

CHAPTER 1: INTRODUCTION

1.1 Introduction

Since *Equus caballus* horses and *E. asinus* donkeys were first exploited as domestic animals, their distributions have been drastically altered by humans. The native horse now exists only in captivity. Outside of captivity, the existence of the native wild donkey is confined to a small population in the Danakil region of Ethiopia. While indigenous populations are endangered through habitat loss and competition with humans, populations of domestic and feral horses and donkeys are prevalent worldwide (Berger 1986, Clutton-Brock 1987).

Along with four other species, horses and donkeys are members of the family Equidae, in which only one genus currently occurs. Other extant equids include: *E. burchelli* the plains zebra, *E. zebra* the mountain zebra, *E. grevyi* the Grevy's zebra, and *E. hemionus* the Asiatic hemione (also known regionally as the onager, kulan or kiang). An additional species, the quagga of southern Africa, became extinct in the 1880s when the last known animal died in captivity. Various subspecies occur within each species but phenotypic differences are few, even between species (Waring 1983), and the taxonomy of the family is not uniformly agreed upon (Berger 1986). For example, some authors refer to native wild donkeys as *E. africanus*, and native wild horses as *E. przewalski*, while others relegate these to subspecies within *E. asinus* and *E. caballus* respectively. In captivity, various combinations of the species have been crossbred and are found to produce infertile hybrid offspring (Groves 1974).

Historically, the native equid species largely occurred allopatrically, with relatively narrow zones of sympatry occurring between: the plains zebra and Grevy's zebra in Kenya and Ethiopia; the donkey and Grevy's zebra in northern Africa, and; the plains and mountain zebras in southern Africa. However, the ranges of native horses and donkeys were quite disjunct (Keast 1965, Joubert 1972, Clutton-Brock 1987, Bauer et al. 1994). During the Pleistocene¹, the native wild horse was an inhabitant of the steppes and tundra of northern and central Asia, and Europe. By the end of the last

¹ The Pleistocene is a geological time period that occurred from around 1.8 or 1.5 million years ago to 11,000 years ago; during this period four great ice ages occurred.

post-glacial its range appears to have been reduced by encroaching forests. The native donkey is first known from northern Africa in the early Pleistocene. In ancient times its range extended from the Atlas Mountains to the Red Sea (Clutton-Brock 1987).

The horse was probably first domesticated in the Eurasian grasslands of the Ukraine and Caucasus around 6000 years ago, well into the Neolithic period. It appears the donkey was first domesticated in Egypt or Sudan at least 5500 years ago (Clutton-Brock 1987, Simpson 1951). Once established, the domestication of horses and donkeys soon spread throughout Asia and eventually to Europe, as mounted cavalry, chariots and carts revolutionised warfare and trade (Zeuner 1963). Both species had probably reached western Asia by the early Bronze Age, and their presence is recorded in early historical records kept in the ancient civilisation of Mesopotamia, around 3800 years ago (1800 BC) (Mason 1984). The economic exploitation of these species had become well established in Europe by the Iron Age and included industry, agriculture and general transport (Zeuner 1963). So important was their role, that the first European colonists transported domestic horses and donkeys with them to America and Australia in the 16th and 18th centuries AD, respectively. The widespread need for these power-producing animals lasted until about the middle of the 19th century, when industrialisation and mechanisation of transport became prevalent in developed countries (Mason 1984, Clutton-Brock 1987).

The process of feralisation has occurred since domestication began and, consequently, populations of feral horses and donkeys occur in numerous parts of the world (Lever 1985, Clutton-Brock 1987). The term *feral* is used to describe wild animals whose ancestors were once domestic (Berger 1986). Domestic horses and donkeys once escaped or released, can readily adapt to survival in the wild under a broad spectrum of ecological conditions. Feral animals may be distinguished from free-ranging domestic stock as being subject to natural selection rather than artificial or human selection (Allaby 1991). Donkeys and horses as domestic species, are among those considered least affected by artificial selection, probably because human exploitation of them has centred on their already inherent speed and strength (Simpson 1951, Clutton-Brock 1987).

Large populations of feral horses and donkeys now occur on the Australian and North American continents, and their distributions have been correlated with the spread of European exploration and settlement (McKnight 1964, McKnight 1976). Australia has by far the largest populations in the world, with estimates of horse numbers ranging from 300 000 to 600 000. The majority occur in the remote and extensive cattle-grazing districts of the Northern Territory and Queensland, and in parts of Western Australia and South Australia. Very small scattered populations also occur in New South Wales and Victoria. In the early 1980s, the population of horses in the Northern Territory was estimated at 206 000. Within the Northern Territory, horses are described as common in the Victoria River District, Gulf country, Alice Springs area, and to a lesser extent Arnhem Land (Dobbie et al. 1993). Although not as widespread as horses, feral donkeys occur over much of the interior and north of the Australian continent; the largest concentrations exist in the Victoria River District of the Northern Territory and the adjacent Kimberley region in the north of Western Australia (McKnight 1976). For the whole of the Northern Territory, feral donkey numbers have been estimated at up to 140 000 (Whitehead 1986).

Aerial survey results indicate populations of around 67 000 feral donkeys and 44 000 feral horses in the Victoria River District alone (Saalfield unpub. 1996). Much of their geographic ranges overlap with one another, and/or with that of *Bos taurus* cattle. Cattle numbers in the district are estimated at around 400 000 (Saalfield 1992 pers. comm.). While the majority are free-ranging domestic stock, a small number of feral cattle occur.

Feral ungulates are perceived as a considerable problem to the pastoral industry and to conservation; they are accused of competing with free-ranging domestic cattle and wildlife, and causing damage to both the environment and infrastructure (McKnight 1976, Letts et al. 1979, McCool et al. 1981b, Berman unpub., Dobbie et al. 1993). The control of feral animals is also considered essential to managing the potential risk of the spread of exotic disease (O'Brien et al. 1991). During the 1980s and 1990s, feral cattle were targeted for eradication under the Brucellosis and Tuberculosis Eradication Campaign administered by the Northern Territory and Commonwealth

Governments (Dobbie et al. 1993). In Queensland, feral horses and donkeys are declared noxious animals, and in Western Australia donkeys are declared pests. In the Northern Territory, both species may be given pest status and their management may be enforced under any of four Acts of legislation². Pest management is generally based on reduction of population size and density.

While State and Territory Acts of legislation are administered by government agencies, land managers are responsible for managing feral animals (SSCAW 1991, Dobbie et al. 1993). In national parks, the need for management is as much political as it is impact-driven. Unmanaged populations of feral animals may provide a source, or be perceived as providing a source of animals to invade other properties. In addition, government agencies with delegated responsibility for feral animal management, such as the Northern Territory Parks and Wildlife Commission, are obliged to 'clean up their own back yard' on lands under their direct management, prior to providing advice to other land managers. In 1996 (i.e. subsequent to data collection for this study), 4164 feral donkeys, 2604 feral horses and 675 feral cattle were culled in Gregory National Park in the Victoria River District. From aerial surveys, 5000 feral animals were estimated as remaining within the park (Saalfield 1999 pers. comm.).

Despite their perceived net negative value, a number of feral horses and donkeys are exploited as an economic resource for commercial harvest (Dobbie et al. 1993) (mostly as pet meat, fodder for farmed crocodiles, or exported for human consumption), and to a lesser extent, in tourism. Donkey carcasses yield less meat than those of horses, and donkeys generally have less commercial value. Wild horses are often portrayed as a symbol of Australia's pioneering heritage, or as an aesthetic asset in themselves. Animal welfare groups express concern as to harvesting and transportation conditions (SSCAW 1991, Dobbie et al. 1993), and high levels of public feeling over feral horse culling were demonstrated in 1991, when 7,000 letters of concern were sent from Australian and international sources, to the Commonwealth Department of Primary Industries and Energy (Conservation Commission of the

² In the Northern Territory, pest management may be administered under the following Acts of legislation: the *Territory Parks and Wildlife Conservation Act 1988*, the *Stock Diseases Act 1956-89*, and the *Soil and Land Utilisation Act 1985*. In addition, the *Northern Territory Pastoral Land Act 1992* establishes the pastoral board which can require pastoralists to control feral animals deemed to be causing land degradation (Dobbie et al. 1993).

Northern Territory 1991). Accordingly, feral equids present a complex management problem.

National guidelines for managing vertebrate pests (Dobbie et al. 1993), emphasise the need for management of impacts rather than the pest *per se*, and for consideration of concurrent influences on sustainable land use, such as total grazing pressure with domestic animals and other animal pests, climate, weeds, soil degradation and commodity prices. Recommendations for further action regarding the management of feral horses included the investigation of the biology and environmental impact of feral horses in the wet-dry tropics. This information was identified as lacking and was deemed essential to determining the necessary extent of feral horse management in these areas. Currently, management plans for the wet-dry tropics are based on the assumption that feral horses and donkeys are having an impact, and strategies are formulated in the absence of sound objective data pertaining to their local ecology.

From studies in central Australia, Berman and Jarman (1988) concluded that horses help denude large areas of vegetation and foul water-holes with carcasses. However, they also showed that the indirect impacts of feral horses were difficult to quantify, and that direct environmental changes such as vegetation damage were largely indistinguishable from those of cattle. Dyring (1990) quantified impacts of trampling on soils and vegetation on tracks and stream-banks in subalpine and montane environments in Victoria, and reported that feral horses appeared to either originate or perpetuate changes in the environment. Cattle had not grazed Dyring's study area in the decade prior to the study but were previously present.

Berman (unpub.) and Berman and Jarman (1987) examined the ecology of feral horses in central Australia, including diet, habitat use, interactions with cattle, reproduction, physical condition and social organisation. Using ground-transect survey methods, they found that the components of habitat that most influenced the distribution of horses and cattle were distance from drinking water, relative abundance of annual and palatable perennial grasses, and topography or relief. Among sympatric populations of the two species, horses were more mobile and more selective than cattle. Habitat overlap ranged from 29 to 73%, dietary overlap within

the grass component of their faeces ranged from 42 to 86%, and both habitat and dietary overlap were highest after good rainfall. Condition of horses, foaling rate, harem group size and the mare/stallion ratio were found to decline as the quality and quantity of pasture declined. Berman (unpub.) and Dobbie and Berman (1990) studied the home ranges and movement of feral horses in central Australia, using radio telemetry. Horses were found to have an affinity with their home range, and the population appeared to be more or less separated into harem areas and bachelor areas, influenced by the permanence of water supply. Dobbie and Berman (1991) applied these findings to local management strategies.

Choquenot (unpub., 1990, 1991) examined the population ecology and rates of increase of feral donkeys in the Victoria River District using removal experiments in which two populations of donkeys were counted by aerial survey before and after culling, and data was collected from autopsied donkeys. One of these populations was at or close to equilibrium density while the other was below equilibrium density and recovering from culling. Over a twelve-month period, the size of the former population remained stable, while the size of the recovering population increased by over 20 per cent, with breeding occurring over a discrete season from September to February, and peaking in October and November. McCool et al. (1981) also presented data from 197 donkeys autopsied on the East Kimberley/Northern Territory border, which indicated the occurrence of a breeding season between September and February.

Choquenot (1991) demonstrated that the donkey populations he studied conformed to predictions of the food hypothesis, with abundance being ultimately regulated by food-related juvenile mortality. Differences in juvenile mortality were associated with the nutritional status of lactating females, which in turn was determined by density-dependent competition for quality forage (Choquenot 1991, Freeland and Choquenot 1990). The effects of competition for forage upon juvenile mortality synchronised lactation with the annual flush of quality forage at the onset of the

monsoonal wet season (Choquenot 1991). When both populations were reduced in density by 40 per cent or more, finite rates of population increase were 23 and 28 per cent per annum, with the latter believed to be the maximum potential rate of increase for the species in northern Australia (Choquenot 1990). By constructing numerical models predicting the relative cost of ongoing control, Choquenot (unpub.) also examined the implications of the estimated rate of population increase for the cost of long-term control of feral donkey populations.

Otherwise, research on feral horses and donkeys in Australia has largely concentrated on mapping broad-scale distribution and abundance (McKnight 1976, Graham et al. 1982, Bowman 1985, Graham et al. 1986, Bayliss and Yeomans 1989a, Low and Hewett 1990, Saalfield unpub. 1992 pers. comm., Saalfield unpub. 1996).

Aspects of the behaviour and ecology of wild native, free-ranging domestic, and feral equids living under montane, sub-arctic, cold temperate, warm temperate and mediterranean, semi-arid/steppe, and arid/desert conditions have been studied in Africa, North America, Europe, and to a lesser extent in Asia (e.g. Klingel 1965, Joubert 1972, Klingel 1974, Moehlman unpub., Klingel 1977, Penzhorn 1984, Rubenstein 1986, Ginsberg unpub., Becker and Ginsberg 1990; Feist and McCullough 1975, Berger 1977, Douglas and Norment 1977, Woodward 1979, Miller 1981, McCort 1984, Keiper and Houpt 1984, Berger 1986, Ganskopp and Vavra 1986, Johnson 1987, Stevens 1990; Tyler 1972, Duncan 1983, Mayes and Duncan 1986; Wolfe 1979 and Kaseda 1983). Such studies have demonstrated that equids, like other mammals, neither disperse nor relate to one another randomly; members of a population are found in distinct patterns of dispersion, grouping, and ranging (Crook et al. 1976, Jarman and Jarman 1979). The behaviour that produces a species' social organisation and ecology is adaptive and, as demonstrated in equids, is characteristic of the species. Subtle variations in the ecology of a species occur between populations in different types of environments and, within a given population, aspects such as dispersion and habitat usage within a range are usually subject to seasonal trends.

In Africa, North America and Europe, studies of habitat utilisation and forage selection by equids and their sympatric species have demonstrated the occurrence of resource partitioning within ungulate communities, and provided insights into interspecific competition and facilitation as influential factors (e.g. Bell 1969, Bell 1971, Jarman and Sinclair 1979, Maddock 1979, Pennycuik 1979, McNaughton 1990; Hubbard and Hansen 1976, Hansen and Clark 1977, Hansen et al. 1977, Olsen and Hansen 1977, Salter and Hudson 1980, Seegmiller and Ohmart 1981, Hanley 1982, Hanley and Hanley 1982, Miller 1983; Edwards and Hollis 1982, and Pratt et al. 1986).

However, our understanding of the adaptive strategy of the Equidae is not complete. In Australia, knowledge of the foraging and ranging needs of feral equids, and the role of competition in relationships between them and other free-ranging ungulates, is limited to populations of horses and cattle in the central arid zone. Globally, little is known of the resource ecology of donkeys in the wet-dry tropics, and virtually nothing is known of that of horses in the wet-dry tropics. In addition, virtually nothing is known of their ecological interactions and separation in areas where their ranges overlap. Given that the few wild native equids that still occupy parts of their indigenous range tend to be restricted to marginal remnants of them, it is beneficial and opportune to examine the ecological role of modern equids, in even the most recent and artificially formed of herbivore communities. This information has potential applications for the conservation of threatened native equids as well as the management of feral populations.

1.2 Aims:

This study examines spatial and temporal aspects of the resource ecology and ecological separation of feral horses and feral donkeys in an area of range overlap in the wet-dry tropics of northern Australia.

Specifically, the study aims to:

- determine and compare the relative abundance of feral horses and feral donkeys in the study area, within and between seasons;
- examine and compare seasonal patterns of distribution of the two species over the study area and in relation to land systems (landform and vegetation patterns);
- examine and compare patterns of land unit (landform and vegetation) habitat use and preference of feral horses and donkeys in the study area, within and between seasons; and,
- assess the usefulness and limitations of methodologies used.

