CHAPTER THREE

DENSITY, DISTRIBUTION AND HABITAT USE

3.1 Introduction

This section of the project focussed on the abundance and distribution of Black-striped Wallabies at Brigalow Research Station, and investigated possible reasons for the population's heterogenous distribution over the area.

Estimated animal density is crucial knowledge when discussing the level of impact presented by a population of that species, especially when density manipulation becomes a surrogate for damage mitigation. It was expected that, through determining the density of the species at various locations on the Station, an estimate could be made regarding the species' overall density and distribution. Direct visual counts of individuals are seen as an appropriate way to determine local or habitat-specific densities of a medium to large macropod species (Southwell 1989).

Determining whether individuals of a population are sedentary or mobile in the short- and long-term would also give some indication of the spatial scale at which management must be planned and implemented. Estimates of spatial and temporal use of habitats at an individual level can be readily determined by radio-tracking (Lee *et al.* 1985).

To understand the overall impact of the species, we needed to evaluate the heterogeneity of distribution of Black-striped Wallabies' occupancy (intensity of use through habitat preference) within apparently homogenous habitats (shelter habitats and adjacent pastures used for foraging). For example, how deep in the scrub do the wallabies prefer to shelter and how far out into the pasture do they graze?

Pellet counts have been used to estimate the density and distribution of populations of animal species (Hill 1981, Jarman and Capararo 1997, Hone and Martin 1998). Research into the validity of using faecal pellet counts for population estimation has established that the methodology is appropriate, taking into account assumptions regarding failure to detect all pellets, and error in species identification and counting (Pahl *et al.* 1999, Barnes 2001). In this study faecal pellet counts were undertaken along transects evenly spread over the Reference Site to determine detailed usage of the area by the wallaby.

Finally, the heterogeneity in a population's density and distribution may be explained by preferences for a general habitat, or specific habitat variables (e.g. vegetation density, density of shade canopy or presence of a particular vegetation species) as was found by Hockings (1981), Lunney and O'Connell (1988), Lindenmayer *et al.* (1994) and Bos *et al.* (2002) in the animal species they studied. Understanding the reasons for differences in usage of the various habitats available also aids species management. The final part of this Chapter seeks to determine whether the apparent heterogeneity in distribution could be explained by the existence of a relationship between faecal pellet density and one or more habitat attributes.

3.2 Methodology

3.2.1 General Wallaby Densities

Methods for determining species density, appropriate for medium-sized macropods have been reviewed extensively. Southwell (1989) reported that estimations by direct observational counts, during vehicular and on-foot transect surveys are practical. For this study, spotlight drive counting and stationary observation counting were undertaken to estimate density of Black-striped Wallabies in different areas of the Reference Site. Collected seasonally, the data would also indicate how stable the overall density and distribution of the population was throughout the year.

3.2.1.1 Vehicular Surveys

Counts using vehicular surveys, similar to those undertaken by Edwards *et al.* (2000), were undertaken on one night in October 2002 and two nights in January 2003. Surveys began at approximately 2030h each evening (i.e. more than one hour after dark) and were undertaken with one observer standing on the back of a 4WD vehicle holding a 30W halogen bulb spotlight (Lightforce Australia Pty Ltd, Hindmarsh, South Australia). The vehicle was driven at approximately 15km/h along an 11.62km set route. The route was divided into segments to aid in analysis and enable comparison of densities with stationary observation counts. The beginning and end of each segment were most easily determined by aligning them with the intersecting fence lines (paddock boundaries in Figure 3.1). The spotlighting route was limited in that roads did not transect through the remnant vegetation and only the interface of the scrub and pasture could be surveyed.

Figure 3.1 Segments of the spotlight drive route that was undertaken to count the number of Black-striped Wallabies around the Reference Site.

All macropods observed were recorded by the standing observer, except those that crossed in front of the vehicle, which were recorded by the driver. Double counting would not be completely avoided; however, communication between the driver and standing observer ensured that double-counting was minimal. All macropods seen were counted, and, where possible, their distance from the vehicle and the angle of the sighting relative to the vehicle's path was recorded. Sighting angle was based on straight ahead being 0^o, perpendicular to the left 90^o, and directly behind 180^o. Counting could not be undertaken effectively on the right side of the vehicle, as the remnant vegetation reduced visibility to only a few metres. In some areas the large number of macropods made it impossible to record the distance and angle of all individuals counted. In such cases the animals were generally counted at 90^o to the vehicle and the total number counted were recorded as being at variable distances. For this reason the package software 'Distance' (Buckland *et al.* 1993) could not be utilised for the calculation of density.

Density was determined for the surveyed spotlight area as follows. The maximum distance reached by the spotlight was determined to be 100m (see Section 3.3.1). The length of each segment was multiplied by the determined maximum spotlight distance, to give the area surveyed for each segment and the total spotlight route. Segments were also assigned to one of the five Sampling Areas as described in Section 2.4.2. The density of Black-striped Wallabies was then calculated for each segment, and the total spotlight route, by dividing the number of animals counted in each segment by that segment area (Table 3.1).

Table 3.1 Segment lengths and areas along the spotlight route taken for counting Black-striped Wallabies on Brigalow Research Station, 2002-2003.

Segment Number	Segment Length (km)	Segment Area (km^2)	Sampling Area
1	0.87	0.087	1
2	1.57	0.157	1
3	0.33	0.033	2
4	1.33	0.133	2
5	1.03	0.103	3
6	0.92	0.092	4
7	1.50	0.150	4
8	0.40	0.040	4
9	0.81	0.081	4
10	0.94	0.094	5
11	1.92	0.192	5
TOTAL	11.62	1.162	

Counts were analysed by REML (Residual Maximum Likelihood) (Genstat 2002) with the fixed effects of Night, Sampling Area and their interaction.

3.2.1.2 Stationary Observation Counts

To estimate the number of wallabies sheltering in, and emerging from, the various areas of the Reference Site, stationary observation counting was also undertaken at selected vantage points on the track between the sheltering scrub and the pasture on most evenings during each seasonal field trip (October 2000, January 2001, March/April 2001, July 2001, September/October 2001, January 2002, April 2002 and October 2002). Generally, during each fieldtrip a minimum of two count sessions were undertaken within each Sampling Area, with nominated observation count sites visited at least once each season. Shortly before dusk the observer arrived at the nominated observation count site by vehicle, turned off the engine and remained seated within the car. The time of arrival was recorded, along with the general weather conditions and the time at which darkness fell. Noting the time, counting began when the first wallaby emerged from the scrub and crossed the track, or made a substantial advance towards crossing it. A 30W halogen bulb spotlight (Lightforce Australia Pty Ltd, Hindmarsh, South Australia) was switched on and pointed directly down the middle of the track when it became too dark to see the wallabies by natural light. Any wallaby emerging from the scrub up to 150m in front of the observer was counted. Any wallaby that returned to the scrub during the counting session was subtracted from the total. Again noting the time, counting ceased when the number of wallabies emerging from the shelter scrub had become negligible. During the second year of fieldwork, after emergence ceased, spotlight walks were undertaken through the scrub two to three hours after dusk to establish whether any animals still remained in the scrub.

Count data, emergence start times and lengths of time spent emerging for each Sampling Area were analysed by REML (Genstat 2002) with the fixed effects of Year, Season and Sampling Area. All interactions were tested, with non-significant factors removed from the model.

3.2.2 Movement Patterns

Knowledge of an individual's usage of the area was required to help establish impact levels over the Reference Site and adjacent pastures. Determining or following an animal's movement pattern is achievable by trapping individuals and attaching radio-collars for tracking (Lee *et al.* 1985).

Black-striped wallabies were trapped using four standard 38x38x69cm wire cage traps (Mascot Wireworks, Endfield, Sydney) baited with fresh lucerne hay (*Medicago sativa*). The traps were placed at different locations around the Reference Site so animals from different areas of the Reference Site could be radio-collared and tracked. Pre-baiting was undertaken prior to the trap nights by placing small piles of fresh lucerne hay in chosen locations. After a couple of weeks, it was decided whether wallabies were feeding from the lucerne piles or not, and if so, an open trap was left nearby the lucerne hay. Every couple of days the pile of lucerne hay was replenished, each time placing the pile closer to the open trap and finally placing it inside the trap, encouraging the wallabies to enter the trap. Wallabies were regularly entering the open traps after 3-4 weeks of pre-baiting. Trapping was undertaken over a number of nights during October 2000 and July/August 2001.

Modification of the trap technique was required after it was discovered that larger wallabies were brushing their backs against the door when trying to enter the trap, pushing the door upwards and thereby setting off the trap mechanism. However, as the wallabies were only part of the way in the trap, the trap mechanism could not engage fully and the wallabies were able to back out. To overcome this problem the traps were placed on a raised platform of earth and secured with a steel picket on either side (Figure 3.2). This successfully allowed the larger wallabies to enter the trap without touching the trap door. The trap mechanism was then able to engage properly, when the wallabies placed their weight on a trip plate on the floor of the cage trap as they moved into it to reach the lucerne hay.

Figure 3.2 Modified trapping technique to facilitate capture of larger Black-striped Wallabies.

Traps were checked approximately 2h after dusk, emptied if successful in trapping an animal, reset, and checked again around midnight. Any juveniles or sub-adults were released immediately from the trap without being handled. Adult wallabies were removed from the trap by grasping the base of the animal's tail, lifting the animal out of the trap and placing it in a hessian sack. The use of a sedative was not required in any instance. Wallabies were weighed, sexed, fitted with a radio-collar, and released near the trap location. The maximum time taken between removing the animal from the trap to its release was less than 20 minutes.

The radio-collars, set at 151MHz frequency, were supplied by Titley Electronics Pty Ltd (Ballina, NSW, Australia), with a battery life of approximately 18 months. A weak link, designed to detach at approximately 12 months, was incorporated within the band of the collar to enable retrieval of the collar before the battery expired.

As only one radio-receiver and operator were available for this study, no simultaneous cross-bearings on locations could be obtained. Using a Sirtrack antenna and Telonics TR-4 receiver, the location of each radio-collared wallaby was investigated at least once a day during seasonal field trips, and between field trips on day and weekend visits to the Research Station. The clock time of each radio-tracking event was recorded, whether or not the animal was located. Radio-tracking was usually undertaken before and after morning and afternoon sessions of fieldwork, and therefore was undertaken at similar times each day (i.e. early morning, late morning, early afternoon, late afternoon, evening). Although not standardised, the methodology ensured that each wallaby was radio-tracked daily, and that the timings of the radio-tracking for each individual were randomly distributed between morning, afternoon, evening and night periods. During field trips with overnight stays, most radio-collared wallabies were actually radio-tracked more than once a day, as fixes were taken of each wallaby on most evenings and/or nights, as well as during the day. While radio-collared wallabies were rarely tracked more than once during morning and afternoon periods, they were often tracked numerous times during evening and night periods, as these were periods of increased movement.

Results of radio-tracking could not be analysed statistically or used to define home ranges due to inadequacies in the technique used. Instead, wallaby locations were displayed on a 1ha grid using a variety of coloured symbols representing different diurnal and seasonal periods. It was hoped this would establish whether individual wallabies were sedentary, staying in a small part of the remnant area, or moved about within the remnant area and if so, to what extent. The test periods Day (0500 to 1700hours), Evening (1700 to 1900 hours) and Night (1900 to 0500 hours) were chosen as they were thought to best categorise wallaby activity periods; resting, movement to feeding areas, and feeding respectively. Seasonal periods followed calendar seasons; Summer (December to February), Autumn (March to May), Winter (June to August), and Spring (September to November).

3.2.3 Utilisation of Remnant Vegetation

The distribution of wallaby occupancy within the different vegetation communities, or the areas selected and utilised by the wallabies for sheltering and feeding, were inferred based on faecal pellet counts and an assumption that defecation was random in space and time.

As summarised in Table 2.1 (Section 2.4.3), faecal pellet counts were undertaken on three different occasions to determine three different sorts of information. This section covers faecal pellet counts undertaken along evenly spaced transects covering the whole Reference Site to determine differences in the degree of utilisation within the remnant area.

Faecal pellets counts were also undertaken more intensely along transects spaced 50m apart within Sampling Areas 1, 2 and 4. These counts were undertaken in conjunction with monitoring of habitat variables to establish whether there was any correlation between faecal pellet density and habitat structure, and are reported in Section 3.2.4. The third lot of faecal pellet counts were undertaken along transects extending out from the shelter scrub into the pasture paddocks to determine the degree of utilisation of the pasture areas on the Research Station (Section 4.2.2).

In each case Black-striped Wallaby faecal pellet identification was made following the descriptions of Triggs (1997). Black-striped Wallaby faecal pellets are cylindrical coming to a point on one end. They are generally up to 25mm long and 10mm wide. Variations in size and shape do occur, with some pellets shorter and squarer. Identification of faecal pellets was made somewhat easier by the substantial absence of any other common macropod species of similar size in the area. Pellets were recorded as either being Recent or Old. Recent faecal pellets were distinguished from Old faecal pellets by the presence of a mucous shine and being darker in colour. Recent and Old faecal pellet were counted separately due to differences in accumulation rates of each; Recent faecal pellets have a faster rate of decay than Old pellets.

Following the findings of Johnson and Jarman (1987), Johnson *et al.* (1987) and Southwell (1989) pellets were counted individually (Figure 3.3), not as groups (i.e. whole defecations).

Figure 3.3 Black-striped Wallaby faecal pellets. The 18 pellets in this figure are characteristically cylindrical and up to 25mm long and10mm wide.

