CHAPTER 9
MANAGEMENT

9.1 Introduction

In Australia horses have no significant checks on their population growth through predation (apart from human) or pathogenic disease. During years with abundant rainfall and pasture growth horses breed quickly. However, during drought, reproductive rate is low and many die of starvation or thirst (Chapter 7 and 8). Active management of feral horses is supported by Government for ethical, economic and conservation reasons.

All habitats used by cattle were also used by feral horses during my study (Chapter 5). This and the fact that feral horses ate pasture species also eaten by cattle (Chapter 3) indicated a high potential for competition between these two ungulates in central Australia. Managers of pastoral properties which are overrun by feral horses are justifiably concerned about the impact that uncontrolled horses may have on their cattle enterprises (Berman & Jarman, 1987).

Likewise managers of National Parks and others concerned for the environment believe that feral horses influence the distribution and density of native plants and animals. This belief is supported by correlative evidence in Chapter 8. To protect the natural environment (native plants and animals) horse numbers must be controlled at much lower levels.

The three main groups interested in feral horses (pastoral, environmental and animal welfare) are often in conflict but I believe they should have a common aim: to control feral horse numbers, and keep their populations at acceptable levels. But what is an acceptable level? Eradication would be acceptable to most environmentalists and many pastoralists. Eradication would, however, be very expensive and perhaps practically impossible in many areas. Furthermore, once numbers are reduced the incentive to eradicate would be reduced. In fact, people would tend to want to protect the few remaining wild horses. Therefore total eradication, I believe, can be excluded as a possible solution. Population control is the only way. What, then, is an acceptable population size for feral horses and how should that level be attained and maintained?

Feral horses generally inhabit the most inaccessible country where they are difficult, if not impossible, to catch. Mustering by helicopter and trapping horses in yards as they come to drink are the two main methods used to catch feral horses. Captured horses can be sold for around $100 per head (net) and are generally exported as meat for human consumption (Berman, 1991). Where horses cannot be caught, the only current alternative for reducing their numbers is by shooting from helicopter. However, shooting from helicopter is expensive, wasteful, distasteful and by itself, is not, in my opinion, a long-term solution. The use of fertility control to stabilise the feral horse population has been proposed by animal welfare groups opposed to lethal methods of population control and there has been some success with small populations of approachable horses in North America (Kirkpatrick et al., 1990). Nevertheless, in central Australia there appear to be severe difficulties to overcome before fertility control is a viable management option (Berman & Jarman, 1987; Berman & Dobbie, 1990).

This chapter describes the results of attempts to control feral horses on my study property from 1984 to 1990. The difficulties involved and how they were overcome to achieve a significant reduction in feral horse numbers are discussed. I describe how this information, combined with that contained in other chapters of my thesis, and in the scientific literature, can be used to improve management of feral horses in central Australia. A conceptual model is presented as a basis for planning and increasing the efficiency of control operations.

9.2 Feral horse control on my study property

9.2.1 Difficulties

Most data for my thesis were collected on a property (2112 km^2) 70 km north east of Alice Springs (see Chapter 2). The rough terrain, soils and vegetation are characteristic of areas carrying the highest densities of horses in central Australia. The rugged topography, difficult access and numerous natural watering points inhibit effective control. Like many stations in the central ranges, the boundary is not completely fenced and there are few internal fences. The managers of the property have been battling for many years to reduce feral horse numbers. Not only did they have to contend with the difficult terrain and seemingly very cunning horses, they had also to contend with horse-meat buyers, Government employees, scientists, animal welfare groups and environmentalists, all "pushing and pulling" in different directions. Eradicate, protect, shoot or sell, which is the best option?

9.2.2 Control/harvest operations

The pastoralist trapped feral horses in yards as they came to drink and mustered them into yards using helicopters. The number of horses removed, the date of removal, and the method of capture were obtained from station records.

9.2.3 Dry weather trapping

During most of 1984, 1985 and early 1986 there was very little rain and virtually no pasture growth (Chapters 2 and 3). The dry conditions were ideal for trapping horses. Trapping was most successful in the northern part of the station where there are few long term natural watering points. Horses were also trapped in the central part of the station but many avoided the trap yards by using alternative watering points (Berman, 1991).

9.2.4 Fencing alternative water and trapping

In 1987, 1988 and 1989, dams and water-holes were fenced using conventional barbed wire on some and electric fencing on others. Fencing forced horses to use other waters where they could be trapped. However, on two occasions within hours of setting the traps, rain fell washing fences away and allowing the horses to drink wherever they liked. This prevented trapping in both cases until the following summer (Dobbie & Berman, 1990).

9.2.5 Helicopter musters

By the end of 1989 most horses that could be trapped had been. The remainder were in areas too rugged to erect trap yards or enter with trucks. In these areas the manager allowed a contract musterer to try helicopter mustering. At that time helicopter mustering was considered expensive and risky. However, the musterer, using three helicopters, proved very successful (Berman, 1991).

9.2.6 Monitoring population size

The aerial surveys conducted in March 1986, March 1988 and October 1988 (Chapter 7) indicated the feral horse population size at these times. Using the 1986 population estimate as a starting point, a model of change in the feral horse population was produced incorporating control/harvest rates and birth and death rates (Chapter 7).

Figure 7.14 shows that the modelled change in population corresponded well with population estimates from aerial survey. This indicates that the important population parameters were included in the model and reasonable estimates determined. Extrapolating back in time from March 1986 to March 1985 indicates that there were about 3,000 horses on the station before any harvest began. The model predicted a population of about 300 horses after the final muster in 1990. This represents a 90% reduction in the population during 5 years of harvesting.

Using a survival rate of 95% (Wolfe, 1986) and reproductive rate of 27% (Chapter 7) the model predicted the population would return to pre-control level from a 70% reduction in 3.5 very good rainfall years. After a 90% reduction, the population would take 6 very good years to return to 30% of its original size.

9.2.7 The outcome

The methods used to control feral horses on the study property were influenced by weather, terrain, economics and the opinions of city-based Australian and overseas interest groups.

Dry weather helped the initial stages of the control program and the sale of horses that were captured provided funds for further control. The purchase and erection of electric fences, and the grading of tracks enabled trapping in areas where it was previously not viable. Helicopter mustering proved to be far more successful than expected due to the highly skilled contract musterer and helicopter pilots involved, and to the fact that few of the horses had ever been chased by a helicopter before.

The aerial surveys and population model allowed me to assess the success of control by giving an estimate of the pre and post control population size. The model (Chapter 7) allowed estimation of the rate of recovery after control. This indicates when control needs to be repeated. Such information is vital for planning of efficient long-term control but managers usually make no attempt to obtain it. Many managers are enticed by "quick fix shoot-outs" with very little planning nor quantitative assessment of success. A 70% reduction is relatively easy to obtain and merely appears effective because the horses that remain are probably the hardest to see. Unfortunately a reduction of 70% is not effective because in 3 years it may have to be repeated, whereas a 90% reduction is far more difficult and expensive (Choquenot, 1988) but is far more effective in terms of the length of time before recovery to previous numbers.

No shooting was necessary on the study property. However, in other areas of central Australia, where unsuccessful helicopter musters have inadvertently trained horses to be unmusterable, shooting may be the only option. At various stages during this study there was pressure placed on the manager, by Government agencies, to shoot horses from helicopter at a cost of at least $10 per head (Berman & Jarman, 1987). A 90% reduction by shooting would have cost the manager at least $20,000 compared to an income of around $300,000 achieved by harvesting. Shooting appears a very poor choice based on economics alone. However, a significant reduction by harvesting can take a long time and may offer no immediate relief from environmental and economic damage. Also, harvesting requires considerable, careful planning and many managers feel they cannot afford to spend time and money on such planning. Long-term planning, however, based on a good understanding of home range and movement patterns of horses should be an integral part of all control operations, even helicopter shoots (Dobbie & Berman, 1990).

9.3 A model for efficient planning of control

Chapters 3,4,5 and 8 show how the location and permanence of drinking water influences the behaviour patterns, distribution and environmental impact of feral horses in central Australia. After completing the report to the CCNT in 1987 (Berman & Jarman, 1987) I believed that the key to controlling feral horses was to control their access to drinking water. This was tested by fencing off watering points in an effort to force horses to where they could be trapped. This worked very well (Berman 1991). However, there were many horses that avoided being trapped, either because of flooding rain, or because they inhabited areas too rugged to erect trap yards or drive trucks. I now believe controlling access of horses to water is only part of "the key" to controlling feral horses.

Miller (1979) suggested that the feral horse herd was a logical management unit. In Chapter 6 I defined a herd as all the horses that "know" each other and have in the past interacted to form an interband dominance hierarchy. Such a hierarchy has been demonstrated to occur in Wyoming's Red Desert by Miller and Denniston (1979). Although, further work is required to establish whether herds are structured social units in central Australia, Dobbie and Berman (1990) reported the study area to be divided into 'harem' and 'bachelor' areas. I reported in Chapters 5 and 6 that the different feral horse social groups appeared to use different habitat. Bachelor groups tended to be seen at watering points surrounded by the greatest proportion of alluvial flats growing perennial grasses and poisonous plants, whereas large harems were more likely to be seen in areas dominated by land types that grew mainly annual grasses. Dobbie and Berman (1990) found the permanence of a watering point to be an important factor determining the ratio of bachelors to large harem groups. Large harems were more likely to be seen at permanent watering points while bachelors were seen at ephemeral waters or in areas long distances from permanent water.

In Chapter 6 I proposed that large harems are the most mature social groups. They may have been able to mature because they inhabit the most stable or suitable habitat. They live in areas where they are less likely to die from poisonous plants or thirst, or be trapped, whereas small harem groups and bachelors may tend to colonise empty or less suitable habitat in an attempt to avoid dominant groups. I can therefore distinguish between feral horse "source" and "sink" habitats. The need for such distinction has been discussed by several authors (Lidicker, 1975; Van Horne, 1983) and was emphasised by Pulliam (1988). In sink habitats, within-habitat reproduction is insufficient to balance local mortality. Populations may persist in sink habitats by continued immigration from more productive (Pulliam, 1988) or less hostile habitats.

For feral horses in central Australia the source habitat contains permanent drinking water, minimal poisonous plants, a predominance of land types dominated by annual pasture, many alternative watering points for avoidance of trapyards and few or no places where trapyards can be erected or trucks driven. During drought the horses in source areas are least likely to die of thirst, resort to poisonous plants, or be captured, whereas in sink habitats, during dry times horses may perish from thirst, poisonous plants or be captured. The long-term mortality rate is higher in sink areas than local reproduction. The most mature social groups (i.e. large harems) occur in source habitat where mortality is lower than it is in sink areas. Bachelors and small harems migrate from source to sink where there may be no permanent water, where they can be trapped or they are exposed to poisonous plants. If seasonal conditions are favourable such as they were in the 1970s much of the sink habitat may not be hostile. Plenty of rain provides plentiful drinking water, and abundant non-toxic food. In good seasons mustering and trapping is most difficult and is least likely to occur because environmental and economic damage is perceived to be small. So during good seasons, source areas essentially expand and sink areas contract. The unpredictable climate of central Australia may see 10 good years followed by 10 drought years. A horse may rely on a water-hole for 10 years then perish because it dries up. However, those watering places that are truly permanent have water even during the driest years and allow horses that use them to survive the hard times.

Morton (1990) used the source and sink idea as a basis to help explain why arid Australia has lost many of its small to medium sized mammals. Presumably, prior to European settlement, during the long droughts, native mammals survived only in the most favourable habitats (source habitats). Since the introduction of foxes, cats, horses, cattle, sheep, rabbits, camels, donkeys, pigs and goats the drought refuge areas for native mammals were heavily used by introduced animals causing extinctions. Currently several of the native mammals are being reintroduced into parts of their former range (Delroy et al., 1986; Southgate, 1987; Lundie-Jenkins, 1989) or managed to prevent their disappearance from places where only remnant populations exist (Lundie-Jenkins, 1989). Morton believes that reintroduced populations "will only be viable in the long term if they are situated in pockets of relatively fertile, moist country......The identification and management of these refuges are among the greatest challenges faced by ecologists in inland Australia today."

In my opinion, identification of feral horse source habitat is important for controlling their numbers. Effort should be concentrated in source areas. Placing fences around permanent watering points is an example of this approach. Concentrating mustering or shooting effort in relatively small (300-400 km^2) management areas also follows the above principle (Dobbie & Berman 1990). In the long term nature will take care of horses that occupy sink areas (Figure 9.1). If time and money is limiting then sink areas can be left out of the management operation.

Other pest animals, such as rabbits may be controlled using the same principle. When I first visited the study area in 1984 there were rabbits just about everywhere.

However, during the dry years of 1985 and early 1986 rabbits were restricted to a few source areas, perhaps these areas were the most fertile or moist. Control should be centred on these source areas even during good seasons when rabbits appear to be everywhere.

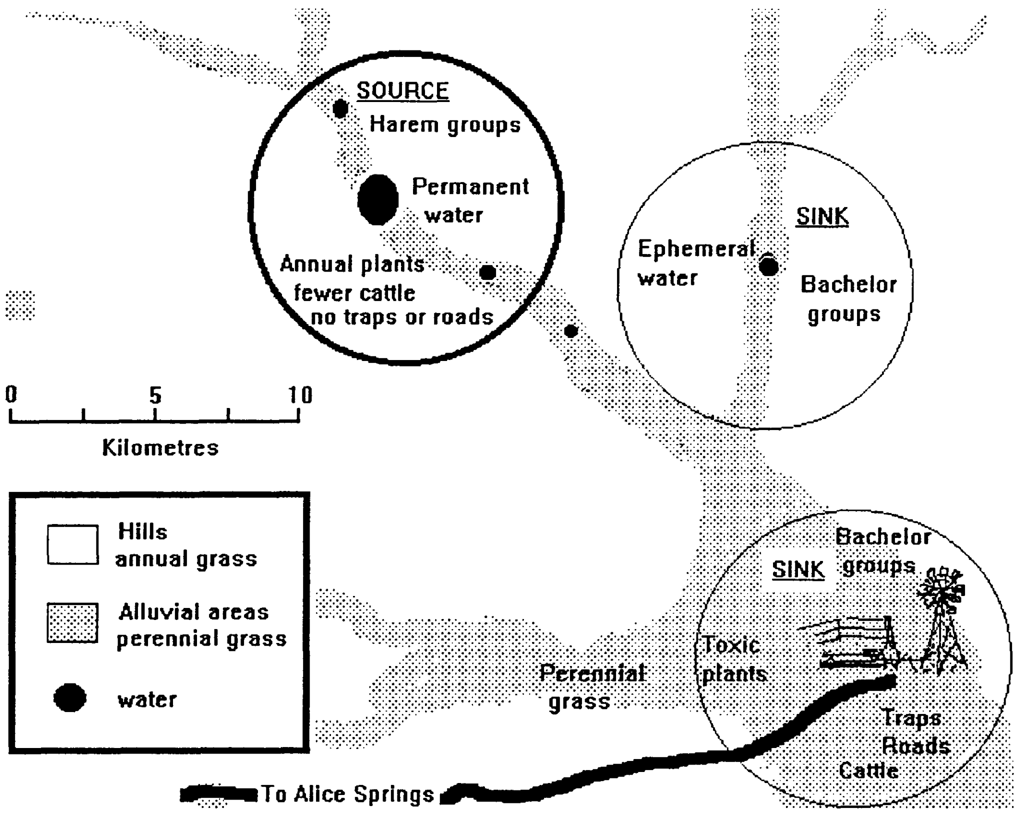


Figure 9.1: Diagram showing 'source' areas where control operations should focus and 'sink' areas where control can be conducted if possible but after 'source' areas have been adequately treated.

The daunting task of controlling so many pest animals over such a large area is no longer so difficult if managers can identify source habitat and concentrate their effort in a few key areas and let nature take care of the rest.

9.4 Potential of fertility control

Up until now I have been assuming managers of horses have available to them lethal methods such as harvest or shooting. Compared to being shot from helicopter horses may suffer more from muster and transport. This aspect requires further work to determine which method is the most humane or how each method may be made as humane as possible. Are there more humane methods?

A significant threat to control operations on the study property was opposition from animal welfare groups. Experience in North America shows that such groups cannot be ignored (Arnold, 1986). Without visiting feral horse habitat in central Australia, city people cannot fully appreciate the problem. A vital, but often overlooked aspect of research is its role in providing a means of de-fusing conflict between groups interested in the feral horse problem.

To this end the CCNT is to publish a technical manual for managers and has co-operated in the preparation of a television documentary on Australian feral horses. Even so, this can only show the public that there is no easy solution. To many people, having horses shot or slaughtered for meat is totally unacceptable. For this reason animal welfare groups have proposed the use of fertility control. Research to develop methods suitable for horses has been conducted in North America (e.g. Goodloe et al., 1988; Kirkpatrick et al., 1990).

Bomford (1990) reviewed in detail the literature to assess the potential use of fertility control for management of wildlife populations in Australia. She concluded "no drug or technique has been convincingly demonstrated to have value for cost-effective population control of widespread and abundant wildlife species". There are indeed many limitations still to overcome before fertility control is a generally useful wildlife management technique. However, Kirkpatrick et al. (1990) successfully inhibited the fertility of uncaptured free-roaming (but habituated) horses by means of remotely delivered immunocontraception.

