CHAPTER SIX

DESCRIBING THE POPULATION

6.1 Introduction

Little is known of Black-striped Wallaby population dynamics, particularly in such high densities as found on Brigalow Research Station. Determining a population's distribution of ages at death allows age-specific mortality and survivorship rates to be calculated (Caughley 1977). This then allows the population's rate of increase to be calculated. As the project progressed it became clear that valuable information regarding the natural and anthropogenic influences on the wallaby's population size and structure could be gained by recording the details of any carcasses, and by collecting, sexing and ageing the large number of skulls found on the Station.

A number of studies have measured the relationship between age and various structural anatomical attributes of macropods e.g. hind leg, tail and head length (Kirkpatrick 1965, Wood *et al.* 1981, Hendrikz and Johnson 1999). However, these measurements have limitations as age indicators, primarily because their usefulness declines with age, as rate of growth declines.

Measurement of skull length, width and molar progression has been used by various researchers to age a number of different animal species. Kirkpatrick (1964) showed that molar progression could be used for ageing macropods quite accurately and studies of macropod age using molar progression have been undertaken on the Red Kangaroo (*Macropus rufus*) (Sharman *et al.* 1964); the Agile Wallaby (*M. agilis*) (Kirkpatrick and

Johnson 1969); and the Parma Wallaby (*M. parma*) (Maynes 1972) for example. This technique, when applied to skulls recovered from naturally-occurring carcasses, is especially appealing as there is no impact on the population. However, to be able to use molar progression as an estimate of growth, a known index is required for the species under study. Unfortunately, published indexes are limited to the above species plus the Eastern Grey Kangaroo (*M. giganteus*), the Common Wallaroo (*M. robustus*) and the Red-necked Wallaby (*M. rufogriseus*) (Kirkpatrick 1965) and there is no index available for the Black-striped Wallaby.

Skull collection for determination of age at death was included in the methods of research of this project as it provided a snapshot of the population's structure over the previous 5 to 10 years (dependent upon how long the skulls remain after death). Based on the information that would be gained, inferences would be made regarding the numerical stability of the population at Brigalow Research Station. Skull collection and measurement was undertaken in the hope that a number of population descriptors could be established, such as the age structure (at death) of the population, whether the population was stable or drastically increasing or decreasing, or if fecundity and mortality rates fluctuated with time, weather or agricultural activities.

Where possible, recent carcasses were also inspected in an attempt to establish the cause of mortality (i.e. natural predation, seasonal conditions, natural biology of the species). Such information is useful in fully understanding how the Black-striped Wallaby population interacts with the Research Station's environment, seasonally and yearly, and may be useful for planning of management strategies for the species.

6.2 Methodology

6.2.1 Ageing and Sexing from Skulls

All Black-striped Wallaby skulls that were found on the Station were collected and the location and date of collection was recorded. Where skulls were also collected from carcasses, the sex of the animal was also recorded (see Section 6.2.2).

Collected skulls were soaked in a weak (10%) solution of bleach (Hurricane Bleach Solution, Campbell Consumer Products, Sydney, Australia) for 2 to 12hrs. The skulls were then cleaned of flesh, rinsed in water, air-dried and stored in sealed plastic bags.

Skull width and length were measured. The measured zygomatic width was between the outer edges of the zygomatic arches. The length was measured from the anterior edge of the premaxillary bones to the occiput, the posterior edge of cranium, using described reference points (Kirkpatrick 1964, Triggs 1997). The molar progression distance (molar index) was calculated following the methodology of Kirkpatrick (1964) and then substituted in a molar index ageing equation to give the animal's age in days. At the time of this study a molar index ageing equation for Black-striped Wallabies did not exist but it was considered that the equation developed to age Red-necked Wallaby skulls (Kirkpatrick 1965) would be the best alternative, as that species is the closest in size and structure to Black-striped Wallabies (P. Johnson pers. comm.).

Molar indices were therefore entered into the molar index ageing equation,

$$\log \text{age} = 2.2340 + 0.3716\ \text{MI}$$

where age is the age in days and MI is the molar index as determined from skull measurement.

Ages in days were converted to approximate year intervals; <1yr, 1-2yrs, 2-3yrs and so on, for comparison of the numbers of skulls collected within each age category.

Although a large number of skulls were collected, very few had known sex information. Therefore, to maximise sample size for age-specific mortality calculation it was useful to sex the unsexed skulls. Plots of skull length by width, length by age and width by age were undertaken and results suggested two different groups of skull lengths, i.e. a bimodal grouping of skull lengths against age.

Reference to Jarman (1989) suggested that the difference was sex-linked. To test this assumption skulls from animals of known sex were placed into separate data sets and graphed. Two hyperbolic lines, $y = ax/(b+x)$, where y is length of skull, x is age in months and 'a' and 'b' are constants were then fitted to the known-sex data, using Sigmaplot (Sigmaplot 2002 8.0 for Windows, SPSS Inc., Chicago), to determine the 'a' and 'b' values, one set for males and one set for females.

The hyperbolic equations for the male data and female data expressed as $y(b+x)/ax = 1$ provided two natural indices (equal to 1 in the ideal situation) which could be applied to data of unknown sex. The range of each index was set by allowing 'a' and 'b' to vary by $\pm$ two standard errors, as determined by Sigmaplot regression.

Using the hyperbolic equation, values between the determined index plus 2 standard errors and minus 2 standard errors were calculated using a and b values from the male-based and female-based hyperbolas in the length-versus-age plot. These values covered two areas, and animals whose length-for-age values fell within the higher index area were assumed to males and those in the lower area, females (see Figure 6.5). The length and age values for those skulls of unknown sex but measurable length and age were then applied to the hyperbola equation to determine whether their calculated index value fell within the male or female index areas. Skulls aged under 48 months of age could not be distinguished by skull length:age to sex relationship and were not classified.

The increased sample size of 'sexed' aged skulls allowed the calculation of static (time specific) life-tables and hence mortality rates, following the methodology of Caughley (1977), for both the male and female components of the population.

6.2.2 Carcass Records

Throughout the duration of field work (June 2000-April 2003), details of any wallaby carcasses found on the Station were recorded (date, location, sex, size, cause of death and approximate time since death).

Each record was assigned to a calendar Season (summer, autumn, winter, spring) and locations of carcasses were assigned to a Sampling Area (1-5), as described in Section 2.4.2. Sex was determined as male, female or unknown; and size classes were small (juvenile size), medium (adult female or young male size), large and very large (adult male size). Cause-of-death categories included 'unknown' (cause could not be positively ascertained), 'dingo' (determined if there was any evidence of dingoes such as tracks or scratchings on the ground, bite marks or chewing on the carcasses), 'wallaby fence' (where animals were found caught in or up against the fence) and ‘human interaction’ (hit by a car or getting caught in a fenced-off area). Where a combination of two causes was possible (e.g. dingo and wallaby fence), the principal cause was recorded (i.e. dingo).

Counts of carcasses within each grouping (Season, Sampling Area, Sex, Size) were tabulated in the various Cause of Death categories. In addition, where carcasses provided skulls and molar index, age was estimated as explained in Section 6.2.1.

6.3 Results

6.3.1 Ageing and Sexing Skulls

A total of 812 skulls were collected. Some skulls could not be measured or aged as they were broken into pieces, or missing the back of the molar row, the front of the dentary, the molar row or half the skull. Therefore of the total collected only 690 skulls could be measured width-wise, 500 measured length-wise, 488 measured both ways and 667 aged.

Close relationships between length and age of skulls, and width and age of skulls were apparent (Figures 6.1 and 6.2). Comparison to the macropod skull-length-to-age, and skull-width-to-age relationships reported by Jarman (1989) show that the results from this study are like other macropod species, with the length and width of animals’ skulls increasing proportionately with age, unt l they reach maturity.