CHAPTER 2: STUDY AREA, STUDY ANIMALS AND METHODS

2.1 The study area and animals

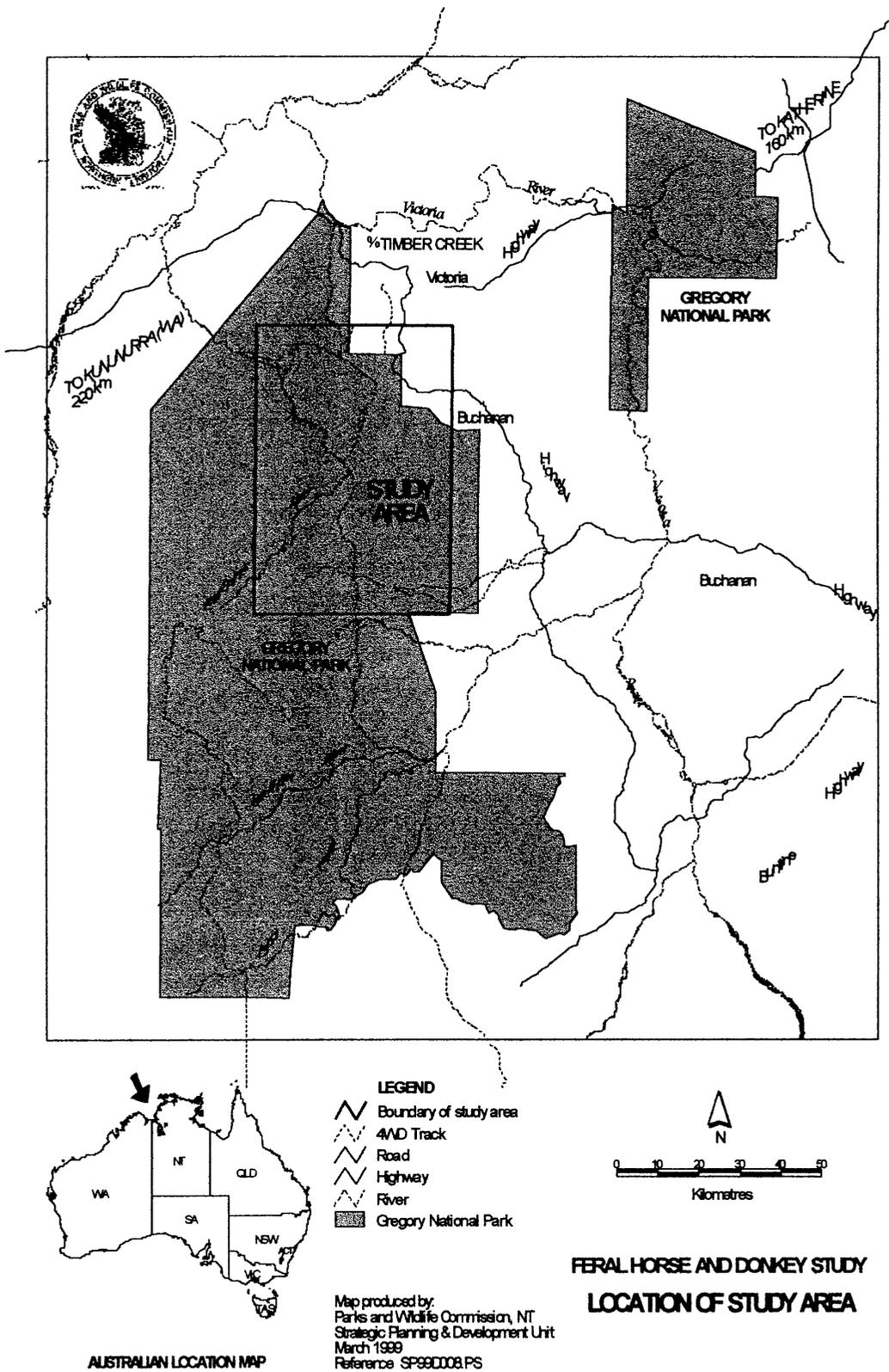
2.1.1 Location

The study was conducted in a 3195 km² area (approximately 50 km x 61 km) bound by latitudes 15°49'30"S and 16°25'30"S, and longitudes 130°13'0"E and 130°40'0"E, and located in the Victoria River District in the north-west of the Northern Territory, Australia (Figure 2.1). Appendix A provides transect coordinates. Most of the study area lies within the Bullita Sector of Gregory National Park, with a small area straddling the adjacent Fitzroy pastoral lease and Wanimiyn aboriginal land. The study area was chosen for its proximity to Bullita Out Station Homestead, from where the study was conducted. The homestead is situated on a bank of the East Baines River and is approximately central to the study area.

The main vehicular access route through the study area ran north from the homestead to adjoin the Victoria Highway near the township of Timber Creek (population ~500). South of the homestead the access track was four-wheel-drive only and difficult to traverse. The Buchanan Highway bisects a small area of the north-east corner of the study area. Elsewhere, vehicular access is largely restricted to four-wheel-drive tracks and tourist/recreational visitation in the park sector is low. Two aboriginal living areas are excised from the park at Barrac Barrac and Bob's Yard.

Land tenure adjoining the park includes several pastoral leases (Amanbidji, Auvergne, Fitzroy, Humbert River, Limbunya, and Victoria River Downs) and the Wanimiyn Aboriginal Land Trust. The predominant land use outside the park is cattle grazing and the park itself is comprised of the former Bullita pastoral lease area as well as parts of several existing pastoral leases. These areas were considered marginal for cattle production and were easily acquired for reservation. The proposed Gregory National Park was approved in July 1984 and the Bullita Sector area was acquired soon after. Aboriginal people occupied the district prior to European settlement.

Figure 2.1: Map of feral horse and donkey study area.



The park boundary was unfenced, and fence-lines erected in former periods of pastoral land use had been derelict for many years prior to the study. Very small holding paddocks existed for domestic horses at Bullita Out Station Homestead, and in the excised Aboriginal settlement area at Barrac Barrac. In terms of influencing animal distribution, the only significant fence-line was on Fitzroy Pastoral Lease in the vicinity of the Buchanan Highway, in a very small area of the extreme north-eastern corner of the study area. Feral animals occurred on both sides of the fence.

2.1.2 Climate and seasons

The study area lies within the wet-dry tropics, a climatic zone characterised by an annual rainfall of 600-1600 mm (Landsberg et al. 1966). The area also fits into the Semi-Arid Zone described by Hooper et al. (1987) (cited in Wilson et al. 1990), characterised by a higher temperature range than the Humid Zone to the north and a mean annual rainfall of 500-1000 mm. Petheram and Kok (1983) described the area of the Victoria River District and Kimberley Region as semi-arid monsoonal. The area is strongly influenced by the monsoon, and rainfall distribution is highly seasonal with almost all rainfall occurring over an annual summer wet season that lasts between 4 months in the southern wet-dry tropics and 7 months in the north. An outstanding feature of the climate is the reliability of the incidence of the wet season.

The highest rainfall recordings in the Victoria River District occur between November and March. However, the duration, intensity and onset of the wet season show appreciable variability (Ridpath 1985). The number of rain days averages around 40 per year, and the amount of annual rainfall may vary by as much as 50 to 60% (Wilson et al. 1990). Mean annual rainfall figures for Bullita, Victoria River Downs (to the south) and Timber Creek (to the north) are 759 mm, 618 mm and 813 mm respectively (Table 2.1). Given that the wet season occurs as a series of short wet periods (rather than as continuous wet weather) and much of the rain falls in isolated intense storms, rainfall is patchy in space as well as time. Appreciable run-off occurs from the medium-textured surface-soils (Stewart 1970) and from rock-outcrop and stony surfaces.

Table 2.1: Means and medians for precipitation at Bullita Outstation in the period from 1916 to 1979 using all available data (Bureau of Meteorology).

Data\Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Mean rainfall (mm)	170	184	136	22	5	2	4	1	3	29	73	130	759
Median rainfall (mm)	170	162	107	3	-	0	0	0	0	8	53	140	729
No of rainfall observations	23	23	21	21	22	23	23	23	23	24	25	25	
Mean no of rain days	11	11	8	8	1	0	0	0	1	5	6	9	52
No of rain day observations	21	21	20	20	21	23	23	23	23	21	20	22	

The wet-dry tropics lie within the consistently hottest region of Australia, with maximum daily temperatures peaking around 38°C during the late dry and early wet seasons, when humidity is also very high (Table 2.2). Humidity levels can vary considerably within a season or month (Slatyer 1970). Minimum temperatures are lowest during the middle of the dry season. The mean daily minimum for the month of July is 10.6°C at Victoria River Downs (Table 2.3). Locally three broad seasons are recognised: (1) a cool, dry season from about April or May through August and into the first part of September; (2) a hot, humid, late dry/pre-wet season or 'build up' beginning during September with a rise in humidity, and lasting through to the full onset of the wet season some time in December, and; (3) a wet season proper from December through March and part of April.

The prevailing wind is south-easterly in the dry season. In the wet season it is north-westerly, though more variable. Changes in length of day with time of year are not marked with the difference between the longest and shortest days in the order of only 2 hours (Slatyer 1970). Bushfires, either natural or man-made (mostly the latter), are an annual occurrence. Within the study area burns tend to be patchy in space.

Tropical evaporation rates are permanently high. At Kununurra and Katherine the mean annual evaporation totals are 2625 mm and 2200 mm respectively, with the highest evaporation rates occurring during the build-up (Slatyer 1970). Ridpath (1985) described the biota in the wet-dry tropics as having to survive a drastic alternation of soil moisture each year, amounting to a change between the hydric status of a desert and that of a rainforest.

Soil moisture availability is the most important factor limiting plant growth in the area and native pastures respond rapidly to the summer rains, providing a flush of palatable and nutritious forage (Slatyer 1970, Petheram and Kok 1983). The start of the period of initial pasture growth ranges from the end of November in the wettest areas of the wet-dry tropics, to early January in the driest areas, and varies between years in any given area. Most variability in growing conditions between years occurs during the transitions between wet and dry seasons (Ridpath 1985). Slatyer (1970) reported the

Table 2.2: Mean relative humidity (%) at Timber Creek (Bureau of Meteorology).

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annum
1981		88	70	54	50	46	-	45	48	46	67	67	
1982	76	86	78	55	46	43	40	41	43	41	61	72	57
1983	70	77	84	62	48	44	40	45	52	51	59	69	58
1984	84	78	80	62	52	43	50	48	47	51	57	75	61
1985	72	83	80	65	52	43	49	54	33	60	-	68	-
1986	78	78	72	46	50	46	-	46	51	62	55	65	-
1987	77	86	66	55	-	-	-	-	-	55	68	69	-
1988	-	-	69	54	-	-	-	38	45	57	65	80	-
1989	76	75	84	-	55	48	-	34	45	-	58	66	-
1990	78	75	76	57	57	44	-	44	-	56	63	68	-
1991	84	90	74	61	46	59	-	44	57	-	69	68	-
Average	77	81	76	57	51	46	43	44	47	53	62	70	
Highest	84	90	84	65	57	59	50	54	57	62	69	80	
Lowest	70	75	66	46	46	43	40	34	33	41	55	65	
No of Entries	9	10	11	10	9	9	4	10	9	9	10	11	

Table 2.3: Climatic data for Victoria River Downs and Timber Creek (Reproduced from Bowman et al. 1988).

Data\Month	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
Victoria River Downs													
Mean precipitation (mm)	145	142	106	19	6	2	3	1	4	17	61	112	618
Mean no of rain days	11	10	8	2	1	0	0	0	1	2	6	9	50
Mean daily maximum temperature (°C)	37.0	35.5	34.7	34.7	31.7	29.6	29.0	32.3	35.5	37.7	38.3	38.1	34.5
Mean daily minimum temperature (°C)	25.0	23.9	23.2	19.8	16.3	12.2	10.8	14.1	18.0	22.0	23.5	24.2	19.8
Timber Creek													
Mean precipitation (mm)	197	201	157	25	5	2	1	0.4	4	27	66	128	833
Mean no of rain days	12	12	9	2	1	0	0	0	1	3	6	9	55

mean duration of pasture growth in land systems dominating the south of the study area as 10 weeks, and in the north as 17 weeks. The period of rapid pasture growth is exceeded by the duration of useful pasture (Slatyer 1970). However, nutrients are rapidly lost from the leaves of perennial grasses at the end of the wet season (Norman 1963), and free-range domestic animal production during the dry season is limited more by herbage quality than quantity (Tothill and Mott 1985). Declining protein and phosphorus content of mature pastures have generally been regarded as the major factors effecting livestock production, but research has shown that the balance of such important dietary constituents as calcium, phosphorus, protein and energy also undergo marked changes as the pastures dry off (Petheram and Kok 1983).

2.1.3 Geomorphology and land systems

The study area lies on the Victoria River Plateau, an area of Adelaidean sediments produced by cycles of marine deposition, and subjected to subsequent uplift. After a period of erosion these rocks were overlain by a sequence of sandstone and shale. The partly dissected plateau is underlain by sandstone, siltstone and carbonate rocks of the Auvergne and Bullita geological groups. The oldest sediments are sandstone and dolomitic rocks and the dolomite contains stromatolites. As a result of volcanic activity in the early Cambrian, some basalt is interbedded with sandstone and chert (Paterson 1970, Traves 1970).

Altitude within the study area ranges between 100m and 350m above sea level. Most of the area comprises mesas, buttes, cuestas, hogbacks, vales and karst areas. Some of the major watercourses have broad flat-bottomed valleys. Rock-paved plains and low, rounded, terraced hills formed on relatively soft siltstone and dolomite also occur. Sandstone and chert (Paterson et al. 1970) cap some of the hills. This combination of units is included in the Tanmurra and Humbert Land Systems described by Stewart et al. (1970).

Tablelands consisting of structural plateaus and benches occupy much of the eastern edge and south-eastern quarter of the study area. In most cases the tablelands are bounded by steep scarps and capped by resistant sandstone. Local relief is in the

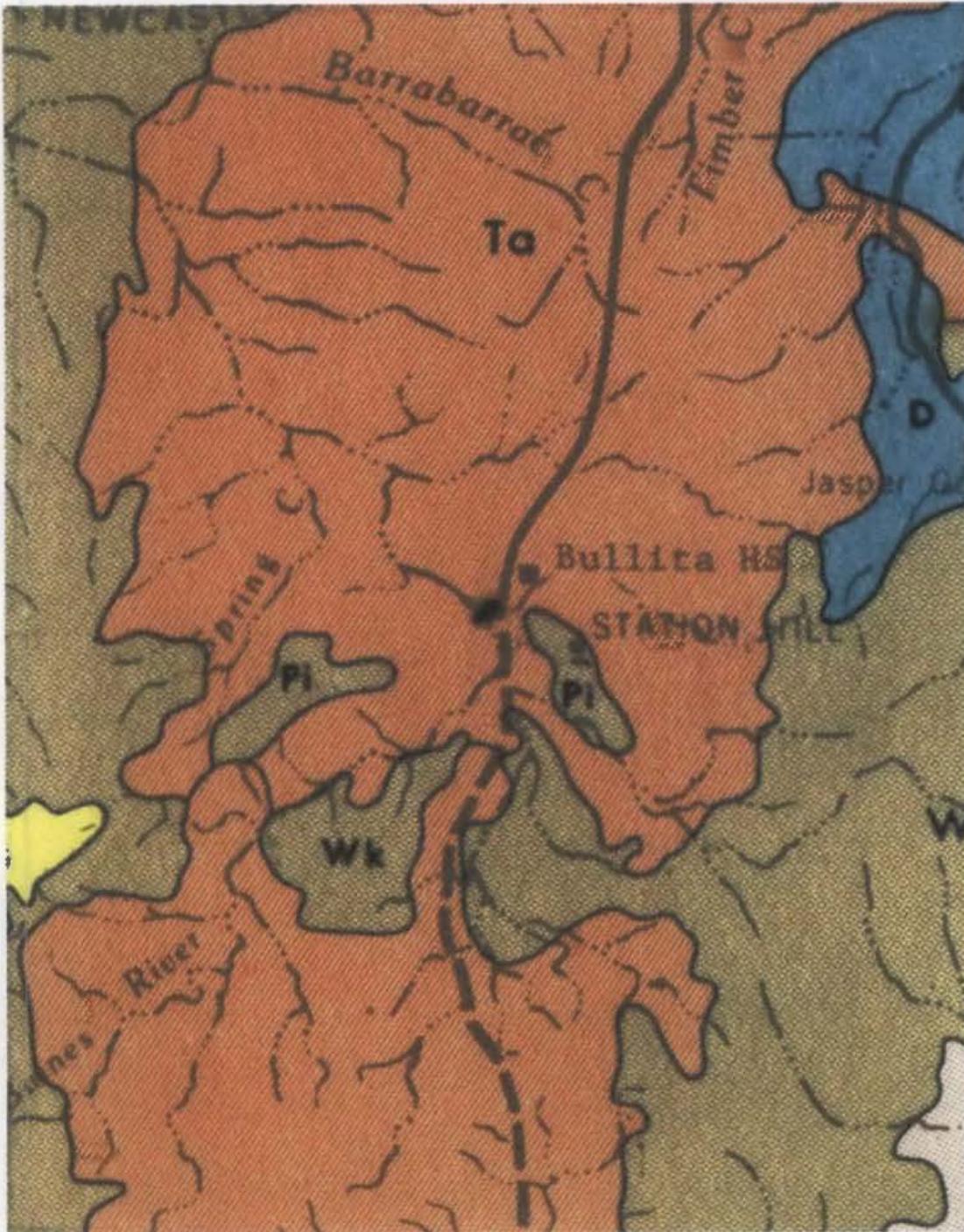
order of 150 to 250 m high. Near the study area boundary, the tableland is incised by gorges. Lateritic and ferruginous soils occur in places. This physiographic unit equates to the Wickham Land System. In the southeastern corner a valley described as 'undulating country on limestone and shale with shallow calcareous soils' is mapped as the Gordon Land System. A very small occurrence on the western margin of the study area is mapped by Stewart et al. (1970) as Geebee Land System.