Turner (pers. comm.) who works with Kirkpatrick believes that fertility control has great potential for use on feral horses in central Australia.

9.4.1 The Alice Springs feral horse population

There were 82,000 feral horses estimated for the Alice Springs area of 388,000 km^2 (Graham et al., 1986) in 1984. The survey indicated that feral horses were concentrated in rugged, hilly country where there are many natural watering points (Bowman 1985). In March 1988 a survey by Low and Hewett (1988) indicated that the Alice Springs feral horse population size had decreased by 70 to 80% since 1984. A run of relatively dry years has caused many horses to die of starvation or thirst, decreased the birth rate and improved the chances of successful harvest. Although there has been a decrease in the central Australian feral horse population it will most probably return to disturbingly high numbers in three or four years if rainfall and pasture growth are good (see section 9.2.6 and Chapter 7).

To artificially control the fertility of 82,000 feral horses over 388,000 km^2 would be prohibitively expensive, if not impossible. However, reduced numbers due to drought, harvest and culling make the task a little less daunting. Dobbie and Berman (1990) suggested that management over whole regions or properties should not be attempted. Effort should be concentrated in small management areas (300 to 400 km^2) within properties. Although Dobbie and Berman (1990) were referring mainly to management by mustering, trapping or shooting, the use of small management areas may also facilitate fertility control.

9.4.2 A cattle station population

Why do managers responsible for feral horse control generally laugh at the thought of using contraceptives? Probably because there are so many horses (1000 to 4000 on some properties) and treatment appears prohibitively expensive, difficult and time consuming. Fertility control does not reduce the number of horses in the short term.

Nevertheless, managers may look more favourably on fertility control once the total number of horses has been reduced by other methods. Permanent waters serve as long-term centres of horse dependency during inevitable drought and may be viewed as the foci for distinct "management areas" for feral horse control (Dobbie & Berman 1990). Fertility control activities should be concentrated around permanent waters.

Assume a manager had surplus money from sale of the horses that he was able to muster. How would he artificially reduce the fertility of the remaining horses? To administer an anti-fertility agent the horses must be caught in a yard or shot with a dart. Unfortunately, they cannot be easily caught or shot. That is why they are where they are in such large numbers. Hills and trees make mustering by helicopter, motor bike or horse back difficult if not impossible. Trapping horses in yards as they come to drink can usually only be done during drought when most of the alternative waters have dried up. At these times reproductive rates and survival rates are naturally low (Berman & Jarman 1987) and there is less need for artificial fertility control. Infertility must be induced during good years because reproduction and survival are highest then. Unfortunately it is also then that horses are most difficult to catch or dart. A long-acting anti-fertility agent (5-7 years) would overcome this problem and allow treatment during dry periods to act during good seasons. Such a drug has not yet been found (Bomford, 1990).

But keeping in mind the fact that feral horses are where they are because they cannot be easily caught or shot, how would a property manager treat horses with a fertility control agent?

9.4.3 From the air?

I suspect it is easier to effectively shoot a horse with a bullet than a dart or pellet containing an anti-fertility agent. However, operations where horses and donkeys were shot from helicopter can be used as analogies to aerial fertility control to assess its potential. Shooting from helicopter is a quick and effective way to reduce the size of large mammal populations. Nevertheless, in the Northern Territory total eradication is rarely if ever achieved. In fact once 70% of the population has been shot the cost per animal increases dramatically (Choquenot, 1988). In a fertility control operation treated and untreated animals would be difficult to distinguish. Those that remain untreated would continue to produce fertile offspring.

An effective 43% reduction in the 1981 donkey population (92,953) of the Victoria River District (North-west Northern Territory) was obtained by shooting 83,025 donkeys during a four year period (1981-1984) (Choquenot, 1988). The numbers of donkeys shot each year were 14,667, 30,214, 24,576 and 13,568, for 1981 to 1984 respectively. The donkeys that avoided being shot reproduced rapidly so in fact the population was only reduced to 52,760 although the total number of donkeys shot was 85% of the pre-shoot population. If the donkeys had been treated with a contraceptive that acted for 12 months instead of a bullet there would be only 13,568 with induced infertility at the end of the four years. Assuming a long-acting (>4 years) anti-fertility agent (as far as we know there is no such thing) was used instead of a bullet as many as 52,760 donkeys would remain untreated after 4 years.

This analogy gives us insight into the difficulties that might be associated with delivery of an anti-fertility agent by gun from the air. Even with improved dart or pellet guns that match the efficiency of the best conventional rifles and with a means of identifying treated animals, delivery of drug by helicopter is not a practical option. The costs are too great and a successful outcome unlikely.

9.4.4 From the ground?

Unfortunately, central Australian feral horses are not as approachable as those treated by Kirkpatrick et al. (1990) on Assateague Island. Kirkpatrick et al. (1990) darted 21 mares from the ground, at distances from 25 to 30 metres with a gun, and 8 were initially treated with a jab-stick. I found the only way to effectively dart central Australian feral horses was by waiting in ambush at water-holes. No horses were successfully immobilised anywhere other than at water-holes or bores. They were too flighty and difficult to approach closer than 70 to 100 metres whilst grazing. Three hundred hours were required to immobilise the first 6 horses. There were more frequent chances to dart horses in dry times when the number of horses visiting the major water-holes per day increased. My ability to select the correct water-hole and best hiding positions improved with practice. However, delivering a dose of drug using a dart gun is a very tricky and time-consuming business.

Most groups of horses contain more than 1 adult. For the purposes of delivering an anti-fertility agent a gun with the ability to hold 5 to 10 darts at the correct temperature would be required. Many horses visit water during darkness (Table 1) so a night scope would be required to deliver drug by shooting at night.

9.5 Conclusion

Managers require mustering, trapping and shooting for successful control of feral horses on central Australian properties. A sufficient reduction in population size can be achieved by harvest and sale of horses even in the most difficult areas. Shooting from helicopter is vital for control of horses where harvest has failed or a quick reduction in numbers is required to alleviate impact. All control operations must be well planned and their success monitored. Control activities should be concentrated in source areas where long term survival of horses is greatest. For example the area around permanent waters can be viewed as foci for "management areas" (300 to 400 km^2). Sink areas may be left untouched or left until source areas have been treated. Without a continuing influx of horses from source areas the population of sink areas should decline.

Once feral horse populations are initially reduced by mustering, trapping or shooting, a manager may consider using fertility control. Improved dart or pellet guns are required to deliver the anti-fertility agent. A means of identifying horses that have been previously treated would be valuable. Treating horses by ambushing them at important water-holes may work but would be time consuming. A series of wet years could seriously limit this option unless anti-fertility agents are long-acting (5-7 years). Further research is required to test the feasibility of treating horses automatically or by dart at important watering-points. Wildlife, cattle, and tourists also wander through the bush in central Australia. It would not be acceptable to render these other animals infertile or damage them in any way.

Whether to reduce impact on the cattle industry or the environment, or to avoid the situation where thousands of horses perish during drought, all interest groups should have the same objective. Feral horse numbers need to be controlled. The challenge remains to develop cheap and effective methods for administration of a long-acting anti-fertility agent. I believe fertility control could then be a useful option for small populations of horses. However, the key to controlling feral horses is good planning and efficient use of all the available options. One technique alone cannot reduce the impact of feral horses and save them from starvation during drought.

Plate 9: Horses are mustered by helicopter (a to c), shot from helicopter (d) or trapped in yards when they come to drink (f). Fencing off water (e) can force horses to drink elsewhere protecting the environment nearby from their impact or improving trap success at other watering-points. In some areas, "sink areas" where waterholes dry up or where there are poisonous plants (e.g. *Swainsona*) (h), mortality rate may exceed reproduction. These areas rely on immigration from "source areas" to maintain populations. Management should be concentrated in "source areas" where water is permanent, poisonous plants are scarce and large harem groups common.

CHAPTER 10
SYNTHESIS AND DISCUSSION

10.1 Introduction

In the preceding chapters (3-8) I have answered many questions about the ecology of feral horses in central Australia. In this chapter I compare some of these answers with those reported for ungulates in other parts of the world while discussing the interactions between horses and cattle, horses and horses, and horses and humans. This discussion leads to more questions for which I propose some answers and suggest some further research required to reveal more answers and most probably more questions.

10.2 Horses spend most of their time feeding

a) Do horses eat more than cattle?

It is common belief that horses eat more than cattle. This belief may have arisen because they appear to be continually grazing whereas cattle spend most of the day lying in the shade. As can be expected from published differences between ruminants and non-ruminants (see Table 10.1) time spent feeding by horses in my study (73-81%) is higher than that reported for cattle (37-47%) by Low et al. (1980). Low's study area was approximately 100 km west of the Hale Plain. The fact that horses spend more time feeding (Chapter 3) does not necessarily mean that they eat more than cattle.

Cattle are ruminants and have a larger digestive tract than the non-ruminating horses (see section 1.4). Cattle appear to eat a large amount in a relatively short time and then spend much of the rest of their time ruminating. By ruminating (chewing their cud) they can process the fibrous material more thoroughly than horses. Horses with their relatively small gut (capacity about 40% less than that of cattle) feed more continuously (Chapter 3). The time saved by not having to ruminate is probably used to select the better quality food (Chapter 4). Horses also have less bulk of gut to carry around, presumably allowing them greater mobility than cattle. The greater mobility also contributes to their ability to be selective.

Table 10.1: Time spent grazing or browsing by horses and other ungulates. Methods include recording the number of animals engaged in activities during transect counts or at regular intervals. I also used continuous observation.

Ungulate	Time feeding (%)	Night or day	Location and method and pasture conditions	Ref
Feral horse	73-79% 74-81% 76% 83%	Both (male) Both (female) Night Day	Central Australia; Continuous record of activity of radio-marked groups during 3 hour sample periods spaced 2 hours apart.	1
	33% 90%	Day Day	Transect counts; green grass. Transect counts; dry grass.	
Feral horse	75%	Day	Western Alberta; scan sampling 5-15 min. intervals.	2
Feral pony	55%	Night	Assateague Island; scan, 1 min	3
Feral horse	63% 35% 84%	Day Summer Day Winter Day	Granite Range north-west Nevada	4
Horse	38%	Both	Stabled with pelleted ration constantly available	5
Horse	70%	Both	Poland, in a forest reserve	6
Horse	51-60% 59-63%	Both (male) Both (female)	Camargue, France	7
Donkey	52%	Both	Northern Panamint Range California	8
Cattle	42% 37% 47%	Both Day Night	Central Australia	9
Red Deer	47-76% 17-42%	Day Night	Isle of Rhum off Scotland	10
African Buffalo	63-69%	Both	Serengeti National Park, Tanzania	11
Impala	33-45%	Both (female)		12
Hindgut fermenters	58% 59%	Both Day	Mean for 5 species	13
Ruminants	42% 49%	Both Day	Mean for 12 species	13

1. This thesis, 2. Salter and Hudson (1979), 3. Keiper and Keenan (1980), 4. Berger (1986) 5. Ralston *et al.* (1979), 6. Kownacki *et al.* (1978), 7. Duncan (1980), 8. Moehlman (1974), 9. Low *et al.* (1980), 10. Clutton-Brock *et al.* (1982), 11. Sinclair (1977), 12. Jarman and Jarman (1979), 13. Brunnell and Gillingham (1985)

Experimental studies indicate that, weight for weight, horses and cattle eat similar quantities of plants per day. On a metabolic body size basis ($W_{kg}^{0.73}$) horses consumed daily 79 g/kg$^{0.73}$ and cattle 72 g/kg$^{0.73}$ of loose hay in an experiment conducted by Haenlein et al. (1962) (see also Nutrient Requirements of Beef Cattle and Nutrient Requirements of Horses, published by the Committee on Animal Nutrition, Board on Agriculture, National Research Council of USA). Horses theoretically have the ability to substantially increase the rate of passage of food through the gut if necessary and probably do so when diet is of poor quality to enable them to eat a greater bulk of plants and thus obtain sufficient nutrient. Cattle are less flexible because food particles must be broken down to a small size by rumination before they are allowed to continue along the gut (Janis, 1976). Horses have been reported to be less efficient than cattle in utilising the energy in poorer forages (crude fibre greater than 15%) (Hintz, 1969) and probably increase their rate of intake (amount of food per day) accordingly when only poor quality plants are available. The digestive efficiency of horses and cattle appear to be comparable for high quality forages (crude fibre less than 15%) (Hintz, 1969).

Most central Australian grasses were found by Siebert et al. (1968) to have crude fibre contents of 20% or greater and therefore horses may need to eat a larger amount of such grass per day than cattle to obtain the same total nutrients. For plants with more than 15% crude fibre the digestion coefficients for organic matter and for crude fibre obtained for horses were about 85% and 75%, respectively, of the values obtained for sheep and cattle (Hintz, 1969). This suggests that if horses and cattle took the same poor quality diet (greater than 15% crude fibre) then horses would have to eat perhaps 15% more to receive the same amount of nutrient as cattle.

It is important to note that horses and cattle appeared to select diets of different quality during my study. When excellent quality grasses were available the diet quality of horses averaged 20% higher than the diet of cattle. By selecting a higher quality diet horses may maintain a daily intake of vegetation similar to that of cattle.

b) Are they less efficient digesters?

Many people assume that horses are less efficient digesters of plants than are ruminants such as cattle. This again may result from observation of horses spending more time feeding than cattle. Furthermore, relative inefficiency in digestion of the non-ruminant is thought to explain well the dominance of the artiodactyls (ruminants) over the perissodactyls (non-ruminants) since the Miocene (Colbert, 1969; Janis, 1976). However, there is evidence to say horses may not be less efficient digesters than cattle. Horses were reported by Linerode (1966) to have a 3 times faster rate of passage through the gut than ruminants, and other workers have found similar results (Alexander & Benzie, 1951; Alexander, 1946; Balch, 1950). Yet the faster rate of passage does not appear to significantly reduce cellulolytic activity below that of the ruminant. Evidence for this is that cotton threads suspended in a horse large intestine disappeared quicker than those suspended in the rumen of a cow (Alexander, 1952). This suggests that equine caecal and colon fermentation is more efficient than rumen fermentation. Therefore it is debatable whether horses have a less efficient digestive system than cattle and thus they may not require a greater daily intake of pasture to compensate for inefficient digestion. Why then did the artiodactyls apparently have a competitive advantage over the perissodactyls?

c) Why eat more annual grass than cattle?

Why do horses head for the hills and maintain a diet of predominantly annual grass when conditions are dry? They presumably could stay on the alluvial flats close to water as the cattle do and survive on the more fibrous perennial grasses. Zebra in the Serengeti choose to eat the fibrous stems of grasses while the ruminants eat the leaves which have higher protein content (Bell, 1970; Owaga, 1975). Horses in central Australia could presumably increase their rate of intake to obtain sufficient nutrient from the fibrous perennial grasses. Cattle cannot so increase their consumption rate and appear to supplement their protein and other nutrient requirements from trees, shrubs and forbs (dicots) enabling them to utilise the fibrous and less nutritious perennial grasses. Ruminants in the Serengeti delay their dry-season departure from the upper catena where they consistently take higher proportions of browse than zebra (Bell, 1970).

Why should zebra and horses appear to leave the richer sources of nutrient to the ruminants? A possible explanation is that the non-ruminant cannot cope as well with the secondary chemical compounds that are more likely to be present in dicots or in the leaves of grasses (literature reviewed by McNaughton, 1979). The importance of secondary chemical compounds produced by plants for defence against herbivores has been emphasised by several authors (e.g. Culvenor, 1970; Freeland & Janzen, 1974; Van Soest, 1982).

I believe one reason horses did not use the flats as much as cattle was that they are less able than cattle to detoxify secondary plant compounds that are produced as defence against herbivores. To survive and reproduce relatively better than other members of their species, horses must avoid areas where they are likely to eat poisonous plants.

The presence of chemical defences in plants and the presumed relative inability of equids to detoxify these compounds can explain why horses are mobile grazers. Secondary chemical compounds generally occur in the least ephemeral plant species (Odum, 1969). Mobility in equids may have first evolved in response to the need to evade predators. However, the selective advantage of mobility was perhaps heightened by their need to quickly obtain ephemeral plants with little chemical defence before the ruminants could eat them. Annual plants tend to avoid herbivores by completing their life cycle in a short time. A herbivore requires mobility to utilise such "mobile" plants. Furthermore, the presence of chemical defences being more common in dicots than in grasses (Culvenor, 1970) should be a strong selection pressure for herbivores to evolve characteristics suitable for grazing rather than browsing.

There are at least two ways a herbivore species can protect itself from secondary chemical defences. One option is to develop an efficient detoxification mechanism and another is to select plants or plant parts that are least likely to be toxic. The first option appears to have evolved in the artiodactyls and the second evolved in the equids. Horses are mobile and select annual plants (Chapters 4 & 5) which are least likely to contain secondary chemical compounds (Odum, 1969). Zebra have been described as pioneering species in a grazing succession (Bell, 1970). They use areas before the ruminants move in. Likewise as conditions dried during my study horses used areas distant from water and grazed in the hills before cattle. Perhaps horses and zebra are seeking the non-toxic plants or plant parts before the ruminants can eat them. If the ruminants can in fact detoxify secondary plant compounds relatively better than non-ruminants, then they are able to utilise both plants that use chemical defence (dicots and perennials) and those that use 'avoidance' (grasses and annuals), thereby giving ruminants a competitive advantage (Figure 10.1).

