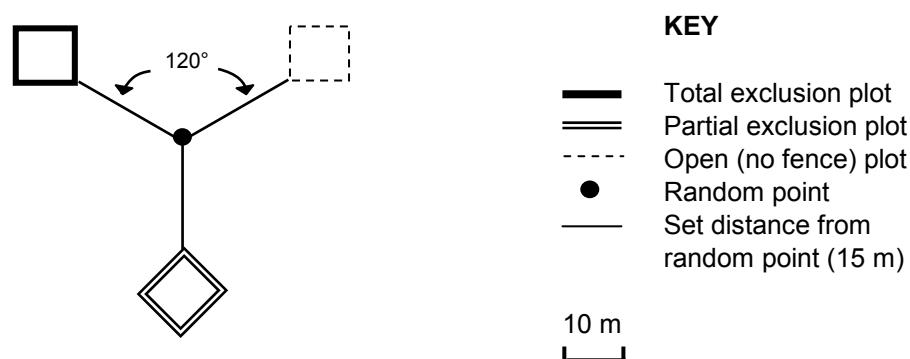


Figure 5.3. Exclusion unit spatial layout adapted from Bennett and Coulson, 2008, located in Yarra Ranges National Park. Exclusion units were constructed October – December 2005.

The total exclusion plot excluded all terrestrial, medium to large herbivores (Figure 5.4b). The partial exclusion plot excluded sambar but allowed access to native herbivores by a 300-mm gap at the base of the fence (Figure 5.4a). The open plot (no fence) allowed access to all species. Through a process of deduction, browsing by sambar could be ascertained and differentiated from that of native species by subtracting the offtake in partial plots from the open plots, while native herbivore browsing was determined by subtracting the offtake from the partial plots from the total plots.

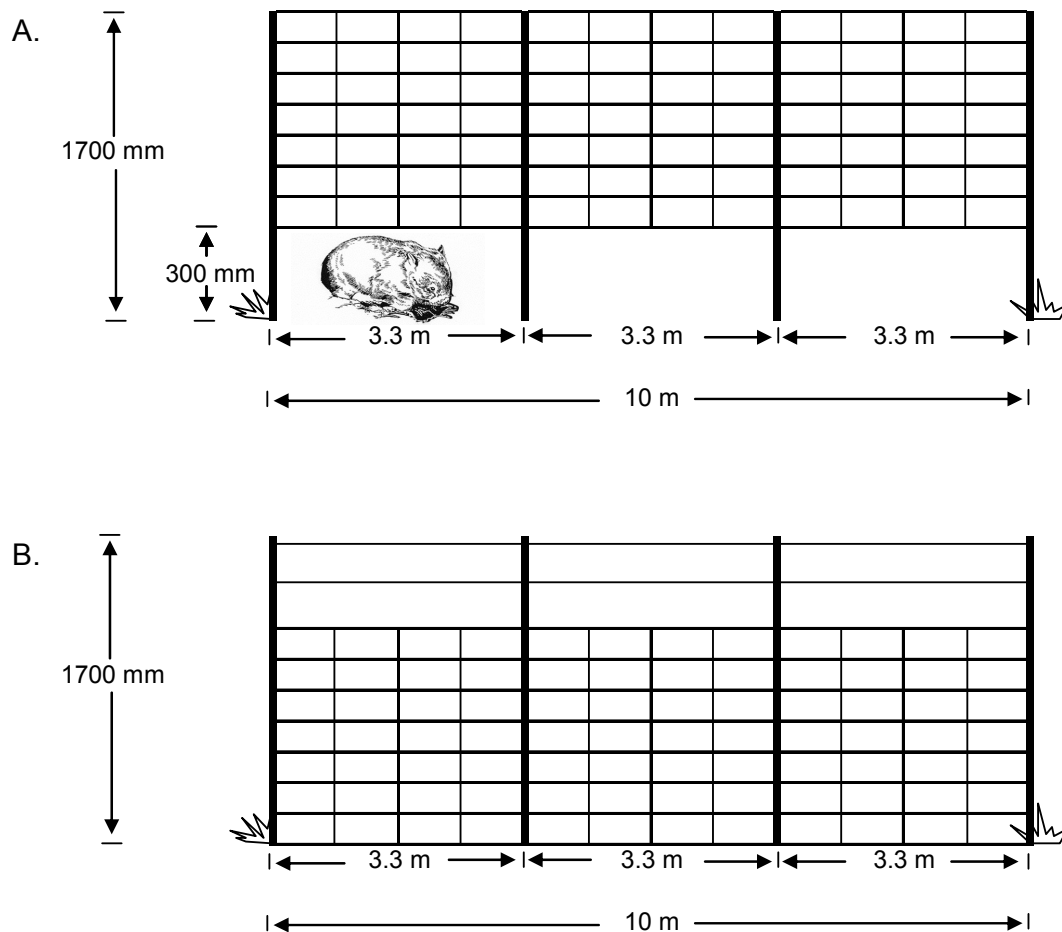


Figure 5.4. Schematic of exclusion plot design adapted from Bennett and Coulson, 2008, Yarra Ranges National Park. **A.** Partial exclusion plot is designed to exclude sambar but allow access to native species and **B.** Total exclusion plot is designed to exclude all medium to large terrestrial herbivores, including sambar, common wombats and swamp wallabies.

Faecal pellet group transect survey

To substantiate the allocation of exclusion units as being located in high and low sambar density areas, a faecal pellet group (FPG) survey was conducted along a triangular transect around each of the exclusion units (Figure 5.5). The total transect distance was 210 m. These surveys used the same circular plot size ($r = 2$ m) and transect distance interval between survey plots (10 m) that were used for the faecal pellet group surveys conducted on and in close proximity to open flats in 2005 (Chapter 2). The FPG transect survey at each unit was conducted at the time of the final plant survey, Winter 2007 between June and August 2007. In each plot the number of sambar FPGs and the number of pellets per FPG were recorded, in addition to the presence of common wombat and swamp wallaby scat.

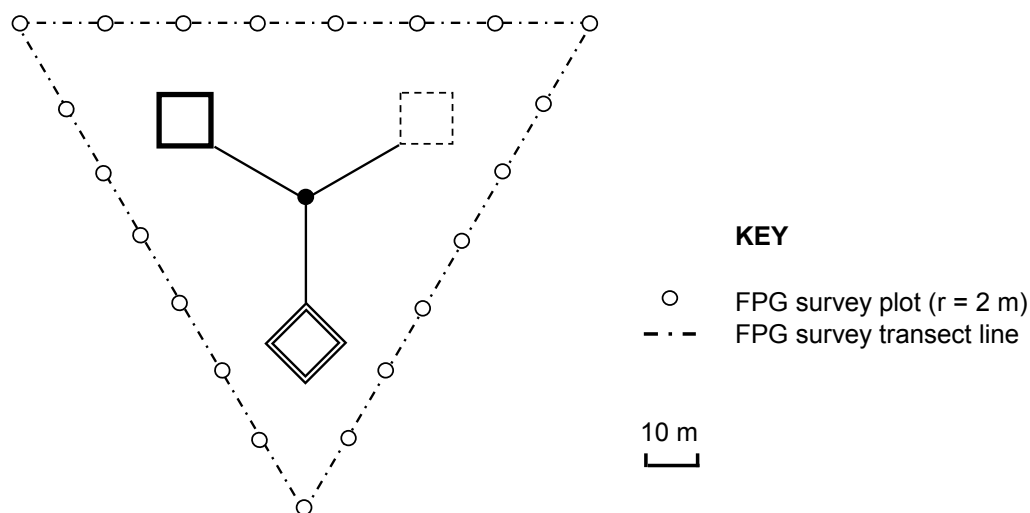


Figure 5.5. Spatial layout of a triangular faecal pellet group (FPG) transect survey around an exclusion unit (see Figure 5.3), conducted in Yarra Ranges National Park, June – August 2007. Survey plots were circular ($r = 2$ m) and had a 10 m interval between survey plots. FPG transect surveys were conducted at each exclusion unit during the final plant survey, Winter 2007.

Exclusion unit survey

The 41 exclusion units (123 plots) were surveyed on 3 successive occasions with an approximate 6 month interval: May – August (autumn – winter) 2006, December – February (summer) 2006-2007 and June – August (winter) 2007. These surveys will be referred to as Winter 2006, Summer 2007 and Winter 2007, respectively.

The gap at the base of the partial plots was initially 500 mm, but was reduced to 300 mm following evidence of yearling sambar entering the partial plots on The Flats (Chapter 4). While there was little evidence of sambar entering partial plots located in the forest during the Summer 2007 survey, all plots were modified following this survey to a 300-mm gap as shown to be effective for partial plots located on The Flats (Chapter 4) (Bennett and Coulson 2008).

The presence of faecal pellets of sambar, common wombat and swamp wallaby was noted if observed inside any of the treatment plots or in the vicinity of exclusion units. During the first survey, Winter 2006, a maximum of 20 understorey plants were selected in each plot if available and marked at the base with tie wire and a numbered aluminium tag. These understorey plants encompassed a variety of understorey shrubs, tree-ferns, ground ferns and on occasion juvenile trees. A maximum of 5 individuals for a single species within each plot were included in the survey. Species surveyed were replicated if available in all treatment plots within a given unit and between units. On average there were 15 plants surveyed per plot, for a total of 1912 plant individuals covering 31 plant species, with eight species replicated over 100 times.

For each tagged individual, the total height was measured with a 2-m ruler, together with signs of old and new browsing, rubbing and stem breakage, which were all noted as presence or absence. Old browse was classified by the observation of a browsed stem anywhere on the plant that had longer, new growth occurring around or immediately adjacent to the truncated stem (Figure 5.6a). New browse often showed a variation in colour, such as pale stem or green colour underneath the bark, which did not occur with old browse, and was classed as a browsed stem where the truncated stem was located on the outermost margin of the plant (Figure 5.6a).

On each tagged plant individual, 1 – 3 branches were selected and marked with tie wire and a coloured bead that corresponded to a height range (Figure 5.6b). Unbrowsed branches were selected wherever possible, and only one branch was tagged within a particular height range for any individual plant. In total 3528 bead-marked branches were surveyed. Hazel pomaderris (*Pomaderris aspera*) was a species commonly present at the study site. As an understorey tree, the main foliage-bearing branches were usually several meters above the ground, however some hazel pomaderris individuals had

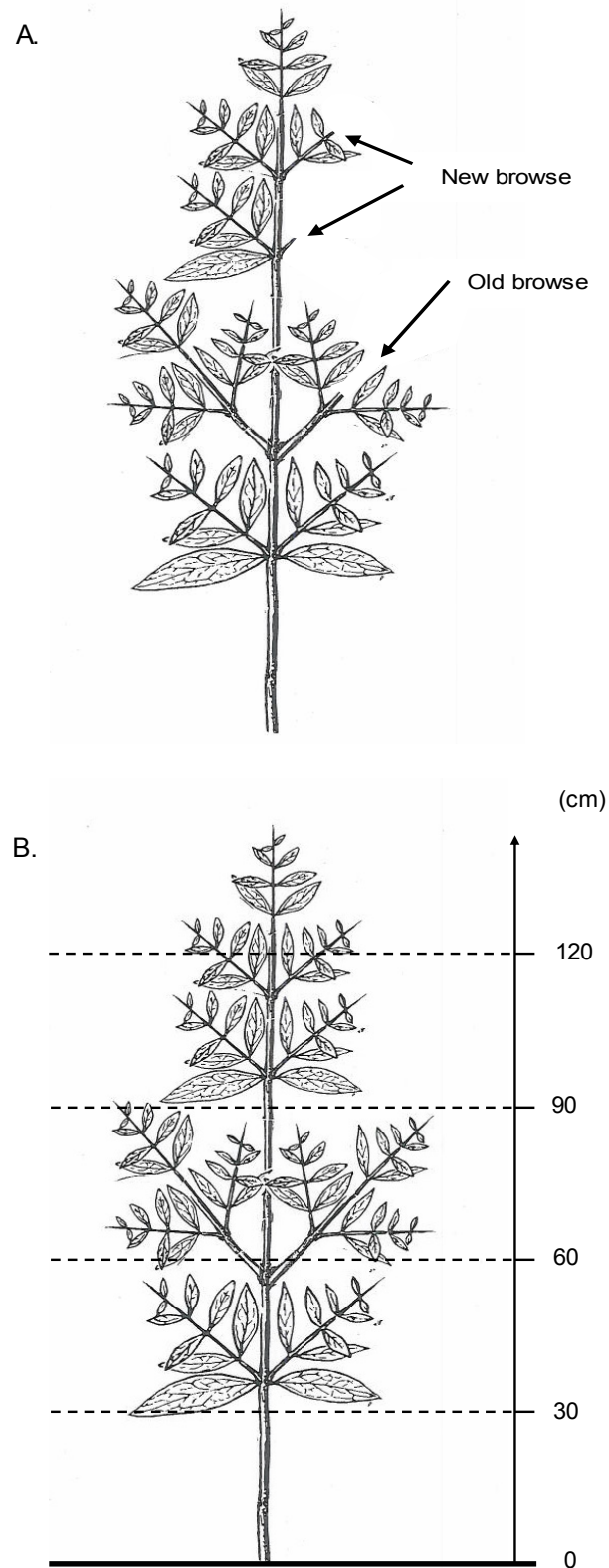


Figure 5.6. Schematic of an understory shrub showing **A.** 'Old browse' with longer, new growth occurring around or immediately adjacent to the truncated stem and 'new browse' a truncated stem on the outer-most margin of the plant, and **B.** 30 cm height range intervals. Up to 3 branches were selected on each individual plant and marked with a coloured bead that corresponded to a height range, Yarra Ranges National Park, 2006 – 2007.

epicormic shoots located on the lower trunk. Where available, for this tree species only, these shoots were also included in the survey. For each of the marked branches the stem diameter was measured, using digital callipers, from as close as possible to the trunk or main stem from which the tagged branch diverged. The size of the branch was measured with a ruler, taking a length, width and height measurement of each branch, which were then converted into a volume. This volume measurement provides a surrogate for true biomass. Plants were grouped into either ferns or shrubs and analysed separately, as the correlation between true biomass and both volume and stem diameter, was expected to vary between plants with different morphological characteristics.

To verify this surrogate measure of biomass, a number of plant branches were surveyed. These branches were unbrowsed and located outside exclusion units, encompassing a variety of species that were commonly surveyed in exclusion plots. These branches were cut as close to the main stem as possible, placed in a paper bag, oven dried for 3 days at 60°C, then weighed using an electronic balance.

In the two subsequent surveys the previously tagged plants and marked branches were re-surveyed to assess browsing within the exclusion units encompassing the three plot treatments. During the second survey (Summer 2007), the stem diameter of tagged branches was not measured, as it was deemed unlikely to differ from the previous survey given the short time lapse between surveys.

Results

Herbivore density

The mean number of sambar FPGs at exclusion units was normalised by a log transformation. Exclusion units were categorised with distance from The Flats and analysis of variance (ANOVA) showed that the number of FPGs was greatest in close proximity to The Flats, significantly decreased at units located 251 – 1000 m from The Flats and significantly decreased again with all categories over 1000 m ($F_{3,37} = 41.43$, $P < 0.001$). Exclusion units located in the O'Shannassy catchment showed similar results to the two categories over 251 m from The Flats (Figure 5.7). The number of pellets in each transect followed the same pattern ($F_{3,37} = 6.37$, $P < 0.001$) and decreased with distance from The Flats, with exclusion units in the O'Shannassy catchment similar to all distance categories over 250 m from The Flats in the Upper Yarra catchment.

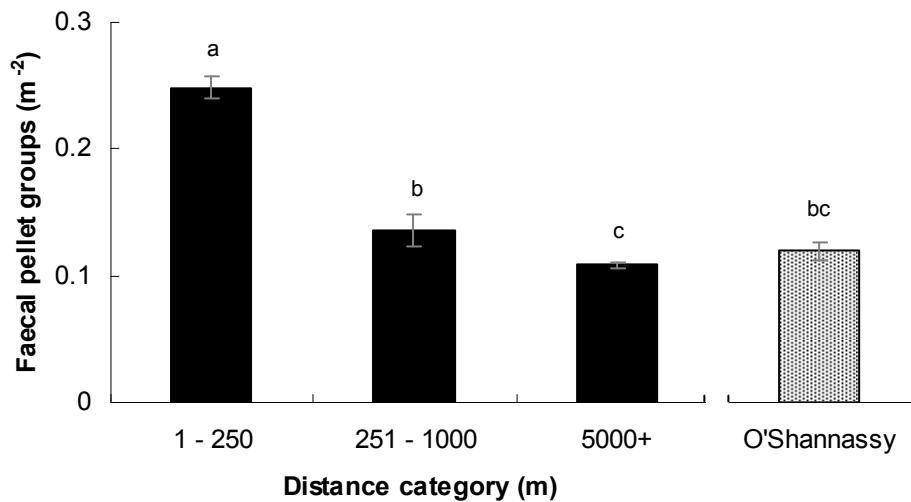


Figure 5.7. Mean number of sambar faecal pellet groups (FPGs) (\pm standard error) per transect at exclusion units categorised by distance from The Flats, Upper Yarra catchment and compared with exclusion units in the O'Shannassy catchment, Yarra Ranges National Park, 2007. Significant differences between distance categories, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a – c, where $a > b > c$.