Faecal pellet distribution was ascertained over the Reference Site by counting faecal pellets along 19 transects, evenly spaced approximately 400m apart, during two Survey Periods (September 2000 and 2001), and along 10 transects, evenly spaced approximately 800m apart, during two Survey Periods in 2002 (March and October). Each transect was assigned to Sampling Area 1, 2, 3 or 4. Within a circular 0.75m^2 area (i.e. a circular quadrat with 0.5m radius), counts were undertaken along each transect at 10m intervals. These count data were classified into Distance-from-edge categories. Distance-from-edge is the interval of distance from the shelter vegetation-pasture interface, or Reference Site edge; thus, those 10m intervals between 0 and 40m from the scrub edge were classified as within the Distance-from-edge category 1; 41-80m, category 2; 81-120m, category 3; 121-160m, category 4; 161-200m, category 5; and >200m, category 6). Categories of 40m were chosen so that the average of four values was being analysed statistically (too few would not give a good estimate of variance).

For each Survey Period, the counts of Recent and Old faecal pellets at each position, were converted to density (m^{-2}) and analysed by REML (Genstat 2002). The effect of Survey Period rather than Season was analysed as only one survey was undertaken during Autumn, compared to three undertaken during Spring. Therefore, the fixed effects of Survey Period, Sampling Area and Distance-from-edge category and all interactions were tested, with non-significant factors removed from the model. Results are presented as predicted means.

3.2.4 Shelter Preferences based on Habitat Structure

In an attempt to explain variations in numbers of faecal pellets counted over transects throughout the Reference Site (see Section 3.3.3), faecal pellet counts were undertaken more intensely in conjunction with recording of habitat variables, along three transects, spaced 50m apart at the centre of each of Sampling Areas 1, 2 and 4. Sampling Area 1 transects were approximately 550m long and contained remnant Brigalow vegetation only. Sampling Area 2 transects were 800m long containing Buffel grass pasture, remnant Brigalow vegetation and Brigalow regrowth. Sampling Area 4 transects were approximately 550m long and contained mixed pasture and Softwood scrub components (refer Section 2.4.2). Correlations between faecal pellet numbers and habitat variables would show if animals exhibited habitat preference.

Techniques for identifying and recording Recent and Old pellets were the same as those used to count faecal pellets along the Reference Site transects (Section 3.2.3). Habitat description parameters were recorded from within the same quadrat at the same time using the methods listed below (Table 3 2).

Table 3.2 Habitat variables recorded with faecal pellets counts at 4m intervals along the three transects within three Sampling Areas.

Habitat Variable	Measurement Specifications
1. Vegetation Height	Each quadrat was divided into quarters and the vegetation height measurements taken within each quarter. The mean, maximum and minimum height for each quadrat was then calculated.
2. Individual Vegetation Species	The number of different species in each quadrat was recorded. Because of heavy grazing not all species could be identified and were therefore recorded as 'unknown'. For analysis, species were grouped into plant categories (tree, shrub, grass, forb and sedge).
3. Ground Cover by Individual Species	The percentage of ground covered by individual species was recorded. Overlapping of species was not allowed so the amount of ground cover possible was always a maximum of 100%.
4. Total Cover by Vegetation	The total percentage of ground covered by vegetation was recorded. In January only the total percent cover of all vegetation was recorded. In April, July and October the percentages of the three separate vegetation groupings (grass, forb and sedge) were recorded.
5. Bare Ground	The amount of bare ground within each quadrat was recorded as a percentage of quadrat area.
6. Leaf Litter	The amount of ground covered by leaf litter (leaves, logs, stumps, stones, branches and bark) was recorded as a percentage of quadrat area.
7. Trees and Shrubs	The number and types of trees and shrubs (including seedlings) in each quadrat were recorded. A tree or shrub was defined as being any vegetation species with woody stem or trunk.
8. Canopy Cover	The percent shade cover was determined by estimating the percentage of sky obscured by leaves and/or tree branches 1m above ground level.
9. Biomass Rank	A 5-point biomass ranking scale was established at the beginning of each seasonal trip following the method of Haydock and Shaw (1975). Quadrats were placed on a highest- and a lowest-yielding area and designated Rank 5 and Rank 1 respectively. Rank 3 was chosen by estimating a quadrat of biomass half way between Ranks 5 and 1. Ranks 2 and 4 were chosen by estimating a quadrat that had a biomass yield between Rank 1 and 3, and between Rank 3 and 5, respectively. Rank 0 contained no edible biomass. Reference photographs were taken of each rank. Sample quadrats were cut and dried to constant weight in a 75°C oven.
10. Visual Density Estimates	See description below

The sum of parameters 4, 5 and 6 should equal 100%, as living plant matter was not considered to overlap with bare ground or leaf litter. Estimations of visual density, or visibility, were recorded along each transect during January 2001 and July 2001, similar to those undertaken by Nudds (1977), Lunney and O'Connell (1988) and Spence (1998). A sheet of canvas 30cm x 90cm in size was painted with 27 chequered 10cm x 10cm squares. The canvas was sectioned into three heights 0-30cm, 30-60cm and 60-90cm. At each 25m sighting position along the transect, a volunteer paced out in three directions (left, 90°; right, 270°; and forward, 0°) from the transect position, to two distances, 12.5m and 25m, each marking a visibility test point. At each test point the volunteer held up the canvas sheet leaving the bottom edge at ground level and with the chequered squares facing the observer. At the transect position the counter viewed the canvas from a height of approximately 1m above the ground (simulating wallaby eye-height), and counted the number of squares fully and partially visible in each third. The volunteer and counter then moved along the transect to the next 25m interval, and repeated the process, until the end of the transect was reached. Visibility in the fourth direction (backwards, 180°) was also recorded at the 25m distance for each transect position, by taking the forward direction of the previous point.

At both distances and at each of the three heights, bottom 0-30cm, middle 30-60cm, and top 60-90cm, the number of fully visible squares and partially visible squares recorded in each direction were averaged to give the mean number of squares fully visible and the mean number of squares partially visible at each position. The mean number of squares partially visible was then halved and summed with the mean number of squares fully visible to give one value for each of the six data variables (12.5m top, 12.5m middle, 12.5m bottom, 25m top, 25m middle and 25m bottom) at each position.

During January, April, July and October 2001 faecal pellet counts and habitat monitoring was carried out at 4m intervals along each of the transects within $0.25m^2$ quadrats (square quadrats with 0.5m sides), placed squarely at the toe of the recorder.

For analysis, the data set was simplified in a number of ways. Season was simplified from four categories to two - 'wet' (December and April) and 'dry' (July and October). Each Sampling Area was divided into Environment type (refer Section 2.4.2). Transects in Sampling Area 1 contained one Environment type (fenced Brigalow scrub, 1), Sampling Area 2 contained three Environment types (Buffel grass, *Cenchrus ciliaris*, 2; unfenced Brigalow scrub, 3; native grass with regrowth, 4) and Sampling Area 4 contained two Environment types (mixed improved pastures, 5; Softwood Scrub, 6). The six Environment types were also classified as Scrub or Pasture, Table 3.3.

Table 3.3 Classifying the transects whose habitat variables were monitored for correlation with faecal pellet density.

Sampling Area	Vegetation Category	Environment Type No.	Environment Type
1	Scrub	1	Fenced Brigalow scrub
2	Pasture	2	Buffel grass
	Scrub	3	Unfenced Brigalow scrub
	Pasture	4	Native grass with regrowth
4	Pasture	5	Mixed improved pastures
	Scrub	6	Softwood Scrub

Environment type was confounded with Sampling Area and there was no replication of Environment type between Sampling Areas. Therefore, analyses were done using the Environment type, not Sampling Area, as the factor in the linear model.

Transects were divided into 50m Distance-from-edge categories. Each 4m interval along the transects was therefore given a Distance-from-edge category based on its distance from the shelter vegetation/paddock interface, or Reference Site edge (0-48m, category 1; 52-100m, category 2; 104-148m, category 3; 152-200m, category 4; 204-248m, category 5; and 252-300m, category 6; >300m, 7). The habitat variables and faecal pellet densities recorded at each 4m interval were grouped and averaged within each Distance-from-edge category accordingly.

Some Sampling Areas (Vegetation Categories) had more Distance-from-edge categories than others because Sampling Area transects differed in length. Distance-from-edge categories of 50m were chosen (in difference to the 40m categories used for the Reference Site Faecal Pellet Counts) because the density board sightings were taken at 25m intervals, therefore a 50m Distance-from-edge category not only allowed the averaging of two lots of visibility values for each Distance-from-edge category but also allowed that data to be aligned with the other habitat variables measured.

To test whether wallaby density was heterogeneously distributed, counts of faecal pellets were undertaken as explained in Section 3.2.3. These counts were then correlated with the hypothesized heterogeneity in habitat types to determine whether the apparent heterogeneity in Black-striped Wallaby distribution could be explained by habitat preferences.

The Sampling Sites analysed for correlations between habitat and wallaby use were firstly described by faecal pellet densities. These descriptions also served to establish the feasibility of using Recent and Old faecal pellet densities, by comparing them with results from Section 3.3.3. Recent and Old faecal pellet counts frequencies were found to follow a Poisson distribution. Within each Environment Type, Recent and Old faecal pellets were then analysed by REML (Genstat 2002), testing for the fixed effects of Season and Distance-from-edge and their interactions. Where significant interactions were present, pairwise comparisons of predicted means were compared for significance using the Least Significant Difference method (accepting $p<0.05$ as indicating significance). Results are presented as predicted means (m^{-2}).

The habitat variables data had a large number of zeros, creating complications in the correlation analysis. To reduce the number of zeros in the habitat variables data set, each 50m Distance-from-edge group was categorised by Recent faecal pellet category and Old faecal pellet category. The faecal pellet density categories ($0m^{-2}$, category 0; 0-$4m^{-2}$, category 1; 4-$8m^{-2}$, category 2; 8-$12m^{-2}$, category 3; and $>12m^{-2}$, category 4) were chosen based on a histogram showing that those categories contained roughly equal number of individual data counts.

Each variable was found to follow a Poisson distribution. The data of a number of variables were scaled between 0 and 100%, i.e. a proportion of a total of 100, and therefore required transformation. The percentage values (x) of bare ground, ground covered by vegetation, ground covered by the combined leaf litter and ground covered by each vegetation type were transformed to a ratio of each variable to the sum of the other percentage ground cover values ([x]:[100-x]). The percentage cover values of each species were firstly grouped into appropriate vegetation categories. Their combined percentage cover was then transformed to the ratio value by dividing it by the sum of the other species' percentage ground cover values. The ranked visibility data (values between a minimum and maximum, i.e. 0-9) were taken to be pseudo-random discrete values with Poisson distribution and were not transformed. The mean seasonal values of the remaining variables (mean, maximum and minimum height of vegetation, number of plant species and number of shrubs/trees) were also analysed without transformation.

Each habitat variate or transformed variate was then analysed by REML testing for the fixed effect of Recent and Old faecal pellet category with Environment Type and Season as random factors.

3.3 Results

3.3.1 General Wallaby Densities

3.3.1.1 Drive Spotlight Counts

Drive spotlight counts were undertaken to determine the density of Black-striped Wallabies around the Reference Site. The drive route was segmented to enable comparison of densities with the stationary observation counts and to relate the densities to faecal pellet counts in the different Sampling Areas. Unfortunately, spotlight drive counting could not be undertaken regularly due to unavailability of a driver and time constraints on the researcher, nor could the entire perimeter of the Reference Site be covered due to inaccessibility (*Parthenium* sp. and boggy soil).

The area covered in each spotlight survey was calculated from the records of distances at which animals were detected. However, only 14.3% of animals sighted were recorded at specified distances as the large numbers of animals seen and their mobility made it difficult to record all distances. This also made it impossible to use software packages, such as Distance (Buckland *et al.* 1993), to calculate sighting-decay curves for the whole data set.

Of the animals counted at recorded distances, 97.7% observed were within 100m from the vehicle (Table 3.4).

Table 3.4 Black-striped wallabies seen at each 10m Distance category. Includes all wallabies at recorded distances over the three spotlight nights, but not those that were recorded as at 'variable' distance.

Angle	0	10	20	30	40	45	60	70	80	90	100	Total
Distance												
0-9m	6	5				2			1	12	1	27
10-19m	4	4							2	15		25
20-29m	3	1	2	1						16		23
30-39m	3	7						2		30		42
40-49m	4	2			1	1				16		24
50-59m	8	7	1						2	15		33
60-69m	2	2	1							27		32
70-79m	11	5				2	3	3	2	11		37
80-89m	9	2		1						2		14
90-99m										3		3
>100m	3									3		6
Total	53	35	4	2	1	5	3	5	7	150	1	266

These data indicate that sightability fell sharply at a distance between 80 and 100m from the vehicle. So, to give a conservative estimate of densities, 100m was taken as the maximum distance within which the majority of wallabies would be detected when spotlighting.

Using this effective spotlight distance of 100m and the spotlight drive route length of 11.62kms, the spotlight-surveyed area totalled 1.162km^2. The overall densities of

Black-striped wallabies were calculated to be 418.2km^{-2}, 674.7km^{-2} and 459.6km^{-2} on the three survey nights. These calculated densities apply for the survey spotlight area (i.e. the remnant vegetation/pasture interface) only, not the entire Research Station.

REML analysis of the data was problematic as the wallaby density values from Sampling Area 1 were considerably different from the other Sampling Areas. When analysed, the wallaby density of Sampling Areas 1 and 5 were not different, however the means and standard errors suggest that wallaby density in Sampling Areas 1 and 5 were different (Table 3.5). Analysis also indicated the wallaby density in Sampling Areas 1 and 5 were significantly lower than Sampling Areas 2, 3 and 4, but Sampling Areas 2, 3 and 4 were not significantly different to each other. The highest density of wallabies was found in Sampling Area 4 (Softwood Scrub).