An area of gently sloping plateaus formed on Jasper Gorge Sandstone (Brocklehurst et al. in press), occurs on the western edge of the study area in the Newcastle Range, and coincides with the Pinkerton Land System. The northeastern corner of the study area comprises inland erosional plains characterised by undulating country interspersed with low residuals, and with alluvium occurring on the creeks (Paterson 1970, Brocklehurst et al. in press). The Dinnabung Land System represents this subunit.

Skeletal sands, lithosols and rock outcrop on hilly land systems dominate the study area. Deeper soils and pastures described as useful by Stewart et al. (1970) are confined to gentle slopes and undulating alluvial plains. Red and yellow earths are common and medium to heavy black cracking clays occur on poorly drained sites (Brocklehurst et al. in press). The soils of the wet-dry tropics are uniformly infertile, largely due to the antiquity of parent material and heavy leaching of nutrients (Ridpath 1985). In particular, most soils in the region are low or deficient in nitrogen and phosphorus (Norman 1963).

The broad land systems described by Stewart et al. (1970) (Figure 2.2) are arranged under pastureland categories. Together the Tanmurra and Humbert Land Systems were described as hilly country with useful pastures in valley areas, but overall as mainly too rough or stony for stock. The Tanmurra Land System was distinguished as ridges, hogbacks, cuervas, and structural plateaus on limestone or dolomitic rocks, with rock outcrop and boulders, and vegetation comprising deciduous sparse low woodland over upland tall grass (rainfall 650 – 875 mm). Humbert Land System was described as ridges, hogbacks, cuervas, and structural plateaus on dolomite, with rock

Figure 2.2: Land systems within feral horse and donkey study area, Gregory National Park, 1993 – 1994 (from Stewart et al. 1970). Area of figure coincides with study area.



Ta: Tanmurra Land System Wk: Wickham Land System Pi: Pinkerton Land System
 Hu: Humbert Land System Di: Dinnabung Land System Go: Gordon Land System
 G: Geebee Land System _____: Dry season 4WD track - - - - -: 4WD only track

outcrops and boulders, and vegetation comprising bloodwood-southern box sparse low woodland over arid short grass (rainfall 425 – 675 mm).

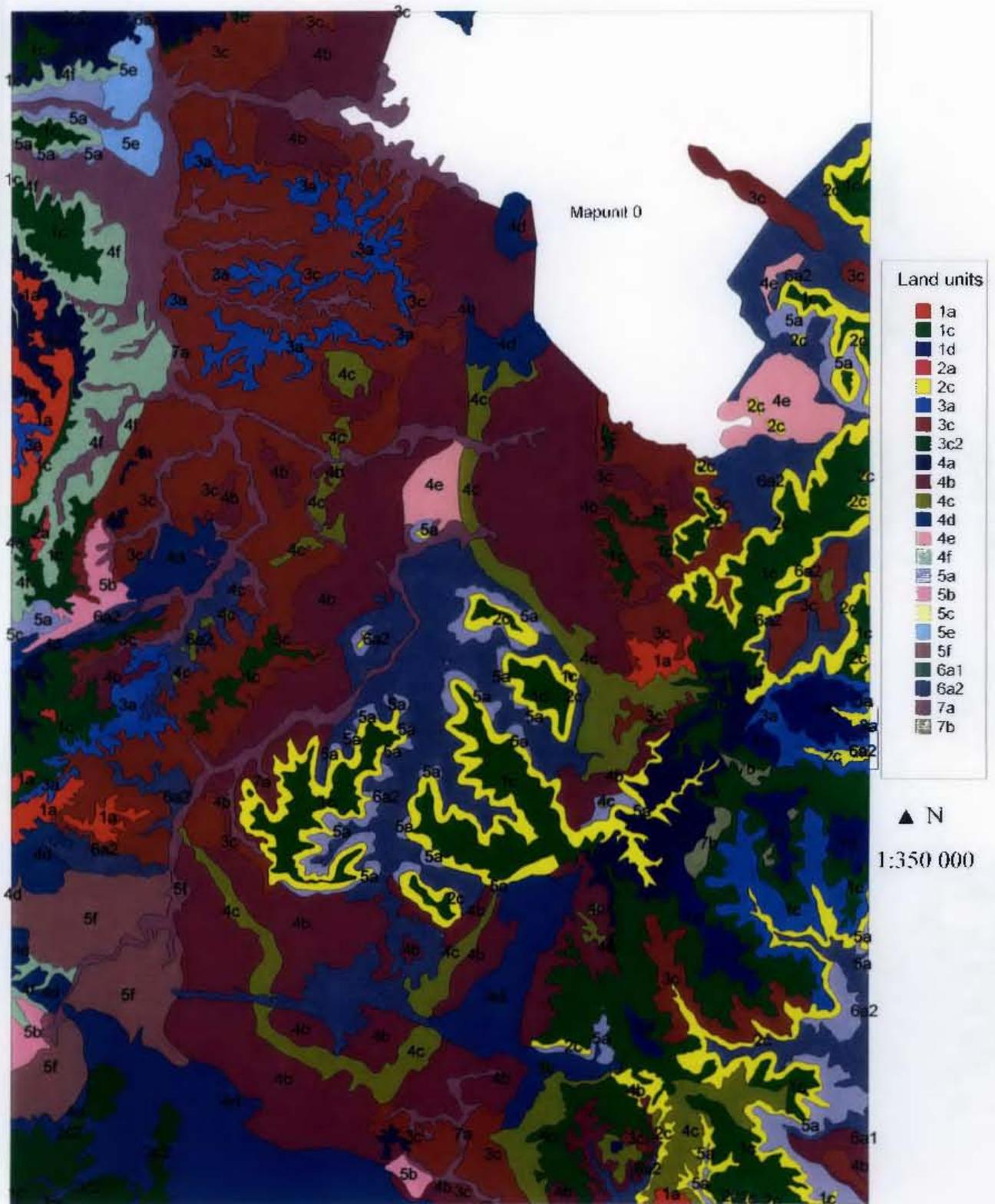
Together, Wickham and Pinkerton Land Systems were classified as rugged hilly country with rock outcrop or skeletal soils. This pastureland was also described as mainly too rough or stony for stock. However, it includes fewer valley areas and these valleys support poor pastures only. Wickham Land System was distinguished as ridges, hogbacks, cuervas, and structural plateaus of sandstone, siltstone and shale, with rock outcrop and skeletal soils, and vegetation comprising snappy gum low woodland over soft spinifex (rainfall 375 – 675 mm). Pinkerton Land System was described as ridges, hogbacks, cuervas, and structural plateaus of sandstone, siltstone and shale, with rock outcrop and skeletal soils, and vegetation comprising stringybark bloodwood woodland over upland tall grass (rainfall 625 - 1250 mm) (Stewart et al. 1970).

The Dinnabung Land System was classified under gently undulating plains with leached loamy soils having low stock-carrying capacity. It was described as occurring on dolomite and shale, with moderate limestone rock outcrop, and vegetation comprising northern box – bloodwood woodland over Tippera tall grass or upland tall grass (rainfall 600 – 1250 mm). The Gordon Land System was classified as gently undulating plains with calcareous soils and low to moderate stock carrying capacity. It was described as occurring on limestone and shale, with shallow calcareous soils, and vegetation comprising bloodwood – southern box sparse low woodland over arid short grass (rainfall 425 – 600 mm). Geebee Land System was classified as lateritic plains with gravelly red soils, snappy gum sparse low woodland over soft spinifex, and low stock carrying capacity (rainfall 375 – 625 mm) (Stewart et al. 1970).

2.1.4 Land units and vegetation

The vegetation of the region is typified by open woodlands with grassy understoreys. It is transitional between taller denser woodlands and forests to the north, and more arid vegetation to the south (Gillison 1983). The study area was stratified into units of habitat type using land units described and mapped (Figure 2.3) at a scale of

Figure 2.3: Land unit map for feral horse and donkey study area, Gregory National Park 1993-4. Reproduced from Brocklehurst et al. (in press).



Note: Area of figure coincides with study area.

1:100,000 by Brocklehurst et al. (in press). Brocklehurst et al. classified thirty-two land units using landform and vegetation descriptions and following the methods of McDonald et al. (1984). Twenty-one land units and one undifferentiated map unit (Map Unit 0) occurred within the study area (Figure 2.3). Descriptions are provided in Table 2.4. Generally the land units did not equate to a singular vegetation community, and were described on the basis of the dominant vegetation. Throughout the national park, sixty-nine vegetation communities were defined by analysis Brocklehurst et al. (in press).

Table 2.4: Descriptions of the land units of Gregory National Park, as defined and mapped by Brocklehurst et al. (in press). Land units are grouped by landform pattern.

LEVEL PLATEAU SURFACES

Main soil group: lithosols.

Land Unit 1a

Geology: Paj (Massive quartz sandstone), Ti

Distribution/description: On low lying plateau and plains. Soils are siliceous sands or lithosols. Rock outcrops usually absent but may reach 35% in some areas.

Vegetation: *Eucalyptus dichromophloia*/*Eucalyptus ferrugenia* mid-high woodland to open woodland with *Plectrachne pungens* hummock grassland.

Land units with similar vegetation: 1c

Land Unit 1c

Geology: Paj (Massive quartz sandstone)

Distribution/description: On flat topped plateaus and mesa surfaces. Soils are shallow sands or lithosols. Slopes vary from 1° to 3°.

Vegetation: *Eucalyptus dichromophloia* mid-high open woodland with hummock grassland understorey.

Associated vegetation types: Varies throughout. Where plateaus surface is broken, *E. miniata* and *E. phoenicea* mid-high open woodland to mid-high woodland can occur. On mesa rims *E. brevifolia* mid-high woodland/open woodland may occur.

Land units with similar vegetation: 1a

Land Unit 1d

Geology: T1 (Laterite and ferruginous lateritic soils).

Distribution/description: On flat plateau surfaces where deeper soils have developed. Soils are lithosols over laterite. Most slopes less than 1%.

Vegetation: *Eucalyptus ferruginea* mid-high open woodland to mid-high woodland with *Plectrarchne* sp. Hummock grassland understorey.

Associated vegetation types: Patches of *Melaleuca viridiflora* and *M. minutifolia* low open forest can occur.

Land units with similar vegetation: 5b

PLATEAUS SIDESLOPES

Main soil group: lithosols and siliceous sands.

Land Unit 2a

Geology: Ela

Distribution/description: On rises, basalt hills and sideslopes of the plateaus. Slopes are up to 24°. Soils are lithosols or areas of bare rock.

Vegetation: *Eucalyptus tectifera*/*E. terminalis* mid-high open woodland with *Sorghum* sp. grassland.

Associated vegetation types: On plateaus surfaces with similar geology, *E. ferruginea* and *E. grandiflora* mid-high open woodlands may occur.

Land units with similar vegetation: 3c.

Land Unit 2c

Geology: Pby (Greyish green and reddish brown siltstone, dolomitic sandstone, dolomite)

Distribution/description: On moderate to steep sideslopes of plateaus and hills. Soils are siliceous sands or lithosols. Slopes up to 60%.

Vegetation: *Eucalyptus brevifolia* mid-high open woodlands/*Plectrachne pungens* hummock grasslands.

DISSECTED PLATEAUS AND RUGGED HILLS

Main soil group: lithosols.

Land Unit 3a

Geology: Paj (Massive quartz sandstone)

Distribution/description: On rugged sandstone hills and dissected plateaus. Slopes are steep with 70% - 90% rock outcrop. Soils are lithosols.

Vegetation: *Eucalyptus brevifolia* mid-high open woodland with *Plectrachne* spp. and *Triodia* spp. hummock grass understorey.

Associated vegetation types: Occurs adjacent to or within *Eucalyptus dichromophloia* mid-high open woodlands of less dissected plateau surfaces and land Unit 1c.

Landunits with similar vegetation: 1c, 5c.

Land Unit 3c

Geology: Pbs (Interbedded dolomite and dolomitic siltstone; minor sandstone and chert).

Distribution/description: On undulating to steep hills with very shallow siliceous sands. Rock outcrop varies from 10%- 90%. Mostly adjacent to flat-topped plateaus.

Vegetation: *Eucalyptus terminalis*/*E. tectifera* mid-high open woodland to woodland with *Sorghum* spp. tussock grassland understorey.

Associated vegetation types: In areas of open rock, dry Monsoon vine forest with *Strychnos lucida*, *Ziziphus quadrilocularis* and *Pouteria sericea* can occur. Other areas may contain *Sorghum* sp. tussock grassland with no overstorey species.

Land Unit 3c2

Geology: Paj (Massive quartz sandstone)

Distribution/description: On undulating and low hills. Soils are shallow lithosols. Rock outcrop varies from 0 - 40%. Mostly adjacent to flat-topped plateaus.

Vegetation: *Eucalyptus brevifolia*/*E. phoenicea* mid-high to low woodland with hummock grassland understorey.

DISSECTED PLATEAUS AND LOW HILLS

Main soil group: lithosols, siliceous sands, and calcareous sands.

Land Unit 4a

Geology: Pby (Greyish green and reddish brown siltstone, dolomitic sandstone, dolomite), Paj (Massive quartz sandstone)

Distribution/description: On rolling low hills sloping down to the West Baines River. Rock outcrops vary from 20% to 40%.

Vegetation: *Eucalyptus phoenicea*/*E. tectifera* mid-high open woodland with tussock or hummock grassland understorey. *E. phoenicea* occurs on hilltops on sandstone outcrops. *E. terminalis* and *E. tectifera* occur on sideslopes or lower slopes.

Land Unit 4b

Geology: Pbs (Interbedded dolomite and dolomitic siltstone; minor sandstone and chert).

Distribution/description: On dolomite rises and low rolling hills. The underlying geology is the Skull Creek formation with fine to medium dolomitic siltstone and

sandstones. Soils are generally shallow lithosols with occasional deeper pockets. Slope varies from 1° to 6°.

Vegetation: *Terminalia arostrata*, *Lysiphyllum cunninghamii*, *Eucalyptus tectifera* mid-high open woodland with annual *Sorghum* spp. tall tussock grassland.

Associated vegetation: Areas of dolomitic outcrop or platforms with pockets of soil may support *Strychnos lucida*/*Ziziphus quadrilocularis* open forest. Slight dolomitic rises may support *Hakea arborescens* mid-high woodland. Bare areas with short grasses and forbs, and *Acacia lysiphloia* tall shrublands with scattered emergent *E. tectifera* or *E. terminalis* are also found.

