A Test of the Hutchinson Theory of Interspecific Competition

Richard John William Bosworth
B.Env.Sc. Honours (The University of Adelaide)

Submitted for the Degree of Doctor of Philosophy
In the School of
Animal and Veterinary Sciences,
Faculty of Sciences,
University of Adelaide

January 2012
# Table of Contents

A Test of the Hutchinson Theory of Interspecific Competition ........................................... i
Table of Contents ................................................................................................................. ii
List of Tables ...................................................................................................................... vi
List of Figures ................................................................................................................... viii
Abstract .............................................................................................................................. xx
Declaration ...................................................................................................................... xxiv
Acknowledgements .......................................................................................................... xxv

Chapter 1 General Introduction ........................................................................................... 1
  1.1 Introduction ........................................................................................................... 1
    1.1.1 Project Aims............................................................................................... 6

Chapter 2 Literature Review ................................................................................................ 7
  2.1 Introduction ........................................................................................................... 7
  2.2 Competition ........................................................................................................... 8
    2.2.1 General Competition.................................................................................... 8
    2.2.2 Intra and Interspecific Competition ............................................................ 9
    2.2.3 Resource partitioning .................................................................................. 11
    2.2.4 Dietary overlap ......................................................................................... 12
    2.2.5 Metabolic rate ......................................................................................... 14
    2.2.6 Summary ................................................................................................. 15
  2.3 Hutchinson Theory .............................................................................................. 16
    2.3.1 Background ............................................................................................... 16
    2.3.2 Scientific Debate ....................................................................................... 16
    2.3.3 Competition Models ................................................................................ 18
    2.3.4 Alternative explanations ........................................................................... 19
    2.3.5 Summary ................................................................................................. 20
  2.4 Agricultural expansion ........................................................................................ 21
    2.4.1 Agricultural expansion in Australia and on Kangaroo Island ..................... 21
    2.4.2 Herbivore impact in Australia and Kangaroo Island .................................. 22
    2.4.3 Summary ................................................................................................. 24
  2.5 Species of Interest ............................................................................................... 24
    2.5.1 Tammar Wallaby (Macropus eugenii Desmarest) ....................................... 24
      2.5.1.1 Description.......................................................................................... 25
    2.5.2 Western Grey Kangaroo (Macropus fuliginosus Desmarest, 1817) ............ 26
      2.5.2.1 Description.......................................................................................... 26

9.3 Results ...................................................................................................................... 175
9.4 Discussion ............................................................................................................... 181

Chapter 10 General Conclusion ............................................................................... 185
Appendix 1 Drug use and methods ........................................................................... 191
Appendix 2 Cuticle pictures and pant identification .................................................. 197
References .................................................................................................................. 202

List of Tables

Table 1.1 Thesis Structure .......................................................................................... 6

Table 3.1 Description of the five stages of alpha-chloralose ingestion ...................... 45

Table 4.1 Results of ANOVA analysis (P = 0.05 significance level) of pasture on both
sides of a recently erected boundary fence in Chris’s paddock on a sheep property, Borda
Vale at Cape Borda. Abbreviations: Spr – Spring, Sum – Summer and Aut – Autumn. ..64

Table 4.2 Results of ANOVA analysis (P = 0.05 significance level) of pasture on both
sides of a recently erected boundary fence in High paddock on a sheep property, Borda
Vale at Cape Borda. Abbreviations: Spr – Spring, Sum – Summer and Aut – Autumn. ..65

Table 5.1 List of plant species, common names and corresponding identification codes
from cuticle analysis of plants occurring at the study site. D = Dicotyledon and M =
Monocotyledon. The order is not sequential in the monocotyledon section to enable plants
with the same genus to appear together. ........................................................................... 77

Table 5.2 Diets of four herbivores on the north-western region of Kangaroo Island in
October 2006. Significant results are in bold red and plant species with dashes through the
square indicates the species was not present in the diets. ............................................. 81

Table 5.3 Pianka’s index C on the dietary overlap among Tammar wallaby, Western Grey
Kangaroo, Goat and Sheep in the north-western region of Kangaroo Island during Spring
2006. C = 0 indicates no overlap and C = 1 indicates complete overlap. ....................... 83

Table 5.4 Diets of four herbivores on the north-western region of Kangaroo Island in
January 2007. Significant results are in bold red and plant species with dashes through the
square indicates the species was not present in the diets. ............................................. 86
Table 5.5 Pianka’s index C on the dietary overlap among Tammar wallaby, Western Grey Kangaroo, Goat and Sheep in the north-western region of Kangaroo Island during Summer 2007. C = 0 indicates no overlap and C = 1 indicates complete overlap.

Table 5.6 Analysis results of the diets of four herbivores on the north-western region of Kangaroo Island in May 2007. Significant results are in bold red and plant species with dashes through the square indicates the species was not present in the diets.

Table 5.7 Pianka’s index C on the dietary overlap among Tammar wallaby, Western Grey Kangaroo, Goat and Sheep in the north-western region of Kangaroo Island during autumn 2007. C = 0 indicates no overlap and C = 1 indicates complete overlap.

Table 5.8 Diets of four herbivores on the north-western region of Kangaroo Island in October 2007. Significant results are in bold red and plant species with dashes through the square indicates the species was not present in the diets.

Table 5.9 Pianka’s index C on the dietary overlap among Tammar wallaby, Western Grey Kangaroo, Goat and Sheep in the north-western region of Kangaroo Island during spring 2007. C = 0 indicates no overlap and C = 1 indicates complete overlap.

Table 6.1 Allocation of Condition Scores to animals on the basis of their Condition Score Index.

Table 8.1 Averaged rank value of five test mammals for each species, the lower the ranked value indicated a preference for that food variety.

Table 8.2 Identification number and weights of each wallaby in the oat seed trial from 24th November to 7th December 2008 inclusive.

Table 9.1 A visual summary diagram of absolute morphological features that was significantly different among the four herbivore species. Colour differences across rows signify features that are significantly different between species.

Table 9.2 A visual summary diagram of standardised morphological features that was significantly different among the four herbivore species. Colour differences across rows signify features that are significantly different between species.
List of Figures

Figure 2.1 Female tammar wallabies in the fauna yard pen at the Roseworthy Campus, University of Adelaide.................................................................25

Figure 2.2 Kangaroo Island western grey kangaroos in holding yards at Roseworthy campus, University of Adelaide.....................................................27

Figure 2.3 Merino sheep in a holding yard at the Roseworthy farm, University of Adelaide..........................................................................................29

Figure 2.4 Distribution and density of sheep within Australia. Source www.meares.com.au/resource/sheep01.htm. Accessed (21/8/06)..............................30

Figure 2.5 Feral goats in a holding yard at the Roseworthy campus of the University of Adelaide.........................................................................................31

Figure 3.1 Capturing of the wallabies at Roseworthy campus fauna yards using nets. The wallaby was placed into a hessian bag (in background hung on fence), hung on a frame and transported............................................................................................44

Figure 4.1 Satellite image of the two areas on the north-western side of Kangaroo Island, Cape Borda property, the circled area on the left and De Mole River property, the circled area on the right. Image courtesy of Google maps ............................................................50

Figure 4.2 First study site at Borda Vale, Chris's Paddock. Image courtesy of Google maps .................................................................................................50

Figure 4.3 Second study site on Borda Vale, High Paddock. Image courtesy of Google maps ..................................................................................................50

Figure 4.4 Third study site, Duncan’s Paddock. Image courtesy of Google maps........51

Figure 4.5 Monthly rainfall (mm on Y axis) totals over an 18 month period from May 2006 until October 2007. Months with an asterisk indicate months when pasture assessment occurred...............................................................................................53
Figure 4.6 Monthly mean overnight temperature (on the Y axis is in Celsius) for an 18 month period recorded at Cape Borda weather station which includes pasture assessment months with an asterisk. .......................................................................................................................... 54

Figure 4.7 Monthly mean day temperature (on the Y axis is in Celsius) for an 18 month period recorded at Cape Borda weather station which includes pasture assessment months with an asterisk. ................................................................................................................. 54

Figure 4.8 Percentage cover of moss in the pasture at the three sites in spring 2006 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. .......................................................................................................................... 55

Figure 4.9 Percentage cover of clover in the pasture at the three sites in spring 2006 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. .......................................................................................................................... 56

Figure 4.10 Percentage cover of daisy in the pasture at the three sites in spring 2006 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. .......................................................................................................................... 56

Figure 4.11 Percentage cover of grass in the pasture at the three sites in spring 2006 (P=0.006, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. .......................................................................................................................... 57

Figure 4.12 Percentage cover of bare ground in the pasture at the three sites during summer 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. .......................................................................................................................... 58

Figure 4.13 Percentage cover of moss in the pasture at the three sites in summer 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. .......................................................................................................................... 58

Figure 4.14 Percentage cover of daisy in the pasture at the three sites during summer 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. .......................................................................................................................... 59

Figure 4.15 Percentage cover of bare ground in the pasture at the three sites in autumn 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. .......................................................................................................................... 60
Figure 4.16 Percentage cover of moss in the pasture at the three sites in autumn 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. ................................................................. 60

Figure 4.17 Percentage cover of daisy in the pasture at the three sites in autumn 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. ................................................................. 61

Figure 4.18 Percentage cover of grass in the pasture at the three sites in autumn 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. ................................................................. 61

Figure 4.19 Percentage cover of moss in the pasture at the three sites in spring 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. ................................................................. 62

Figure 4.20 Percentage cover of daisy in the pasture at the three sites in spring 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites. ................................................................. 62

Figure 5.1 Spring diet of sheep in Kangaroo Island’s north-western region in 2006. ....... 78

Figure 5.2 Spring diet of goats in Kangaroo Island’s north-western region in 2006. ........ 79

Figure 5.3 Spring diet of kangaroos in Kangaroo Island’s north-western region in 2006. 79

Figure 5.4 Spring diet of wallabies in Kangaroo Island’s north-western region in 2006. 80

Figure 5.5 Dicotyledon species *Allocasuarina verticillata* P=0.042 (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ................................................................. 81

Figure 5.6 Monocotyledon species *Vulpia myuros* in diets of four herbivores P=0.002 (df = 15). The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ................................................................. 82

Figure 5.7 Monocotyledon genus *Ehrharta* in diets of four herbivores P<0.001 (df = 15). The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ................................................................. 82
Figure 5.8 Summer diet of sheep in Kangaroo Island’s north-western region in 2007.

Figure 5.9 Summer diet of goats in Kangaroo Island’s north-western region in 2007.

Figure 5.10 Summer diet of kangaroos in Kangaroo Island’s north-western region in 2007.

Figure 5.11 Summer diet of wallabies in Kangaroo Island’s north-western region in 2007.

Figure 5.12 Micotyledon species *Acacia leiophylla* in diets of four herbivores $P=0.004$ (df = 14). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

Figure 5.13 Monocotyledon species *Vulpia myuros* in diets of four herbivores $P=0.012$ (df = 14). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

Figure 5.14 Monocotyledon species *Vulpia bromoides* in diets of four herbivores $P<0.001$ (df = 14). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

Figure 5.15 Monocotyledon species *Bromus hordeaceus* in diets of four herbivores $P=0.002$ (df = 14). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

Figure 5.16 Unidentified monocotyledon species in diets of four herbivores $P=0.039$ (df = 14). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

Figure 5.17 Autumn diet of sheep in Kangaroo Island’s north-western region in 2007.

Figure 5.18 Autumn diet of goats in Kangaroo Island’s north-western region in 2007.

Figure 5.19 Autumn diet of kangaroos in Kangaroo Island’s north-western region in 2007.

Figure 5.20 Autumn diet of wallabies in Kangaroo Island’s north-western region in 2007.
Figure 5.21 Dicotyledon species *Trifolium subterraneum* $P=0.001$ (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ................................................................. 94

Figure 5.22 Dicotyledon species *Allocasuarina verticillata* $P=0.038$ (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ................................................................. 94

Figure 5.23 Dicotyledon species *Dodonaea viscosa* $P=0.003$ (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ................................................................. 95

Figure 5.24 Dicotyledon species *Astroloma conostephiodies* $P=0.019$ (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ................................................................. 95

Figure 5.25 Monocotyledon species *Vulpia myuros* in diets of four herbivores $P=0.044$ (df = 15). The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ..................................................................................................... 96

Figure 5.26 Unidentified monocotyledon species in diets of four herbivores $P<0.001$ (df = 15). The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ..................................................................................................... 97

Figure 5.27 Spring diet of sheep in Kangaroo Island’s north-western region in 2007..... 98

Figure 5.28 Spring diet of goats in Kangaroo Island’s north-western region in 2007...... 99

Figure 5.29 Spring diet of kangaroos in Kangaroo Island’s north-western region in 2007. ............................................................................................................................................ 99

Figure 5.30 Spring diet of wallabies in Kangaroo Island’s north-western region in 2007. .......................................................................................................................................... 100

Figure 5.31 Dicotyledon species *Arctotheca calendula* $P=0.045$ (df = 14) in diets of four herbivores. The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species. ..................................................................................................... 101
Figure 5.32 Dicotyledon species *Acacia leiophylla* $P=0.009$ (df = 14) in diets of four herbivores. The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species................................................................. 102

Figure 5.33 Dicotyledon species *Juncus pallidus* $P<0.001$ (df = 14) in diets of four herbivores. The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species................................................................. 102

Figure 6.1 Comparison of mean body weight (kg) in lactating and non-lactating wallabies captured during drought conditions. There were no significant differences between the mean body weights of lactating ($n = 11$, mean ± SEM) and non-lactating ($n = 17$, mean ± SEM) wallabies ($P = 0.104$, ns). .......................................................................................... 114

Figure 6.2 Comparison of the initial mean body weight (kg) of 11 wallabies that were lactating at capture with their mean body weight after six months non-lactating on a high quality diet (Paired T-Test $P < 0.001$, SEM = 0.330) ............................................................................... 114

Figure 6.3 Comparison of the initial mean body weight (kg) of 17 wallabies that were non-lactating at capture with their mean body weight after six months on a high quality diet (Paired t-test $P = 0.047$, SEM = 0.191) ........................................................................ 115

Figure 6.4 Change in the spectra of condition scores of wallabies captured during a drought and after 6 months on high quality feed ................................................................. 116

Figure 6.5 Correlation between CSI (Condition Score Index) on the Y axis and KFI (Kidney Fat Index) on the X axis ($R^2 = 0.48$) ................................................................................. 116

Figure 6.6 Relationship between CSI (Condition Score Index) on the X axis and left perirenal fat mass (Standardised Fat Index) on the Y axis ($R^2 = 0.52$). ................................. 117

Figure 6.7 Correlations between CSI (Condition Score Index) on the X axis and CMI (Crus Muscle Index) on the Y axis. A quadratic line has been fitted ($R^2 = 0.94$) to define the point of inflection to define the boundary between CS2 and CS3. Whilst a second linear line has been fitted ($R^2 = 0.76$) highlighting the relationship between CSI (Condition Score Index) and CMI (Crus Muscle Index) >CSI 7.9 ................................................................................. 117

Figure 7.1 Diagram of pen layout. Each single species pen had 4 animals except for wallaby pen that had 16 animals and had approximately similar grazing pressure to the 3 and 4 species pens. Mixed 4 spp. pens contained 1 kangaroo, 1 goat, 1 sheep and 4
tammar wallabies while the mixed 3 spp. pens contained 1 kangaroo, 1 goat and 1 sheep.

Figure 7.2 Mean rye grass plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.578 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.3 Mean young Oat grass plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.929 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.4 Mean caltrop plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.82 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.5 Mean lucerne plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.681 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.6 Mean marsh mallow plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.23 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.7 Mean potato weed plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.46 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.8 Mean wire weed plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.282 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.9 Mean potato weed plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.8 at 0.05 significance level, means + SEM, df = 5) there was no significant difference between species pens.

Figure 7.10 Potato weed mean weight (g) between 3 species and 4 species pens (P = 0.161 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.
Figure 7.11 Lucerne plant mean wet weight (g) between 3 species and 4 species pens (P = 0.111 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens. .............................................................. 134

Figure 7.12 Rye grass plant mean weight (g) between 3 species and 4 species pens (P = 0.11 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens. .............................................................. 134

Figure 7.13 Caltrop mean weight (g) between 3 species and 4 species pens (P = 0.207 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens. .............................................................. 134

Figure 7.14 Marsh Mallow mean weight (g) between 3 species and 4 species pens (P = 0.32 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens. .............................................................. 135

Figure 7.15 Wire weed mean weight (g) between 3 species and 4 species pens (P = 0.002 at 0.05 significance level, means + SEM, df = 5). A significant difference was detected between species pens indicated by different alphabetical characters. ...................... 135

Figure 7.16 Mean number of Lucerne plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P <0.001 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ....... 136

Figure 7.17 Mean number of Rye grass plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ....... 136

Figure 7.18 Mean number of young Oat grass present (m²) in all single species and control pens (P = 0.259 at 0.05 significance level, means + SEM, df = 69). Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ....... 137

Figure 7.19 Mean number of Caltrop plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P = 0.024 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ....... 137
Figure 7.20 Mean number of Marsh mallow plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P = 0.013 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. .......................................................................................................................................... 138

Figure 7.21 Mean number of Potato weed plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC......... 139

Figure 7.22 Mean number of Wire weed plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ....... 139

Figure 7.23 Mean weight (g) of Lucerne plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ....... 140

Figure 7.24 Mean weight (g) of Rye grass plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means ± SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ....... 140

Figure 7.25 Mean weight (g) of young Oat plants present (m²) in all single species and control pens. No significant differences (P = 0.379 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC........................................................ 141

Figure 7.26 Mean weight (g) of Caltrop plants present (m²) in all single species and control pens. No significant differences (P = 0.67 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ................................................................. 141

Figure 7.27 Mean weight (g) of Marsh mallow plants present (m²) in all single species and control pens. No significant differences (P = 0.92 at 0.05 significance level, means +
Figure 7.28 Mean weight (g) of Potato weed plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ....................................................... 142

Figure 7.29 Mean weight (g) of Wire weed plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC. ....... 143

Figure 8.1 Mean time spent in seconds by wallabies (n=5, df = 19) at the food range available (P = 0.01 ± SEM). The different alphabetical characters indicate significant differences (P<0.05) among the fodder varieties. ............................................................ 153

Figure 8.2 Mean number of bites taken by wallabies at each variety of the food range offered (P = 0.01 ± SEM, n=5, df = 19). The different alphabetical characters indicate significant differences (P<0.05) among the fodder varieties. .................................................... 154

Figure 8.3 Mean number of steps taken by wallabies to reach each variety of the fodder range offered (P = 0.13, n=5, df = 19). ............................................................................ 154

Figure 8.4 Mean time spent in seconds by kangaroos at the food range available (P = 0.003 ± SEM, n=5, df = 19). The different alphabetical characters indicate significant differences (P<0.05) among the fodder varieties. ............................................................ 155

Figure 8.5 Mean number of bites taken by kangaroos at each variety of the fodder range offered (P = 0.203, n=5, df = 19). .................................................................................... 156

Figure 8.6 Mean number of steps taken by kangaroos to reach each variety of the food range offered (P = 0.028 ± SEM, n=5, df = 19). The different alphabetical characters indicate significant differences (P<0.05) among the fodder varieties. ............................ 156

Figure 8.7 Mean time spent in seconds by goats at the fodder range available (P = 0.251 ± SEM, n=5, df = 19). ................................................................................................. 157
Figure 8.8 Mean number of bites taken by goats at each variety of the food range offered (P = 0.403 ± SEM, n=5, df = 19). ................................................................. 158

Figure 8.9 Mean number of steps taken by goats to reach each variety of the food range offered (P = 0.537 ± SEM, n=5, df = 19). ..................................................... 158

Figure 8.10 Mean time spent in seconds by sheep at the selection of fodder available (P < 0.001 ± SEM, n=5, df = 19). The different alphabetical characters indicate significant differences (P<0.05) amongst the fodder varieties. ..................................................... 160

Figure 8.11 Mean number of bites taken by sheep at each variety of the food range offered (P < 0.001 ± SEM, n=5, df = 19). The different alphabetical characters indicate significant differences (P<0.05) among the fodder varieties. ........................................... 160

Figure 8.12 Mean number of steps taken by sheep to reach each variety of the food range offered (P = 0.005 ± SEM, n=5, df = 19). The different alphabetical characters indicate significant differences (P<0.05) among the fodder varieties. ........................................... 161

Figure 8.13 Standardised time percentage each of the four herbivore species spent consuming the pasture plant Lucerne. ......................................................... 162

Figure 8.14 Standardised time percentage each of the four herbivore species spent consuming the pasture plant Rye grass. ......................................................... 162

Figure 8.15 Standardised time percentage each of the four herbivore species spent consuming the pasture plant Oat grass. ......................................................... 163

Figure 8.16 Standardised time percentage each of the four herbivore species spent consuming Oat seeds. ................................................................. 163

Figure 8.17 Wallaby weight in kg at each weighing period for the oat trial. .................. 166

Figure 8.18 Mean weight (kg) loss of wallabies (n = 6) at the data collection days compared to the mean of initial weight. Each weighing day recorded significant weight loss. The different alphabetical characters indicate significant differences (P <0.001 at the 0.05 significance level, means ± SEM, df = 5) among weighting times. .................... 166

Figure 8.19 Change in wallaby condition score over the duration of the oat seed trial. Numbers on the X axis represent the wallaby while numbers on the Y axis represent Condition Scores (CS). ................................................................. 167
Figure 8.20 Total percentage of weight loss for each wallaby during the oat trial. The wallaby order is the same as fig. 8.19. ................................................................. 168

Figure 9.1 Comparison of the four test species’ mean body weight (kg). Different alphabetical characters indicate significant differences (P <0.001 at 0.05 significance level, means + SEM, n=20, df = 19) among species. ................................................................. 175

Figure 9.2 Average lip length (mm) of of the four species (P <0.001, means + SEM, n=20, df = 19). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species........................................................................ 176

Figure 9.3 Standardised lip length (mm) to body weight (kg) (P = 0.036, mean + SEM, n=20, df = 19). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species........................................................................ 176

Figure 9.4 Mean left incisor/pad row length (mm) (P <0.001, means + SEM, n=20, df = 19). Different alphabetical characters indicate significant differences (P <0.001 at 0.05 significance level) among species........................................................................ 177

Figure 9.5 Standardised incisor row length (mm) to body weight (kg) of the four test species (P<0.001, mean + SEM, n=20, df = 19). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species........................................... 177

Figure 9.6 Mean tongue length (mm), n=20, df = 19. Different alphabetical characters indicate significant differences (P <0.001 at 0.05 significance level, means + SEM) among species................................................................. 178

Figure 9.7 Standardised tongue length to body weight of the four test species (P<0.001, mean + SEM). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species................................................................. 178

Figure 9.8 Mean lower jaw width (mm) (P<0.001, means + SEM), n=20, df = 19. Different alphabetical characters indicate significant differences (at 0.05 significance level) among species ................................................................. 179

Figure 9.9 Standardised width of dental arcade to body weight of the four test species (P<0.008, mean + SEM). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species................................................................. 179
Abstract

Kangaroo Island is of high conservational significance with the largest remaining interface between native vegetation and agriculture in South Australia. The two main native herbivores on Kangaroo Island are the western grey kangaroo and the tammar wallaby. Two introduced herbivores, sheep and feral goat, also contributed to the study. All animal species coexist in the north western districts of Kangaroo Island. All species coexisted at the Borda Vale property, Cape Borda and Correll property de Mole River field sites.

Competition between mammals on Kangaroo Island was investigated to determine if the Hutchinson Theory of Interspecific Competition could be either rejected or not-rejected. Hutchinson’s theory states that an animal needs to be at least 2.1 times either larger or smaller in body weight than another competitor in the same environment to escape the influences of interspecific competition. The current investigation was two pronged; comprising field studies with subsequent analysis of plant cuticles from faecal matter, and secondly scientific trials on the mainland held at The University of Adelaide, Roseworthy campus, South Australia. The in situ field studies involved collecting faecal samples from each species and pasture comparison at three sites. The pasture structure on both sides of the recently erected boundary fence at two sites on Borda Vale was determined. Plant cuticles from faecal samples provide insight to the dietary composition for each species, and any dietary overlap between species. The body condition of all herbivores in the trial was assessed prior to the pen trials. Recognised body condition assessment methods for sheep and goat were available, but not for the macropods. Therefore, a condition score system (CS) was devised utilising biological indices as the basis of the CS system. Pen
trials included species-specific pens and mixed species pens, a total of eleven half hectare pens. Each pen had the same pasture plant structure with a plant survey determining the level of competition among the four species. A palatability/cafeteria trial of the pen plant species was undertaken by placing replicated plant specific pots in a test arena to record food preference for each animal species. Animals from each of the four species had mouth characteristic data recorded to detect any morphological differences which could provide an alternative explanation to the Hutchinson theory.