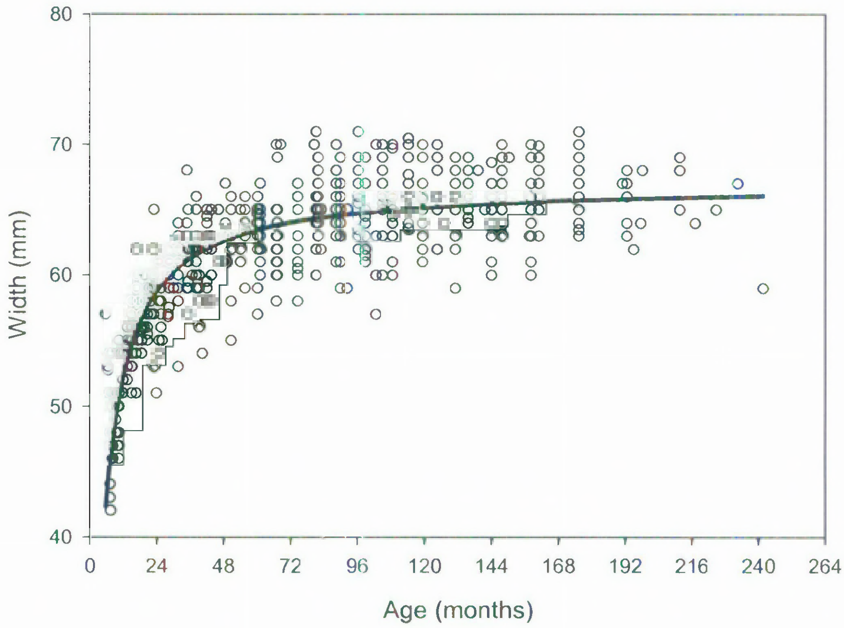

Figure 6.1 Plot of skull width (mm) by estimated age (months), fitted with hyperbola $y=66.98x/(3.332+x)$, $r^2 = 0.7249$, $p<0.0001$.

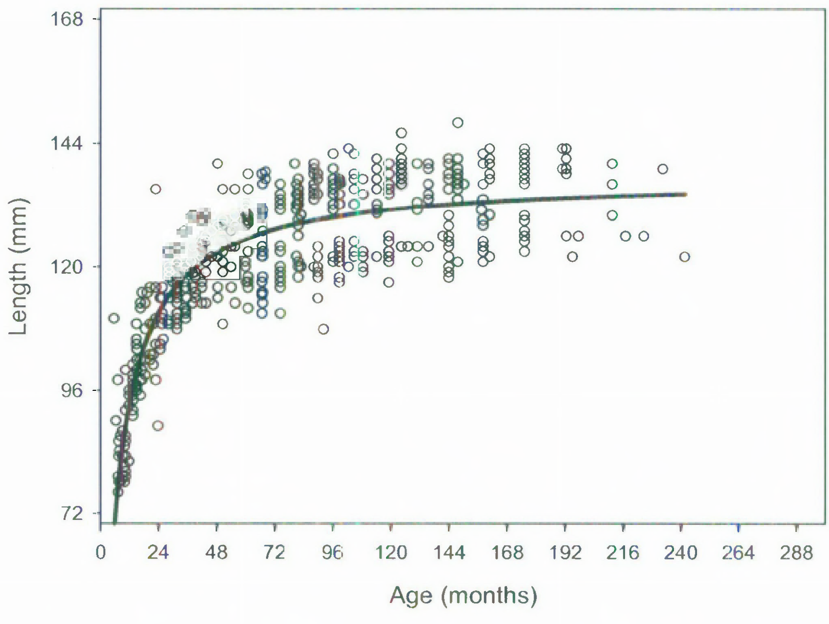

Figure 6.2 Plot of skull length (mm) by estimated age (months), fitted with hyperbola $y=137.2x/(5.641+x)$, $r^2 = 0.7548$, $p<0.0001$.

The plot of age by length (Figure 6.2) suggests two discernible groups with respectively shorter and longer skulls at the same age. Unfortunately, when the skulls were collected they were usually from animals of unknown sex; in this case only 64 out of the 812 skulls were from animals of known sex. To find out more about the mortality of the population and to look for any differences between males and females, knowledge of individual's sex is required. As males in sexually dimorphic macropod species have larger skulls than females at the same age (Jarman 1989) it was hypothesized that this was to be the cause of the differences seen in Figure 6.2.

To test the hypothesis that there was a sex-linked skull-length-to-age relationship, investigations were undertaken on all skulls of known sex. However of the 64 known-sex skulls, only sixty could be aged, and another 9 lacked one or more measurement parameters (i.e. skull length, width or both), leaving 51 usable skulls from animals of known sex (34 male, 17 female). An additional male was removed from the data set as he was an extreme outlier. Therefore, using the data from a total of 50 animals, 33 males and 17 females, skull length was regressed against age in months, hyperbolic curves were fitted and the strength and significance of the regressions were assessed. The curve formulae and regression results were: males $y = 144.67x / (7.19 + x)$, $r^2 = 0.8952$, $p<0.0001$, se(a) = 1.5146, se(b) = 0.5444 and females $y = 126.9x / (4.887 + x)$, $r^2 = 0.8907$, $p<0.0001$, se(a) = 1.1882, se(b) = 0.5273 (Figure 6.3).

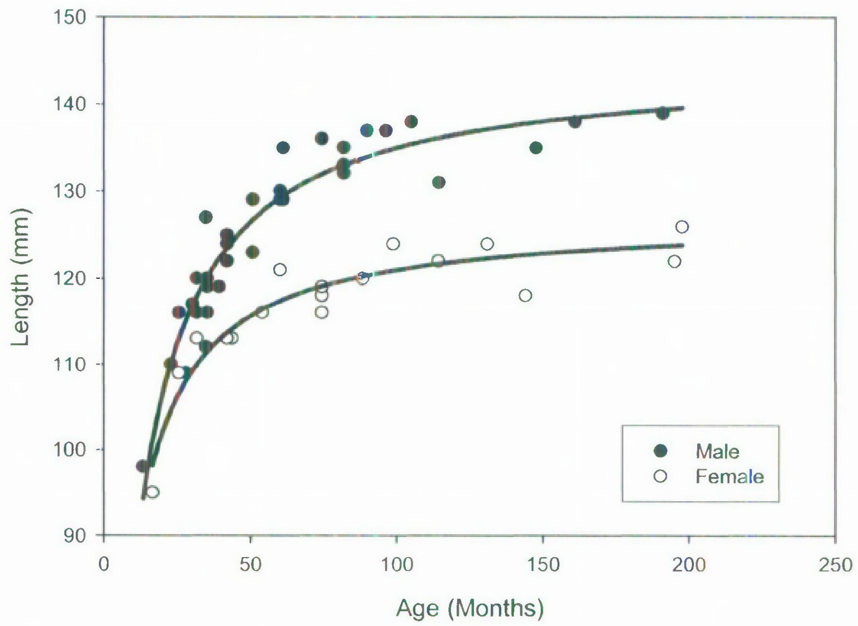

Figure 6.3 The length (mm) and age (months) of skulls collected from known-sex carcasses with fitted hyperbola lines.

Figure 6.3 shows a good fit of the data to the respective male and female hyperbolic equations, and it was therefore decided that the equations were appropriate for use as indices to determine the sex of the unknown-sex skulls. The sex of 487 skulls, including 436 unknown-sex skulls with measurable lengths and determinable age (from molar index) and the 51 known-sex skulls used for creating the index, were determined (Figure 6.4).