The oat grasses which dominate the pasture of the hills and stony terraces with five-minute grass made up a large proportion of the diet of horses on the Hale Plain. These grass species generally have the highest protein content and are less fibrous than other grasses. However, they are sparsely distributed, relatively small plants, growing close to the ground. To utilise their high quality a herbivore must be mobile, have plenty of time to spend searching and be able to take the many small mouthfuls required. This is the strategy of horses and they have many adaptations for it (see Chapter 1).

d) Is there competition between horses and cattle in central Australia?

Fifty percent of pastoralists interviewed by Bowman (1987) in the Alice Springs district considered feral horses were a problem. They ranked damage to fences and competition with cattle for feed as the major damages caused. It is common perception that feral horses eat food needed by cattle (Squires, 1981). This, however, has not been proven. They certainly eat plant species eaten by cattle (Chapter 4) in similar places (Chapter 5) but do feral horses eat food **needed** by cattle? Were the oat grasses (*Enneapogon*) that were eaten by horses in the hills required by cattle to maintain fecundity, survivorship or growth? If so, ecological competition was occurring (Begon et al., 1990). The cattle, however, turned to dicots and perennial grasses on the alluvial flats while horses were searching for annual grasses in the hills. Only after the extended dry period were cattle beginning to use the hills. It is then that they may have needed the oat

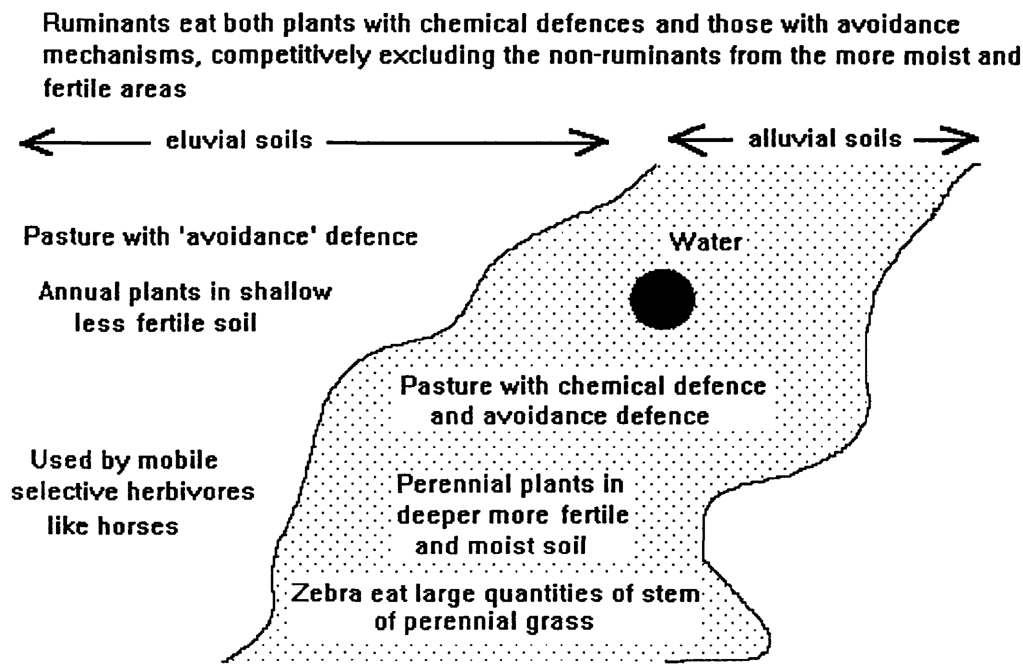


Figure 10.1 Diagram to explain the competitive advantage ruminants may have over non-ruminants and the way horses and zebra have adapted to survive the competition.

grasses that the horses had previously removed.

Further evidence for competition, I believe, was that the similarity in habitat use and diet was greatest when forage was most abundant. That is, overlap was greatest when the effects of competition were least likely to be present. If it is not eaten, forage is available for at least 2 years after it has grown. If it is eaten, then it is not available for any horse or cow that needs it. If sufficient rain falls to replace the eaten pasture before it is needed then competition does not occur. The complete competitive process may therefore take, for example, as long as two years.

Studies of natural communities usually show closely related, coexisting species either live in different sorts of places or use different sorts of food. For example ungulates in the

Serengeti use different habitat for much of the time or eat different species of plant or different parts of plants (Jarman & Sinclair, 1979). This is consistent with my findings for horses and cattle in central Australia (Chapters 4-5). However, observing differences between species does not necessarily mean that competition has caused the differences. Neither do observed differences rule out competition.

Many North American and Canadian studies have included analyses of the diets of feral horses and sympatric ungulates, which often include cattle. Overlap with cattle in diet was usually great, and greater than with any other sympatric ungulates. For example, the dietary overlap between horses and cattle in western Alberta was 66% (Salter & Hudson, 1980), in the Wyoming Red Desert was 72% in summer and 84% in winter (Krysl et al., 1984b) and in Colorado 77% (Hansen et al., 1977). The mean overlap within the grass component of the faeces (measured at genus level) estimated for this study was 61% which is similar to North American results. It must be remembered that grazing relationships can be complex. Horses and cattle may take different parts of plants and the two ungulates may feed on the same plants in different places. These factors were not always considered during other studies.

In Western Alberta over 90% of the sites utilised by cattle in summer had received prior use by horses. However, there was little overlap during the time when cattle were actually present (Salter & Hudson, 1980). Similarly in Wyoming's Red Desert on a yearly basis most of the horses and cattle were found in the same vegetation type but peak occupancy was in different seasons (Miller, 1983). For the present 3-year study of central Australian horses and cattle the long-term habitat overlap was 61%. Habitat overlap was greatest soon after rain (73%) and least after an extended dry period (29%).

Squires (1981) stated that competition between donkeys and cattle for food and water is obvious. This assumption was based on anecdotal evidence. No studies have been conducted to determine just what donkeys eat in Australia and how much food they eat that is suitable for cattle. Because horses, cattle and donkeys all appear to eat grass they are assumed to compete. Similarly in the sheep grazing areas of Australia, kangaroos are considered by pastoralists to compete with stock for food. However, Squires (1981) reviewed dietary studies conducted by the CSIRO and results suggest that although kangaroos and sheep may eat the same species of plants, they often prefer different species and in different proportions in different places. Squires believed this to be evidence against direct competition, especially when food is readily available. In general, the kangaroo prefers short green grass. The longer growth, both green and dry, is left to livestock. Kangaroos have a stronger preference for the richer type of country than cattle or sheep (Squires, 1981). This, however, does not rule out the possibility of competition. Cattle and sheep may at some stage need the short green grass in the richer country.

The facts that habitat and diet of horses and cattle overlap, and that this overlap is greatest when high quality forage is most abundant (Chapters 4-5), indicates there is great potential for competition between the two introduced ungulates. I postulate the degree of competition between horses and cattle varies depending on the proportions of different types of vegetation, soil and landform, the density of stock and the time since rain induced pasture growth. Scientists from more predictable climates might recommend an experimental manipulation to prove without doubt that competition occurs. This would be agreeable. However, all other variables would have to be kept constant while the ratio of horses to cattle was manipulated. Horses could be removed from or reduced in some areas and left or increased in other areas, and the growth and reproduction of cattle monitored. Such experiments would be extremely difficult to run in central Australia because of the extreme spatial and temporal variation in rainfall and the heterogeneity of soil, vegetation and landform. There is also variation in the distribution and abundance of other potentially competing herbivores such as rabbits, donkeys, and kangaroos. Furthermore the frequency of calves killed by dingoes varies in time and space. Nevertheless, I believe such an experiment should be attempted to determine the degree of ecological competition between feral horses and cattle in central Australia and thus provide a measure of the level of control necessary to alleviate damage. The knowledge of the ecology of feral horses contained in my thesis would be essential for interpretation of experimental results.

e) Is there facilitation between horses and cattle?

Although there appears to be great potential for competition between horses and cattle in central Australia there is also potential for facilitation. This interaction involves one species providing a feeding benefit for another (Vesey-Fitzgerald, 1960). Possible examples of facilitation have been reported for ungulates elsewhere. Zebra are thought to "open up the tall, coarse grasses by removing stems, thus exposing the leaves at the base of the plants and allowing greater access for wildebeest, which need a higher proportion of leaf in their diet" (Bell, 1970). By removing grasses, horses and cattle promote growth of shrubs and forbs, both of which are consumed by deer in North America (Berger, 1986). Other examples appear to exist in Australia where sheep or cattle facilitate kangaroos by converting tall dry herbage to a short sward (Squires, 1981; Newsome and Corbett, 1977).

I suspect the following facilitative interactions may occur between horses and cattle in central Australia. Horses dig holes in the sand of river beds to obtain water. Cattle appear unable to do this but use water in holes dug by horses. Horses therefore facilitate the use by cattle of pasture more distant from free water. Horses appear more susceptible to poisonous plants than cattle. Of particular note is the fact that horses are made sick and often eventually die if they eat Birdsville's indigo (*Indigophera linneae*). Cattle, however, are not affected and can utilise the high protein content of this succulent plant. I suggest that cattle, by eating toxic plants may remove or reduce the risk of poisoning for horses. Thus cattle may facilitate pasture use by horses by changing the composition of the pasture.

10.3 Basic pattern of social organisation: Similar variation

As mentioned in section 1.3 many researchers have reported variations to the basic pattern of social organisation set out by Klingel (1972), and from work by Hoffmann (1983) I expected to find further variation in central Australia. However, the feral horses that I studied appeared to exhibit no further variations on the patterns of social organisation revealed for horses studied elsewhere in the world (Chapter 6). Researchers may therefore have recorded the full range of social options available to the horse. We are now perhaps in a position to revise the basic pattern set out by Klingel (1972) for horses.

a) What determines the variations on the basic pattern?

Many factors may influence the social system of ungulates such as body size, feeding style, food-item abundance and dispersion, and antipredator behaviour (Jarman & Jarman, 1979). Each species, genus or family of ungulates appears to have a range of social options available to them that is fixed by their phylogenetic history (Wrangham & Rubenstein, 1986), physical size, shape, length of legs, acuteness of hearing, digestive system and so on. These physical attributes can change (i.e. evolve), but relatively slowly. So the range of social options available to a taxonomic group of animals can change only very slowly, whereas populations of the same species, observed in different regions or times, may exhibit different social behaviours "selected" from that species' possible range. For our purposes this range is virtually fixed and once all the social options are identified the factors that influence them can be determined.

Many authors have attributed differences in equid social organisation to environmental factors (Woodward, 1979; Moehlman, 1974; McCort, 1979; Miller, 1979; Rubenstein, 1981). Rubenstein (1981) concluded that habitat structure, distribution of food and water, diversity and quality of vegetation, as well as sex ratio and age structure of the population may influence the social system. Most differences occur between locations but Miller (1979) and Rubenstein (1981) reported changes in horse social organisation during their study periods. In the Wyoming Red Desert the proportion of multiple-male bands decreased during a severe winter (Miller, 1979). On Shackleford Banks some horses were territorial (Rubenstein, 1986). On this small island male infants generally die at a higher rate than female infants. Consequently Rubenstein initially found there to be twice as many adult females as males. During a series of mild winters male mortality was less than normal and there was an increase in the proportion of bachelor males. This and the aging of the harem stallions was the reason given for increased harem stallion overthrows, reduced group sizes, and disappearance of all the territories (Rubenstein, 1986). So environmental factors were reported to have caused a change in the social system principally by altering the sex ratio or more generally the balance between the strengths of harem and bachelor males.

But did the social system really change? In my opinion just the social options used by the Shackleford Banks population changed. During the course of most studies the social system, that is the range of social options available to an animal of that physical or physiological type, is essentially fixed. What has been observed by those who have reported changes in the social system are merely changes in details of the overall social system. Based on studies of a number of Serengeti ungulate species, particularly antelope, Jarman and Jarman (1979) suggested "the details of social organisation are imposed on the basic grouping by discriminatory behaviour relating to reproduction, mainly mother-young association and the behaviour of males in securing mating rights." Evidence from my study and from Rubenstein's showing changes in either the condition of adult males or in the sex ratio indicate that Jarman and Jarman's (1979) suggestion holds true for horses as well. I believe the social system of horses is essentially fixed but the short term expression from the range of options are determined by discriminatory behaviour relating to reproduction which in turn is influenced by environmental factors.

b) The horse social system simplified?

In Table 10.2 I present a model of the horse social system that is essentially a hierarchy of social options reported for horses. I have placed the options in order of least to most complex. This order ascends from what I assume is generally the least beneficial (i.e. single individual) to the most beneficial for both sexes (i.e. territoriality) based on the order of reported costs to males associated with maintaining each option and the reproductive potential for males and females for each option (Rubenstein, 1986; Berger, 1986). The order of social options may also correspond to developmental stages from the least to the most mature. I propose that territoriality is the most mature social option (i.e. it takes time to develop and the adult members are relatively mature) and single individuals are usually the least mature adult individuals in a population.

Table 10.2: Range of social options available to feral horses and the presumed costs and benefits of each option.

Cost	Social group type	Benefit	Feed	Breed	Total
1,3,7,8	Single individual	2,4,5,6	3	-2	0
2,7,8	Bachelor group	1,3,4,5,6	3	-2	2
2,4,6,8	Multiple-male harem group	1,3,5,7	-1	0	0
2,4,6	Single-male harem group	1,3,5,7	-1	1	1
2,4,5	Territorial single-male harem group	1,3,6,7,8	-1	2	2

Costs	Benefits
1...Vulnerable to predators (dogs, lions etc)	1...Anti-predation (dogs, lions etc)
Feeding related	Feeding related
2...Intra-specific competition for food	2...Minimal intra-specific food competition
3...Single knowledge of resource location	3...Multiple knowledge of resource location
4...Grazing time taken by social interactions	4...Plenty of time to graze
5...Immobility - cannot respond to unpredictable resources	5...Mobility - can respond to unpredictable resources
6...Cannot always choose preferred grazing area	6...Can choose preferred grazing location
Breeding related	Breeding related
7...Minimal chances for breeding	7...Good breeding potential
8...Chances of mating with inadequate partner	8...Reduced harassment by other males

I have further tabulated some advantages and disadvantages I consider important to members that choose each social option (Table 10.2). The feeding-related costs and benefits are numbered from 2 to 6 and the breeding related costs and benefits are numbered 7 and 8. Each cost and each benefit was assigned a value of 1 and then tallied for each social group type to give a total cost and benefit score. The costs were subtracted from the benefits associated with feeding to determine which social option gives the best feeding, breeding or total advantage to individual members of groups. This analysis is indeed crude and I may have omitted some important factors; however, the results suggest that the model is sensible. For instance, the scores indicate that bachelors and single individuals have feeding advantages over members of other groups but they sacrifice breeding advantages for feeding. This explains why bachelors were in better body condition than harem stallions for most of my study and why, as pasture quality and quantity declines, group sizes decrease when harem stallions require more feeding advantages while bachelors seek more breeding advantages. The overall score reflects roughly the basic pattern described for feral horses by Klingel (1972) and is equivalent to the proportions of each social option revealed by the numerous studies of feral horses throughout the world. The only exception is territoriality which has a high total score due mainly to breeding advantages (Table 10.2).

Klingel's (1972) description of equid social systems set in my mind the belief that horses are not territorial. I was most surprised when I discovered the report that feral horses maintained well-defined, non-overlapping territories on an island off the coast of North Carolina (Rubenstein, 1981). According to Klingel, asses and Grevy's zebra are territorial, but not horses. Admittedly territoriality does not appear to be common in horses and they appear to require very special environmental and demographic conditions to become truly territorial. However, territoriality does occur and therefore is a social option for horses given suitable circumstances. Rubenstein (1981) suggested "territoriality would exist in all horse populations if the cost associated with maintaining it were offset by large enough benefits." I feel that Rubenstein believed territoriality to be the ultimate system of social organisation for horses and that if there is sufficient resources a stallion will maintain a territory. The benefits would be increased reproductive success due to reliable resources (food, water, mates and habitat for predator evasion), stability of the social group, and reduced harassment of mares by other stallions. Such harassment and the instability caused by it can reduce the reproductive rate of horses (Berger, 1986).

c) Horses should be considered territorial

To complete this discussion of social organisation I propose an idea that may "ruffle a few feathers", particularly of people who know more about zebra and asses than I do.

However, I believe my idea should simplify our perception of equid social organisation. It is that all equids should be considered "territorial". A territory is an area defended by one member of a species against intrusion by other members of the same species (Keeton, 1972). Using this broad definition all equids defend territories. They are not as territorial as small ungulates like the dik-dik (Jarman & Jarman, 1979) which could be described as being perfectly territorial. However, equids merely exhibit variations from true territoriality since they cannot normally obtain sufficient food resources to enable them to defend true territories.