Table 3.5 The mean density of Black-striped Wallabies in each Sampling Area.

Sampling Area	Density (km^{-2})	Mean SEM
1	29^{b}	3
2	547^{a}	143
3	534^{a}	274
4	1127^{a}	236
5	91^{b}	19

Estimated means and mean standard errors of means (SEM) from REML, n=31. Values with like superscript letters are not significantly different, p<0.001.

Differences in densities between Sampling Areas were recorded each night (Figure 3.4). For Sampling Areas 1, 2, 4 and 5 the counts for each night followed the same pattern. However in Sampling Area 3, the counts of the third night were unusually low.

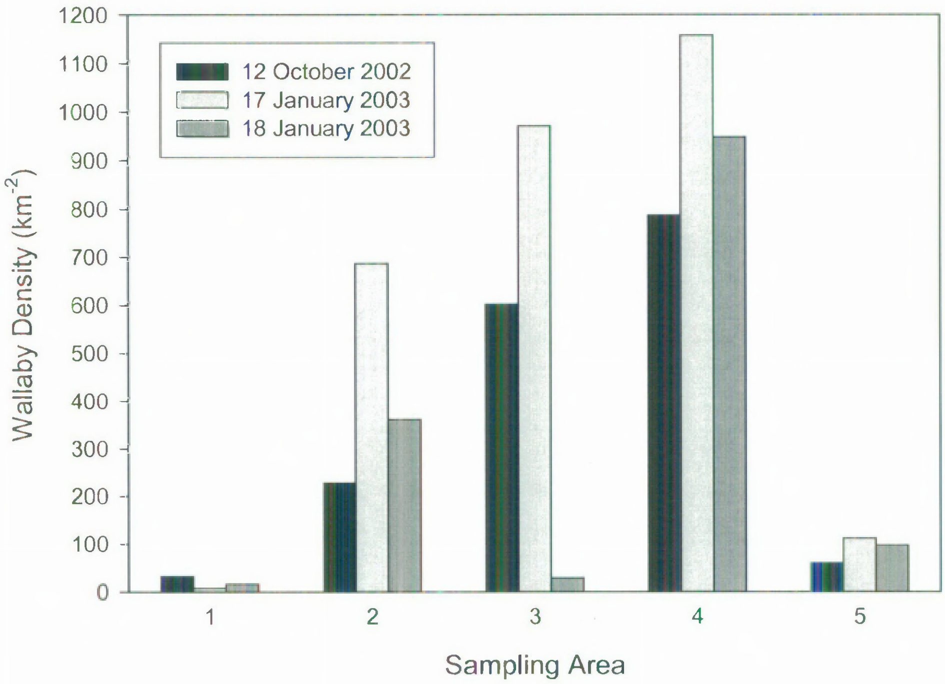


Figure 3.4 Densities of Black-striped Wallabies in each Sampling Area on each spotlight night.

3.3.1.2 Stationary Observation Counts

Stationary observation counts were undertaken as another means of measuring the apparent heterogeneity in Black-striped Wallaby distribution at Brigalow Research Station. Counts were undertaken on 42 evenings with 10, 23 and 9 count sessions undertaken in 2000, 2001 and 2002 respectively. These were spread over all four seasons with 10, 10, 6 and 16 counts undertaken in summer, autumn, winter and spring respectively. All Sampling Areas were monitored; with 6 counts in Sampling Area 1 (fenced Brigalow), 11 counts in Sampling Areas 2 & 3 (unfenced Brigalow), 24 counts in Sampling Area 4 (softwood scrub) and 1 count in Sampling Area 5 (cropping land).

Table 3.6 summarises the observation counting data showing the number of monitorings that were undertaken in each Sampling Area, the mean length of time and emergence, and the mean number of Black-striped Wallabies counted. There was no significant difference due to Area in the time emergence began (data not shown) or the length of time during which animals emerged. However, the number of animals differed significantly between Sampling Areas; with significantly fewer animals counted at Sampling Area 1 (fenced Brigalow) than Sampling Areas 4 (Softwood scrub) or 5 (cropping). The number of animals counted at Sampling Area 2/3 (Brigalow forest) was in between that of Sampling Areas 1 and 4 but did not differ significantly with either.

Table 3.6 The length of time emergence persisted and the mean number of animals emerging at the various Sampling Areas.

Sampling Area	No. of Monitorings	Emergence Period (min)	Mean SEM	Mean No. Animals	Mean SEM
1. Fenced Brigalow	6	-------	------	0^{b}	------
2/3. Brigalow	11	23^{a}	8	36^{ab}	3
4. Softwood Scrub	24	29^{a}	8	79^{a}	2
5. Cropping	1	16^{a}	------	109^{a}	------

Estimated means and mean standard errors of means (SEM) from REML, n=42. Figures in each column with like superscript letters are not significantly different, $p<0.05$.

The one high count of animals in the cropping area does not support the spotlight data, which showed fewer wallabies there. This number is biased as it is based on only one counting session, undertaken during July 2001 to establish if wallabies used the area and whether the site was suitable for repeated observations counts. However, radio-tracking results (Section 3.3.2) suggest that it is possible that crop presence may change the feeding behaviour of the wallabies in the area. In July 2001 there was sorghum stubble present (harvested one month earlier) probably providing green shoots. At the time of spotlighting in October 2002 and January 2003 the cropping area was bare as the sorghum crop for that season had failed in September 2002.

The interaction of Sampling Site and Season was analysed but found to be not significant. The number of animals emerging was not significantly affected by Season alone either (Table 3.7), although more animals were counted during the winter season.

Table 3.7 The affect of Season on the mean number of Black-striped Wallabies counted in stationary observation counts.

Season	No. of Monitorings	Mean No. Animals	Mean SEM
Summer	10	51[a]	15
Autumn	10	49[a]	17
Winter	16	70[a]	21
Spring	10	45[a]	10

Estimated means and mean standard errors of means (SEM) from REML, n=46, $p<0.05$.

Seasonally, there was no significant difference in the length of time spent emerging either; however, there were seasonal differences in the time the animals started to emerge (Table 3.8). Animals emerged later during the summer months than the autumn, winter and spring months and there was also a significant difference between the spring and winter emergence times.

Table 3.8 Mean emergence start time and length of time (AEST) spent emerging by Black-striped Wallabies in different seasons.

Season	No. of Monitorings	Emergence Time (hr:min)	Mean SEM	Emergence Period (min)	Mean SEM
Summer	8	19:03[a]	0.08	21[a]	3
Autumn	8	18:15[bc]	0.11	17[a]	2
Winter	13	17:79[c]	0.03	31[a]	3
Spring	5	18:27[b]	0.04	22[a]	2

Estimated means and mean standard errors of means (SEM) from REML, n=34. Values with like superscript letters, within columns, are not significantly different, $p<0.05$.

Stationary observation counting also provided opportunistic information about the activities and behaviour of wallabies that was not tested by quantitative data-gathering in this study. The observations are reported here because they might deserve examination in other studies since they suggest some social structuring in emergence to feed in the paddocks.

Individual wallabies emerge from the shelter scrub shortly before dusk. It appeared that larger male wallabies emerged first, with medium sized animals following soon after. Generally, the majority of wallabies moved out within an half hour period, however a few individuals (especially females with young-at-foot) waited some time until after dark to emerge. During summer months individuals 'played about' a lot, moving back and forth from pasture to scrub seemingly uncommitted to feeding. In drier months, however, animals seemed to move straight out to pasture with more purpose.

Disturbance during night-time grazing (e.g. a vehicle driving past) usually provoked a mass movement of individuals back towards the shelter scrub, although some larger animals remained where they were, unless directly approached.

Spotlight walks through different sections of the remnant vegetation a couple hours after dark found very few wallabies still within the shelter vegetation, suggesting that all individuals had emerged to feed in the adjacent pasture paddocks.

3.3.2 Movement Patterns

Trapping, radio-collaring and radio-tracking of a small number of individual wallabies was undertaken so that the general movement patterns of the Black-striped Wallaby population around the Reference Site, and adjacent pastures, could be assessed. A number of problems were experienced with radio-tracking including shifts in radio-collar frequencies, death of radio-collared animals from dingo predation, inability to keep track of some individuals whose locations could not be established regularly and failure to retrieve some radio-collars as the batteries ran out before the weak link detached. In addition, interpretation of the radio-tracking is limited by the lack of accurate locations (obtained from simultaneous cross-bearings) and disturbance of the wallabies by the researcher's presence.

Over 7 nights during October 2000 and July/August 2001, 13 wallabies were trapped; however, two were too young for radio-collaring and were therefore released without being handled. Wallabies were trapped from a number of locations with 1, 4, 1 and 5 individuals trapped in Sampling Areas 1, 2, 3 and 4 respectively (see Figures 3.5 and 3.6).

Of the 11 radio-collars fitted (to 5 male and 6 female wallabies), 4 were recovered from dead animals, 2 were retrieved after falling off shortly after attachment and 5 were never retrieved as the batteries expired before the weak link detached or the animal died. The radio-collars appeared to shift frequency on a number of occasions, sometimes making it difficult to relocate animals, particularly after a period of absence from the field.

Radio-tracking was undertaken many times during each field trip at various times throughout the day and night (Table 3.9).

Table 3.9 The number of times each radio-collared wallaby was radio-tracked during day, evening and night periods.

Animal	Day	Evening	Night	Total
038	21	4	6	31
050	14	5	4	23
068	41	4	18	63
280	39	5	21	65
429	10	3	4	17
809	33	8	16	57
889	37	16	17	70
719A	4	2	1	7
719B	57	12	33	102
749A	4	3	1	8
749B	9	3	3	15
Totals	269	65	124	458

Of 458 attempts at radio-tracking, 345 were successful in locating signals (Table 3.10). There were only two daytime detections definitively located in pasture. These were of collars on carcasses (068 and 809). Living animals were never detected outside the Reference Site or 'Scrub' during daylight hours, although some locations were close to the scrub/pasture interface. During evening and night time radio-tracking a large proportion of detections were within the scrub (97 out of 137, 71%); however the 'Scrub' grouping does not give details of distance from scrub/pasture interface or edge. It is possible that in a number of cases wallabies had been in the pasture feeding, until the approach of the researcher's vehicle caused them to return to the scrub in fright. The single researcher's need to keep moving and get approximate simultaneous cross-bearings on signals, inevitably disturbed the wallabies more than would simultaneous tracking from fixed stations by several observers. Thus, the method probably underestimated use of the pasture.

Table 3.10 The number of times each radio-collared wallaby was detected in the Reference Site (remnant vegetation) and in the pasture.

Animal	Daytime Detections		Evening Detections		Night time Detections		Total
	Pasture	Scrub	Pasture	Scrub	Pasture	Scrub	
038		8		2		3	13
050		8		5	1	3	17
068	1	31		3	4	4	43
280		20	1	2	3	7	33
429		10	3		2	2	17
809	1	26	1	5	4	8	45
889		31		12	5	5	53
719A		4		2	1		7
719B		56	3	8	6	24	97
749A		3		2			5
749B		9	3		3		15
Totals	2	206	11	41	29	56	345

Locations of each animal were placed on 1ha (100x100m) grids overlain on a map of the Research Station. Colours and symbols have been utilised to differentiate diurnal locations (day, evening, night), Figure 3.5a-e, and seasonal locations (Figure 3.6a-e).

a) Radio-collared females 038, 809, and 719B and male 889.