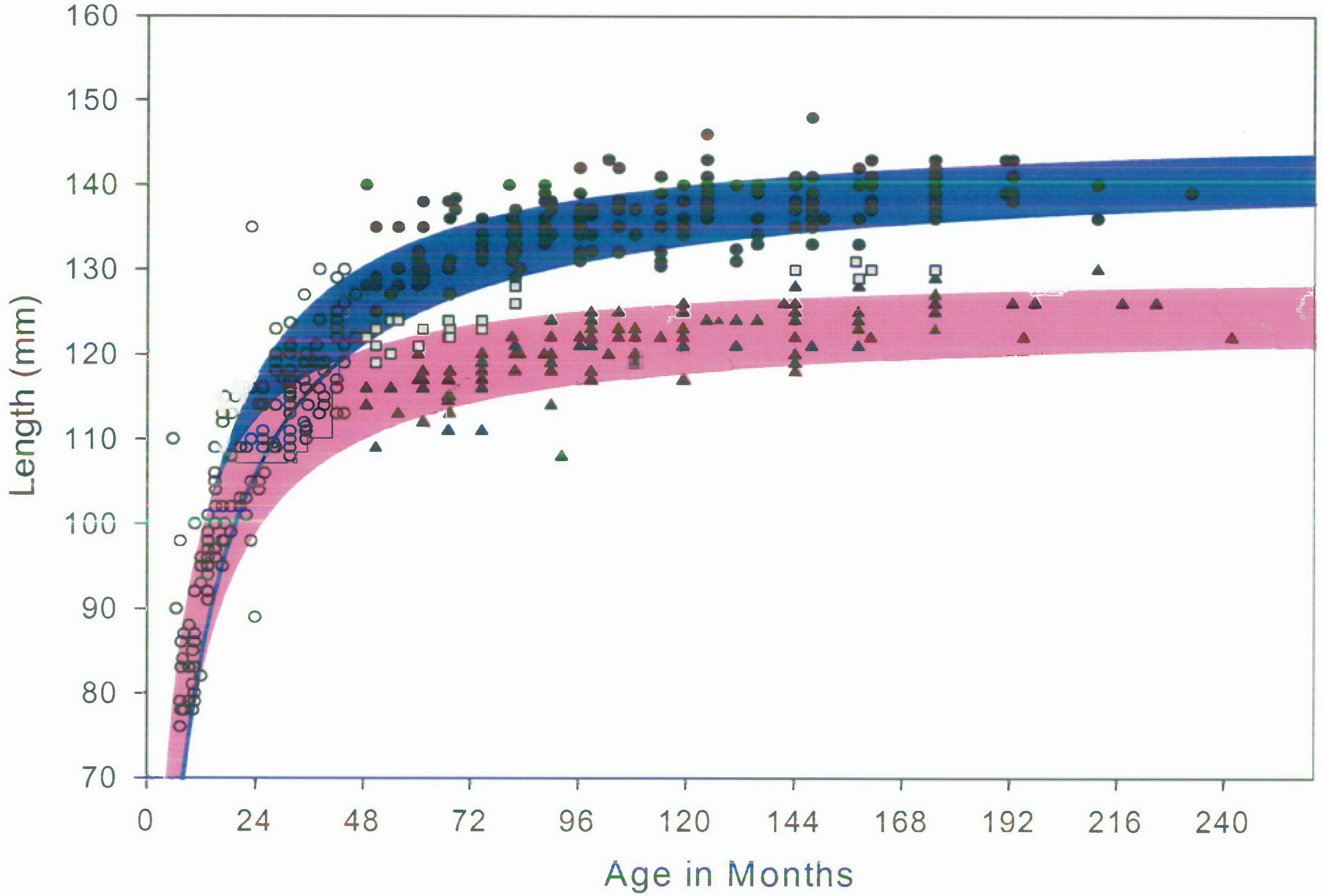

Figure 6.4 Determining the sex of unknown-sex skulls. The coloured areas include values within two standard deviations of the mean, as determined by the 'male' and 'female' hyperbolic equations. Symbols falling on the blue area were determined to be males (●) and on the pink, females (▲). Animals under 48months old could not be differentiated (○) and some skulls fell in the 'unsure' area (□).

Of the 487 skulls, 184 were determined to be male and 114 were determined to be female (including and confirming the 34 known males and 17 known females). On inspection, it was noted that 26 skulls fell below the male index but above the female index. Any skulls within this area could be small males or large females and those skulls were not assigned a sex. It was also decided that the skulls of Black-striped Wallabies under 48 months could not be confidently sexed because of the convergence of the sex-specific length-for-age curves below that age threshold. There were 163 skulls under 48 months of age, which were rejected for sexing.

The known-sex skulls corresponded with the determined-sex skulls very well with only one known male determined as unsure (i.e. it fell between the male and female index areas). Thirteen males and 3 females were too young to be determined accurately. Only the extreme outlier male was determined incorrectly as a female, justifying his removal from the data set used to create the index.

The sex information was then used to categorise each skull. Out of interest the feasibility of a sex-linked skull-width-to-age relationship was investigated (Figure 6.5) but found to be not as defined as the sex-linked skull-length-to-age relationships (Figure 6.6).

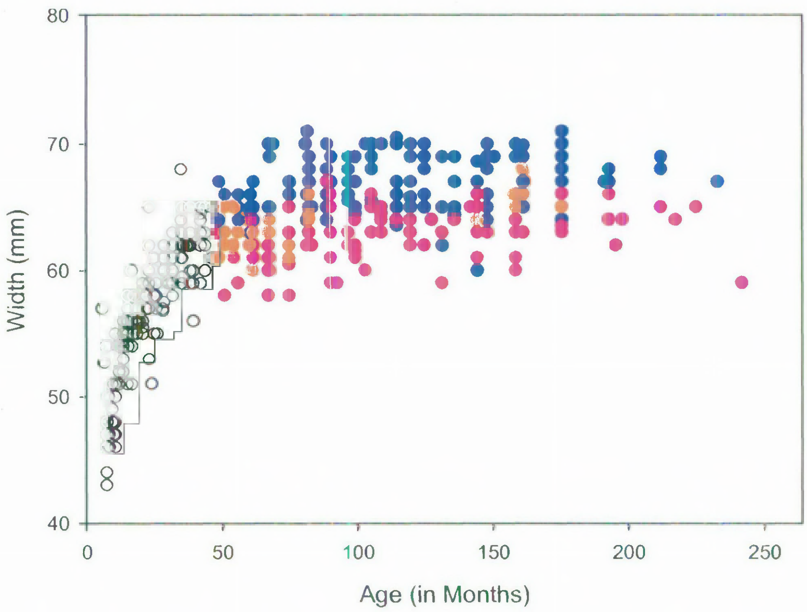

Figure 6.5 The skull width to age relationship for determined-sex Black-striped wallaby skulls collected on Brigalow Research Station. Representative symbols stand for (•) males, (•) females, (•) unsure, and (o) under 48 months.

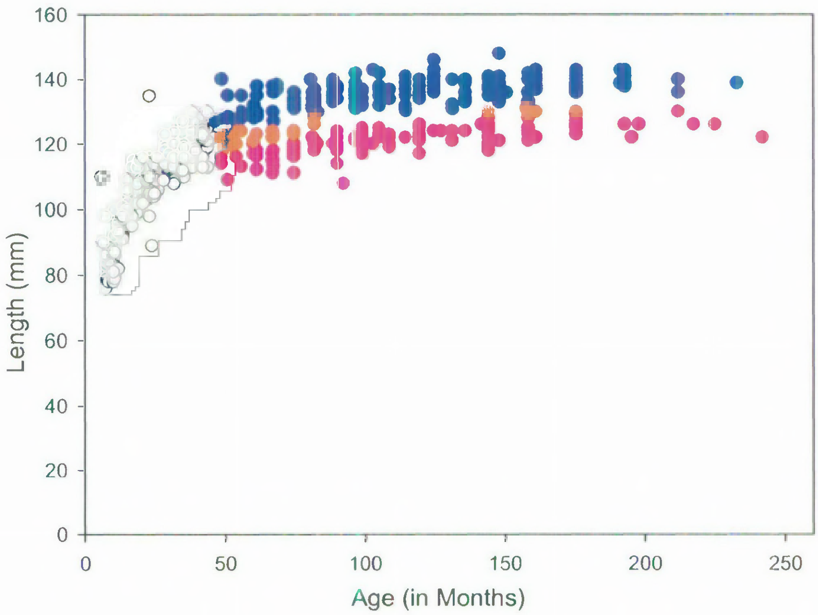

Figure 6.6 The skull length to age relationship for determined-sex Black-striped wallaby skulls collected on Brigalow Research Station. Representative symbols stand for (•) males, (•) females, (•) unsure, and (o) under 48 months.