"Migratory wildebeest males abandon spatially fixed territories....they accompany the females and set up very temporary, even mobile, territories....no bigger than the area a male can keep free from other males by his immediate presence." (Jarman & Jarman, 1979). This description of a territorial ungulate fits closely the behaviour of horses. Why are wildebeest generally considered territorial animals while horses are not? Simply because horses have rarely been seen to defend spatially fixed territories. But are mobile territories much different to those that are fixed? Dominant harem stallions are defending the breeding advantages that territoriality provides (Table 10.2). However, normally their territory must be mobile because the abundance and location of food and water is unpredictable in areas where they live.

Asses and Grevy's zebra males defend territories in habitat where estrous females are likely to wander or stay to feed (Klingel, 1972; Rubenstein, 1986). These so-called territorial equids are no closer to being truly territorial than the horse that defends an area around his mares. Asses and horses use slightly different strategies to maintain some of the territorial benefits. The strategy used by asses is perhaps more suited to predictable seasonal climate because they defend spatially fixed territories, whereas horses which defend mobile territories around a harem of mares are more suited to places where food and water are unpredictable or sparsely distributed where mobility is advantageous. The distribution of equids (Figure 1.1) indicates that those that defend spatially fixed territories generally live closer to the equator than those that form mobile territories around a harem. In Australia the major concentrations of feral donkeys are in the Kimberley and

Victoria River Districts where the rainfall and resulting pasture growth is seasonal and predictable. Although feral horses also live in these areas they are not as successful as the donkeys. Their domain appears to be in the more unpredictable areas of central Australia.

10.4 Conclusions

The mobility of horses is exhibited not only in their digestive system, feeding strategy and body structure, but also in their social system. Horses are able to utilise cellulose-rich, short grassy plant material and have evolved speed and a feeding strategy enabling them to evade predators and locate and utilise sparsely distributed food and water. In central Australia the speed of horses is necessary to avoid pastoralists on horseback or motor bikes, or in helicopters. Mobility allows them to climb hills and walk up to 50 km from water to obtain food during drought. Their teeth and lips are suited to grazing high-quality annual grasses close to the ground, and their digestive system is suited to long periods of relatively uninterrupted grazing which allows them time to be selective, and time to walk to areas where cattle are not; where the best grasses and least toxic plants occur.

A major difference between horses and cattle may lie in their ability to detoxify secondary chemical compounds in plants that they eat. Pregastric fermentation may have evolved primarily as a detoxification mechanism giving herbivores that possessed it a competitive advantage over those that used hind-gut fermentation. I propose that at least part of the mobility of horses evolved as a means to obtain the "mobile" plants (i.e. small ephemerals), which were least likely to be toxic, before these plants were eaten by sympatric (pregastric fermenting) artiodactyls.

The mobility of horses perhaps saved them from extinction which was the fate of most other perissodactyls. Mobility that presumably evolved in response to competition, predation or sparsely distributed and unpredictable resources preadapted horses for domestication. Humans used the mobility of horses for transport all over Asia and Europe and "in return" humans reintroduced horses to America and introduced them to Australia.

The timing and amount of rainfall determines the quality and quantity of pasture (Chapter 4) that directly and indirectly influences the reproductive and mortality rates of feral horses in central Australia. Disease from ingested toxins also strongly influence the distribution of feral horse populations (Chapter 5; McKnight, 1976). However, the activity of humans is the primary influence controlling the distribution and density of feral horses in central Australia (Chapter 5).

Relatively free of disease and predators I believe horses in central Australia have had a decided advantage over native herbivores which must cope with the predators and diseases (pathogenic and poisoning) that they evolved with. The central Australian plant community was perhaps relatively naive with respect to equids. Such conditions are common for introduced ungulates and generally lead to an initial irruption where the population increases until it exceeds the carrying capacity (see section 1.8). Resultant overutilisation of extensive areas of vegetation usually causes the population to drop below the initial carrying capacity. Previous authors have emphasised habitat changes such as a reduction in the abundance of preferred food due to selective grazing as the main cause of the decline below the initial carrying capacity. I believe disease (pathogenic or toxic) or increases in predator numbers or improvement in the specific efficiency of predators may also be important.

In North America in 1971 protection laws permitted the population of feral horses to increase dramatically (McCort, 1984) indicating that there had previously been considerable control by humans. By far the most dramatic change in the feral horse population studied by me resulted from capture by humans. Whether these horses are killed and eaten by people or used for other purposes, the interaction between humans and horses is essentially predator-prey. Those of us who have been closely associated with horses may consider people who eat horses as 'cannibals'. Whatever the name, the result is the same; horses are captured and removed from the population. Apart from the relatively short period of domestication (2,500 to 5,000 years), for much of the last one million years humans have preyed upon horses (Clutton-Brock, 1987).

Horses have certainly caused major changes to habitat in central Australia most likely reducing the carrying capacity below the initial level. They have done this by removing pasture and increasing the rate of soil erosion (Chapter 8). Prior to 1985 there were many failed attempts to capture feral horses in central Australia. The predators (humans) perceived a high density of feral horses and began a research programme that resulted in this thesis. The understanding of feral horse ecology presented in this thesis should lead to improvement in the efficiency of management of feral horses (Chapter 9). Efficient predators (the pastoralist and scientist) played the major role in reducing numbers after the irruption of feral horses, at least on my study area.

Will feral horses continue to cause the environment to deteriorate? Will they cause more native plants and animals to become extinct? Will feral horses reduce the suitability of the central Australian environment to humans by reducing the viability of the land for cattle production? Will the erosion, bare ground, piles of dung, lack of native plants and animals make central Australia less suitable for tourists? Or can humans, a predator that horses evolved with, help restore some sort of balance?

REFERENCES

Alexander, F. (1946). The rate of passage of food residues through the digestive tract of the horse. *J. Comp. Path.* 56:266-268.

Alexander, F. (1952). Some functions of the large intestine of the horse. *Quart. J. Exp. Physiol.* 37:205-214.

Alexander, F. and Benzie, D. (1951). A radiological study of the digestive tract of the foal. *Quart. J. Exp. Physiol.* 36:213.

Arnold, D. (1986). Sterilizing wild horses. *The Western Horseman* June:15-35.

Askew, K. and Mitchell, A.S. (1978). *The fodder trees and shrubs of the Northern Territory.* (Extension bulletin no. 16). Darwin: Division of Primary Industry.

Balch, C.C. (1950). Factors effecting the utilization of food by dairy cows. I. The rate of passage of food through the digestive tract. *Brit. J. Nutr.* 4:361.

Balch, C.C. and Johnson, V.W. (1950). Factors effecting the utilization of food by dairy cows. II. Factors influencing the rate of breakdown of cellulose (cotton thread) in the rumen of the cow. *Brit. J. Nutr.* 4:389.

Begon, M., Harper, J.L. and Townsend, C.R. (1990). *Ecology: individuals, populations and communities.* Melbourne: Blackwell Scientific Publications.

Belbin, L. (1987). *PATN: Pattern analysis package.* Canberra: CSIRO, Division of Wildlife and Rangelands Research.

Bell, R.H.V. (1970). The use of the herb layer by grazing ungulates in the Serengeti. In A. Watson (Ed.), *Animal populations in relation to their food resources* (pp. 11-23). Oxford: Blackwell Scientific Publications.

Belovski,, G.E. (1981). Optimal activity times and habitat choice of moose. *Oecologia* 48:220-30.

Belschner, H.G. (1982). *Horse diseases.* Sydney: Angus and Robertson.

Berger, J. (1983). Induced abortion and social factors in wild horses. *Nature* 303:59-61

Berger, J. (1986). *Wild horses of the Great Basin.* Chicago: University of Chicago Press.

Berman, D.McK. (1991). Control of feral horses on a central Australian property. In *9th Australian Vertebrate Pest Control Conference: Handbook of Working Papers*, Adelaide, SA: South Australian Animal and Plant Control Commission.

Berman, D.McK. and Dobbie, W.D. (1990). Reducing the fertility of feral horses in central Australia: Potential field difficulties. In *Fertility Control in Wildlife Conference: Program and Speakers' Papers*, Melbourne, Australia: Atkinson Conference Services Pty. Ltd.

Berman, D.McK. and Jarman, P.J. (1987). *Feral horses in the Northern Territory Vol.I: The ecology of feral horses in central Australia and their interaction with cattle.* (Internal document). Alice Springs: Conservation Commission of the Northern Territory.

Berman, D.McK. and Jarman, P.J. (1988). *Feral horses in the Northern Territory Vol.IV: Environmental impact of feral horses in central Australia.* (Internal document). Alice Springs: Conservation Commission of the Northern Territory.

Bokonyi, S. (1974). *The Przwalsky horse.* London: Souvenir Press.

Bomford, M. (1990). *The role for fertility control in wildlife management?* (Bulletin No. 7). Canberra: Department of Primary Industries and Energy Bureau of Rural Resources. Australian Government Publishing Service.

Bowman, A.J. (1985). *Analysis of aerial survey data from the Alice Springs District and implications for feral horse management.* Unpublished B.Nat.Res. Project, University of New England, NSW.

Bowman, A.J. (1987). *Feral horses in the Northern Territory Vol. III: Economic viability and producer preference for management strategies of Feral Horses.* (Internal document). Alice Springs: Conservation Commission of the Northern Territory.

Boy, V. and Duncan, P. (1980). Time-budgets of Camargue horses. I. Developmental changes in the time budgets of foals. *Behaviour* 71:187-202

Brown, R.F. (1981). Drought forage utilisation, and their effects on the survival and recruitment of grasses of the mulga (*Acacia aneura*) woodlands. In *Australian Rangeland Society Biennial Conference Papers*, 3:213.

Brunnel, F.L. and Gillingham, M.P. (1985). Foraging behaviour: Dynamics of dinning out. In Hudson, R.J. and White, R.G. (Eds.), *Bioenergetics of wild herbivores*, Florida: CRC Press.

Buckley, R. (1985). Development in the central Australian arid zone: current assessment. *J. Arid Environ.* 8:173-189.

Butler, J., Achuff, P. and Johnston, J. (1986) Arjin Mountains Nature Reserve Xinjiang People's Republic of China: Management recommendations and resource summary. International Union for Conservation of Nature and Natural Resources (Commission on National Parks and Protected Areas) - World Wildlife Fund - China - Joint Expedition.

Campbell, G.A. (1989). *Feral horses in Western Australian.* Perth: Agriculture Protection Board, WA.

Caughley, G.C. (1970). Eruption of ungulate populations, with emphasis on Himalayan thar in New Zealand. *Ecology* 52:53-72.

Caughley, G.C. (1977). *Analysis of vertebrate populations.* London: Wiley and Sons.

Caughley, G.C. and Grice, C.J. (1982). A correction factor for counting emus from the air, and its application to counts in Western Australia. *Aust. Wild. Res.* 9:253-259

Chapman, D.G., and D.S. Robson (1960). The analysis of a catch curve. *Biometrics* 16: 354-368.

Chippendale, G.M. (1962). Botanical examination of kangaroo stomach contents and cattle rumen contents. *Aust. J. Sc.* 25(1):21-22.

Chippendale, G.M. (1968). *A study of the diet of cattle in central Australia as determined by rumen samples.* (Technical Bulletin. No.1). Darwin, N.T.: Primary Industries Branch, Northern Territory Administration.

Choquenot, D. (1988). *Feral donkeys in northern Australia: population dynamics and cost of control.* Unpublished M.Sc. thesis, Canberra College of Advanced Education, ACT.

Christian, C.S. and Stewart, G.A. (1953). *General report on survey of Katherine-Darwin region, 1946.* (Land Research Series No. 1). Melbourne: CSIRO.

Cifelli, R.L. (1981) Patterns of evolution among the Artiodactyla and Perissodactyla (Mammalia). *Evolution* 35(3): 433-440

Clutton-Brock, J. (1987). *A natural history of domesticated mammals.* Austin Texas: University of Texas Press.

Clutton-Brock, T.H., Guinness, F.E., and Albon, S.D. (1982). *Red Deer: Behavior and Ecology of Two Sexes.* Chicago: University of Chicago Press.

Colbert, E.H. (1969). *Evolution of the Vertebrates.* (2nd ed.). New York: John Wiley.

Cole, L.C. (1949). The measurement of interspecific association. *Ecology* 30:411-424

Condon, R.W. (1986). *A reconnaissance erosion survey of part of the Victoria River District, N.T.* (Internal document). Darwin: Land Conservation Unit, Conservation Commission of the N.T.

Cook, C.W. (1966). Factors affecting utilisation of mountain slopes by cattle. *J. Range Manage.* 19:200-204.

Culvenor, C.C.J. (1970). Toxic Plants - a re-evaluation. *Search* 1(3):103-110.

Delroy, L.B., Earl, J., Radbone, I., Robinson, A.C. and Hewett, M. (1986). The breeding and re-establishment of the brush-tailed bettong, *Bettongia penicillata*, in South Australia. *Aust. Wildl. Res.* 13:387-396.

Department of Primary Production (1982). *Central Australian range herbarium.* Northern Territory Department of Primary Production.

Dobbie, W.R. and Berman, D.McK. (1990). *Movement and home range of feral horses in central Australia.* (Internal document). Alice Springs: Conservation Commission of the Northern Territory.

Duncan, P. (1980). Time-budgets of Camargue horses. II. Time-budgets of adults. *Behaviour* 72:26-49.

Duncan, P., Harvey, P.H., and Wells, S.M. (1984). On lactation and associated behaviour in a natural herd of horses. *Anim. Behav.* 32:255-263

Eberhardt, L.L., Majorowicz, A.K. and Wilcox, J.A. (1982). Apparent rates of increase for 2 feral horse (*Equus caballus*) herds. *Wildl. Manage.* 46(2):367-374

Ebhardt, H. (1957). Drei unterschiedliche Verhaltensweisen von Islandpferden in norddeutschen Freighehegen. *Saugetierk. Mitt.* 2:145-154.

Eisenberg, J.F. (1981). *The Mammalian radiations: an analysis of trends in evolution, adaptation and behaviour.* Chicago: The University of Chicago Press.

Evans, J.W., Borton, A., Hintz, H.F. and Dale Van Vleck, L. (1977). *The Horse.* San Francisco: W.H. Freeman and company.

Feist, J.D. (1971). *Behaviour of feral horses in the Pryor Mountain Wild Horse Range.* Unpublished M.Sc. thesis, University of Michigan, Ann Arbor.

Foley, J.C. (1957). *Droughts in Australia: Review of records from earliest years of settlement to 1955.* (Bulletin No. 43) Commonwealth of Australia Bureau of Meteorology.

Foran, B.D. (1980). Change in range condition with distance from watering point and its implications for field survey. *Aust. Rangel. J.* 2(1):59-66.

Foran, B.D. (1986). The impact of rabbits and cattle on an arid calcareous shrubby grassland in central Australia. *Vegetatio.* 66:49-59.

Foran, B.D., Bastin G. and Hill, B. (1985). The pasture dynamics and management of two rangeland communities in the Victoria River District of the Northern Territory. *Aust. Rangel. J.* 7(2):107-113.

Foran, B.D., Bastin, G., Remenga, E., and Hyde, K.W. (1982). The response to season, exclosure, and distance from water of three central Australian pasture types grazed by cattle. *Aust. Rangel. J.* 4(1):5-15.

Freeland, W.J. and Janzen, D.H. (1974). Strategies in herbivory by mammals: the role of plant secondary compounds. *Am. Nat.* 108:269-289.

Friedel, M.H. (1985). The population structure and density of central Australian trees and shrubs, and relationships to range condition, rabbit abundance and soil. *Aust. Rangel. J.* 7(2):130-139.

Friedel, M.H. and Shaw, K. (1987). Evaluation of methods for monitoring sparse patterned vegetation in arid rangelands. I. Herbage. *J. Environ. Manage.* 25:297-308.

Gates, S. (1979). A study of home ranges of free-ranging exmoor ponies. *Mammal Review* 9:3-8

Geering, W.A. and Forman, A.J. (1987). *Animal health in Australia. Volume 9. Exotic diseases.* Canberra: Australian Government Publishing Service.

Gobel, F. and Zeeb, K. (1963). Primitivpferde und ihre Haltung. *Tierarztl. Umsch.* 18:67-71.

Goodloe, R., Warren, R.J. and Sharp, D.C. (1988). Sterilization of feral horses by immunization against LHRH. *Proc. Wildl. Dis. Assoc.* 37:25.

Graham, A., Begg, R., Graham, P. and Raskin, S. (1982a). *An aerial survey of feral buffalo in the Northern Territory.* (Technical Report). Darwin: Conservation Commission of the Northern Territory.

Graham, A., Johnson, K. and Graham, P. (1986). *An aerial survey of horses and* *other large animals in the Alice Springs and Gulf regions.* (Technical Report No. 28). Darwin: Conservation Commission of the Northern Territory.

Graham, A., Raskin, S., McConnell, M. and Begg, R. (1982b). *An aerial survey of feral donkeys in the V.R.D.* (Technical Report). Darwin: Conservation Commission of the Northern Territory.

Grant, R. (1986). *Pastoral land survey of the Hale Plain - The Garden station.* Alice Springs: Land Conservation Unit, Conservation Commission of the Northern Territory.