Swamp wallabies and common wombats were present in all areas surveyed, but the density of swamp wallabies ($F_{3,37} = 1.88$, $P = 0.150$) and common wombats ($F_{3,37} = 1.74$, $P = 0.177$) was not influenced by proximity to The Flats (Figure 5.8).

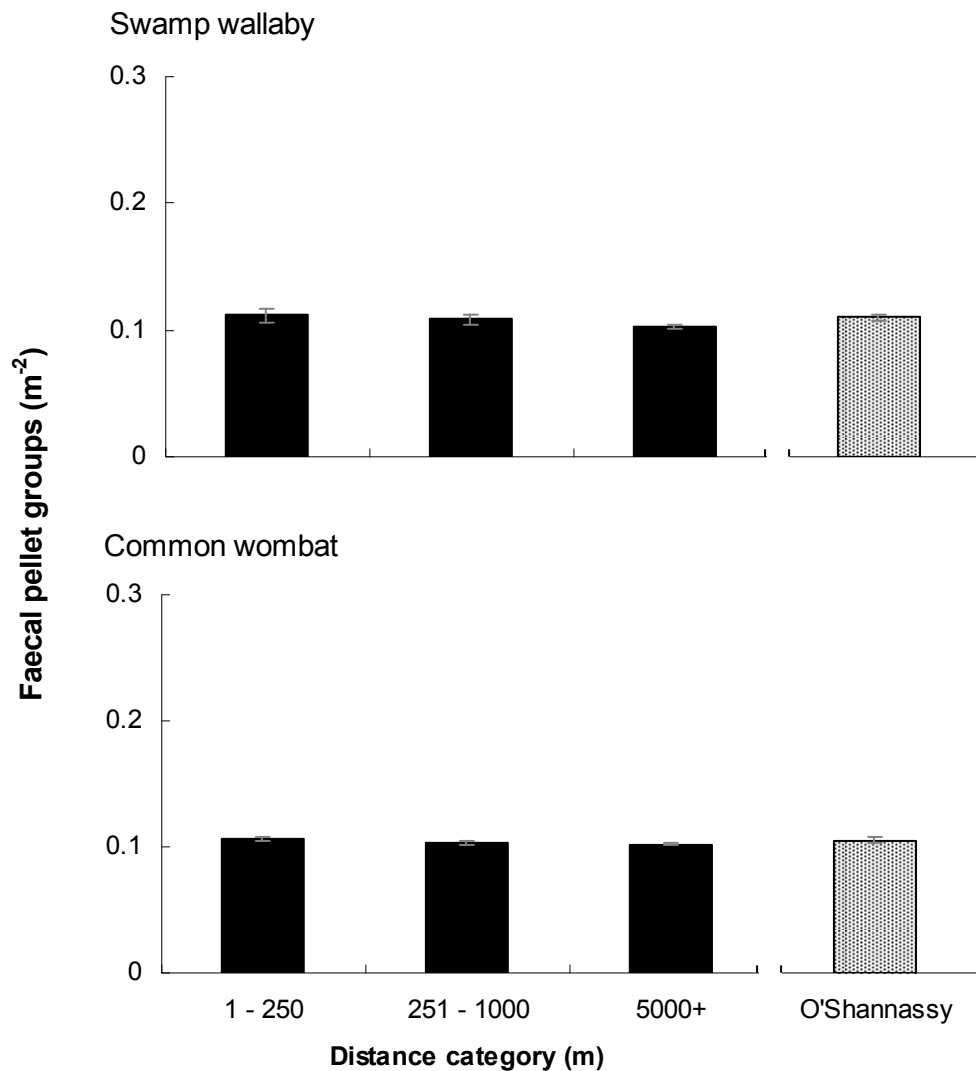


Figure 5.8. Mean number of swamp wallaby and common wombat faecal pellet groups (FPGs) (\pm standard error) per transect at exclusion units categorised by distance from The Flats, Upper Yarra catchment and compared with exclusion units in the O'Shannassy catchment, Yarra Ranges National Park, 2007.

Ecological Vegetation Class (EVC)

Ordination analysis was carried out utilising the program *Canoco* (canonical community ordination). This program relates species composition of plant communities to aspects of the environment, or as used here, to determine the level of relatedness based on species representation between plots. This information was then categorised into EVCs and sambar density. *Canoco* generates new variables based on the similarity of species in each plot, therefore the values on the axes are arbitrary (Quinn and Keough 2003) and are not shown. Visually, similarity of plots is determined by distance of one plot to another, i.e. the closer the plots, the more similar the species representation (Figure 5.9).

Exclusion plots located in Shrubby Foothill Forest contained the lowest level of similarity of species representation between plots. Shrubby Foothill Forest and Riparian Forest were the most dissimilar EVCs, while there was partial overlap of species representation between Damp Forest and Wet Forest (Figure 5.9a). The location of exclusion plots, despite some overlap, also showed distinct groupings between high and low sambar density areas within the Upper Yarra catchment and with the O'Shannassy catchment (Figure 5.9b). Therefore when both factors are combined (Figure 5.9c), the greatest similarity of species representation occurred between exclusion plots that were located in an area of the same sambar density and EVC.

ANOVA showed the amount of new browse (browse that had occurred after plot construction) was not consistent with EVC in any survey. Restricted maximum likelihood (REML) analysis showed there was also no relationship in any survey between browsing when further divided into plot treatment types with EVC (Table 5.2).

Table 5.2. Analysis of variance between new browse and Ecological Vegetation Class (EVC) and restricted maximum likelihood (REML) analysis between new browse, EVC and exclusion plot treatment, Yarra Ranges National Park, 2006 – 2007.

	Survey	Statistic	d.f.	P value
EVC	Winter 2006	$F = 2.24$	3,37	0.100
	Summer 2007	$F = 0.75$	3,37	0.530
	Winter 2007	$F = 0.37$	3,37	0.774
EVC & plot treatment	Winter 2006	Wald = 4.30	3	0.231
	Summer 2007	Wald = 0.34	3	0.952
	Winter 2007	Wald = 0.32	3	0.956

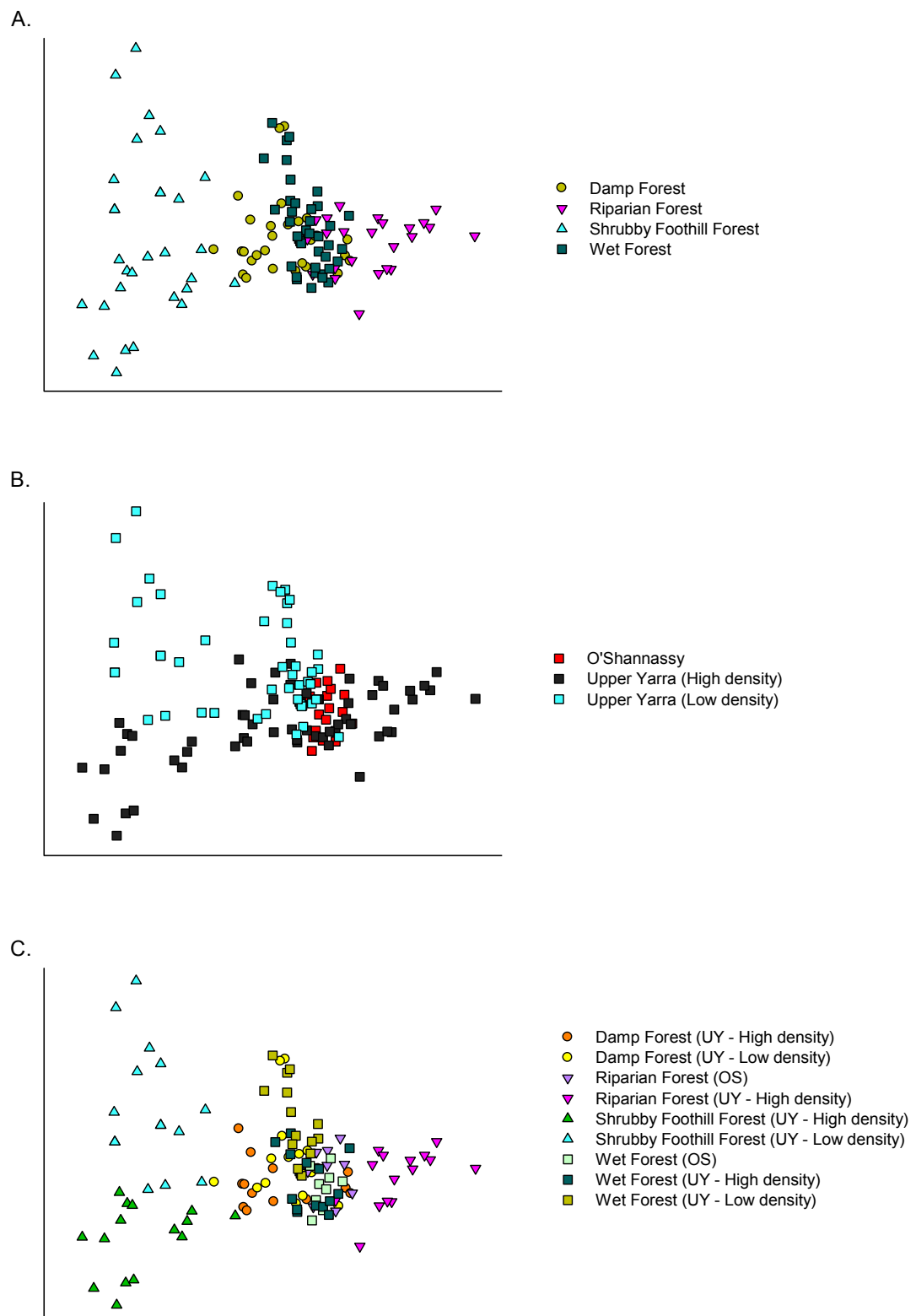


Figure 5.9. Non-metric representation of exclusion plots based on species composition in Yarra Ranges National Park, 2006 – 2007 categorised by **A.** Ecological Vegetation Class **B.** Catchment/sambar density and **C.** Both Ecological Vegetation Class and catchment/sambar density, where distance of one plot to another indicates the level of similarity.

Plants browsed

ANOVA showed that the proportion of plants that exhibited ‘old browse’ (occurring prior to plot construction) was not significantly different between treatments ($F_{2,80} = 1.86$, $P = 0.163$) in Winter 2006. In comparison, plant ‘new browse’ (occurring after plot construction) was significantly more frequent in the open plots than the partial plots, and more frequent in the partial plots than in the total treatment plots ($F_{2,80} = 36.33$, $P < 0.001$) (Figure 5.10). This pattern was repeated for new browse in Summer 2007 ($F_{2,80} = 146.15$, $P < 0.001$) and Winter 2007 ($F_{2,80} = 120.10$, $P < 0.001$) (Figure 5.11).

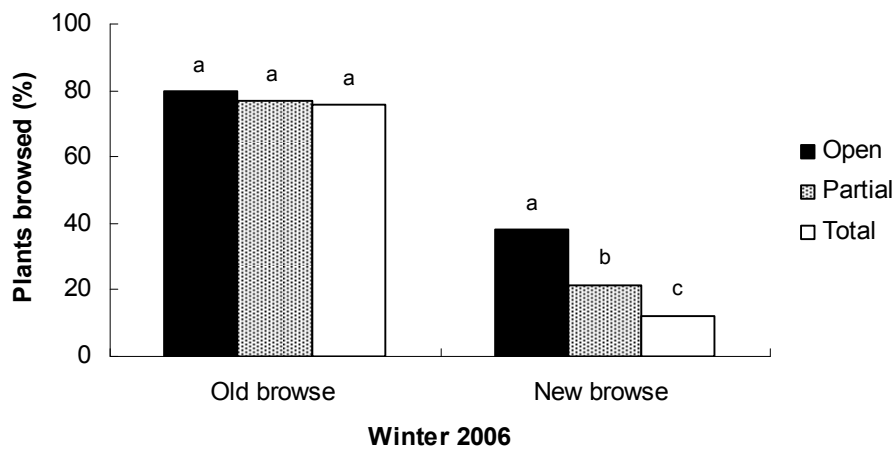


Figure 5.10. Percentage of plants in each treatment that were browsed, in Yarra Ranges National Park, 2006 – 2007. ‘Old browse’ had occurred before plot construction, while ‘New browse’ occurred after plot construction. Significant differences between plot treatments, calculated by Fisher’s least significant difference post hoc test, are indicated by the letters a – c, where $a > b > c$.

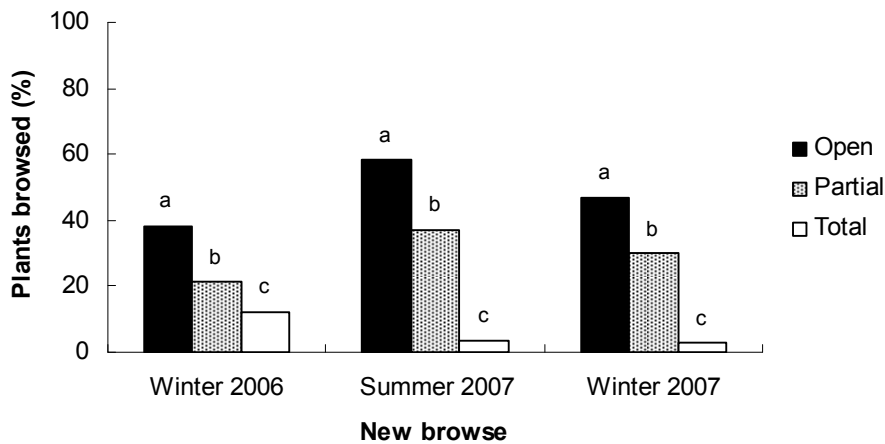


Figure 5.11. Percentage of plants in each treatment that were browsed, Yarra Ranges National Park, 2006 – 2007. Significant differences between plot treatments, calculated by Fisher’s least significant difference post hoc test, are indicated by the letters a – c, where $a > b > c$.

The frequency of antler rubbing was not common in any survey and, as determined by ANOVA, did not vary with plot treatment in Winter 2006 ($F_{2,80} = 2.96$, $P = 0.057$), although the trend was strong. During Summer 2007, seven of 1912 plants surveyed had experienced rubbing damage, all located in open plots ($F_{2,80} = 3.88$, $P = 0.025$), while no rubbing was recorded in Winter 2007. The frequency of broken main stems on plants was not influenced by plot treatment in Winter 2006 ($F_{2,80} = 1.87$, $P = 0.160$), Summer 2007 ($F_{2,80} = 0.13$, $P = 0.874$) or Winter 2007 ($F_{2,80} = 0.68$, $P = 0.512$).

REML analysis showed that overall, the mean height of plants varied significantly with plot treatment ($\text{Wald}_2 = 7.64$, $P = 0.022$), and between surveys ($\text{Wald}_2 = 40.77$, $P < 0.001$), with significant interaction between both plot treatment and survey ($\text{Wald}_4 = 16.72$, $P < 0.001$). Fisher's least significant difference post hoc test showed no statistical difference in the mean height of plants between treatment types in Winter 2006. However in Summer 2007 and Winter 2007, plants in the open and partial plots were significantly shorter than those in the total plots (Figure 5.12a). When the same data was considered in terms of treatment type, the height of plants located in open plots did not vary significantly between surveys. The height of plants in the partial plots however did vary, with plants significantly taller in Summer 2007 than Winter 2006, while Winter 2007 was not significantly different from either of these surveys. In the total plots, Summer 2007 and Winter 2007 were both significantly taller than Winter 2006 (Figure 5.12b). When plants were categorised by distance from The Flats, there was no significant difference in the height of plants with distance from The Flats ($\text{Wald}_3 = 3.46$, $P = 0.326$) or when further divided into plot treatment within each distance category ($\text{Wald}_6 = 4.32$, $P = 0.633$).