Figure 6.7 also shows that a large proportion of the skulls collected were of 1 to 3 years of age and from that point the number of skulls collected within each yearly age group fell gradually. There were very few collected skulls less than 1 year old.

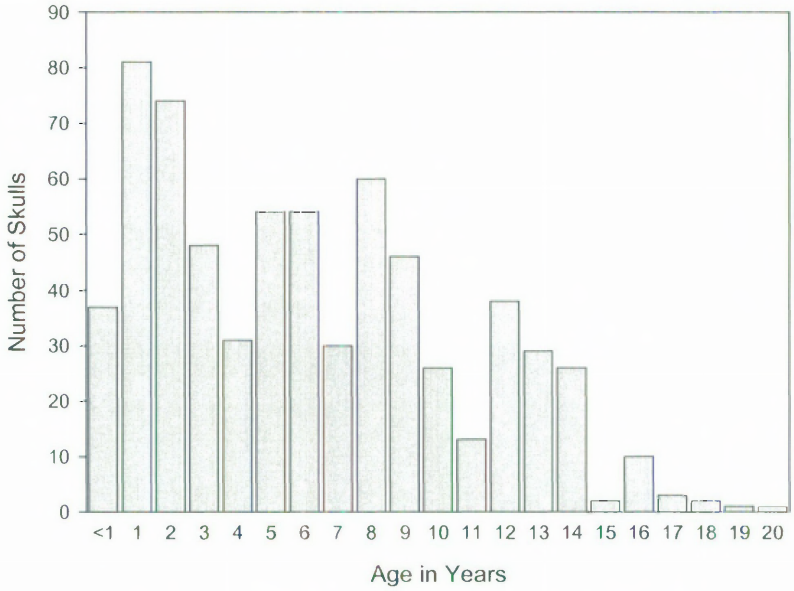

Figure 6.7 Number of skulls collected in each yearly age group.

The determined-sex information allowed better interpretation of the population's male:female age structure, and male and female mortality rates. The large number of determined-sex male skulls suggests there were more males than females in the population, with a higher number of male skulls collected in each yearly age group. The ratio of males to females did not differ between age groups (Figure 6.8).

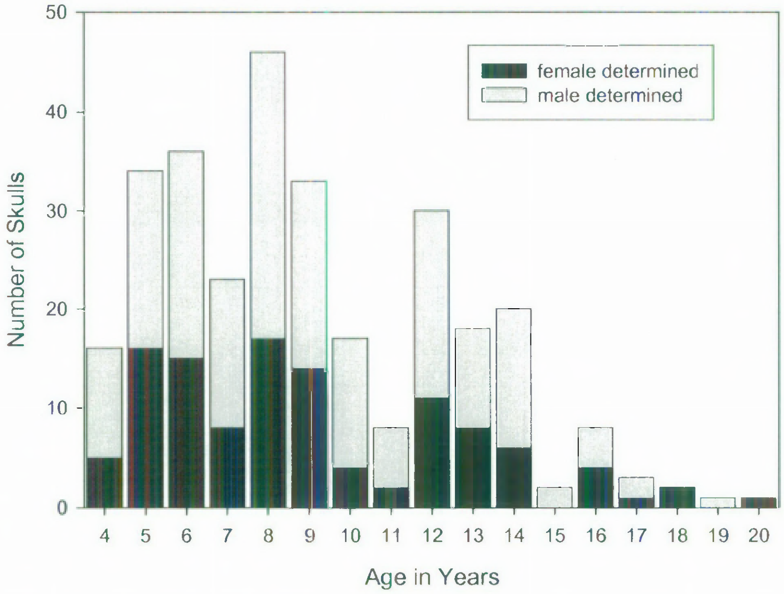

Figure 6.8 Number of female-determined skulls and male-determined skulls collected in each yearly age group. Skulls aged less than 4 years could not be sex-determined.

Using the number of skulls counted within each yearly age group (Figure 6.7) the following static or time-specific life-table (Table 6.1) was created.

Table 6.1 Life table for Black-striped Wallabies on Brigalow Research Station.

Age (x)	Number reaching age interval (fx)	Survival (lx)	Frequency of Mortality (dx)	Mortality Rate (qx)	Survival Rate (px)
	667	1.000	0.057	0.057	0.943
1	629	0.943	0.121	0.129	0.871
2	548	0.822	0.111	0.135	0.865
3	474	0.711	0.072	0.101	0.899
4	426	0.639	0.046	0.073	0.927
5	395	0.592	0.081	0.137	0.863
6	341	0.511	0.081	0.158	0.842
7	287	0.430	0.045	0.105	0.895
8	257	0.385	0.090	0.233	0.767
9	197	0.295	0.069	0.234	0.766
10	151	0.226	0.039	0.172	0.828
11	125	0.187	0.019	0.104	0.896
12	112	0.168	0.057	0.339	0.661
13	74	0.111	0.043	0.392	0.608
14	45	0.067	0.039	0.578	0.422
15	19	0.028	0.003	0.105	0.895
16	17	0.025	0.015	0.588	0.412
17	7	0.010	0.004	0.429	0.571
18	4	0.006	0.003	0.500	0.500
19	2	0.003	0.001	0.500	0.500
20	1	0.001	0.001	1.000	0.000

The table shows that the median age at death is between 6 and 7 years. Moreover, the mortality rate (qx) for young adults (year classes 2-7) is low, averaging 0.118; for year classes 8-11 it is variable, but averaging 0.186; and for old adults in year-classes 12 to 19, mortality rate rises to a mean of 0.429.

The information within a life table is often more easily interpreted as mortality curves (Figure 6.9). Creating life tables using male-determined and female-determined skulls gave two very similar mortality rates, suggesting little difference between the sexes in age-specific mortality (Figure 6.9).

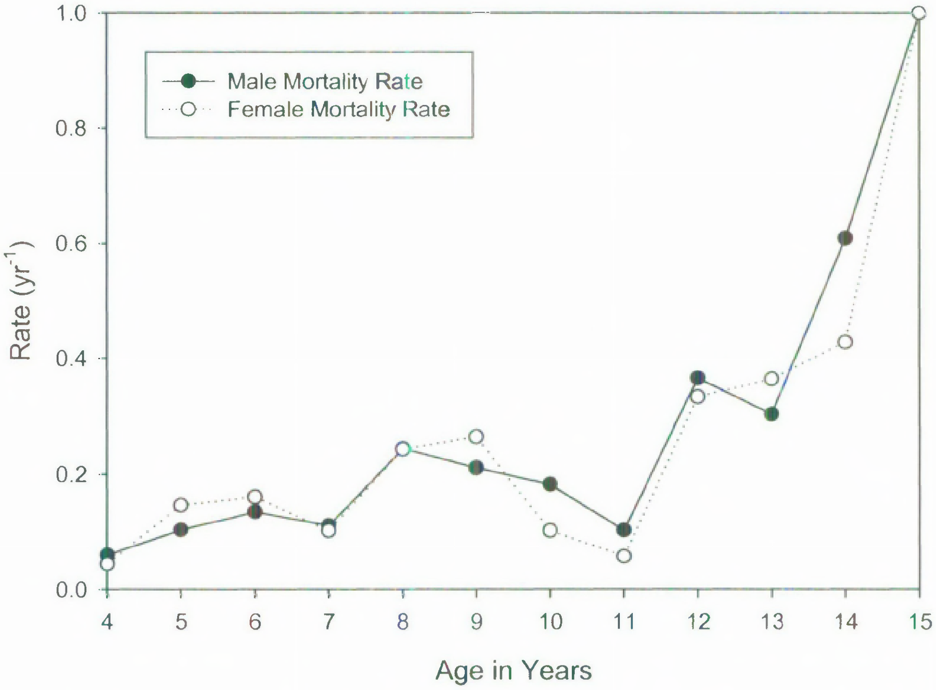

Figure 6.9 Mortality curves of male and female Black-striped Wallabies, from sex-determined skulls, collected at Brigalow Research Station, 2000-2003.