Pasture at all three sites fluctuated with seasonal condition, with the exception of bryophytes, that were only present in pastures on Borda Vale. The dietary overlap results (average \( C 0.14 \)) indicated a low dietary overlap among the four herbivores throughout the four seasons. However, the greatest average seasonal dietary overlap result was between pairs of herbivores, occurring in spring \((C 0.76 \text{ and } C 0.85)\), when regrowth is at its greatest. In summer \((C 0.70)\) and autumn \((C 0.67)\) the dietary overlap decreased slightly, due to diversification of plant species eaten, with the increase of native browse vegetation in the diet. The wallaby, the smallest competitor, is in direct competition with the three larger competitors, with the greatest competition for resources being with the kangaroo \((C 0.90)\) throughout the seasons.

The condition score (CS) indices were applied to both macropods. However; the focus was mainly on the CS system for the tammar wallaby. The development of the CS system included four body indices. The system has five condition score levels, ranging from level one, representing an animal in very poor body condition, to level five, representing an animal in optimal condition. The boundary between being fit for this trial work and not fit occurred at CS 2 and CS 3. Locomotive performance was impaired below CS 3.
Therefore, animals that failed to achieve CS 3 status were rejected from inclusion in the trials.

The two pen trials, one replicated and one pseudo-replicated, indicated that all herbivore species ate all of the pasture species on offer. Only a proportion of the competitive interactions between the mammalian grazing herbivores of Kangaroo Island were consistent with the predictions of the Hutchinson Theory. The results of the study produced some instances in which the smallest animal was the more effective forager. In several instances, no differences were detected, and in two instances (*Althaea officinalis* and *Heliotropium europaeum*) two of the larger grazers were more effective than the wallaby. Also, there was an instance in which one large herbivore had an advantage over another large herbivore for *Tribulus terrestris*. However, it appeared that the wallaby ate none of the oat grain (*Avena sativa*) even though it was the most abundant potential food source available in the trial pens. Further investigations of the palatability of fodder in the pen trial are indicated.

Further investigation into the association between the wallaby and ingestion of oat grain were undertaken. Wallabies ate oat grain only as a last resort, and were not able to maintain good body condition on a diet of oats. The finding that wallabies find oat grain unpalatable has ramifications for the farmers and conservation management on Kangaroo Island during drought condition, when hand feeding of oat grain is the major form of supplementary feeding of sheep.

Many factors may explain the lack of support for the Hutchinson Theory of size displacement in this study. The absolute morphological characteristics of lip length, incisor length, tongue length and lower dental arcade width of the wallaby were
statistically smaller than all the larger herbivores species in this study. Although the morphological differences (corrected for scale) in mouth structures revealed some statistically different characteristic among the four herbivores with no wallaby characteristic being statistically smaller or larger than all of the larger herbivores species. Other factors that could explain species diet separations, thereby reducing direct competition, are discussed including, height of reach, eye sight, height of vegetation preferences, temporal and diurnal separation.

The Hutchinson Theory is not supported in the current field study either, with the wallaby clearly in direct competition with the three larger herbivores on Kangaroo Island with the greatest competitor of the wallaby being the kangaroo. The pen trials only provided weak support for the Hutchinson Theory which provides only one explanation of competitive separation. Therefore, this theory is simplistic when there are many alternative explanations that allow dietary separation and reduce direct interspecific competition. This research highlights management issues that have important implications for the farmer and conservation managers on Kangaroo Island.
Declaration

This work is the result of my own investigation. The content herein has not been accepted for the award of any other degree or diploma in any university or other tertiary institution to Richard Bosworth and, to the best of my knowledge and belief, contains no material previously written or published by any other persons except where due reference is made in the text.

I give my consent for this thesis when deposited in the University Library, being made available for loan or photocopying, subject to the provisions of the Copyright Act 1968.

I also give permission for the digital version of my thesis to be made available on the web, via the University’s digital research repository, the Library catalogue, the Australian Digital Thesis Program (ADTP) and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

Richard Bosworth

January 2012
Acknowledgements

The birth of the Aboriginal Flag occurred at Tarndanyangga / Victoria Square, Adelaide, in July 1971 at a land rights rally. Later that same year, the Aboriginal Flag was flown at the Aboriginal Tent Embassy in Canberra. Today, the Aboriginal Flag has become a powerful symbol for Reconciliation and hope for many Indigenous and non-Indigenous people throughout Australia.

The Aboriginal Flag was designed by Harold Thomas. Harold is a Luritji man who currently resides in the Northern Territory. Harold was born in Alice Springs and was the first Aboriginal person to graduate from an Australian Art School.

The Aboriginal Flag is divided horizontally into two equal halves of black and red, with a yellow circle in the centre. The black symbolises Aboriginal people; the red symbolises the mother earth and the ochre, which is used by Aboriginal people in ceremonies, the yellow, the sun, the constant giver and renewer of life.

I would like to acknowledge the Ngarrindjerri and Kaurna people who are the traditional owners of the land where my research work was conducted and completed. I am also very respectful of the sensitivity of conducting research on a sacred site and I am grateful for...
the Elders of the Ngarrindjerri Nation for giving me permission to access Kangaroo Island, for without this permission I would not have undertaken this research project.

Throughout my tertiary educational journey, Wilto Yerlo at the University of Adelaide has provided cultural support, a sense of where I belong and personal support without any reservations since 2000, when I started this journey with the Foundation Science course.

To Professor Roger Thomas, Dean of Aboriginal Education: Wilto Yerlo and the whole team both past and present, thank you. Daniel Turner your support and friendship have made this journey possible, you have always had a friendly ear to listen to my problems (except when you have been on bloody holidays) and I sincerely thank you with all of my being. To all the members of the Indigenous Research Focus Group, thank you, for your words of wisdom, encouragement and cultural grounding.

To my supervisory team Dr Philip Stott and Professor Gordon Howarth thank you for your help, assistance and advice through my candidature. I am eternally grateful to Phil who passed on so much knowledge in dealing with the many animal husbandry problems that arose with the four herbivore species both wild and domestic.

Financial support has been a vital component for my research, for without the support this research would not have been possible. I am very proud and yet humbled and astounded to be the first Indigenous PhD Candidate in the Faculty of Sciences at the University of Adelaide. The University of Adelaide through the Faculty of Sciences has provided a Divisional Scholarship for my living cost for the three and a half years of my research, while the Federal Government has provided essential assistance for both living expenses through Abstudy and my total project cost through the Discovery Indigenous Researchers Development Grant from the Australian Research Council.
This project was authorised by the University of Adelaide Animal Ethics Committee, approval numbers S-103-2006 and S-047-2008 and scientific research permit for the capture and keeping of wildlife from the Department for Environment and Heritage, permit number G25303.

To the staff at Animal and Plant Control Board on Kangaroo Island, especially Keith Hodder and Pip Masters, thank you for your assistance in helping me to find property owners where all four herbivore species were present, and were also willing to help with this research. Property owners Duncan and Coral Correll at Western River and Borda Vale manager Neil and Annie Arnald at Cape Borda, thank you for hospitality and for providing access to your properties for faecal collection on the many occasions, enabling the establishment of the extent of competition in the area.

Thank you to all of the people, too many to name individually, that have assisted with this project in various ways, your contributions were very much appreciated.

To my family; especially Lois, my wife and life partner: I am grateful to you all for your love, encouragement and patience. Thank you for your understanding and always being there for me. Lois you are my rock and an inspiration to me by the way you push through adversity and never let your health issues prevent you from providing assistance to my project when required. I am eternally grateful for your companionship during the field trips on Kangaroo Island and your assistance with capturing and handling of my research animals.
Chapter 1

General Introduction

1.1 Introduction

Australian species represent only a small percentage of the estimated world’s mammals. Most are the descendants of the original monotremes and marsupials that were present when the southern super-continent of Gondwana fractured into land masses of today including Australia. Eutherian mammals colonised Australia by chance via island hopping (rodents) and flying (bats) from Asia in the late Cenozoic era (Cox 2000). Before European colonisation of Australia (in 1788) the majority of mammals were marsupials, which are grouped into four orders, and one order of monotremes, with most species endemic to Australia (Van Dyck and Strahan 2008).

European agriculture and pastoral practices have had profound effects on the Australian environment, with soil erosion, soil salinity, loss of flora, and extinction of fauna (Graetz and Wilson 1984; Leigh and Wilson 1970). Large scale clearing of flora resulted from the introduction of cropping, and extensive grazing by introduced eutherian mammals (rabbits *Oryctolagus cuniculus*, hares *Lepus europeaus*, sheep *Ovis aries*, cattle *Bos primigenius*, pigs *Sus crofa*, goats *Capra hircus*, horses *Equus caballus*, donkeys *Equus asinus* and camels *Camelus dromedarius*) with most species escaping and establishing feral populations (worldwide and in Australia) (Bradshaw, Field *et al.* 2007; Carrion, Donlan *et al.* 2007; McCann and Garcelon 2008), which have increased grazing pressure on the remaining native vegetation (Graetz and Wilson 1984).
The associated loss of habitat has led to mammal extinction and reduced habitat range and quality for other mammal species. The establishment of open sown pastures and extra watering points for the introduced domesticated herbivores in Australia has altered the environment in favour of some native herbivore species, while disadvantaging others to the point that they have been forced into extinction (Pople and Grigg 1999).

Increases in populations of some native mammal species, along with establishment of feral populations of introduced mammals, has resulted in increased inter-specific competition for food resources on land grazed by domestic stock, either on cleared pastures in higher rainfall regions or on native pastures in more arid inland areas where artificial stock watering points have resulted in population explosions in certain kangaroo species (Pople and Grigg 1999; Underhill, Grigg et al. 2007). The environmental factor limiting kangaroo populations was changed from water availability to food availability.

Current management practice to control the total grazing pressure in areas of increased macropod populations is by culling those native species perceived to be in direct competition with domestic stock (Pople and Grigg 1999). There is known dietary overlap between some native and domestic herbivores, but studies of the full extent of competition between all native species has only been based on larger native herbivores. The presence or absence of dietary overlap among a group of herbivores alone does not provide conclusive evidence of competition (Connell 1980). The existence of dietary overlap, can be an indication of a low degree of interspecific competition as the species could tolerate the overlap due to evolutionary divergence had taken place in the past (Connell 1980). However, the absence of dietary overlap can also indicate a strong segregation in diet composition, or be a sign that the competition for resources among species is high (Connell 1980).
The culling of macropod species to reduce the perceived direct competition with domestic stock should be replaced with the native species being incorporated into the farming or pastoral enterprise substituting the domestic stock (Chapman 2003; Cooney, Baumber et al. 2009; Sales and Dingle 1998). A very good example is the culling of kangaroos harvested for human and pet consumption, both domestically and internationally. This adds to the national economy. As discussed previously, the full extent of direct competition between native and introduced mammals has not been investigated with respect to smaller native herbivores in the same habitat.

Hutchinson (1959) proposed that coexistence of species in the same habitat, competing for the same resources, was possible by differences in length of identical morphological features: those features were required to be 1.3 x longer or shorter than a competing species to avoid inter-specific competition. The length ration can be extrapolated to a weight ratio of 2.1 and these ratios continue to occupy ecologists today (Millien 2004; Parra, Loreau et al. 1999). Nevertheless, there has been no unequivocal support for Hutchinson’s theory. This is discussed in greater detail in Chapter 2.

Examples of coexistence of species with similar requirements can be found world-wide for many species including mammals (Homolka 1987; Jarman 1971; Li, Jiang et al. 2010; Li, Jiang et al. 2008; Matthews, Neiswenter et al. 2010), birds (Riegert, Lovy et al. 2009), carnivorous plants and spiders (Jennings, Krupa et al. 2010), fish (Teixeira and Cabral 2010) and amphibians (Crawford, Shepard et al. 2009; Willson, Winne et al. 2010). In South Australia, kangaroos, sheep and feral goats graze on the same pastures in the arid inland. Kangaroo Island (KI), in South Australia, represents the largest interface between agriculture/pastoralism and native vegetation in South Australia. KI is inhabited by
kangaroos, wallabies, and sheep grazing on improved pastures, with feral goats added to the herbivore mix mainly in the north western areas of the island. Three of the KI herbivore species have an adult weight range that overlaps (within the 2.1 ratio range) while the fourth species, the tammar wallaby, is more than 2.1 × less than the larger herbivores.

The description, adult weight range and diet of each of the four KI herbivore species are discussed in expanded detail in the ensuing chapter (Chapter 2). The capture methods utilised to transport the macropod species throughout the study are discussed in Chapter 3.

Kangaroo Island herbivore populations were selected for this study due to the size structure between the four main herbivores of the island and the relative ease of access to sites where all four species coexist. Furthermore, the management of these species is vital for agriculture/pastoralism and conservation of native vegetation in what is one of Australia’s 15 biodiversity “hot spots” (Anon 2004).

Investigation of inter-specific competition between the mammalian herbivores of KI was carried out utilising a field study over a 12 month period on the island itself and in manipulated pen trials at the Roseworthy campus of the University of Adelaide. The field study involved pasture biomass structure at each site (Chapter 4) and collection of faecal matter and reference plants to identify plants consumed by cuticle analysis (Chapter 5). Developing a condition score system was required to ensure the macropods were physically fit to be included in the pen trials, similar to current condition scoring systems for domestic animals (Chapter 6). Pen trials involved replicated mixed species pens and pseudo-replicated single species pens with a central ungrazed lane way as the control.
Greater detail is provided in **Chapter 7**. To validate the grazing pen trials, a palatability trial of sown plants and seed fodder (studied in the pen trial **Chapter 7**) was conducted, with further investigation involving the tammar wallaby and the palatability of oat grain (**Chapter 8**). Discussion into alternative explanations of interspecific competition between herbivores other than the Hutchinson theory is explored in **Chapter 9**. The last chapter (**Chapter 10**) provides general discussion of the entire study.
1.1.1 Project Aims

This study aimed to determine whether the characteristics of the interactions between selected mammalian herbivores (tammar wallaby *Macropus eugenii*, western grey kangaroo *Macropus fuliginosus*, feral goat *Capra hircus* and sheep *Ovis aries*) on Kangaroo Island were consistent with the Hutchinson Theory of Interspecific Competition. This project tested the Hutchinson Theory utilising a three-pronged approach. Firstly, an observational component provided the baseline of interspecific competition between the four herbivore species studied in their natural environment without any interference from the collection team. Secondly, it carried out pen trials to test the Hutchinson theory using mixed herbivore species pens and single species pens. Thirdly, a palatability trial aimed to verify the results from the experimental testing of the Hutchinson Theory. Further investigations would be proposed if there were any anomalies associated with either the Hutchinson or palatability trials.

Table 1.1 Thesis Structure

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2</td>
<td>Review of Literature</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Capture Methods</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Pasture Assessment on Kangaroo Island</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Dietary Overlap of Four Herbivores on Kangaroo Island</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Condition Score</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Competition Trials</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>Food Preference of Four Kangaroo Island Herbivores</td>
</tr>
<tr>
<td>Chapter 9</td>
<td>Alternative Explanation</td>
</tr>
<tr>
<td>Chapter 10</td>
<td>General Discussion</td>
</tr>
</tbody>
</table>
Chapter 2

Literature Review

2.1 Introduction

This literature review focuses on areas of investigation including competition and in particular interspecific competition between herbivores, with Kangaroo Island, Australia as a focus. The review examines:

- The problems caused by the interface between agriculture/pastoralism and the native vegetation on both mainland of Australia and on Kangaroo Island. The four mammalian species of interest were:
  - Tammar wallaby (Macropus eugenii)
  - Western grey kangaroo (Macropus fuliginosus)
  - Goat (Capra hircus)
  - Sheep (Ovis aries)

- These species will be studied in relation to competition, diet and distribution in Australia and on Kangaroo Island.

- The Hutchinson theory of interspecific competition. Discussion on the Hutchinson theory and the debate that has risen since the initial hypothesis was proposed by Hutchinson in 1959, that animals of differing length and size ratios are able to escape interspecific competition.

- The methods utilised for determining the ability of a pasture to provide sustenance to all the herbivores both domestic and native.

- Investigations of the most appropriate methods of capture of all the herbivores species in this research study, in captivity and in their natural habitat.
• Once captured, the methods of determining if an individual animal is fit enough to be included in the proposed trial.

2.2 Competition

2.2.1 General Competition

Since the development of single and multi-cellular organisms, there has been competition for the same resource, to varying degrees. If two species have identical realised niche requirements, and are in the same habitat, then the competitive exclusion principle will apply if one species has an advantage, however slight, over its competitor. Eventually this will result in extinction of the second competitor, unless it undergoes an evolutionary shift towards a different ecological niche in that habitat, or face extinction (Namgail, van Wieren et al. 2010). Grinnell (1924) was the first to use the word ‘niche’ to describe ecological positions of species in nature, and Elton (1966) developed the framework of niche theory in relation to food webs of species. However, Hutchinson and Mac Arthur (1959c; Stephenson, Bleich et al. 2002) described the ecological niche as a hypervolume and multi dimensional, a development that Vandermeer (1972) regarded as revolution in niche theory. The combination of these concepts of “niche” provides a total overview of what resources needed for each species to exist and therefore, can be described as its ecological or environmental niche (Vandermeer 1972). According to Arlettaz et al. (1997), niche theory predicts that stable coexistence of species within a community would require a mechanism of resource partitioning when resources are limited. The coexistence of four grazing herbivores on Kangaroo Island, therefore, implies that some form of resource partitioning occurs.

Resource partitioning develops in many ways and forms with each particular form related to responses by organisms to competition. Competition has been considered a
fundamental biotic process that has directly influenced the abundance and distribution of species since the development of single and multi-cellular organisms (Connell 1983; Huitu, Norrdahl et al. 2004). Competition for resources has a detrimental effect on an organism growth rate in relation to the increased density of another species when in direct competition (Huitu, Norrdahl et al. 2004). One such mechanism of resource partitioning occurs when natural or man-made geographical features limit the access of one or more species from accessing a resource, for example a boundary fence and dams (Wang, Huang et al. 2010).

At least five different competition interactions can affect a species: intraspecific, interspecific, interference, exploitative and diffuse (Ricklefs and Miller 1999). Each type of competition has different effects on any one population or species.

2.2.2 Intra and Interspecific Competition

Intraspecific competition is the term for competition between individuals of the same species and is an underlying factor determining population size and may induce evolutionary changes to the species’ genotype (Ricklefs and Miller 1999), whereas interspecific competition represents competition between different species which may also induce evolutionary changes resulting in niche separation (Hutchinson 1959; Newsome 1971; Sinclair 1985; Wilson 1991b). Interference competition represents the action of one individual preventing another individual from accessing a resource. Interference competition can be expressed by aggressive behaviour (Faas and Weckerly 2010), and can be both interspecific and intraspecific. Heller (1971) documented interspecific aggression amongst four different species of chipmunks due to overlapping fundamental niches. Furthermore, adult rabbits, both male and female, express intraspecific aggression at different space and time (Mykytowycz and Dudzinski 1972).
Male rabbits use aggression to establish and maintain the social hierarchy, and in defence of its territory and associated resources. Female rabbits are aggressive towards kittens of other females, which has been associated with injury, and kitten death, thus preserving a greater share of available resources for her kittens. Ricklefs and Miller (1999) indicated that exploitative competition results in different species exploiting the same resource, but at a different space and time whereas diffuse competition is associated with many species that are all competing simultaneously for a range of resources.

Interspecific competition between domestic (sheep and cattle) and native (kangaroo) herbivores has been investigated by many authors (Andrew and Lange 1986; Edwards, Croft et al. 1996; Newsome 1971; Squires 1982; Wilson 1991a; Wilson 1991b) in the rangelands of mainland Australia and worldwide, for example, livestock and wild ungulates in India (Dave and Jhala 2011). All the Australian studies indicated that when resources in the grazing areas of mainland Australia become restricted, herbivore diets change to reflect plant availability, with increasing dietary overlap and greater interspecific competition for the limited resource. Other authors have examined interspecific competition amongst herbivores and other mammals in other parts of the world (Eccard and Ylonen 2003; Faas and Weckerly 2010; Hibert, Calenge et al. 2010; Huitu, Norrdahl et al. 2004; Hutchinson and MacArthur 1959b; Latham 1999; Sinclair 1985; Young, Palmer et al. 2005) and found that fierce competition for resources plays a vital role in the development and survival of all organisms.

Sinclair (1985) studied the forces that shape the African ungulate community, concluding that both interspecific competition and predation influence the structure of the ungulate community to differing degrees, depending on the species. Most herbivore species had dietary overlap with other herbivore species but were predated in greater numbers.
Therefore, predation was the main driving force. All herbivore species studied had varying degrees of each process, interspecific competition and predation, indicating that both processes played a role in structuring of the ungulate community. Sinclair (1985) stated that interspecific competition is no longer the theoretically dominating evolutionary process for the African ungulate community. Another process which permits coexistence between competitors in the African ungulate community is competitive disequilibrium. It can only apply between two species that live long enough to span cyclic environmental variations. The two species are direct competitors, but one has the advantage either seasonally or during a particular phase of the circadian light cycle (Drabek 1994; Harrington and MacDonald 2008; Neale and Sacks 2001). However, an overview of ungulate communities in European forests, with respect to interspecific competition between species concluded that interspecific competition is a major driving force for the ungulate community, especially when large predators are generally absent from the system and rarely influence the structure of the ungulate community (Latham 1999).

### 2.2.3 Resource partitioning

Competition has led to resources being partitioned such that many organisms are able to coexist in a habitat at the same trophic level. The Niche theory combines both concepts from Grinnell (1924) and Elton (1966) to provide a total overview of the requirements of each animal to exist, therefore describing the ecological or environmental niche (Vandermeer 1972). The Grinnell (1924) concept described an animal’s ecological position in nature, stating that the niche is the distribution unit of a species, while the Elton (1966) concept determined that the food web of an animal constituted the framework to describe its niche.
The size of an organism plays an important role in its distribution and associated niche breadth (Gardezi and da Silva 1999). The largest divergences of mammal populations are from small bodied mammals and small bodied taxa have a greater number of niches compared to larger bodied mammals. The presence of larger and dominant species forces the subordinate species to narrow its realized niche in the presence of the dominant species and it therefore becomes a specialist thereby reducing the niche overlap with the dominant species (Morse 1974). When there are multiple species present that have dominant periods, all species will modify/reduce their realized niche breadth when all are present (Haken and Batzli 1996; Morse 1974; Stewart, Bowyer et al. 2002) while Hutchinson (1959) advocates there is an unequivocal relationship between the size of the animal and the number of micro habitats utilised.

Climatic conditions and ecological events strongly affect resource partitioning along with evolutionary forces (Meserve 1981). Resource partitioning for herbivore species can occur in relation to the slope of the terrain, elevation, difference in the vegetative communities and levels of human activity (Stewart, Bowyer et al. 2010; Stewart, Bowyer et al. 2002). Vegetative growth is due to climatic conditions, and the height of the plants utilised by herbivores also plays a role in the resources being partitioned (Voeten and Prins 1999).

### 2.2.4 Dietary overlap

For competition to be an evolutionary force, or to force resource partitioning between organisms, there needs to be an overlap of the required resources for the organisms. To better understand dietary overlap, analysis of each organism diet preference will need to be undertaken (Haken and Batzli 1996; Meserve 1981; Newsome 1971; Wilson 1991b; Woolnough and Johnson 2000). Either high or low dietary overlaps among competing
animals alone does not provide strong evidence of competition, hence the “ghost of the past” (Connell 1980; Connell 1983; Dugger, Anthony et al. 2011; Rabosky, Cowan et al. 2011) Dietary overlap is not always constant throughout a given period of time; it fluctuates at different times of the year and when different resources are available, while some organisms are able to vary their diet to compensate and negate the extra pressures due to competition (Robley, Short et al. 2001). The response of organisms to the overlap in required resource manifests in a variety of ways (mentioned previously) to reduce or avoid competition. Organisms need to have at least 1 food item that they have a competitive advantage that can be a refuge at critical times when competition due to dietary overlap is at its greatest (Homolka 1987; Jarman 1971; Robley, Short et al. 2001). Organism that have only a small percentage of available resources in their diet will experience extensive overlap compared to organisms which have a greater percentage of available resources in their diet (Jarman 1971) and organisms that contain minimal dietary overlap would experience minimal competition (Robley, Short et al. 2001). Models have been used to indicate or predict the levels of dietary overlap between organisms (Feinsinger, Spears et al. 1981; Fortin, Boyce et al. 2004). Models are able to indicate that dietary overlap of foraging animals can buffer the effects of competition and buffer the intake rate from food patch depletion (Fortin, Boyce et al. 2004). This buffering allows for each competing organism to survive in the face of competition, provided that dietary overlap is not total. A degree of similarity between the frequency distribution of resources utilised by a population and the frequency distribution of the total resources available, and quantified as Proportional Similarity (PS) Index to model dietary overlap (Feinsinger, Spears et al. 1981; La Morgia and Bassano 2009; Li, Jiang et al. 2008; Parkes and Forsyth 2008; Torstenson, Mosley et al. 2006).
2.2.5 Metabolic rate

The metabolic rate of animals is not constant through the animal kingdom. Metabolic rate influences the dietary intake of each animal along with other physiological characteristics (McNab 2005), and differing metabolic rates also provide an advantage if the metabolic rate of one competitor is lower than another. Animals that have evolved low basal metabolic rates usually lose less heat through conductance and this combination facilitates energy conservation, especially when there is a limited energy resource available (Mc Nab 2002).