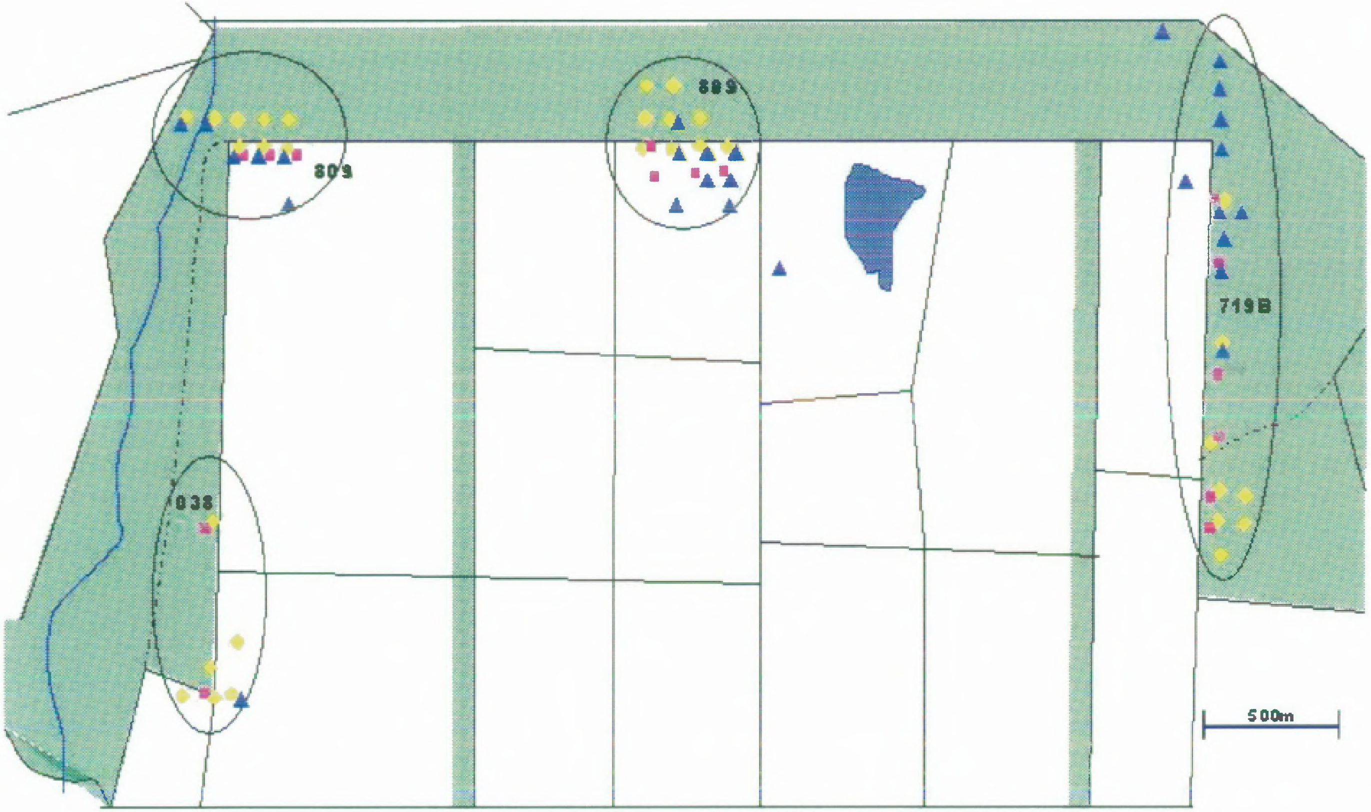
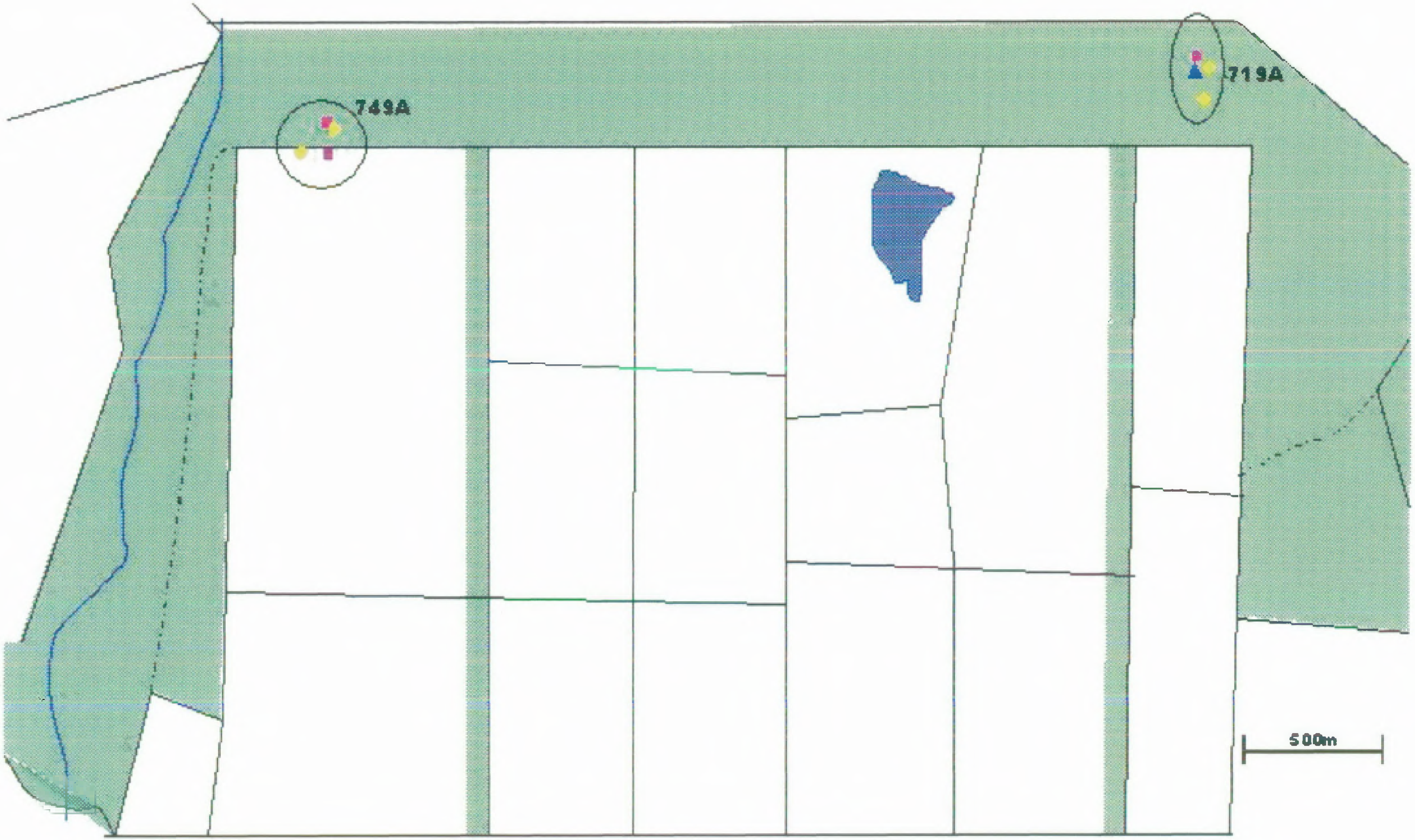
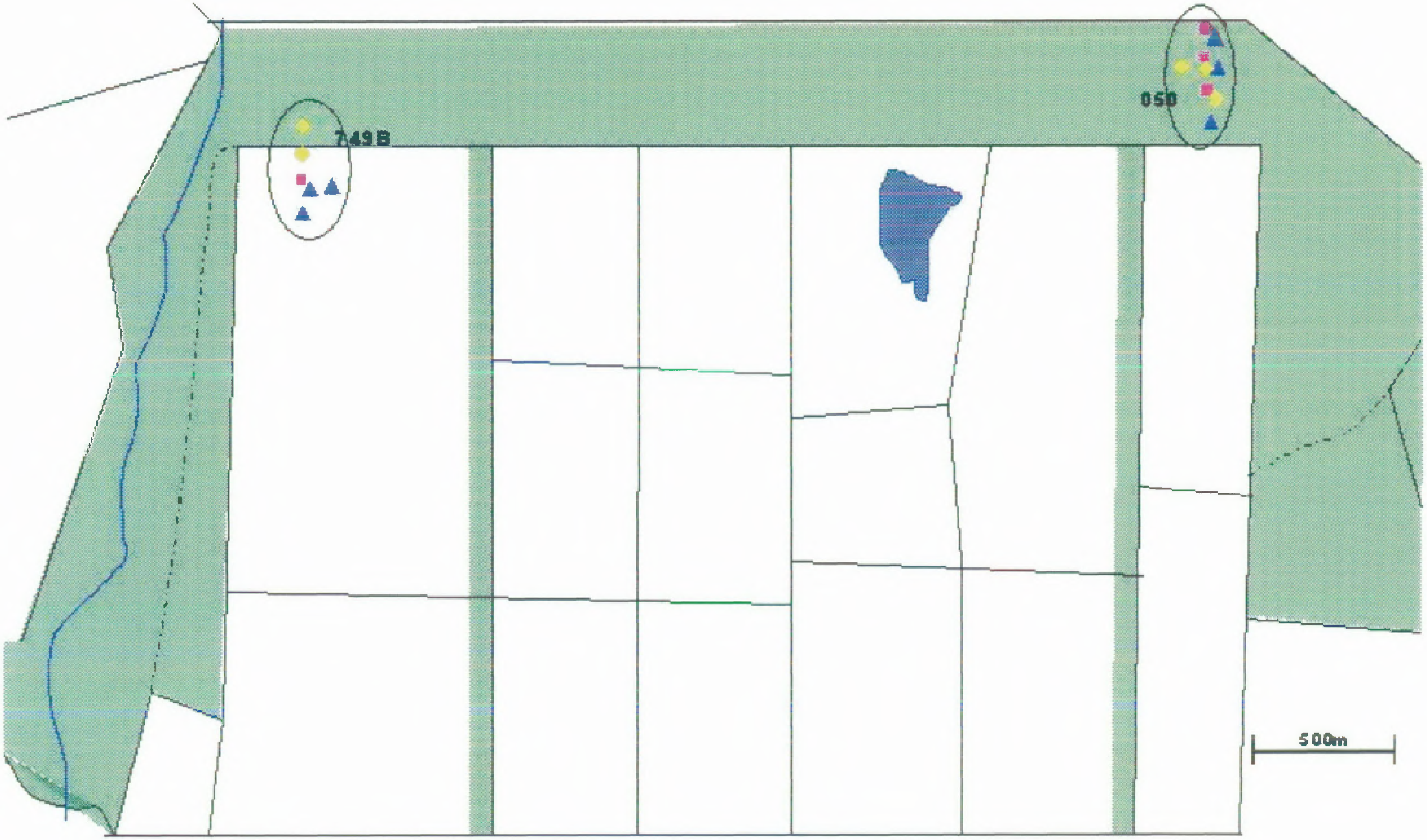


Figure 3.5a-e. Daily radio-tracking locations. Clusters of symbols for each individual are circled. Daytime locations (0500-1700hrs) are represented by yellow diamonds, evening locations (1700-1900hrs) by pink squares and night locations (1900-0500hrs) by blue triangles.

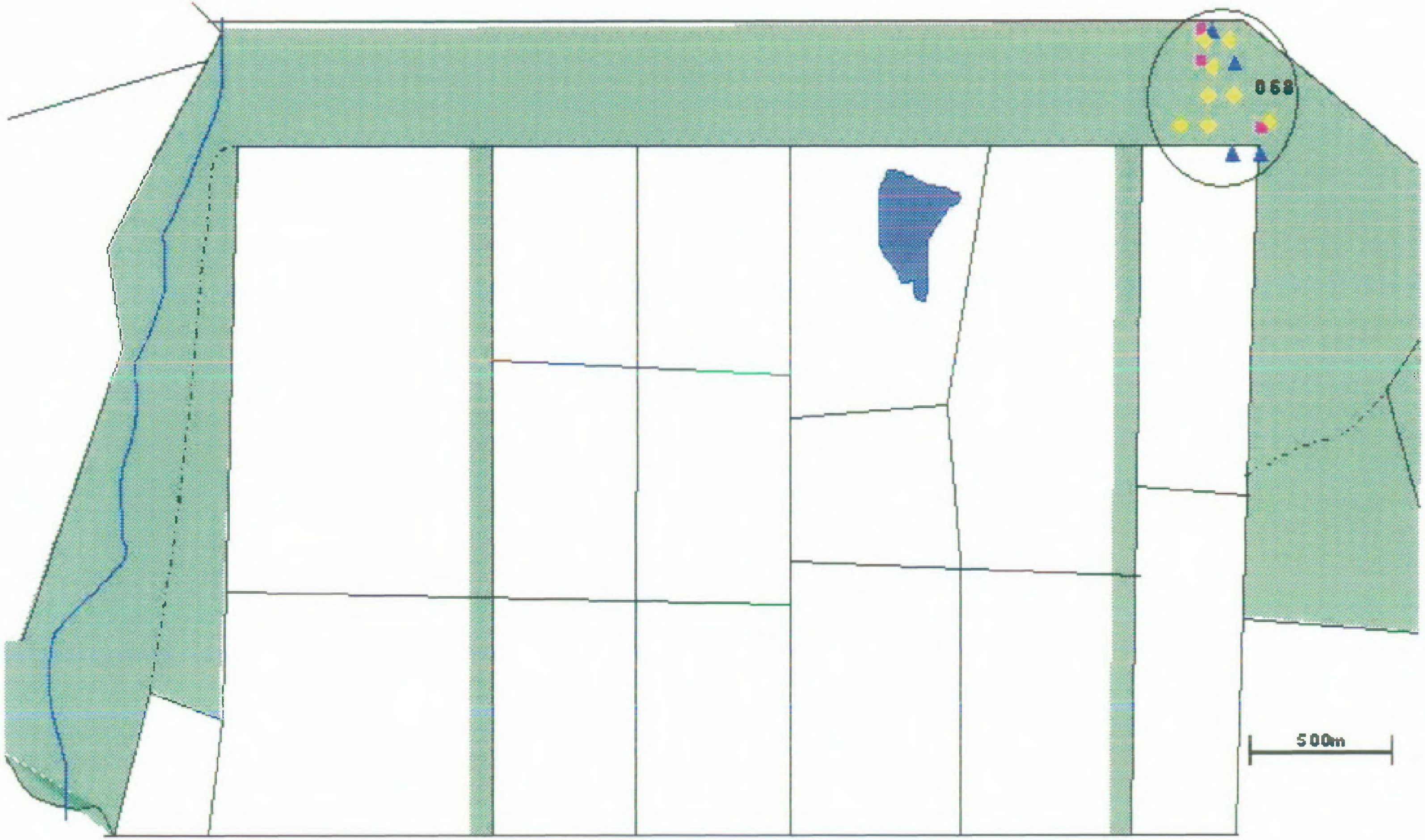
b) Radio-collared male 749A and female 719A.