6.3.2 Carcass records

During the period of carcass recording (June 2000 to April 2003), 177 carcasses were recorded on the Station. Carcasses were most commonly recorded during spring (39.5%), with only 30%, 8.5% and 22% of carcasses recorded during summer, autumn and winter respectively. Accounting for a difference in the numbers of days spent in the field by the observer each season it would seem that there were more carcasses present during spring and summer. The mean number of carcasses found for each day spent in the field was above average during spring and summer but below during autumn (Table 6.2).

Table 6.2 Number of male, female and unknown-sex carcasses recorded each season on Brigalow Research Station.

Season	Female	Male	Unknown Sex	Total	Days in Field	Daily Rate
Summer	5	20	28	53	30	1.77
Autumn	3	5	7	15	32	0.47
Winter	6	14	19	39	32	1.22
Spring	14	30	26	70	49	1.43
Total	28	68	81	177	143	1.24

Just over double the number of males as females were recorded; however, nearly half of the carcasses (48%) could not be sexed. To use the sexing index created in Section 6.3.1 wallaby age must be determinable. Only 90 carcasses were ageable, 60 of which were of known sex. It was decided not to try to sex the remaining 30 carcasses, as it was unlikely to add any reasonable amount of information to the data set. With such a high level of uncertainty it is hard to draw any firm conclusions regarding the real proportion of male and female carcasses; however, based on the results of the skull sexing (more males than females) the ratio of male to female carcasses would be as expected.

The cause-of-death categories were summarised against both carcass sex and size. A high proportion of carcasses could not be placed in a definite cause-of-death category, with 'unknown' cause-of-death making up 103 (58.2%) of the total sexed carcasses (Table 6.3). However, fifty-five carcasses (31.1%), of which there were 24 males and 14 females, were determined to be due to dingo attack, by far the greatest single postulated cause of death.

Table 6.3 The number of male, female and unknown-sex animals in each cause-of-death recorded, Brigalow Research Station, June 2000 to April 2003.

Cause-of-Death	Female	Male	Unknown Sex	Total
Dingo	14	24	17	55
Wallaby fence	2	6	2	10
Human interaction	4	5	0	9
Unknown	8	33	62	103
Total	28	68	81	177

A large proportion of the carcasses recorded were of medium and large size (45.4% and 31.9% respectively) with an additional 19.6% being small carcasses and 3% being very large carcasses (Table 6.4).

Table 6.4 The number of small, medium, large and very large carcasses recorded within each cause-of-death category. Fourteen carcasses could not be sized as they were too decomposed and/or eaten by dingoes.

Cause-of-Death	Small	Medium	Large	Very Large	Total
Dingo	13	22	19	1	55
Wallaby fence	0	2	7	0	9
Human interaction	3	1	5	0	9
Unknown	16	49	21	4	90
Total	32	74	52	5	163

Of the medium and large carcasses recorded, a large proportion was determined to be from dingo kills (29.7% and 36.5% respectively), with the 'wallaby fence' and 'human interaction' categories combined accounting for only 4.1% and 23.1% of the medium and large carcasses recorded respectively. However, cause-of-death was unknown for large numbers of medium and large carcasses (30% and 40.4% respectively). Removing the number of 'unknowns' from percentage calculations would mean that 81% of small carcasses, 88% of medium carcasses and 61% of large carcasses were from dingo kills.

Organising carcasses by Cause-of-Death and Sampling Area shows Sampling Area 1 had the highest proportion of carcasses recorded (62%) with Sampling Areas 4, 3, 5 and 2 having decreasing numbers of carcasses recorded (24.3%, 10.2%, 2.3%, 1.1% respectively), (Table 6.5).

Table 6.5 The number of Black-striped Wallaby carcasses found in each Sampling Area on Brigalow Research Station from 2000-2003 for each Cause-of-Death category.

Sampling Area	Unknown	Dingo	Wallaby fence	Human interaction	Total
1	63	36	10	1	110
2	2	0	-	0	2
3	10	4	-	4	18
4	25	14	-	4	43
5	3	1	-	0	4
Total	103	55	10	9	177

Aside from the high number of carcasses found in Sampling Area 1, comparisons of the number of carcasses recorded in Sampling Areas 2, 3, 4 and 5 reflect the relative densities of live animals counted during observation counts and spotlighting (see Section 3.3.1). It would therefore seem that the circumstances surrounding the presence of wallaby carcasses in Sampling Area 1, for whatever reason, are not normal.

Forty-six of the 110 carcasses recorded in Sampling Area 1 were found along M-lane, the wallaby-fenced roadway that runs along the edge of the shelter scrub and M paddock (refer Section 2.4.2, Figure 2.10). An additional 39 of the 110 animals recorded in Sampling Area 1 were found on the paddock side of the wallaby fence at the southern end of the Catchment Study Site. However, over half (57.3%) of the carcasses found in Sampling Area 1 were recorded with 'Unknown' cause-of-death, as the carcasses did not give definitive clues to the cause (i.e. no bite marks or scratchings present).

Of the 177 carcasses found only 90 could be aged and of those 60 were of known sex, 42 males and 18 females. The age structure of the skulls from carcasses recorded (effectively a sample of the entire skull collection) shows proportions of animals in each age class that are similar to those of the entire skull data set. Just over half of the carcasses found (56.7%) were between 2 and 6 years of age; with similar proportions displayed for males (28 of 42 carcasses aged 2-6yrs), females (9 of 18 carcasses) and unknown sex (14 of 30 carcasses), Figure 6.10.

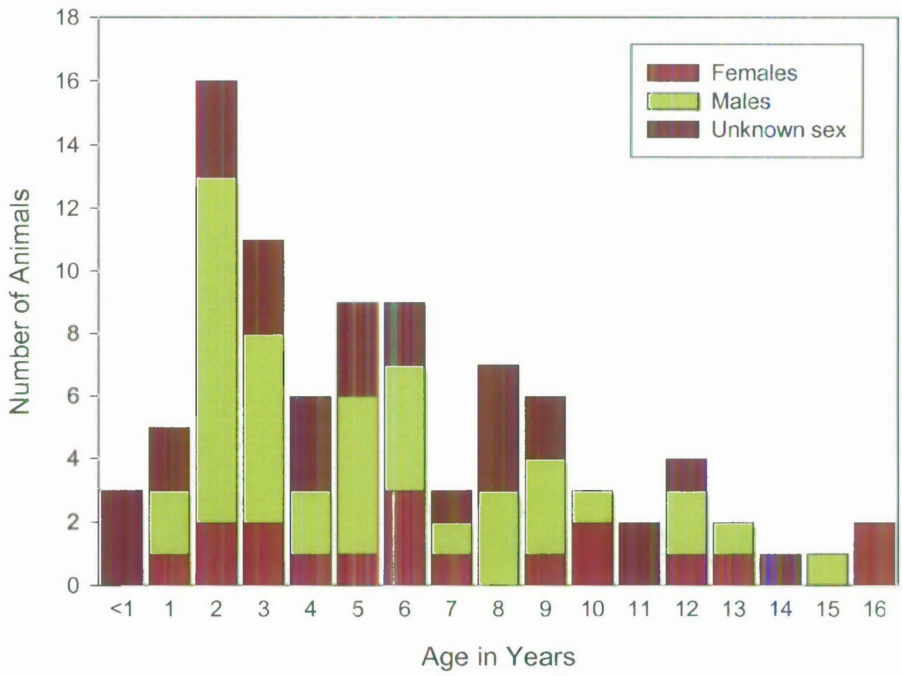

Figure 6.10 Number of male, female and unknown-sex carcasses in each yearly age group, from Brigalow Research Station 2000-2003, n=90.