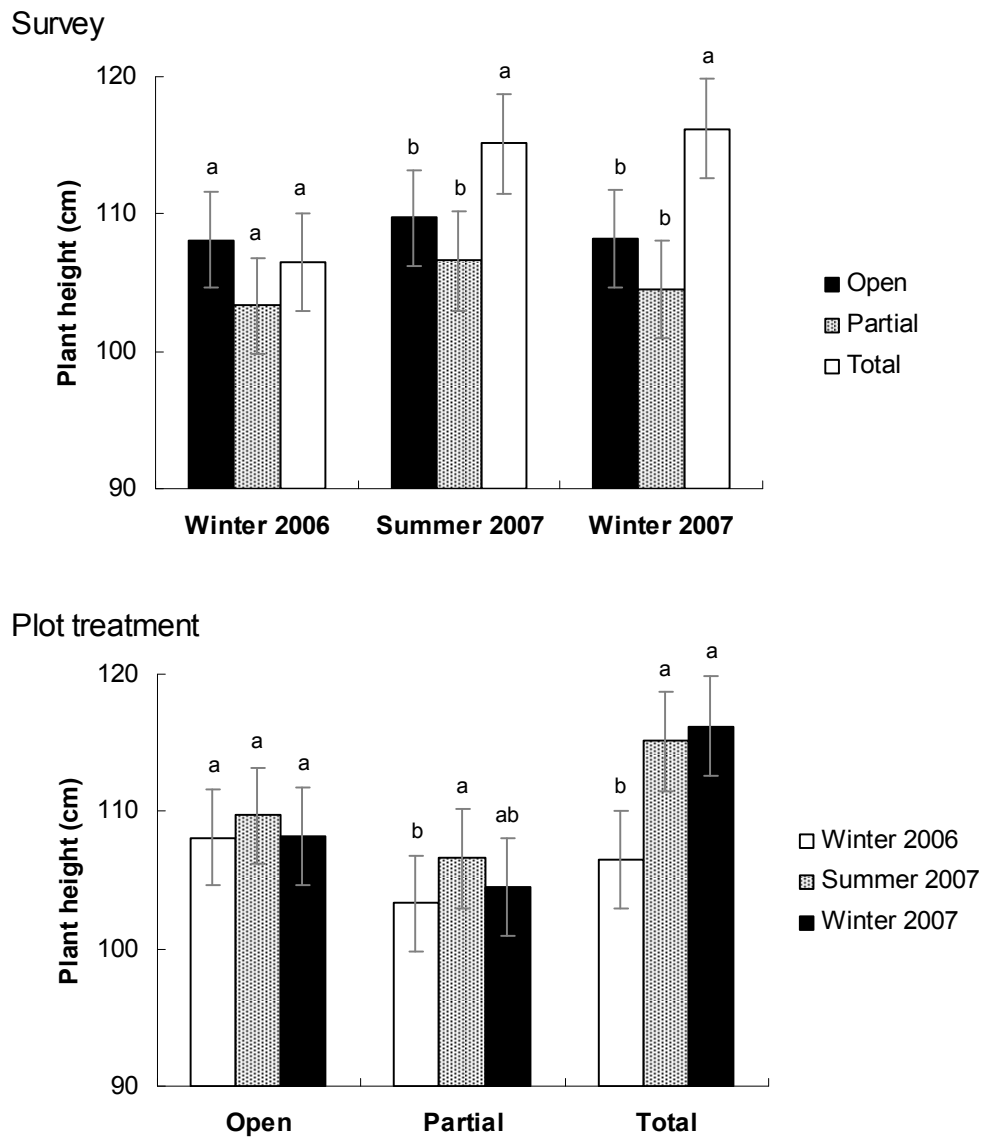


Figure 5.12. Mean height of plants (\pm standard error) in exclusion units, Yarra Ranges National Park, categorised by survey and plot treatment, 2006 – 2007. Note y-axis scale begins at 90 cm. Significant differences between surveys and plot treatment, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a and b, where $a > b$.

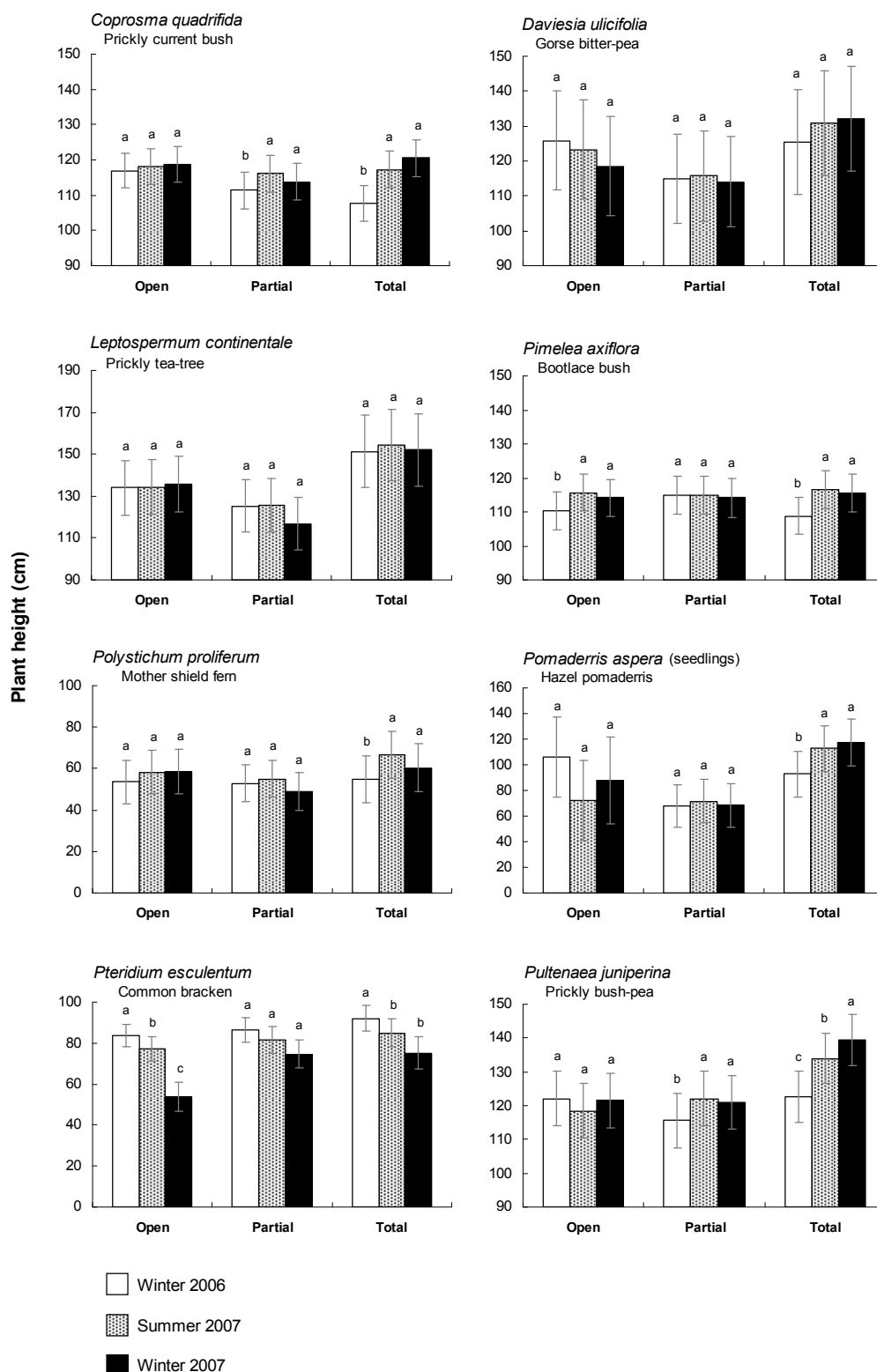


Figure 5.13. Mean height (\pm standard error) of main species surveyed categorised by plot treatment over time in Yarra Ranges National Park, 2006 – 2007. Note different y-axis scales between each species. Hazel pomaderris (*Pomaderris aspera*) includes seedlings only (trees omitted). Significant differences between surveys within each species-plot treatment, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a – c, where $a > b > c$.

Overall, the eight main species showed significant variation with plot treatment ($\text{Wald}_2 = 6.35, P < 0.042$), species ($\text{Wald}_7 = 23.22, P < 0.001$) and survey ($\text{Wald}_2 = 22.50, P < 0.001$) with significant interaction between all three fixed effects ($\text{Wald}_{28} = 54.01, P = 0.002$). However, Fisher's least significant difference post hoc test revealed that individual species showed some inconsistency in height change between surveys (Figure 5.13). No species showed a height change between surveys in the open plots except common bracken (*Pteridium esculentum*), which decreased significantly between each survey, and bootlace bush (*Pimelea axiflora*), which increased between Winter 2006 and Summer 2007. Most species that were located in the partial plots also showed no height change between any of the surveys, except prickly currant bush (*Coprosma quadrifida*) and prickly bush-pea (*Pultenaea juniperina*), which both significantly increased in Summer 2007 and then remained at a similar height in Winter 2007. However in the total plots, all species increased in height, except gorse bitter-pea (*Daviesia ulicifolia*) and prickly tea-tree (*Leptospermum continentale*), which showed no significant change between surveys, and common bracken, which decreased in height over time.

Branches browsed

The amount of browsing averaged across all marked branches categorised by treatment type, showed through REML analysis and Fisher's least significant difference post hoc test that the open plots had approximately 45% more browsing in Summer 2007 ($\text{Wald}_2 = 80.28, P < 0.001$) and 40% more browsing in Winter 2007 ($\text{Wald}_2 = 63.67, P < 0.001$) than the partial plots, while browsing in the total plots was negligible (Figure 5.14). The initial survey, Winter 2006, was not included in this analysis because it contained a large proportion of branches that had specifically been selected as not browsed.

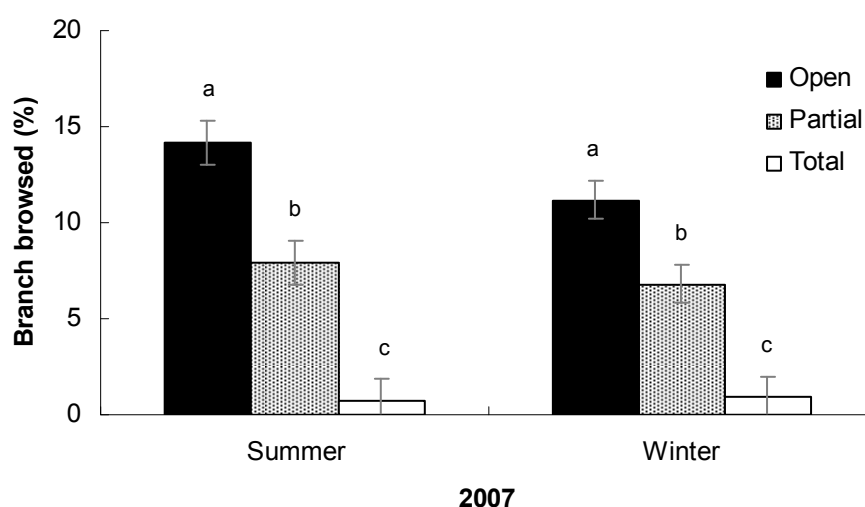


Figure 5.14. Mean percentage (\pm standard error) of marked branches browsed categorised by plot treatment, Yarra Ranges National Park in Summer 2007 and Winter 2007. Significant differences between plot treatments, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a – c, where $a > b > c$.

In Winter 2006, marked branches in the height categories between 0 and 120 cm showed no difference in browsing recorded as presence or absence between height ranges or between the partial and open treatments. However there was significantly less browsing in the 121+ cm category ($\text{Wald}_4 = 11.90$, $P = 0.018$), and Fisher's least significant difference post hoc test showed significantly less browsing in the partial plots than the open plots within this height category (Figure 5.15). Overall, there was no difference in the amount of browsing between height ranges in Summer 2007 ($\text{Wald}_4 = 3.28$, $P = 0.511$) or Winter 2007 ($\text{Wald}_4 = 6.44$, $P = 0.169$). Fisher's least significant difference post hoc test showed that there was also no difference in the amount of browsing between the partial and open plots up to 60 cm in height. However all height categories over 61 cm showed significantly greater browsing in the open plots than the partial plots (Figure 5.15).

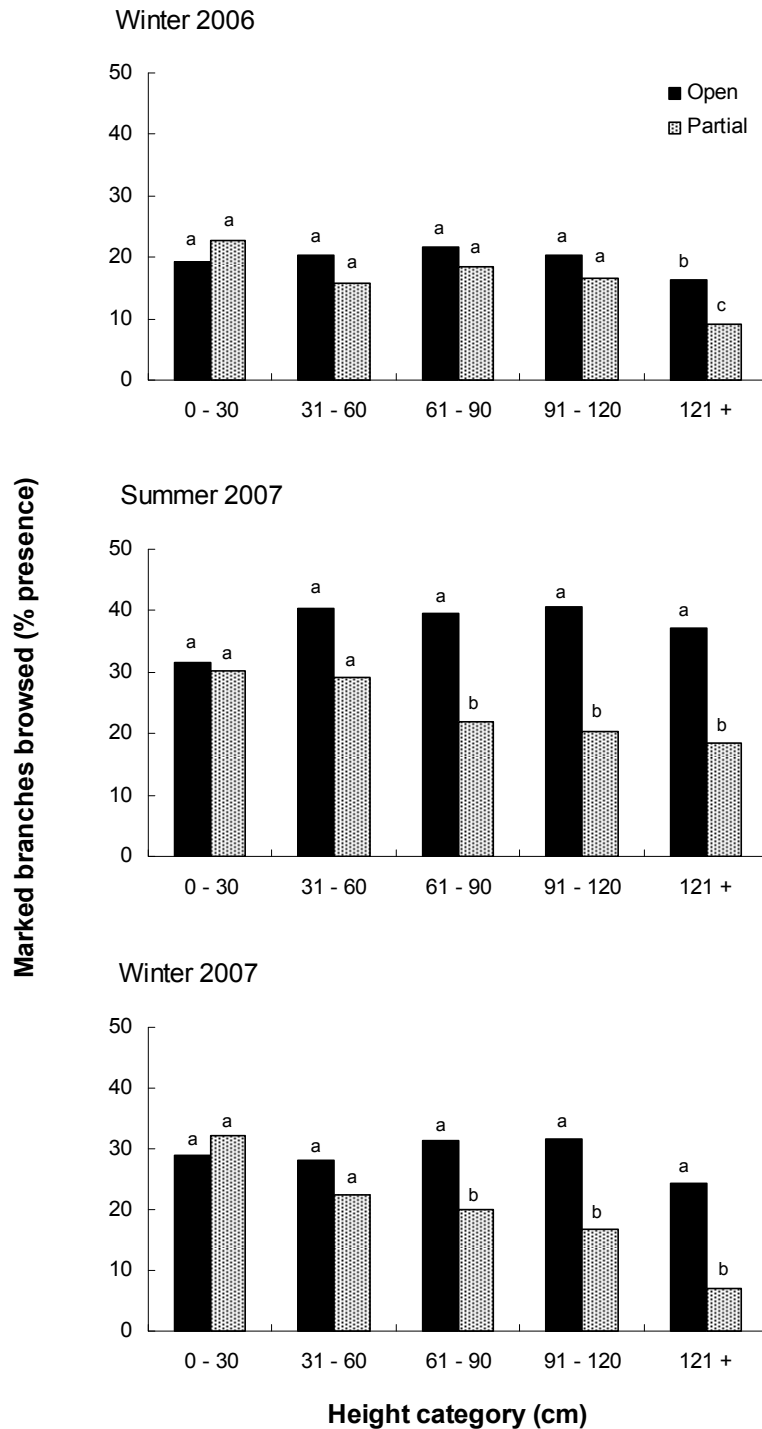


Figure 5.15. The percentage of marked branches exhibiting browsing in the partial and open treatment plots, Yarra Ranges National Park, 2006 – 2007. Significant differences between plot treatments, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a and b, where $a > b$.