Griffin, G.F. and Friedel, M.H. (1985). Discontinuous change in central Australia: Some implications of major ecological events for land management. *J. Arid Environment* 9:63-80.

Groves, C. (1974) Horses, asses and zebra in the wild. David and Charles. London

Haenlein, G.F.W., Richards, C.R. and Mitchell, W.H. (1962). Effect of the size of grind and the level of intake of pelleted alfalfa hay on its nutritive value in cows and sheep. *J. Dairy Sci.* 45:693.

Hansen, R.M., Clark, R.C. and Lawhorn, W. (1977). Foods of wild horses, deer and cattle in the Douglas Mountain area, Colorado. *J. Range Manage.* 30(2):116-118.

Hildebrand, M. (1974). *Analysis of Vertebrate Structure.* New York: Wiley.

Hindmarsh, K. (1980). Studying the impact of cattle in central Australia. *Rural Research* 107:4-9. CSIRO publication.

Hintz, H.F. (1969). Review article: Equine nutrition. Comparisons of digestion coefficients obtained with cattle, sheep, rabbits and horses. *The Veterinarian* 6:45-51.

Hodder, R.M. and Low, W.A. (1978). Grazing distribution of free-ranging cattle at three sites in the Alice Springs district, central Australia. *Aust. Rangel. J.* 1(2):95-105.

Hoffmann, R.(1983). Social organization patterns of several feral horse and feral ass populations in central Australia. *Z. Saeugetierkd* 48(2):124-126.

Honour, V.G., Birrell, W.K., Collins, K.J., Faull, J.F. and Ord, I.G. (1969). *The Jacaranda Atlas.* Brisbane: Jacaranda Press.

Howard, W.E. (1964). Introduced browsing mammals and habitat stability in New Zealand. *J. Wildl. Manage.* 28:421-429.

Hume, I.D. and Warner, A.C.I. (1980). In Y. Ruckebusch and P. Thivend (Eds.), *Digestive Physiology and Metabolism in Ruminant.* Lancaster: M.T.P. Press.

Janis, C. (1976). The evolutionary strategy of the Equidae and the origins of rumen and cecal digestion. *Evolution* 30:757-774.

Jarman, P.J. (1974). The social organisation of antelope in relation to their ecology. *Behaviour* 48:215-267.

Jarman, P.J. and Jarman, M.V. (1979). The dynamics of ungulate social organisation. In A.R.E. Sinclair and M. Norton-Griffiths (Eds.), *Serengeti: dynamics of an ecosystem,* (pp.185-220). Chicago: University of Chicago Press.

Jarman, P.J. and Johnson, K.A. (1977). Exotic mammals, indigenous mammals, and land-use. *Proc. Ecol. Soc. Aust.* 9:82-87.

Jarman, P.J. and Sinclair, A.R.E. (1979). Feeding strategy and the patterning of resource partitioning in ungulates. In A.R.E. Sinclair and M. Norton-Griffiths (Eds.), *Serengeti: dynamics of an ecosystem,* pp.130-163. Chicago: University of Chicago Press.

Jolly, G. (1969). Sampling methods for aerial surveys of wildlife population. *E. Afr. Agric. For. J.* 34: 46-49.

Jolly, G. and Watson, R.M. (1979). Aerial survey methods in the quantitative assessment of ecological resources. In *Sampling Biological Population. Statistical Ecology Series Vol. 5.* Fairland: USA Int. Coop. Publishing House.

Kaseda, Y. Nozawa, K. and Mogi, K. (1984). Separation and independence of offsprings from the harem groups in Misaki horses. *Japanese Journal of Zootechnical Science* 55(11):852-857

Keeton, W.T. (1972). *Biological Sciences.* New York: W.W. Norton and Company Inc.

Keiper, R.R. (1976). Social organisation of feral ponies. *Proc. Penn. Acad. Sci.* 50:69-70.

Keiper, R.R. and Keenan, M.A. (1980). Nocturnal activity patterns of feral ponies. *J. Mammal.* 66:116-18.

Kirkpatrick, J.F., Irwin, K.M. Liu, and Turner, J.W. (1990). Remotely-delivered immunocontraception in feral horses. *Wildl. Soc. Bull.* 18:326-330.

Klimov, V.V. and Orlov, V.N. (1982). Present state and problems of conservation of *Equus przewalski. Soviet J. Zool.* 61:1862-69.

Klingel, H. (1965). Notes on the biology of the Plains Zebra, *Equus quagga boehmi.* Matschie. *E. Afr. Wildl. J.* 3:86-88.

Klingel, H. (1969). The social organization and population ecology of the plains zebra (*Equus quagga*). *Zoologica Afr.* 4(2):249-263.

Klingel, H. (1972). Social behaviour of African Equidae. *Zoologica Afr.* 7:175-185.

Klingel, H. (1974). A comparison of the Social Behaviour of the Equidae. In V. Geist and F. Walther (Eds.), *The behaviour of ungulates and its relations to management*, (New series 24). Morges, Switzerland: IUCN Pub.

Klingel, H. (1982). Social organization of feral horses. *J. Reprod. Fert. Suppl.* 32:1-7.

Kohnke, J. (1979). What makes your horse a horse. *Horse and Rider* December:12-15.

Kownacki, M., Sasimowski, E., Budzynski, M., Jezierski, T., Kapron, M., Jelen, B. Jaworska, M., Dziedzic, R., Seweryn, A., and Solmka, Z. (1978). Observations of the twenty-four hours rhythm of natural behaviour of Polish primitive horse bred for conservation of genetic resources in a forest reserve. *Genetica Polonica* 19:61-77.

Krebs, C.J. (1985). *Ecology: the experimental analysis of distribution and abundance.* New York: Harper and Row.

Krysl, L.J., Smith, M.A., Sowell, B.F., Hubbert, M.E., Plumb, G.E. and Waggoner, J.W. (1984a). Impact of feral horses on vegetation in the cold desert biome. U.S.A. In *Second International Rangeland Congress Abstracts*. Adelaide. May 1984.

Krysl, L.J., Sowell, B.F., Hubbert, M.E., Plumb, G.E., Jewett, T.K., Smith M.A. and Waggoner J.W. (1984b). Horses and cattle grazing in the Wyoming Red Desert, II. Dietary quality *J. Range Manage.* 37(3):252-256.

Lazarides, M. (1970). *The grasses of central Australia*. Canberra: Australian National University Press.

Leader-Williams, N.L. (1988). *Reindeer on South Georgia: The ecology of an introduced population.* Cambridge: Cambridge University Press.

Letts, G.A. (1964). Feral animals in the Northern Territory. *Aust. Vet. J.* 40:84-88.

Letts, G.A., Bassingthwaite, A. and de Vos, W.L. (1979). *Feral animals in the Northern Territory. Report of a Board of Inquiry.* Darwin: N.T. Government Printer.

Leys, D.M. (1977). *Pasture utilisation by free-ranging cattle in central Australia.* Unpublished B.A.(Hons) thesis, Australian National University, Canberra.

Lidicker, W.Z., Jr. (1975). The role of dispersal in the demography of small mammals. In F.B. Golley, K. Petrusewicz and L. Ryszkowski, *Small mammals: their productivity and population dynamics.* (pp.103-128). New York: Cambridge University Press.

Linerode, P. A. (1966). Studies on the synthesis and absorption of B complex vitamins in the equine. PhD thesis. The Ohio State University.

Low, W.A. and M.R.Hewett (1988). *An aerial survey of horses and other large animals in the central ranges of the Alice Springs District.* (Internal document). Alice Springs: Conservation Commission of the Northern Territory.

Low, W.A., Foster, E. and Berman, D.McK. (1991). *The environmental implications of removal of horses from Finke Gorge National Park.* (Internal Document) Alice Springs: Conservation Commission of the Northern Territory.

Low, W.A., Muller, W.J. and Dudzinski, M.L. (1980). Grazing intensity of cattle on a complex of rangeland communities in central Australia. *Australian Rangelands Journal* 2:76-82.

Lundie-Jenkins, G.W. (1989). *The ecology and management of the rufous hare-wallaby Lagorchestes hirsutus in the Tanami Desert.* (Internal document) Alice Springs: Conservation Commission of the Northern Territory.

McCort, W.D. (1979). The feral asses (*Equus asinus*) of Ossabau Island, Georgia: Mating system and the effect of vasectomies as a population control procedure. In R.H. Denniston (Ed.), *Symposium on the ecology and behavior of wild and feral equids*, (pp. 71-83). Laramie: University of Wyoming.

McCort, W.D.(1984). Behaviour of feral horses and ponies. *J. Anim. Sci.* 58(2):493-499.

McKnight, T. (1976). *Friendly vermin; A survey of feral livestock in Australia.* Berkeley and Los Angeles: University of California Press.

McMahon, G.L., Tester, J.R. and Siniff, D.B. (1986). Foaling rate and survival of feral horses in western Nevada. *J. Range Manage.* 39(4):296.

McMahon, T.A., Finlayson, B.L., Haines, A. and R. Srikanthan (1987). Runoff variability: a global perspective. In *Proceedings of the Vancouver Symposium, August 1987, The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources.* (pp.3-11). IAHS Publ. no. 168.

McNaughton, S.J. (1979). Grassland-herbivore dynamics. In A.R.E. Sinclair and M. Norton-Griffiths, (Eds.). *Serengeti: dynamics of an ecosystem,* (pp.130-163). Chicago: University of Chicago Press.

Miller, R and Denniston, R.H. II (1979). Interband dominance in feral horses. *Z. Tierpsychol.* 51:41-47.

Miller, R. (1979). Band organization and stability in Red Desert feral horses. In R.H. Denniston (Ed.), *Proceedings of Conference, Ecology and Behaviour of Feral Equids*, (pp.113-123).

Miller, R. (1983). Seasonal movements and home ranges of feral horse bands in Wyoming's Red Desert. *J. Range Manage.* 36(2):199-201.

Moehlman, P.D. (1974). *Behaviour and ecology of Feral Asses (Equus asinus).* Unpublished Ph.D. thesis, University of Wisconsin, Madison.

Mohr, E. (1971). *The Asiatic wild horse.* London: Allen and Co.

Moir, R.J. (1968). Ruminant digestion and evolution. In W. Heidel (Ed.), *Handbook of Physiology*, (pp. 2673-2694). Washington, D.C.: American Physiological Society.

Morris, D. (1965). *The Mammals.* London: Hodder and Stoughton.

Morton, S.R. (1990). The impact of European settlement on the vertebrate animals of arid Australia: a conceptual model. *Proc. Ecol. Soc. Aust.* 16:201-213.

Munton, P.N., Clutton-Brock, J. and Rudge, M.R. (1984). Introduction to workshop on feral mammals. In *Feral mammals - problems and potential.* IIIrd International Theriological Conference, Helsinki, August 1982, IUCN.

Newsome, A.E. and Corbet, L.K. (1977). The effects of native, feral and domestic animals on the productivity of the Australian rangelands. In *The impact of herbivores on arid and semi-arid rangelands*, (pp. 331-356). Perth: Australian Rangeland Society.

Newsome, A.E., Corbett, L.K., Catling, P.C. and Burt, R.J. (1983). The feeding ecology of the dingo *Canis-familiaris-dingo* 1. Stomach contents from trapping in Southeastern Australia and the non-target wildlife also caught in dingo traps. *Aust. Wildl. Res.* 10(3):477-486.

Odum, E.P. (1969). The strategy of ecosystem development. *Science* 18:262-270.

Oosting, H.J. (1956) The study of plant communities. 2nd ed. E.H. Freeman and Co., San Francisco. 440pp.

Owaga, M.L. (1975). The feeding ecology of wildebeest and zebra in Athi-Kaputei plains. *E. Afr. Wildl. J.* 13:375-383.

Pellegrini, S.W. (1971). Home range, territoriality and movement patterns of wild horses in the Wassuk Range of Western Nevada. Unpublished M.Sc. thesis, University of Nevada.

Penzhorn, B.L. (1985). Reproductive characteristics of a free-ranging population of Cape Mountain zebra (*Equus zebra zebra*). *J. Repro. Fert.* 73:51-57.

Perry, R.A., Mabbutt, J.A., Litchfield, W.H., Quinlan, T., Lazarides, M., Jones, N.O., Slatyer, R.O., Stewart, G.A., Bateman, W. and Ryan, G.R. (1962). *General report on lands of the Alice Springs area, N.T., 1956-57. (Land Research Series No. 6)*, Melbourne: CSIRO.

Pickup, G. and Chewings, V.H. (1988). Estimating the distribution of grazing and patterns of cattle movement in a large arid zone paddock: An approach using animal distribution models and landsat imagery. *J. Remote Sensing* 9(9):1469-1490.

Pulliam, R.H. (1988). Sources, sinks, and population regulation. *Am. Nat.* 132(5):652-661.

Ralston, S.L., Van den Broek, G., and Baile, C.A. (1979). Feed intake patterns and associated blood glucose, free fatty acid and insulin changes in ponies. *J. Anim. Sci.* 49:838-845.

Rand, M.C., Greenberg, A.E., and Taras, M.J. (1975). *Standard methods for the examination of water and wastewater.* (14th edition). Washington, D.C.: American Public Health Ass.

Riney, T. (1964). *The impact of introductions of large herbivores on the tropical environment.* (New series 4) (pp.261-273). Morges, Switzerland: IUCN Publications.

Robinson, D.W. and Slade, L.M. (1974). The current status of knowledge on the nutrition of equines. *J. Anim. Sci.* 39(6):1045-1066.

Romer, A.S. (1966). *Vertebrate Paleontology.* Chicago: University of Chicago Press.

Rowlands, I.W. (1981). Perspectives in perissodactyls. *Equine Vet. J.* 13(2):85-87.

Rubenstein, D.I. (1981). Behavioural ecology of island Feral Horses. *Equine Vet. J.* 13(1):27-34.

Rubenstein, D.I. (1986). Ecology and sociality in horses and zebra. In D.I. Rubenstein and R.W. Wrangham (Eds.). *Ecological Aspects of Social Evolution.* Princeton: Princeton University Press.

Salter, R.E. and Hudson, R.J. (1979). Feeding ecology of feral horses in western Alberta. *J. Range Manage.* 32:221-225.

Salter, R.E. and Hudson, R.J. (1980). Range relationships of feral horses with wild ungulates and cattle in western Alberta. *J. Range Manage.* 33(4):266-271.

Selwyn, E.L. (1981). Poisonous plants of Australia. (Revised edition). Sydney: Angus and Robertson.

Siebert, B.D., Newman, D.M.R. and Nelson, D.J. (1968). The chemical composition of some arid zone pasture species. *Trop. Grass.* 2(1):31-40.

Simpson, G.G. (1951). *Horses.* New York: Oxford University Press.

Sinclair, A.R.E. (1977). *The African Buffalo. A Study of Resource Limitation of Populations.* Chicago: University of Chicago Press.

Sinclair, A.R.E. (1979). Dynamics of a Serengeti ecosystem: Process and pattern. In *Serengeti. Dynamics of an Ecosystem*, eds. A.R.E. Sinclair and Norton-Griffiths, M., pp.1-30. Chicago: University of Chicago Press.

Siniff, D.B., Tester, J.R. and McMahon, G.L. (1986). Foaling rate and survival of feral horses in Western Nevada. *J. Range Manage* 39(4):296-297

Southgate, R. (1987). *Conservation of the bilby Macrotis lagotis (Reid, 1937).* (Internal document) Alice Springs: Conservation Commission of the Northern Territory.

Speed, J.G. and Etherington, M.G. (1952). An aspect of the evolution of British horses. *British Vet. J.* 108:147-153.

Squires, V.R. (1979). Grazing behaviour of free ranging sheep and cattle under arid conditions. *Livestock Intl.*, March/April 6-8.

Squires, V.R. (1981). *Livestock Management in the Arid Zone.* Sydney: Inkata Press.

Tyler, S.J. (1969). *The behaviour and social organisation of the New Forest ponies.* Dissertation, University of Cambridge, Cambridge.

Tyler, S.J. (1972). The behaviour and social organisation of the New Forest ponies. *Animal Behaviour Monographs*, 5(Part 2). London: Bailliere Tindall.

Van Horne, B. (1983). Density as a misleading indicator of habitat quality. *J. Wildl. Manage.* 47:893-901.

Van Soest, P.J. (1982). *Nutritional Ecology of the Ruminant.* Corvallis, Oregon, USA: O&B BOOKS Inc.

Vesey-Fitzgerald, D.F. (1960). Grazing succession amongst East African game animals. *J. Mammal.* 41:161-170.

Vorgelegt von Kamal, E.H.A. (1985). *Altersbestimmung von Pferdefeten aus Warmblut- und Vollblutzucht.* Inaugural-dissertation zur Erlangung des Grades eines Doctor Medicineae Veterinariae durch die Tierarztliche Hochschule Hannover.

Waring, G.H. (1983). *Horse behaviour: The behavioural traits and adaptations of domestic and Wild Horses, including ponies.* Park Ridge, New Jersey: Noyes Publications.