The number of carcasses in each cause-of-death category for each year of age (Figure 6.11) suggests that dingoes play an important role in mortality at most ages, particularly up to 10 years of age, although the large number of carcasses within the unknown cause category once again makes it hard to make any firm conclusions. Ratios of dingo-caused to unknown-caused carcasses did not significantly differ between <8 years and ≥ 8 years, suggesting that dingoes seem to be a constant mortality factor through life. Overall, dingoes were identified as the cause of death for 31% of the 177 carcasses collected at Brigalow Research Station from 2000-2003, and for 35% of male deaths and 50% of female deaths. These proportions of male and female deaths are not significantly different.

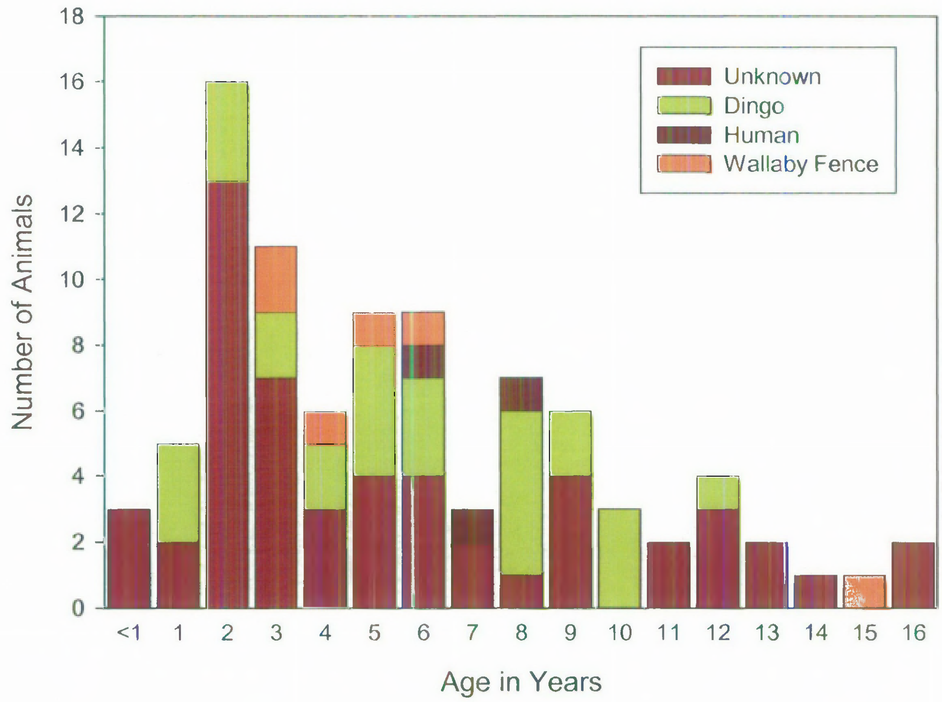

Figure 6.11 Number of animals in each Cause-of-death category for each yearly age group, n=90.

Assuming a considerable number of carcasses are therefore due to dingoes, it was of interest to see dingo-predation was a seasonal effect. The seasonal incidence of predation by dingoes on Black-striped Wallabies is compared with other sources of mortality in Figure 6.12. However, once again the high proportion of 'unknown' carcasses makes interpretation difficult. Removing the 'unknown' carcasses though, does suggest that dingoes are more active in killing Black-striped Wallabies during winter and spring than in the other seasons.

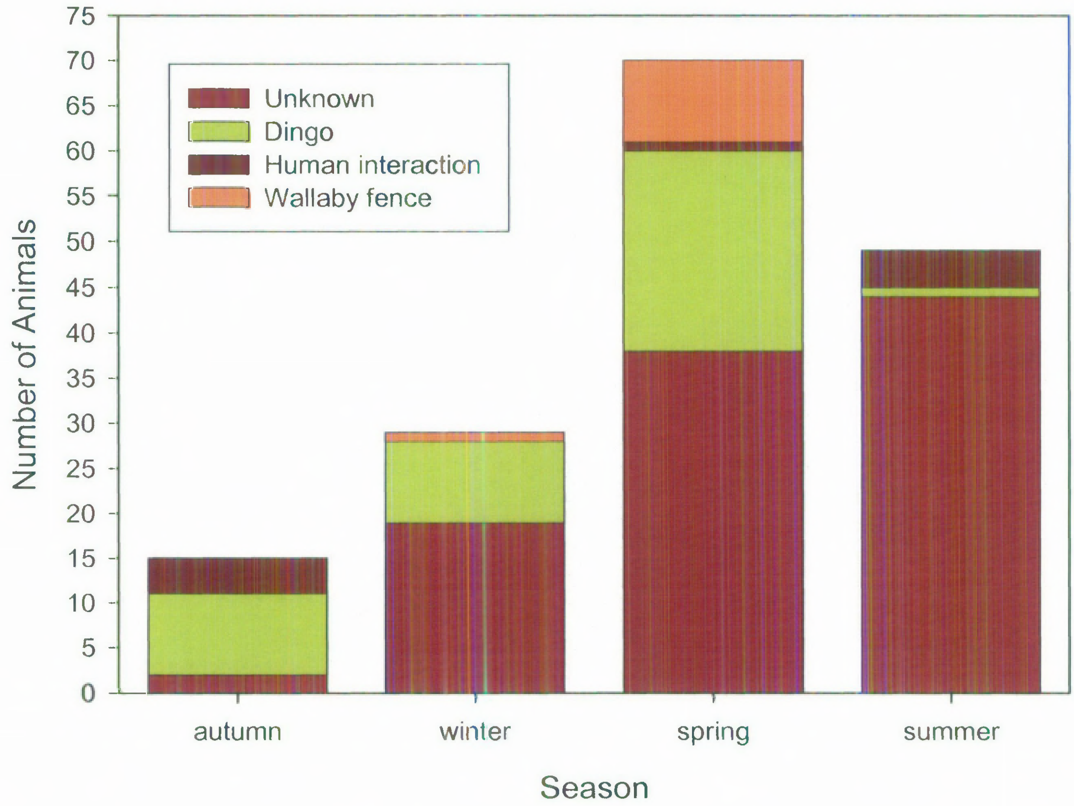

Figure 6.12 The interaction of Season and Cause-of-Death on the number of carcasses found on Brigalow Research Station, 2000-2003, n=177.

The 90 aged carcasses were also categorized by season of collection to establish whether the number of carcasses within each yearly age group was influenced by season. However, autumn and winter contained only 3 and 13 ageable carcasses, respectively. Such low numbers in these seasons made further analysis difficult.

6.4 Discussion

The primary aim of this Chapter was to gain a better understanding of the Black-striped Wallaby population's dynamics, particularly of the population on Brigalow Research Station as it was at such high density. Based on the ageing of the large number of skulls (667), it is thought that the age-at-death structure of the Black-striped Wallaby population on Brigalow Research Station was similar to other macropod species, with a high number of juveniles and young adults (Quin 1989). The calculated life-table also suggests that the wallabies were like most macropods, (refer Quin 1989) with a high mortality in older age (>11yrs), low and consistent mortality rates until about 7 years of age and the median age at death between 6 and 7 years of age. The low mortality at young age is possibly influenced by the methodology or due to a technical issue. The life table is created from the number of skulls found in each age class compared to the total number found. Very few skulls under the age of one year were found; however, this does necessarily reflect the number of wallabies less than one year old in the population as skulls from young animals may less readily survive to be found. It is generally accepted that skulls of young animals are more fragile than skulls of older animals. Therefore they are probably more susceptible to natural deterioration and more easily destroyed by predators.

The difference in skull-length-to-age relationships between males and females found in this study was very similar to that reported by Jarman (1989); utilising these sex-related relationships, after testing them with the few known-sex skull data, allowed the remaining unknown-sex but known-age skulls to be sex-determined. When the determined-sex information was applied to the skull collection, similar age-specific mortality rates were found for males and females. However, the number of male-determined skulls was much greater than the number of females; and this trend was also noted when recording male and female carcasses. Higher numbers of males may be explained by male immigration or female emigration, birth of more males than females, or differential mortality as pre-weaned young (Johnson 1989); however, none of these explanations could be verified within the parameters of this study. While skull collection and ageing has given some information regarding the structure of the wallaby population and the mortality rates of males and females, it does not highlight possible reasons for mortality or the impact of the different causes of death; important information when planning management of an animal population.