Land units with similar vegetation: 4c

Land Unit 4c

Geology: Pbu (Massive interbedded fine to coarse clastic dolomite; stromalite bed at top)

Distribution/description: On steep low hills. Soils are lithosols. Areas of bare rock platform occur.

Vegetation: *Terminalia arostrata*/*Eucalyptus tectifera* mid-high open woodland with tussock grassland understorey.

Associated vegetation: Elements of karst landscape occur within the unit, with *Strychnos lucida* open forest. *Terminalia canescens*/*Cochlospermum fraseri* low woodland also occurs. *Acacia lysiphloia* tall shrublands (mostly found on land unit 4d) may also be present.

Land units with similar vegetation: 4b

Land Unit 4d

Geology: Pbt (Interbedded fine grained sandstone, dolomitic siltstone, dolomite).

Distribution/description: On low rolling hills and rises, particularly to the south of Bullita homestead. It also occurs on dolomitic hillocks between plateaus. Soils are lithosols derived from fine-grained sandstone, dolomitic siltstone or dolomite. Slopes vary between 1° and 6°.

Vegetation: *Acacia lysiphloia* tall shrubland with scattered emergent *Eucalyptus tectifica* and/or *E. terminalis*.

Associated vegetation types: Patches of *E.terminalis* and *E. tectifica* mid-high woodland to mid-high open woodland (Land Unit 6a2) can occur.

Land Unit 4e

Geology: Pby (Greyish green and reddish brown siltstone, dolomitic sandstone, dolomite)

Distribution/description: On plains. Soils are lithosols. Rock outcrop to 20%.

Vegetation: *Eucalyptus tectifica* mid-high woodland with *Sehima nervosa*, *Heteropogon contortus* tussock grassland understorey.

Land Unit 4f

Geology: Pig (Interbedded chocolate and greyish green siltstone and fine sandstone).

Distribution/description: West and south of Bullita. Mostly steep sideslopes. Soils are lithosols (20cm - 100 cm deep). Slopes vary from 3° to 22°. Rock outcrops form from 5% to 35% of the ground surface cover.

Vegetation: *Eucalyptus brevifolia* or *E. tectifica* mid-high open woodland with mixed tussock or hummock grassland understorey. *E.tectifica* occurs on steep, rocky slopes and *E. brevifolia* occurs on the lesser slopes (3° - 12°).

RISES AND PLAINS

Main soil group: lithosols and siliceous sands.

Land Unit 5a

Geology: Czs (Sand, red and yellow soil, some ferruginous rubble, colluvium).

Distribution/description: On footslopes of mesas and plateaus. Soils are sandy colluvium derived from surrounding plateaus. Generally eroded and depauperate vegetation or devegetated (scalds).

Vegetation: *Eucalyptus pruinosa* low open woodland with tussock grassland/short forb and grass understorey.

Associated vegetation types: *Acacia lysophloia* tall shrubland (Land Unit 4d) may occur on broken dolomite hillocks within the larger unit.

Land Unit 5b

Geology: Pim

Distribution/description: On shallow siliceous sands (<30cm) on plains or low hills located on flat-topped plateaus. Slopes less than 2° with 5% rock outcrop.

Vegetation: *Eucalyptus ferruginea* mid-high open woodland with hummock grassland understorey.

Land units with similar vegetation: 1d

Land Unit 5e

Geology: Phu

Distribution/description: On hills and low hills in the Wickham River region. Soils are lithosols. Slopes vary from 6° to 20°.

Vegetation: *Eucalyptus terminalis* mid-high open woodland with *Triodia* spp. open hummock grassland.

Associated vegetation: Contains elements of the Monsoon vine-forests on bare sheet rock areas.

Land units with similar vegetation: 3c

Land Unit 5f

Geology: Pbt (Interbedded fine grained sandstone, dolomitic silstone, dolomite).

Distribution/description: On low hills and plains. Soils are siliceous sands or lithosols. Rock outcrop varies from 0% to 90%.

Vegetation: *Acacia lysophloia/Eucalyptus terminalis* mid-high open woodland with hummock/tussock grassland understorey.

Land units with similar vegetation: 4d.

ALLUVIAL PLAINS

Main soil group: black earths, siliceous sands and alluvial soils.

Land Unit 6a2

Geology: Czs (Sand, red and yellow soil, some ferruginous rubble, colluvium)/Qa

Distribution/description: On alluvial plains forming valley floors and flats between plateaus. Slopes are between 1° and 2°. Residual dolomitic rock outcrops occur. Soils are siliceous sands or lithosols (10cm - 600cm).

Vegetation: *Eucalyptus tectifica*/*E. terminalis* mid-high open woodland to mid-high woodland with tall tussock grassland understorey.

Associated vegetation types: On dolomitic outcrops, *Hakea arborescens* mid-high woodland is found. *Acacia lysiphloia* communities and *E. pruinosa* low open woodlands can also occur within this unit.

RIVER SYSTEMS

Main soil group: alluvial soils, lithosols, red and yellow earths and calcareous sands.

Land Unit 7a

Geology: Qa/Czs (Sand, red and yellow soil, some ferruginous rubble, colluvium).

Distribution/description: Occurs along small, seasonally dry creeklines. Soils are unconsolidated alluvial sands or gravels varying in depth. Areas of bare rock occur.

Vegetation: *Lophostemon grandiflora*/*Terminalia platyphylla* open forest to open woodland.

Associated vegetation types: In areas of more permanent water and on larger river systems, the vegetation is similar to that described for 6a2.

Land units with similar vegetation: 6a2

Land Unit 7b

Geology: Qa, Czs (Sand, red and yellow soil, some ferruginous rubble, colluvium).

Distribution/description: In upland drainage depressions. Soils are shallow lithosols (<30cm deep).

Vegetation: *Melaleuca minutifolia* mid-high woodland to mid-high open woodland with tussock grassland understorey.

Associated vegetation types: *Terminalia* spp. mid-high open woodlands may occur.

Land units with similar vegetation: 6a2

UNMAPPED AREA**Map Unit 0**

Area unmapped for land units. Mapped as Dinnabung and Tanmurra Land Systems (Stewart *et. al.* 1970). Predominately Land Unit 6a2 (undulating alluvial plains with woodland or open woodland over tall tussock grassland) and Land Unit 4b (rises and low hills with open woodland over *Sorghum* spp. grassland). Smaller areas of several other land units occur.

2.1.5 The study species***2.1.5.1 Local populations***

The study area supported populations of three introduced non-native ungulate species: *Equus caballus* feral horses, *E. asinus* feral donkeys, and *Bos taurus* cattle. The animals were wild, that is free ranging and subject to no human contact or management other than occasional culling by shooting. Prior to the period of study, any culling had been conducted from the ground using routes accessible by four-wheel-drive vehicle. Consequently, the animals were generally fearful of humans and difficult to approach and observe. Feral horses and donkeys outnumbered feral cattle and were the principal target species for this study. Feral cattle had recently been

targeted for eradication under the Brucellosis and Tuberculosis Eradication Campaign (BTEC). In addition, while local people occasionally hunted feral equids for pet meat or for land management purposes, feral cattle were persistently hunted for human consumption.

Feral horses were of small station-thoroughbred, stock-horse type, estimated as mostly around 15 hands high at the wither when mature. Almost all the horses were bay, brown, grey or chestnut, with or without white face markings and socks. The donkeys were significantly smaller than the horses, and were estimated as mostly around 12-13 hands high. Donkeys were white, grey-dun, dark brown with white extremities and occasionally roan. None of the observed donkeys had leg stripes.

The occurrence of some mules or hybrids resulting from interbreeding between donkeys and horses was recorded in ground studies. A copy of a draft paper on the occurrence of mules in the study area is attached as Appendix B.

2.1.5.2 The ecology of the study species

The Equidae evolved as grazers of open savanna-like environments. They generally weigh between 250 kg and 450 kg (Berger 1986). As large-bodied caecal digesters with complex dentition, they are well adapted to maintaining themselves on a relatively coarse, low quality diet, that is, low-protein, high-fibre grasses (Simpson 1951, Janis 1976, Bell 1971). Unlike ruminants, equids can vary the rate of gut clearance and compensate for poor forage by eating more. They have been described as seeking to improve the predictability of their food supply by maximising the area over which they forage (Geist 1974, Pennycuik 1979). Equids need to drink daily or close to daily; their large body size and locomotor adaptations (such as spring and check ligaments in the fetlock joint), enable them to cruise at speed for considerable distances, and therefore increase their foraging radius from water during dry times (Pennycuik 1979). Large size and mobility also enhance their predator avoidance (Jarman and Jarman 1979, Penzhorn 1984).

A number of virtually identical behaviour patterns and interactions have been recorded in the various equid species (Klingel 1974). This is true of many maintenance and comfort behaviours, as well as those involved in greeting, fighting, mating, social grooming, and importantly, mother-young interactions. In all species the young reside with mothers until either independent or sexually mature, and non-breeding males live alone as bachelors or in bachelor groups (Klingel 1974, Berger 1977, Berger 1986). However, inter-individual relationships may be quite different between species (and even populations), and may be correlated with their diverse patterns of social organisation (Klingel 1974, Rubenstein 1986).

Horses, *Equus burchelli* plains zebra and *E. zebra* mountain zebra, live in closed-membership groups consisting of adult females, their young, and typically a single adult male (Klingel 1974, Rubenstein 1986). Females form permanent or long-lasting relationships (over periods from months to many years) with relative or non-relative females (Penzhorn 1984, Berger 1986). The male maintains mating rights to the females by dominating other adult males that try to associate with the group. Though he may maintain the harem group by driving, herding, and chasing members as well as intruders, he is not always the most dominant member of the group (Berger 1977, Waring 1983, McCort 1984). Harem holding or 'female defence polygyny' (Emlen and Oring 1977) has been referred to as a following strategy (Rubenstein and Wrangham 1986). Males solve the problem of finding highly mobile females by remaining with them.

In contrast, *E. grevyi* Grevy's zebra and donkeys typically exhibit social systems in which female bonds are more ephemeral; temporary aggregations of one or both sexes are common, but mature, breeding males live alone, each in a large territory (Klingel 1974, Rubenstein 1986). Separate grouping of females with foals, and those without, may occur (Woodward 1979, Rubenstein 1986). Woodward (1979) described discernible patterns of social and spatial organisation among feral asses in California as being few.

The onagers have been little studied and insufficient data are available to determine the exact nature of their social systems. Klingel (1977) recorded no apparent associations among any two or more adults, though he described his observations as too short-term to be conclusive.

In donkeys and Grevy's zebra, Klingel (1977) interpreted territorial males as dominant over all conspecifics in their territory (at least other adult males), and adults as dominant over sub-adults and juveniles. In territorial species only a portion of the adult males will be holding territories at any one time, and hence are able to gain undisputed matings (Jarman and Jarman 1973, 1979). In a feral donkey population in California, Moehlman (unpub.) found that a few dominant males occupied areas closest to water, with more subordinate males occupying areas further out. Rubenstein (1986) described Grevy's zebra females in an area of northern Kenya, as ranging between ten and fifteen kilometres a day along major movement routes. Males established their territories along these routes; some were nearer to peripheral water holes that offered protection from predators while drinking, while others were nearer areas of highest grass biomass. Although all types of territories were visited by the wandering females, females with new foals stopped ranging long distances and took up long-term residence (two to three months) near safe water. Since equid females come into oestrus shortly after giving birth, territorial males increased their mating and paternity success by associating with a newly arrived sedentary mother (Rubenstein 1986). Territory holding or 'resource defence polygyny' (Emlen and Oring 1977) has been described as a sit-and-wait strategy (Rubenstein and Wrangham 1986).

Territories are not necessarily maintained throughout the year. For example, Grevy's zebra males hold their territories throughout the growing (rainy) season, which is also the breeding and foaling season, but may abandon them for part of the year (Klingel 1977). Donkey territories observed by Moehlman (unpub.) in an arid area of California were maintained from March through August.

Berger (1977) described the social hierarchies that occur among the horse males and plains and mountain zebras, and the territories of Grevy's zebra and donkeys as

having basic similarities. He suggested that they are resultant extremes of a continuum and that hierarchies exist in both types of female defence; one being expressed spatially, the other socially.

2.1.6 Period of study

The author lived at Bullita Out Station Homestead for nearly four years from early 1990 to late 1993, and traversed the study area by vehicle, on quad-bike, on horseback and on foot on a regular basis, and by air occasionally. In addition to formal studies conducted on the ground and by aerial survey, numerous opportunistic observations were recorded during this period.

This study was conducted over a nine-month period from May 1993 to February 1994. Four aerial surveys of the entire study area were conducted to coincide with seasonal conditions.

Survey dates were:

- (1) 1-3 May 1993: cool, early dry season;
- (2) 9-10 August 1993: cool, mid dry season;
- (3) 11-12 November 1993: hot, humid, late dry season or pre-wet season; and,
- (4) 10-11 February 1994: wet season.

2.2 Data collection

As herbivores often make habitat selection decisions at various levels of resolution (Johnson 1980, Manly et al. 1993), surveys were conducted at two spatial and temporal scales: at the broader scale the distribution of animals was examined at the level of home ranges within a geographic range, that is, feeding or living patches defined by land systems, while at the finer scale intensity of habitat use was examined within the home range, that is, feeding or living sites defined by land units.

All sampling was approached systematically. Systematic sampling provided comprehensive coverage and had the advantage of relative objectivity as it enabled

the distribution of animals to be determined before the habitat was stratified according to human preconceptions (Taylor and Friend 1984).

The distribution and abundance of feral horses and donkeys was sampled in a 3195 km² area by aerial survey. The survey was conducted four times, at three-monthly intervals over a 9-month period (May, August, November and February), and was timed to sample distributions during recognisable seasons (refer section 2.1.6). Surveys were designed to yield a linear index or relative estimate of density.

The mid-lines of thirty-six approximately 48 km long (27 minutes of longitude), east-west parallel transects, spaced at approximately 1.85 km (one minute of latitude), were flown in a four-seater Cessna 182 high-wing aircraft at an average ground speed of 185 km/h (100 knots) and an average altitude of 60 m (200 ft) above ground level (determined by radar altimeter). The transect width of 400 m (200 m either side of the aircraft) was delineated at survey altitude by fibreglass rods attached to the aircraft, as per Marsh and Sinclair (1989). The survey yielded a sampling intensity of 23%. Groups of horses, donkeys and cattle within the transect strip were counted by three observers, two starboard and one port. The two starboard observers positioned in front and rear seats, counted independently of one another in the same transect half to provide a double-count. Starboard observers were acoustically isolated from one another by head-phones and the noise of the aircraft. Starboard sightings were recorded onto an audio-cassette via a two-track tape recorder and the port sightings were recorded on a separate audio cassette.

The orientation of transects was chosen to cross the river and the major geomorphic and vegetation gradients in the study area at right angles, in order to sample as many land units as possible, and in an attempt to minimise variation in density between transects.

The date and time of day at which transects were flown, direction of travel, the identity and seating position of the observer, and the transect number were recorded at the commencement of each transect. As a priority, observers recorded the species, number of individual animals, and the number of foals present in each animal group

sighted ($n \geq 1$). In all cases, the number of animals in a group was sufficiently small to permit counting rather than estimating of numbers. The location of animals in the habitat, habitat type, and the activity of animals were also recorded, along with opportunistic comments on animal body condition, age-class, sex, reproductive status and any unusual or identifying features. For horses, the type of social group, either bachelor or harem, was discernible from the air in some cases, regardless of the presence or absence of foals. In addition, the presence of water in and outside the transect, the presence of pads (well-defined animal walking tracks) and the land unit in the sample strip were recorded. Time between sightings was also sufficient to permit records of animals sighted outside the transect. However, these data were considered of little use as the distances of sightings from the transect midline were not estimated. No attempt was made to re-identify animals from surveys in previous seasons. A sample of the data set is included as Appendix C.