Wells, A.T., Ranford, L.C., Stewart, A.J., Cook, P.J., and Shaw, R.D., (1967). *Geology of the north-eastern part of the Amadeus Basin, Northern Territory.* Bureau of Mineral Resources, Australia, Report 113.

Welsh, D.A. (1973). The life of Sable Island's wild horses. *Canadian Nature* 2(2):7-14.

Wilson, G.R., Harrington, G.N., Wilson, A.D. and Young, M.D. (1984). Biological conservation. In G.N. Harrington, A.D. Wilson and M.D. Young (Eds.) *Management of Australia's Rangelands* Melbourne: CSIRO.

Wolfe, M.L. (1986). Population dynamics of feral horses in western North America. *J. Equine Vet. Sci.* 6:1-5.

Wood, B., D.Blandford and C. Harrison (1979). *The land systems and erosion on part of Hubert River Station.* Darwin, N.T.: Land Conservation Unit, Territory Parks and Wildlife Commission.

Woods, L.E. (1983). *Land Degradation in Australia.* Canberra: Australian Government Publishing Service.

Woodward, S.L. (1979). The social system of feral asses (*Equus asinus*). *Z. Tierpsychol.* 49:304-316.

Wurst, A.J. (1987). *The management of feral horses in the Alice Springs pastoral district of the Northern Territory.* Unpublished M.Nat.Res. thesis, University of New England, Armidale.

Zar, J.H. (1984). *Biostatistical analysis.* Englewood Cliffs, N.J.: Prentice-Hall, Inc.

APPENDIX

APPENDIX I: Groups of horses and cattle followed for the purposes of determining time budgets. Detailed analysis was conducted on data for samples denoted by *.

Date	Species	Start	Finish	Grp size	Group description and comment
13 July 85	Cattle	1800	1819	5	Unidentified group. (Testing Pocket Computer program.)
14 July 85	Horses	0843	0930	5	"Brumby One". (Testing program and determining list of activity categories for horses)
19 July 85	Cattle	1339	1606	5	Unidentified group. (Testing observation technique and determining list of activity categories for cattle)
22-23 July 85	Horses	1711	0908	7	"Brumby One". (First attempt at long period. Night too dark for direct observation. Radio signal was monitored all night in an attempt to determine activity but was useful only to monitor movement. The group moved no more than 200 metres during the night. Observations were recommenced after sunrise)
20 July 85	Cattle	1036	1749	5	Unidentified group. (Lost sight of them and could not relocate the same group)
21 July 85	Cattle	0859	1606	5	Unidentified group. (Lost sight of them)
07 Aug 85	Horses	0936	1052	8	"Fat Black Brumby". (At this stage he had not been radio-collared so when I lost sight of the group I was unable to relocate them)
12 Sep 85	Horses	1448	1705	1	"Bachelor 88". (This horse lost his collar and was not observed again)

Table continued next page.

Date	Species	Start	Finish	Grp size	Group description and comment
19 Sep 85	Horses	1140	1411	7	"Brumby One". (Frightened by me they disappeared into the mulga trees and I was unable to approach close enough again to continue observation)
26 Nov 85	Horses	1109	1350	8	"Fat Black Brumby". (Could not find them to start second 3 hour observation period)
26 Nov 85	Horses	1802	1938	4	"Bruce Brumby". (Found this group while trying to relocate "Fat Black Brumby" so decided to use them instead. However, aborted exercise because cloud was covering moon and observation was impossible)
*27-28 Nov 85	Horses	1002	0920	6	"Fat Black Brumby". (At last I was able to follow a group for 24 hours without frightening them or losing visibility)
24 Feb 86	Horses	1524	1642	4	"Bruce Brumby". (In rugged tree covered hills I was unable to approach close enough for observation without disturbing them)

Table continued next page.

Date	Species	Start	Finish	Group size	Group description and comment
*26-27 Mar 86	Horses	14.32	08.21	3	"Bay Brumby".
24 Jun 86	Horses	15.40	23.22	3	"Bay Brumby". (Lost the horses in tree covered hills. My horse threw a shoe and became foot-sore.)
25 Jun 86	Horses	15.35	16.08	4	"Bay Brumby". (Hills too rugged and trees preventing observation without disturbing horses.)
*19-20 Aug 86	Horses	16.49	11.04	5	"Brumby One".
20 Aug 86	Cattle	13.44	19.42	2	"Doreen Cow". (Lost her during night. She was very wary. We followed her signal but she was always one step a head of us.)

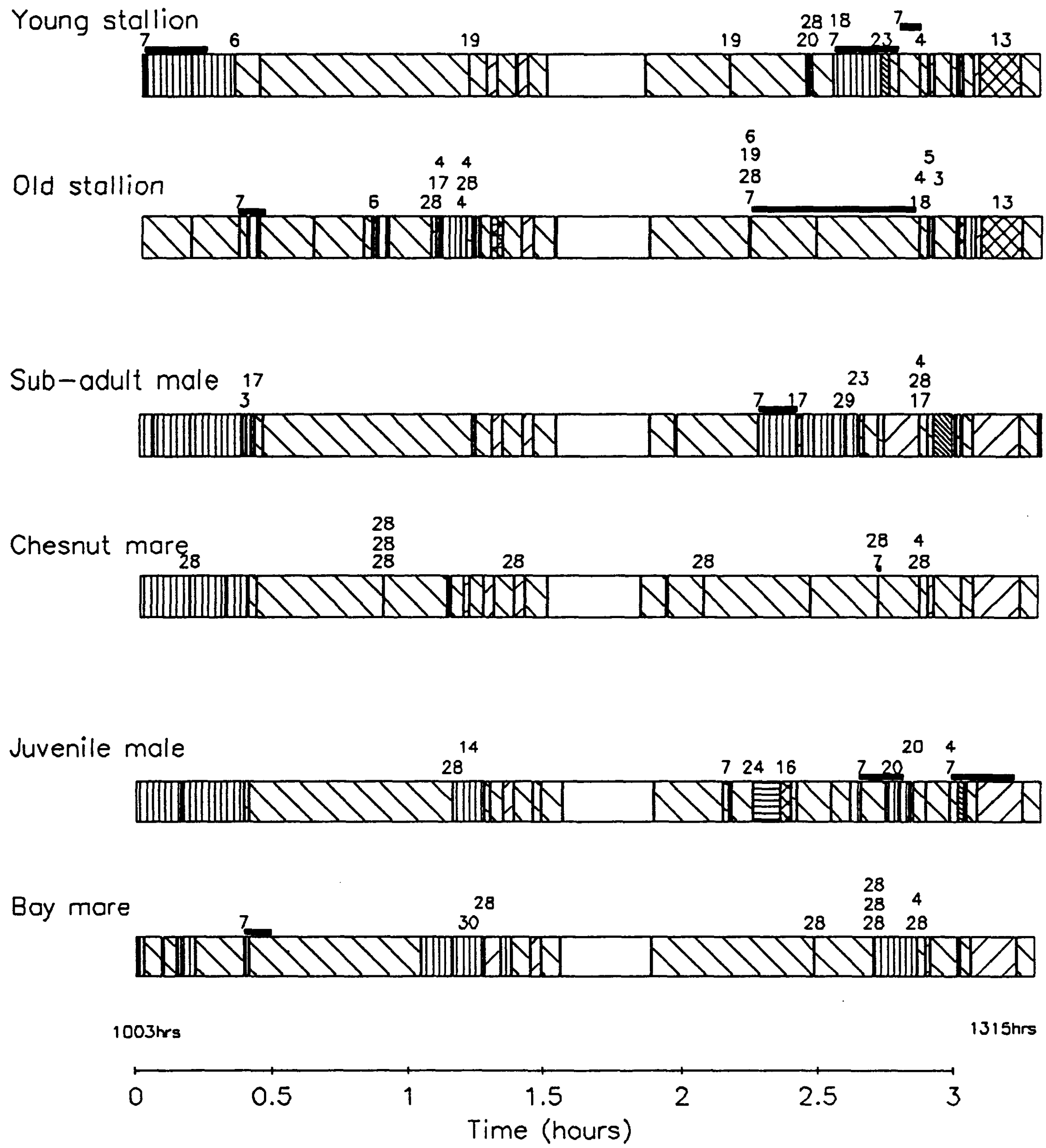
APPENDIX II: Figures showing the pattern of activity for 3 feral horse groups radio-tracked on the Hale Plain. These figures illustrate the type of data and detail I was able to record for all members of an entire group simultaneously using the Sharp Pocket Computer PC1500A. The following key applies to all figures in this appendix.

Key

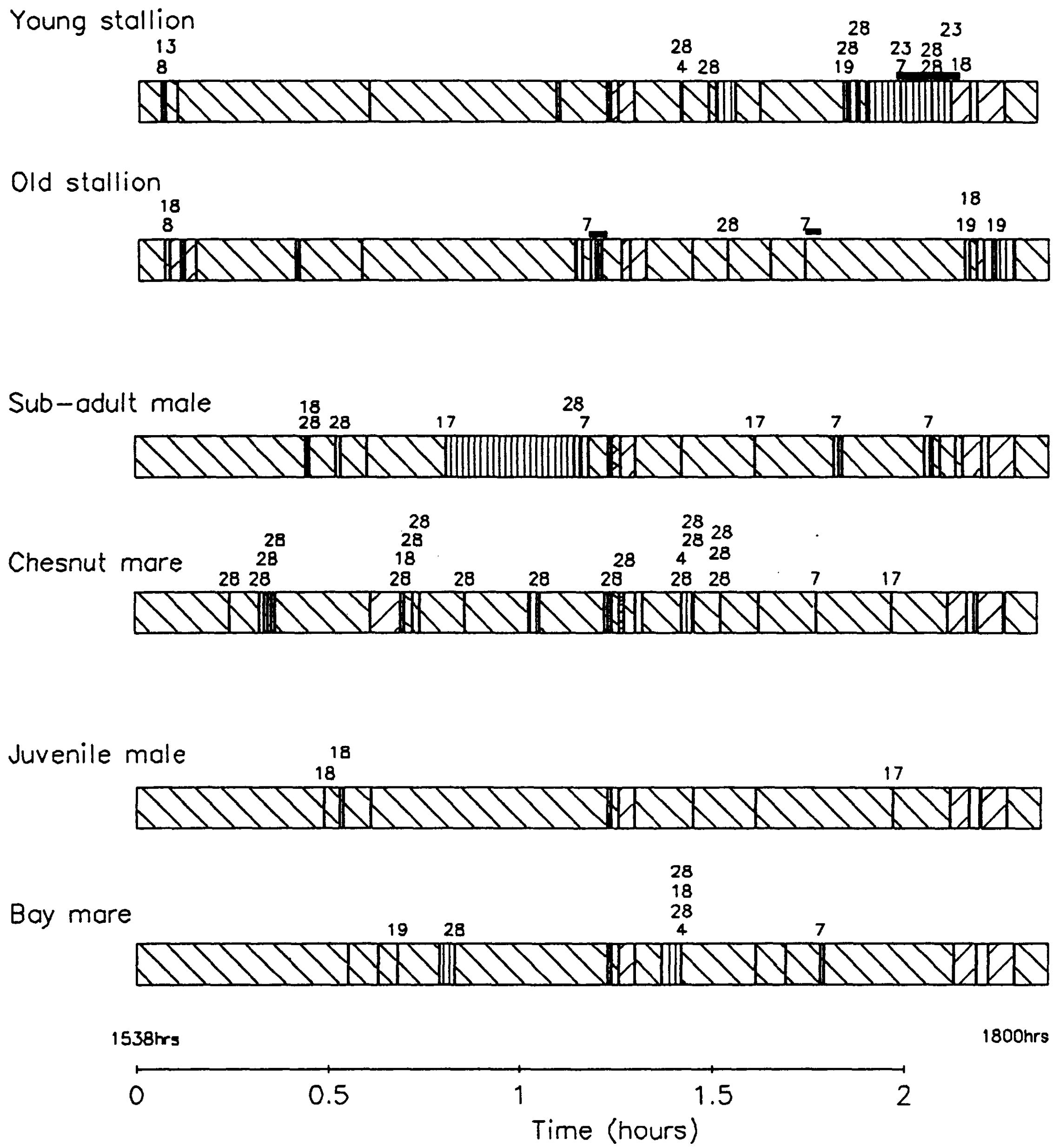
1. Grazing
2. Standing
3. Lying
5. Walking
6. Trotting
9. Drinking
13. Fighting

4. Frightened
7. In shade
8. Galloping
10. Browsing
11. Mating
12. Playing
14. Sucking
16. Lying laterally
17. Autogrooming

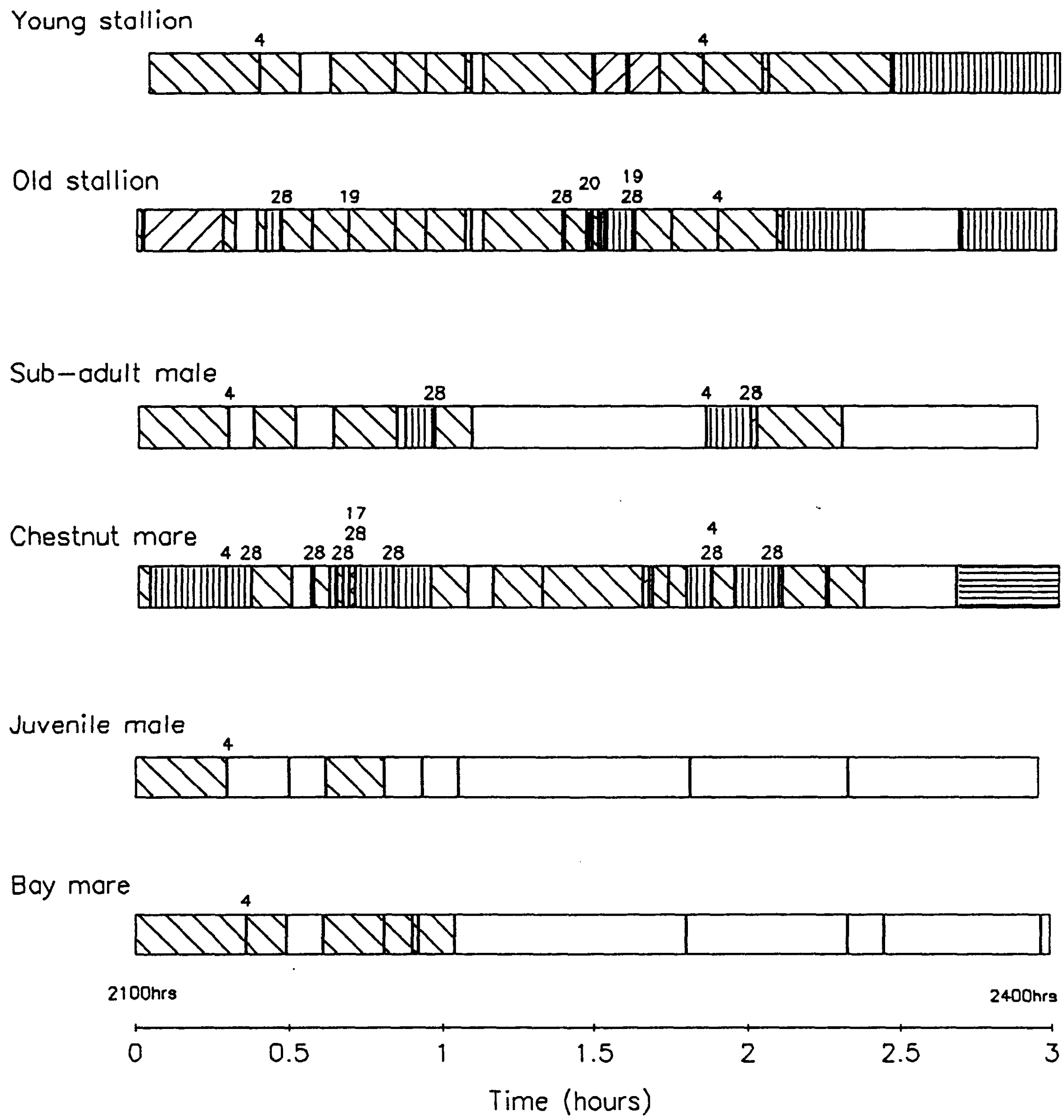
18. Defecating
19. Urinating
20. Rubbing
21. Grooming
23. Sleep
24. Rolling
27. Unknown
28. Looking round
29. Stretching
30. Nursing