Marsupials maintain a lower basal metabolic rate than the eutherians, with no marsupial species sustaining a high basal metabolic rate by mammalian standards (Mc Nab 2005). The Australian native marsupials, including the kangaroo, maintain a basal metabolic rate between 0.72 and 0.75 mL O₂ h⁻¹ (Withers, Cooper et al. 2006) while the introduced eutherian competitor, the sheep, possesses a basal metabolic rate that is 30% higher than the marsupial (Dawson and Hulbert 1970; Dawson, Munn et al. 2000). The kangaroo is therefore a more efficient grazer on Australian rangelands because it requires less herbage to survive than the sheep, which needs to consume a greater biomass to survive. As a consequence of their lower metabolic rate, marsupials usually inhabit warmer locations and are less tolerant of cold environments compared to eutherians, which also have reproduction rates that correspond to the higher metabolic rate (Mc Nab 2005).

Marsupials and eutherians are only able to coexist in habitats providing unreliable food resources in which an animal with a low metabolic rate is not disadvantaged. However, the eutherian reproduction rate will be compromised in habitats providing lower grade food resources (Mc Nab 2005).
2.2.6 Summary

The forces of competition, a fundamental biotic process, result in partitioning of resources with each organism responding differently, which in turn increases biodiversity among organisms that are enabled to co-exist in a particular habitat. Resource partitioning allows dietary overlap between competing species, with the dominant species forcing the subordinate species to reduce the dietary overlap and become a specialist relying on a smaller resource base. Dietary overlap is variable depending on the time of the year and the resource availability, but any organism needs to have a food supply that they have a competitive advantage, thereby creating a refuge from competition otherwise, it would be forced into extinction.

As with the different niches in any one habitat, different organisms consist of differing physiological characteristics that provide an advantage at certain times compared to other competitors. One such characteristic is the metabolic rate that provides an advantage for a competitor in relation to the type and amount of dietary intake needed to survive. Organisms that are able to maintain a lower metabolic rate usually conserve energy well, especially under circumstances of low energy availability but have a slower reproductive rate.

The overarching hypothesis is that evolutionary processes provide resource partitioning among co-existing organisms in the same habitat, and at the same trophic level to reduce dietary overlap, and that the overlap is reduced cyclically, thereby, allowing many species to exist.
2.3 Hutchinson Theory

2.3.1 Background

The physical size of animals, of different species and increases in flora diversification correspond to increases in fauna diversity near the tropics (Hutchinson 1959). Hutchinson pondered the question as to the differences necessary to minimise competition between two animal species that appear to utilise the same ecological niche to prevent further interspecific competition. Morphological measurements were recorded of coexisting species utilising the same resources, revealing that the culmen in birds and the skulls in some mammals differed in a mean ratio of 1.28 from the larger to the smaller form. This ratio could be used to indicate the size difference needed for the two species to occupy different niches in the identical habitats and trophic levels (Hutchinson 1959). The Hutchinson theory of a length ratio of 1.3 can be extrapolated to a weight ratio of 2.1, since weight varies to the third power of length $1.28^3 \cong 2.1$ (Eadie, Broekhoven et al. 1987). However, there is still a debate on the use of the Hutchinson ratio as a basis for the size difference needed for a competitor to avoid interspecific competition.

2.3.2 Scientific Debate

There are many man-made assemblages that contain a ratio of 1.3 from the largest to the smallest form (Horn and May 1977; Maiorana 1978). These assemblages range from many musical instruments, bicycle wheel diameters, sets of plates, glasses, animal figurines and cooking utensils: Horn & May (1977) suggested that the Hutchinson rule could be derived more from generalities concerning assemblages than from any biological process. Furthermore, size-displacement of species was due to species divergence at a constant percentage, regardless of body size, due to a constant amount of variability in morphology (Maiorana 1978). Roth (1981) expressed the opinion that the dataset from which Hutchinson derived his hypothesis (only 13 ratios) was inadequate. The sample
sets were from only a small variety of organisms with the most (6) ratios coming from Galapagos finches. Even though the author stated a weakness in the sample size, Roth (1981) stated the Hutchinson 1.3 rule has become recognised as a biological constant. Even after 50 years the Hutchinson 1.3 rule is still divisive, there are studies for and against the rule. There has been a recent study that supports the Hutchinson 1.3 rule, even though the ratios varied from 1.16 to 1.376 (Millien 2004) whereas another study does not support the 1.3 rule and goes on to state that Hutchinson’s rule is invalid (Parra, Loreau et al. 1999).

Previous reports that support the Hutchinson 1.3 ratio rule (for either linear measurements or extrapolated to 2.1 for weight measurements) have used species that are congeneric, or in the same guild, or are closely related taxonomically (Roth 1981). Also, previous studies were incomplete with vital data missing (Simberloff and Boecklen 1981) while some of the previous studies did not mention if the species studied were completely or partially sympatric, had dietary overlap or had microhabitat differences (Roth 1981).

A study on avian communities suggested that use of ratios of morphological characteristics for predicting interspecific competition would lead to incorrect relationships between competitors due to the lack of consistency in those morphological features (Wiens and Rotenberry 1981). The variability in the morphological features that are ecologically important from the larger to the smaller species appear not to be attributed to the variation or separation of the prey size captured (Wiens and Rotenberry 1981). Furthermore, it has been suggested that Hutchinson discovered that animal sizes are distributed log normally in nature, and not from evolutionary processes to avoid interspecific competition (Eadie, Broekhoven et al. 1987); while many other inanimate objects including biscuit crumbs, sand and gravel particles are log normally distributed.
(Koch 1966). The use of size and weight ratios would not enlighten scientists on the mechanisms structuring animal communities unless it can be demonstrated that log normal distributions are in response to interspecific competition (Eadie, Broekhoven et al. 1987).

Most studies that have focused on testing the Hutchinson rule using suites of three or more species have often been repeated and interpreted as a result of interspecific competition but have not been subjected to statistical analysis (Simberloff and Boecklen 1981). Many of the data sets that support the Hutchinson rule were incomplete and therefore not able to be statistically tested. Of the data sets that were able to be tested only a few were able to support the rule at the .05 level (Simberloff and Boecklen 1981). In conclusion, the Hutchinson “1.3 rule” is in no sense a rule of nature and is only very weakly supported from published results (Simberloff and Boecklen 1981), while there is a pattern suggesting support for the Hutchinson rule but not at the 1.3 ratio level for distribution of sympatric species (Roth 1981).

2.3.3 Competition Models

Competition models are valuable tools that have the ability to show and predict relationships between variables in ecological situations (Case and Taper 2000; Fortin, Boyce et al. 2004; Hutchinson and MacArthur 1959c; MacArthur and Pianka 1996). Competition models have been utilised to describe many variables including interspecific competition (Beals, Gross et al. 1999). One such model for interspecific competition is the Lotka-Volterra model that focuses on the competitive interactions between organisms that provides insight into the impact of different factors on outcomes of competitive interactions (Begon, Harper et al. 1990).
2.3.4 Alternative explanations

As discussed earlier, the mechanisms that force changes to niche selection and diversification are many and varied, yet are not limited to those mechanisms discussed.

Each species has similar physiological features yet there is variation between those features. For example, lip and teeth structure between macropods, sheep and goat. Sheep and goats have teeth (dental pads) that come together almost perpendicular to each other, while macropod teeth come together to form a point and are able to select specific plants in the swards of vegetation compared to sheep and goats. Macropods, unlike sheep and goats also have a split lip that is able to be drawn away from the teeth structure that aids in the specific selection of vegetation.

Temporal differences are also a mechanism that reduce interspecific competition for animal species (Neale and Sacks 2001), irrespective of whether the competition is due to introduced invasive species to a habitat (Harrington and MacDonald 2008). The use of the same habitat with other sympatric species that have dietary overlap requires temporal separation to enable all species to survive. For example, the native European polecat avoids interspecific competition with the American mink in the United Kingdom because it is nocturnally active, whereas the mink is diurnally active (Harrington and MacDonald 2008). The sympatric species of bobcats (diurnal) and coyotes (nocturnal) have broad and overlapping diets but utilise the temporal separation and other niche differences to avoid direct competition (Neale and Sacks 2001).

Different spatial uses of a habitat, such as elevation, slope, thermal conditions and use of space are all environmental alternatives that could explain differences that arise from interspecific competition and explain why there are so many species (Stewart, Bowyer et
al. 2002). Human interference in the natural habitats of animals has provided some species an advantage that they have exploited compared to other competitors in the same habitat. Examples of this type of avoidance of interspecific competition have been described in many species including insects are abundant, (De Barro, Liu et al. 2010; Foucaud, Orivel et al. 2009) to birds (Attum, Eason et al. 2006; Gutzwiller, Clements et al. 1998; Skagen, Knight et al. 1991) to reptiles (Attum, Eason et al. 2006) and mammals (Selas, Johnsen et al. 2010).

Body size and species richness have been linked to resources (Mc Nab 2010) available with evolutionary innovation to reduce competition (McClain and Boyer 2009).

2.3.5 Summary

The Hutchinson theory can be utilised to explain why there are a large number of species in a habitat at the same trophic level. Since inception of the theory there has been debate as to whether the theory is a biological constant or just generalities concerning man-made assemblages. As yet, there have not been any scientifically manipulated trials undertaken to test the Hutchinson theory. There are alternatives that also provide insights to competition, and in particular interspecific competition, which indicate that to understand the process of competition is a complicated procedure that requires understanding of many facets. The use of competition models is one method of determining the relationship between variables in nature without affecting the existence of vulnerable species.
2.4 Agricultural expansion

2.4.1 Agricultural expansion in Australia and on Kangaroo Island

Since the early evolutionary process of *Homo sapiens* in Africa and subsequent radiation through the world (Hublin 2009; Tattersall 2009), the environment has been altered to suit the requirements of humans. Agricultural subsistence has seen the destruction of many natural habitats around the world to feed the ever-expanding human population at the expense of the environment and the flora and fauna in each habitat (Ehrlich 2009; Kastner and Nonhebel 2010). Habitat modification is just one of the human induced processes that have impacted upon both flora and fauna. Introduction of domesticated mammal species into Australia, including both herbivores and carnivores, has created un-natural competition and predation on the existing flora and fauna. Large land clearance has left fragmented habitats that allow some species of flora and fauna to thrive, while other species have been forced into extinction (Graetz and Wilson 1984; Leigh and Wilson 1970; Mc Kinney, Kick *et al.* 2010). In Australia, the fragmented habitats left are the only refuges for some species that have been driven to near extinction, or forced into local extinction (Anon 2001b; Dawson 1995; Mac Nally and Bennett 1997; Major, Christie *et al.* 2003; Williams, Morgan *et al.* 2006; Yeoman and Mac Nally 2005).

The expansion of agriculture and pastoralism into mainland Australia rangelands has resulted in the substantial loss of shrubs and has caused extensive soil erosion (Graetz and Wilson 1984; Leigh and Wilson 1970; Mc Kinney, Kick *et al.* 2010). Overgrazing in the rangelands was not regulated in South Australian early history, but the overgrazing resulted in changes to the Pastoral Act of 1936 which originally had a concept of minimum stock carrying capacity per lease and introduced the concept of a maximum stock carrying capacity for each lease. This change was aimed at reducing grazing pressure on the rangelands. However, there had been significant loss of vegetation density
between 1948 and 1970 (Dawson and Ellis 1994; Graetz and Wilson 1984). The Pastoral Act had assumed that only livestock caused vegetation degradation, however the concept of total grazing pressure was introduced, which recognised that pest species such as rabbits, and native species such as kangaroos, also contributed to vegetation degradation (Dawson and Ellis 1994).

Kangaroo Island is of high conservational significance and is one of Australia’s 15 biodiversity ‘hotspots’ (Anon 2004). Kangaroo Island was the first site for European settlement in South Australia, although large-scale land clearance did not occur until after the Second World War due to the predominance of ironstone soils (Anon 1986) which are not conducive to agriculture. Kangaroo Island has an area of 440,000 hectares (Anon 2001b; Jenkins and Wright 1988; Jennings, Clarke et al. 1989) with the highest proportion of native vegetation remaining of all agricultural regions in South Australia (Anon 2001a). Native vegetation on the island covers 207,161 ha (47%) with 132,665 ha (30%) protected in national parks and reserves, while the remaining vegetation is highly fragmented into small areas less than 20 ha each that survived because they were deemed less suitable for agriculture (Anon 2001b). The land clearances and associated pasture replacements had reached alarming levels in the 1970s such that legal limits were necessary as concerns for native vegetation increased (Jennings, Clarke et al. 1989).

2.4.2 Herbivore impact in Australia and Kangaroo Island

Increased agricultural and pastoral activity has resulted not only in the loss of vegetation through habitat destruction by land clearing (Kastner and Nonhebel 2010) and overgrazing, but also a dramatic loss of native fauna from the mainland including some of the smaller macropod species (Pople and Grigg 1999). Even today, plant species are under threat in the rangelands. For example, the Western Myall (Acacia papyrocarpa) is
disappearing from the open rangelands due to grazing pressures from both native and introduced herbivores (Bosworth 2005). Unfortunately, the consequence for this semi-arid and arid region is that the vegetation community is being irreversibly altered (Auld 1993). The earlier expansion of agriculture and pastoralism has resulted in extra watering points being available to the wildlife for drinking, including the kangaroo, and has resulted in some larger species of kangaroo increasing in abundance and density (James, Landsberg et al. 1999). The water points became the focal point for all sheep, cattle and kangaroos. In extreme cases, this had resulted in total denudation of vegetation close to the watering point (Andrew 1988; James, Landsberg et al. 1999). Therefore, the limiting factor for an increase of the kangaroo population has now shifted from water to food resources, increasing grazing pressures on the rangelands. Meanwhile, cattle and sheep improve the habitat through facilitative grazing that benefits the kangaroo, which has contributed to an increased kangaroo population (Newsome 1975). Competition between these herbivore species is exacerbated during the summer when food resources are limited (Newsome 1971; Wilson 1991b) and kangaroo populations are culled by the pastoralist or harvested by professional shooters. This cycle of habitat destruction and increases in density of some native herbivores has been replicated on Kangaroo Island, although at a later time period.

On Kangaroo Island, increases in pasture have provided large grass areas resulting in a population explosion of the tammar wallaby (Anon 2006) to the level of it being considered a pest species, even though it is all but extinct on the mainland of South Australia. Tammar wallaby diet consists mainly of grasses (Lentle, Stafford et al. 1998a; Strathan 1995) with unsustainable grazing pressures being imposed on some of the areas on Kangaroo Island containing threatened plant species (Anon 2004). Wallabies are currently culled in large numbers under pest destruction permits, with the carcasses
wasted (Wright and Stott 1999). The national interest in providing an environmentally sustainable Australia would be better served if wallabies were integrated into the farming system (Wilson 2004). However the biological basis for a wallaby management plan must be established before the legal requirements for use of wallaby products can be met under the South Australian National Parks and Wildlife Act.

2.4.3 Summary
Agriculture and pastoralism have both combined to provide sustenance for the human population, although at the expense of the native flora and fauna; this has been compounded by extensive land clearance and habitat destruction by overgrazing by introduced herbivores. Many species of both flora and fauna have been systematically forced into extinction in Australia since 1788. Conservation of the remaining natural habitats is in the nation’s best interest; therefore, the efficient utilisation of all resources is critical. Integration of the kangaroo on the mainland and the tammar wallaby on Kangaroo Island into agricultural/pastoral enterprises would provide additional income and reduce the total grazing pressures on the environment. Integration of wildlife into agriculture/pastoralism enterprises would be a mutually beneficial situation for the enterprise and the environment.

2.5 Species of Interest

2.5.1 Tammar Wallaby (*Macropus eugenii* Desmarest)
Prior to European settlement there were at least two distinct sub-species of Tammar Wallaby found on the mainland of South Australia (*M. e. eugenii* and *M. e. decres*) (DEH 2005b), with a third sub-species recognised in Western Australia (*M. e. derbianus*) (Anon 2005). Through extensive habitat clearance (DEH 2005a) and the introduction of carnivores, the fox (*Vulpes vulpes*) and feral cats (Smith and Hinds 1995), populations of
the tammar wallaby have declined dramatically to the point that they are all but extinct on the mainland of South Australia, with only populations existing on offshore islands, including Kangaroo Island, where they are abundant and are considered a pest species by many farmers. Wright and Stott (1999) reported that there are only nine confirmed locations on mainland Australia where the tammar exists, with all nine locations in Western Australia.

2.5.1.1 Description

The tammar wallaby is one of the smaller members of the family Macropodidae, with a weight range from 5 to 7 kg (DEH 2005b), while the Kangaroo Island population is larger and has a wider weight range from, 4 to 10 kg, depending on the sex of the animal (Archer, Flannery et al. 1985; Smith and Hinds 1995). The Tammar wallaby has a dark greyish-brown upper body coat with a pale buff-grey undercoat; the sides of its body and on the limbs are rufous especially on the male specimens (Smith and Hinds 1995), with most individuals displaying a faint white check stripe (DEH 2005b).

Figure 2.1 Female tammar wallabies in the fauna yard pen at the Roseworthy Campus, University of Adelaide.
2.5.1.2  Diet, Habitat description and Distribution

The tammar wallaby is primarily a nocturnal feeder on grasslands with its diet almost entirely consisting of monocots (grasses) with some dicots (forbs) (Anon 2005; DEH 2005b; Wright and Stott 1999). The wallaby shelters in dense natural bushland vegetation during the day (Christensen and Maisey 1987) to escape a natural predator, the Wedge-tailed Eagle, (*Aquila audax*) (DEH 2005b) and moves into the open grasslands to feed at night (DEH 2005b; Smith and Hinds 1995; Wright and Stott 1999). Therefore, the tammar is an ecotonal species because it utilises two distinct habitats to fulfil its daily requirements (Hillyard 2001) in regard to sustenance and safety. The tammar moves across the ecotone after sunset to feed on the pastures or in clearings dominated by monocot species (Lentle, Stafford *et al.* 1998a). Tammar wallabies are mainly grazers (66.5%) however, they are also browsers depending on resource availability (Lentle, Stafford *et al.* 1998c). Water intake is mainly through consumption of high water content plant species (Nagy, Bradley *et al.* 1990) although wallabies are not restricted to that supply. The tammar has been known to consume seawater (salt water) when fresh water is not available (Kinnear, Purohit *et al.* 1969).

2.5.2  Western Grey Kangaroo (*Macropus fuliginosus* Desmarest, 1817)

The Western Grey kangaroo species comprises 3 subspecies, *M. f. fuliginosus* on Kangaroo Island and some mainland populations, *M. f. ocydromus* locally from York, Western Australia and *M. f. melanops* the most predominant species on the mainland (Poole 1995).

2.5.2.1  Description

The Kangaroo Island subspecies of Western grey kangaroo has a weight range from 23 kg to 55 kg with a different weight range for each sex (Menkhorst 2001; Poole 1995). The
female is smaller in body size and has a lower weight upper limit compared to the male, with the female having the higher lower limits in both body length and weight. The mainland Western Grey Kangaroo has a light brown-grey upper body coat and a pale grey undercoat on its belly and chest areas (Menkhorst 2001; Ride 1970), whereas the coat of the Kangaroo Island subspecies is sooty brown all over, and is usually thick (Menkhorst 2001). A distinguishing feature is a finely haired muzzle compared to other species of kangaroo except for *Macropus giganteus* (Poole 1995).

Figure 2.2 Kangaroo Island western grey kangaroos in holding yards at Roseworthy campus, University of Adelaide.

2.5.2.2 **Diet, Habitat description and Distribution**

The Western grey kangaroo is distributed throughout the southern reaches of the continent of Australia; it is distributed in 5 states, including South Australia, where it is present on both the mainland and on Kangaroo Island (Poole 1995). The kangaroo is similar to the tammar wallaby with respect to feeding habits. It is primarily a nocturnal feeder grazing on grasslands, with its diet consisting of monocots (grasses) with some dicots (forbs) including browsing on some shrubs (Andrew and Lange 1986; Dawson 1995; Edwards, Croft *et al.* 1996; Griffiths and Barker 1966; Menkhorst 2001). The
kangaroo shelters in dense natural bushland vegetation to rest during the day (Menkhorst 2001) and moves into the open grasslands to feed at night. Therefore, the western grey kangaroo is an ecotonal species because it utilises two distinct habitats to fulfil its daily requirements (Menkhorst 2001) in regard to sustenance and safety, and given its diet, it is thus a putative competitor to the tammar wallaby.

2.5.3 Sheep (Ovis aries)
Sheep have been domesticated from wild populations of Oriental mouflon (Ovis orientalis) that once roamed dry mountainous regions of central and south-western Asia approximately 10,000 years ago (Vigne 2011; Zeuner 1963). Wild sheep originally radiated out of Asia into Europe and Africa, with human distribution of domesticated sheep occurring 2000 years BC into other areas (Cottle 1991). Sheep were introduced into Australia shortly after European settlement in 1788 and by 1860 there were 20.1 million animals in the rangelands, and by 1891, 106 million animals occupied all possible grazing lands (Cottle 1991) with little regard for natural vegetation. Even though the numbers have fluctuated due to environmental conditions such as drought and the world market for meat and wool, the population of sheep in Australia during the 1980s was c.172 million (Cottle 1991).

2.5.3.1 Description
Merino sheep are the predominant sheep breed in Australia, with a weight range for adult animals from 45 to 90 kg, depending on the sex of the animal, with the females being the smaller gender (Cottle 1991). The fleece of the sheep is predominantly whitish, and covers most of the body including the head and legs, excluding the face and feet. Folds are apparent in the neck and wrinkles in the body of the fleece (Cottle 1991). The strain of
Merino in South Australia has a more open face and has fewer body wrinkles than other strains (Cottle 1991).

![Merino sheep in a holding yard at the Roseworthy farm, University of Adelaide.](image)

2.5.3.2 **Diet, Habitat description and Distribution**

Being a domesticated species, sheep graze mainly in fenced areas of pasture of either native vegetation or introduced agricultural species such as Lucerne (*Medicago sativa*) or medic (*Medicago truncatula*). The diet consists primarily of dicot species although it also includes monocots species (Griffiths and Barker 1966). Sheep are distributed through Australia except for areas in the remote central and north-western areas of Australia as indicated in figure 2.4. Feral populations of sheep have not been established due to the maintenance requirement of shearing and other animal husbandry procedures. If sheep have managed to escape the wool becomes extremely heavy and weighs down the animal to the extent of it not being able to function normally.
2.5.4 Goats (Capra hircus)

Goats also have been domesticated from wild populations of bezoar goat (Capra aegagrus) that once roamed dry mountainous regions of central and south-western Asia approximately 10,000 years ago (Taberlet, Coissac et al. 2011). Goats were also introduced at the time of European colonisation of the Australian continent in 1788. Goats were a source of sustenance from its milk to its meat produced after slaughtering (Henzell 1995; Parkes, Henzell et al. 1996). Since its introduction, feral populations have established in every state and territory of Australia excluding Northern Territory, including islands along the north and northeast coast (Henzell 1995). New South Wales has the greatest distribution covering most of the state (Henzell 1995). In South Australia, goat populations can be found in the Flinders Ranges, in semi-arid and arid regions north and northwest of Port Augusta, along with populations in north-western parts of
Kangaroo Island and some populations located in the southeast along the border with Victoria (Henzell 1995).