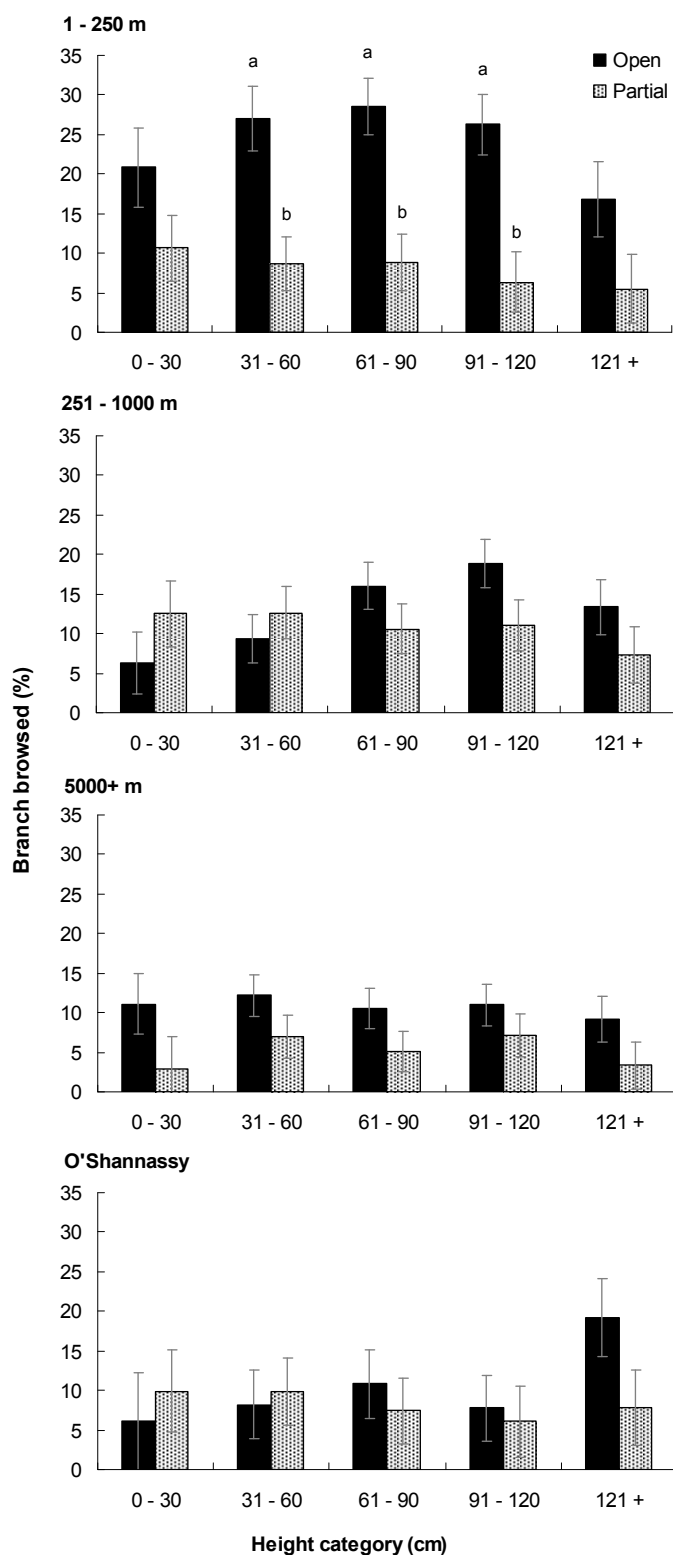


Figure 5.16. Mean percentage (\pm standard error) of marked branches browsed in open and partial plots, categorised by branch height and distance from The Flats in the Upper Yarra and compared with O'Shannassy catchment in Summer 2007. Significant differences between plot treatment pairs, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a and b, where $a > b$, otherwise there is no statistical difference between plot treatment pairs.

Mean percentage of marked branches browsed categorised by distance from The Flats showed that the greatest magnitude of browsing occurred in the high density area 1 – 250 m from The Flats, where browsing in the height categories 31 – 60, 61 – 90 and 91 – 120 cm were significantly more intensely browsed, regardless of species (Figure 5.16). The offtake by sambar categorised by density was therefore the greatest in the 1 – 250 m distance category (Figure 5.17), and approached twice the amount in the other distance categories and in the O’Shannassy catchment, which have a lower sambar density.

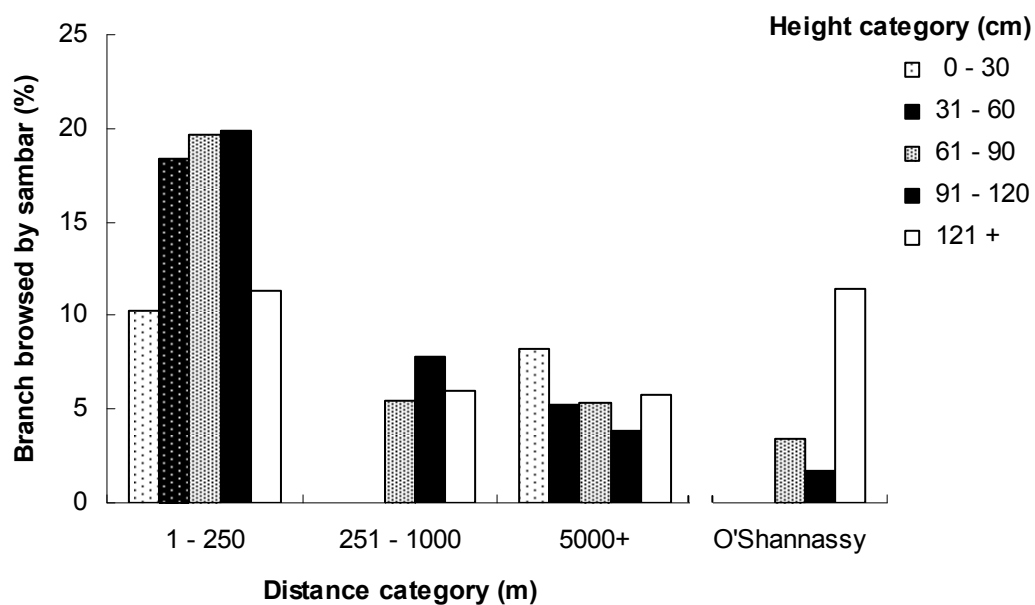


Figure 5.17. Mean percentage of marked branches browsed by sambar, categorised by height class and distance from The Flats in Upper Yarra catchment and compared with O’Shannassy catchment, Yarra Ranges National Park, Summer 2007.

REML analysis of all species in the partial and open plots showed that in Summer 2007, the magnitude of browsing varied significantly with species ($\text{Wald}_{28} = 151.50$, $P < 0.001$) and plot treatment ($\text{Wald}_1 = 13.62$, $P < 0.001$), with a significant interaction between the fixed effects ($\text{Wald}_{26} = 49.59$, $P = 0.002$). This was repeated in Winter 2007 for species ($\text{Wald}_{26} = 251.08$, $P < 0.001$) and plot treatment ($\text{Wald}_1 = 11.33$, $P < 0.001$), with a significant interaction between species and plot treatment ($\text{Wald}_{26} = 2.99$, $P < 0.001$). The heterogeneous distribution of plant species in treatment plots provided an uneven sample size of each species, so browsing preferences for individual plant species were likely to be biased given the small sample-size of some species. However when the presence of browsing on the marked branches was considered, some trends were apparent. These were classified as ‘frequently browsed’ $> 30\%$, ‘occasionally browsed’ $< 30 - > 15\%$ and ‘rarely browsed’ $< 15\%$ (Table 5.3). The plant species listed as frequently browsed were generally favoured in both open and partial plot treatments. Three species, hazel pomaderris, prickly tea-tree, and prickly bush-pea were browsed to a significantly greater extent in the open plots. While the sample sizes were small, parrot pea (*Dillwynia phyllicoides*) a small shrub in this study growing to a maximum of 40 cm, was highly browsed in both treatments. Privet mock-olive (*Notelea ligustrina*) and Victorian Christmas bush (*Prostanthera lasianthos*) were found only in exclusion units located in areas of low sambar density and were highly browsed. Six species listed in Table 5.3 were prickly, five of which were among the most frequently browsed species.

For each of the eight common species, 75 - 274 individuals were surveyed in the partial and open exclusion plots. REML analysis, using the estimated percentage of browsing on each marked branch of these eight species, showed there was significant variation in the magnitude of browsing between species ($\text{Wald}_7 = 13.04$, $P < 0.001$) and plot treatment ($\text{Wald}_1 = 15.82$, $P < 0.001$) in Summer 2007, with a significant interaction between the two fixed effects ($\text{Wald}_7 = 3.30$, $P = 0.002$). These findings were repeated in Winter 2007, with significant differences in the magnitude of browsing with species ($\text{Wald}_7 = 22.08$, $P < 0.001$) and plot treatment ($\text{Wald}_1 = 8.61$, $P < 0.003$), and a significant interaction between both species and plot treatment ($\text{Wald}_7 = 6.72$, $P < 0.001$) (Table 5.4).

Table 5.3. Browsing frequency of species comparing partial and open treatment plots and Summer 2007 and Winter 2007 surveys, Yarra Ranges National Park 2006 – 2007. Species indicated by P possess prickles, and species indicated by * were consistently more frequently browsed in open plots than partial plots. Species are categorised by mean % of marked branches showing browse in open plots: Frequently > 30%, Occasionally < 30 – > 15% and Rarely < 15%. Significant differences between plot treatments, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a and b, where $a > b$.

Species	Plot treatment	Summer		Winter	
		n	% browsed	n	% browsed
Frequently browsed					
^P <i>Bursaria spinosa</i>	Open	7	43	7	29
Sweet bursaria	Partial	8	50	8	25
^P <i>Coprosma quadrifida</i>	Open	295	58	278	46
Prickly current bush	Partial	274	49	260	43
^P <i>Daviesia ulicifolia</i>	Open	33	70	33	58
Gorse bitter-pea	Partial	38	63	38	42
<i>Dillwynia phyllicoides</i>	Open	10	60	10	50
Parrot pea	Partial	8	75	5	100
* ^P <i>Leptospermum continentale</i>	Open	32	69 ^a	28	54 ^a
Prickly tea-tree	Partial	41	12 ^b	40	18 ^b
<i>Notelea ligustrina</i>	Open	16	50	16	38
Privet mock-olive	Partial	19	37	19	11
* <i>Pomaderris aspera</i>	Open	56	57 ^a	48	60 ^a
Hazel pomaderris	Partial	51	39 ^b	49	35 ^b
<i>Prostanthera lasianthos</i>	Open	6	17	6	67 ^a
Victorian Christmas bush	Partial	3	0	3	0 ^b
* ^P <i>Pultenaea juniperina</i>	Open	95	60 ^a	89	48 ^a
Prickly bush-pea	Partial	101	17 ^b	93	10 ^b
Occasionally browsed					
<i>Acacia mucronata</i>	Open	6	0	7	29
Narrow-leaf wattle	Partial	10	0	10	0
<i>Culcita dubia</i>	Open	10	4	2	0
False bracken	Partial	14	43	2	0
<i>Pimelea axiflora</i>	Open	195	29	179	16
Bootlace bush	Partial	175	14	158	14
<i>Polystichum proliferum</i>	Open	28	29	19	16
Mother shield fern	Partial	38	18	29	10
<i>Ziera arborescens</i>	Open	6	0	6	33
Stinkwood	Partial	9	0	6	17
Rarely browsed					
<i>Blechnum nudum</i>	Open	8	25	2	0
Fishbone water fern	Partial	9	0	5	0
<i>Cyathea australis</i>	Open	25	8	20	5
Rough tree-fern	Partial	32	16	28	11
<i>Dicksonia antarctica</i>	Open	16	6	12	8
Smooth tree-fern	Partial	14	29	11	0
^P <i>Hakea sericea</i>	Open	7	0	5	0
Bushy needlewood	Partial	10	0	10	0
<i>Hovea rosmarinifolia</i>	Open	22	18	22	46
Mountain beauty	Partial	12	0	12	0
<i>Kunzea ericoides</i>	Open	12	0	12	0
Burgan	Partial	15	0	15	0
<i>Lomatia fraseri</i>	Open	13	15	13	0
Tree lomatia	Partial	9	0	9	0
<i>Olearia argophylla</i>	Open	7	29	6	0
Musk daisy-bush	Partial	6	17	6	0
<i>Polyscias sambucifolia</i>	Open	12	17	11	0
Elderberry panax	Partial	2	0	2	0
<i>Pultenaea muelleri</i>	Open	17	6	17	0
Mueller's bush-pea	Partial	22	6	22	0
<i>Pteridium esculentum</i>	Open	140	16 ^a	113	4
Common bracken	Partial	136	6 ^b	119	0
<i>Tasmannia lanceolata</i>	Open	12	0	12	0
Mountain pepper	Partial	5	0	5	0

Table 5.4. Species browsing preference based on the mean percentage of each marked branch browsed (\pm standard error) in open and partial plots in Summer 2007 and Winter 2007. Species are ranked from 1. most browsed to 8. least browsed. Significant differences within survey-plot treatments, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a – d, where $a > b > c > d$.

Summer 2007			
Open		Partial	
1. <i>Pomaderris aspera</i> Hazel pomaderris	29.4 \pm 3.4 ^a	1. <i>Pomaderris aspera</i> Hazel pomaderris	17.2 \pm 3.6 ^a
2. <i>Leptospermum continentale</i> Prickly tea-tree	26.0 \pm 4.9 ^a	2. <i>Daviesia ulicifolia</i> Gorse bitter-pea	15.3 \pm 4.4 ^a
3. <i>Daviesia ulicifolia</i> Gorse bitter-pea	25.3 \pm 5.0 ^a	3. <i>Coprosma quadrifida</i> Prickly current bush	14.9 \pm 1.9 ^a
4. <i>Pultenaea juniperina</i> Prickly bush-pea	23.8 \pm 3.0 ^{ab}	4. <i>Polystichum proliferum</i> Mother shield fern	7.6 \pm 3.8 ^b
5. <i>Coprosma quadrifida</i> Prickly current bush	17.5 \pm 1.8 ^{bc}	5. <i>Pultenaea juniperina</i> Prickly bush-pea	3.8 \pm 2.9 ^b
6. <i>Pteridium esculentum</i> Common bracken	12.8 \pm 2.3 ^c	6. <i>Pimelea axiflora</i> Bootlace bush	3.7 \pm 2.2 ^{bc}
7. <i>Polystichum proliferum</i> Mother shield fern	9.9 \pm 4.4 ^{cd}	7. <i>Pteridium esculentum</i> Common bracken	2.7 \pm 2.3 ^c
8. <i>Pimelea axiflora</i> Bootlace bush	6.6 \pm 2.1 ^d	8. <i>Leptospermum continentale</i> Prickly tea-tree	2.3 \pm 4.4 ^c
Winter 2007			
Open		Partial	
1. <i>Pomaderris aspera</i> Hazel pomaderris	34.1 \pm 3.1 ^a	1. <i>Pomaderris aspera</i> Hazel pomaderris	15.9 \pm 3.2 ^a
2. <i>Leptospermum continentale</i> Prickly tea-tree	26.6 \pm 4.4 ^a	2. <i>Coprosma quadrifida</i> Prickly current bush	14.9 \pm 1.6 ^a
3. <i>Pultenaea juniperina</i> Prickly bush-pea	22.4 \pm 2.6 ^a	3. <i>Daviesia ulicifolia</i> Gorse bitter-pea	7.6 \pm 3.8 ^b
4. <i>Coprosma quadrifida</i> Prickly current bush	13.1 \pm 1.5 ^b	4. <i>Leptospermum continentale</i> Prickly tea-tree	4.9 \pm 3.9 ^b
5. <i>Daviesia ulicifolia</i> Gorse bitter-pea	10.7 \pm 4.3 ^{bc}	5. <i>Pultenaea juniperina</i> Prickly bush-pea	4.4 \pm 2.6 ^b
6. <i>Polystichum proliferum</i> Mother shield fern	3.2 \pm 4.6 ^c	6. <i>Polystichum proliferum</i> Mother shield fern	3.3 \pm 3.7 ^b
7. <i>Pimelea axiflora</i> Bootlace bush	3.0 \pm 1.8 ^c	7. <i>Pimelea axiflora</i> Bootlace bush	2.9 \pm 1.9 ^b
8. <i>Pteridium esculentum</i> Common bracken	2.3 \pm 2.1 ^c	8. <i>Pteridium esculentum</i> Common bracken	0.1 \pm 2.1 ^b

Hazel pomaderris was one of the most preferred species and was browsed to the greatest extent in both partial and open treatments in Summer 2007 and Winter 2007. Gorse bitter-pea was highly browsed in both treatments during Summer 2007, but was less preferred in Winter 2007. Common bracken was browsed most in the open plots in Summer 2007, and mother shield fern (*Polystichum proliferum*) was browsed most in partial plots in Summer 2007, but otherwise both species were amongst the least preferred in both treatments. The three species browsed to the greatest extent in open plots were hazel pomaderris, prickly tea-tree and prickly bush-pea, followed by gorse bitter-pea and prickly currant bush. The two most favoured species in the partial plots were hazel pomaderris and prickly currant bush, and with exception of apparent seasonal selection of gorse bitter-pea, all other species were browsed significantly less. In general, the least preferred species were common bracken, mother shield fern and bootlace bush, in both open and partial plots (Table 5.4).