The rear starboard observer had extensive experience in aerial survey of various types of wildlife, including feral horses and donkeys in the Victoria River District (Saalfield 1992 pers. comm.). While the port and front starboard observers had little aerial survey experience prior to this study, each had a strong interest in horses and donkeys and was capable of distinguishing sex and age classes where visibility and observation time permitted. In addition, both these observers were resident in the district and had an intimate knowledge of the area and type of country sampled. For the third (November) survey the rear starboard observer was not available and was substituted with another observer with prior experience in aerial survey. In an aerial census of wild horses in western Utah, Frei et al. (1979) showed that observer experience had a significant effect on the number of animals counted in a survey, with more experienced observers obtaining higher counts than observers with little or no experience. Better counts were also obtained from those familiar with the area on the ground and from the air.

The pilot was responsible for navigation and located transects using a Global Positioning System (GPS) in which the end point coordinates had been stored. The start and finish of each transect was indicated to the observers and the survey recording equipment by the pilot (by sight and sound). As a consequence of the

survey design, consecutive transects were flown in alternate directions (either east-west or west-east). Transects were flown in daylight hours. The time taken to fly each transect was approximately 16 minutes. Each survey took 2 working days to complete, including ferry time to refuelling stations, refuelling time and midday breaks. Transects were sampled in numerical order with approximately half of the survey area covered each day. No attempt was made to account for behavioural changes in habitat use by animals with time of day. However, the results of on-ground observations suggested that the patterns of habitat use by the target species, horses and donkeys, did not alter noticeably with time of day.

On completion of the survey, the voice-tape recordings were transcribed using a stop watch to record the lapse time to each sighting recorded after commencement of a transect flight. Sightings were then edited onto computer files in EXCEL, and the longitude of each sighting on a given transect was calculated from the elapsed time of the sighting as a proportion of time taken to fly the transect, for which latitudinal and longitudinal coordinates were known, as shown in Appendix C. Constant aircraft and tape speeds were assumed. From the derived coordinates, sightings were digitally mapped and stored as point data with attributes, using the MAPINFO geographic information system. Data were analysed and statistical tests run in EXCEL. Graphics were produced in WORD.

CHAPTER 3: DENSITY AND ABUNDANCE

3.1 Introduction

Ecology is the scientific study of the interactions that determine the distribution and abundance of organisms (Krebs 1985). For any species, a thorough understanding of its ecology is essential to the establishment of well-based management programs (Johnson 1980), and determining population abundance is fundamental.

Broad-scale aerial survey, using fixed-wing aircraft, is often the only practical way of sampling population abundance in large mammals occupying large areas (Caughley 1977, Johnson 1980). Aerial surveys provide three types of information from which management regimes can be determined, including: (1) estimates of population density; (2) description of the distribution of animals over an area or areas, and; (3) if repeated, identification of any trends in population size over time (Southwell 1989, Pople 1999). For example, using repeated aerial surveys, Choquenot (1990, 1991) examined the abundance and rates of increase of two feral donkey populations in the VRD, and that of two feral horse populations in Oregon was investigated by Eberhardt et al. (1982).

The effectiveness of survey techniques used to monitor populations is critical to the management of large ungulates. This effectiveness is usually defined in terms of accuracy, repeatability and precision, with the relative importance of these three properties being determined by the specific aims of the monitoring program (Cairns 1999).

Accuracy, or bias, is the closeness of a measured value to its true value (Krebs 1989, Cairns 1999). Transect based survey techniques are recognised as being negatively biased (Caughley 1977, Caughley 1980, Caughley and Grice 1982) and much research has focused on visibility bias in aerial counts of red, eastern grey, and western grey kangaroos in inland Australia. This interest arises from the reliance of management plans for kangaroos, on annual estimates of their absolute abundance (Choquenot 1995). If visibility bias can be estimated, it can be used to correct the raw sighting index, and translate it into an actual or absolute population abundance estimate

(McCallum 1999). While indices of density (abundance per area e.g. number per square kilometre) are useful for comparative purposes (particularly of one population over time), absolute population estimates are often necessary, such as for setting harvesting quotas for kangaroos, or to derive minimum off-take requirements for feral animals (McCallum 1999).

Visibility or sightability is the probability of seeing an animal, given that it is present within the area being counted (McCallum 1999). Visibility bias encompasses two sources of bias: perception bias and availability bias. Perception bias is the proportion of groups of the target species that are visible in the transect yet missed by observers. Availability bias is due to those animals that are not available because they are concealed (such as by topography, dense vegetation, turbid water or other animals) (Marsh and Sinclair 1989).

If the aim of a sampling program is to monitor the size of a population over time, then repeatability and precision become more important than accuracy. Precision (exactness) is defined as variation arising from sampling error (Southwell 1989). Precision is determined by the variability of density between sampling units and the number of entities (animal groups) counted (Caughley and Sinclair 1994). It is influenced directly by sampling intensity and the more clumped the animals, the more sampling units are needed (Caughley 1980, Southwell 1989). Precision is obtained not only by taking a large sample, but by sampling in the most efficient manner, and through rigid standardisation of survey methods (Caughley and Sinclair 1994). Precise estimates have low coefficients of variation.

Repeatability generally refers to the closeness of repeated measurements (Southwell 1989) or constancy of bias among samples (Pople 1999), and reflects variation inherent in the technique. A monitoring technique is generally repeatable if it is unaffected by the conditions under which it is used, that is, any proportional difference in population size between any two areas or times is reflected in the same proportional difference in the index derived by that technique. Conducting aerial surveys in a standardised way under standardised conditions should lead to repeatable and comparable indices of abundance (Southwell 1989).

In aerial surveys, animals are counted as groups and as individuals within groups, and mean group size estimates are used in the calculation of population estimates. As group size is also an important aspect of a species' social system, group size data is presented in this chapter. Rubenstein (1986) described group sizes, spatial dispersion and mating systems, as changing in response to changes in environmental forces. How this shaping process operates depends on how environmental forces affect the behavioural decisions of individuals attempting to increase their reproductive success.

This chapter compares (a) population abundance estimates between species; (b) population abundance estimates within species between survey months, and over the period of survey, and; (c) patterns of population change over time between species. The results are examined in terms of accuracy, precision and repeatability in order to assess their usefulness and the applicability of methods.

3.2 Methods

3.2.1 Correcting for perception bias in the aerial survey

Several authors have demonstrated that aerial survey counts are negatively biased, that is, population abundance is underestimated (Caughley 1977, Samuel and Pollock 1981, Caughley and Grice 1982, Bayliss and Yeomens 1989, Marsh and Sinclair 1989). To estimate the true number of groups available to observers, a survey-specific perception correction factor was derived for each species in each season using the starboard double-count, as per the methods of Marsh and Sinclair (1989), based on the Petersen mark-recapture model used by Caughley (1977). Two assumptions are implicit in this method: (1) that the two counts are uncolluded; and, (2) that there is a constant probability of seeing an entity on a given survey (equal sightability). However, it is generally accepted that the second assumption is not critical (Caughley and Sinclair 1994).

The perception correction factor (C) was calculated following Marsh and Sinclair (1989):

$$C = \frac{(S_f + b)(S_r + b)}{b(S_f + S_r + b)} \quad \text{equation 3.1}$$

Where: S_f = number of groups seen by the starboard-front observer only,
 S_r = number of groups seen by the starboard-rear observer only, and
 b = number of groups seen by both observers.

The estimated coefficient of variation (CV) of the perception factor was calculated following Marsh and Sinclair (1989):

$$CV = \frac{S_f + S_r}{S_f + S_r + b} \cdot \frac{S_f S_r}{\sqrt{b(S_f + b)(S_r + b)}} \quad \text{equation 3.2}$$

Observer detection probabilities (P) were calculated following Caughley and Grice (1982):

$$P_f = \frac{b}{b + S_r} \quad \text{and} \quad P_r = \frac{b}{b + S_f} \quad \text{equation 3.3}$$

The use of the two-track tape recorder, in conjunction with recorded observer comments on animals and habitat, reduced errors in deciding which groups were sighted by both observers (Marsh and Sinclair 1989). When in doubt, animals were categorised as seen by both starboard observers if sightings of the same species were recorded within 10 seconds (600 m) by each observer.

For each species, the corrected number of animals per sample unit was obtained by multiplying the correction factor by the number of groups of animals and the mean group size of the species. Mean group size was based on all within-transect sightings. No attempt was made to incorporate Marsh and Sinclair's environmental or availability correction factors (developed for dugongs).

3.2.2 Population density estimates

Following Caughley and Sinclair (1994), total corrected density (D) was estimated as the sum of the strip transect counts (y) divided by the sum of the area of strip transects (a):

$$D = \Sigma y / \Sigma a \quad \text{equation 3.4}$$

With the standard error calculated by:

$$SE = n / \Sigma a \sqrt{(1/n(n-1))(\Sigma y^2 + D^2 \Sigma a^2 - 2D \Sigma ay)} \cdot \sqrt{(1 - (\Sigma a)/A)} \quad \text{equation 3.5}$$

where n = the number of sampling units and A = the survey area.

The estimated overall densities of each species in the survey area were then extrapolated using the ratio estimate, that is, the sum of the product of the density estimate of each sample unit (D_h), and the *proportion* of the total area occupied by each sample unit (U_h), as per Morgan (1986):

$$D = \Sigma (U_h D_h) \quad \text{equation 3.6}$$

Confidence intervals for overall density estimates were derived by calculating the standard error of the overall estimate:

$$SE = \sqrt{\frac{\Sigma [(U_h^2 S_h^2)]}{n_h}} \quad \text{equation 3.7}$$

where S_h is the standard deviation and n_h is the number of samples.

Density estimates (D: animals per square km) were in turn used to calculate abundance or the estimated number of animals (Y) in the survey area (A), as per Caughley (1977), and Caughley and Sinclair (1994):

$$Y = AD$$

The standard error of Y was calculated by:

$$SE = \frac{An}{\Sigma a} \sqrt{\frac{1}{n(n-1)} (\Sigma y^2 + D^2 \Sigma a^2 - 2D \Sigma ay) \sqrt{1 - (\Sigma a)/A}} \quad \text{equation 3.8}$$

Within each of the four aerial surveys, data from port and starboard observer stations were pooled and treated as a single sample for analysis. Transects were used as the main sample units for overall density estimates.

3.3 Results

3.3.1 General observations

Thirty-six strip transects were flown in each of four seasonal aerial surveys of the 3195km² study area. Surveys were conducted in May, August, November and February as planned. Over the four surveys, 510 horse groups and 100 donkey groups were sighted within strip transects, yielding sighting rates of 13.2 horse groups per hour (0.22/min) and 2.6 donkey groups per hour (0.04/min). No mixed groups were recorded. Table 3.1 shows the number of groups sighted, mean group size and perception correction factors derived for each of the four seasonal aerial surveys.

Only 8 cattle group sightings of 27 individuals were recorded throughout the four aerial surveys. Within surveys, a maximum number of three cattle group sightings was recorded in May (12 individuals, 1 group on each of transects 12, 24 and 32). Consequently, this species was not included in further analyses. Using data from the May aerial survey, the uncorrected density of cattle in the study area was calculated at 0.017/km² and abundance at 55 cattle.

Two horse groups sighted contained a mule. The groups occurred adjacent to one another in the same strip transect (15) and survey (May), with one group observed on the port side and the other group observed on the starboard side of the aircraft. Recorded sightings of the two mules were confirmed by on-ground observation in the same area. For analysis, the mules were counted as horses.

In February, a group of 4 dead donkeys was sighted during survey, near the East Baines River at Barrac Barrac. It was evident that the animals had been shot very recently. Dead animals were excluded from the data set.

3.3.2 Double count and perception correction factors

The simultaneous counts by starboard observers produced survey-specific correction factors for perception bias averaging 1.09 for horses and 1.20 for donkeys over the four surveys. This indicates that on average 92% of horse groups and 84% of donkey groups estimated to be available, were detected by one or more of the two starboard observers. The coefficient of variation for all correction factors was below 20% and sufficiently precise at the 80% confidence level (Table 3.1).

Over the four surveys, detection probabilities (equation 3.3) for each starboard-team observer averaged 0.72 for horse groups, and 0.56 for donkey groups. The mean difference in detection rates between starboard observers (i.e. the proportion of all recorded starboard sightings that were detected by a particular starboard observer) was 0.04 (range 0.01 to 0.09) for horse groups and 0.25 (range 0.20 to 0.36) for donkey groups (Table 3.2). The difference in these means was statistically significant (T-test, $t = 5.195$, 6 df, $P < 0.05$).

The starboard-front observer sighted a total of 257 horse groups and 44 donkey groups over the four surveys, and the starboard-rear observer sighted 251 horse groups and 35 donkey groups. In combination, the two observers sighted 325 horse groups and 57 donkey groups. The increase in groups sighted on the starboard side of the aircraft due to the presence of a second observer, was 23% (front observer) or 21% (rear observer) for horse groups, and 39% (front observer) or 23% (rear observer) for donkey groups. When starboard and port sightings were combined, 14% (front observer) or 13% (rear observer) more sightings were recorded due to the presence of a second starboard-side observer (i.e. with a total of three observers instead of two).

Table 3.1: Counts of feral horse groups and feral donkey groups sighted by each of three observers, and perception correction factors derived from starboard double-counts (Petersen estimator) in each of four aerial surveys of feral horses and feral donkeys in Gregory National Park, 1993-1994.

Season	Number of groups recorded by observers ¹					Correction factor (CV)	Mean group size (CV)
	S _f	S _r	b	Port	Total		
Horses							
May 1993	14	15	47	37	113	1.06 (0.01)	3.87 (0.06)
August 1993	17	21	37	56	131	1.13 (0.03)	3.33 (0.05)
November 1993	18	16 ²	59	42	135	1.05 (0.01)	3.84 (0.05)
February 1994	25	16	40	50	131	1.12 (0.03)	4.05 (0.06)
Total	74	68	183	185	510		
Donkeys							
May 1993	5	2	6	16	29	1.13 (0.07)	3.96 (0.11)
August 1993	3	7	5	5	20	1.28 (0.14)	3.75 (0.16)
November 1993	6	1 ²	6	8	21	1.08 (0.06)	2.57 (0.18)
February 1994	8	3	5	14	30	1.30 (0.15)	3.43 (0.11)
Total	22	13	22	43	100		

¹ S_f = seen by starboard-front observer only; S_r = seen by starboard-rear observer only; b = seen by both starboard observers; Port = seen by port-side observer.

² Different person in starboard-rear observer position in November than in other months.

Over the four surveys, the front and rear-starboard observers each detected 97% of all individual horses detected within jointly sighted groups. The proportion of individual donkeys detected by each starboard observer were 95% (front) and 99% (rear), yielding an overall difference of 4% between observers (Table 3.3). In the November 1993 and February 1994 surveys (i.e. the last two conducted), both observers detected 100% of all individual donkeys detected. The mean differences in the proportion of individual animals sighted on the starboard side of the aircraft by each of the starboard observers, were 1.5% for horses and 2.7% for donkeys.

For horses, the mean group size of groups detected by both starboard observers was higher than the mean group size of groups detected by only one starboard observer in all months, but only significantly so in August (T-test, $t = 2.10$, 74 df, $P < 0.05$) and November (T-test, $t = 3.00$, 89 df, $P < 0.05$) (Table 3.4). For donkeys, the mean group size of groups detected by both observers was higher in August and February, and lower in May and November, than the mean group size of groups detected by one observer. Differences between the two means were not significant for donkeys in any survey month (Table 3.4).

A significant association was found between the proportion of horse singletons and non-singleton groups detected by one observer relative to that detected by both observers. For horses, the proportion of singleton groups detected by one observer only, was lower than expected relative to the proportion detected by both observers (Chi-squared test, $\chi^2 = 8.079$, 1df, $P < 0.05$). No significant association was found for donkeys (Chi-squared test, $\chi^2 = 1.569$, 1df, $P = 0.210$ /ns).