2.5.4.1 Description

The feral goat has a characteristic appearance, with a shorthaired coat that can be either predominantly single coloured or have different coloured patches with short curled tails and curved horns. The weight range varies from 15 to 79 kilograms depending on the sex, with the female being smaller in all size measurements (Henzell 1995; Parkes, Henzell et al. 1996).

![Feral goats in a holding yard at the Roseworthy campus of the University of Adelaide.](image)

2.5.4.2 Diet, Habitat description and Distribution

The feral goat is a hardy species and inhabits areas that are normally uninhabitable by other grazing animals in arid and semi-arid areas of Australia, along with some areas that are used for domestic herbivore grazing. Goats are browsers and will eat virtually every type of plant up to 1.8 metres in height (Henzell 1995), with their diet being dominated by shrubs (71%) with other forbs (27%) as indicated by Mellado et al. (2005). Goats will consume plant species that are toxic to other herbivore species (Parkes, Henzell et al. 1996). Trees and shrubs are the major component of the goat diet, although it will
consume grasses and ephemerals when available, with most plant species eaten to some extent (Henzell 1995). Composition of shrubs in goat diets is influenced by environmental conditions, even though shrubs still represent a minimum of 48% of its diet in the wet period (Genin and Pijoan 1993). If goats do not consume large quantities of plants with a high water content, they require another source of water, even to the extent of the animals swimming between off shore islands to gain access to fresh water (Henzell 1995). Goats can drink seawater to survive, although goat kidneys showed no morphological adaptation of the consumption of seawater (Parkes 1993; Parkes, Henzell et al. 1996). Therefore, the feral goat is versatile and extremely adaptive, and without any predators to limit its population, could cause major environmental damage and become a major disease vector if left uncontrolled.

2.5.5 Summary

All species studied in this project had diets that overlapped to varying degrees, with no one species having a distinct diet compared to the others. All species ate both monocotyledons and dicotyledons; however, the percentages of each plant type varied due to environmental conditions and when interspecific competition forces differences in plant preferences. The female of all species studied have lower body weights and are more consistent in size, therefore, they were be the desired gender for this study. Females were less aggressive and therefore easier to handle compared to the male of each species. The female kangaroo is smaller and did not escape from an enclosure with 1.6 metre fences. With the desired mix of animals being gender specific, this prevented any breeding during the pen trial, thereby, enabling the grazing pressure to be consistently maintained. Male members of each species that have not been castrated are usually aggressive when in mixed and single gender population, therefore, they were not utilised in the trial pens unless they had been castrated to change temperament. Size and weights
of males in all species studied were larger compared to the female gender, which could also pose problems with containing the animals in the exclosure and for handling during the trial to investigate weight loss or gain.

2.6 Carrying Capacity

To determine the pasture quality and its associated stock carrying capacity in providing the minimum energy requirements for the maximum number of animals on that pasture is measured in units of Dry Sheep Equivalent (DSE). The DSE rating is derived from many assumptions of weight and growth rates (Davies 2004). The standard DSE unit is derived from the amount of feed required by a 45 kg Merino sheep to maintain its weight as long as the sheep is non-lactating and non-pregnant (McLaren 1997). The standard DSE unit has been varied, with regard to weight of sheep, from 40 kg (Charry, Kemp et al. 2003) to 50 kg (Davies 2004) The standard measurement of DSE is utilised by various pastoral enterprises including sheep, cattle (Davies 2004), Alpacas (Charry, Kemp et al. 2003) and wildlife species such as kangaroo (Grigg 2002; Landsberg and Stol 1996; Temby 2003).

2.6.1 Variation in DSE units

2.6.1.1 Domestic

The DSE unit can be adjusted depending on the type of animal that is being stocked on a particular pasture. Davies (2004) utilised a 50 kg sheep as the bases of the DSE rating for comparisons of different beef enterprises. Cattle are much larger animal with greater food requirements to maintain its body weight. Hence, each animal has a DSE rating of 6 for a 450 kg animal (Davies 2004).
The Alpaca DSE unit was derived from a 40 kg sheep to determine the stocking rate of Alpacas but was modified after 3 years allowing higher carrying capacity per hectare (Charry, Kemp et al. 2003).

2.6.1.2 Wildlife
A wildlife application to examine the impact on the rangeland paddocks concluded that marsupial macropods had a lower metabolic rate than introduced eutherian mammals. Past assumptions that the kangaroo DSE rating of 0.7 has been over-estimated and required modification (Grigg 2002). Once the kangaroos’ lower body weights and lower field metabolic rates are included in the DSE calculation, the kangaroo could have a DSE rating of 0.2 – 0.15.

2.6.2 Summary
DSE ratings of pastures, areas, and locations vary according to the animal and pasture condition. DSE ratings provide a valuable tool in the management of herbivores and pastures. The use of DSE ratings ensures the pasture does not become overgrazed and that the animal receives maintenance level nutrition.

2.7 Condition Score
2.7.1 Domestic
Body condition scoring of domestic livestock has been utilised for many years as a simple technique for determining animal condition for livestock market reporting. Body condition scores have been described and utilised for cattle (Earle 1976; Everitt 1962; Ezanno, Ickowicz et al. 2003), sheep (Hopkins 1988; Jefferies 1961; Russel, Doney et al. 1969) and goats (Mellado, Rodriguez et al. 2004; Santucci and Maestrini 1985). The condition scores (CS) for the above animals were derived from visual recognition of the
characteristics, or from subjective manual palpation of the animal. The purpose of this assessment tool is to provide a means by which buyers on the farm or in the saleyards can quickly assess the live animals on offer and carcass attributes, including proportions of muscle and fat (Mc Gregor 2007).

Livestock body CS with the lowest numerical value describes animals in an emaciated state and near death. Animals in a very good body condition are allocated the highest numerical value. Several originating authors (Jefferies 1961; Mellado, Rodriguez et al. 2004; Russel, Doney et al. 1969) established systems with CS ranges from zero to five whereas others (Greenwood, May et al. 1993; Tesfaye 2005) have established systems with CS from one to five.

2.7.2 Wildlife

Condition indices have been utilised worldwide for many species of wildlife to determine animal body condition, from deer species (Cook, Cook et al. 2001; Stephenson, Bleich et al. 2002), to sea lions (Pitcher and Calkins 2000), and mammals in Australia including macropod species (Bakker and Main 1980; Stirrat 2003; Woolnough, Foley et al. 1997). Condition indices have also been utilised to describe body conditions for two introduced predators, foxes and cats in the Flinders Ranges, South Australia (Holden and Mutze 2002).

To date, there has not been any CS system available for application to native macropod species within Australia. However, Stirrat (2003) utilised a condition index derived from the ratio of leg length to body mass for the body condition of the agile wallaby (Macropus agilis), and condition indices have been utilised as a management tool for many wildlife species (Cook, Cook et al. 2001; Krebs and Singleton 1993; Woolnough, Foley et al.
Harvesters supplying the kangaroo meat industry perform a visual assessment and a mental calculation of the potential dressed weight of the carcass of sighted animals before choosing which ones to shoot, and as a consequence only larger animals are selected (Tenhumberg, Tyre et al. 2004). Thickness of the macropod tail is another method for determining the body condition of some macropods (Stirrat 2003). Animals in good body condition have thicker tails at the base with fatty deposits covering the vertebral spine and transverse processes (Stirrat 2003).

2.7.3 Summary
The use of body condition scores has been a common practice in domesticated livestock industry to determine the amount of meat and fat on a carcass of an animal in the meat industry. However, the same practice of utilising a body condition score for wildlife has not been developed, perhaps due to the small percentage of wildlife utilised in the meat industry. Wildlife research has utilised many and varied condition indices to describe body condition, hence, fitness for many scientific purposes, including describing fecundity rate, habitat quality and overall body condition. However, there has not been a condition score system developed for macropod species which includes multiple condition indices.

2.8 Capture Techniques for Macropod species

2.8.1 Non Drug Capture
There are different ways to capture wildlife that utilise existing fences and naturally occurring barriers to prevent escape of the target species (Andrewartha and Barker 1969; Coulson 1996; Keep and Fox 1971). There are also different types of portable fences that can be erected. Some have cages attached to small openings of the portable fence to capture the macropods (Vernes 1993). Other portable fences are used as holding
boundaries or direction funnels to areas where people are waiting with hand nets to capture macropods. The use of scrapes, either naturally washed out by erosion, or from macropods digging the soil away from the base of the existing fences, are able to be take advantage of to capture macropods (Coulson 1996). Macropods push up the wire and scrape out the dirt to allow passage from one side of the fence to the other. Once established, the scrapes are utilised nightly. Knowledge of macropod behaviour has been exploited such that use of a draw-string trap can be deployed, especially when other capture techniques are not viable due to the terrain, danger for the catchers or prohibitive cost (Coulson 1996).

Another method for capturing macropods is by using a spotlight and a high powered rifle to create a shockwave at the head height of the animal. This method has been described as stunning (Robertson and Gepp 1982). The use of a spotlight shone on the animal temporarily blinds it, and then a shot is fired just above its head. The combination of the two processes, light and air disturbance, disorientates the animal for only a short time: this allows a team of people to run from the dark with a bag, to capture the animal.

The capture methods described above have consequences that could be fatal for each individual animal, macropods can suffer from post capture myopathy (Coulson 1996).

2.8.2 Drug Capture

The use of drugs administered orally is a common practice in catching many wild animals, both avian (Belant and Seamans 1997; Hayes, Hartup et al. 2003; Hofman and Weaver 1980; Lovett and Williams 1966; Nelson 1994) and Australian mammals (Arnold, Steven et al. 1986; Norbury, Norbury et al. 1994). All the previously mentioned studies utilised a powder form soporific drug called alpha-chloralose. The drug was either
used to lace the food or available drinking water of the target animals. Alpha-chloralose according to Lovett and Williams (1966) is a very effective anaesthetic drug when given orally and is very stable in water when exposed to sunlight. The drug has remained effective after a minimum of 30 hours exposure in humid condition in Florida (Lovett and Williams 1966). Alpha-chloralose does not dissolve efficiently in cold water with small amounts not suspended in the water even after a few hours of stirring. If the water/drug solution is heated gently the alpha-chloralose will dissolve completely in 20-30 minutes and does not fall out of suspension once the water is cooled.

Alpha-chloralose has been utilised to lace the supplementary food source of many avian species throughout the world (Belant and Seamans 1997; Hayes, Hartup et al. 2003; Hofman and Weaver 1980; Lovett and Williams 1966; Nelson 1994). The alpha-chloralose is dissolved in water and poured into containers which contain the dry supplementary feed. The water is absorbed by the feed usually after 24 hours (Arnold, Steven et al. 1986; Hofman and Weaver 1980) and the outer surface of the feed is coated with the drug. Different substances have been added to the drug solution, such as white oil, starch and sugar, to enhance contact of the drug to the outer coating of the feed (Lovett and Williams 1966; Nelson 1994).

Alpha-chloralose is a good choice of drug to use on wildlife as it has only a few undesirable side effects and is practically tasteless (Norbury, Norbury et al. 1994). If alpha-chloralose is to be used over a period of time, or used on consecutive days, animals will develop an aversion to taking the bait or drinking drugged water (Arnold, Steven et al. 1986). Therefore, switching between the means by which the drug is to be mixed and administered is essential.
One of the undesirable side effect of alpha-chloralose is that the drug is self-administered by each individual animal, and overdoses are caused by the animal consuming large amounts over a short time (Arnold, Steven et al. 1986). The drug remains in the system for days and can be reactivated during the cold ambient nightly temperatures, leaving the animal susceptible to predation if it evades capture on the first instance of the drug being effective (Arnold, Steven et al. 1986).

Zoletil 100 is another commercial anaesthetic drug that is delivered by mechanical devices. This drug is used widely from veterinarians in clinics for cats and dogs to uses in zoos for the capture of larger species of wildlife. Zoletil is placed into a dart (method discussed in chapter three) and shot into the animal by either a blow pipe or a dart rifle.

The acquisition and use of projectile syringes, along with the anaesthetic drugs used, and the weapons used to propel them are restricted by several Acts of Parliament (Jones 1976). The Acts determine which members of the public have access to the drugs and equipment.

Blow pipes have been used by humans for many centuries as a tool for hunting wildlife. Indigenous people in the Amazon basin utilised small curare tipped darts and were able to dart their prey from three or more metres away (Wentges 1975) while Ruedi and Voellm (1976) have been able to use a blow pipe to dart animals up to 15 metres away.

The advent of rifles has enhanced the use of dart syringes for delivering drugs to wildlife at greater distances than could be achieved by blow pipes, without the dangers associated with large man eating wildlife (Nath, Bose et al. 2002). The darts have been modified
over time to be fired from the rifle and to ensure that the drugs are delivered into the animal in an efficient manner (Lochmiller and Grant 1983; Warren, Schauer et al. 1979).

2.8.3 Summary

The use of drugs to capture target species is one technique that allows many animals to be caught at the same time with minimal personnel but requires the use of restricted materials and specialised equipment. Alpha-chloralose and Zoletil 100 affect each animal differently for varying lengths of time. Therefore, they need to be monitored very closely after the drug has been administered. Monitoring could be required for several days.

Fences, either portable or permanent, are essential tools for the capture of macropods if they are small and able to be captured by the use of hand nets. However, the use of existing fences that provide no potential escape route for the animal pose the risk of post capture myopathy (Coulson 1996) due to stress.

All trapping techniques discussed for macropods, whether performed by the use of drugs or by physical means provides a risk of death for the macropod. The main concerns that should be reduced by awareness of the captors are post capture myopathy (Montane, Marco et al. 2002) or by drug induced death from predation or overdose or injury while ataxic.
Chapter 3

Processing Experimental Animals

Methods described in this chapter are applicable to chapters six, seven, eight and nine of this thesis.

3.1 Assessment of Body condition

A body condition score (CS) was used to select all test species (sheep, goat, kangaroo and wallaby) for inclusion in the grazing and palatability trials. Standard scoring systems were derived from visual body characteristics and from manual palpation. Standard scoring systems rate for domesticated livestock from 1-5 with livestock in CS 1 in very poor condition and at a CS of 5 represented an animal in optimal condition. Scoring systems have been used for sheep (Hopkins 1988; Jefferies 1961; Russel, Doney et al. 1969) and goats (Mellado, Rodriguez et al. 2004; Santucci and Maestrini 1985) and a new technique for the macropod species particularly for the wallaby that utilises not only body weight/foot length index as used in previous wildlife studies (Moss and Croft 1999; Nave, Coulson et al. 2002; Rose and Flowers 2005; Stirrat 2003). Other body condition indices such as kidney/kidney fat and gastrocnemius muscle/tibia length indices were required to verify the condition score system in conjunction with the body weight/foot length index devised for wallabies. The previously mentioned other indices provided additional evidence of body condition to provide boundaries between CSs. Chapter 6 provides greater detail in relation to other factors of wallaby condition which validated the condition score system for that species. In the current study body condition of kangaroos was determined only by using body weight/foot length index.
Step 1  the right foot (pes) of both macropod species was measured for inclusion as an index of body condition. Measurements were made to an accuracy of ± 1 mm, from the proximal end of the tuber calcaneus to the distal end of the fourth digit at the base of the claw.

Step 2  each animal was weighed

Step 3  the weight of the individual animal was divided by the pes length to the power of 3 to allow for scaling to provide the condition score index (CSI) for that animal.

This index calculation provided a range of wallabies with different body condition indices that were allocated to a new condition score (CS) system ranging from 1–5. Each condition score level contained a range of condition score index values (CSI). At a CSI > 8.25 the wallaby was determined to be fit for inclusion in future trials, representing the boundary between CS 2 and CS 3.

### 3.2 Source of experimental animals

Four herbivore species, tammar wallaby (*Macropus eugenii*), western grey kangaroo (*Macropus fuliginosus*), feral goat (*Capra hircus*) and domesticated sheep (*Ovis aries*) were used to test inter-specific competition.

The wallabies were captured by a local contractor on Kangaroo Island, South Australia using various methods including stunning (Robertson and Gepp 1982) and the use of wallaby proof fencing (Coulson 1996; Keep and Fox 1971). The contractor then sexed each animal and placed female animals into a holding pen until sufficient animals had been caught for transportation to Roseworthy Campus.
Kangaroos used in the trials were also captured on Kangaroo Island, using methods similar to those used for wallabies including stunning (Robertson and Gepp 1982). Only adult females were selected for capture. Feral female goats were captured by local contractors from arid and semi arid regions in South Australia and New South Wales. Merino sheep (wethers) of similar age and weights were selected from a flock on Roseworthy campus.

On arrival at Roseworthy campus fauna holding yards, all wildlife were drenched with an anthelmintic (oral dose of 1 ml per 5 kg, Cydectin, Fort Dodge Australia Pty Ltd, Baulkham Hills NSW) to reduce the parasitic worm population in each animal and hence reduce variability within each animal population. Each animal was weighed and ear-tagged for identification. The kangaroos and wallabies were checked for pouch young and signs of lactation. Any pouch young were removed and euthanised.

### 3.3 Transporting of experimental animals

All animals except for the sheep were transferred to the trial pens after a period of adjustment to fences in the holding yards. Goats and sheep were loaded onto a covered trailer and transported to trial pens. Wallabies were netted and transported to the pens in hessian bags suspended from a frame. The larger less tractable kangaroos had to be sedated with alpha-chloralose before being transported.
3.4 Sedation of Kangaroos

The description of use, dose rates and administering of sedative drugs; alpha-chloralose and Zoletil 100 (1:1 Zolazepam and Tileta-mine; Virbac, Peakhurst, New South Wales, Australia) for the transportation of kangaroos will be discussed.

Alpha-chloralose was administered mixed with fodder seeds. The kangaroos were provided with lupins for three consecutive evenings (the lupin seeds were placed out in the enclosure on plastic lids) to become accustomed to the lupins. On the late afternoon of the fourth day, lupins laced with alpha-chloralose were placed in their pen. The laced lupin mix was obtained by placing 45 g of alpha-chloralose powder into a container; seven litres of tap water was poured into the container, heated (Nelson 1994) and stirred until the alpha-chloralose was dissolved (Arnold, Steven et al. 1986). At this point, 1mm of white oil was added to the mixture to provide an oily surface on the lupins to enhance the adherence of the drug to the lupin surface, and reduce the odour and taste of the drug,
even though the drug is virtually tasteless (Norbury, Norbury et al. 1994). Once dissolved, the solution was poured into another container containing 6 kg of whole lupins. The lupin/water mix was left for 24 hours for the water to be absorbed by the lupins, the alpha-chloralose, would be attached to the testa of the lupins ready for distribution in kangaroo pens.

At dawn the next morning (day five) the kangaroos that had eaten the lupins were in different drug induced states (Arnold, Steven et al. 1986) as described in table 3.1.

Table 3.1 Description of the five stages of alpha-chloralose ingestion.

<table>
<thead>
<tr>
<th>Stages</th>
<th>Description of each stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kangaroo comatose no response to stimuli</td>
</tr>
<tr>
<td>2</td>
<td>Kangaroo lying on ground, slight response to stimuli, not able to stand</td>
</tr>
<tr>
<td>3</td>
<td>Kangaroo able to stand but not too stable</td>
</tr>
<tr>
<td>4</td>
<td>Kangaroo upright and able to move but showing signs of drowsiness</td>
</tr>
<tr>
<td>5</td>
<td>Kangaroo alert with no sign of drowsiness</td>
</tr>
</tbody>
</table>

Kangaroos judged to be in stages one to three were easily captured and bagged for transportation.

The alpha-chloralose drug had residual effects and the kangaroos were continually monitored and frequently rolled over to reduce respiratory problems until the effects of the drug had worn off. The effects appeared to be reduced, or totally eliminated, during days with high ambient temperatures, although the low night ambient temperatures reactivated the sedative. This residual effect could persist for several days (Arnold, Steven et al. 1986). Therefore, affected kangaroos were monitored daily until no
kangaroos suffered from the effects of the alpha-chloralose. Kangaroos that avoided capture were darted and transported as discussed previously.

Zoletil 100 is an anaesthetic, a sedative for dogs (Guzel 2006; Savvas, Plevraki et al. 2005), cats, zoo animals, tigers (Kreeger and Armstrong 2010), wild animals, (Carlini, Negrete et al. 2009; Geschke and Chilvers 2009; Kaunda 2001; Lynch and Martin 2003; Tast, Halli et al. 2000; von Degerfeld 2005), lions (Stander and Vdbmorkel 1991) and misuse by humans for recreational purposes (Ching-Chang, Yen-Yue et al. 2009). In the current study, distilled water (3 ml) was injected into a vial containing 500 mgs of powered Zoletil; resulting in a total of at a concentration of 166 mg/ml. The average weight of the kangaroos was 30 kg, and the dose rate was 17 mg/kg, which was within the safe working limits for the drug (Stott 1990).

Further information on the darts and methods for loading the darts is described in Appendix 1
Chapter 4

Pasture Assessment on Kangaroo Island

4.1 Introduction

Kangaroo Island has the most intimate interface between agriculture and native vegetation in South Australia, and the shrublands constitute an important natural resource that is exploited (Karmiris and Nastis 2010) and often destroyed by humans to enhance profitability of agriculture. Conservation of the remaining native vegetation is of high importance for both the flora and fauna of Kangaroo Island. Increased land clearance has altered the natural environment with large pockets of native vegetation being left due to their unsuitability for agriculture (Anon 2001a).

Kangaroo Island hosts two native macropod herbivores, the tammar wallaby and western grey kangaroo: both of these mammals exploit its fragmented habitat and cleared pastures. The expansion of agriculture has introduced exotic herbivores to the island, with some individuals escaping to form feral populations, thereby increasing grazing pressures on the native vegetation (Anon 2004). Feral and domestic populations of hard-hoofed animals can cause soil management issues due to trampling of fragile biological soil crusts (BCS).

In arid and semi-arid pastures, biological soil crust species, including bryophytes, are an integral component in the structure of natural pastures (Martínez, Escudero et al. 2006) that assist with the reduction of soil erosion (Herrick, Van Zee et al.; Liu, Han et al. 2009) and influence the Nitrogen cycle in arid and semi-arid ecosystems (Castillo-Monroy, Maestre et al. 2010; Li, Zkao et al. 2011). Therefore, soil crust structure is important for conservation in naturally arid and semi-arid pastures (Bowker, Belnap et al.)
2005), but not as crucial in high precipitation other than in its influence on the vulnerability of the soils to erosion.

Introduced herbivores destroy soil crust structure with their hard hoofs, with the greatest damage occurring during drought conditions or when paddocks are over-grazed (Eldridge 1998; Williams, Eldridge et al. 2008) and around watering points (Facelli and Springbett 2009). The herbivores also facilitate conditions through soil crust degradation that allow some plant species to be increasers at the disadvantage of other plant species in the same environment (Facelli and Springbett 2009). As a consequence, native pastures have been restructured with facilitative grazing that benefits some macropod populations (Newsome 1975). Soil crust structure is very important, and crust disturbance has serious implications for maintenance of ecosystem management (Read, Duncan et al. 2008). The introduction of hard-hoofed herbivore species has not only increased soil degradation and erosion; but has also increased the interspecific competition for native vegetation food resources.

This chapter investigates the pasture composition, including all plant and bare ground coverage, of three study sites in the north-western region of Kangaroo Island to see if there were any differences among the three sites. Further pasture compositions at two of the three study sites were investigated, on both sides of a recently erected boundary fence as to whether any of the herbivore species facilitated growth of the pasture plant species.
4.2 Methods

4.2.1 Study sites

The study was conducted on sheep grazing farms within the distribution of the feral goat population. As is almost universally the case on Kangaroo Island, these farms were also populated by tammar wallabies and western grey kangaroos. To ensure that the same pasture species occurred on both sides of fences separating paddocks from scrub, sites were chosen at which a new fence had been erected along a line a few metres into the paddock from the line of a pre-existing fence. There had to be an unobstructed area of pasture 30 m long and 2 m wide alongside either side of the new fence. Unfortunately, only two sites were found that satisfy the above criteria because of the limited distribution of the feral goat on Kangaroo Island at the time of the study. A third site had a separating fence between pasture and native vegetation, but also had a large opening so all species could pass from one area into another, unimpeded.

All three sites chosen were situated along the northern coast of the far-western region of the island. Two sites, Chris’s Paddock and High Paddock, were located 2.6 km apart on Borda Vale farm at Cape Borda, and the third site, Duncan’s Paddock, was located 20 km further east along the coast on the Correll property at De Mole River.