Biomass browsed

To determine the biomass in a given branch, plants were grouped according to morphological similarities into ferns and shrubs. A natural log transformation was applied to the measurements biomass weight, volume and stem diameter. A regression analysis showed a significant linear relationship for ferns between biomass and volume where $Fern\ biomass = 0.02volume^{0.78}$ (Figure 5.18a). A similar relationship was observed between fern biomass and stem diameter (adjusted $R^2 = 90.6\%$, $P < 0.001$), where $Fern\ biomass = 0.172stem\ diameter^{2.16}$ (Figure 5.18b). The relationship for shrubs was also significant, although with comparatively more variability than the relationships described for ferns. These relationships are described in the equations: $Shrub\ biomass = 0.02volume^{0.57}$, (adjusted $R^2 = 77.6\%$, $P < 0.001$) (Figure 5.18c) and $Shrub\ biomass = 0.25stem\ diameter^{2.27}$, (adjusted $R^2 = 76.4\%$, $P < 0.001$) (Figure 5.18d).

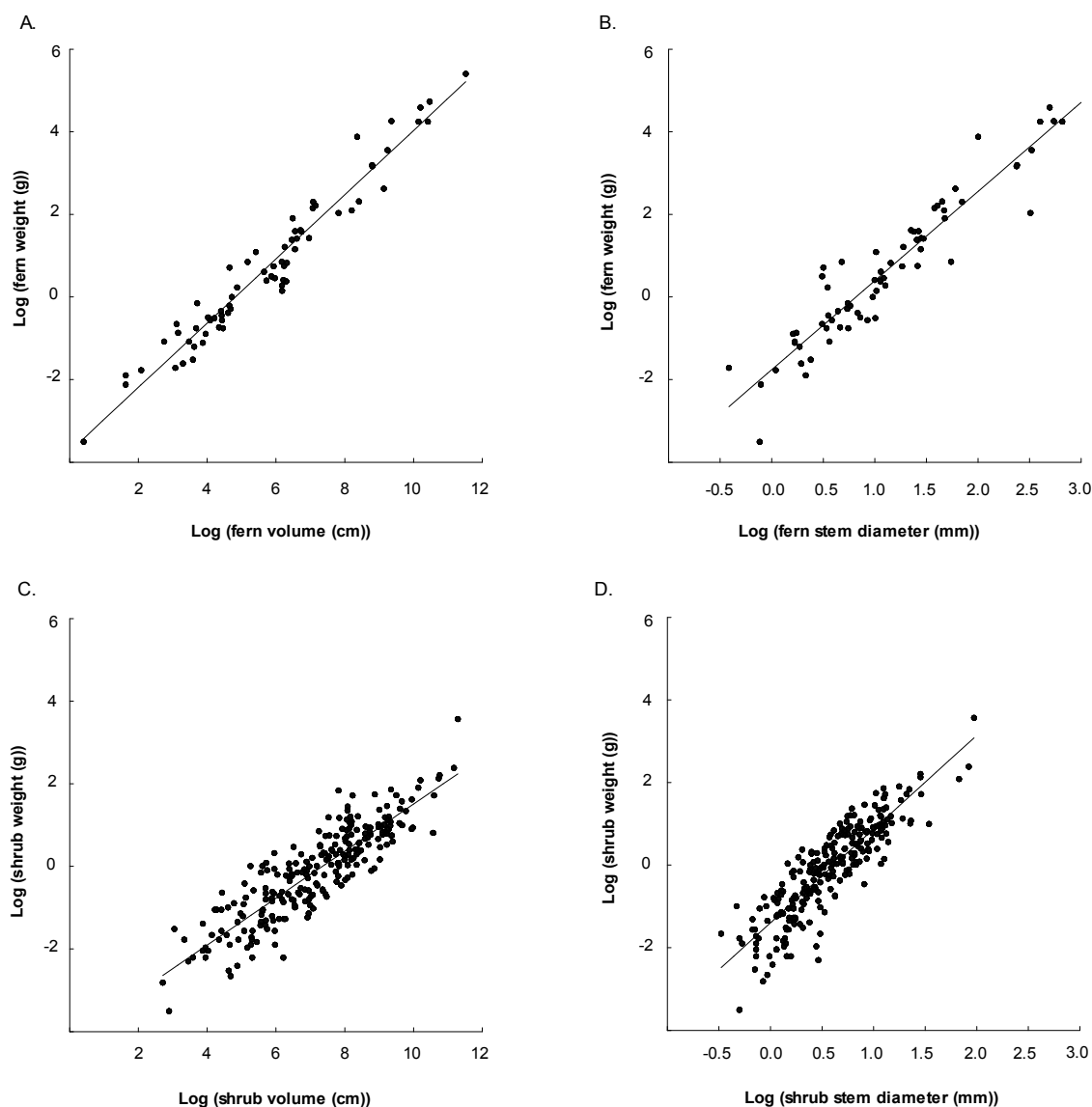


Figure 5.18. Linear regression of unbrowsed plant branches in Yarra Ranges National Park, 2007, where biomass is explained by **A.** Fern frond volume **B.** Fern frond stem diameter **C.** Shrub branch volume **D.** Shrub branch stem diameter. Note different x-axis scales between volume and stem diameter.

Four highly-browsed species of shrubs were also analysed separately (Table 5.5). Analysis of these species separately showed that the coefficient of determination (R^2) generally improved, although the R^2 for hazel pomaderris decreased for both measurements, and the regression for stem diameter for sweet bursaria also showed a lower R^2 than that of all shrubs combined. Samples of another two frequently surveyed, highly browsed species, prickly tea-tree and gorse bitter-pea, were not collected due to difficulty in locating sufficient branches that had not been browsed.

Table 5.5. Linear regression analysis between branch weight (g), and the field measurements of volume (cm³) and stem diameter (mm) for four highly browsed species, Yarra Ranges National Park, 2006 – 2007.

Species	Measurement	Adjusted R^2	P value	Equation: <i>branch weight</i> =
<i>Bursaria spinosa</i>	Volume	83.1%	< 0.001	$0.04\text{Volume}^{0.51}$
Sweet bursaria	Stem diameter	63.2%	< 0.001	$0.20\text{Stem diameter}^{2.71}$
<i>Coprosma quadrifida</i>	Volume	90.6%	< 0.001	$0.01\text{Volume}^{0.58}$
Prickly currant bush	Stem diameter	85.3%	< 0.001	$0.15\text{Stem diameter}^{2.73}$
<i>Pomaderris aspera</i>	Volume	50.6%	< 0.001	$0.02\text{Volume}^{0.53}$
Hazel pomaderris	Stem diameter	57.4%	< 0.001	$0.44\text{Stem diameter}^{1.53}$
<i>Pultenaea juniperina</i>	Volume	85.7%	< 0.001	$0.01\text{Volume}^{0.71}$
Prickly bush-pea	Stem diameter	89.7%	< 0.001	$0.38\text{Stem diameter}^{2.41}$

A natural log transformation was applied to the volume of each branch measured in exclusion units, and showed through REML analysis there was significant variation between treatments ($\text{Wald}_2 = 14.26$, $P < 0.001$) and surveys ($\text{Wald}_2 = 243.75$, $P < 0.001$), with a significant interaction between these two fixed effects ($\text{Wald}_4 = 97.19$, $P < 0.001$). Fisher's least significant difference post hoc test revealed that the mean volume of branches were not significantly different during Winter 2006. The volume of the branches in all plot treatments increased by Summer 2007, when branches in the open and partial treatments were similar in volume, while the volume of branches in total plots was significantly greater. Winter 2007 showed significant differentiation between all plot treatments, with the mean volume of branches in the total plots 38.4% greater than in the partial plots and 54.3% greater than in open plots, while the volume of branches in partial plots was 25.8% greater than the open plots (Figure 5.19).

Separate analysis of each element of the volume measurement, length, width and height, are shown in Table 5.7. None of the measurements were significantly different during treatments in Winter 2006. However during Summer 2007 and Winter 2007, branches were significantly shorter in length in the open plots than in the partial and total plots, while in comparison, the width and height of branches in open and partial plots were significantly shorter than in the total plots.

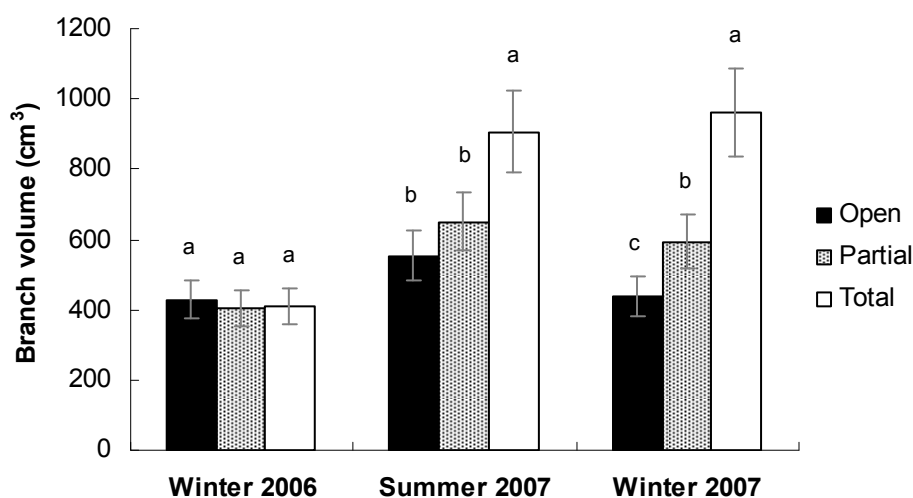


Figure 5.19. Mean branch volume (\pm standard error) in each plot treatment categorised by survey, Yarra Ranges National Park, 2006 – 2007. Significant differences between plot treatments within each survey, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a – c, where $a > b > c$.

Table 5.6. Mean branch measurements (\pm standard error) surveyed on a variety of shrubs and ferns in exclusion plots, Yarra Ranges National Park 2006 – 2007. Significant differences between plot treatments, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a and b, where $a > b$.

	Winter 2006	Summer 2007	Winter 2007
Length (cm)			
Open	26.2 \pm 2.0 ^a	28.4 \pm 2.1 ^b	28.3 \pm 2.1 ^b
Partial	26.6 \pm 2.1 ^a	31.2 \pm 2.1 ^a	32.1 \pm 2.1 ^a
Total	24.6 \pm 2.1 ^a	31.6 \pm 2.1 ^a	32.8 \pm 2.1 ^a
Width (cm)			
Open	11.7 \pm 0.8 ^a	13.5 \pm 0.8 ^b	12.6 \pm 0.8 ^b
Partial	11.7 \pm 0.8 ^a	14.4 \pm 0.8 ^b	13.5 \pm 0.8 ^b
Total	11.1 \pm 0.8 ^a	14.3 \pm 0.8 ^a	15.0 \pm 0.8 ^a
Height (cm)			
Open	5.7 \pm 0.4 ^a	6.8 \pm 0.4 ^b	6.6 \pm 0.4 ^b
Partial	5.4 \pm 0.4 ^a	6.8 \pm 0.4 ^b	6.8 \pm 0.4 ^b
Total	5.8 \pm 0.4 ^a	8.2 \pm 0.4 ^a	9.0 \pm 0.4 ^a

Regression analysis was utilised to investigate the relationship of volume and stem diameter for browsed and unbrowsed branches. Four separate analyses were performed for each of the plant groups ferns and shrubs, in the treatment plots partial and open, during Winter 2007 (Figure 5.20). The regression for browsed and unbrowsed shrub branches was significantly different for both open ($R^2 = 42.3\%$, $F_{2,734} = 270.47$, $P < 0.001$) and partial ($R^2 = 58.8\%$, $F_{2,708} = 507.57$, $P < 0.001$) plot treatments, with the fitted line shown in Table 5.7.

Table 5.7. Linear regression analysis where branch volume (cm^3) is explained by stem diameter for browsed and unbrowsed shrub branches and fern fronds, Yarra Ranges National Park, 2006 – 2007.

	Plot treatment	Not browsed	Browsed
Shrubs	Open	$234.86 \text{stem diameter}^{2.87}$	$59.98 \text{stem diameter}^{2.87}$
	Partial	$276.44 \text{stem diameter}^{2.81}$	$70.88 \text{stem diameter}^{2.81}$
Ferns	Open	$13.45 \text{stem diameter}^{2.65}$	$73.91 \text{stem diameter}^{2.46}$
	Partial	$15.08 \text{stem diameter}^{2.65}$	$27.12 \text{stem diameter}^{2.40}$

There was no significant interaction between stem diameter and browsing in the open plots (estimated effect -0.09, s.e. 0.29, $P = 0.747$) or partial plots (estimated effect 0.08, s.e. 0.22, $P = 0.713$). Browsing is estimated to decrease the volume of shrubs in both partial and open treatments by a factor of approximately four: partial by 3.90 (log volume 1.36, s.e. = 0.10) and open by 3.92 (log volume 1.37, s.e. = 0.13). The regression for browsed and unbrowsed fern fronds was also significantly different for both open ($R^2 = 88.7\%$, $F_{2,159} = 633.23$, $P < 0.001$) and partial ($R^2 = 88.7\%$, $F_{2,189} = 754.37$, $P < 0.001$) plot treatments (Figure 5.20), with the fitted line shown in Table 5.7. There was no significant interaction between stem diameter and browsing in the partial plots (estimated effect 0.20, s.e. 0.19, $P = 0.291$), but there was in open plots (estimated effect 0.89, s.e. 0.19, $P < 0.001$). Browsing was estimated to decrease the volume of shrubs at a stem diameter of, for example, 0.6 mm (equal to log stem diameter of -0.5, Figures 5.20a & b) by a factor of 2.04 in the partial plots and by a factor of 6.11 in the open treatments.

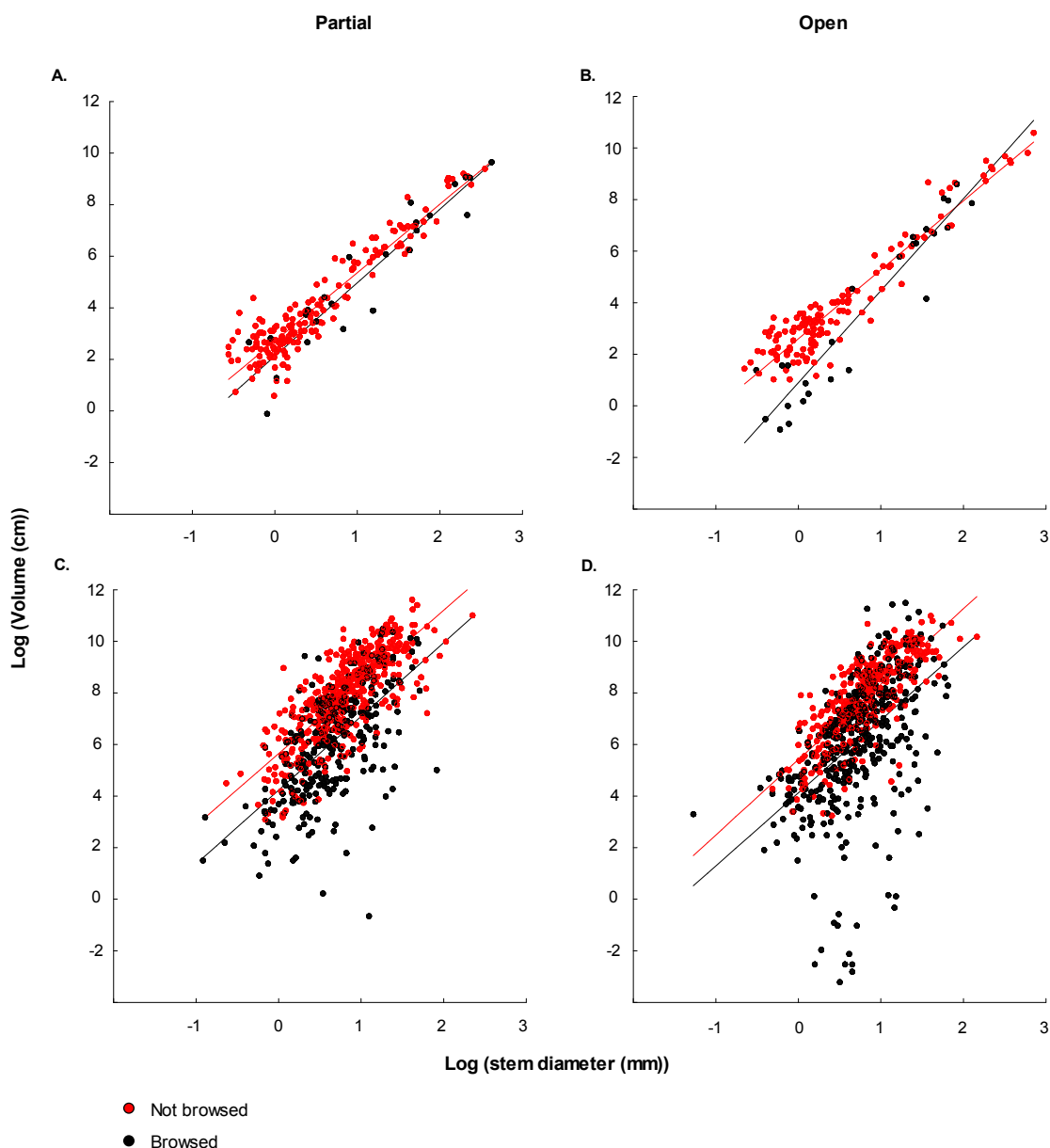


Figure 5.20. Linear regression of browsed (presence) and unbrowsed plant branches in partial and open treatment plots, Yarra Ranges National Park, Winter 2007, where stem diameter explains **A.** Fern volume in partial plots **B.** Fern volume in open plots **C.** Shrub volume in partial plots **D.** Shrub volume in open plots.