Combining data from all four aerial surveys and using only those land units where sample sizes were greater than 10 groups, detection probabilities were derived for land units. Data was sufficient to allow a qualitative comparison of detection probabilities in 8 land units for horses and in 3 land units for donkeys (Table 3.5). Detection probabilities for horses appeared to be relatively low in the *Acacia* tall shrublands on low hills and rises (Land Unit 4d), *Acacia-Eucalyptus* open woodlands on low hills and plains (Land Unit 5f), and the Riparian zones with *Lophostemon-Terminalia* open forest to open woodland. In the field, the vegetation cover in these

Table 3.2: Probabilities of detection (P) of feral horse groups and feral donkey groups, by starboard-front (P_f) and starboard-rear (P_r) observers, in each of four aerial surveys in Gregory National Park, 1993-1994.

Survey	May 1993			August 1993			November 1993			February 1994		
Observer	P_f	P_r	mean	P_f	P_r	mean	P_f	P_r	mean	P_f	P_r	mean
Horse groups	0.77	0.76	0.77	0.64	0.68	0.66	0.79	0.77	0.78	0.71	0.62	0.66
Donkey groups	0.75	0.54	0.64	0.42	0.62	0.52	0.86	0.50	0.68	0.62	0.38	0.50

Table 3.3: Proportion (%) of groups, and individuals within jointly sighted groups, of feral horses and donkeys detected by each starboard-team observer (i.e. detection rates) in each of four aerial surveys in Gregory National Park, 1993-1994.

Survey	May 1993		August 1993		November 1993		February 1994	
Observer	front	rear	front	rear	front	rear	front	rear
Horses								
Groups	80	81	72	77	83	80	80	69
Individuals	95	97	96	99	97	97	99	98
Donkeys								
Groups	85	61	53	80	92	54	81	50
Individuals	89	100	95	95	100	100	100	100

Table 3.4: Comparison of mean group size of horse groups and donkey groups detected by both starboard observers, with mean group size of groups detected by only one starboard observer.

Mean group size of groups	May 1993	August 1993	November 1993	February 1994	Total
Horses					
Detected by both observers (a)	3.78 (n = 47)	3.64 (n = 36)	4.25 (n = 59)	3.95 (n = 40)	3.90
Detected by only one observer (b)	3.45 (n = 29)	3.00 (n = 40)	2.91 (n = 34)	3.29 (n = 41)	3.12
Difference (a-b)	+0.33	+0.64	+1.33	+0.66	+0.78
Difference as proportion of a (%)	9	22	31	17	20
Donkeys					
Detected by both observers (a)	3.50 (n = 6)	4.80 (n = 5)	2.00 (n = 6)	4.00 (n = 5)	3.57
Detected by only one observer (b)	4.00 (n = 7)	2.70 (n = 10)	2.43 (n = 7)	3.36 (n = 11)	3.12
Difference (a-b)	-0.50	+2.10	-0.43	+0.64	+0.45
Difference as proportion of a (%)	14	44	21	16	13

Table 3.5: Starboard observer detection probabilities for horse groups and donkey groups sighted in each of several land units during four aerial surveys in Gregory National Park, May 1993 – February 1994.

Land Unit	Topography	Vegetation	P _f	P _r	Mean P	Sample Size (n)
Horses						
4c	Steep low hills.	<i>Eucalyptus</i> open woodland.	0.83	1.0	0.92	18
4b	Rises and low hills.	<i>Eucalyptus</i> open woodland.	0.81	0.80	0.80	82
0			0.75	0.73	0.74	56
6a2	Alluvial plains.	<i>Eucalyptus</i> open woodland to woodland.	0.70	0.74	0.71	25
3c	Undulating to steep hills.	<i>Eucalyptus</i> open woodland to woodland.	0.73	0.69	0.71	40
4d	Low hills and rises.	<i>Acacia</i> tall shrubland.	0.61	0.46	0.53	31
7a	Riparian zone.	<i>Lophostemon-Terminalia</i> open forest to open woodland.	0.43	0.62	0.52	29
5f	Low hills and plains.	<i>Acacia-Eucalyptus</i> open woodland.	0.54	0.43	0.49	19
Donkeys						
7a	Riparian zone.	<i>Lophostemon-Terminalia</i> open forest to open woodland.	0.71	0.50	0.61	12
3c	Undulating to steep hills.	<i>Eucalyptus</i> open woodland to woodland.	0.62	0.56	0.59	12
6a2	Alluvial plains.	<i>Eucalyptus</i> open woodland to woodland.	0.50	0.50	0.50	15

land units was observed to be dense. However, insufficient data was available to demonstrate an association between vegetation cover and probability of detection through statistical analyses.

3.3.3 Group size

Horse group size ranged from 1 to 17 and donkey group size ranged from 1 to 12. Over the four aerial surveys, most horse groups (81%) and most donkey groups (84%) comprised between 1 and 5 animals (Figure 3.1, Figure 3.2). The mean horse group size of 3.77 was not significantly different from the mean donkey group size of 3.43 (T-test, $t = 1.168$, 140df, ns). While mean group size was not significantly different between species within the May (T-test, $t = 0.196$, 42 df, ns), August (T-test, $t = 0.679$, 22 df, ns), and February (T-test, $t = 1.163$, 159 df, ns) aerial surveys separately, it was significantly greater for horses than for donkeys in the November aerial survey (T-test, $t = 2.365$, 154 df, $P < 0.05$) (Table 3.1). When data for the four aerial surveys was combined, variance in group size was not significantly different between donkeys (5.40) and horses (5.32) (F-test, $F = 1.015$; 99, 509 df; ns). In addition, there was no significant difference in variance in group size between species in the May (F-test, $S^2=5.35$ horse, $S^2=5.89$ donkey; $F = 1.101$; 28, 112 df; ns), November (F-test, $S^2=5.33$ horse, $S^2=4.36$ donkey; $F = 1.224$; 134, 20 df; ns) or February (F-test, $S^2=7.37$ horse, $S^2=4.11$ donkey; $F = 1.800$; 130, 29 df; ns) surveys. However, in the August survey, when variance in donkey group size (7.25) was at its greatest, and that of horses (3.08) was at its lowest, the difference between the two was significant (F-test, $F = 2.351$; 19, 130 df; $P < 0.05$) (Figure 3.3, Figure 3.4).

As Cochran's C test statistic revealed a significant departure from homogeneity of variance in group size between survey months for both surveys (horses: $C = 0.536$, 4 k, 126 df; donkeys: $C = 0.504$, 4 k, 24 df), these data were transformed to logarithms (after the addition of 0.1) for analysis (following Caughley and Sinclair 1994). Mean horse group size did not vary significantly between survey months (1-way ANOVA, $F = 1.011$, 3, 506 df, $P = 0.387$ /ns). Change in mean donkey group size was not significant at the 95% confidence level (1-way ANOVA, $F = 2.384$, 3, 96 df, $P = 0.074$), it was significant at the 90% confidence level.

Figure 3.1: Size-class distribution of feral horse groups (n = 510) sighted in strip transects over four aerial surveys, Gregory National Park, May 1993 - February 1994.

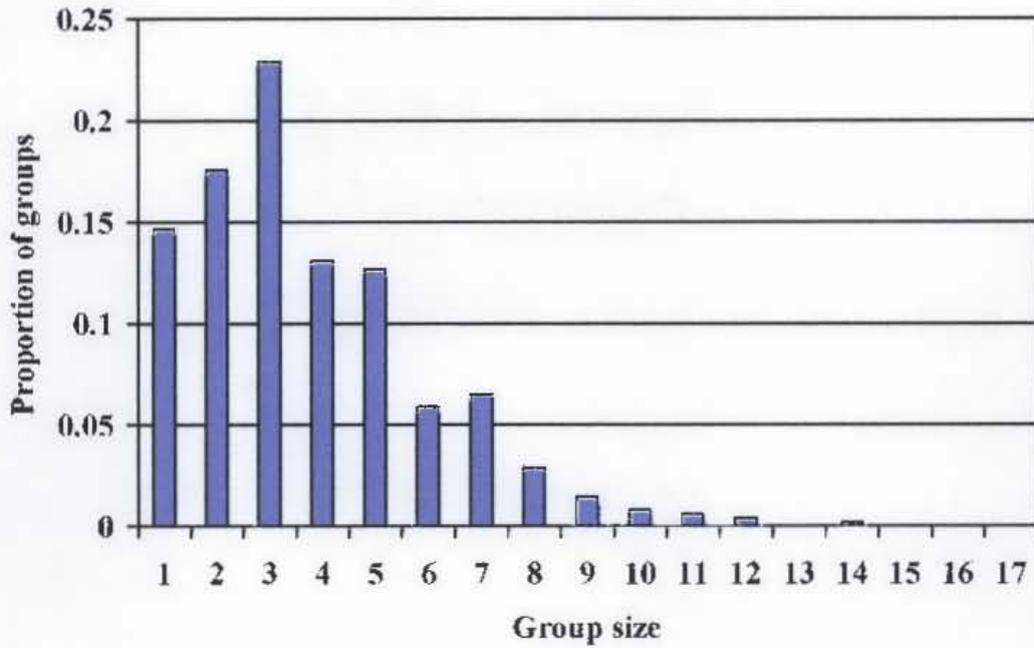


Figure 3.2: Size-class distribution of feral donkey groups (n = 100) sighted in strip transects over four aerial surveys, Gregory National Park, May 1993 - February 1994.

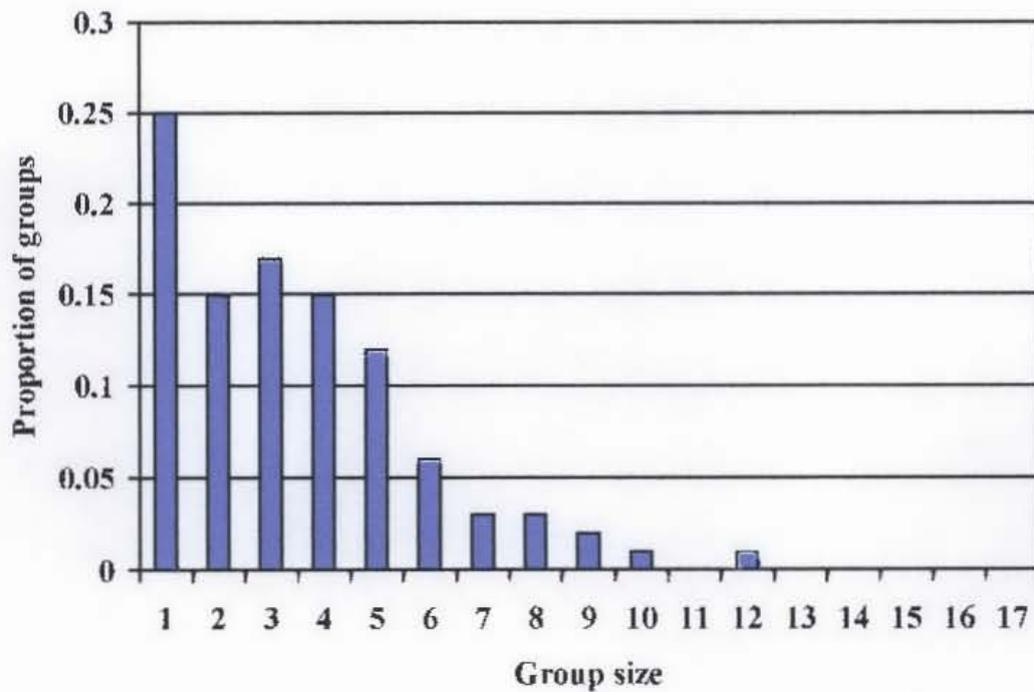


Figure 3.3: Size-class distribution of feral horse groups (n = 510) sighted in strip transects in each of four aerial surveys, Gregory National Park, May 1993 - February 1994.

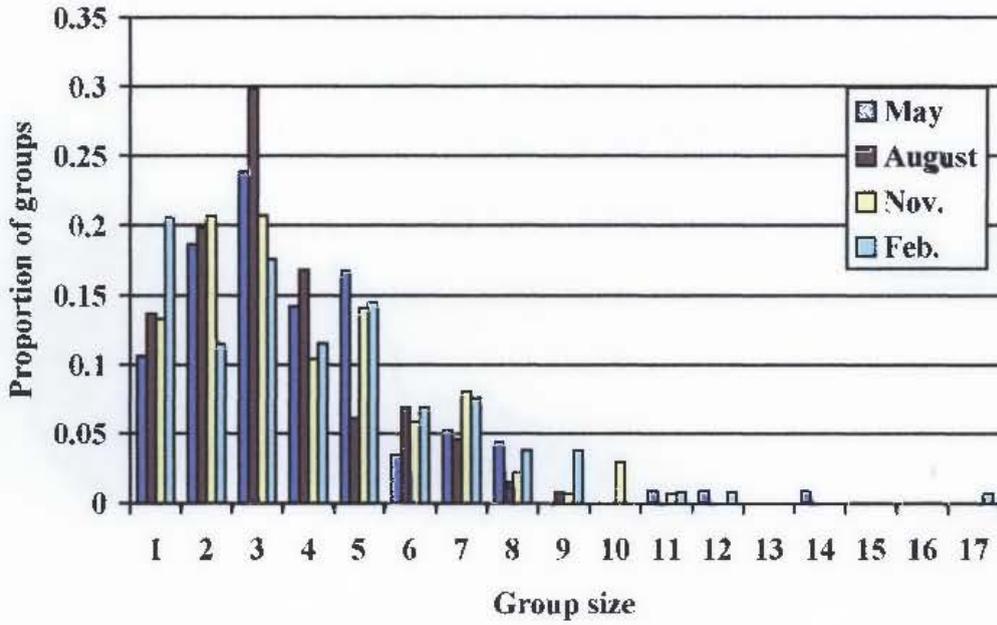


Figure 3.4: Size-class distribution of feral donkey groups (n = 100) sighted in strip transects in each of four aerial surveys, Gregory National Park, May 1993 - February 1994.

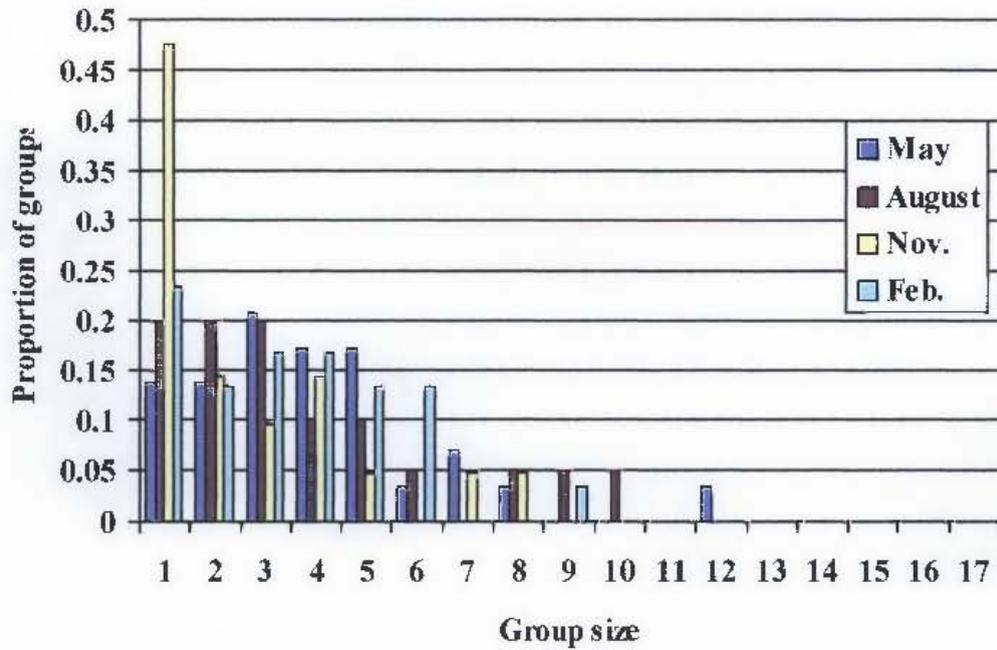


Table 3.6 shows the proportion of singletons among feral horse and feral donkey groups sighted in each of four aerial surveys. While there was no significant difference in the proportion of singleton groups relative to non-singleton groups between seasons for horses (Chi-squared test, $\chi^2 = 5.213$, 3 df, ns), the number of singleton horse groups in February appears to be relatively high. However, for donkeys, the proportion of singleton groups to non-singleton groups was significantly different between months. In November, the observed number of singletons was almost twice the expected value (Chi-squared test, $\chi^2 = 7.984$, 3 df, $P < 0.05$).