There were indications that the fences at Borda Vale posed a barrier to only sheep. Scraped-out soil from under the fences characteristic of kangaroo and wallaby crossing points were numerous, and observations by the owner (and others) revealed that goats readily jumped the fences whilst wallabies readily passed between the wires of the fences.
Figure 4.1 Satellite image of the two areas on the north-western side of Kangaroo Island, Cape Borda property, the circled area on the left and De Mole River property, the circled area on the right. Image courtesy of Google maps

Figure 4.2 First study site at Borda Vale, Chris's Paddock. Image courtesy of Google maps.

Figure 4.3 Second study site on Borda Vale, High Paddock. Image courtesy of Google maps.
4.2.2 Transect specifications

On the Borda Vale property, five pairs of transects (one of each pair on the inside, designated “paddock”, and the other outside, designated “coastal”, of the same length of fence) were established on the pasture at each of Chris’s and High Paddock sites. Each transect was 30 m long and 1.5 m wide and 0.5 m from the fence.

On the Correll property, paired transects were not possible, due to the absence of pasture on both sides of the boundary fence. Therefore, only two transects on the pasture in Duncan’s Paddock were taken. Each transect was 50 m long and 1.5 m wide. As a consequence of terracing, the transects at this site were 20 m away from the boundary fence.

4.2.3 Plant Cover Survey

Plant cover surveys were conducted in the 4\textsuperscript{th} week in October 2006, 2\textsuperscript{nd} week in January 2007, 3\textsuperscript{rd} week in May 2007 and the 4\textsuperscript{th} week in October 2007 which cover a 13 month period. There were 10 transects at site one, 10 transects at site two and 2 transects at site three. At each transect, there were five one metre square quadrats at randomly selected intervals, which were then kept constant over the four sampling periods. In each quadrat,
visual percentage coverage of each plant species present was estimated, including bare
ground and rocks. Analysis performed utilising the statistical package GenStat 11th
Edition. On sites one and two analysis was performed from data obtained either side of a
recently erected boundary fence which limited the movement of sheep.

4.2.4 Plant Cover Analysis
Multivariate analysis will be performed using 2 and 3 factor ANOVA analysis. Plant
cover data was collected in percentage values. Therefore, the data was firstly transformed
into proportions, then arcsin transformed to enable an ANOVA to be performed utilising
the statistical package GenStat 11th Edition, with the reverse procedure performed to
provide percentage results.

4.2.5 Rainfall and Temperature
Rainfall and temperature data were sourced from The Commonwealth of Australia,
Bureau of Meteorology, meteorological station identification number 022801, latitude -
35.75, longitude 136.60, height 158.0 m, positioned at Cape Borda, Kangaroo Island, 5
km from Chris’s paddock.

4.3 Results
4.3.1 Rainfall and Temperature
Monthly rainfall and temperature were recorded at Cape Borda station over an 18 month
period from May 2006 until October 2007, the last month of pasture assessment, and are
presented in Figures 4.18 – 4.20. The near total rainfall in April 2007 was recorded from
the 26th until 29th when 126.8 mm was recorded out of 128.4 mm for the month. March,
April and May 2007 rainfall were above long term averages for the months while April
and May were greater than 150% of the monthly average. The highest overnight mean
minimum temperature occurred in February 2007, with the lowest overnight mean minimum temperature occurring in both June 2006 and 2007. The highest day maximum temperature also occurred in February 2007, with the lowest day mean maximum temperature occurring in July 2006. Daily maximum and Daily mean temperatures were higher in March, April and May 2007 with March and April recording daily maximum temperatures greater than 2°C of the long term average daily maximum temperature.

Figure 4.5 Monthly rainfall (mm on Y axis) totals over an 18 month period from May 2006 until October 2007. Months with an asterisk indicate months when pasture assessment occurred.
Figure 4.6 Monthly mean overnight temperature (on the Y axis is in Celsius) for an 18 month period recorded at Cape Borda weather station which includes pasture assessment months with an asterisk.

Figure 4.7 Monthly mean day temperature (on the Y axis is in Celsius) for an 18 month period recorded at Cape Borda weather station which includes pasture assessment months with an asterisk.

4.3.2 Pasture Comparison at three sites

Pasture cover was evaluated at three sites from spring 2006 to 2007. Multivariate analysis was performed with the results being no different from a one-way ANOVA therefore, the
result of the one-way AVOVA are reported. Only two categories of cover remained highly statistically significant throughout the evaluation period, while all categories of cover were significant at some time during the assessment period. The assessed categories included bare ground, moss (Family Bryophyte), clover (*Trifolium subterraneum*), daisy (*Arctotheca calendula*) and grasses (Family Gramineae).

4.3.2.1  **Spring 2006**

Categories assessed and subsequent analysis results during the evaluation period between the three sites were: Bare ground *P*=0.252, Moss *P*< 0.001, Clover *P*< 0.001, Daisy *P*<0.001 and Grass *P*=0.006. High paddock was significantly different to Chris’s and Duncan’s paddocks with respect to moss (fig. 4.8) and grass coverage (fig. 4.11) while Chris’s and Duncan’s paddocks had significantly greater clover coverage (fig. 4.9). Chris’s paddock had significantly higher daisy coverage in the pasture than High and Duncan’s paddocks (fig. 4.10)

![Figure 4.8 Percentage cover of moss in the pasture at the three sites in spring 2006 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.](image)
Figure 4.9 Percentage cover of clover in the pasture at the three sites in spring 2006 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.

Figure 4.10 Percentage cover of daisy in the pasture at the three sites in spring 2006 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.
Figure 4.11 Percentage cover of grass in the pasture at the three sites in spring 2006 (P=0.006, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.

4.3.2.2 Summer 2007

Categories assessed and subsequent analysis results during the evaluation period between the three sites were: Bare ground P<0.001, Moss P<0.001, Clover P=0.137, Daisy P<0.001 and Grass P=0.087. Differences in the proportions of bare ground percentage in the pastures were highly significant among the three sites, with Chris’s paddock having the greatest amount of bare ground (10.6%), Duncan’s paddock intermediate (3.3%), and High paddock the least (1.9%) (fig. 4.12). Differences in the proportions of moss coverage were highly significant. High paddock contained 37.7% moss coverage, followed by Chris’s paddock with 3.6% whereas Duncan’s paddock did not contain any moss in the assessed pasture (fig. 4.13). Daisy, a dicotyledonous weed species, was only recorded in two of the three pastures assessed. Chris’s paddock coverage (10.6%) was significantly different to both High (0.5%) and Duncan’s (0%) paddocks, which were not significantly different from each other (fig. 4.14).
Figure 4.12 Percentage cover of bare ground in the pasture at the three sites during summer 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.

Figure 4.13 Percentage cover of moss in the pasture at the three sites in summer 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.
4.3.2.3 Autumn 2007

Categories assessed, and subsequent analysis results during the evaluation period between the three sites were: Bare ground $P<0.001$, Moss $P<0.001$, Clover $P=0.526$, Daisy $P<0.001$ and Grass $P<0.001$. Bare ground was apparent in all pastures of the three sites, with Chris’s paddock significantly greater than the other two sites, which were not statistically different to each other (fig. 4.15). Moss coverage was statistically different in each of the three sites with High paddock recording 72.2% moss coverage; Chris’s paddock had far less moss coverage with only 14.4%, while Duncan’s paddock had no moss coverage in the assessed pasture (fig. 4.16). Daisy plants were present in all three pastures examined, with Chris’s (11.3%) and Duncan’s (5.3%) paddocks not significantly different to each other. However, both had significantly greater daisy coverage present in the pasture than High paddock (0.8%) (fig.4.17). Grass in the pastures was highly significant among the three sites, with all sites being significantly different from each other (fig.4.15). Duncan’s paddock had 39.9% of the pasture covered in grass which was five times greater than Chris’s paddock, with 7.6% grass coverage, while High paddock had the lowest grass coverage of all three sites, with 3.8% in the pasture (fig. 4.18).
Figure 4.15 Percentage cover of bare ground in the pasture at the three sites in autumn 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.

Figure 4.16 Percentage cover of moss in the pasture at the three sites in autumn 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.
Figure 4.17 Percentage cover of daisy in the pasture at the three sites in autumn 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean ± SEM) among sites.

Figure 4.18 Percentage cover of grass in the pasture at the three sites in autumn 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean ± SEM) among sites.

4.3.2.4 Spring 2007

Categories assessed and subsequent analysis results during the evaluation period between the three sites were: Bare ground P=0.547, Moss P<0.001, Clover P=0.736, Daisy P<0.001 and Grass P=0.112. Only two categories were statistically different among the three pasture sites during spring 2007. Moss coverage was statistically greater in High paddock (25.9%) compared to only 0.7% coverage in Chris’s paddock, which was not statistically significant from Duncan’s paddock, which did not have any moss in the
assessed pasture (fig. 4.19). Daisy plant coverage was significantly greater in both Chris’s (20.6%) and Duncan’s (15.5%) paddocks which were not statistically different from each other compared to High paddock, which had 6.3% daisy coverage in the pasture (fig 4.20).

Figure 4.19 Percentage cover of moss in the pasture at the three sites in spring 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.

Figure 4.20 Percentage cover of daisy in the pasture at the three sites in spring 2007 (P<0.001, df = 59). Different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among sites.
4.3.3 Pasture Comparison on both sides of a boundary fence

Multivariate analysis was performed with the results being no different from a one-way ANOVA therefore, the result of the one-way AVOVA are reported. Results differed between the two sites over the assessment period, with Chris’s paddock producing the greatest number of significant results over time. Chris’s paddock boundary site was predominantly along the cliff top, flanking the coast, while High Paddock boundary predominantly bordered by natural ravine leading away from the coast.

4.3.3.1 Chris’s paddock

Five pasture characteristics were recorded for both sides of the boundary fence, with each characteristic recorded on four different occasions over a 13 month period. Twelve of the twenty parameters were either highly significantly, or significantly different, covering all five assessment categories over the evaluation period (Table 4.1). There were eight results, with the pasture side of the boundary recording the greater percentage, with the remaining four results on the coast side of the fence. Bare ground was statistically greater on the pasture side during summer and autumn 2007 even though bare ground increased dramatically on both sides at the autumn assessment (Table 4.1). Moss percentage was statistically greater on the coast side, (three out of four assessment periods) while daisy percentage was significantly greater on the pasture side of the fence for the entire evaluation period (Table 4.1). Clover percentage was significantly higher on the pasture side of the fence for both spring 2006 and spring 2007. The final significant result was found in the grass coverage on the coast side of the fence during spring 2006 (Table 4.1).
Table 4.1 Results of ANOVA analysis (P = 0.05 significance level) of pasture on both sides of a recently erected boundary fence in Chris’s paddock on a sheep property, Borda Vale at Cape Borda. Abbreviations: Spr – Spring, Sum – Summer and Aut – Autumn.

<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
<th>Bare Ground %</th>
<th>Moss %</th>
<th>Daisy %</th>
<th>Clover %</th>
<th>Grass %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spr-06</td>
<td>Paddock</td>
<td>1.5 NS</td>
<td>0.4 Sig</td>
<td>7.8 Sig</td>
<td>20.6 Sig</td>
<td>63.8 Sig</td>
</tr>
<tr>
<td></td>
<td>Coast</td>
<td>3.2 P = 0.178</td>
<td>3.3 P = 0.002</td>
<td>3.3 P = 0.044</td>
<td>10.5 P = 0.002</td>
<td>71.6 P = 0.034</td>
</tr>
<tr>
<td>Sum-07</td>
<td>Paddock</td>
<td>10.6 Sig</td>
<td>3.6 NS</td>
<td>10.6 Sig</td>
<td>7.1 NS</td>
<td>55.5 NS</td>
</tr>
<tr>
<td></td>
<td>Coast</td>
<td>3.8 P = 0.016</td>
<td>8.9 P = 0.064</td>
<td>2.4 P &lt; 0.001</td>
<td>6.8 P = 0.912</td>
<td>60.7 P = 0.382</td>
</tr>
<tr>
<td>Aut-07</td>
<td>Paddock</td>
<td>49.5 Sig</td>
<td>14.4 Sig</td>
<td>11.3 Sig</td>
<td>9.9 NS</td>
<td>7.6 NS</td>
</tr>
<tr>
<td></td>
<td>Coast</td>
<td>35.2 P = 0.011</td>
<td>27.9 P = 0.019</td>
<td>5.4 P = 0.029</td>
<td>10.3 P = 0.907</td>
<td>9.4 P = 0.32</td>
</tr>
<tr>
<td>Spr-07</td>
<td>Paddock</td>
<td>10.3 NS</td>
<td>0.7 Sig</td>
<td>20.6 Sig</td>
<td>19.2 Sig</td>
<td>41.0 NS</td>
</tr>
<tr>
<td></td>
<td>Coast</td>
<td>10.0 P = 0.946</td>
<td>8.2 P = 0.002</td>
<td>10.1 P = 0.011</td>
<td>7.2 P = 0.002</td>
<td>46.3 P = 0.348</td>
</tr>
</tbody>
</table>

4.3.3.2 High Paddock

As previously described for pasture assessment in the previous section, the same numbers of tests were recorded. Only three out of twenty results were highly significantly or significantly different; all of these results occurred in autumn of 2007 (Table 4.2). Bare ground coverage was significantly greater on the coast side of the fence with 22.8% of the total area bare compared to 12.6% bare ground on the pasture side of the boundary fence. Moss coverage was highly significant on the paddock (72.7%) side of the boundary fence compared to the coast (56.4%) side. Grass coverage was significantly greater in the pasture on the coast (5.5%) side compared to the pasture on the paddock (3.8%) side of the fence (table 4.2).
Table 4.2 Results of ANOVA analysis (P = 0.05 significance level) of pasture on both sides of a recently erected boundary fence in High paddock on a sheep property, Borda Vale at Cape Borda. Abbreviations: Spr – Spring, Sum – Summer and Aut – Autumn.

<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
<th>Bare Ground %</th>
<th>Moss %</th>
<th>Daisy %</th>
<th>Clover %</th>
<th>Grass %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spr-06</td>
<td>Paddock</td>
<td>1.1 NS</td>
<td>5.6 NS</td>
<td>1.3 NS</td>
<td>14.2 NS</td>
<td>73.9 NS</td>
</tr>
<tr>
<td></td>
<td>Coast</td>
<td>3.1 P = 0.08</td>
<td>5.4 P = 0.881</td>
<td>0.3 P = 0.068</td>
<td>12.7 P = 0.409</td>
<td>74.5 P = 0.86</td>
</tr>
<tr>
<td>Sum-07</td>
<td>Paddock</td>
<td>1.9 NS</td>
<td>37.7 NS</td>
<td>0.6 NS</td>
<td>10.9 NS</td>
<td>43.4 NS</td>
</tr>
<tr>
<td></td>
<td>Coast</td>
<td>3.1 P = 0.398</td>
<td>30.0 P = 0.71</td>
<td>0.4 P = 0.608</td>
<td>11.1 P = 0.931</td>
<td>45.1 P = 0.244</td>
</tr>
<tr>
<td>Aut-07</td>
<td>Paddock</td>
<td>12.6 Sig</td>
<td>72.7 Sig</td>
<td>0.7 NS</td>
<td>7.8 NS</td>
<td>3.8 Sig</td>
</tr>
<tr>
<td></td>
<td>Coast</td>
<td>22.8 P = 0.008</td>
<td>56.4 P&lt;0.001</td>
<td>0.7 P = 0.992</td>
<td>11.4 P = 0.016</td>
<td>5.5 P = 0.039</td>
</tr>
<tr>
<td>Spr-07</td>
<td>Paddock</td>
<td>8.1 NS</td>
<td>25.9 NS</td>
<td>6.3 NS</td>
<td>34.2 NS</td>
<td>34.4 NS</td>
</tr>
<tr>
<td></td>
<td>Coast</td>
<td>10.3 P = 0.373</td>
<td>12.5 P = 0.055</td>
<td>8.0 P = 0.637</td>
<td>17.1 P = 0.415</td>
<td>33.0 P = 0.792</td>
</tr>
</tbody>
</table>

4.4 Discussion

The pasture at all three sites, High, Chris’s and Duncan’s paddocks varied with seasonal conditions. Moss did not appear in Duncan’s paddock at all during the assessment period. This could have been due to the location of the paddock or the constant high percentage of grass cover, also there was no tree cover creating shade on the pasture. Most species of bryophyte populations increase with tree cover, and only a very small percentage are able to survive in open paddocks (Austrheim, Hassel et al. 2005). Furthermore, High paddock contained extremely large expanses of moss, even though this trial data was recorded within close proximity to the boundary fence and along the native vegetation/paddock interface and not in the paddock proper. The fact that the high percentages were obtained in this area could have been due to environmental conditions (Fraham 2007) required for their short life cycle, such as shade, sub-surface water or sitting water which facilitates sexual reproduction in mosses (Rosenstiel and Eppley 2009). The seasonal decline in precipitation was reflected in increases of bare ground, also decreases in plant cover of both clover and grasses at all three sites. The breaking of the season with a large precipitation event occurring in late April followed by rain spread relatively evenly.
through May 2007 (fig. 4.5), reflected in October, when cover of clover and grasses increased corresponding with bare ground decreasing in all pasture sites. Bryophyte cover decreased in High and Chris’s paddocks after the precipitation events, possibly due to the hard hoofs of sheep trampling the soil (Read, Duncan et al. 2008; Williams, Eldridge et al. 2008) to graze on new plant growth (St. Clair, Johansen et al. 2007). *Arctotheca calendula* (Daisy) cover increased in all pastures for May and October 07. This could have been due to multiple explanations including: precipitation events, plenty of alternative and more palatable food available, decreasing the sheep’s interest in daisy or a result of low stocking rates in those pastures (Birrell and Thompson 2006). At low stocking rate *Arctotheca calendula* has the ability to become a major component in the pasture (Birrell and Thompson 2006).

The comparisons of pasture on both sides of the paddock boundary fence in two study sites: Chris’s and High paddocks, produced different results for the factors being assessed. Chris’s paddock produced the greatest number of tests, with significant, or highly significant, results between paddock and coast pastures at the same location. Bare ground was significantly different, with the pasture having greater areas with no ground cover. A possible explanation could have been greater stocking rates in the pasture compared to the coast side of the boundary fence. However, that same scenario was not applicable to High paddock, with greater bare ground in the coast side during Autumn, unless there were greater numbers of wild herbivores in the area than sheep in the pasture. Moss was significantly greater on the coast pasture in three of the four assessment periods at Chris’s paddock, while it was only significant at one assessment period in the pasture in High paddock. This was possibly due to factors that were discussed previously regarding bryophytes. The main factor (I would suggest) for the moss results would be the abundant shade from the *Allocasuarina verticillata* trees along the coastline cliffs in
Chris’s paddock and eucalyptus trees along the ravine in High paddock. *Arctotheca calendula* (Daisy) was significantly greater in the paddock pasture during all assessment periods at Chris’s paddock only. Daisy has a relative lower optimal germination temperature of 25°C than clover with optimal germination condition in February and March if early precipitation occurs (Turner, Thomson *et al.* 2001). If optimal conditions are not met, and precipitation occurs later, (not until June) then germination may be dramatically reduced by 80 percent (Thomson, Ewing *et al.* 1998). Maximum day temperatures during February and March 2007 were in the region of optimal germination temperatures. However, precipitation was not ideal until late April. Therefore, the mechanisms discussed by Turner, Thomson *et al.* (2001) do not entirely explain the increased presence in the paddock pasture in Chris’s paddock. Since temperature and precipitation were not optimal for the germination of seeds in the seed bank, then another contributing factor could have been the stocking rate in Chris’s paddock. This must have been low (Birrell and Thompson 2006) which allowed the weed species to increase in the pasture.

Conditions were suitable for the germination of daisy and subterranean clover from late March 2007. Well above average rainfall, combined with above average temperatures in April and May, would have ensured continued growth of these two plants. *Trifolium subterraneum* is an important pasture plant which had significantly greater cover in the paddock pasture of Chris’s paddock compared to the coast pasture on two assessment periods, with both periods in spring. Some plants benefit from grazing by herbivores (termed facilitative grazing) (Darabant, Rai *et al.* 2007; Facelli and Springbett 2009). Furthermore, facilitation of plant species can occur by one herbivore for the benefit of another (Colman, Mysterud *et al.* 2009; Stahl, Van Der Graaf *et al.* 2006; van der Wal, van Wijnen *et al.* 2000). Sheep facilitate the growth rate of *Trifolium subterraneum*, even
though its growth season is from autumn to spring (Frame 2008). The mechanism that allows the facilitation of *Trifolium subterraneum* or *Arctotheca calendula* in the pasture is unknown, a possible mechanism could be the removal of taller competing vegetation (van der Wal, van Wijnen et al. 2000). In the current study, the pasture on both sides of the boundary fence at both sites was completely different, with no consistent result obtained for either pasture in the paddock or on the coast side. However, the facilitation of *Trifolium subterraneum* is strengthen by the results in both paddocks in spring even though there was not any significant result achieved in High paddock. The differences could have been due to environmental factors not investigated during the pasture assessment, even though both sites were on the same property. Pasture plant cover is linked to the dietary requirement of the herbivores grazing the pasture. Therefore, the dietary overlap of the herbivores was explored further in Chapter 5.
Chapter 5

Dietary overlap of four herbivores on Kangaroo Island

5.1 Introduction

Competition for food resources between grazing herbivore species is not consistent throughout the year, with dietary overlap changing seasonally (Robley, Short et al. 2001; Sietses, Faupin et al. 2009; Torstenson, Mosley et al. 2006). In many cases, dietary overlap is exacerbated during summer (La Morgia and Bassano 2009; Robley, Short et al. 2001; Torstenson, Mosley et al. 2006) and in drought conditions when resources are limited. The competitive exclusion principle states that if two competitors share 100 percent of their diet, then one competitor could gain an advantage that will force the other competitor into either local extinction or total extinction (Veen, Sheldon et al. 2010). If competing animal species are able to co-exist in the same environment, it demonstrates that the competition is not complete among the competing species; therefore, there must be some mechanism of avoidance of competition. Studies are required to investigate the dietary overlap of the Kangaroo Island herbivores for the management of pastoral enterprises and for conservation management. A common method to determine the level of dietary overlap and assumed competition for resources that are non-invasive and non-disruptive to the species under focus is the analysis of plant cuticles extracted from faecal samples.

Faecal collection and plant cuticle analysis have been used for determining levels of dietary overlap and implied competition for resources for many suites of herbivores in Australia (Davis, Coulson et al. 2008; Dawson and Ellis 1996; Robley, Short et al. 2001;
Sprent and McArthur 2002; Woolnough and Johnson 2000) and worldwide (Prins, De Boer et al. 2006; Sietses, Faupin et al. 2009; Vila, Borrelli et al. 2009). Each of the aforementioned studies included a reference collection of plant species found in their respective study areas to enable the histological identification of the plant cuticles in either stomach contents or in each mammalian species’ faecal matter.

Home ranges of the wild herbivores being studied vary according to their size, mobility and seasonal requirements (Arnold, Stevens et al. 1992). Each of the three wild herbivores in this study had different sized home ranges. The western grey kangaroos have individual overlapping home ranges which allow for the coexistence of mobs of kangaroo in any one habitat and allows for social interactions (Arnold, Stevens et al. 1992). The western grey kangaroos are mainly sedentary and do not frequently shift their home range (Arnold, Stevens et al. 1992). The western grey kangaroo has a relatively small home range, therefore, the kangaroo does not disperse over large distances (Waudby, Petit et al. 2007). Another study has reported that the observed range length of 17 individual eastern grey kangaroos was 2.1 km (Coulson 1993). Kangaroos have a core home range of approximately 3 ha, which ranges up to 10 times that area during night grazing. Kangaroos have been located during night observations 1 km from their core home range (Arnold, Stevens et al. 1992).

Goats in Australia have been released, or have escaped, to produce areas where feral populations have established. The home range of feral goats (on Moreton Island off the coast of Queensland, Australia) in a composite mixed herd is approximately 13.7 km$^2$ while male herd home range is approximately 18.8 km$^2$ and female herd home range is 14.6 km$^2$ (O'Brien 1984). Goats, like kangaroos, have a core home range. Adult males have a mean core home range of approximately 200 km$^2$, and adult females have a mean
core home range of approximately 36 km² in a wheat growing area of Western Australia (King 1992). The home range depends on conditions such as plant diversification and abundance and other environmental conditions, and presumably the habitat for goats in the wheat areas of Western Australia is much less favourable than the habitat on Moreton Island, explaining the discrepancy in the home ranges recorded in these two environments.