The recording of carcasses gave information regarding causes of mortality for the different ages of male and female wallabies. Although carcasses were picked up in a consistent manner, more carcasses were found in spring than summer or winter and only a few were found in autumn, suggesting some seasonal interaction with cause-of-death. There may be some methodological influence on seasonal difference in numbers of carcasses found, for example environmental factors affecting the 'findability' of carcasses. It may be harder to find carcasses during the summer-wet seasons as they could be hidden in the long grass. If this were the case though, the number of animals dying during summer would be even higher than determined from carcasses records. Nominating a seasonal time of death may also be subject to error as it was hard to estimate how long an animal had been dead, particularly after the carcass was a few days old. However, it could be determined if the animal was more than a number of weeks old, which would therefore place the time of death in the previous season.

Therefore it still seems likely that there is a seasonal effect in the number of carcasses found. Data suggests that dingoes are most likely the primary cause of death, with three-quarters of all identifiable deaths attributed to dingoes, the rest being caused by human interference. That proportion was consistent across sex-, age- and size-classes of wallabies. Although the majority of carcasses found showed signs of dingo predation, there were a large number of carcasses with no visible death signs. An explanation for the high number of carcasses found with no cause of death sign may lie with one joey, which was found alive and seemingly in very good condition with no external bite marks but unable to move. When euthanased and skinned, bruising under the skin suggested that she had been attacked by Dingo. It is possible that a large proportion of the carcasses recorded as of 'unknown cause-of-death' were actually dingo-related casualties as bite marks were concealed by fur. It is widely accepted that for many populations of macropod species predation by dingoes occurs wherever the two species live together (Shephard 1981, Newsome *et al.* 1983, Robertshaw and Harden 1985, 1986, 1989, Wright 1993).

The seasonal variation in the number of carcasses found may also be explained by a high number of dingo-caused deaths. Dingoes breed during winter to spring, with young pups becoming independent during summer at three to four months of age (Corbett 1995). Increased predation due to a higher number of dingoes in the area during summer may explain the higher number of dingo-killed carcasses during that time. In addition, during short summer nights wallabies may need to emerge from shelter while it is still light to begin feeding giving dingoes more opportunity for successful predation. However, results of Section 3.3.1 (observation counts) suggest that the wallabies adjust their emergence time seasonally to coincide with the fall of darkness.

In spite of Sampling Area 1 having the lowest Black-striped Wallaby density the majority of wallaby carcasses were found within it, and a high proportion of those found were determined to be dingo-related deaths. Travelling focussed around the edge of the Reference Site, and so carcass locations were biased to this section of the Research Station; however, bias between Sampling Areas is unlikely as there was equal opportunity to find carcasses along the route. While grazing at night, wallabies are more vulnerable to predation and rely upon dense forested habitat in close proximity to feeding areas for protection. The presence of a barrier fence may mean wallabies are less able to access the dense vegetation used for protection. The wallaby mesh fence on Brigalow Research Station may therefore, aid dingoes in successfully predating on Black-striped Wallabies. It is also possible that at the onset of dawn disorientated wallabies (e.g. if spooked by dingoes) unable to find their way back to sheltering scrub due to a barrier fence are left vulnerable to heat-stress and predation from birds such as Wedge-tailed Eagles.

In summary, skull collection, ageing and sexing suggest that the age structure of the population of Black-striped Wallabies on Brigalow Research Station is similar to other macropod species populations, although a higher proportion of males than females is suggested. Mortality rates for both males and females are also similar to those found in other macropod populations, with a high incidence of dingo attack on both male and female Black-striped Wallabies, of all age-classes, evident. The use of dingoes as a natural management tool deserves further investigation.

CHAPTER SEVEN

CONCLUSIONS AND IMPLICATIONS FOR MANAGEMENT

Black-striped Wallaby distribution and overall abundance have declined since European settlement; nevertheless, the species is still viewed as a pest in many areas of the central Queensland Brigalow Belt where suitably sized patches of preferred shelter habitat remain. Prior to agricultural modification of the landscape, Black-striped Wallabies spent the day resting or sheltering under scrub vegetation emerging into natural clearings at dusk to feed on native grasses and browse species. However, with the introduction of sown pastures and crops in areas adjacent to remnant or regrowth fragments, and the reduction of the wallabies' main predator, the dingo, the species has utilised the easy access to abundant nutritious pastures in a predator-reduced environment to become locally abundant in areas where suitable shelter habitat remains.

The reduction in Black-striped Wallaby numbers in New South Wales, but apparent explosion in local population densities in areas of Queensland, therefore requires a two-pronged management approach to ensure the long-term survival of the species at sustainable population densities. Currently, management for either situation is undertaken on a case-by-case basis; however, a strategic Black-striped Wallaby management plan has not yet been formulated for Brigalow Research Station where the species is in high density, a situation found on other similar cattle properties and of concern to beef producers.

Little research has been undertaken on Black-striped Wallabies particularly in a pest situation and it was unknown whether pest populations function the same way as lower-density populations. Applying a management strategy to a population of Black-striped Wallabies that is not functioning as expected may be unsuccessful. This project aimed to fill the knowledge gap regarding the functioning of high-density Black-striped Wallaby populations and determine the implications for management of the species.

The specific objectives of the project were:

a) to determine the level of impact Black-striped Wallaby grazing was having on the remnant scrub habitat and adjacent pastures on Brigalow Research Station,

b) to determine the wallabies' interaction with, and degree of impact on, the various remnant vegetation types used for sheltering,

c) to establish if the population was functioning similarly to lower-density Black-striped Wallaby populations, specifically in feeding and sheltering preferences, and

d) to discuss the findings of the project in terms of their implications for management of the species.

7.1 Findings of the Study

- Comparisons with Black-striped Wallaby densities reported at other sites confirmed that there was an unusually high density of wallabies on Brigalow Research Station, but the population was confined to the remnant Reference Site and pasture paddocks directly adjacent. It was established that the population had a heterogeneous distribution throughout the Reference Site with a higher density of wallabies in the Softwood Scrub compared to the fenced and unfenced Brigalow forests.

- Few significant relationships were found between the population's faecal pellet distribution and the structural habitat attributes studied. Therefore, it was concluded that other factors may influence the wallabies' preferences for habitat use. Black-striped Wallabies are reportedly found in a number of shelter habitats including dry vine thickets, rainforest margins, Brigalow scrub, lantana thickets and even 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 overall structural attributes and contains, or is adjacent to, sufficient food resources.

- The wallabies exhibited certain preferences for resting areas within the shelter habitats with individuals avoiding camping too near the open edge of the shelter habitat (preferring to rest at least 80m from the scrub edge) but yet not penetrating more deeply into it as they might. Reasons for this preference are unclear although the presence or density of dingoes may be an influencing factor. These results indicated that remnant size might be used to encourage or discourage occupation of remnants by Black-striped Wallabies.

- As found in previous studies (Evans 1996), radio-tracking confirmed that Black-striped Wallabies have relatively small home-ranges and in most cases move only as far out as necessary onto the adjacent open grassed paddocks at dusk to feed, returning to the shelter scrub around dawn. There were exceptions to these movement patterns largely due to a seasonal change in food availability and behavioural adaptation in response to the establishment of a wallaby barrier fence. These observations may also provide points of control for management of Black-striped Wallaby populations.

- As previously reported (Jarman *et al.* 1991, Dawson *et al.* 1992, Ellis *et al.* 1992, Evans and Jarman 1999) the species was found to eat a large number of plant species, in all seasons throughout the Reference Site. The wide variety of species eaten included small proportions of highly abundant introduced pasture species, much higher proportions of less abundant native grasses, and a small percentage of browse and forbs. This study did not find any evidence to suggest that the wallaby had changed its natural feeding habits in response to pastoral development. The plant species within the remnant scrub were equally, or more significantly, important to the diet and the wallaby was not relying upon crops or introduced pastures (e.g. Buffel grass) for survival. The indications are that Black-striped Wallabies overlap with cattle in eating pasture species, but prefer certain native plant species when available. As cattle were fenced out from the scrub at the Study Site, their influence on wallaby behaviour (in terms of feeding and habitat preference) could not be studied.