The mean volume of branches in each distance category was significantly different ($Wald_3 = 15.18$, $P = 0.002$), with Fisher's least significant difference post hoc test revealing the volume of branches in distance categories between 1 and 1000 m was significantly less than over 5000 m in the Upper Yarra and in the O'Shannassy catchment (Figure 5.21).

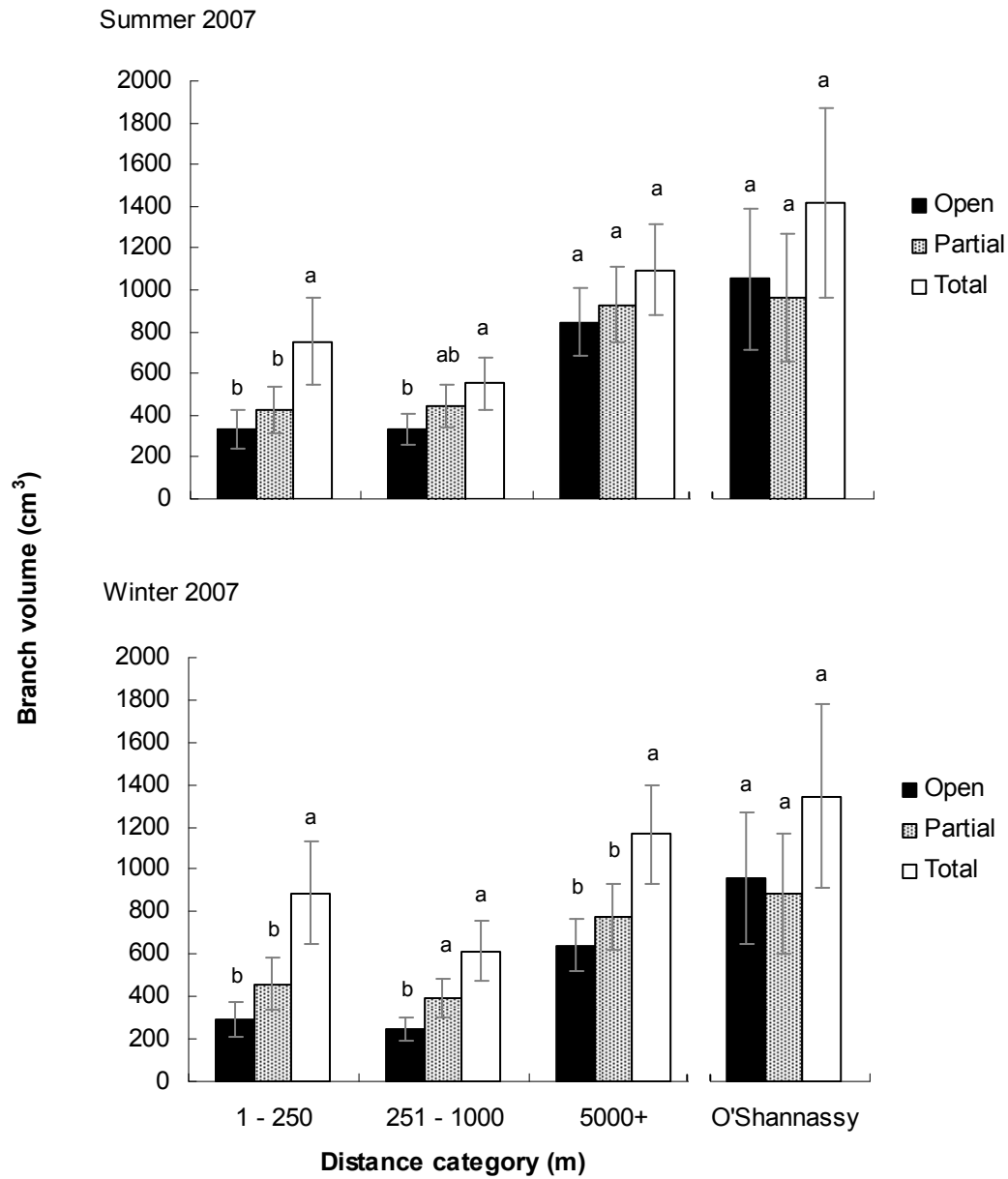


Figure 5.21. Mean branch volume (\pm standard error) in each plot treatment categorised by distance from The Flats and compared with O'Shannassy, Yarra Ranges National Park, 2006 – 2007. Significant differences between plot treatments within each distance category, calculated by Fisher's least significant difference post hoc test, are indicated by the letters a – c, where $a > b > c$.

Discussion

Herbivore density

The density of sambar, as indexed by faecal pellet groups, was greatest at exclusion units located within 250 m of The Flats in 2007. This confirmed results obtained in 2005, using the zig-zag FPG transect method (Chapter 2). The density of sambar in the O'Shannassy catchment was comparable to the density of sambar in the Upper Yarra catchment over 250 m from The Flats. These results indicate that the high density of sambar in proximity to The Flats is unique within the YRNP. Swamp wallabies and common wombats were not influenced by distance to The Flats, and these species were present in all stratified areas of the catchments surveyed.

Ecological Vegetation Class

Characterisation of species representation in exclusion plots within each EVC showed distinct groupings. As expected, given that it was the only dry forest type in the study, Shrubby Foothill Forest was the most dissimilar to the other EVCs. Riparian forest was also relatively distinct, due to the dominance of fern species in the understorey of this EVC. Exclusion units located in Riparian Forest in the O'Shannassy catchment were represented by species that were more similar to species characterised in Wet Forest than that of Riparian Forest in the Upper Yarra catchment. Damp Forest and Wet Forest were the most similar and overlapped to the greatest extent, but were still distinguishable. Further division of each EVC, according to sambar density, revealed marked differentiation in the three EVCs in which density was tested: Shrubby Foothill Forest, Damp Forest and Wet Forest. The effect of exclusion units on species representation was considered negligible due to the short time over which the units had been established, therefore these results indicate a shift in species representation may have already occurred in these EVCs close to The Flats. The abundance of plant species that are intolerant to high deer densities, either through the effects of browsing e.g. (Husheer *et al.* 2005) or physical effects such as trampling (Tsujino and Yumoto 2004), are likely to be reduced within 250 m of The Flats. Further study is required to specifically test plant species diversity in high and low sambar density areas, as results from this study may in some instances be unrelated to sambar impacts. For example, Mueller's bush-pea (*Pultenaea muelleri*) in the EVC Shrubby Foothill Forest, was present

in only one plot (7%) in close proximity to The Flats, compared with 50% of plots located over 5000 m from The Flats, suggesting a sambar-related impact. However this species was very rarely browsed, and was a common and locally abundant species in some areas of the catchment.

Plant effects

Evidence of old browse (occurring prior to plot construction) showed that 80% of shrubs had experienced browsing in the past. The presence of new browse (occurring after plot construction) showed that on average there was 19.0% more browsing in open plots than partial plots, representing the quantity of plants browsed by sambar and 30.2% more browsing in partial plots than total plots, the mean number of plants browsed by native herbivores. The new browse classification in total plots during the initial survey, Winter 2006, was 11.9% compared with 3.6% Summer 2007 and 3.1% Winter 2007. This elevated result is likely due to the classification methodology of old browse and new browse, which relies on plants to continually grow around the browsed stem. While in most cases this did occur, two commonly surveyed species, gorse bitter-pea and in particular prickly tea-tree, were both shown in this study to grow more slowly than other species. Further investigation showed that these two species were commonly classified with new browse in the total plots during Winter 2006, falsely inflating the browse score.

Rubbing on understorey shrubs was not common: just seven individuals were rubbed in Summer 2007 and none in Winter 2007, of 1912 plants surveyed, compared with 12 of 124 surveyed shiny nematolepis saplings (Chapter 3). This difference may have occurred because shiny nematolepis are more attractive to sambar or the location of the saplings on the road verge was an important factor in sapling selection for effective signposting. On average, broken branches occurred on 6% of plants, however it was not consistent with treatment type. Sambar therefore do not appear to contribute greatly to the breakage of stems on understorey plants, and other mechanisms such falling sticks and branches from surrounding overstorey trees are the most likely cause.

Deer browsing activities can reduce or retard the growth rate of tree saplings and understorey shrubs (Vila *et al.* 2003; Olesen and Madsen 2008). There was no significant variation in height between surveys for plants subject to sambar browsing, indicating

that browsing by sambar in the forest understorey will generally prevent plants from exceeding the observed mean height of around 110 cm. While native herbivores also prevented a large amount of growth, there was a small but significant increase in Summer 2007, with the mean height of plants in partial plots slightly taller (mean 1.6 cm) in Winter 2007, when compared with the initial survey, Winter 2006. This indicates that, while growth in height may be impeded by native herbivores, a positive increase may still be expected in the absence of sambar. In contrast, the plants that were protected from browsing by all terrestrial herbivores in the total plots increased by 8.6 cm in Summer 2007, and continued to increase for an overall mean height growth increase of 9.7 cm by Winter 2007.

Sambar and native herbivores generally browsed the same species, although in differing order of preference. In this study only nine species were browsed frequently, five of which were prickly. Thorns, prickles and spines are a form of plant defence against herbivory, while other plant species invest in chemical defences (Hanley *et al.* 2007).

In Australia, during the Pleistocene (1.8 million – 10 000 years before present) herbivores that were present are today collectively known as the megafauna. Browsers that were distributed across Victoria included several species of short-faced kangaroos (*Sthenurus* spp.) (Johnson 2006). Some of these shrubs may have evolved structural defences in response to these large browsers, as did some shrubs in New Zealand to aid in defence against the now extinct browsing moas (Bond *et al.* 2004). Among the common species surveyed, prickly currant bush may be such an example. In the absence of heavy browsing this species is often tall and spindly, with relatively sparse branches. Where this species is subject to a large amount of browsing, it becomes highly branched, dense and hedge-like. The new growth protruding from this structure is browsed, preventing an increase in height but the shape and spinescent branchlets (small side branches that have developed sharp, spiny ends), serve to protect the core of the plant.

The two prickly species selected to a greater extent in the open than the partial plots were prickly bush-pea and prickly tea-tree. The leaves of both species end in a sharp point, giving an overall prickly texture, while prickly currant bush has spinescent branchlets, sweet bursaria has spinescent branchlets and sometimes also thorns, and gorse bitter-pea has both sharp-ended leaves and spinescent branchlets. Cooper and Owen-Smith (1986) showed that smaller herbivores were more efficient at browsing

leaves from spiny shrubs than larger herbivores due to the comparatively smaller size of the mouth. Therefore prickly bush-pea and prickly tea-tree may be browsed to a greater extent by sambar based on these morphological characteristics because the benefits, i.e. quantity of biomass obtained per unit of time, are greater than browsing the species with spinescent branchlets. Swamp wallabies however are a much smaller species, which with a smaller mouth, are likely to be able to browse these spiny species more efficiently. The spiny species are still browsed by sambar, as shown by a greater quantity of browsing in the open plots than the partial plots. If spinescent branchlets deter browsing, sambar are likely to select the high nutrient new growth on which spines are absent (Hanley *et al.* 2007). Two species, gorse bitter-pea and in particular prickly tea-tree did not significantly increase height over the year between the first and third surveys. Although gorse bitter-pea showed a general trend of increasing height in the total plots, prickly tea-tree did not show any change, despite being protected from browsing in the total plots. This indicates that these species are slower growing, less tolerant of browsing than other species such as prickly bush-pea, or are both slow growing and intolerant of browsing. Gorse bitter-pea and prickly tea-tree may therefore be more vulnerable to a local decrease in abundance due to selective browsing than the other preferred species.

Eight species were frequently surveyed in exclusion units, five of which were frequently browsed in the partial and open plots: hazel pomaderris, prickly currant bush, gorse bitter-pea, prickly bush-pea, and prickly tea-tree. Hazel pomaderris was favoured most by both sambar and native herbivores. Hazel pomaderris is distinctly different morphologically to the other highly browsed species, as it is an understorey tree species, it does not have prickles and has large leaves: 6-14 cm long by 2-5 cm wide (Costermans 1983). The attractiveness of this species to all herbivores suggest that chemical defences are also minimal, and that this species invests energy in rapid growth to quickly attain a height above the reach of browsers (Hanley *et al.* 2007). In comparison, the other four species are all prickly shrubs with small leaves between 5 – 20 mm long and 1 – 5 mm wide (Costermans 1983). Hazel pomaderris is likely to provide a large quantity of biomass to herbivores and without prickles, may be consumed more efficiently. Individuals of this species are largely protected from browsing impacts once they attain a height above that at which terrestrial herbivores browse. However the seedlings and

saplings are susceptible to selective browsing, so recruitment of hazel pomaderris may be restricted in some areas.

There were also several species that were observed to have been browsed in the low sambar density areas: elderberry panax (*Polyscias sambucifolia*), privet mock-olive and Victorian Christmas bush. All these species had small sample sizes which may have influenced each species' preference ranking. Privet mock-olive and Victorian Christmas bush were both highly browsed species. Conversely the tagged samples of elderberry panax were browsed very little and was therefore categorised as a rarely browsed species. However, frequent observations of browsed individuals outside the exclusion units in low sambar density areas, indicates this may not have been a true representation of the palatability of this species. This may have occurred because sambar select only the new growth on this species, and the tagged branches were therefore avoided. One elderberry panax individual was observed in the high sambar density area, but it was growing within a pile of logs on the side of the road and was therefore largely inaccessible to browsers. The few branches that were accessible however, had been severely browsed.

Branch effects

Overall there was greater browsing of tagged branches in the open plots than in the partial plots. This occurred in all height ranges in all location categories except in the two lowest height categories (0 – 60 cm) from 251 – 1000 m from The Flats and in the O'Shannassy.

Open plots had greater presence of browsing in all height categories except the lowest, 0 – 30 cm. There was significantly more browsing over the height of 60 cm between the partial and open, showing that sambar most commonly browse on branches over this height. Browsing over this height range was similar to that found by Motta (2003), where the most vulnerable branches were those located 80 – 140 cm, and by Relva and Veblen (1998), who found branches were most commonly browsed 50 – 100 cm. Renaud *et al.* (2003) found exact correspondence of preferred feeding height with shoulder height. Given that sambar are a large species, with stags and hinds averaging 127 cm and 109 cm respectively (Bentley 1998), the relatively uniform height of around

110 cm of shrubs located in the forest edge (< 250 m), suggests that sambar browse shrubs down to this height.

The magnitude of sambar browsing was most commonly 5 – 10%, however browsing in the forest edge (< 250 m), where sambar density was greatest, was elevated to almost 20% in the three height ranges between 30 and 120 cm. Interestingly, sambar browsing was elevated in the 30 – 61 cm height category in the forest edge, when overall it was shown sambar more commonly browse over 60 cm. Observations of sambar at The Flats showed that the most common class was hinds, with the remaining individuals comprised of yearlings, calves and young stags (Chapter 2), so these smaller individuals may have browsed at a lower height. Alternatively, forage may have been depleted in the upper height categories, so browsing had by necessity moved to the lower, less preferred height range.

The level of browsing in the height ranges over 90 cm in the partial plots was higher than expected. Despite little sign of sambar in the partial plots before plot modification following the Summer 2007 survey, it may still have occurred and contributed to the browsing of branches in the higher height ranges. However, swamp wallabies can pull branches located over 1 m from the ground down to an accessible feeding height using their fore-paws (K. Handasyde, The University of Melbourne pers. comm.), and are thus able to browse branches located higher than would otherwise be expected. Other native species, such as bobucks, may also have accessed some shrub branches in the higher height categories from surroundings trees.