Tammar wallabies have been reintroduced in Innes National Park and have a mean core home range of 3.8 ha and a total mean home range of 15.9 ha, with lesser home ranges in winter (Kemp 2010). Home ranges of wallabies have varied between the sexes for several wallaby species including the tammar wallaby (Fisher 2000; Kemp 2010; Stirrat 2003). However, Inns (1980) observed no difference in home ranges between the sexes in his study of Kangaroo Island tammar wallabies. The home range of tammar wallabies did vary with season, however, with home range greatest in summer (44.1 ± 18.1 ha) and smallest in winter (19.1 ± 10.6 ha) (Inns 1980).

This chapter investigated the dietary interactions among the four competing herbivore species of interest in their naturally-occurring habitat located on Kangaroo Island. The habitat encompasses both areas of native shrubs and modified pastures. Dietary overlap among the four herbivore species during the different seasons was investigated by cuticle analysis of faecal matter.

5.2 Methods

Plant cuticle analysis was utilised to determine the diets of the four herbivore species. Plants occurring at the study site were collected, identified and processed to obtain a reference library of plant cuticles of known species. Fresh faecal samples were collected
at each study site, identified to the species of origin and processed to obtain plant cuticles. The cuticles in the faecal samples were compared with the cuticles in the reference library of known plant species to determine the diet of the herbivore of origin. Histological identification of plant cuticles have been used extensively in many studies spanning many decades (Brad Witt, Berghammer et al. 2000; Griffiths and Barker 1966; Karmiris and Nastis 2010; Shrestha, Wegge et al. 2005; Sparks and Malechek 1968; Storr 1960).

### 5.2.1 Faecal Collection Study Sites

Strict sampling criteria were set for the faecal collection on pasture areas on Kangaroo Island. The most critical criterion was that faecal evidence of feral goats along with kangaroo, wallaby and sheep had been present. The other criteria were the same as detailed in the previous chapter. All faecal collection occurred within each transect at each site.

### 5.2.2 Faecal Identification and Preparation

An animal species’ faecal shape is relatively consistent; however, seasonal differences are possible. Therefore, faecal shape characteristic is ideal to identify faeces from different species (Grant 1974). Faecal identification was determined utilising several steps (keys) to identify faecal material from different species using the field guides of Morrison (1981) and Triggs (1996).

Identification of faecal pellets from different species became difficult after rain, which altered the pellet shape and induced seed germination and hence pasture growth (Barker 1987). Correct identification of each species’ faecal material shape and colour is critical. Therefore, referencing and normalisation occurred before collection, with animals kept in captivity on the Roseworthy campus and at other close locations.
5.2.3 Tammar Wallaby (*Macropus eugenii*)

The wallabies’ scat is cylindrical and can range in size from 2-2.5cm long and 1-1.5 wide with a slight taper at one end. Scats are usually found in a small group of two pellets as either singular pieces or as two pellets together to form a larger scat. The scats comprised entirely of vegetative matter.

5.2.4 Western Grey Kangaroo (*Macropus fuliginosus*)

Kangaroo scats are squarish or oblong in shape, with rounded corners and a small point taper formed at the ends, ranging in size from 2.5-3 cm long and 2-2.5 cm wide. Scats are usually found in groups for four to eight pellets sometimes as single pellets, as a clump or jointed as a string of pellets. The pellet shape from any one animal is variable, with different shapes being deposited at the same time (Triggs 1996).

5.2.5 Sheep (*Ovis aries*)

Sheep scats are rounded, oval or cylindrical, with ends being rounded or dimpled. They range in size from 1.5 cm round individual pellets to clumps of pellets from 3-3.5 cm in width and 5 cm in length. Scats can be found as individual pellets in large groups or a mixture of individual pellets and a clump. All are composed of vegetative matter.

5.2.6 Goat (*Capra hircus*)

Goat scats are similar to that of the sheep and can be found to be round, oval or cylindrical and have a similar size range. Goat pellets are usually pointed at both ends, which distinguish them from the sheep scats.
5.2.7 Plant Reference Collection

Two samples from each plant that could have been included in herbivore diets were taken. The plants samples taken were from plants that showed signs of being eaten. A representative proportion of the plant, including leaf, flowers and stem <150 mm long was dried for specific identification and a 1cm² leaf section was preserved in 90% ethanol for cuticular reference. The samples were given matching codes for identification.

5.2.8 Formal Identification of plant species

Samples were identified utilising microscopic and histological features following the keys to plant identification in Flora of South Australia series (Black 1986). The identification was verified by the South Australian Herbarium.

5.2.9 Cuticle Identification – Reference collection

Ethanol preserved samples were mainly utilised to procure the waxy cuticle of the plant. A sub-sample was removed from the ethanol solution, cut into approximately 3 mm² pieces, and placed into a Petri dish with 15 ml of a sodium hypochlorite solution (concentration 35 g/L, domestic bleach) added. Individual Petri dishes were identified using the sample identification number. The solution was then covered and left for 24 hours at room temperature. All samples were then transferred into Reverse Osmosis (RO) water and rinsed. Each sample was then placed individually into a 0.1% dye (Genetian Violet) water solution for approximately five minutes. Dyed samples were then rinsed with RO water and placed onto a microscope slide. To preserve the sample on the slide a few drops of a glycerol solution (75% glycerol and 25% RO water) were added. A cover-slip was placed over the sample and the edges were sealed with clear nail polish. Cuticles of individual plant were photographed at 100x and 200x magnification for ease of
identifying faecal cuticle particles in the sample. Photographs of the plant cuticle appear in Appendix 2.

5.2.10 Faecal Preparation

Faecal samples were oven-dried at 40°C for 24 h. For each herbivore species, samples collected across all transects were pooled for each site and a subsample from each site was ground through a 1-mm screen, and mixed to ensure homogeneity (Karmiris and Nastis 2010). A subsample was taken from the ground sample for each species and each site and placed in a centrifuge tube with sodium hypochlorite solution (concentration 35 g/L, domestic bleach) for 24 h. The sample was placed in the centrifuge for four minutes at 1000 rpm and excess fluid removed, RO water was added. After any liquid was added, samples were hand shaken to ensure rinsing or dyeing was consistent. The samples were placed back into the centrifuge three times as previously described. A 0.1% dye (Genetian Violet) water solution was added and washed out after 10 minutes. Samples of the dyed cuticles were placed onto three slides for analysis. The sample slides were then fixed by the same procedure as described in section 5.2.9.

5.2.11 Histological Reference

Histological identification of plant epidermal structures was performed similar to Brad Witt, Berghammer et al. (2000) and Karmiris and Nastis (2010). Reference collections of plant species found on the study site are essential for the histological identification of plant cuticles in the faecal samples of the studied herbivores (Karmiris and Nastis 2010; Sanders, Dahl et al. 1980).
5.2.12 Histological Analysis

Each plant cuticle present in 20 fields of view was identified at 100 x magnification on each slide (Karmiris and Nastis 2010). The frequency of a plant species cuticle recorded was divided by the total frequency of all cuticles observed to provide the proportion in that herbivore’s diet. To obtain a measure of dietary overlap, Pianka’s equation was utilised (Pianka 1973). Pianka’s equation has been used for dietary overlap studies in avian species (Goutner and Alivizatos 2003), amphibian species (Crawford, Shepard et al. 2009), mammalian herbivore species (Li, Jiang et al. 2008) and mammalian carnivore species (Matsuo and Ochiai 2009; van der Merwe, Tambling et al. 2009). The measured dietary overlap between possible pairs of 4 herbivores with Pianka’s $C$ (Pianka 1973):

$$C = \frac{\Sigma P_{ij}P_{ik}}{\sqrt{\Sigma P_{ij}^2 \Sigma P_{ik}^2}}$$ (1)

Calculation of dietary overlap among the 4 herbivore species:

$$C = \frac{\Sigma P_{ij}P_{ik}P_{il}P_{im}}{\sqrt{\Sigma P_{ij}^2 \Sigma P_{ik}^2 \Sigma P_{il}^2 \Sigma P_{im}^2}}$$ (2)

$P_{ij}$, $P_{ik}$, $P_{il}$ and $P_{im}$ are proportions of the $i$th partition of a given food in all faecal samples of species $j$, $k$, $l$ and $m$, respectively, where $C = 0$ indicates no overlap and $C = 1$ indicates complete overlap. Plant species that were not present in a herbivore species’ faecal sample, but were present in another herbivore species’ sample, were given a value of 0.001, thereby, avoiding zero values (Aebischer, Robertson et al. 1993; Soininen, Hübner et al. 2010), to enable Pianka’s index to be calculated.
5.3 Results

5.3.1 Cuticle Analysis

The reference collection contained 28 plant samples, 16 dicotyledon species and 12 monocotyledon species. Only three monocotyledon species did not appear in the diet of any of the four herbivores, for the entire in situ experiment from October 2006 to October 2007 (Table 5.1).

Table 5.1 List of plant species, common names and corresponding identification codes from cuticle analysis of plants occurring at the study site. D = Dicotyledon and M = Monocotyledon. The order is not sequential in the monocotyledon section to enable plants with the same genus to appear together.

<table>
<thead>
<tr>
<th></th>
<th>Family</th>
<th>Genus</th>
<th>Species</th>
<th>Sub Species</th>
<th>Common Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Leguminosae</td>
<td>Trifolium</td>
<td>subterraneum</td>
<td>—</td>
<td>Sub Clover</td>
</tr>
<tr>
<td>D2</td>
<td>Compositae</td>
<td>Arctotheca</td>
<td>calendula</td>
<td>—</td>
<td>Capeweed</td>
</tr>
<tr>
<td>D3</td>
<td>Cyperaceae</td>
<td>Lepidosperma</td>
<td>viscidum</td>
<td>—</td>
<td>Sticky sword-edge</td>
</tr>
<tr>
<td>D4</td>
<td>Leguminosae</td>
<td>Acacia</td>
<td>paradoxa</td>
<td>—</td>
<td>Kangaroo Thorn</td>
</tr>
<tr>
<td>D5</td>
<td>Casuarinaceae</td>
<td>Allocasuarina</td>
<td>verticillata</td>
<td>—</td>
<td>Drooping sheoak</td>
</tr>
<tr>
<td>D6</td>
<td>Sapindaceae</td>
<td>Dodonea</td>
<td>viscosa</td>
<td>ssp spatulata</td>
<td>Sticky hop-bush</td>
</tr>
<tr>
<td>D7</td>
<td>Dilleniaceae</td>
<td>Hibbertia</td>
<td>riparia</td>
<td>—</td>
<td>Erect guinea-flower</td>
</tr>
<tr>
<td>D8</td>
<td>Epacridaceae</td>
<td>Astroloma</td>
<td>conostephoides</td>
<td>—</td>
<td>Flame heath</td>
</tr>
<tr>
<td>D9</td>
<td>Leguminosae</td>
<td>Pultenea</td>
<td>villifera</td>
<td>var. glabrescens</td>
<td>Yellow bush-pea</td>
</tr>
<tr>
<td>D10</td>
<td>Stackhousiaceae</td>
<td>Stackhousia</td>
<td>aspericocca</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>D11</td>
<td>Leguminosae</td>
<td>Acacia</td>
<td>leiophylla</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>D12</td>
<td>Dilleniaceae</td>
<td>Hibbertia</td>
<td>aspera</td>
<td>—</td>
<td>Guinea-flower</td>
</tr>
<tr>
<td>D13</td>
<td>Myrtaceae</td>
<td>Baeckea</td>
<td>ramosissima</td>
<td>—</td>
<td>Rosy baeckea</td>
</tr>
<tr>
<td></td>
<td>Myrtaceae</td>
<td>Euromyntus</td>
<td>ramosissima</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>D14</td>
<td>Cyperaceae</td>
<td>Lepidosperma</td>
<td>canescens</td>
<td>—</td>
<td>Hoary rapier-sedge</td>
</tr>
<tr>
<td>D15</td>
<td>Tremandraceae</td>
<td>Tetraetheca</td>
<td>halmaturina</td>
<td>—</td>
<td>Curly pink-bells</td>
</tr>
<tr>
<td>D16</td>
<td>Juncaceae</td>
<td>Juncus</td>
<td>pallidus</td>
<td>—</td>
<td>Pale rush</td>
</tr>
<tr>
<td>M1*</td>
<td>Gramineae</td>
<td>unident.genus</td>
<td>—</td>
<td>—</td>
<td>Grass</td>
</tr>
<tr>
<td>M2*</td>
<td>Gramineae</td>
<td>unident.genus</td>
<td>—</td>
<td>—</td>
<td>Grass</td>
</tr>
<tr>
<td>M3</td>
<td>Gramineae</td>
<td>Vulpia</td>
<td>myuros</td>
<td>—</td>
<td>Fox-tail fescue</td>
</tr>
<tr>
<td>M5</td>
<td>Gramineae</td>
<td>Vulpia</td>
<td>bromoides</td>
<td>—</td>
<td>Squirrel-tail fescue</td>
</tr>
<tr>
<td>M4</td>
<td>Gramineae</td>
<td>Bromus</td>
<td>hordeaceus</td>
<td>ssp hordeaceus</td>
<td>Soft brome</td>
</tr>
<tr>
<td>M9</td>
<td>Gramineae</td>
<td>Bromus</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>M12</td>
<td>Gramineae</td>
<td>Bromus</td>
<td>madritensis</td>
<td>—</td>
<td>Madrid brome</td>
</tr>
<tr>
<td>M6</td>
<td>Gramineae</td>
<td>unident.genus</td>
<td>—</td>
<td>Annual/perennials</td>
<td>—</td>
</tr>
<tr>
<td>M7</td>
<td>Gramineae</td>
<td>Ehrharta</td>
<td>unident. Sp.</td>
<td>—</td>
<td>Annual/perennials</td>
</tr>
<tr>
<td>M8</td>
<td>Gramineae</td>
<td>unident.genus</td>
<td>—</td>
<td>Annual/perennials</td>
<td>—</td>
</tr>
<tr>
<td>M10</td>
<td>Gramineae</td>
<td>Lolium</td>
<td>rigidum</td>
<td>—</td>
<td>Wimmera ryegrass</td>
</tr>
<tr>
<td>M11*</td>
<td>Gramineae</td>
<td>Holcus</td>
<td>lanatus</td>
<td>—</td>
<td>Yorkshire fog</td>
</tr>
</tbody>
</table>

* Did not appear in the faeces of any species
5.3.1.1  **Spring 2006**

Sheep diet comprised 23% dicotyledon species with *Trifolium subterraneum* at 12%, and 77% monocotyledon species dominated by *Vulpia myuros* (37%) (fig. 5.1). Goat diet consisted of more dicotyledon species (59% with *Dodonaea viscosa* the greatest at 19%), than monocotyledon species (41% with gramineae *Ehrharta* at 14%) with three dicot and two monocot species in double figures, which is totally opposite to the other three herbivore species (fig. 5.2) Kangaroo diet consisted of only 14% dicotyledon species with *Allocasuarina verticillata* at 4%, and 86% monocotyledon species with gramineae *Ehrharta* dominant (fig. 5.3). Wallaby diet consisted of 26% dicotyledon species of which *Dodonaea viscosa* was the greatest at 9%. Monocotyledon species constituted 74% of the wallaby diet which was dominated by *Vulpia myuros* (34%) (fig. 5.4)

Figure 5.1 Spring diet of sheep in Kangaroo Island’s north-western region in 2006.
Figure 5.2 Spring diet of goats in Kangaroo Island’s north-western region in 2006.

Figure 5.3 Spring diet of kangaroos in Kangaroo Island’s north-western region in 2006.
Three significant differences existed among the four herbivores diets of the 26 plant reference species examined for the spring of 2006 (Table 5.2). The three significant differences were one dicotyledon species, D5 Allocasuarina verticillata $P=0.042$ (fig. 5.5) and two monocotyledon species, M3 Vulpia myuros $P=0.002$ (fig. 5.6) and M7 Ehrharta sp. $P<.001$ (fig. 5.7).
Table 5.2 Diets of four herbivores on the north-western region of Kangaroo Island in October 2006. Significant results are in bold red and plant species with dashes through the square indicates the species was not present in the diets.

<table>
<thead>
<tr>
<th>Dicotyledon</th>
<th>Monocotyledon</th>
</tr>
</thead>
<tbody>
<tr>
<td>D 1 - <em>Trifolium subterraneum</em></td>
<td>M 1 - unident. genus</td>
</tr>
<tr>
<td>0.066 NS</td>
<td>—</td>
</tr>
<tr>
<td>D 2 - <em>Arctotheca calendula</em></td>
<td>M 2 - unident. genus</td>
</tr>
<tr>
<td>0.498 NS</td>
<td>—</td>
</tr>
<tr>
<td>D 3 - <em>Lepidosperma viscidum</em></td>
<td>M 3 - <em>Vulpia myuros</em></td>
</tr>
<tr>
<td>0.498 NS</td>
<td>0.002 Sig</td>
</tr>
<tr>
<td>D 4 - <em>Acacia paradoxa</em></td>
<td>M 4 - <em>Bromus hordeaceus</em></td>
</tr>
<tr>
<td>—</td>
<td>0.206 NS</td>
</tr>
<tr>
<td>D 5 - <em>Allocasuarina verticillata</em></td>
<td>0.042 Sig</td>
</tr>
<tr>
<td>0.042 Sig</td>
<td>M 5 - <em>Vulpia bromoides</em></td>
</tr>
<tr>
<td>D 6 - <em>Dodonaea viscosa</em></td>
<td>0.627 NS</td>
</tr>
<tr>
<td>0.058 NS</td>
<td>M 6 - unident. genus</td>
</tr>
<tr>
<td>D 7 - <em>Hibbertia riparia</em></td>
<td>0.523 NS</td>
</tr>
<tr>
<td>0.499 NS</td>
<td>M 7 - <em>Ehrharta</em></td>
</tr>
<tr>
<td>D 8 - <em>Astroloba conostiphidies</em></td>
<td>&lt;.001 Sig</td>
</tr>
<tr>
<td>0.995 NS</td>
<td>M 8 - unident. genus</td>
</tr>
<tr>
<td>D 9 - <em>Pultenea villifera</em></td>
<td>M 9 - <em>Bromus</em></td>
</tr>
<tr>
<td>0.552 NS</td>
<td>0.552 NS</td>
</tr>
<tr>
<td>D 10 - <em>Stackhousia aspericocca</em></td>
<td>M 10 - <em>Lolium rigidum</em></td>
</tr>
<tr>
<td>—</td>
<td>0.310 NS</td>
</tr>
<tr>
<td>D 11 - <em>Acacia leiophylla</em></td>
<td>M 11 - <em>Holcus lanatus</em></td>
</tr>
<tr>
<td>0.214 NS</td>
<td>—</td>
</tr>
<tr>
<td>D 12 - <em>Hibbertia aspera</em></td>
<td>M 12 - <em>Bromus madritensis</em></td>
</tr>
<tr>
<td>0.581 NS</td>
<td>0.567 NS</td>
</tr>
</tbody>
</table>

*Allocasuarina verticillata* cuticles were observed in three of the four herbivore faecal samples; sheep faecal samples did not contain any *Allocasuarina verticillata* cuticles. Goat samples had significantly greater numbers of cuticles than all the other herbivores. Furthermore, there were no significant differences between the wallaby, goat and sheep (fig. 5.5)

Figure 5.5 Dicotyledon species *Allocasuarina verticillata* $P=0.042$ (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences ($P<0.05$, mean $\pm$ SEM) among species.
*Vulpia myuros* cuticles were observed in all four herbivore faecal samples. Wallaby, kangaroo and sheep faecal cuticles were not significantly different to each other, although all three were significantly different to goat observations (fig. 5.6).

![Figure 5.6](image)

Figure 5.6 Monocotyledon species *Vulpia myuros* in diets of four herbivores $P=0.002$ (df = 15). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

*Ehrharta* sp. cuticles were observed in all four herbivore faecal samples. Kangaroo faecal cuticle numbers were significantly greater than all the other herbivores, with observations for wallaby, goat and sheep not significantly different (fig. 5.7).

![Figure 5.7](image)

Figure 5.7 Monocotyledon genus *Ehrharta* in diets of four herbivores $P<0.001$ (df = 15). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.
Dietary overlap was relatively high between pairs of herbivores, with lower dietary overlap recorded when analysing three or four herbivores together in the same habitat during spring 2006. The highest dietary overlap was between wallaby and sheep with a $C$ value of 94 (Table 5.3).

Table 5.3 Pianka’s index $C$ on the dietary overlap among Tammar wallaby, Western Grey Kangaroo, Goat and Sheep in the north-western region of Kangaroo Island during Spring 2006. $C = 0$ indicates no overlap and $C = 1$ indicates complete overlap.

<table>
<thead>
<tr>
<th>Species</th>
<th>$C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wallaby vs Kangaroo vs Goat vs Sheep</td>
<td>0.15</td>
</tr>
<tr>
<td>Kangaroo vs wallaby vs Goat</td>
<td>0.27</td>
</tr>
<tr>
<td>Kangaroo vs Sheep</td>
<td>0.80</td>
</tr>
<tr>
<td>Kangaroo vs Goat</td>
<td>0.59</td>
</tr>
<tr>
<td>Wallaby vs Sheep</td>
<td>0.94</td>
</tr>
<tr>
<td>Goat vs Sheep</td>
<td>0.63</td>
</tr>
<tr>
<td>Wallaby vs Goat</td>
<td>0.72</td>
</tr>
<tr>
<td>Wallaby vs Kangaroo</td>
<td>0.89</td>
</tr>
</tbody>
</table>

5.3.1.2  Summer 2007

Sheep diet consisted of 38% dicotyledon species dominated by Allocasuarina verticillata at 10%, and 62% monocotyledon species with Vulpia myuros (39%) dominant (fig. 5.8).

Goat diet was made up of 70% dicotyledon species dominated by three species Acacia leiophylla (19%), Allocasuarina verticillata (17%) and Astroloma conostephiodies (15%) while 30% monocotyledon species were dominated by Vulpia myuros at 16% (fig. 5.9).

Kangaroo diet consisted of 42% dicotyledon species with Allocasuarina verticillata (14%) and 58% monocotyledon species with both Vulpia myuros and Bromus hordeaceus at 16% (fig. 5.10). Wallaby diet comprised 55% dicotyledon species dominated by Allocasuarina verticillata (17%) with 45% monocotyledon species dominated by three species, the gramineae Ehrharta sp. (13%), Vulpia myuros (12%) and Bromus hordeaceus (11%) (fig. 5.11).
Figure 5.8 Summer diet of sheep in Kangaroo Island’s north-western region in 2007.

Figure 5.9 Summer diet of goats in Kangaroo Island’s north-western region in 2007.
Figure 5.10 Summer diet of kangaroos in Kangaroo Island’s north-western region in 2007.

Figure 5.11 Summer diet of wallabies in Kangaroo Island’s north-western region in 2007.

Five significant differences existed among the four herbivores diets of the 26 plant reference species examined for the summer of 2007 (Table 5.4). Only one dicotyledon species D11 *Acacia leiophylla* $P=0.004$ (fig. 5.12) and four monocotyledon species M3
**Vulpia myuros** P=0.012 (fig. 5.13), M5 **Vulpia bromoides** P<.001 (fig. 5.14), M4 **Bromus hordeaceus** P=0.002 (fig. 5.15) and M6 an unidentified grass P=0.039 (fig. 5.16).

Table 5.4 Diets of four herbivores on the north-western region of Kangaroo Island in January 2007. Significant results are in bold red and plant species with dashes through the square indicates the species was not present in the diets.