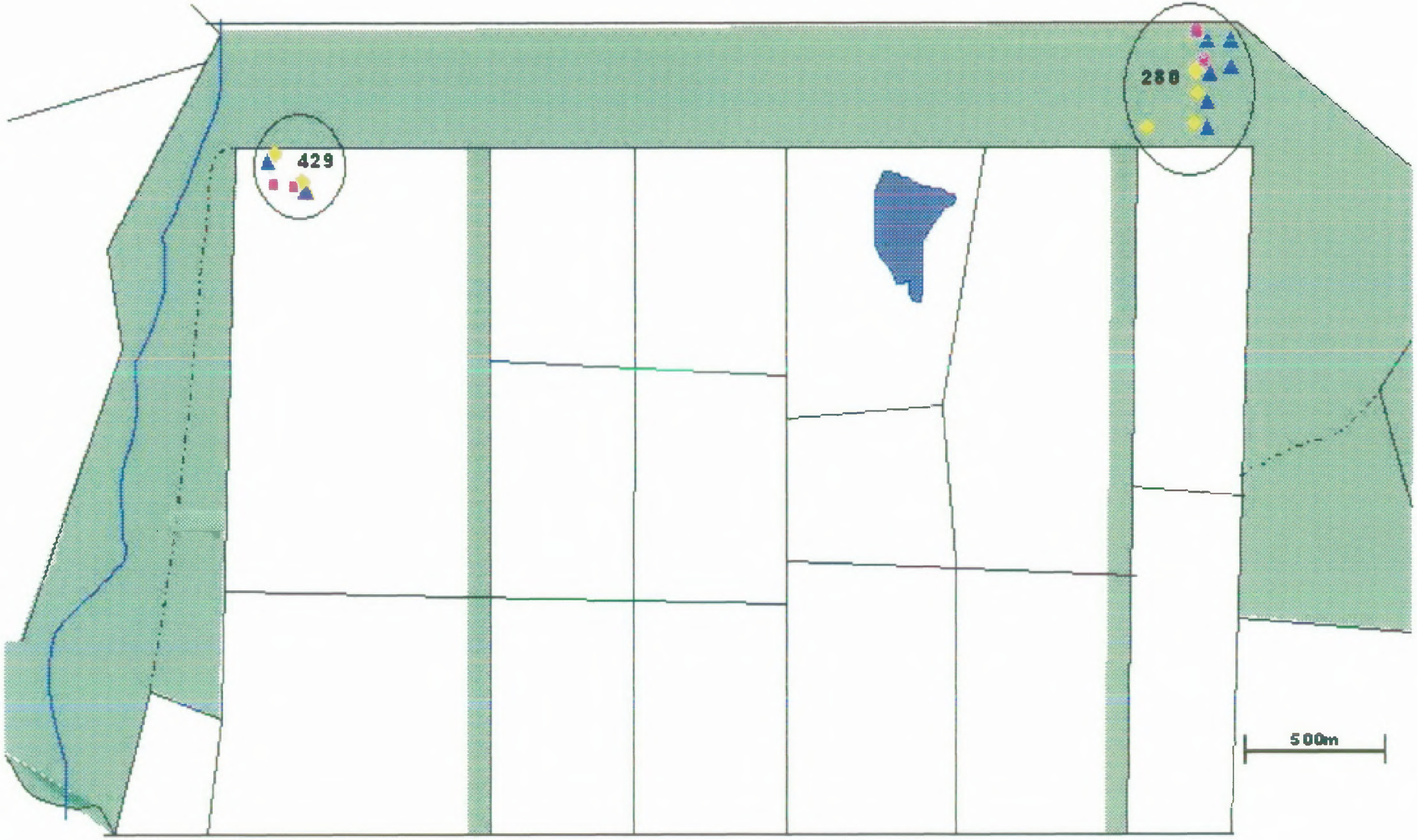
c) Radio-collared males 749B and 050.



d) Radio-collared female 068.



e) Radio-collared male 429 and female 280.



a) Radio-collared females 038, 809, and 719B and male 889.

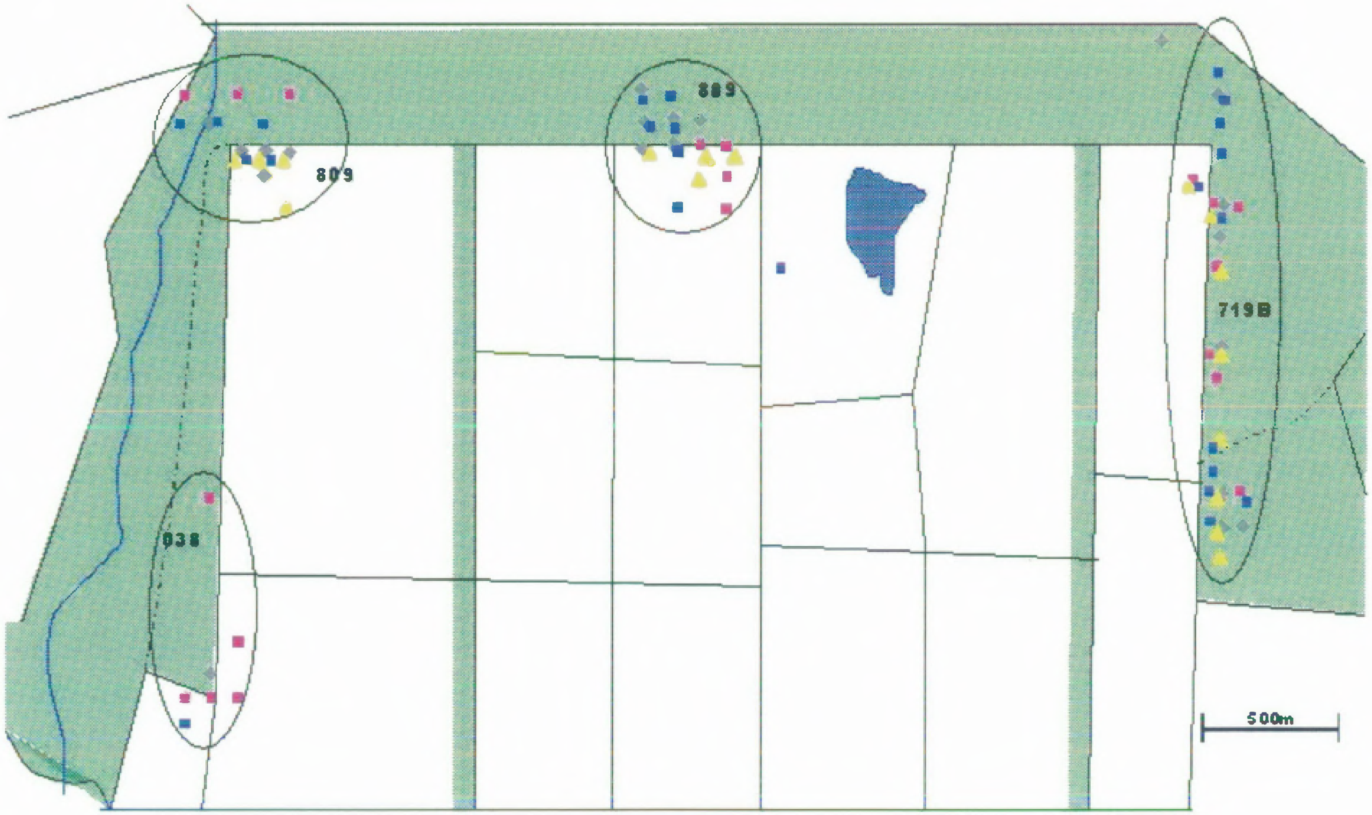
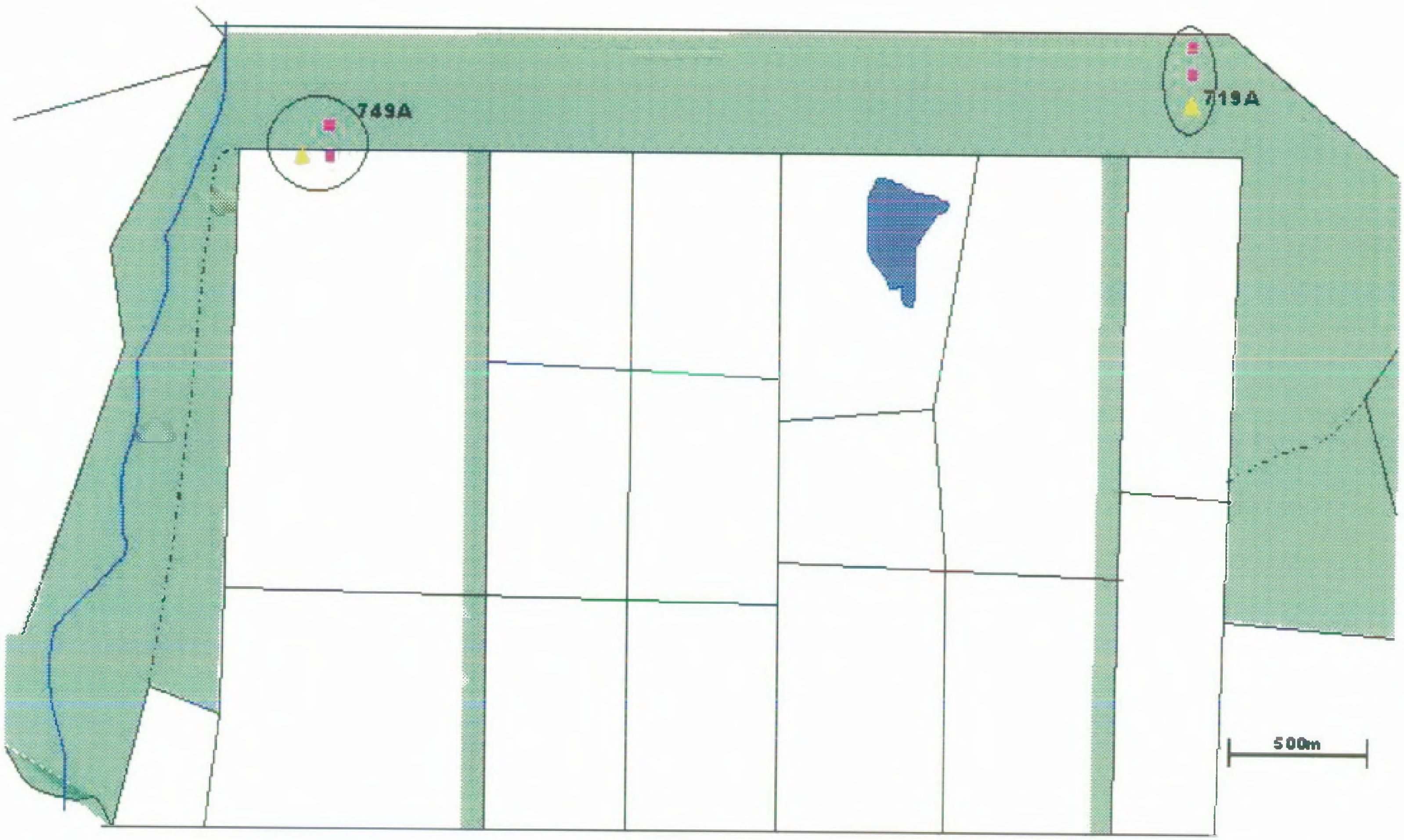
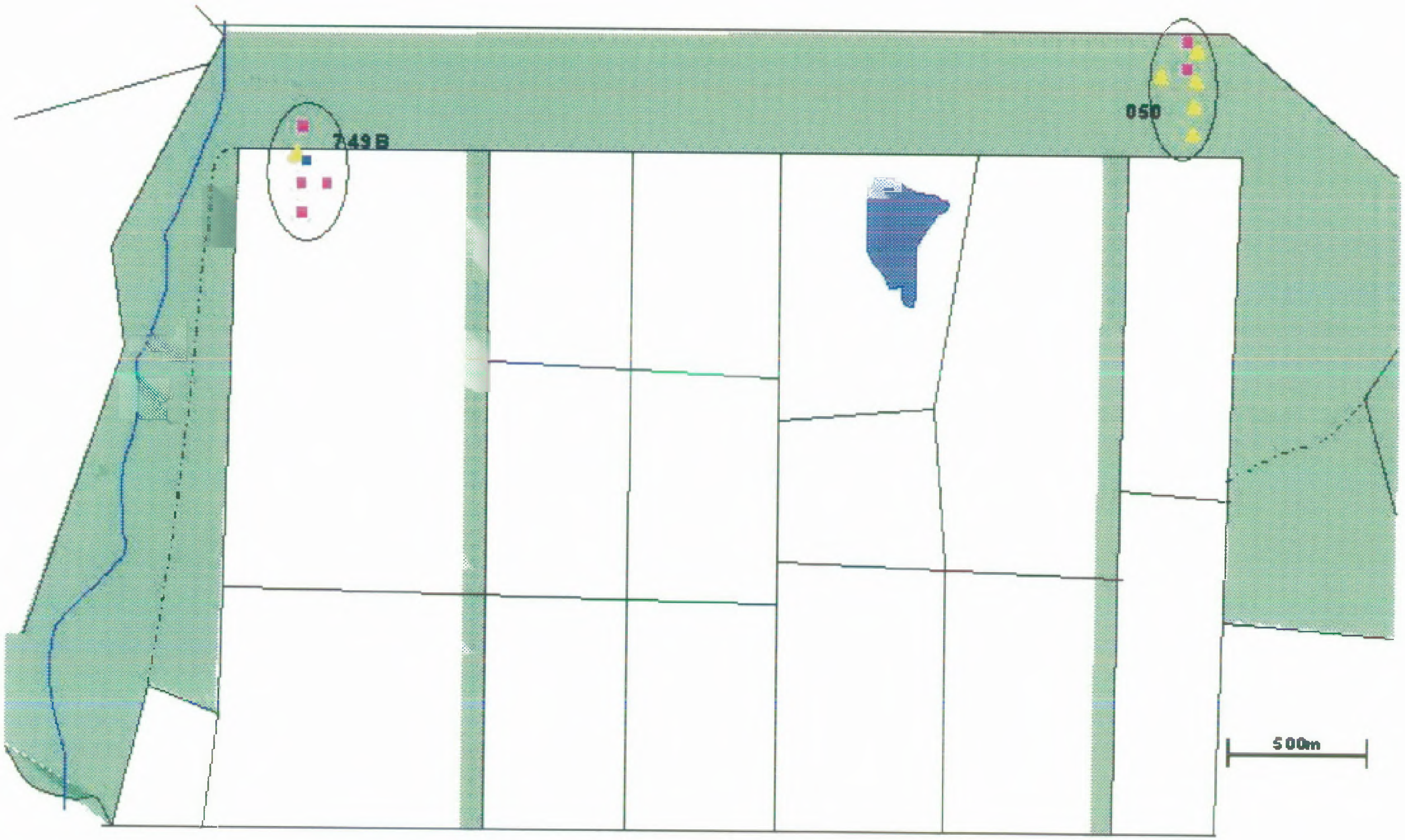


Figure 3.6a-e. Seasonal radio-tracking locations. Clusters of symbols for each individual are circled. Summer locations are represented by yellow triangles, Autumn locations by grey diamonds, Winter locations by blue squares and spring locations by pink squares.

b) Radio-collared male 749A and female 719A.