Biomass effects

The samples of fern and shrub branches showed that biomass was significantly correlated with branch stem diameter and volume. These relationships can be used in future surveys to determine the approximate biomass of a branch given either of these field measurements. This negates the need for destructive sampling, which is not possible when the primary objective of a study is to observe the growth of specific branches and the effect of browsing over time. Generally, the species-specific relationships provided a more accurate estimation of branch biomass and should be used where possible.

The mean volume of biomass in Winter 2007 was significantly different between all plot treatments. Native herbivores reduced branch volume by 38.4%, while sambar reduced branch volume a further 41.4%. Consideration of each element of the volume measurement separately showed that native herbivores, on average, do not decrease the length of branches; only the width and height were significantly decreased. In contrast sambar, decreased all three dimensions. While native herbivores do browse apical stems, on average the length of branches was not affected, likely because the majority of wallaby browsing occurred on the lower branches. Overall, the volume of branches was significantly less in the distance categories 0 – 1000 m from The Flats than over 5000 m and in the O'Shannassy (Figure 5.21). In comparison, sambar density was found in 2007 to be greatest at exclusion units < 250 m from The Flats (Figure 5.7), similar to density levels recorded in 2005 (Figure 2.17), when site occupancy was greatest in the distance categories up to 1000 m from The Flats (Figure 2.16). Considered together, these findings demonstrate a negative correlation between branch volume and sambar density.

CHAPTER 6

General discussion



*Upper Yarra reservoir, Yarra Ranges National Park,
August 2008*

CHAPTER 6

General discussion

Principal findings

This study investigated elements of the ecology of sambar (*Cervus unicolor*) and the associated impacts in the YRNP. The majority of impacts were centred on and in proximity to open, ephemeral grass and herb-rich areas adjacent to the Upper Yarra reservoir. This study specifically established:

- Aggregations of up to 70 individuals, predominantly hinds, at a density of approximately 200 km⁻² occurred on The Flats adjacent to the Upper Yarra reservoir. This is the largest aggregation recorded in the world for this species (Chapter 2). Sambar contributed most to the offtake of forage at The Flats, which comprised a substantial proportion of their daily food requirements (Chapter 4).
- The cull reduced the time spent by sambar on The Flats, as determined by faecal pellet accumulation plots, and significantly reduced faecal pellet load and forage offtake (Chapter 4).
- Sambar density was highest on open herb-rich flats adjacent to the Upper Yarra reservoir and in forested areas bordering the open flats. Occupancy in the Upper Yarra catchment is greatest within 1000 m of these open flats (Chapter 2). Comparison with density estimates for the nearby O'Shannassy catchment indicated the density of sambar on open flats adjacent to the Upper Yarra reservoir and in forest edges (< 250 m) bordering open flats, is unique within the YRNP (Chapter 5).
- Sambar impact on forest understoreys through rubbing activities (Chapter 3) but more commonly through browsing (Chapter 5). Sambar have significant impacts on forest understoreys:
 - Rubbing activities by sambar decrease the health of the threatened understorey tree, shiny nematolepis (*Nematolepis wilsonii*) as demonstrated by a decrease of relative foliage cover. Sambar thrashing activities also

reduced relative foliage cover of shiny nematolepis saplings. Rubbed trees and thrashed saplings typically experienced damage to over half the stem circumference. Partial exclusion plots effectively prevent rubbing on the trunks of mature shiny nematolepis trees and prevent thrashing of shiny nematolepis saplings (Chapter 3).

- Sambar most frequently browsed hazel pomaderris (*Pomaderris aspera*), prickly tea-tree (*Leptospermum continentale*), prickly bush-pea, (*Pultenaea juniperina*) gorse bitter-pea (*Daviesia ulicifolia*) and prickly currant bush (*Coprosma quadrijida*) among the common plant species. Two highly-selected species, Victorian Christmas bush (*Prostanthera lasianthos*) and Privet mock-olive (*Notelaea ligustrina*) were absent in high sambar density areas (Chapter 5).
- Sambar prevented the vertical growth of plants in the understorey through browsing. In comparison, native herbivores impeded vertical growth but still allowed a height increase. In the absence of herbivore browsing, all common species significantly increased in height over one year except gorse bitter-pea (*Daviesia ulicifolia*) and prickly tea-tree (*Leptospermum continentale*) (Chapter 5).
- Sambar most commonly browse above 60 cm in height, however in high density areas where forage may be depleted, sambar also consumed similar quantities of forage in the 31 – 60 cm height range (Chapter 5).
- Browsing by sambar significantly reduced biomass in forest understoreys throughout the catchment. Plant biomass was most significantly reduced within < 1 km of The Flats (Chapter 5) where sambar occupancy and density was greatest (Chapters 2 & 5).

Ecological significance and future directions

This section outlines the importance of findings at the local scale within the YRNP, and in a broader ecological context. Recommendations and future directions for research are also highlighted.

Open herb-rich flats

The high density of sambar recorded in proximity to The Flats confirms the anecdotal reports of large numbers of sambar in this area. The occurrence of this high density sambar population in close proximity to the Upper Yarra reservoir has management implications for Melbourne's water supply.

Faecal pellet load

Deer species can host micro-organisms such as *Escherichia coli* (McDowall 2007), *Giardia* spp. (Paziewska *et al.* 2007) and *Cryptosporidium* spp. (Chalmers *et al.* 2005; Paziewska *et al.* 2007). Micro-organisms from sambar faecal pellets deposited in surrounding forest also have the potential to enter the reservoir system through soil or groundwater despite the presence of vegetation adjacent to the reservoir (Atwill *et al.* 2002; Darnault *et al.* 2003; Davies *et al.* 2004). Melbourne Water, in collaboration with The University of Melbourne, have undertaken an investigation of pathogens transmitted via sambar faecal pellets on The Flats that, following a rise in reservoir level, may be added to the reservoir system.

The potential for contamination with water-borne pathogens increases with quantity of faecal pellets. Faecal pellet weight was determined to allow an estimation of the quantity of faecal pellets deposited on The Flats. Ten pellets were sampled from 15 fresh FPGs collected on The Flats. Pellets were collected in a plastic bag and weighed using an electronic balance to provide a fresh pellet weight, and then oven dried in a paper bag for 5 days at 70 °C to provide a dry pellet weight. Mean fresh pellet weight was 1.77 g and mean dry weight 0.59 g. The number of pellets deposited by sambar per day was determined by faecal pellet accumulation surveys (Chapter 4). This was then extrapolated to estimate the weight of pellets deposited on the Open Herb-rich Zone of The Flats, the area of The Flats most frequently flooded and where sambar are most commonly observed. Given that The Flats appear to be exposed for six months of the

year, an estimation of the faecal pellet load on The Flats over 6 months (with no decomposition) was 7.4 t (Table 6.1). However, density estimates of sambar on The Flats during a cull using faecal pellet accumulation plots (Chapter 4) demonstrated shooting pressure (1 - 2 nights/week) may reduce the faecal pellet load on The Flats by almost half (Table 6.1).

Table 6.1. Faecal pellet load in the Open Herb-rich Zone of The Flats, Yarra Ranges National Park

	Pellet weight (g)	Cull	No cull
Faecal pellets m ⁻² day ⁻¹		0.11	0.21
Faecal pellets OHZ* kg day ⁻¹	1.77 ^a	63.7	121.5
Faecal pellets OHZ* tonnes 6 months ⁻¹	0.59 ^b	3.9	7.4

* OHZ - Open Herb-rich Zone of The Flats covering approximately 32.7 ha (Chapter 4)

^a fresh pellet weight

^b dry pellet weight

Biomass offtake

Herbivores can substantially reduce grassland biomass through grazing (Lenzi-Grillini *et al.* 1996; Trdan and Vidrih 2008). Heavy grazing has been associated with alteration of plant species composition (Dorrough *et al.* 2004; Bakker *et al.* 2006; Dorrough *et al.* 2007) and subsequent flow-on effects may also occur. For example, insect functional groups and species composition may be modified (Cagnolo *et al.* 2002; Hartley *et al.* 2003), soil nitrogen, sodium and potassium and microbes may decrease with heavy grazing (Li *et al.* 2005), although conversely, soil microbial biomass may increase due to the addition of faeces on grasslands (van der Wal *et al.* 2004). High levels of faeces on grasslands have also been shown to raise soil nutrient content, and thereby increase plant growth through an increased availability to plants of phosphorus (Moe and Wegge 2008) and nitrogen (Frank and Evans 1997).

A number of the grass and herb species at The Flats are not native (N. Walsh, Royal Botanic Gardens Melbourne pers. comm.) and the impact on these species is of little concern. All species at The Flats appear able to tolerate substantial grazing; indeed species that do not tolerate grazing may have already declined or become absent at this

site. Among the native species present, hypsela (*Hypsela tridens*), is a forb that is classified as rare in Victoria due to a limited distribution and the blown-grass (*Lachnagrostis* aff. *filiformis*) may be a previously undescribed species or sub-species (A. Brown, Department of Primary Industries pers. comm.). While both of these species appear to tolerate grazing due to their persistent and local abundance, the morphological difference between grazed and ungrazed plants in exclusion plots was distinct.

Sambar offtake at The Flats was estimated at $193.1 - 999.1 \text{ kg day}^{-1}$, or $5.8 - 30.0 \text{ t month}^{-1}$ of biomass dry weight. When a cull was conducted during June and July 2008, biomass offtake by sambar decreased by approximately 3.6 t month^{-1} dry weight. These results indicate a reduction of the sambar density or a reduction of time the population spend on The Flats through shooting pressure, would also increase the available biomass. The sambar population at The Flats is open to migration from other areas within the YRNP and outside the park, and a continuous, sustained cull program in the YRNP is likely to be required to decrease the density of sambar adjacent to the Upper Yarra reservoir. Other areas of research may include:

1. An investigation into the effects of a cull on sambar behaviour and use of The Flats over time may provide greater insight into the efficacy of a long-term cull program. Less costly measures, such as acoustic scaring devices commonly used to deter birds from crops, could also be investigated
2. Exploration of the effects of reduced sambar density on faecal pellet load, rare plant species, such as hypsela (*Hypsela tridens*) and potentially the blown-grass (*Lachnagrostis* aff. *filiformis*), plant species diversity and overall biomass production. In addition, the distribution and abundance of native herbivores on and in proximity to The Flats could be investigated and compared with other areas of catchment

Forest understorey impacts

Shiny nematolepis

Sambar impose a new threat to the population of shiny nematolepis in addition to that of native animals and storms. Deaths of shiny nematolepis individuals often cannot be

attributed solely to sambar, however the added impact is likely to result in further decline of this threatened population.

Stochastic events such as storms and wildfire could potentially be devastating to such a small localised population. In recognition of this threat, the Department of Sustainability and Environment and Royal Botanic Gardens are planning to establish and maintain genetically diverse *ex situ* populations of shiny nematolepis in O'Shannassy and Upper Yarra catchments (A. Webster, Department of Sustainability and Environment pers. comm.). The Royal Botanic Gardens Melbourne currently hold a representative collection of 6500 seeds and 400 plants, of which most of the plants are to be used in the establishment of these new populations (N. Walsh, Royal Botanic Gardens Melbourne pers. comm.).

Several actions are recommended to preserve the shiny nematolepis population.

1. Complete tagging of all mature individuals and continue to monitor the health of the population. Raw data and exclusion plot maps featuring numbered locations of shiny nematolepis trees and saplings surveyed in this study are available to assist with future monitoring
2. Construct partial plots around all stands of shiny nematolepis mature trees to prevent access by sambar deer whilst allowing access by native species
3. Construct partial fences along the road side to protect all seedlings from incidental thrashing by sambar
4. Further investigate use of artificial 'disturbance' to recreate conditions of the road verge to enhance seedling recruitment
5. Further investigate the impact on shiny nematolepis by yellow-tailed black cockatoos and borer species (including their life cycle) to increase understanding of all threats to shiny nematolepis and instigate mitigation processes if necessary

Browsing impacts

Many studies have found a positive correlation between deer density and browsing impact (Husheer and Robertson 2005; Tremblay *et al.* 2007). This study also showed a positive correlation of sambar density and magnitude of browsing. Forest edges adjacent to The Flats (< 250 m) received the greatest browsing pressure. The forest surrounding open flats up to 1000 m may also sustain greater browsing pressure than other areas of the Upper Yarra catchment. Although other areas of the park received considerably less browsing damage, all browsing by sambar is additional browsing pressure on individual plants that did not occur prior to the 1860s.

Reversal of browsing impacts through a reduction or omission of deer has been effective in some cases (Husheer and Robertson 2005). However recovery for forested systems following a period of intensive deer browsing is often slow (Morecroft *et al.* 2001), and in some cases may not be possible. De la Cretaz and Kelty (2002) reported that following intense, selective browsing of woody understorey species by deer, a dense layer of ferns established, which prevented the woody species from regenerating. Other studies have also reported dramatic shifts in species representation of forest understoreys as being potentially irreversible, despite a reduction of deer density (Stromayer and Warren 1997; Coomes *et al.* 2002).

Recommendations and potential areas of research are:

1. To continue to monitor exclusion plots at intervals, investigating elements such as understorey plant height growth comparisons, seedling density, species diversity including decline or recovery, and structural changes. Raw data and exclusion plot maps showing the numbered locations of each understorey plant surveyed in exclusion plots are available to assist with future monitoring programs
2. Investigation of other impacts of high sambar densities on forest understoreys, such as the diversity and abundance of fauna species in comparison with low sambar density areas of the catchment. Key taxonomic groups may include insects, birds and small mammals

3. To develop methods for rapid vegetation assessments of browsing damage used in conjunction with faecal pellet surveys, which will aid in the identification of areas that have sustained browsing impacts. This will allow mitigation measures to be prioritised and focussed on specific areas. Based on the results of this study, potential indicators that could be further investigated for adoption in a rapid assessment methodology might include:
 - Use of volume or stem diameter branch measurements to provide an immediate quantification of biomass removal
 - Surveys may focus on key species that are preferentially browsed, potentially identified by their morphological characteristics. For example in this study, species that were preferentially browsed had a morphology that allowed the greatest biomass removal per unit of time
 - Areas in which selective browsing has altered species composition may be determined by conducting species presence surveys, given prior, local knowledge of plant species diversity in a particular forest type

Clearly, the existence of The Flats in the Upper Yarra catchment drives the density distribution of sambar and the associated browsing impacts in forest understoreys adjacent to the reservoir. Maintaining the Upper Yarra reservoir at a high level would remove the availability of this food resource, however in the current, and arguably permanent, period of below average rainfall, maintaining the reservoir at near capacity is not possible. Fencing such a large area is unlikely to be effective due to the attractiveness of the resource, with construction and maintenance costs also prohibitive. It appears that a sustained culling program may be the only practical option to reduce the density of sambar at this locality.

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Appendix 1

EVALUATION OF AN EXCLUSION PLOT DESIGN FOR DETERMINING THE IMPACTS OF NATIVE AND EXOTIC HERBIVORES ON FOREST UNDERSTOREYS

AMI BENNETT AND GRAEME COULSON

Cervus unicolor (sambar) were introduced to Australia in the 1860s (Bentley 1998) and have since expanded their range throughout eastern Victoria and more recently into New South Wales and the Australian Capital Territory (Moriarty 2004). They are a large deer; mature hinds weigh 130–150 kg and stand up to 1150 mm at the shoulder and stags weigh 200–250 kg and are up to 1300 mm at the shoulder (Bentley 1998; Mason 2006). *C. unicolor* are opportunistic in their food selection, and depending on availability may be classed as predominantly browsers (Burke 1982; Ngampongsai 1987; Shea *et al.* 1990; Semiadi *et al.* 1995), grazers (Padmalal *et al.* 2003) or intermediate feeders consuming approximately equal quantities of both browse and graze food plants (King 1990; Varman and Sukumar 1993; Stafford 1997). Selective browsing by *C. unicolor* may impact on species abundance and distribution, and thereby alter species composition of forest types, while social behaviours, such as rubbing and wallowing, may lead to impacts on water quality and biodiversity.

Exclusion plots have often been used to evaluate the impacts of browsers and grazers (Opperman and Merenlender 2000; Takada *et al.* 2001). However, impacts of browsing herbivores can be difficult to determine if multiple species occupy the same habitat (Kelton and Skipworth 1987; Stockwell 2003). One solution to this problem is the use of selective exclosures, which allow a chosen species to enter exclosures while preventing access by other species, thereby allowing quantification of browsing impacts of individual species (Baxter *et al.* 2001; Neave and Tanton 1989). The most common large native terrestrial herbivores in the study area are *Wallabia bicolor* (swamp wallaby), which are predominantly browsers (Hollis *et al.* 1986; Jarman and Phillips 1989; Osawa 1990), and *Vombatus ursinus* (common wombat), which are grazers and feed

almost exclusively on grasses (Evans *et al.* 2006). Both species are considerably smaller than *C. unicolor*: adult *Wallabia bicolor* weigh up to 25 kg (Di Stefano *et al.* 2005) and are up to 40 cm high at the back when crouched (pers. obs.), whereas adult *Vombatus ursinus* weigh up to 35 kg and reach 25 cm at the shoulder (Triggs 1988).