<table>
<thead>
<tr>
<th></th>
<th>Dicotyledon</th>
<th>Monocotyledon</th>
</tr>
</thead>
<tbody>
<tr>
<td>D 1</td>
<td><em>Trifolium subterraneum</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.055 NS</td>
<td></td>
</tr>
<tr>
<td>D 2</td>
<td><em>Arctotheca calendula</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.141 NS</td>
<td></td>
</tr>
<tr>
<td>D 3</td>
<td><em>Lepidosperma viscidum</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.474 NS</td>
<td></td>
</tr>
<tr>
<td>D 4</td>
<td><em>Acacia paradoxa</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.547 NS</td>
<td></td>
</tr>
<tr>
<td>D 5</td>
<td><em>Allocasuarina verticillata</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.059 NS</td>
<td></td>
</tr>
<tr>
<td>D 6</td>
<td><em>Dodonaea viscosa</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.994 NS</td>
<td></td>
</tr>
<tr>
<td>D 7</td>
<td><em>Hibbertia riparia</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.087 NS</td>
<td></td>
</tr>
<tr>
<td>D 8</td>
<td><em>Astroloma conostephoides</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.355 NS</td>
<td></td>
</tr>
<tr>
<td>D 9</td>
<td><em>Pultenea villifera</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>D 10</td>
<td><em>Stackhousia aspericocca</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.287 NS</td>
<td></td>
</tr>
<tr>
<td>D 11</td>
<td><em>Acacia leiophylla</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.004 Sig</td>
<td></td>
</tr>
<tr>
<td>D 12</td>
<td><em>Hibbertia aspera</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>D 13</td>
<td><em>Euromyntus ramosissima</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.664 NS</td>
<td></td>
</tr>
<tr>
<td>D 14</td>
<td><em>Lepidosperma canescens</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>D 15</td>
<td><em>Teltratheca halimaturina</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.631 NS</td>
<td></td>
</tr>
<tr>
<td>D 16</td>
<td><em>Juncus pallidus</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.474 NS</td>
<td></td>
</tr>
<tr>
<td>M 1</td>
<td>unident. genus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>M 2</td>
<td>unident. genus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>M 3</td>
<td><em>Vulpia myuros</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.012 Sig</td>
<td></td>
</tr>
<tr>
<td>M 4</td>
<td><em>Bromus hordeaceus</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.002 Sig</td>
<td></td>
</tr>
<tr>
<td>M 5</td>
<td><em>Vulpia bromoides</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;.001 Sig</td>
<td></td>
</tr>
<tr>
<td>M 6</td>
<td>unident. genus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.039 Sig</td>
<td></td>
</tr>
</tbody>
</table>

*Acacia leiophylla* cuticle was observed in three of the four herbivore faecal samples. Goat faecal cuticle numbers were statistically greater than the other three herbivores, with no cuticles of *Acacia leiophylla* found in kangaroo faecal samples during the summer of 2007 (fig. 5.12).
Figure 5.12 Micotyledon species *Acacia leiophylla* in diets of four herbivores $P=0.004$ (df = 14). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

*Vulpia myuros* cuticles were observed in all four herbivore species faecal samples. Sheep and kangaroo faecal cuticle numbers were not significantly different from each other. However, goat and wallaby faecal cuticle numbers were significantly lower than sheep (fig. 5.13).

Figure 5.13 Monocotyledon species *Vulpia myuros* in diets of four herbivores $P=0.012$ (df = 14). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

*Vulpia bromoides* cuticles were observed in three of the four herbivore species faecal samples, with none observed in sheep faecal samples. Kangaroo faecal cuticle numbers were significantly greater than wallaby cuticle numbers. Furthermore, wallaby and goat
observations were not significantly different, in contrast to the wallaby and sheep faecal cuticle numbers (fig. 5.14).

![Bar chart](image)

Figure 5.14 Monocotyledon species *Vulpia bromoides* in diets of four herbivores *P*<0.001 (df = 14). The different alphabetical characters indicate significant differences (*P*<0.05, mean ± SEM) among species.

*Bromus hordeaceus* cuticles were only observed in faecal samples of the macropod species, no cuticles were observed in goat and sheep samples. Kangaroo faecal cuticle numbers were not significantly different than wallaby, although kangaroo faecal cuticle numbers were statistically different to goat and sheep. Wallaby faecal cuticle numbers were not statistically different to kangaroo, goat or sheep (fig. 5.15).

![Bar chart](image)

Figure 5.15 Monocotyledon species *Bromus hordeaceus* in diets of four herbivores *P*=0.002 (df = 14). The different alphabetical characters indicate significant differences (*P*<0.05, mean ± SEM) among species.
The unidentified grass cuticles were not observed in all four herbivore faecal samples; kangaroo samples did not have the unidentified grass cuticles present. Sheep samples had the greatest number of cuticles observed, however, there were no statistically significant differences in the faecal cuticle numbers of either goat or wallaby samples. Furthermore, there were no significant differences among the observations of wallaby, goat and kangaroo (fig. 5.16).

Figure 5.16 Unidentified monocotyledon species in diets of four herbivores $P=0.039$ (df = 14). The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

Dietary overlap was relatively high between pairs of herbivores, with lower dietary overlap when analysing three or four herbivores together in the same habitat during summer 2007. The highest dietary overlap was between wallaby and kangaroo with a $C$ value of 0.95 (Table 5.5).
Table 5.5 Pianka’s index C on the dietary overlap among Tammar wallaby, Western Grey Kangaroo, Goat and Sheep in the north-western region of Kangaroo Island during Summer 2007. C = 0 indicates no overlap and C = 1 indicates complete overlap.

<table>
<thead>
<tr>
<th>Species</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wallaby vs Kangaroo vs Goat vs Sheep</td>
<td>0.10</td>
</tr>
<tr>
<td>Kangaroo vs wallaby vs Goat</td>
<td>0.27</td>
</tr>
<tr>
<td>Kangaroo vs Sheep</td>
<td>0.64</td>
</tr>
<tr>
<td>Kangaroo vs Goat</td>
<td>0.62</td>
</tr>
<tr>
<td>Wallaby vs Sheep</td>
<td>0.63</td>
</tr>
<tr>
<td>Goat vs Sheep</td>
<td>0.63</td>
</tr>
<tr>
<td>Wallaby vs Goat</td>
<td>0.70</td>
</tr>
<tr>
<td>Wallaby vs Kangaroo</td>
<td>0.95</td>
</tr>
</tbody>
</table>

5.3.1.3 Autumn 2007

Sheep diet comprised 41% dicotyledon species and 59% monocotyledon species. Dicotyledon species were dominated by *Trifolium subterraneum* (10%) and *Allocasuarina verticillata* (9%) with the monocotyledon species dominated by *Vulpia myuros* (24%) (fig. 5.17). Goat diet consisted of 58% dicotyledon species, dominated by *Acacia leiophylla* (20%) and *Allocasuarina verticillata* (14%) with monocotyledon species 24% of the diet dominated by *Vulpia myuros* (15%) (fig. 5.18). Kangaroo diet consisted of 53% dicotyledon species dominated by *Dodonaea viscosa* (22%) with monocotyledon species at 47% dominated by *Vulpia myuros* (16%) and *Vulpia bromoides* (11%) (fig. 5.19). Wallaby diet comprised 67% dicotyledon species dominated by *Allocasuarina verticillata* (26%) and *Dodonaea viscosa* (23%) while monocotyledon species were 33% dominated by *Vulpia myuros* (14%) and *Vulpia bromoides* (8%) (fig. 5.20).
Figure 5.17 Autumn diet of sheep in Kangaroo Island’s north-western region in 2007.

Figure 5.18 Autumn diet of goats in Kangaroo Island’s north-western region in 2007.
Figure 5.19 Autumn diet of kangaroos in Kangaroo Island’s north-western region in 2007.

Figure 5.20 Autumn diet of wallabies in Kangaroo Island’s north-western region in 2007.

There were six significant differences among the four herbivores diets of the 26 plant reference species examined for the autumn of 2007 (Table 5.6). There were four dicotyledon species, D1 *Trifolium subterraneum* $P=0.001$ (fig. 5.21), D5 *Allocasuarina verticillata* $P=0.038$ (fig. 5.22), D6 *Dodonaea viscosa* $P=0.003$ (fig. 5.23) and D8
Astroloma conostephiodies $P=0.019$ (fig. 5.24), and two monocotyledon species M3 *Vulpia myuros* $P=0.044$ (fig. 5.25) and M6 an unidentified grass $P=0.039$ (fig. 5.26).

Table 5.6 Analysis results of the diets of four herbivores on the north-western region of Kangaroo Island in May 2007. Significant results are in bold red and plant species with dashes through the square indicates the species was not present in the diets.

<table>
<thead>
<tr>
<th>Dicotyledon</th>
<th>Monocotyledon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D 1 - Trifolium subterraneum</strong></td>
<td><strong>M 1 - unident. genus</strong></td>
</tr>
<tr>
<td>0.001 Sig</td>
<td>—</td>
</tr>
<tr>
<td><strong>D 2 - Arctotheca calendula</strong></td>
<td><strong>M 2 - unident. genus</strong></td>
</tr>
<tr>
<td>0.259 NS</td>
<td>—</td>
</tr>
<tr>
<td><strong>D 3 - Lepidosperma viscida</strong></td>
<td><strong>M 3 - Vulpia myuros</strong></td>
</tr>
<tr>
<td>0.054 NS</td>
<td>0.044 Sig</td>
</tr>
<tr>
<td><strong>D 4 - Acacia paradoxa</strong></td>
<td><strong>M 4 - Bromus hordeaceus</strong></td>
</tr>
<tr>
<td>0.426 NS</td>
<td>0.181 NS</td>
</tr>
<tr>
<td><strong>D 5 - Allocasuarina verticillata</strong></td>
<td><strong>M 5 - Vulpia bromoides</strong></td>
</tr>
<tr>
<td>0.038 Sig</td>
<td>0.053 NS</td>
</tr>
<tr>
<td><strong>D 6 - Dodonaea viscosa</strong></td>
<td><strong>M 6 - unident. genus</strong></td>
</tr>
<tr>
<td>0.003 Sig</td>
<td>&lt;0.001 Sig</td>
</tr>
<tr>
<td><strong>D 7 - Hibbertia riparia</strong></td>
<td><strong>M 7 - Ehrharta</strong></td>
</tr>
<tr>
<td>0.593 NS</td>
<td>0.423 NS</td>
</tr>
<tr>
<td><strong>D 8 - Astroloma conostephiodies</strong></td>
<td><strong>M 8 - unident. genus</strong></td>
</tr>
<tr>
<td><strong>D 9 - Pultenea villifera</strong></td>
<td>—</td>
</tr>
<tr>
<td>0.486 NS</td>
<td>—</td>
</tr>
<tr>
<td><strong>D 10 - Stackhousia aspericocca</strong></td>
<td><strong>M 9 - Bromus</strong></td>
</tr>
<tr>
<td>0.539 NS</td>
<td>0.889 NS</td>
</tr>
<tr>
<td><strong>D 11 - Acacia leiophylla</strong></td>
<td><strong>M 10 - Lolium rigidum</strong></td>
</tr>
<tr>
<td>0.059 NS</td>
<td>0.160 NS</td>
</tr>
<tr>
<td><strong>D 12 - Hibbertia aspera</strong></td>
<td><strong>M 11 - Holcus lanatus</strong></td>
</tr>
<tr>
<td>0.426 NS</td>
<td>—</td>
</tr>
<tr>
<td><strong>D 13 - Euromyntus ramosissima</strong></td>
<td><strong>M 12 - Bromus madritensis</strong></td>
</tr>
<tr>
<td>0.426 NS</td>
<td>0.306 NS</td>
</tr>
</tbody>
</table>

Trifolium subterraneum cuticle was observed in the faecal samples of all four herbivores. Observations in sheep faecal samples were significantly greater than wallaby, kangaroo and goat observation, although wallaby, kangaroo and goat faecal cuticle numbers were not statistically different (fig. 5.21).
**Figure 5.21** Dicotyledon species *Trifolium subterraneum* $P=0.001$ (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

*Allocasuarina verticillata* cuticles were observed in faecal samples from all four herbivore species. Wallaby faecal cuticle numbers were significantly different to sheep faecal cuticle numbers however; wallaby faecal cuticle numbers were not significantly different to either kangaroo or goat observations. Furthermore kangaroo and goat faecal cuticle numbers were not statistically different to sheep observations (fig. 5.22).

**Figure 5.22** Dicotyledon species *Allocasuarina verticillata* $P=0.038$ (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

*Dodonaea viscosa* cuticles were observed in all four herbivore faecal samples. Kangaroo and wallaby faecal cuticle numbers were not statistically different from each other, also
goat and sheep observations were not statistically different from each other. However, kangaroo and wallaby faecal cuticle numbers were significantly different to those for goat and sheep (fig. 5.23).

Figure 5.23 Dicotyledon species Dodonaea viscosa $P=0.003$ (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

Astroloma conostephiodies cuticles were present in all four herbivore faecal samples. Kangaroo cuticle observations were statistically different to sheep, although kangaroo faecal cuticle numbers were not significantly different to both wallaby and goat. However, wallaby, goat and sheep faecal cuticle numbers were not significantly different (fig. 5.24).

Figure 5.24 Dicotyledon species Astroloma conostephiodies $P=0.019$ (df = 15) in diets of four herbivores. The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.
*Vulpia myuros* cuticles were observed in the faecal samples of all four herbivores. Sheep faecal cuticles were significantly greater than wallaby, kangaroo and goat however; wallaby, kangaroo and goat faecal cuticles were not significantly different from each other (fig. 5.25).

![Bar chart showing faecal cuticles](image)

**Figure 5.25** Monocotyledon species *Vulpia myuros* in diets of four herbivores P=0.044 (df = 15). The different alphabetical characters indicate significant differences (P<0.05, mean + SEM) among species.

The unidentified grass cuticles were only observed in sheep and goat faecal samples. Sheep faecal cuticles were not significantly greater than goat, however; sheep faecal cuticles were statistically greater than both wallaby and kangaroo. Furthermore, goat, wallaby and kangaroo faecal cuticles of this plant were not significantly different to each other (fig. 5.26).
Dietary overlap was relatively high between pairs of herbivores, with lower dietary overlap when analysing three or four herbivores together in the same habitat during autumn 2007. The greatest dietary overlap was between wallaby and kangaroo with a $C$ value of 0.88 (Table 5.7).

Table 5.7 Pianka’s index $C$ on the dietary overlap among Tammar wallaby, Western Grey Kangaroo, Goat and Sheep in the north-western region of Kangaroo Island during autumn 2007. $C = 0$ indicates no overlap and $C = 1$ indicates complete overlap.

<table>
<thead>
<tr>
<th>Species</th>
<th>$C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wallaby vs Kangaroo vs Goat vs Sheep</td>
<td>0.09</td>
</tr>
<tr>
<td>Kangaroo vs wallaby vs Goat</td>
<td>0.21</td>
</tr>
<tr>
<td>Kangaroo vs Sheep</td>
<td>0.67</td>
</tr>
<tr>
<td>Kangaroo vs Goat</td>
<td>0.59</td>
</tr>
<tr>
<td>Wallaby vs Sheep</td>
<td>0.63</td>
</tr>
<tr>
<td>Goat vs Sheep</td>
<td>0.63</td>
</tr>
<tr>
<td>Wallaby vs Goat</td>
<td>0.62</td>
</tr>
<tr>
<td>Wallaby vs Kangaroo</td>
<td>0.88</td>
</tr>
</tbody>
</table>
Sheep diet during spring of 2007 consisted of 46% dicotyledon and 54% monocotyledon species. The dicots were dominated by *Dodonaea viscosa* (15%) and *Trifolium subterraneum* (11%) while the monocots were dominated by *Vulpia myuros* (21%) (fig. 5.27). Goat diet consisted of 56% dicotyledon species and 44% monocotyledon species. The dicots were dominated by *Dodonaea viscosa* (15%), *Acacia leiophylla* (15%) and *Allocasuarina verticillata* (9%) while the monocots were dominated by *Vulpia myuros* (20%) (fig. 5.28). Kangaroo diet comprised 38% dicotyledon and 62% monocotyledon species. The dicots were dominated by *Dodonaea viscosa* (11%) and *Allocasuarina verticillata* (9%) while the monocots were dominated by *Vulpia myuros* (27%) (fig. 5.29). Wallaby summer diet consisted of 49% dicotyledon and 51% monocotyledon species. The dicots were dominated by *Allocasuarina verticillata* (10%), *Dodonaea viscosa* (9%) and *Trifolium subterraneum* (9%) while the monocots were dominated by *Vulpia myuros* (27%) (fig. 5.30).
Figure 5.28 Spring diet of goats in Kangaroo Island’s north-western region in 2007.

Figure 5.29 Spring diet of kangaroos in Kangaroo Island’s north-western region in 2007.
There were three significant differences among the four herbivores diets of the 26 plant reference species examined for the spring of 2007 (Table 5.8). All three significant differences were found in the dicotyledon species only, D2 *Arctotheca calendula* $P=0.045$ (fig. 5.31), D11 *Acacia leiophylla* $P=0.009$ (fig. 5.32) and D16 *Juncus pallidus* $P<0.001$ (fig. 5.33).
Table 5.8 Diets of four herbivores on the north-western region of Kangaroo Island in October 2007. Significant results are in bold red and plant species with dashes through the square indicates the species was not present in the diets.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dicotyledon</strong></td>
<td></td>
<td><strong>Monocotyledon</strong></td>
<td></td>
</tr>
<tr>
<td>D 1 - <em>Trifolium subterraneum</em></td>
<td>0.550 NS</td>
<td>M 1 - unident. genus</td>
<td>—</td>
</tr>
<tr>
<td>D 2 - <em>Arctotheca calendula</em></td>
<td>0.045 Sig</td>
<td>M 2 - unident. genus</td>
<td>—</td>
</tr>
<tr>
<td>D 3 - <em>Lepidosperma viscidum</em></td>
<td>0.518 NS</td>
<td>M 3 - <em>Vulpia myuros</em></td>
<td>0.692 NS</td>
</tr>
<tr>
<td>D 4 - <em>Acacia paradoxa</em></td>
<td>0.701 NS</td>
<td>M 4 - <em>Bromus hordeaceus</em></td>
<td>0.918 NS</td>
</tr>
<tr>
<td>D 5 - <em>Allocasuarina verticillata</em></td>
<td>0.096 NS</td>
<td>M 5 - <em>Vulpia bromoides</em></td>
<td>0.567 NS</td>
</tr>
<tr>
<td>D 6 - <em>Dodonea viscosa</em></td>
<td>0.486 NS</td>
<td>M 6 - unident. genus</td>
<td>0.183 NS</td>
</tr>
<tr>
<td>D 7 - <em>Hibbertia riparia</em></td>
<td>0.364 NS</td>
<td>M 7 - <em>Ehrharta</em></td>
<td>0.096 NS</td>
</tr>
<tr>
<td>D 8 - <em>Astroloka conostephoides</em></td>
<td>0.297 NS</td>
<td>M 8 - unident. genus</td>
<td>—</td>
</tr>
<tr>
<td>D 9 - <em>Pultenea villifera</em></td>
<td>0.831 NS</td>
<td>M 9 - <em>Bromus</em></td>
<td>0.192 NS</td>
</tr>
<tr>
<td>D 10 - <em>Stackhousia aspericocca</em></td>
<td>0.067 NS</td>
<td>M 10 - <em>Lolium rigidum</em></td>
<td>0.564 NS</td>
</tr>
<tr>
<td>D 11 - <em>Acacia leiophylla</em></td>
<td>0.009 Sig</td>
<td>M 11 - <em>Holcus lanatus</em></td>
<td>—</td>
</tr>
<tr>
<td>D 12 - <em>Stackhousia aspericocca</em></td>
<td>0.067 NS</td>
<td>M 12 - <em>Bromus madritensis</em></td>
<td>0.168 NS</td>
</tr>
<tr>
<td>D 13 - <em>Euromyntus ramosissima</em></td>
<td>0.290 NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D 14 - <em>Lepidosperma canescens</em></td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D 15 - <em>Teltratheca halmaturina</em></td>
<td>0.067 NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D 16 - <em>Juncus pallidus</em></td>
<td>&lt;.001 Sig</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Arctotheca calendula* cuticles were observed in all four herbivore species’ faecal samples. Sheep faecal cuticle numbers were significantly different to wallaby, kangaroo and goat observations. Furthermore, wallaby, kangaroo and goat faecal cuticle numbers were not significantly different (fig 5.31).

Figure 5.31 Dicotyledon species *Arctotheca calendula* P=0.045 (df = 14) in diets of four herbivores. The different alphabetical characters indicate significant differences (P<0.05, mean ± SEM) among species.
Acacia leiophylla cuticles were observed in three of the four herbivore species’ faecal samples. Goat faecal cuticle numbers were not statistically different to wallaby cuticle numbers. However; goat faecal cuticle numbers were significantly greater than kangaroo and sheep cuticle numbers. Furthermore, wallaby, kangaroo and sheep faecal cuticle numbers were not statistically different (fig. 5.32).

![Figure 5.32](image)

**Figure 5.32** Dicotyledon species *Acacia leiophylla* $P=0.009$ (df = 14) in diets of four herbivores. The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.

Juncus pallidus cuticles were only observed in goat faecal samples of the four herbivore faecal samples during spring 2007. Therefore the goat faecal cuticle numbers were significantly greater than wallaby, kangaroo and sheep cuticle numbers (fig. 5.33).

![Figure 5.33](image)

**Figure 5.33** Dicotyledon species *Juncus pallidus* $P<0.001$ (df = 14) in diets of four herbivores. The different alphabetical characters indicate significant differences ($P<0.05$, mean + SEM) among species.
Dietary overlap was relatively high between pairs of herbivores, with lower dietary overlap when analysing three or four herbivores together in the same habitat during autumn 2007. The highest dietary overlap was between wallaby and kangaroo with a $C$ value of 0.89 (Table 5.9).

Table 5.9 Pianka’s index $C$ on the dietary overlap among Tammar wallaby, Western Grey Kangaroo, Goat and Sheep in the north-western region of Kangaroo Island during spring 2007. $C = 0$ indicates no overlap and $C = 1$ indicates complete overlap.

<table>
<thead>
<tr>
<th>Species</th>
<th>$C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wallaby vs Kangaroo vs Goat vs Sheep</td>
<td>0.23</td>
</tr>
<tr>
<td>Kangaroo vs wallaby vs Goat</td>
<td>0.41</td>
</tr>
<tr>
<td>Kangaroo vs Sheep</td>
<td>0.85</td>
</tr>
<tr>
<td>Kangaroo vs Goat</td>
<td>0.83</td>
</tr>
<tr>
<td>Wallaby vs Sheep</td>
<td>0.87</td>
</tr>
<tr>
<td>Goat vs Sheep</td>
<td>0.80</td>
</tr>
<tr>
<td>Wallaby vs Goat</td>
<td>0.85</td>
</tr>
<tr>
<td>Wallaby vs Kangaroo</td>
<td>0.89</td>
</tr>
</tbody>
</table>

5.4 Discussion

Dietary overlap between all species’ dyads was high. There was constantly high dietary overlap in all seasons. However, the greatest dietary overlap, occurring in spring when plant growth was at a maximum. The large dietary overlap during spring indicates that the inferred competition for resources was at a minimum, and all species were able to cope with the large dietary overlap, indication lack of interspecific competition. A primary concern of sheep graziers on Kangaroo Island was the suggested competition between sheep and wallabies for pasture. Although the dietary overlap between wallabies and sheep was high during the spring period, it corresponded with a time when pasture biomass was also high. The suggested competition between sheep and wallabies diminished markedly under drought conditions, when the wallaby decreased its intake of hayed grasses and markedly increased its intake of native vegetation. However, the wallaby maintained a high level of dietary overlap with the kangaroo under all seasons.
The feral goat is a species of concern, both to the grazier and to environmental managers on Kangaroo Island. The dietary overlap between the feral goat and the other herbivores was generally moderate, primarily because of its intake of *Acacia leiophylla*, a species generally shunned by the other herbivores, although it was chosen to some extent by the wallaby under good seasonal conditions. The goat also browsed *Allocasuarina verticillata* to a greater extent than did the other herbivores. However, the plant formed a high proportion of the diet of the wallaby under drought conditions, although the juxtaposition of the date of heavy rainfall in the last 4 days of April 2007 and the sampling period in the second week in May 2007 suggests that wallabies accessed germinating *A. verticillata* plants. *Astroloma conostephoides*, another native species was browsed by the goat to a greater extent compared to the other herbivores, although it was approached by the kangaroo. The preference of the goat for native trees and shrubs justifies the concern of environmental managers, particularly for any vulnerable species of native tree or shrub. However, the goat’s consumption of pasture plants was least of any of the four herbivore species, showing that there was less implied competition with sheep for pasture than was the case with the two macropod herbivores.

The results of diet analysis of the four herbivores indicated some plants were not accessible to all herbivores due to the boundary fence on the property. The fences were designed and erected to prevent the loss of sheep down the cliffs. The fences were not a barrier to the wallaby, kangaroo and goat entering or leaving the pastures.

Not all of the animal species studied were wild, with one species restrained from roaming through the native shrubbery. However, three wild animal species were able to roam the area freely between the two study sites. The study sites were 2.6 km apart on the same
sheep property therefore, for this study to be considered valid, the home range of each species was researched from other studies. The native herbivores, the kangaroo and wallaby home ranges were less than the distance between the two sites, therefore the possibility of an animal from either species depositing faecal matter at both sites was negligible. However, the goat has a large home range and the possibility of the independence of the faecal sample could have been compromised, and the possibility of pseudo replication for this species must be considered.