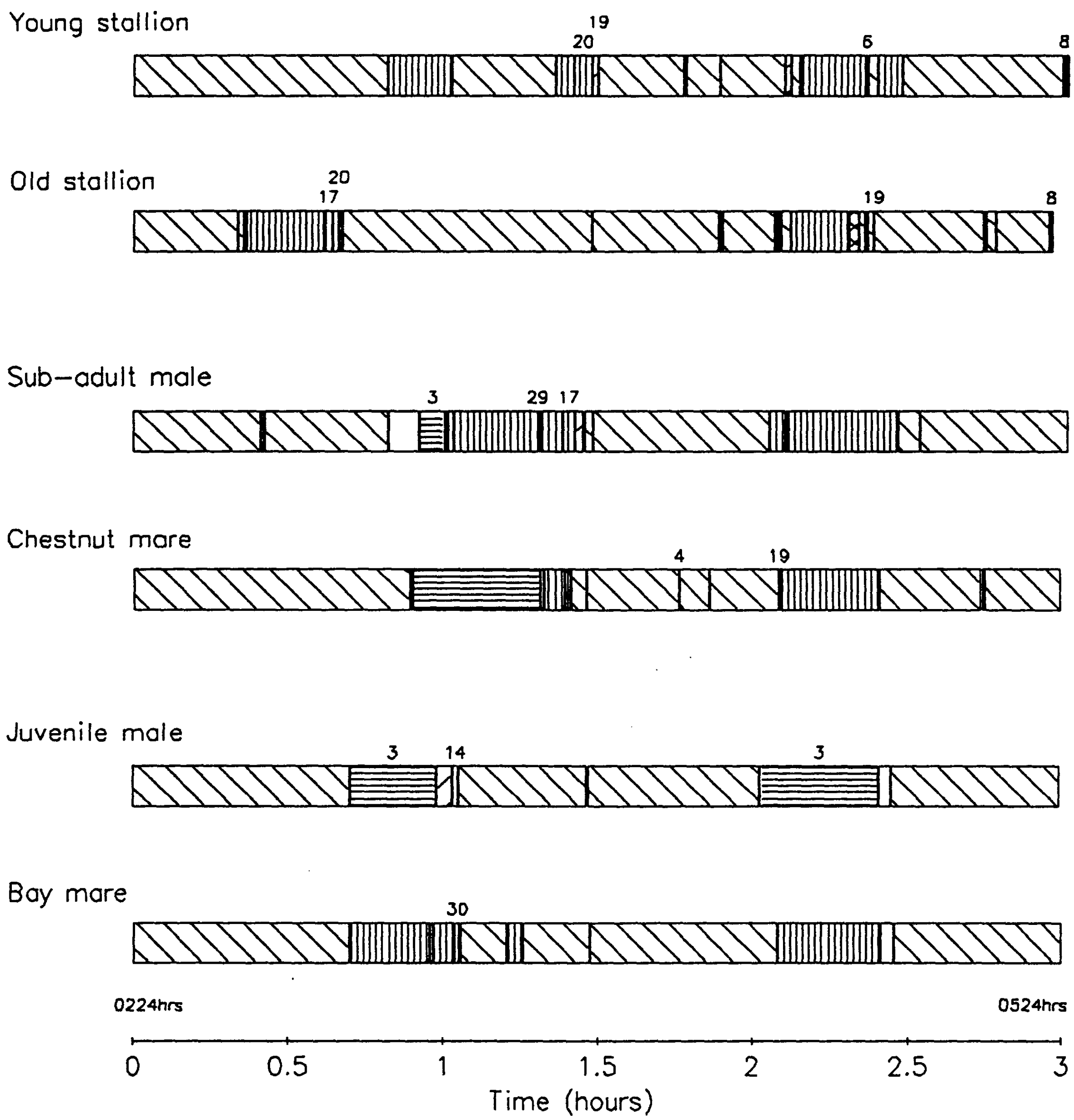
Appendix II figure 1: Sequence of activities recorded for "Black Brumby" and his group on the 27 November 1985 (1st watch).



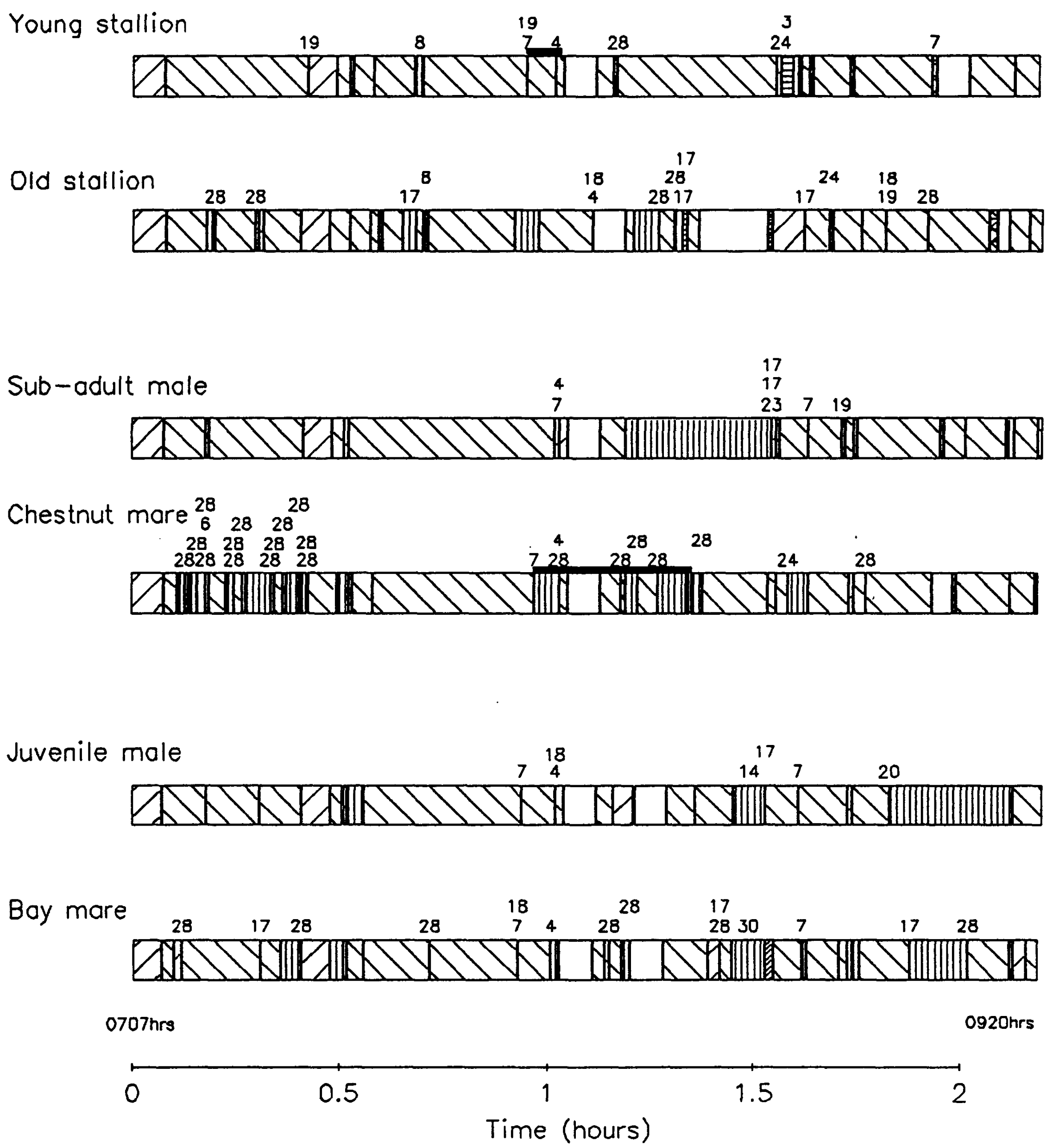
Appendix II figure 2: Sequence of activities recorded for "Black Brumby" and his group on the 27 November 1985 (2nd watch).



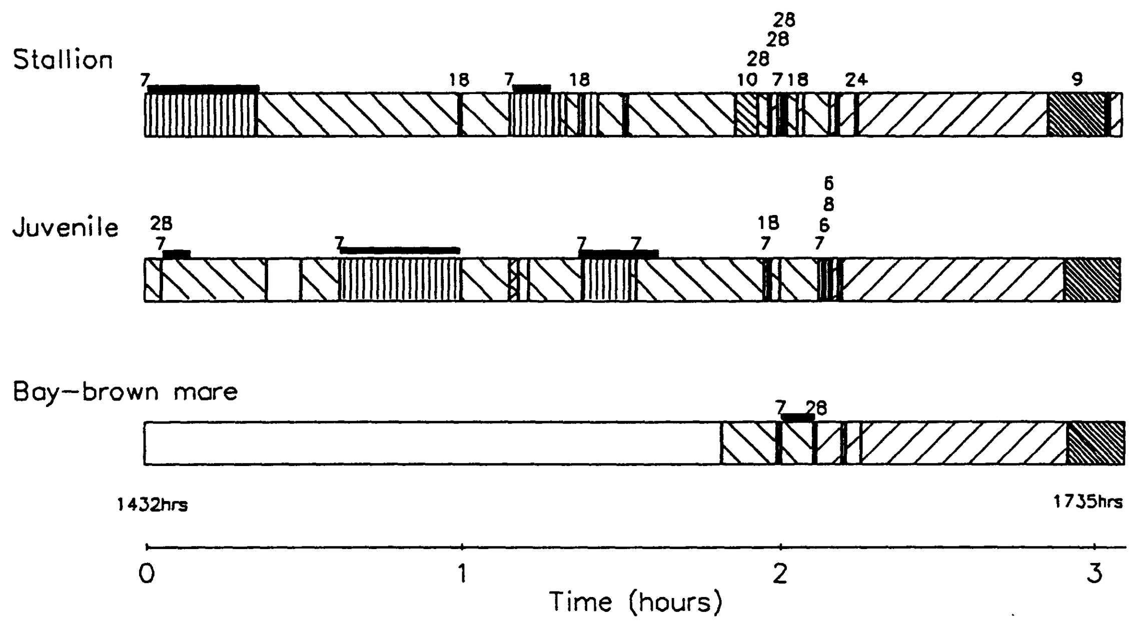
Appendix II figure 3: Sequence of activities recorded for "Black Brumby" and his group on the 27 November 1985 (3rd watch).



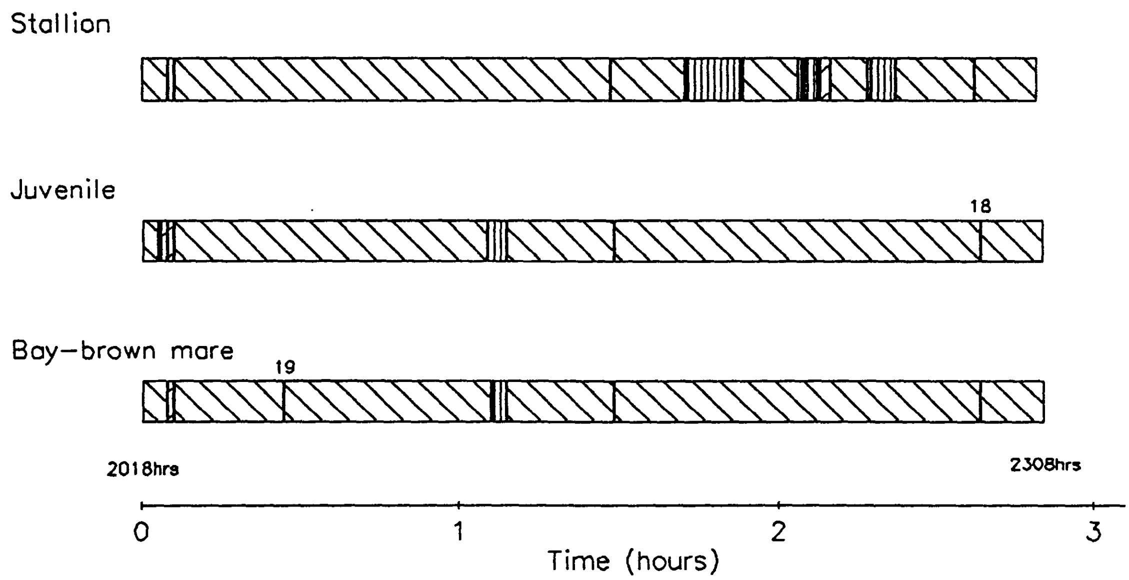
Appendix II figure 4: Sequence of activities recorded for "Black Brumby" and his group on the 28 November 1985 (4th watch).



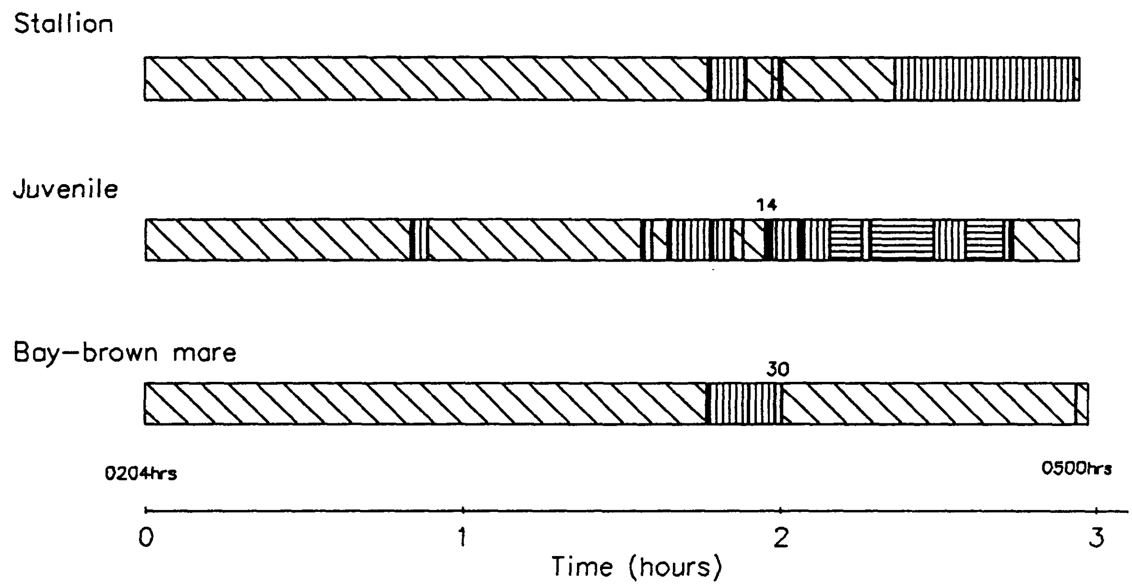
Appendix II figure 5: Sequence of activities recorded for "Black Brumby" and his group on the 28 November 1985 (5th watch).



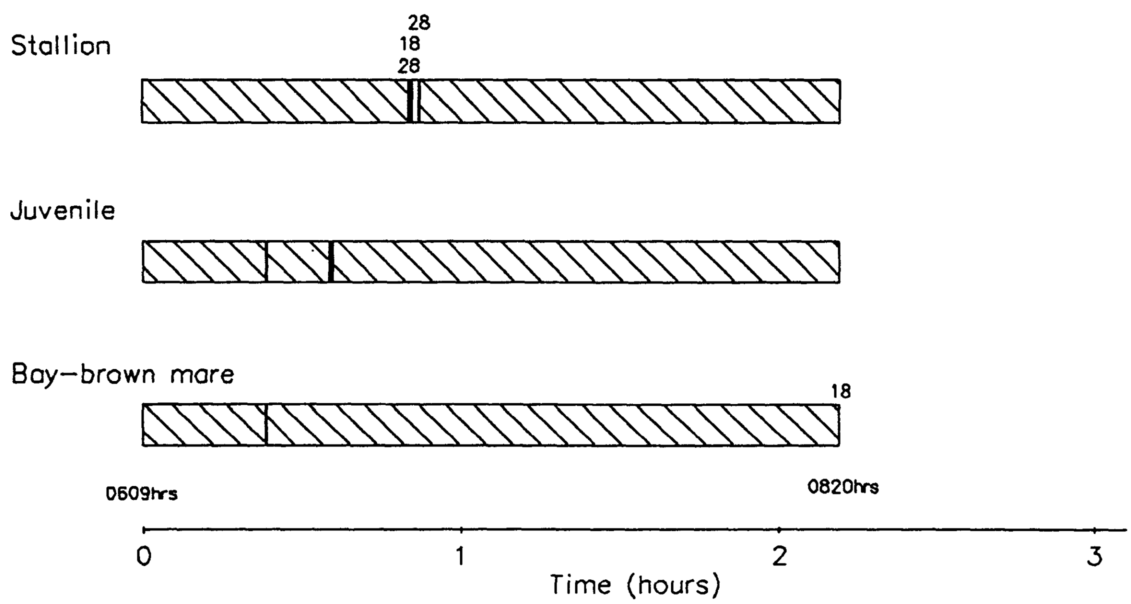
Appendix II figure 6: Sequence of activities recorded for "Bay Brumby" and his group on the 26 March 1986 (1st watch).