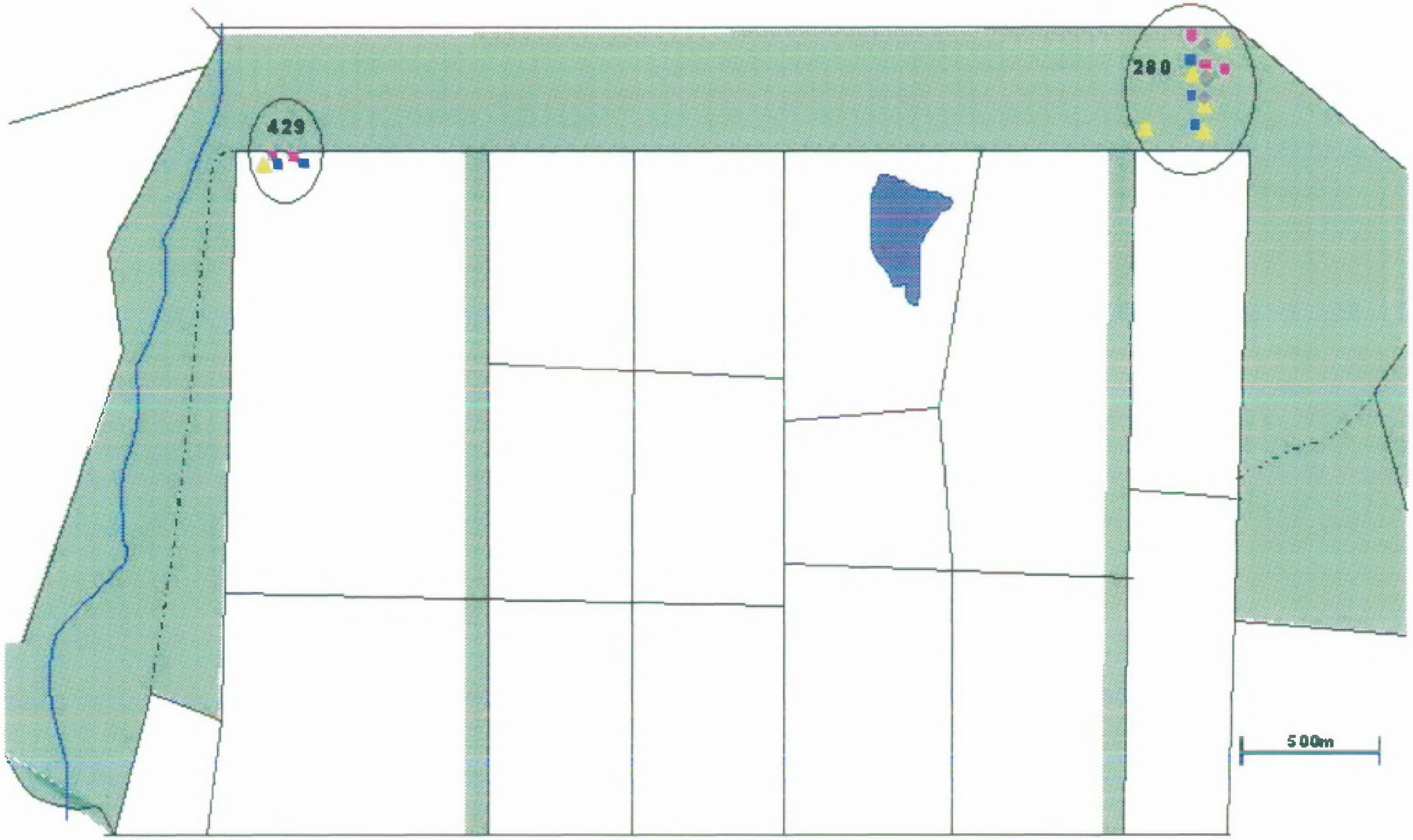


c) Radio-collared males 749B and 050.



d) Radio-collared female 068.

e) Radio-collared male 429 and female 280.



Generally, animal movements were localised. Throughout the year daytime resting positions did not shift more than 4 grid squares (i.e. 400m), except two animals (038 and 719B) showed variations in daytime resting positions up to 600m and 1200m respectively. Wallabies were habitual in their use of adjacent pasture, generally returning to the same area to feed each night, and from season to season. In all cases, but one, the animals ventured out directly from their daytime resting shelter to feed. It may take major disturbance, such as blade-ploughing the paddock on the neighbour's property at north-eastern end of Reference Site, to induce a change in habitual area use (refer Area 2, Animals 068 and 280). However, even when this did occur, movement to another feeding area was not very far, only to the southern side of Reference Site strip. Only female 809 exhibited some changes in her routine. On some occasions she was located on the western side of Roundstone Creek, presumably feeding on the crop in that area, and on other occasions in the pasture paddock on the eastern side of Roundstone Creek, directly adjacent to her daily resting area.

Female 719B, which sheltered in the fenced Brigalow area (Sampling Area 1), exhibited movement behaviour that was very different to the rest, although habitual in itself. Over the period of time that Animal 719B was radio-tracked, on most evenings and nights she travelled in excess of 1.5km along the wallaby fence, presumably to feed in the open pasture at its end. Before sunrise, on every morning she was radio-tracked, she then travelled the 1.5km back to her daily resting location in the centre of the remnant vegetation located at the eastern end of the Reference Site. This movement pattern occurred in every season and on nearly every night the female was radio-tracked. On nights when she was not located at the very end of the wallaby fence, she was found at least half way along it.

3.3.3 Utilisation of Remnant Vegetation

In addition to spotlight and stationary observation counts, undertaken to determine the density differences of Black-striped Wallabies between the different Sampling Areas, faecal pellet counts were undertaken along 19 and 10 evenly spaced transects over the Reference Site to further investigate the apparent heterogeneity in the distribution of wallaby densities.

Each transect was assigned to a Sampling Area. There were significant differences in faecal pellet densities between Sampling Areas and between Survey Periods and there were also significant interactions of those two factors; however, the trends found in each factor differed between the densities of Recent and Old faecal pellets.

Table 3.11 gives the mean densities of Recent and Old pellets in each Sampling Area. There were significantly higher densities of Recent pellets in Sampling Area 4 than Sampling Areas 1 and 2; and while Sampling Area 3 had the second highest density of Recent faecal pellets, this density level was only significantly different to Sampling Area 1. In comparison, the density of Old faecal pellets was reversed, with a greater density of faecal pellets recorded in Sampling Area 2 and Sampling Area 4 significantly contained the lowest density of Old faecal pellets.

Table 3.11 Recent and Old faecal pellet densities (m^{-2}) for each Sampling Area, averaged across all Survey Periods.

Sampling Area	Mean Recent Pellets	Mean SEM	Mean Old Pellets	Mean SEM
1	1.2^{c}	0.1	11.1^{bc}	0.6
2	2.0^{bc}	0.2	20.5^{a}	1.3
3	2.3^{ab}	0.2	13.8^{b}	0.9
4	2.9^{a}	0.4	8.4^{c}	1.0

Estimated means and mean standard errors of means (SEM) from REML, n= 2416. Means with like superscript letters, within columns, are not significantly different, $p<0.05$.

The differences in Recent faecal pellet densities in each Sampling Area between Survey Periods are shown in Table 3.12. Recent faecal pellet densities were significantly higher in Sampling Area 4 (Softwood Scrub) during the first two Surveys; however, there was no difference in Recent faecal pellet densities between Sampling Areas during the second two Survey Periods. The survey mean suggests that there were significant differences in faecal pellets densities at different times. These differences may be related to a seasonal effect; however, there were significant differences in faecal pellet densities between the September Survey Periods. The ranking of Survey Periods was similar for all four Sampling Areas: September 2001 was highest, then September 2002, then March 2002 and September 2000 were similarly low. This consistency across sites suggested either a real year-to-year variation in Black-striped Wallaby densities across the whole Research Station, or a year-to-year variation in survival of Recent faecal pellets.

Table 3.12 The mean densities of Recent faecal pellets (m^{-2}) in each Sampling Area during the different Survey Periods.

Survey Period	Sampling Area 1	Sampling Area 2	Sampling Area 3	Sampling Area 4	Survey Mean
September 2000	0.2^{b}	0.2^{b}	0.7^{ab}	1.9^{a}	$0.7^{\#}$
September 2001	1.9^{c}	3.9^{b}	5.9^{a}	6.6^{a}	$4.6^{\S}$
March 2002	0.8^{a}	1.4^{a}	0.6^{a}	0.9^{a}	$0.9^{\Phi\#}$
September 2002	2.1^{a}	2.3^{a}	1.9^{a}	2.4^{a}	2.2^{Φ}

Estimated means and mean standard errors of means (SEM) from REML, n=2416, mean SEM=0.5. Excluding the last column, means with like superscript letters within rows are not significantly different, $p<0.001$. Means in the last column with like superscript symbols are not significantly different, $p<0.001$.

In contrast, in three of the four Survey Periods, Old faecal pellets densities were significantly higher in Sampling Area 2 (unfenced Brigalow) (Table 3.13). Generally, the density of Old faecal pellets was not significantly different between the remaining Sampling Areas (1, 3 and 4), although Sampling Area 4 recorded the lowest densities in each Survey Period excepting September 2000 when Sampling Area 1 recorded the lowest Old faecal pellet density.

The Survey Period means of Old faecal pellet densities followed a similar pattern as the Recent faecal pellets, with lower densities in the second two survey periods; however, the September 2000 recorded the highest density of Old faecal pellets, although this was not significantly higher than the density recorded in September 2001. There were significantly more Recent faecal pellets recorded in September 2001 than September 2000.

Table 3.13 The mean densities of Old faecal pellets (m^{-2}) in each Sampling Area during the different Survey Periods.

Survey Period	Area 1	Area 2	Area 3	Area 4	Survey Mean
September 2000	13.8^{b}	18.5^{a}	19.2^{a}	19.2^{a}	$17.8^{\S}$
September 2001	12.6^{b}	22.5^{a}	17.1^{b}	7.5^{c}	$14.9^{\S\Phi}$
March 2002	8.0^{b}	21.3^{a}	6.4^{bc}	0.5^{c}	$9.1^{\#}$
September 2002	10.1^{b}	19.3^{a}	12.4^{b}	6.3^{b}	$12.0^{\#\Phi}$

Estimated means and mean standard errors of means (SEM) from REML, n=2416, mean SEM=2.2. Excluding the last column, means with like superscript letters within rows are not significantly different, $p<0.001$. Means within the last column with like superscript symbols are not significantly different, $p<0.001$.

The density of faecal pellets at various depths into the shelter scrub was analysed to determine if Black-striped Wallabies prefer to rest at a particular depth into the scrub. There was no significant interaction of Distance-from-edge with Sampling Area or Survey Period, for either Recent or Old faecal pellet densities. Therefore, mean densities of each faecal pellet type are displayed by Distance-from-edge only (Figure 3.7).

a) Recent faecal pellet densities ***b) Old faecal pellet densities***

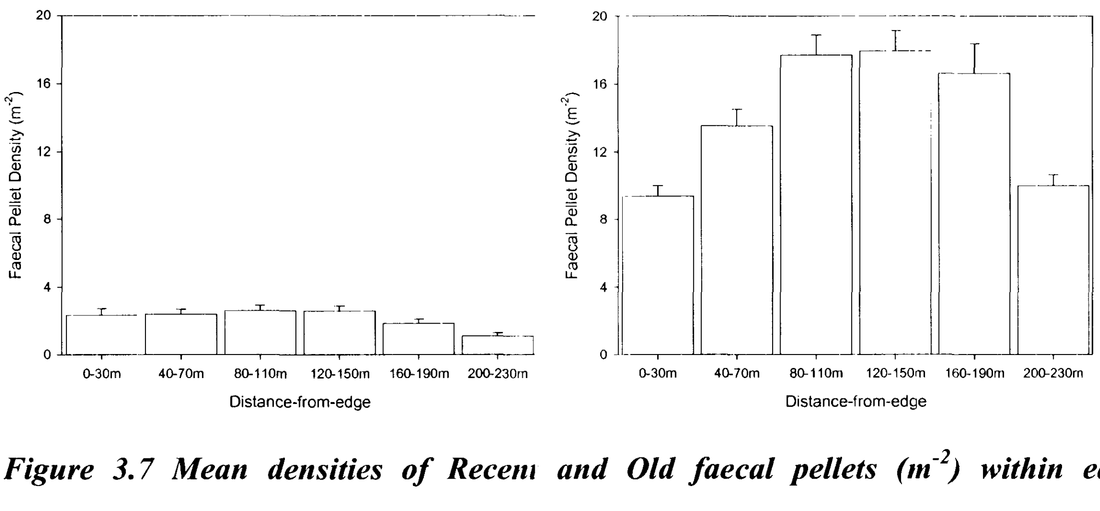


Figure 3.7 Mean densities of Recent and Old faecal pellets (m^{-2}) within each Distance-from-edge category, averaged across all Sampling Areas and all Survey periods (REML, n=2416, mean SEM Recent=0.34, mean SEM Old=1.35).