3.3.4 Population estimates

In the November survey, all data from Transect 31 was lost due to a tape recording failure that was undetected while the aircraft was on-site. This reduced the sampling fraction for the November survey by 0.6%. Calculations for population estimates were adjusted accordingly.

In each of the four surveys the coefficient of variation for population estimates of horses was below 20% and sufficiently precise at the 80% confidence level. While the coefficient of variation was under 20% for donkey population estimates in the May survey, and extremely close to 20% in the February survey; it was insufficiently precise in the August and November surveys (Table 3.7).

Over the four aerial surveys, population estimates derived from strip transects ranged from 2119 to 2727 for horses, and from 274 to 613 for donkeys (Table 3.7). For horses, the population estimates were higher in each successive survey, with increases of 6% between May and August, 14% between August and November, 6% between November and February, and 29% for the duration of the study (i.e. from May 1993 to February 1994). For donkeys, population estimates were highly variable. Although the estimates for the first survey in May 1993 and the last survey in February 1994 were comparable for donkeys, those for August and November 1993 were much lower (the population estimate for donkeys in February was 124% greater than that in November). However, coefficients of variation for donkeys were unacceptably high

Table 3.6: Proportion (%) of singletons (single animals) among feral horse and feral donkey groups sighted in each of four aerial surveys in Gregory National Park, 1993-1994.

Species\month	May 1993	August 1993	November 1993	February 1994	Mean
Horses (n = 76)	11	14	14	21	15
Donkeys (n = 25)	14	20	48	23	25

Table 3.7: Estimates of density and abundance of feral horses and feral donkeys from each of four aerial surveys in Gregory National Park, 1993-1994. Estimates are presented +/- the standard error of the estimate.

Value/season	May 1993	August 1993	November 1993	February 1994
Horses				
Density (no/km ²)	0.66 +/- 0.07	0.70 +/- 0.09	0.80 +/- 0.12	0.85 +/- 0.10
Number in study area	2119 +/- 232	2254 +/- 293	2569 +/- 375	2727 +/- 320
Coefficient of variation (%)	10.95	12.99	14.59	11.91
Donkeys				
Density (no/km ²)	0.19 +/- 0.03	0.14 +/- 0.04	0.08 +/- 0.02	0.19 +/- 0.04
Number in study area	594 +/- 113	440 +/- 129	274 +/- 65	613 +/- 123
Coefficient of variation (%)	18.97	29.36	23.64	20.65

in August and November, and population estimates for these months are not very reliable.

While population estimates were significantly different between transects (i.e. sample units) within surveys for both horses (1-way ANOVA, $F = 3.215$, 35, 3 df, $P < 0.001$) and donkeys (1-way ANOVA, $F = 1.883$, 35, 3 df, $P < 0.05$), the difference between population estimates derived from each of the four seasonal aerial surveys was not statistically significant for horses (1-way ANOVA, $F = 0.929$, 3, 35 df, $P = 0.429$ /ns) or donkeys ($F = 2.049$; 3, 35 df; $P = 0.111$ /ns), but was closer to significant for donkeys at the 10% confidence level.

Population estimates were significantly greater for horses than for donkeys within seasons by 3.5 times in May (2-way ANOVA, $F = 27.326$; 1, 70 df; $P < 0.001$), 5.1 times in August (2-way ANOVA, $F = 25.119$; 1, 70 df; $P < 0.001$), 9.4 times in November (2-way ANOVA, $F = 28.683$; 1, 68df; $P < 0.001$), and 4.4 times in February (2-way ANOVA, $F = 29.684$; 1, 70 df; $P < 0.001$) (Table 3.7).

3.3.5 Groups with foals

Over the four surveys, 23% of sighted horse groups and 9% of sighted donkey groups, included one or more foals. Horse foals ($n = 137$) made up approximately 7% of the population of all horses sighted, while donkey foals ($n = 12$) comprised 3% of the population of all donkeys sighted (Table 3.8).

For horses, the highest number of foals was recorded in February and the lowest in August. The number of horse groups with foals was highest in February, high in November, and relatively low in May and August. While the numbers of donkey foals and donkey groups with foals observed were low, maximums occurred in February and May with only 1 foal in August and no foals in November (Table 3.8).

The highest numbers of foals within any one group were 5 for horses and 3 for donkeys. The mean, mode and median number of foals per horse group were 1.29, 1

and 1. The mean, mode and median number of foals per donkey group were 1.3, 1 and 1.

Twice in the February survey and once in the May and November surveys, horse mares with new born foals were reported as separate from any other horses, that is, not within larger groups at the time of sighting.

Table 3.8: Counts of foals in feral horse and feral donkey groups sighted in each of four aerial surveys in Gregory National Park, 1993-1994.

	May 1993	August 1993	Nov. 1993	Feb. 1994	Total
Horses					
N ^o of foals	22	15	33	67	137
N ^o of groups with foals	16	14	38	48	116
Proportion of groups containing foals (%)	14	11	28	37	23
Foals as proportion of population (%)	5	3	6	13	7
Donkeys					
N ^o of foals	5	1	0	6	12
N ^o of groups with foals	4	1	0	4	9
Proportion of groups containing foals (%)	14	5	0	13	9
Foals as proportion of population (%)	4	1	0	6	3

3.4 Discussion

3.4.1 Population estimates and precision

The results suggest that feral horses were much more abundant than feral donkeys in the study area. In comparison with other surveys covering the Victoria River District (VRD) and Gregory National Park (Appendix D), density estimates from this study were higher for horses and lower for donkeys. However, the other surveys were conducted at broader scales and animals were not evenly distributed throughout the study areas. Densities of native wild *Equus hemionus* have been reported to range from 0.02 to 0.33 individuals/km² in various studies (Gee 1963, Wolfe 1979, Chu et al. 1985 cited in Freeland and Choquenot 1990). In this survey, estimates of donkey density (0.14 to 0.19) fall into the same range, while those of horses (0.6-0.8) are

higher. As national guidelines, Dobbie et al. (1993) recommended target densities of 0.1 per km² or less to control impacts of feral horses.

For horses, coefficients of variation for population estimates were similar to those obtained in other surveys in the Gulf Region, Alice Springs Region (Graham et al. 1986), Top End Region (Bayliss and Yeomans 1989), and VRD (Graham et al. 1982). While the coefficients of variation for donkeys were equivalent to those obtained in several other aerial surveys in the NT (Appendix D), more precise population estimates were obtained for donkeys in the VRD by Saalfield (unpub. 1996) and by Graham et al. (1982), where a much larger number of animals was sampled, and through some use of stratification. Stratification could not be used to improve donkey population estimates in this study, as sample sizes were too small to be further divided. Coefficients of variation associated with Saalfield's (unpub. 1998) population estimates for Gregory National Park were much higher than in this survey for both horses and donkeys, but particularly for donkeys. Lack of precision in that survey can be attributed to low survey intensity at the scale of survey (7.2% compared to 23% for this survey), and the extremely clumped distribution of the animals over the study area.

For each of the four survey months, population estimates derived for horses were acceptably precise. The precision of donkey estimates was acceptable for the May and (probably) February surveys, but not for August or November, when over 30% fewer groups were counted. The most imprecise estimate, in August, may reflect the greater variation in number of donkey groups per transect. Overall, the lower precision of donkey estimates relative to horses is most likely related to the small sample size. The high sampling intensity, relative to that used in broader scale surveys, proved necessary to compensate for the small study area. While the presence of a third observer was required for derivation of survey-specific correction factors, it also proved important in increasing the number of sightings recorded. As replicate surveys were not independent due to the use of the same strip transect sampling units in each survey, estimates could not be merged to improve precision (Caughley and Sinclair 1994).

The results suggest that the repeatability of surveys was better for horses than for donkeys. Low population estimates for donkeys in November were a factor of low group counts, low (probably biased) perception correction factors, and low mean group size. In August, group size was in the normal range, and while the group count was low, the correction factor was relatively high. While a cause for the low November group counts and correction factors is proposed in section 3.4.2.2, no obvious explanation can be offered for low group counts in August and the multitude of possibilities deters speculation at this point.

3.4.2 Visibility bias and accuracy of population estimates

3.4.2.1 The Petersen estimate mark-recapture model and double-count technique

Perception correction factors indicate that 92% of horse groups and 83% of donkey groups estimated as available (i.e. that were visible), were detected by one or more of the two starboard observers throughout the four surveys. As in all other Australian surveys conducted to date, sightability of feral donkeys was lower and derived correction factors higher, for feral donkeys than for feral horses (Graham et al. 1982, Graham et al. 1986, Bayliss and Yeomans 1989, Saalfield unpub. 1996, Saalfield unpub 1998). The lack of consistency between starboard observers in the detection probabilities for donkeys may reflect both the greater difficulty in detection of donkeys as well as the small sample size relative to horses; one observer only had to detect a few more groups than the other to cause a large disparity in detection probabilities between observers.

Low coefficients of variation indicated that the correction factors derived to compensate for perception bias were sufficiently precise for the purposes of these surveys. The accuracy of these correction factors is dependent upon how well the primary assumptions of the methodology are met. The primary assumptions of the Petersen Estimate mark-recapture model used in the double-count technique are as follows:

1. No animal is born or migrates into the population between “marking” (detection by first observer) or “recapturing” (detection by second observer);
2. “Marked” and “unmarked” animals die or leave the area at the same rate;

3. No marks are lost between the two sampling periods and marks are correctly identified and recorded, and;
4. All animals are equally “catchable”(sightable) in the first sample, and “marking” does not affect the probability of “recapture” of an animal (i.e. independence of “marking” and “recapture”) (Krebs 1989, Caughley and Sinclair 1994).

Assumptions 1 and 2 are met because animal groups are detected by observers almost at the same instant. Although the aircraft caused a flight response in some animal groups, it is unlikely that many moved out of the strip transect in the time between detection by front and rear observers.

Assumption 3 was valid because horses and donkeys were easily distinguished from one another from the air and did not occur in mixed groups. A small number of mules may have been mis-identified as horses, because they associate with horses and, from an aircraft, resemble them in appearance. However, mules were rare (Appendix B). If mules had not already been identified from the ground, they would probably have gone unnoticed from the air. The difficulty in identifying which groups were seen by both observers as opposed to only one observer was largely overcome by the use of the two-track tape recorder, as recommended by Marsh and Sinclair (1989). Recorded descriptions of groups according to criteria such as size, social group, activity, behaviour, coloration of individuals, presence of foals and immediate habitat, helped facilitate the matching or discrimination of groups.

Assumption 4 is more difficult to satisfy. Caughley and Grice (1982) identified two basic problems with the double-count technique, both of which are associated with this assumption. These are: (1) non-independence of marking and recapturing due to intercorrelated search images; and, (2) unequal catchability.

Although the chances of marking and recapturing an entity should be uncorrelated, they are not because marking and recapturing occur at the same instant and the search images transmitted to each observer are nearly identical. Caughley and Grice (1982) showed by simulation that the effect of close correlation was to underestimate density, but that the underestimation became serious (negative bias $\mu 10$) only when the mean

of detection probabilities P_f and P_r was <0.45 . Otis et al. (1978) found that large biases were likely, where detection probabilities were heterogeneous (Graham and Bell 1989). While mean starboard detection probabilities were well above 0.45 for horses in all four aerial surveys, mean detection probabilities for donkeys were as low as 0.50 in February and 0.52 in August, that is just at or above the level of sightability at which bias becomes unacceptable and use of the double-count methodology of correction is recommended against (Caughley and Grice 1982, Graham and Bell 1989). Consequently, population estimates derived for donkeys may be underestimated by at least 10% and should be interpreted with caution.

While it is assumed that there is equal sightability between groups of a given species on a given survey, that is, that all groups on a transect have an equal chance of being seen by a given observer, this is not true. Visibility is a function of animal behaviour, the immediate habitat of the animal, and the immediate environment of the observer (Caughley and Grice 1982, Southwell 1989, Pople 1999). Again, the consequence of violation of the assumption is over estimation of detection probabilities and underestimation of correction factors and density.

3.4.2.2 Factors affecting visibility

Visibility is affected by the occurrence of animals in groups, because larger groups have a higher probability of being observed than smaller groups (Samuel and Pollock 1981). The results suggest that for horses, larger groups were generally a little more easily detected than smaller groups, that is, that perception bias was stronger for smaller groups. In an aerial survey across the Victoria River District, Graham and Bell (1989) showed that detection probabilities increased with increasing group size for horses, donkeys and cattle. This may result in underestimation of total population size and overestimation of the mean group size parameters (Samuel and Pollock 1981). In this study, the small sample size of donkeys prevented confident interpretation of the effect of group size on the visibility of that species.

The underestimation of mean group size because not all animals in large groups were counted, is a possible source of error associated with the double-count technique. However, the results showed that observer counts of individuals within jointly sighted

groups were similar. Although Graham et al. (1982) showed that the size of large donkey groups was underestimated by 12% in aerial surveys in the VRD, most donkey groups in this survey were in the 1-5 size class.

Not all groups of animals within a population will occupy the same components or types of components of the habitat at the same time. In particular, pronounced differences in patterns of habitat use are likely between groups comprised of animals in different sex and age-class categories, for example, Berman (unpub.) showed that horse harem and bachelor groups used different habitats in central Australia. Aerial surveys are often adjusted by correction factors to account for the influence of major differences in habitat type, particularly vegetation cover¹, on a district or regional scale (Bayliss and Yeomans 1989, Southwell 1989, Choquenot 1995). However, this study area was almost wholly comprised of open woodland. Although some vegetation types ranged through to woodland in places, vegetation types dense enough to hide animals were limited to narrow bands along some watercourses and patches of Acacia shrubland. These land units comprised 6% and 5% of the study area respectively.

As with dense vegetation, topographic features such as ridges or steep valleys may form obstructions or cast long shadows that reduce the visibility of animals to observers. In addition, topography exerts an influence on operational factors. The necessity to maintain a constant height above ground level dictates that in hilly terrain the pilot should operate the aircraft so that the flight path replicates the profile of the hills being traversed (Grigg et al. 1999). This profile flying also challenges the capacity of the pilot to maintain a constant speed. While Grigg et al. (1999) considered that the tendency for reduced ground speed during the climb up a face would be countered and averaged out by the increase in speed during descent, animal groups occupying areas surveyed while in descent will be less detectable than other groups. If sample size is small, as with donkeys in this survey, there may be little opportunity for the effect to be averaged out.

¹ Bayliss and Yeomans (1989) found that obstructive vegetation cover was the main source of bias in their survey of large feral ungulates in the Top End of the NT, and were able to demonstrate that the visibility of buffalo in aerial surveys decreased markedly and predictably with greater canopy cover.

The influence of habitat on visibility may vary with season as patterns of habitat use by animals (Manly et al. 1993), and features of any particular habitat vary throughout the year. For example, deciduous trees lose their leaves in the early dry season and regain them in the build up season, such that foliage cover becomes denser. Similarly, spear grass (*Sorghum* spp.), capable of obscuring visibility, grows to 2 m tall in the wet season, but is knocked down as it dries out in the early dry season.

The possible affects of time-of-day and temperature on animal behaviour, and subsequently, visibility, were ignored in this study as there is little evidence to suggest it is an important factor in equid surveys. In ground studies, horses and donkeys were observed grazing and travelling in all daylight hours, unlike cattle, which appeared to seek shady resting spots in which to lie still and ruminate each day. In central Australia, Berman (unpub.) found that there was no difference between the nocturnal and diurnal time budgets of feral horses, and that the proportion of time spent grazing did not appear to vary seasonally.