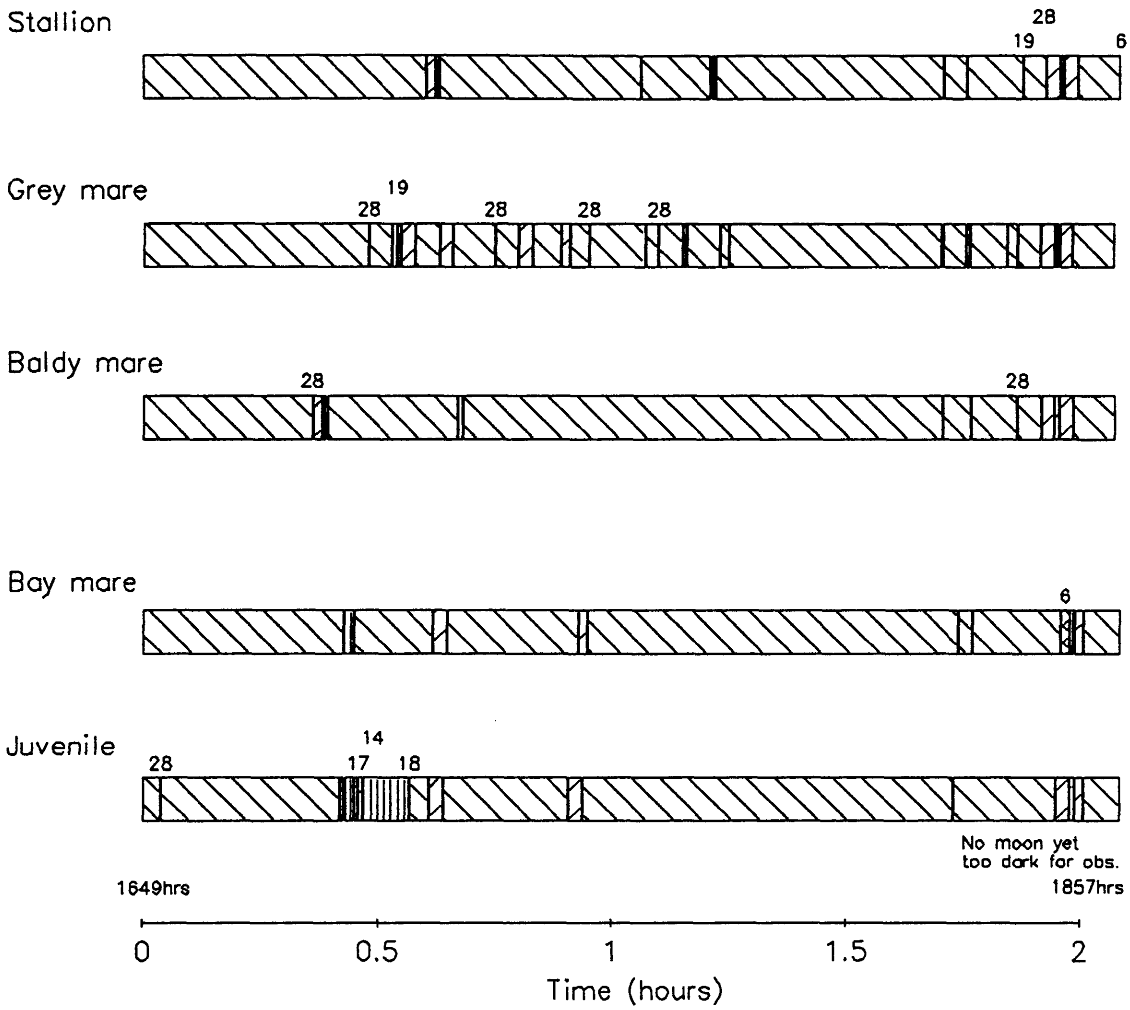
Appendix II figure 7: Sequence of activities recorded for "Bay Brumby" and his group on the 26 March 1986 (2nd watch).



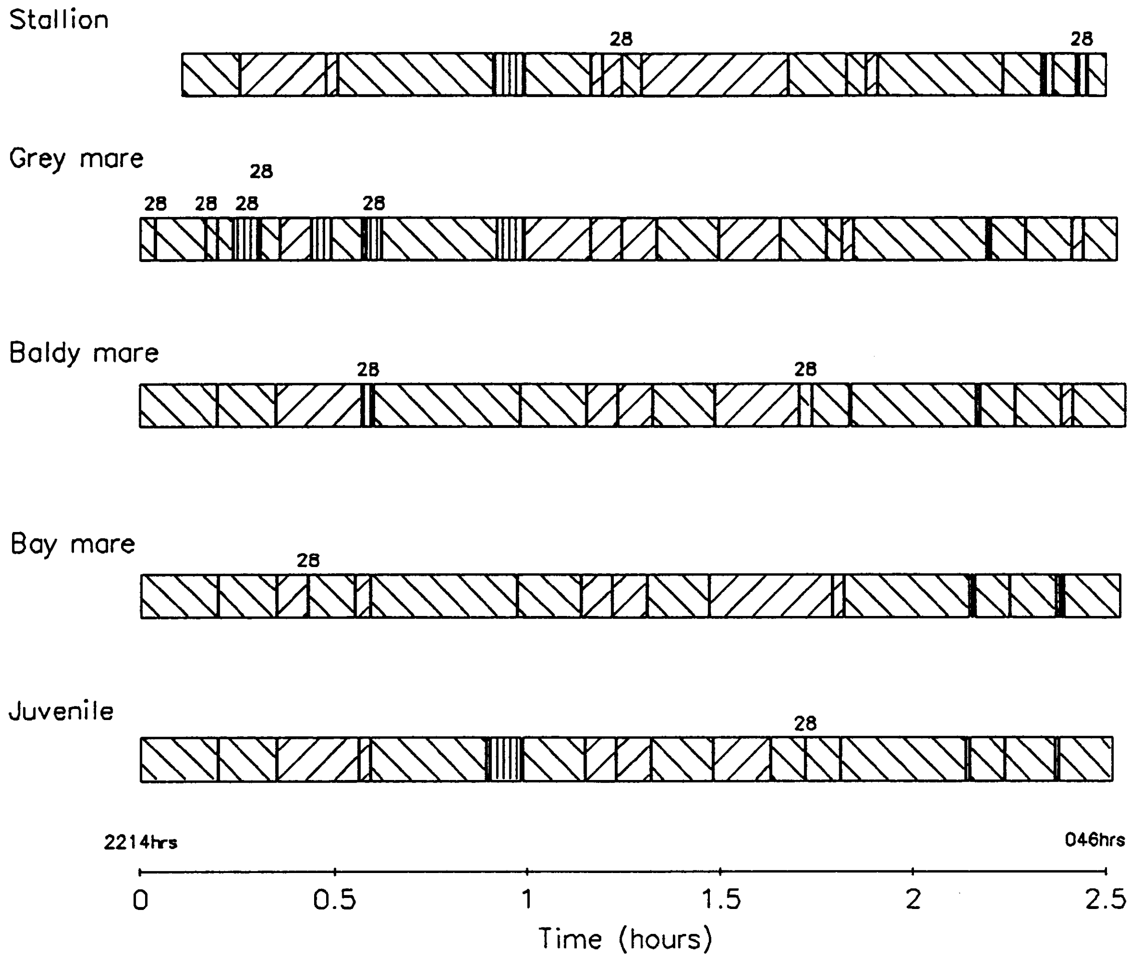
Appendix II figure 8: Sequence of activities recorded for "Bay Brumby" and his group on the 27 March 1986 (3rd watch).



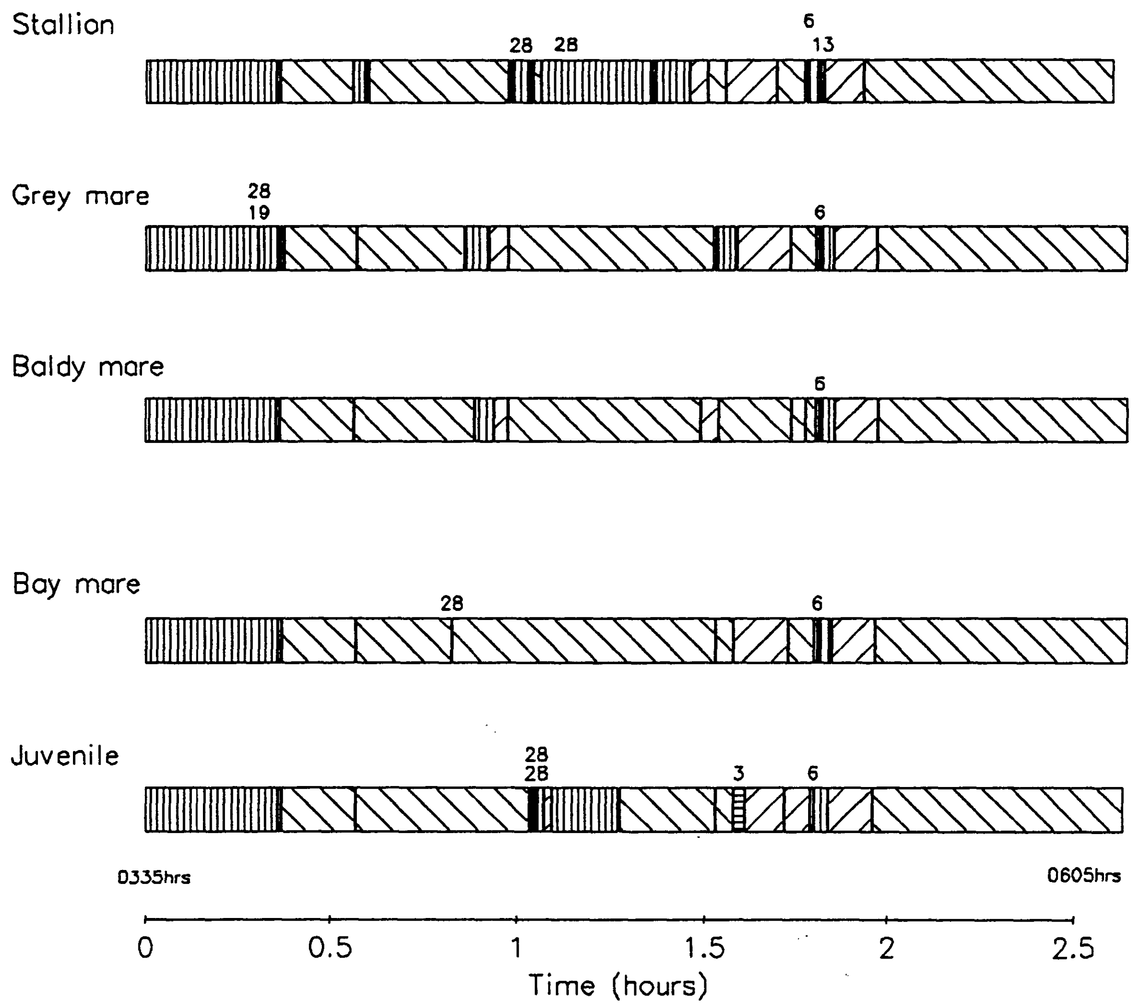
Appendix II figure 9: Sequence of activities recorded for "Bay Brumby" and his group on the 27 March 1986 (4th watch).



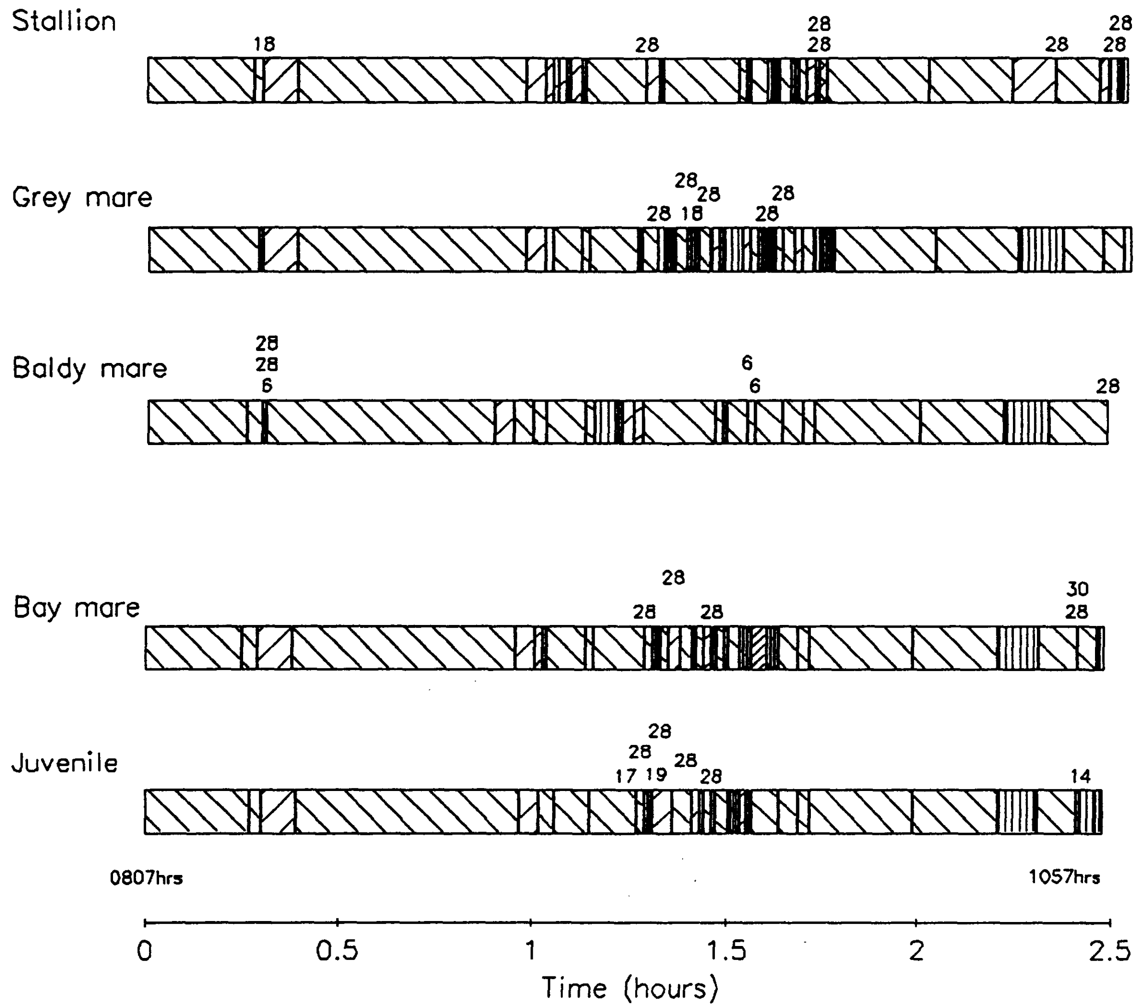
Appendix II figure 10: Sequence of activities recorded for "Brumby One" and his group on 19 August 1986 (1st watch).



Appendix II figure 11: Sequence of activities recorded for "Brumby One" and his group on 19/20 August 1986 (2nd watch).



Appendix II figure 12: Sequence of activities recorded for "Brumby One" and his group on 20 August 1986 (3rd watch).



Appendix II figure 13: Sequence of activities recorded for "Brumby One" and his group on 20 August 1986 (4th watch).

APPENDIX III: Species of grasses recorded on The Garden station and the land unit where they were recorded during the study. The life-style (P = Perennial, SLP = Short-lived-perennial, E = Ephemeral = Annual) and mean height for each species were obtained from Lazarides (1970). Those species reported to be toxic by Selwyn (1981) are indicated.

Species	LAND UNIT							Life Style	Max Height	Toxic	Exotic
	A	B	C	D	E	F	G				
Aristida biglandulosa				*				P	120		
Aristida browniana				*				SLP,E	60		
Aristida contorta			*		*			SLP,E	30	*	
Aristida inaequiglumis					*			P	105		
Aristida latifolia							*	P	135		
Aristida nitidula					*			P	70		
Aristida strigosa		*	*		*			P	120		
Astrebla lappacea						*	*	P	120		
Astrebla pectinata						*	*	P	90		
Bothriochloa ewartiana				*				P	90		
Cenchrus sp.				*				P	90	*	*
Chloris pectinata			*					E	70		
Chloris scariosa			*	*	*			P,E	47		
Chrysopogon fallax				*				P	135		
Cynodon dactylon				*				P	15	*	*
Dichanthium sericeum				*		*		P	60		
Digitaria brownii				*				P	60		
Digitaria coenicola			*	*				P	60		
Enneapogon avenaceus		*	*	*	*	*	*	E,SLP	30		
Enneapogon cylindricus			*					P	22		
Enneapogon polyphyllus		*	*	*	*	*	*	E,SLP	30		
Enteropogon acicularis			*		*			P	40		
Enteropogon ramosus				*				P	105		

Species	LAND UNIT							Life Style	Max Height	Toxic	Exotic
	A	B	C	D	E	F	G				
Eragrostis xerophila						*	*	P	22		
Eriachne helmsii					*			P	90		
Eriachne mucronata		*						P	60		
Eulalia fulva				*				P	90		
Panicum decompositum				*				P	105	*	
Panicum effusum				*				P	60	*	
Sporobolus actinocladus			*		*		*	P	45		
Sporobolus caroli								SLP	75		
Themeda australis		*						P	90		
Themeda avenacea				*				P	160		
Triodia basedowii			*					P	37		
Triodia longiceps	*							P	90		
Tripogon loliiformis			*				*	E,SLP	15		
Triraphis mollis			*	*	*			P	45	*	

Food Quality Classification of Grass Genera

Excellent Quality:	*Enneapogon*
Good Quality :	*Bothriochloa, Cenchrus, Cynodon, Dichanthium, Digitaria, Enteropogon, Eulalia, Panicum, Tripogon.*
Moderate Quality :	*Astrebla, Chrysopogon.*
Poor Quality :	*Aristida, Chloris, Eragrostis, Eriachne, Sporobolus, Themeda, Triraphis.*
Very Poor Quality:	*Triodia* (but this was never detected in faeces in the study).