No significant differences were found between Distance-from-edge categories within the Recent faecal pellets densities. However, there were significant differences between Distance-from-edge categories within the number of Old faecal pellets ($p<0.001$), with significantly higher densities of Old faecal pellets 80-110m and 120-150m from the remnant vegetation/pasture interface, or Reference Site edge.

3.3.4 Shelter Preferences based on Habitat Structure

This section presents the results of faecal pellet counts recorded in conjunction with habitat variables along three transects within Sampling Areas 1, 2 and 4.

Few problems were encountered with field methodology, except not all plant species could be identified. Problems arose statistically however, as the transects were unbalanced in length and the data contained a large number of zeros. Consequently direct correlations could not be undertaken and the method chosen for linking faecal pellet densities to variables was to categorise the faecal pellet densities and use these categories as fixed factors in REML.

A further issue arose from the Reference Site faecal transects (Section 3.3.3), as the distributions of Recent and Old faecal pellet densities were not the same. Moreover, Old faecal pellets did not correctly reflect the proportions of wallaby densities, as determined by spotlight and stationary observation counts. Therefore, it was decided that the variable 'faecal pellet counts' should be analysed prior to comparison with the habitat variables to establish whether the faecal pellet data collected for this section followed similar trends to that of the Reference Site transect data. If differing trends did exist between Recent and Old density to Sampling Area patterns then the habitat variables would need to be compared to the Recent and Old pellets density data separately.

Overall, the densities of Old and Recent faecal pellets collected in conjunction with habitat variables showed similar trends in differences between Sampling Areas and Distance-from-edge categories to those found in Section 3.3.3. Differences between Seasons and Environment Type (pasture and remnant vegetation) were not tested in Section 3.3.3 though.

In this section a higher density of Old and Recent faecal pellets were found in the dryer season (Table 3.14). Higher pellet density during the dry season was also found in the exclosure analyses (Section 4.3.1).

Table 3.14 Recent and Old faecal pellets densities (m^{-2}) each Season.

	Recent Faecal Pellets				Old Faecal Pellets			
Environment Type (n)	Dry	Wet	Mear SEM	Sign.	Dry	Wet	Mean SEM	Sign.
1 (142)	1.0	0.2	0.1	***	5.0	3.7	0.3	***
3 (96)	4.2	0.7	0.4	***	24.1	13.3	1.2	***
6 (87)	6. 6	2.4	0.9	***	6.5	2.3	0.7	***
2 (39)	1.0	0.1	0.3	*	1.8	2.7	0.4	
4 (54)	1.4	0.8	0.2	*	10.7	8.4	0.9	
5 (48)	3.2	1.0	0.4	***	8.3	5.7	0.8	*

Estimated means and mean standard errors o`means (SEM) from REML. Asterisks denote level of significance, * p<0.05, ** p<0.01, *** p<0.001.

Trends of Old and Recent faecal pellets densities in the Distance-from-edge categories of the remnant vegetation (scrub) Environment Types mirrored those seen in the Section 3.3.3. There was no significant difference in the density of Recent faecal pellets (Table

3.15), but a significant increase in Old faecal pellet density approximately 100-200m from the edge (Table 3.16).

Differences in Recent faecal pellet densities between the Distance-from-edge categories of the pasture Environment Types were generally negligible, with only Environment Type 4 (regrowth Brigalow with native grasses) showing significantly higher Recent faecal pellet densities closer to the remnant vegetation than further out into the paddock (Table 3.15). The density of Old faecal pellets was also significantly higher 50-100m from the remnant vegetation in Environment Type 5 (Table 3.16).

Table 3.15 The effect of Distance-from-edge on Recent faecal pellet densities (m^{-2}).

	Distance-from-edge Categories #								
Environment Type (*n*)	1	2	3	4	5	6	7	Mean SEM	Sign.
1 (142)	0.5	0.9	0.6	0.7	0.8	0.8	0.1	0.1	
3 (96)	2.0	2.7	2.5	2.7				0.6	
6 (87)	3.1	5.8	7.5	3.9	4.4	2.3	4.2	1.7	
2 (39)	0.2	1.0	0.5	0.4				0.4	
4 (54)	1.9^{ab}	1.3^{ab}	1.4^{a}	0.7^{ab}	0.0^{b}			0.4	**
5 (48)	2.6	2.7	1.8	1.1				0.6	

Estimated means and mean standard errors of means (SEM) from REML. Means with like superscript letters, within rows, are not significantly different. Asterisks denote level of significance, ** $p<0.01$.

#Distance-from-edge categories; category 1=0-48m, category 2=52-100m, category 3=104-148m, category 4=152-200m, category 5=204-248, category 6=252-300m, category 7= >304m.

Table 3.16 The effect of Distance-from-edge on Old faecal pellet densities (m^{-2}).

Environment Type (n)	Distance-from-edge Categories # 1	2	3	4	5	6	7	Mean SEM	Sign.
1 (142)	4.7	5.0	4.8	4.4	4.3	4.8	2.5	0.6	
3 (96)	8.9^{b}	14.3^{ab}	17.8^{ab}	24.9^{a}				1.7	***
6 (87)	2.6	2.5	5.9	4.3	4.3	6.8	4.6	1.4	
2 (39)	1.7	2.0	2.31	3.0				0.5	
4 (54)	7.4	11.1	10.0	11.0	8.3			1.5	
5 (48)	8.6^{a}	8.9^{ab}	5.4^{b}	5.0^{ab}				1.0	*

Estimated means and mean standard errors of means (SEM) from REML. Means with like superscript letters, within rows, were not significantly different. Asterisks denote level of significance, * $p<0.05$, *** $p<0.001$.

#Distance-from-edge categories; category 1=0-48m, category 2=52-100m, category 3=104-148m, category 4=152-200m, category 5=204-248, category 6=252-300m, category 7= >304m.

Environment Type 5 Old faecal pellets and Environment Type 6 Recent faecal pellets also had significant interaction between Season and Distance-from-edge; however, the interaction was not of relevance to the habitat analyses.

The preliminary analysis of Old and Recent faecal pellet densities established that habitat variable analysis should be done against Old and Recent faecal pellet densities separately, because of trend differences between Sampling Areas (Environment Types) and Seasons. The obvious differences in habitat structure between seasons and environments also meant that Season and Environment Type had to be considered during the analysis (hence their inclusion as random factors). The small amount of significant difference between Distance-from-edge categories was disregarded.

Therefore, analyses of habitat structure variables were undertaken against Recent and Old faecal pellet densities (categorised) with Season and Environment Type as random factors. Table 3.17 shows the difference in the mean value of each habitat variable for each category of Old and Recent faecal pellet density.

In most cases there was no difference in averaged habitat variables with the Recent faecal pellet density categories, except the Maximum and Minimum heights of vegetation, the percent cover by Other major pasture species and the level of Visibility at the 0.3-0.6m height, 25m away. Generally, higher Maximum vegetation height meant lower Recent faecal pellet density and the higher Minimum height coincided with a median density of Recent faecal pellet density. The percent cover by Major pasture species varied with Recent faecal pellet density; highest cover of Major pasture species occurred with no or very low density and very high density of Recent faecal pellets. The significant visibility variable was lower when Recent faecal pellet density was highest.

In comparison, the averaged habitat variables, percent of ground covered by the Cyperus vegetation category, Other major pasture species, Native grass species, Medium-size fleshy forb species and Other forb species and the percentage of Bare ground, differed significantly with Old faecal pellet density. Cover by Other forb and Native grass species was higher when Old faecal pellet density was higher. In contrast, the percent cover by Cyperus vegetation, Other major pasture species and Medium-sized fleshy forbs was high when the density of Old faecal pellets was low.

Table 3.17 Relationship of habitat variables to Recent and Old Black-striped Wallaby faecal pellet densities.

	Recent Faecal Pellet Categories#							Old Faecal Pellet Categories#						
Variate	0	1	2	3	4	Mean SEM	Sign	0	1	2	3	4	Mean SEM	Sign
Bare ground (%)	42.3	33.6	33.9	38.5	52.5	23.4		69.5^{a}	36.9^{b}	35.3^{b}	29.0^{b}	27.4^{b}	19.1	***
Litter cover (%)	45.6	42.6	41.0	35.2	20.9	21.0		42.3	44.2	43.1	41.0	42.6	18.8	
Vegetation cover (%)	50.4	50.1	48.7	48.1	49.3	34.0		48.5	50.6	49.8	49.7	49.3	33.8	
Grass cover (%)	33.7	37.5	38.1	36.5	36.5	26.0		35.4	37.5	35.0	36.0	35.9	25.5	
Sedge cover (%)	0.6	0.3	0.2	0.1	0.2	0.4		0.4^{ab}	0.6^{a}	0.3^{ab}	0.1^{b}	0.2^{b}	0.3	**
Forb cover (%)	2.8	3.1	2.5	2.7	2.2	2.1		5.4	3.5	2.0	2.4	2.9	1.8	
Mean veg. height (mm)	124.6	121.6	106.9	111.0	108.8	65.2		134.7	124.4	118.2	115.0	122.1	64.7	
Maximum veg. height (mm)	174.3^{a}	147.9^{ab}	110.6^{b}	108.2^{b}	129.7^{ab}	80.4	**	196.0	152.9	149.2	139.0	168.5	84.5	
Minimum veg. height (mm)	78.7^{b}	104.9^{a}	110.6^{a}	116.0^{a}	85.5^{b}	56.9	**	93.3	99.4	93.8	98.1	90.7	54.1	
Biomass rank	2.4	2.3	2.2	2.2	2.2	1.4		2.3	2.3	2.3	2.3	2.3	1.4	
No. of veg. species	2.1	2.0	1. 9	1.9	1.8	0.5		1.9	1.9	1.9	2.1	2.2	0.5	
Cenchrus ciliaris (%)	23.1	24.2	24.3	25.9	23.9	19.3		21.8	23.3	23.7	25.3	23.8	19.1	
Other major pasture spp. (%)	5.7^{a}	4.2^{ab}	1.5^{d}	2.0^{cd}	3.5^{bc}	3.4	*	4.9^{b}	6.3^{a}	4.8^{b}	1.3^{c}	2.4^{bc}	3.2	***
Native grass spp. (%)	12.8	13.7	14.6	11.5	13.8	7.2		9.9^{b}	11.7^{b}	13.5^{ab}	15.8^{a}	15.7^{a}	6.6	*
Unknown grass spp. (%)	0.4	0.6	0.4	0.6	0.3	0.6		0.2	0.4	0.55	0.6	0.7	0.5	
Cyperus spp. (%)	1.2	1.0	1.1	0.6	0.9	0.9		0.9	1.2	0.87	1.1	0.9	0.9	
Clovers, mosses and ferns (%)	0.3	0.2	0.1	0.1	0.1	0.2		0.0	0.2	0.2	0.3	0.1	0.2	

Estimated means and mean standard errors of means (SEM) from REML, n=466 for all variates except Visibility n=237. Asterisks denote level of significance *** p<0.001, ** p<0.01 and * p<0.05, and blank, not significant. Environmental Type and Season were included as random factors.

Faecal Pellet categories; category 0=0m^{-2}, category 1=1-4m^{-2}, category 2=4-8m^{-2}, category 3=8-12m^{-2}, category 4= >12m^{-2}.

Table 3.17 *cont.* Relationship of habitat variables to Recent and Old Black-striped Wallaby faecal pellet densities.

	Recent Faecal Pellet Categories#							Old Faecal Pellet Categories#						
Variate	0	1	2	3	4	Mean SEM	Sign.	0	1	2	3	4	Mean SEM	Sign.
Forb (medium size fleshy spp.) (%)	2.9	2.7	2.3	2.8	2.6	2.2		5.6^{a}	3.9^{ab}	1.5^{c}	2.0^{bc}	1.8^{bc}	2.0	***
Forb (shrub size spp.) (%)	0.7	0.5	0.2	0.2	0.2	0.5		1.6	0.4	0.6	0.5	0.4	0.4	
Forb (other) (%)	0.8	0.8	0.7	0.5	0.6	0.6		0.2^{c}	0.8^{ab}	0.5^{bc}	0.9^{ab}	1.1^{a}	0.5	*
Capparis lasiantha (%)	0.04	0.04	0.03	0.04	0.04	0.04		0.02	0.04	0.04	0.03	0.06	0.03	
Vine spp. (%)	0.02	0.02	0.02	0.02	0.02	0.02		0.02	0.02	0.02	0.01	0.01	0.01	
Tree spp. (%)	0.01	0.02	0.01	0.00	0.00	0.04		0.2	0.4	0.3	0.4	0.3	0.1	
Carissa ovata (%)	1.6	1.7	1.2	1.3	0.0	1.8		3.8	1.1	1.5	2.0	1.5	1.5	
Unknown tree spp. (%)	0.3	0.4	0.3	0.2	0.0	0.2		0.01	0.01	0.01	0.05	0.00	0.03	
No. of shrubs or trees	0.6	0.4	0.2	0.3	0.0	0.5		0.3	0.3	0.5	0.5	0.5	0.3	
Canopy shade (%)	23.0	22.5	17.9	25.4	24.1	15.6		23.0	24.1	22.3	20.2	20.1	14.7	
Visibility (12.5m bot)	2.5	2.8	3.6	2.9	0.7	1.0		2.2	2.8	2.6	2.9	2.3	0.8	
Visibility (12.5m mid)	3.9	4.2	4.4	3.9	1.7	1.0		4.7	4.3	4.0	4.0	3.5	0.8	
Visibility (12.5m top)	5.1	5.4	5.6	5.2	2.9	0.9		6.2	5.5	5.3	5.0	4.9	0.6	
Visibility (25m bot)	0.9	1.2	1.7	0.8	0.1	0.6		1.3	1.2	1.1	1.1	1.0	0.4	
Visibility (25m mid)	1.8^{a}	2.2^{a}	3.1^{a}	1.4^{a}	1.1^{b}	0.8	*	3.3	2.2	2.0	1.9	1.8	0.7	
Visibility (25m top)	3.0	3.3	4.0	2.5	1.5	0.9		4.5	3.4	3.1	2.9	2.8	0.7	

Estimated means and mean standard errors of means (SEM) from REML, n=466 for all variates except Visibility n=237. Asterisks denote level of significance *** $p<0.001$, ** $p<0.01$ and * $p<0.05$, and blank, not significant. Environmental Type and Season were included as random factors.