Animals are more easily detected if moving. During aerial survey, for both horses and donkeys, some groups exhibited a flight response and some did not. In ground observations, a tendency for donkeys to remain still and watch approaching humans and vehicles for longer before fleeing than horses was perceived. However, flight response was not measured either on-ground or during aerial survey, and on-ground responses would not necessarily reflect responses to an aircraft overhead. In addition, on-ground, flight responses appeared to vary with seasonal factors such as body condition of animals (apparently in relation to energy levels) and prevailing wind conditions (presumably affecting the animals ability smell the presence or location of a perceived threat). Hence, measurement of flight response may need to be repeated in different seasons.

McCallum (1999) and Pople (1999) described visibility as likely to be dependent on interactions between the factors affecting it, rather than simply being able to be estimated as a multiple of individual probabilities for each of these factors.

3.4.2.3 Perception versus availability

Perception correction factors were derived using only that portion of the population that was available to observers. Negative bias due to the unavailability of entities can not be estimated in the mark-recapture double-count method, and was not accounted for in this study. Separating availability bias from perception bias is difficult because the distinction between visible and invisible populations of animals is likely to be blurred as animals may be only partly obscured or, may shift rapidly from one domain to the other. In terrestrial surveys, overall visibility factors are usually estimated by ground or helicopter counts or, by use of the index manipulation method in removal experiments.

In 1998, Saalfield (unpub. 1998) used removal experiments to calculate overall visibility correction factors for feral horses and feral donkeys aerially surveyed in Gregory National Park. The resultant correction factors were 3.07 (CV 0.66) for horses and 5.88 (CV 0.61) for donkeys, indicating that a mere 32% of all horses, and 17% of all donkeys estimated as present in sample units at the time of survey, were detected. Not only were Saalfield's correction factors much larger than those obtained in this study, they indicated a much greater degree of overall visibility bias for donkeys than for horses. The ratio of Saalfield's (unpub. 1998) horse to donkey correction factors, at 1.92, indicates that donkeys were almost twice as likely to be missed in aerial survey as were horses. In the current study, the ratio of donkey to horse perception correction factors, was close to one (averaged 1.1), implying that availability bias accounted for most of the difference in overall visibility bias between horses and donkeys.

Substituting Saalfield's (unpub. 1998) visibility correction factors for perception correction factors derived in this series of surveys, population estimates would on average, increase by a factor of about 3 for horses and 5 for donkeys. The ratio of horse to donkey density and abundance would be: 2.0 in May, 3.0 in August, 5.0 in November and 2.7 in February, and would average 3.2. Ignoring data from the most inaccurate and imprecise surveys in November and August, the ratio would average 2.35, compared to the average of 4 derived from this survey. That horses were in the order of two to three times as abundant as donkeys in the study area, sits more

comfortably with the author's perception of relative abundance from ground observations near the homestead, but this perception is derived from a majority of observations closer to the homestead as the southern third of the study area was not as frequently traversed. As horses were more abundant in that area, this perception is likely to be biased. Aerial surveys at district level and very fine scale surveys have reported low ratios of horse to donkey density and abundance. For example: 1:0.83 (Graham et al. 1982), 1:0.37 (Saalfield unpub. 1996), 1:0.67 (Saalfield unpub. 1992, Saalfield unpub. 1996), and 1:0.53 (Claymore unpub.). However, such results are very dependent on the scale of survey and species distributions.

While Saalfield's (unpub. 1998) visibility correction factors are very useful for comparison, ideally correction factors should be survey-specific and there are risks attached to transposing them between surveys. Firstly, it is not known whether or by how much availability and overall visibility might vary between seasons or between years. Saalfield (unpub. 1998) surveyed and conducted his removal experiments between 28 and 31 August 1998. Secondly, Saalfield's (unpub. 1998) study area was larger and took in different proportions of the habitat types included in this study.

While visibility correction factors as high as those derived by Saalfield (unpub. 1998) are not unheard of elsewhere², the correction factors derived by Saalfield (unpub. 1998) are much higher than those derived for the same species using the same method, by Graham et al. (1982) in the VRD, and by Bayliss and Yeomans (1989) in the Top End (Table 3.1). Bayliss and Yeomans (1989) found that their removal experiments and the double-count technique produced similar population estimates, suggesting that availability bias was low and that the latter technique was sufficiently accurate. However, both surveys were conducted across regional-scale study areas and it is difficult to interpret comparisons between results derived in different habitat types.

Smaller body size could make donkeys more difficult to see than horses. The average reported mass of feral donkeys in central Australia, at 187 kg, is about half that of feral horses at 396 kg (Eisenberg 1981, cited in Graham and Bell 1989). While

² For example, in Queensland, Pople et al. (1998) derived correction factors for eastern and western grey kangaroos averaging 6.39 and ranging from 3.41 (CV 0.20) to 10.18 (CV 0.90) in various survey blocks.

Graham and Bell (1989) found no significant difference in sightability between donkeys and horses for groups of the same size, their observations were made over a broader survey area and range of habitat types. Coat colour and the effect of camouflage could have a bearing on differences in visibility between animals and between species. In ground surveys it was noticed that grey-dun donkeys when still, were difficult to see in limestone country. Donkeys also appear to dust bathe more often than horses and a covering of dust could have a camouflaging effect in some habitats. Possible differences in the tendency to flee could influence the relative sightabilities of species (refer Section 3.4.2.2).

3.4.2.4 Repeatability (constancy of bias) of surveys between seasons

Caughley (unpub.) identified several factors that can vary between surveys and influence repeatability via their effect on visibility (Pople 1999). Some factors like season, shadow intensity, cloud cover, rain, wind speed and turbulence can be controlled or standardised at their extremes through avoidance. At other times, these and other factors such as flight direction, side-of-plane (looking into the sun reduces visibility) and time of day (which, for example, affects light intensity and observer fatigue) can only be randomised, as they were in this study, thereby contributing to residual noise.

Operational factors such as aircraft speed and height above ground, observer, strip width, and daylight hours, can also be standardised within certain practical limits (Graham and Bell 1989, Pople 1999). Aerial surveys of kangaroos in South Australia have utilised the same pilot for all 21 surveys conducted over a twenty-year period. In this series of four surveys, repeatability could have been improved by having one experienced pilot throughout. However, different pilots flew each survey, and each pilot had vastly different levels of experience with aerial survey and local flying conditions. This factor had an important bearing on the results of the study, because standard height above ground level was not maintained in the November survey, when a very inexperienced pilot was on the survey team. It was recorded that the aircraft was flown at extreme heights over, and at the approach and descent of, plateaux, mesas and high hills. The drastic reduction in visibility was obvious to all observers.

Despite the reduced visibility, correction factors for the November survey were low, possibly the result of a high proportion of groups going undetected by all observers, due to invisibility at extreme height, particularly if detection probabilities were normally low and variable in this terrain (causing increases in correction factors). Graham and Bell (1989) proposed a strong decline in sighting probability with height-above-ground level for solitary equids and groups of up to 4 animals. If it was mainly smaller groups that were missed, large groups could be over represented. However, in areas where the aircraft flew at extreme heights, most groups were probably missed. The effect of height-above-ground level would be greater for donkeys than horses because of the small sample size, the lower mean group size for donkeys in November, the high proportion of singleton donkeys in November, and the lower sightability of donkeys. The fact that relationships between group size and detection probability were found for horses and not donkeys in this study (as opposed to that by Graham et al. 1982), may suggest a confounding factor or factors influencing donkey sightability.

Observer skills are another operational factor that can be standardised in aerial surveys. In this study, only one of the 3 observers (starboard-rear) had extensive aerial survey experience prior to the survey. While the other two observers were very familiar with the local country, conditions and survey species, neither had aerial survey experience. According to Beard (1999), trainees that are used to seeing kangaroos on the ground, may start counting at a higher rate of detection than trainees that are not, but still require training to increase to 100% and acquire consistency. The starboard-front observer's counts of individuals within jointly sighted groups, showed improvement with each survey, and possibly reflect the effect of practice. It is also possible the increase in horse groups counted after the May survey, could be due to observer practice and familiarisation with where horses were likely to be seen in the area. Frei et al. (1979) showed that under similar conditions, aerial survey counts on a wild horse population in Utah, could increase significantly if successive counts were performed by more experienced personnel. However, this was described as an unavoidable variable, since experience will increase every time an aerial survey is conducted.

Skilled observers are also capable of compensating for some fluctuation in survey conditions such as increased height above ground level (Grigg et al. 1999), and would be more likely to perceive and record any deviations from generally accepted survey design. In November, the very experienced starboard-rear observer was not available and a less experienced observer was substituted, potentially altering the results of the double-count relative to other survey months. In addition, in applying the double-count technique, it is assumed that the starboard-front and rear counts are uncolluded. Ideally, the two observers should be screened from one another but screens were not used in this survey. While this factor may not have had a serious effect on the more experienced observer's tally, it may have exerted an influence on perception correction factors when a less experienced starboard-rear observer was substituted.

As each survey took two days to complete, repeatability should also be considered within surveys. However, given that the survey team was constant within surveys, it was assumed that small variations in flying and viewing conditions did not greatly exceed those experienced throughout the course of a single day. It was also assumed that disturbance by aircraft would not cause major movement in animals, or movement of animals surveyed on the first day into areas surveyed on the second day. Observations supported the latter assumption, as animals that fled from the aircraft did not appear to travel long distances before stopping. In addition, some horse groups were recognisable and no recognised groups were recorded more than once in a survey by the same observer.

Comparing density estimates of a population of constant size under a range of survey conditions provides only some assessment of repeatability. Ideally, true density needs to be known so that constancy in bias can be assessed over time (Pople 1999).

3.4.3 Group size

Group size as a factor affecting sightability of groups is discussed in section 4.4.2.2. Rubenstein and Wrangham (1986) listed the common evolutionary causes of sociality, and of variations within group size composition and dispersion as predation pressure, resource distribution and intraspecific competition. In south-eastern Australia, Newsome et al. (1983) reported that a pack of dingoes killed a feral horse foal, and in

this study, dingos were seen chasing horses on one occasion (during aerial survey) and donkeys on another (ground observation). However, Newsome et al. (1983) showed that medium-sized mammals were the staple prey of the dingo populations in their study, and categorised large animals (such as feral horses) as supplementary prey only. As feral equid populations in northern Australia are generally considered relatively predator-free (McCool et al 1981, Freeland and Choquenot 1990), resource distribution and intraspecific competition are the most likely proximate influences on group size in populations that are not subject to heavy culling or harvesting.

For donkeys, the lower mean-group size and higher number of singletons in November may have been due to the dispersal of some animals as food resources became limiting in the very late dry/pre-wet season. If interference among animals and movement through the habitat increase as food-patch size declines with season (Rubenstein 1988), competition within groups of is likely to increase, and should lead to smaller group sizes in areas of reduced forage availability. Also, if this is the main breeding season for feral donkeys, as Choquenot (1991) demonstrated it was in other parts of the district, the large number of singletons could be accounted for by territorial males on territories. Ginsberg (unpub.) showed that territorial male Grevy's zebra spend a disproportionate amount of time alone in comparison to other males.

If the apparent (although statistically insignificant) increase in the proportion of singleton feral horse groups in the February survey was real, it coincides with the time when most horse foals were recorded (refer section 3.4.4 Population parameters). As equid mares often seek isolation when giving birth, either by leaving companions or allowing companions to move away (Waring 1983), one of the possible explanations speculated is that this behaviour may have contributed to the greater proportion of singletons in February. However, the assumption that February was the month in which most horse foals were born could not be confirmed by aerial survey.

While mean group size estimates were sufficiently precise for both species, coefficients of variation were twice as high for donkeys as horses in May and February, and over three times as high for donkeys as horses in August and November. This is probably explained by the low number of donkey groups sighted in surveys. Estimates of mean group size for horses and donkeys are similar to those

reported in other aerial surveys in Australia (Appendix D). The mean group size in a population of feral donkeys studied in Arizona was 4.7 (maximum 21), with no major changes in the frequency of the various social groupings occurring throughout the year (Seegmiller and Ohmart 1981).

In Saalfield's (unpub 1998) surveys of Gregory National Park, donkey group sizes post-cull were much lower at 2.00, than in pre-cull surveys at 5.12, while mean group size for horses was fairly consistent (3.86, 3.62). This suggests that group size in donkeys is more directly influenced by density than it is in horses. Assuming that most animals within groups detected during the culling operation were shot, this would make sense in a species that forms temporary aggregations rather than relatively stable harem groups like horses.

On rare occasions, some horse groups may have aggregated before counting, in the process of fleeing from the aircraft. For example, the one record of a group of 17 horses may have been the result of 2 or 3 groups joining in flight. Normally groups were segregated enough that they could be counted separately even if in flight.

No herding or aggregation of horse groups was indicated by mean group size data. In arid central Australia, Berman (unpub.) reported several sightings of aggregations of from 50 and up to 300 horses. These horses were all near water and many among the largest herd were digging for water. Berger (1986) observed a herd of 210 horses in Oregon; the herd was grazing and comprised distinct but closely aggregated groups. Miller and Denniston (1979) also described herds of horses in Wyoming's Red Desert. In the current study area, water and food resources were more abundant and widespread, and groups are less likely to have reason to aggregate.

3.4.4 Population parameters

A comparison of rates of population increase between species would have provided some insight into the relative success of each species and the role of competition between them. However, rates of change in population estimates between surveys should be treated with caution for both species, as the surveys were not standardised rigidly enough to provide reliable indices of population change.

Differences between donkey population estimates in successive surveys were erratic. If the indices were true, they could only be explained by episodes of major emigration and immigration in the study area, a scenario that seems extremely unlikely as resources were more abundant, and predation less prolific in the National Park than on adjacent pastoral leases. Dobbie and Berman (1990) found feral horses to have high fidelity to their home range and therefore believed immigration and emigration to have insignificant influence on horse population sizes within a three-year time frame.

Berman (unpub.) suggested that birth rates of feral horses in central Australia could reach 25 to 30% in good years with up to 95% survival rate. Rates of increase for two Oregon feral horse herds were estimated from direct aerial counts to be about 20% per year (Eberhardt et al. 1982). Choquenot (1990) demonstrated finite rates of increase of 23% and 28% per annum in populations of feral donkeys in the VRD that were below carrying capacity. While population estimates increased steadily for horses between surveys in this study, and at an overall rate (29%) that could be explained by population increase through recruitment, assuming a peak birthing season late in the year (given the 9 month study period), the proportion of the horse population comprised by foals was not high enough to account for the population increase. In addition, the timing of the largest population increase (November) did not correspond with the season in which most foals were recorded (February). In any case, the count of foals in aerial survey is not necessarily a reliable indicator of recruitment rates, as the detection rate of foals is likely to be lower than that of adult horses, due to the large difference in body size and behaviour. Similarly, possible differences in foal detection rates between species negate interspecific comparisons.

Although foals are recorded in all seasons for horses, the data suggest most births occur from some time after August through to February, with a peak some time between late November and early February. Berman (unpub.) reported a peak season for births in feral horses in central Australia, as between September and February with some fluctuation in onset between years sampled. However, there is no available data on peak breeding or birth seasons for feral horses in the wet-dry tropics. Choquenot (1991) found the season of births for donkeys in the VRD peaked in October and November, just before the onset of the wet season. Although most donkey foals were

recorded in May and February in this study, the sample is too small to be meaningful. In addition, observations of foals of both species might be influenced by seasonal variations in sightability of foals (e.g. foals could be more difficult to see when grass is long in February), and foals may become progressively easier to see as they grow in size.

Despite the status of the study area as an exclusion zone for feral equid culling, from early 1992 and to early 1994, some illegal shooting of both species still occurred; sometimes for the purposes of sport but usually to obtain meat for pets or farmed crocodiles. Shooting occurred near four-wheel drive access routes near the edges of the study area and outside it. In addition to the four dead donkeys recorded during aerial survey at Barrac Barrac (northwest corner of study area), it was reported that about 30 donkeys were removed from Slatey Creek pocket (valley in Wickham Land System on eastern border, Transect 17) and adjacent areas over the 1993 dry season. During the study period, the number of equids removed from the study area through predation by humans, was probably small. As a proportion of sample size, effects would be greater for donkeys than horses but were probably minor for both species.