EXCLUSION PLOT DESIGN

To determine the impacts of *C. unicolor* on forest understoreys and to be able to distinguish these impacts from that of native herbivores, we constructed exclusion plots in 2005 and 2006 in the Yarra Ranges National Park, Victoria, Australia. We arranged 10 x 10 m plots in units consisting of three types: a total exclusion plot, a partial exclusion plot and open (no fence) plot (Figure 1). This layout was chosen to minimise sampling error that may be introduced by spatial variation among the plots in each unit. In practice it was difficult to construct plots exactly as shown in the spatial layout (Figure 1), due to terrain, tree fall and location of understorey shrubs. We often had to move the unit slightly from the random central point, or vary the distances (5–20 m) and angles (40–180°) between plots in order to encompass a variety of understorey species, whilst keeping these species as similar as possible within a given unit.

The cost of materials for each exclusion unit was approximately \$530 (Table 1). To keep the cost per unit to a minimum our fences were designed to eliminate the need for stays (supports) on each corner by replacing two extra supporting poles per corner with the two external star pegs (a saving of \$144 per unit). This also greatly increased the speed of construction and reduced the quantity of materials to be transported to plot locations, which were accessible only by foot.

Bennett, A and Coulson, G, 2008. Evaluation of an exclusion plot design for determining the impacts of native and exotic herbivores on forest understoreys. *Australian Mammalogy* 30: 83–87.

Key words: browsing, *Cervus unicolor*, common wombat, exclusion plots, herbivore impacts, sambar, swamp wallaby, *Vombatus ursinus*, *Wallabia bicolor*.

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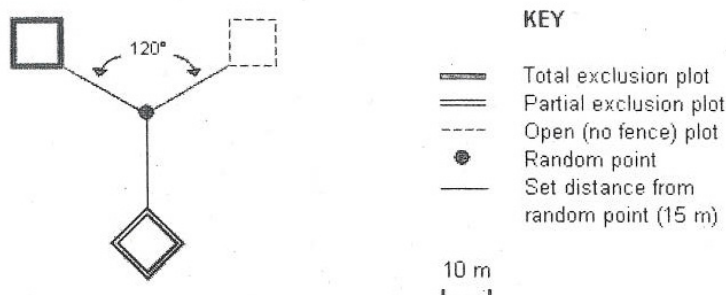


Fig. 1. Plan view of an exclusion unit, showing the ideal arrangement of the total exclusion plot, partial exclusion plot and open (no fence) plot.

Item	Total	Partial	Open	Total No. per unit	Approximate cost	
					Item cost (\$)	Total cost (\$)
2400-mm star picket	12	12	-	24	9.00 ea	216.00
600-mm star peg	8	8	4	20	1.50 ea	30.00
'Acreage' weld-mesh (1200-mm, 10 strand graduated mesh)	40 m	40 m	-	80 m	2.40 / m	192.00
2.5-mm high tensile plain wire	120 m	40 m	-	160 m	0.15 / m	24.00
2-mm tie wire	~5 m	~5 m	-	10 m	0.15 / m	1.50
10-mm turnbuckles	4	4	-	8	2.80 ea	22.40
Gripple® wire joiners	~15	~15	-	30	1.50 ea	45.00
						\$530.90

Table 1. Description and approximate costs of materials used in the construction of one exclusion unit, consisting of a total exclusion plot, a partial exclusion plot and an open (no fence) plot.

We positioned 46 units (138 plots) among five representative Ecological Vegetation Classes (EVCs) throughout the Upper Yarra and O'Shannassy water catchments: Riparian Forest, Wet Forest, Damp Forest and Shrubby Foothill Forest. We installed five of these units at a site in the Upper Yarra catchment known as The Flats, which is an open grass and herb-rich area adjacent to the reservoir, and is periodically covered with water depending on the height of the reservoir. Twenty units were located within 1 km of The Flats, as this area had previously been identified as a major feeding area for *C. unicolor*. Another 15 units were located > 5 km from the reservoir to investigate the relationship between distance from The Flats and degree of understorey impact. A further six units were located in the Wet Forest EVC in the adjacent O'Shannassy catchment. We randomly located units within each EVC by generating random coordinates in Microsoft Excel,

then used these as waypoints in a Garmin eTrex Legend GPS unit to guide us to the location.

The total exclusion plot (Fig. 2) was designed to exclude *C. unicolor*, *W. bicolor* and *V. ursinus*. The partial exclusion plot (Fig. 3) was designed to exclude *C. unicolor* but allow native herbivores access via a 500 mm gap at the base of the fence. Given the much larger body size of *C. unicolor*, we considered that they would be unable to enter through the gap, while native herbivores would continue to use the plot at near-natural levels. The open plot allowed access to all herbivores, so that the relative impacts of *C. unicolor* and native herbivores could be differentiated.

All plots were functioning as intended until winter 2006, when small *C. unicolor* (yearlings) entered the partial plots located on the open area of The Flats via

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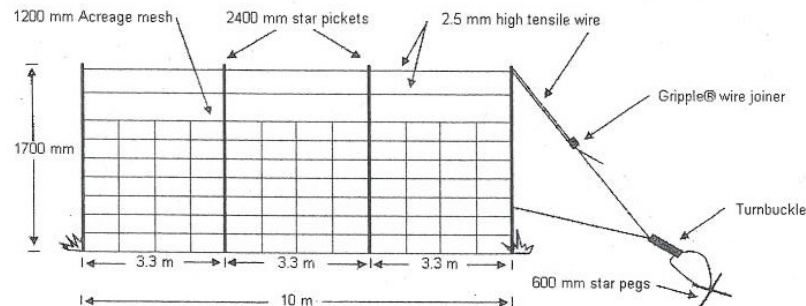


Figure 2. Side elevation of the total exclusion plot, which is designed to exclude all large herbivores.

the 500-mm gap and grazed inside on a number of occasions. *Chenonetta jubata* (wood duck), another species that was not previously considered, also appeared to be grazing in the total plots. To prevent this, we added 40 mm grid, 300 mm width chicken mesh to the base of total exclusion plots, as the original mesh was coarse enough to allow access to *C. jubata*. We also reduced the 500 mm gap on the partial plots to 300 mm using a band of the chicken mesh.

DISCUSSION

The use of exclusion plots can provide powerful information on the impacts of herbivores on individual flora species and community composition, particularly over a mid- to long-term time frame of five to twenty years or more (Barret and Stiling 2006; Bellingham and Allan 2003; Husheer et al. 2003; Wilson et al. 2006). However plots do require ongoing maintenance, particularly for those located in a forested environment where falling trees and branches are the main sources of

damage. One advantage of the design of our exclusions is that they are relatively easy to repair when a branch falls across a fence. Once the branch is cut, the flexible mesh can be stretched back into shape, the poles in most cases can be adequately straightened, and the whole fence can be easily tightened by adjusting the wire through the Gripple® wire joiner and using the turnbuckles on the external end assembly.

This fence design is effective only for the selective exclusion of medium to large-sized, ground-dwelling species, and therefore does not exclude smaller terrestrial mammals or arboreal species such as possums. The fence design may be modified, obviously at extra cost, to exclude all terrestrial species by the addition of appropriately-sized mesh at the base. However, an effective covering to exclude arboreal species would not be feasible in a forest environment due to the presence of trees in the plots and damage caused by falling timber. Furthermore, it may not be possible to adapt this design to suit deer that are significantly smaller than *C. unicolor*, such as *Axis porcinus* (hog deer).

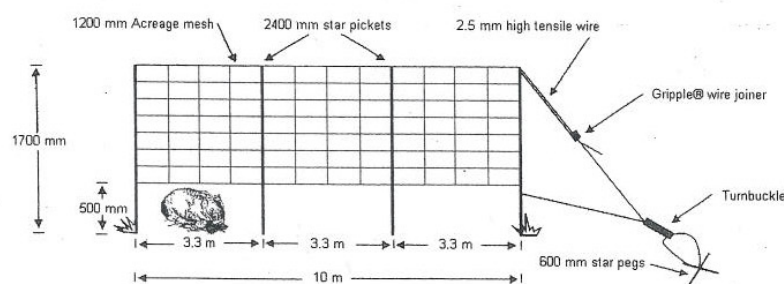


Figure 3. Side elevation of the partial exclusion plot, which is designed to exclude *C. unicolor* while allowing access to native herbivores via the gap at the base of the fence.

We recommend that plots located in the forest are revisited within a few weeks of construction to ensure that *C. unicolor* have not damaged the fence while they are becoming accustomed to these new obstacles. *C. unicolor* did cause considerable damage to some fences, but nothing that was irreparable. When *C. unicolor* are confronted with an obstacle (or fence), they either go around it or attempt to crawl under the obstacle rather than jump over it. The presence of plastic flagging tape did not prevent *C. unicolor* colliding with fences, but shiny, reflective items hanging on or near the fences may be more effective. Following these initial damage checks early on and the first plant survey in winter 2006, 3–6 months after construction, all forest plots appeared to be functioning as intended. We found *W. bicolor* and *V. ursinus* scats in the partial plots, and have seen *C. unicolor* in close proximity to the units, indicating that they have become habituated to the plots, whilst being excluded from partial plots. However, after the second survey in summer 2006–07 approximately a year after construction, it was evident that *C. unicolor* had entered several of the partial exclusion plots in the forest via the 500 mm gap, perhaps due to scarcity of food in a prolonged period of below-average rainfall. We therefore decided to reduce the height of the gap on all partial plots to 300 mm, as shown to be effective for the plots on The Flats. This was considered unlikely to deter use by native herbivores, which were accustomed to entering the partial plots and small enough to fit beneath. To minimise the cost of this modification, we lowered the existing mesh and added a single strand of plain wire to the top, rather than the addition of chicken mesh that was required for the plots on The Flats. Following the third survey in winter 2007, these modifications have apparently been successful in selectively excluding the target species.

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Appendix 2

Yarra Ranges National Park exclusion plot location details

Unit No.	UTM - GDA94		Descriptive location (R = road)	Vicmap 1:25 000 topographic map	Ecological Vegetation Class (EVC)
	N1	N2			
Upper Yarra Catchment					
1	408314	5825650	Furthest unit on flats west (near reservoir water edge)	Upper Yarra 8022-1-2	The Flats
2	408500	5825607	Opposite hide on northern edge of flat	Upper Yarra 8022-1-2	The Flats
3	408924	5825492	Open herb & rush area, close to south bank	Upper Yarra 8022-1-2	The Flats
4	409209	5825570	Mixed rushes grass & herbs, east end	Upper Yarra 8022-1-2	The Flats
5	409325	5825588	East end of Flats, north side Yarra River, mixed rushes grass & herbs	Upper Yarra 8022-1-2	The Flats
6	407999	5825547	R32, on corner, right (south) side up steep hill at approx. 8km	Upper Yarra 8022-1-2	Shrubby Foothill Forest
7	408524	5825181	R32 before 9km marker up hill on south (right) side	Upper Yarra 8022-1-2	Shrubby Foothill Forest
8	408756	5825201	R32, south (right) side just after 9km marker	Upper Yarra 8022-1-2	Damp Forest
9	408850	5825130	R32, south (right) side just after 9km marker	Upper Yarra 8022-1-2	Shrubby Foothill Forest
10	408757	5825703	R32, opposite hide north side Yarra east side Gully 3 on ridge	Upper Yarra 8022-1-2	Wet Forest
11	408451	5825978	R32, across flats north side Yarra west side of gully 2	Upper Yarra 8022-1-2	Damp Forest
12	408163	5826426	Across flats on north side, gully 1 on east side of ridge in land before creek jcn	Upper Yarra 8022-1-2	Damp Forest
13	407871	5826245	Across flats on north side, up gully 1 on west side	Upper Yarra 8022-1-2	Wet forest
14	409689	5825162	R32, on straight before R15, south (right) side	Upper Yarra 8022-1-2	Shrubby Foothill Forest
15	410069	5825054	Near junction of R32 & R15, south side	Upper Yarra 8022-1-2	Damp forest

Unit No.	UTM - GDA94		Descriptive location (R = road)	Vicmap 1:25 000 topographic map	Ecological Vegetation Class (EVC)
	N1	N2			
16	409951	5825274	R32, north (left) side just before R15 junction	Upper Yarra 8022-1-2	Riparian Forest
17	410484	5825291	R32 after 11km marker	Upper Yarra 8022-1-2	Riparian Forest
18	410401	5825510	R32, after R15 at approx 11km, across Yarra River	Upper Yarra 8022-1-2	Riparian Forest
19	410089	5825388	R32, after R15 at approx 11km, across Yarra River	Upper Yarra 8022-1-2	Riparian Forest
20	410312	5825882	East end of flats, over river north side	Upper Yarra 8022-1-2	Wet Forest
21	410235	5825787	East end of flats, over river north side	Upper Yarra 8022-1-2	Wet Forest
22	407298	5825283	R32 near 7 km marker opposite Aldermans flat	Upper Yarra 8022-1-2	Shrubby Foothill Forest
23	409768	5824716	Up R15 on east (left) side	Upper Yarra 8022-1-2	Damp Forest
24	410959	5824855	R32 at approx 12 km, north (left) side over Yarra River	Upper Yarra 8022-1-2	Riparian Forest
25	409770	5826731	Via R7, walk south down ridge from VP D1	Upper Yarra 8022-1-2	Wet Forest
26	406005	5838482	Road 2 - nr 3km marker	Lake Mountain 8022-1-1	Damp Forest
27	406550	5837400	Road 2 - sharp corner with large clearing before 5km marker	Lake Mountain 8022-1-1	Wet Forest
28	407069	5836325	Road 2 - north side b/w 5&7km marker	Lake Mountain 8022-1-1	Shrubby Foothill Forest
29	408458	5837953	Road 25 south of Great Britain Ck	Lake Mountain 8022-1-1	Damp Forest
30	413000	5830108	Road 5 - north of Branch Ck, R4 end	Baker Creek 8122-4-3	Wet Forest
31	412587	5829780	Road 5 - hair pin turn south of Branch Ck	Baker Creek 8122-4-3	Wet Forest
32	412754	5829298	Road 5 on straight south of Branch Ck nr 3km marker	Baker Creek 8122-4-3	Shrubby Foothill Forest
33	414017	5823640	Road 9 - east dog bone bit just before 3km marker	Baker Creek 8122-4-3	Damp Forest

Unit No.	UTM - GDA94		Descriptive location (R = road)	Vicmap 1:25 000 topographic map	Ecological Vegetation Class (EVC)
	N1	N2			
34	414927	5823872	Road 9 - south dog bone bit b/w 5&3km marker	Baker Creek 8122-4-3	Wet Forest
35	414527	5822188	Road 13 on corner after 1km marker	Baker Creek 8122-4-3	Shrubby Foothill Forest
36	416859	5826002	Road 5 - hair pin near Road 10 junction	Baker Creek 8122-4-3	Wet Forest
37	417533	5826610	Road 10 near Baker Ck Crossing	Baker Creek 8122-4-3	Damp Forest
38	417508	5824322	Road 9 - past Fehrings Ck nr 9km marker	Baker Creek 8122-4-3	Shrubby Foothill Forest
39	417525	5824849	Road 9 - past Fehrings Ck nr 9km marker	Baker Creek 8122-4-3	Damp Forest
40	418242	5823079	Road 12 - hair pin after crossing Yarra River	Baker Creek 8122-4-3	Shrubby Foothill Forest
<i>O'Shannassy Catchment</i>					
50	391976	5825512	Road 13, south east of Road 18	O'Shannassy 8022-1-3	Riparian Forest
51	391798	5825725	Road 13 on south corner of Road 18	O'Shannassy 8022-1-3	Riparian Forest
52	391644	5826320	Road 13 north east (up hill) on R18, north of large clearing	O'Shannassy 8022-1-3	Wet Forest
53	394437	5828972	Road 16 on west (right) side	O'Shannassy 8022-1-3	Wet Forest
54	393430	5830461	Road 11 on South (left) side of road	O'Shannassy 8022-1-3	Wet Forest
55	396223	5830328	Road 1 near junction of Road 2 down in river valley	O'Shannassy 8022-1-3	Riparian Forest