- While Black-striped Wallabies may not have changed their dietary composition, the species was found to be removing a substantial amount of biomass from the part of the paddock that was monitored. However, the combined impact of grazing by both cattle and wallabies was more detrimental to the health of the paddock, with less species variety, less biomass, and lower plant height present when both herbivores grazed. It is also possible that cattle-grazing encourages wallaby-grazing by providing more accessible 'green pick'. Lowered plant species diversity was also apparent when herbivore grazing was completely removed and faster-growing introduced pasture species were able to dominate.

- The level of wallaby grazing found in pasture exclosures was unlikely to be applicable to the whole paddock. This study supports previous reports that utilisation of pasture paddocks by Black-striped Wallabies decreases with distance from the safety of the shelter scrub (Kirkpatrick 1995, Evans 1996).

- The importance of foraging by wallabies in the remnant scrub habitats was also made apparent by monitoring exclosures. Significant effects of grazing were seen after just one year of excluding wallaby grazing from control exclosures; for example, within the wallaby-excluded areas native grass species were higher, more abundant and contained more seedheads (i.e. reproduced more effectively), compared to the wallaby-accessed areas. These findings suggest that populations of Black-striped Wallabies will therefore impact on vegetation in the shelter scrub if the density of the population is too high, or if there is reduced access to adjacent pastures due to partial barrier fencing. Unfortunately once again, Black-striped Wallaby impact on scrub vegetation in the presence of cattle could not be studied.

- It is uncertain if the wallaby barrier fence around one end of the Reference Site permanently reduced wallaby density and therefore impact on the scrub in that area. Monitoring of exclosures in scrub habitats showed that feeding on native grasses and forbs is significant, even at low wallaby densities. Although, one radio-tracked wallaby that inhabited that area fed nocturnally at the open end of the fence (i.e. it moved to the end of the fence that allowed it access to pasture).

- Three-quarters of all identifiable male and female mortalities within all age-classes were attributed to dingoes. This suggested that dingoes play a large role in wallaby population management on Brigalow Research Station and may offer a possible 'natural' means for managing wallaby population density.

- The influence of the wallaby barrier fence was also likely to be aiding dingo predation on wallabies with a highest number of dingo-killed carcasses found in the vicinity of wallaby fence.

- A sexing index for Black-striped Wallabies was developed in this study based on the large collection of skull and carcass records. Applying the index to the skull collection suggests the population contained more males than females, but mortality rates were equal for both sexes. There was a higher mortality in older animals (>11yrs) but mortality was low and constant until about 7 years of age.

- The population structure of Black-striped Wallabies on Brigalow Research Station was found to be similar to that of other macropod species (Quin 1989) with a high number of juveniles and young adults. The median age at death (6 to 7 years) was consistent with macropods of similar size (Kirkpatrick 1965).

7.2 Implications for Management for Conservation and Pest Control

The effects of fire, disease outbreak, reduced genetic pool or over-use of resources are greater on isolated populations unable to disperse to other areas. The natural confinement of Black-striped Wallabies to the Reference Site highlights how fragment isolation places a population's survival at risk. Although, agriculturalists may consider confinement advantageous, as the area impacted on by Black-striped Wallabies is limited to the inhabited shelter scrub and adjoining pasture paddocks, and management strategies need only be applied to those areas, not the whole property. Confinement, such as the case on Brigalow Research Station, may be minimized by connectivity of fragments.

Establishing what influences the wallabies' usage of inhabited areas would also aid management of the species by enhancing decisions regarding crop placement. Sowing crops that are eaten by Black-striped Wallabies away from areas where preferred shelter habitat exists is likely to reduce the impact of wallaby grazing on those crops. Better knowledge of preferred shelter habitats would also benefit management strategies aiming at encouraging or preserving the species by enabling the retention or management of habitat with the key structural attributes that govern the wallabies' sheltering preferences.

The size and shape of the inhabited shelter vegetation, and therefore the availability of scrub-edge habitat, are also likely to influence the size of a Black-striped Wallaby population. Fragments wider than 160m are likely to support larger populations of wallabies, while fragments less than 160m wide are not. However, the ratio of fragment edge to area is also an important factor; fragment width is not necessarily determined by fragment size. Long rectangular fragments, such as at Brigalow Research Station, that are more than the optimum edge-to-interior distance wide, provide more preferred sheltering habitat for Black-striped Wallabies than a square block of habitat of the same area. This point has not been made to encourage the partial or complete clearing of fragments of vegetation, rather to be of use to those land managers who wish to know how a particular fragment will support a Black-striped Wallaby population.

There are a number of benefits and disadvantages in using barrier fences for Black-striped Wallaby management. While partial barrier fencing may be less expensive than complete fencing, there is a concern that such a fence will just push the problem onto another area. Black-striped Wallabies will adapt to situations, for example, by travelling some distance to feed if necessary. Partial and complete fencing also raises the concern that, while there is less impact on adjacent crops and pastures, increased pressure will occur within the shelter scrub affecting its health and long-term biodiversity. However, fencing an area completely may mean wallaby density will drop to a level sustained only by the native grass species within the fenced area. A completely fenced fragment, expected to support a population of Black-striped Wallabies not at risk of inbreeding due to a reduced gene pool, would have to be of substantial size.

Fencing is not always appropriate either due to topography, cost or disagreements with neighbours. In such circumstances where wallabies have uninhibited access to pasture paddocks, a sacrifice strip strategy may be an alternative management option. Accepting a loss of 100m or so along the edge of the fragment and factoring this into stocking rates may help to keep paddocks in better condition. Additionally, removal of cattle from that sacrificed area would allow more grass growth, reducing the amount of 'green pick' available for wallabies.

Previous reports (Corbett 1995), as well as this study, suggests that dingoes could be used in management of macropod populations. Intentional boosting of dingo numbers by decreasing control may be an effective Black-striped Wallaby management tool but would need to be weighed up in terms of cost to enterprise through possible stock losses, compared to the gain in pasture from reduced wallaby grazing. On Brigalow Research Station, where there are few calves, a high density of dingoes for the management of Black-striped Wallabies may be feasible.

7.3 Further Research

There is a substantiated need for knowledge regarding Black-striped Wallaby populations, for their management as a pest and threatened species. This project aimed to fill the knowledge gap to some extent; however, there are still many issues that remain unanswered. Future research should focus on the following areas.

1. Determining the sustainable carrying capacity for the species in a range of Brigalow communities and investigating of the long-term effect of high-density wallaby grazing on remnant scrubs.
2. Determining the feeding and sheltering behaviour of the wallaby in their sheltering habitat when cattle are present, and the extent of competition for resources in both paddock and scrub.

3. Establishing reasons for the population's heterogenous distribution. It may be that a habitat type or the availability of food resources has more influence on the species habitat preference than specific structural attributes.
4. Investigating the benefits and disadvantages of different styles of fencing, in terms of providing a barrier to Black-striped wallabies while permitting access to non-target species, and the various costs of materials, building and maintenance.
5. Establishing the effect of completely fencing off an area on the wallabies contained within it and the long-term impacts on the area of shelter habitat.
6. Determining the species' nutritional requirements and how much individual wallabies consume.
7. Investigating the effectiveness/practicality of sacrifice strips (particularly in areas such as Brigalow Research Station where the ability for vegetation manipulation is limited and fencing the remnant would be costly due to the large edge-to-area ratio).
8. Determining the impact of dingo predation on wallaby populations.
9. Studying the practicality and effectiveness of retaining and/or redeveloping fragment connectivity.
10. Investigating the implementation of species management at a landscape scale, integrating the findings of this, and future work, for on-farm management strategies that enables the long-term survival of Black-striped Wallabies but at reasonable low-impact densities.