Faecal Pellet categories; category 0=0m^{-2}, category 1=1-4m^{-2}, category 2=4-8m^{-2}, category 3=8-12m^{-2}, category 4= >12m^{-2}.

3.4 Discussion

Densities of Black-striped Wallabies between 10. and 105 km^{-2} were reported as high by Lundie-Jenkins *et al.* (1998). The density of Black-striped Wallabies inhabiting the patch of remnant forest on Brigalow Research Station during this study was determined to be at least 4 times that recorded by Lundie-Jenkins *et al.* (1998). Lundie-Jenkins *et al.* (1998) noted, that Black-striped Wallaby density was highly correlated with rainfall, probably because of the associated increase in pasture biomass that occurs in times of good rainfall. Brigalow Research Station is rarely stocked at full livestock capacity (A. Barnes pers. comm.) and consequently there is generally a high biomass of introduced and native pasture grass readily available all year round. It is possible that a high abundance of Black-striped Wallabies, centred around the remnant Reference Site on Brigalow Research Station, is due to the year round supply of food; although this study did not establish the amounts of each plant species consumed by the species or the amount of food required by the population to enable its survival.

This high abundance of wallabies is not indicative of the density of wallabies for the entire Research Station. Survey count sampling effort (the number of surveys and length of surveys) was low, as it relied upon the availability (and goodwill) of Research Station farmhands to act as drivers. The spotlight survey route focussed on the areas where Black-striped Wallabies were most abundant, i.e. the remnant vegetation/pasture interface. General observations on the rest of the Station (open paddocks not adjacent to the remnant forest) suggest that densities of wallabies were low in those areas.

Drive spotlighting and stationary observation counts did confirm anecdotal reports of differences in densities over the Reference Site though. The higher density of wallabies at the Softwood Scrub end of the Reference Site justified the further investigation into habitat preferences and is discussed below.

The high number of wallabies made spotlight counting difficult and further attempts to monitor the density of the population would require some consideration of the methods, such as increasing the number of counters. Densities from drive spotlight counts and stationary observation counts concurred, suggesting that perhaps even the use of motion-detector infrared counters to count wallabies as they crossed from shelter habitat to foraging areas would be feasible.

The occurrence of movement times centred around dusk and dawn has also been noted previously with the Bridled Nailtail Wallaby (*Onychogalea fraenata*) and Black-striped Wallaby (Evans 1992), the Brush-tailed Rock-wallaby (*Petrogale penicillata*) (Ralston 1983), the Allied Rock-wallaby (*P. assimilis*) (Horsup 1996), the Red-legged Pademelon (*Thylogale stigmatica*) (Vernes *et al.* 1995) and the Parma Wallaby (*M. parma*), a close relative to the Black-striped Wallaby (Ord *et al.* 1999). The effect of light has been shown to influence the feeding behaviour of other animals (e.g. Hairy-footed Gerbils (*Gerbillurus tytonis*) (Hughes and Ward 1993)) as feeding during nocturnal hours is most likely a strategy that evolved in many herbivores to reduce the risk of predation.

Ord *et al.* (1999) reported that male Parma Wallabies spent almost twice as much time feeding as females. This may simply reflect the fact that males require more feed due to greater energetic requirements, or perhaps being larger and without parenting responsibility males feel less threatened by predation and can therefore emerge and begin feeding while it is still light. Regardless of the reason, a similar occurrence was noted in this study, with larger-sized Black-striped Wallabies emerging earlier than smaller juvenile animals; hence dusk emergence of Black-striped Wallabies from shelter habitat was spread over a period of time. However while emergence time, being closely linked to when darkness fell, differed seasonally, the period of time it took for all the wallabies to emerge each evening did not.

The outcomes of the radio-tracking component of the study were consistent with those of Evans (1996) who found Black-striped Wallabies' home ranges centred on the ecotones between their shelter habitat and foraging areas. That study also reported home ranges of 91 ± 11ha. Although this study did not undertake radio-tracking in similar detail, results suggest that dispersion is minimal and the home ranges of most Black-striped Wallabies on Brigalow Research Station are much smaller than those found by Evans (1996). It may be that individuals do not need to travel so far with an abundance of feed available directly adjacent the shelter habitat. Alternatively, based on the study by Blumstein *et al.* (2002) which showed Tammar wallabies were more aggressive toward non-kin individuals, it may be that the large number of Black-striped Wallabies on Brigalow Research Station force individuals to remain in the area where they were born. This study though did not establish if wallabies inhabiting the same areas were members of family groups.

Evans (1996) reports that male and female Black-striped Wallabies have close to equal home ranges and similarly this study does not suggest any great difference in the distance travelled by males and females, except by the two female wallabies, 809 and 719B. The change in 809's feeding location is most likely attributable to the seasonal change in the crop being grown within her range (wheat during cooler months and sorghum during summer months). Johnson (1987) noted a similar increase in home ranges of Red-necked Wallabies (*M. rufogriseus*) when an area outside their usual home range was cultivated. The awareness of macropods of variability in resources on foraging patches, and their ability to assess the costs and benefits of moving among the patches to exploit the resources has also been shown with Eastern grey kangaroos (*M. giganteus*) (Ramp and Coulson 2002).

The movement patterns of 719B were most likely attributable to the supply of food also. This individual may have been born in the area where she sheltered and was therefore resting with known individuals. However, since that area is now fenced off to wallabies, access to abundant adjacent feed has been removed. It is likely there is not enough feed within the shelter habitat for all the wallabies present, forcing 719B to travel over 1km most evenings to feed (spotlight count data suggested very few wallabies inhabited Sampling Area 1; however, faecal pellet counts suggest a higher density). While it is generally accepted that Black-striped Wallabies move out only a couple of hundred metres from their shelter habitat to graze, Lundie-Jenkins (1999) notes that Black-striped Wallabies have been known to move greater distances during times of drought, i.e. when food is scarce. Feeding locations of 719B were further from her resting location during winter and autumn than in summer and spring.

Establishing that densities of Black-striped Wallabies differed between Sampling Areas, but that the home ranges of individuals were sedentary, warranted the investigation into reasons behind the heterogeneity in distribution.

Further to the heterogeneity in wallaby density between Sampling Areas, faecal pellet densities suggest that wallabies actively selected where they shelter in the daytime. Black-striped Wallabies are regarded as fringe-dwellers; however it was unknown before this study what depth of vegetation they utilise as 'edge' habitat. The preference shown here was to rest anywhere between 80 and 190m from the edge of the Reference Site; that is, they avoided camping too near the open edge of the shelter habitat, yet did not penetrate as deep into it as they might.

Reasons for the heterogenous distribution of Black-striped Wallabies in different areas of the Reference Site (shown by both counts of animals by spotlighting and stationary observation counts, and faecal pellets counts) were unknown. It is generally accepted that distributions of animal populations depend on accessibility of food and water and the availability of preferred sheltering habitat. Brigalow Research Station has an abundance of water throughout the property, both natural during the wetter seasons (gilgais and creeks) and man-made (troughs and dams), thus accessibility to water was thought unlikely to be a major determinant of wallaby distribution. Although biomass of the various grass species within the Reference Site was not determined during this study, the paddocks adjacent to the shelter habitat generally have a good body of grass all year round, suggesting that access to feed is not the primary reason either, although access to a preferred vegetation species within the various vegetation association may be. Moreover, it was suspected that the various types of vegetation associations throughout the Reference Site provide different structural attributes (such as vegetation density, canopy cover, etc.) used by Black-striped Wallabies for sheltering habitat, and the wallabies' preference for certain sheltering structural attributes could therefore be a primary reason for heterogeneity in Black-striped Wallaby distribution. This theory was to be tested by correlating Black-striped Wallaby densities, as determined by faecal pellet counts, with measurements of the vegetation's attributes or habitat variables.

Johnson *et al.* (1987) and Johnson and Jarman (1987) found the use of faecal pellet counts a valid way to measure densities of macropod populations. However, problems with the methodology, including misidentification of species and mis-counting, were encountered by Pahl *et al.* (1999), Bulinski and McArthur (2000) and Barnes (2001). Southwell (1989) discusses the problem of differences in rates of defecation. However, Hill (1978) and Johnson *et al.* (1987) report that macropods rarely defecated whilst inactive or resting during the day and Connelly *et al.* (1999) also noted a positive relationship between grazing and resting times and defecation rates with sheep and macropods. This being the case, the density of faecal pellets recorded within the wallabies' resting shelter habitat during this study suggests that Black-striped Wallabies on Brigalow Research Station spend a considerable amount of time active (possibly feeding) within the remnant habitat; a speculation supported by results in Chapters 4 and 5.

A further problem explained by Southwell (1989) is differing decay rates. While the density of Recent faecal pellets supported the animal counts in each Sampling Area, there was some discrepancy between the ratio of Old faecal pellet density to animal counts in the Fenced Brigalow Forest and Softwood Scrub Sampling Areas. This suggests that there is a higher rate of decay in the Softwood Scrub, as not as many Recent pellets reach Old pellet status.

Decay of faecal pellets occurs from weathering, trampling and removal by dung beetles (Southwell 1989). The anomaly between faecal pellet numbers and wallaby densities between the Sampling Sites may be due to structural differences in the vegetation of the Sampling Sites. Greater grass and shrub cover in Sampling Sites 1 and 2 may offer more protection to faecal pellets from weathering by sun and rain for example. A high density of wallabies in the Softwood Scrub might induce high losses of faecal pellet through trampling. Dung beetles are habitat specific (Doube and MacQueen 1991) and different species prefer different soil types (Vessby and Wiktelius 2003). The presence of a dung beetle species that prefers loamy soil to cracking clay could explain the higher faecal pellet decay rate in the Softwood Scrub area.

The problems with faecal pellet counts described above may explain the lack of association between faecal pellet density and the habitat variables monitored. It was hypothesised that the various habitat variables influenced the wallabies' decision in habitat choice by offering advantages or disadvantages. For example, denser vegetation (visibility data) may offer better protection from predators, or a certain plant species may offer better nutrition. However, very few of the habitat variables were found to differ significantly with the density of faecal pellets.

The analysis was performed with Recent and Old pellets separately because of the Sampling Area differences in faecal pellet persistence discussed above. The density of Old pellets showed more significant difference in habitat variables; however, the density of Old faecal pellets does not portray the densities of wallabies correctly, so it is hard to say if these variables are the cause of Black-striped Wallaby habitat preference or not.

It may be that the most significant structural components of habitat, which actually influence Black-striped Wallaby choice of shelter vegetation, were not chosen for monitoring. However, some habitat variables did differ significantly with Recent faecal pellet density including the maximum and minimum height of vegetation and the level of visibility at median height 25m away. Why those variables differed significantly, but not the visibility variables, biomass rank or percentage vegetation cover is unclear.

The lack of direct relationships between faecal pellet density and habitat variables in this study does not exclude the wallabies' distribution being influenced by specific individual structural habitat variables. Difficulties in analysing these types of data, the presence of complex interactions between variables' effects or the influence of unknown factors (e.g. the presence of dung beetles causing different faecal pellet decay rates) possibly may explain the lack of significant relationships.

Habitat preference has been demonstrated for several mammal species (Hockings 1981, Lunney and O'Connell 1988, Southwell and Fletcher 1988, Fisher 2000, Bos *et al.* 2002, Ramp and Coulson 2002), however only some of these studies specify one or two selective habitat variables that influence habitat choice. Specific individual structural habitat variables may not play a very significant role in habitat choice by Black-striped Wallabies on Brigalow Research Station. Provision of appropriate food and shelter resources from habitat associations as a whole seems to be more important. Nevertheless, a habitat must ultimately be describable by individual characteristics.

Black-striped Wallabies are reportedly found in a number of shelter habitats including dry vine thickets, rainforest margins, Brigalow scrub, lantana thickets and coastal scrubs (Kirkpatrick 1995, Johnson 2003; and anecdotal), suggesting that the species does not necessarily prefer Brigalow forest for shelter, rather it will utilise any vegetation type as long as it has the appropriate structural attributes and contains sufficient food resources. The heterogeneous distribution of Black-striped Wallabies at Brigalow Research Station may be more related to other factors. As explained by Ramp and Coulson (2002), habitat selection is based on factors other that habitat structure, including resource availability and predator risk; neither of these were studied specifically in this study but it is suspected that predation levels do differ between areas of the Reference Site, refer Chapter 6.