The results of this study of dietary overlap of the four Kangaroo Island herbivores is consistent with other studies on larger herbivores (Dawson and Ellis 1996; Edwards, Croft \textit{et al.} 1996; Sietses, Faupin \textit{et al.} 2009) but not consistent with studies with a mixture of different sized herbivores (Karmiris and Nastis 2010). In the current study there was constant dietary overlap during the study period with all the herbivores, even though literature and the Hutchinson Theory indicated that smaller animals in the same environment should not be in direct competition with larger animals. Dietary overlap coefficients higher than 0.6 are considered as a high overlap in diets, that are of biological significance (Karmiris and Nastis 2010) in either forcing changes in the diets or forcing relocation of the animals to reduce dietary overlap. The Pianka value $C$ for all four herbivore dietary overlap was highest in spring 2007 at $C_{0.23}$, with summer ($C_{0.10}$) and autumn ($C_{0.9}$) 2007 results similar. The low $C$ values indicated there was only a low amount of dietary overlap in these four herbivores on Kangaroo Island. However, dietary overlap is greater when analysis is undertaken with only two species at a time. The herbivores with the greatest overlap during all four assessments were the wallaby and kangaroo, with an average $C$ value of 0.90. All possible species pair analyses indicated that all species were in direct competition with each other for resources in their natural habitat. The direct competition with the wallaby by all the larger herbivores studied was
relatively large and greater than $C_{0.60}$. Therefore, the Hutchinson theory of size displacement separation was not valid for this suite of herbivores.

Farm management practices of pastures are crucial. Therefore, understanding the diet of all herbivores that graze the pasture is essential. The principle pasture plant species are annual/perennial plants. In this study there were annual and perennial plants and weeds. The main pasture perennial species in the faecal samples (*Trifolium subterraneum*), was consumed by all herbivore species, with only one season in which the sheep consumed significantly more than the other herbivores. This result indicated that the wallaby, kangaroo and goat were in direct competition for this resource, except in autumn 2007 when the sheep out-competed and had a significant advantage at that time. *Vulpia myuros* is considered an invasive weed grass species that reduces pasture quality, thereby reducing stock carrying capacity on the pasture (Scott and Blair 1987; Tozer, Chapman et al. 2009). However, this plant was eaten by all four herbivores throughout this study. This grass constituted a large proportion of the diet of all the herbivores along with other Gramineae family species. The mix of pasture plant and native vegetation varied through the assessment period.

Native vegetation was consumed by all four herbivores, with some limitation on certain species whether it was from containment, morphological restraints or plant defences. *Allocasuarina verticillata* is one native species that appeared not to have been accessible to sheep, while the goat consumed significantly greater amounts of this species. Native species, unlike pasture species contain toxic chemicals with a function preventing consumption. *Allocasuarina verticillata* is a large tree species that the larger herbivores are able to browse and have an advantage over the smallest herbivore. The trees, as observed on Kangaroo Island, were heavily browsed. However, the wallaby was able to
consume significantly greater amounts of this species than the sheep and it was present in
greater proportion than both the kangaroo and goat in May 2007. A possible explanation
for this finding may have been the germination of seeds in the seed bank after the large
precipitation event at the end of April 2007. The seeds germinate and sprout between 14
to 30 days after good precipitation and ambient temperature of 15°C (Gunn 2001).
Furthermore, another study on the germination of *Allocasuarina verticillata* seeds found
that 50% of seeds had germinated in 5 days (Turnbull and Martensz 1982). Faecal
collection occurred 18 days after the large precipitation event at the end of April 2007.
Accordingly the wallaby appeared to have an advantage, either from its size, or its ability
to locate newly-germinated seedlings.

Conclusion

The dietary overlap results indicated a low dietary overlap among the four herbivores.
However, the greatest dietary overlap result was between pairs of herbivores, which
occurred in spring, when plant growth was at its greatest, because of the coincidence of
warmth and rain in the Kangaroo Island environment. In summer and autumn, the dietary
overlap decreased slightly due to diversification of plant species eaten with the increase of
native browse vegetation in the diet. The increase in diversification and decrease in
dietary overlap was contrary to many other dietary overlap studies that indicated dietary
overlap increases when resources are in short supply during summer and drought
conditions. The wallaby, the smallest competitor, was therefore assumed to be in direct
competition with the three larger competitors, with the greatest competition for resources
occurring between the wallaby and the kangaroo throughout the seasons.
Chapter 6

Condition Score

6.1 Introduction

Droughts are a natural phenomenon (Keyantash and Dracup 2002) in the Australian landscape (McMahon and Finlayson 2003) and in many locations world-wide (Chamaille-Jammes, Fritz et al. 2007; Mendoza, Garcia-Acosta et al. 2007; Siegert, Ruecker et al. 2001). The effect of drought conditions on native macropod herbivores in Australia varies widely depending on drought intensity (Clancy and Croft 1992; Newsome, Stephens et al. 1967) with behavioural changes (Pople, Phinn et al. 2007) and longer evolutionary changes (Dawson, Blaney et al. 2007) occurring to overcome the effects of drought and extreme heat. Drought affects many critical parameters that characterise a healthy macropod population, including birth rate (Cairns and Grigg 1993; Newsome, Stephens et al. 1967), recruitment rate (Cairns and Grigg 1993; Robertson 1986) and body condition (Cairns, Grigg et al. 2000; Caughley, Grice et al. 1988). Female macropods cease breeding approximately three to five months after drought conditions have become extreme (Newsome, Stephens et al. 1967) and with many sub-adults and older kangaroos dying due to malnutrition, recruitment is affected (Cairns and Grigg 1993; Coulson 1989; Ealey and Main 1967; Robertson 1986). Body condition of macropods has been postulated to index individual conditions, and consequently, fitness of a macropod, but to date, a body condition score comparable to those used for domestic herbivores, has not been available.

Body condition scoring of domestic livestock has been utilised for many years as a simple technique for determining animal condition for livestock market reporting. Body
Condition scores have been described and utilised for cattle (Earle 1976; Everitt 1962; Ezanno, Ickowicz et al. 2003), sheep (Hopkins 1988; Jefferies 1961; Russel, Doney et al. 1969) and goats (Mellado, Rodriguez et al. 2004; Santucci and Maestrini 1985). The condition scores (CS) for the above animals were derived from visual recognition of the characteristics, or from subjective manual palpation of the animal. The purpose of this assessment tool was to provide a means by which buyers on the farm or in the saleyards could quickly assess the match between the live animals on offer and carcass attributes including the proportions of muscle and fat (Mc Gregor 2007).

Livestock body CS with the lowest numerical value describes animals in an emaciated state and near death. Animals in a very good body condition are allocated the highest numerical value. Several originating authors (Jefferies 1961; Mellado, Rodriguez et al. 2004; Russel, Doney et al. 1969) established systems with CS ranges from zero to five, whereas others (Greenwood, May et al. 1993; Tesfaye 2005) have established systems with CS ranging from one to five.

To date, there has not been any CS system available for application to native macropod species within Australia. However, Stirrat (2003) did utilise a condition index derived from the ratio of leg length to body mass for the body condition of the agile wallaby (Macropus agilis), and condition indices have been utilised as a management tool for many wildlife species (Cook, Cook et al. 2001; Krebs and Singleton 1993; Woolnough, Foley et al. 1997). Harvesters supplying the kangaroo meat industry perform a visual assessment and a mental calculation of the potential dressed weight of the carcass of sighted animals before choosing which ones to shoot, and as a consequence, only larger animals are selected (Tenhumberg, Tyre et al. 2004). Thickness of the macropod tail is another method for determining the body condition of some macropods (Stirrat 2003).
Animals in good body condition have thicker tails at the base with fatty deposits covering the vertebral spine and transverse processes (Stirrat 2003).

The current study introduces a system to assess condition using the ratio of body weight to foot length in one macropod species, the Tammar Wallaby (Macropus eugenii), to derive a CS. In the current study, the body CS of the macropod was utilised to determine animal fitness for inclusion in a grazing trial. Verification of the proposed condition scoring system was performed utilising various body condition indicators including a kidney fat index (Riney 1955) and a crus muscle index.

6.2 Methods

Female wallabies were trapped on Kangaroo Island between January and March 2007. This was a period of severe drought on the island, ensuring that at least some would be in poor body condition. At the time of capture, animals were assessed for body condition and reproductive status, and any pouched young were euthanized. The same assessment process was applied after several months of feeding in captivity on high quality forage. It was assumed that animals achieving the highest scores after captive feeding would be in peak condition for animals of that species.

In August 2006, Kangaroo Island was officially declared as being in a state of drought (PIRSA 2007). Rainfall from July 2006 was very poor with record dry conditions that continued until the end of April 2007 (PIRSA 2007). Long-term mean annual rainfall for Kingscote, Kangaroo Island is 483 mm, but the annual rainfall for the year 2006 was 282 mm (BOM 2008), with a deficit of 167 mm from long-term monthly averages in the five months prior to capturing of the animals.
All macropods were transported by ferry and road from Kangaroo Island to the Roseworthy Campus of the University of Adelaide. They were suspended in bags in a ventilated vehicle. Wallabies were checked for lactation and pouch young; any pouch young were removed and euthanized. Wallabies were weighed in bags to an accuracy <0.05 kg, using a portable Rinstrum balance (model R320). The length of the right pes was measured to an accuracy of ± 1 mm from the proximal end of the tuber calcaneus to the distal end of the fourth digit at the base of the claw. Ears were tagged for identification. A Condition Score Index (CSI) was calculated by dividing body mass in kg by pes length in m, foot length was multiplied by the power 3 for scaling purposes (Mc Gowan, Skinner et al. 2008). All animals were assigned a Condition Score (CS) resulting from the condition score index (CSI) (Table 6.1). Each condition score range of condition indices was determined by even distribution of recorded wallaby indices therefore, some condition scores were larger than others (Table 6.1).

Table 6.1 Allocation of Condition Scores to animals on the basis of their Condition Score Index.

<table>
<thead>
<tr>
<th>CS</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
</table>

A sub-sample of wallabies was sacrificed and found to carry heavy burdens of parasitic nematodes, a problem exacerbated during drought conditions (Ezenwa 2004). As a consequence, the entire colony was treated with an anthelmintic (oral dose of 1 ml per 5 kg, Cydectin, Fort Dodge Australia Pty Ltd, Baulkham Hills NSW). All animals were then released into an outdoor animal yard with an area of 776 m².

Wallabies were provided with high quality forage pelleted lucerne (alfalfa, *Medicago sativa*) (Munn and Dawson 2003; Munn, Dawson et al. 2006) for a minimum of six months. Ten representative sub-samples of lucerne pellets were submitted to a commercial laboratory (Nutrition Research Laboratory, Pig and Poultry Research Institute, Roseworthy, South Australia) for analyses of gross energy (GE, MJ kg⁻¹), neutral
detergent fibre (NDF, %), acid detergent fibre (ADF, %), crude protein (CP, %), and crude fat (CF, %). Energy was measured using a Parr 1281 Bomb Calorimeter (Parr Instrument Company, 53rd Street, Moline, Illinois) and fibre was measured using an Ankom A220 Fibre Analyser (Ankon Technology Incorporated, O’Neil Road, Macedon, New York), using methods described in Van Soest (1963) and Goering and Van Soest (1970). Crude protein was measured using the Kjeldahl technique as described in Harris (1970). NDF minus ADF was calculated as a measure of the more readily fermentable fibre content of the diet (primarily hemicellulose and fibre-bound lipid). The lucerne pellets contained 94.64% dry matter, 32.83% NDF, 16.07% ADF, 16.75% NDF-ADF, 19.43% crude protein, 5.21% crude fat, and a gross energy value of 18.71 MJ/Kg. At the end of this period, animals were checked for pouch young and reweighed, with the length of the pes measured once more. The data from the wallabies with an increase in the pes length (indicating growth) were not used in subsequent analyses, leaving a sample size of 28 wallabies for the pen trials (Chapter 7).

To verify the proposed condition score, another 21 animals with condition scores ranging from two to five were euthanized using an overdose of pentobarbitone sodium (‘Lethabarb’; Virbac (Australia) Pty Ltd.) and dissected. No captive animals with a condition score of one were available. Kidney fat index (KFI) was determined after Riney (1955) except that the left perirenal fat mass was not transacted at the caudal extremity of the kidney; instead, it was removed in its entirety. This was because the perirenal fat mass of the wallaby tapers as it extends towards the inguinal region, and inclusion of the whole mass avoids the inherent potential error associated with visual judgement of the angle of transection of the mass close to its maximum width. The left kidney and the fat were weighed separately on a portable Tanita balance (model 1479, maximum weight 100g, 0-50g ± 0.01g, 50-100g ± 0.02g). In addition to determining the KFI, a standardised fat
index (SFI) was determined by regressing the mass of the perirenal fat against the mass of the body standardised to body frame size by dividing the mass by the length of the left tibia, which was taken from the proximal end of the tibial crest to the distal articular surface. In addition, a crus muscle index (CMI) was determined using the combined mass of the left Gastrocnemius and Deep Digital Flexor muscles and the length of the left tibia. These muscles were selected because they are crucial to locomotion in the wallaby, and therefore would be conserved except in circumstances of malnutrition; as a combined mass they are also well-defined and therefore easy to ablate. The Achilles tendon was not included in the muscle mass.

Data analysis of the effect of environmental conditions on CS parameters was by Fisher’s exact test, paired t-test and ANOVA, and verification of the proposed condition score was by ANOVA, along with regression analysis of the different indices against condition score. Significant results were further analysed by utilising Tukey post hoc test.

6.3 Results

In this study the mean body weight of lactating wallabies (n=17) during the drought was lower than the weight of non-lactating animals (n=11) (fig. 6.1), although the difference was not statistically significant (P = 0.104), perhaps due to the low sample size. At the time lactating wallabies captured during drought conditions possessed significantly lower body weights (Paired Sample T-Test; P <0.001) compared to their weights after captive feeding (fig. 6.2). The non-lactating wallabies also sustained significantly lower body weights when first captured (Paired Sample T-Test; P = 0.047) compared to the weights after captive feeding (Figure 6.3).
Figure 6.1 Comparison of mean body weight (kg) in lactating and non-lactating wallabies captured during drought conditions. There were no significant differences between the mean body weights of lactating (n = 11, mean ± SEM) and non-lactating (n = 17, mean ± SEM) wallabies (P = 0.104, ns).

Figure 6.2 Comparison of the initial mean body weight (kg) of 11 wallabies that were lactating at capture with their mean body weight after six months non-lactating on a high quality diet (Paired T-Test P < 0.001, SEM = 0.330).
Figure 6.3 Comparison of the initial mean body weight (kg) of 17 wallabies that were non-lactating at capture with their mean body weight after six months on a high quality diet (Paired t-test $P = 0.047$, SEM = 0.191).

Greatest weight to foot length ratio was 13.93 and the lowest was 3.69. In the proposed condition score, the values were assigned to five categories (Table 6.1). A CS of unity represented an animal in very poor body condition, whilst a CS of five represented an animal in optimal condition, with very good muscle condition throughout the body.

Under drought conditions, 85.7% of the 28 wallabies had CS of three or less (fig. 6.4). After supplementary feeding in captivity, 92.8% of the wallabies were classified as CS three or greater (fig. 6.4). The frequency distributions of the CS differed (Fisher’s exact $P < 0.001$) between drought and captive conditions, with significantly more wallabies in poorer condition classes under drought conditions (fig. 6.4). The mean body mass of the wallabies under drought conditions (4.47 kg; SE = 0.27; $n = 28$) was significantly lower ($P = 0.002$) than the mean body weight for the same set of wallabies under captive condition (5.37 kg, SE = 0.27, $n=28$).
Figure 6.4 Change in the spectra of condition scores of wallabies captured during a drought and after 6 months on high quality feed.

There were linear relationships between CSI on the one hand, and KFI and SFI on the other, but the relationship between CSI and KFI (fig. 6.5) was weak ($R^2 = 0.48$). The relationship between the SFI and CSI (fig. 6.6) was also weak ($R^2 = 0.52$). Overall, the relationship between CMI and CSI (fig. 6.7) was quadratic ($R^2 = 0.94$) rather than linear, but above a CMI of 7.9, there was an adequate fit with a linear model ($R^2 = 0.76$) (fig. 6.7).

Figure 6.5 Correlation between CSI (Condition Score Index) on the Y axis and KFI (Kidney Fat Index) on the X axis ($R^2 = 0.48$).
Figure 6.6 Relationship between CSI (Condition Score Index) on the X axis and left perirenal fat mass (Standardised Fat Index) on the Y axis ($R^2 = 0.52$).

Figure 6.7 Correlations between CSI (Condition Score Index) on the X axis and CMI (Crus Muscle Index) on the Y axis. A quadratic line has been fitted ($R^2 = 0.94$) to define the point of inflection to define the boundary between CS2 and CS3. Whilst a second linear line has been fitted ($R^2 = 0.76$) highlighting the relationship between CSI (Condition Score Index) and CMI (Crus Muscle Index) >CSI 7.9.

6.4 Discussion

The chapter provides a method and baseline data to rapidly assess the body condition of samples of wild female tammar wallabies. In this instance, the condition score was used to assess the impact of drought on body condition and to assess body condition before animals were used in scientific trials. This CS tool could be utilised in many ways for research purposes (to minimise variability in samples of animals selected for research projects), for wildlife management (assessing habitat quality, relating habitat
characteristics to CS and to define thresholds of conditions necessary for any given level of population performance) or to assist management of wild populations subject to commercial harvesting.

Droughts are a result of cyclical changes in environmental conditions (Siegert, Ruecker et al. 2001) in many parts of the world (Chamaille-Jammes, Fritz et al. 2007; Mendoza, Garcia-Acosta et al. 2007) including Australia. Droughts alter the hydrology (McMahon and Finlayson 2003) and the vegetative community (Pereira, Duarte et al. 2006) which in turn affect the herbivores that depend on the vegetative community. Droughts in Australia have resulted in reductions of many macropod populations, including red kangaroo (Cairns and Grigg 1993; Newsome, Stephens et al. 1967), western grey kangaroo (Cairns, Grigg et al. 2000), bridled nailtail wallaby (Clancy and Croft 1992; Fisher, Blomberg et al. 2001; Fisher, Hoyle et al. 2000) and euro (Clancy and Croft 1992; Ealey 1967; Ealey and Main 1967).

Drought reduces macropod populations dramatically (Caughley, Grigg et al. 1985; Hill, Barnes et al. 1987; Newsome, Stephens et al. 1967; Robertson 1986) with some species being reduced by >40 % (Caughley, Grigg et al. 1985). Droughts not only reduce body condition due to malnutrition, but also affect recruitment by causing the female to enter anoestrus when food reserves are poor (Cairns and Grigg 1993; Newsome 1964). Also, the young at foot are not able to be maintained on poor quality forage and the lack of milk from the mother (Cairns and Grigg 1993; Newsome, Stephens et al. 1967; Robertson 1986) as a consequence animals that died were always emaciated (Ealey and Main 1967). Macropod populations rapidly increase following significant drought-ending rainfall (Clancy and Croft 1992; Pople, Phinn et al. 2007).
The natural social behaviour during drought conditions of macropods (Pople, Phinn et al. 2007) including the tammar wallaby, is to aggregate with others to decrease the amount of time spent on vigilance, and devote more time to foraging (Blumstein, Evans et al. 1999). If the drought is prolonged, the natural behaviour alters in some macropod species resulting in the animals spending longer periods foraging alone or in smaller groups and being less vigilant (Stirrat 2004), thereby making the animal more susceptible to predation. The need for sustenance drives macropods to come into greater contact with human activity whether it be foraging along roadside culverts or just crossing roadways in search of food, and this results in greater numbers of animals being killed on roads (Coulson 1989). This phenomenon is especially evident on Kangaroo Island.

The current study confirmed the expectation that drought would have a negative impact on body condition in tammar wallabies, with both sets of lactating and non-lactating animals significantly increasing body weight in captivity. However, despite the severity and duration of the drought, the majority of the sampled animals did not appear to have been at short-term risk of death by starvation. Furthermore, the drought slowed the reproduction rate with only 39% of the captured wallabies pregnant or lactating. The lactating animals had significantly lower body weights than the non-lactating animals indicating those animals were in poorer condition. Although it remains unknown, the condition index at which death from starvation occurs, we have posited the baseline of live animals that were allocated CS 1 as a comparison, and 68% of the animals had CS values at least two units above baseline, corresponding to at least 48% greater bodyweight. Also of interest was the 14% of animals that maintained high CSs during the drought. However, in captivity, the CS for these animals was reduced by one level, perhaps due to increased intraspecific competition in the pen, and the change of social hierarchy. Only one wallaby maintained the same condition score in both drought and
captive conditions. This wallaby had a CS of just over three in drought conditions and after captive feeding its weight had increased to be at the high end of CS three: the weight gain for this animal was 0.94 kg.

The KFI (Riney 1955) uses kidney mass as a surrogate for whole body mass, and has been useful in field studies of large animals in which weighing of whole carcasses was impractical. The current study revealed that the CSI could not be reliably substituted for KFI, but the relationship between CSI and SFI demonstrated that CSI is itself reasonable as an indicator of body fat reserves, and has the advantage over both SFI and KFI in that it can be used on live tammar wallabies.

The linear loss of fat as condition declined in the current study suggested that dietary energy availability was limiting and that the ability to withstand a period of drought would depend in part on fat reserves at the beginning of the drought. The quadratic relationship between body condition and the crus muscle index (fig. 6.7) as body condition declined would be expected if there was a contemporaneous loss of muscle and gut mass at differing and declining rates, but with virtually no loss of bone or skin mass, during a period of malnutrition. For wallabies in better condition, the near linear relationship between the decline in CMI and the decline in CSI indicated that locomotory performance would be maintained; however, the steep decline of the crus muscle index at lower body condition scores indicated that locomotory performance, and hence fitness, would have been impaired. This occurred at a CSI of 7.9, which we have set as the division between CS2 and CS3. We therefore recommend that wallabies with a CS less than 3 should not be used in studies of normal locomotion or spatial behaviour.
In conclusion, this work provides a CS system for the female Tammar wallaby during drought conditions and when fed on good quality forage. Furthermore, the CS system could be extended in future studies to include male animals and utilised for determinations of body condition in animals for use in scientific work and in the management of macropod species beyond Kangaroo Island.
Chapter 7

Competition Trials

7.1 Introduction

In any ecosystem, many suites of animals are present in any one habitat, with competition structuring that particular community. Competition forms the basis for interaction between all animals, from nurturing through to survival. Competition has many different forms (Beckerman 2000; Edwards, Croft et al. 1996; Fisher and Lara 1999; Fortin, Boyce et al. 2004; Foucaud, Orivel et al. 2009), and each type is not restricted to any one animal. An animal could therefore be affected by a number of different forms of competition during its life span. Competition starts at birth, with sibling rivalry (Cleasby, Nakagawa et al. 2010; Roulin, Dreiss et al. 2010) for resources (intra-specific completion) which develop into intense intra-specific competition for mates and resources. As juveniles grow into adults, competition between species develops for a variety of resources resulting in inter-specific competition. Animals have evolved different strategies to reduce the effect of assumed direct competition with another competing animal in the same habitat by reducing dietary overlap (Elmhagen, Tannerfeldt et al. 2002).

Dietary overlaps are common and widespread throughout the animal kingdom (Baldi, Pelliza-Sbriller et al. 2004; Edwards, Croft et al. 1996; Huitu, Norrdahl et al. 2004; Hulbert and Anderson 2001); therefore, strategies that reduce dietary overlap are essential. Strategies to overcome dietary overlap have evolved over-time, such as different digestive structures that allow only certain particle sizes to be digested. This allows two mammals that consume the same suite of plants, to be separated by seasonal
difference of the plants (Dekker and van Rooyen 1996) or different decaying stages of plant matter (Greenaway and Raghaven 1998).

Effective foraging is a strategy that maximises the consumption of food resources while minimising time spent foraging, thereby reducing the potential of becoming prey (Abrams and Schmitz 1999). Grazing animals spend most of their daily activity foraging for palatable food sources, whether it is diurnally or nocturnally. Foraging behaviour is influenced by seasonal differences in plant community structure (Omphile, Aganga et al. 2004). Competition has been increased in native ecosystems with the introduction of domesticated animals such as sheep and cattle (Wilson 1991a; Wilson 1991b; Young, Palmer et al. 2005). Sheep are very effective foragers when highly palatable plants are selected. They systematically search until all of that particular plant species has been consumed (Bosworth 2005). During summer, and in drought conditions, less palatable plant species are browsed, therefore the height of competitors restricts the browse that is chosen (Dziba, Scogings et al. 2003).

Competitive interactions between native and introduced herbivores may adversely impact on animals in either category (Matsuo and Ochiai 2009), and may adversely impact on native vegetation and sensitive environments (Govindarajulu, Altwegg et al. 2005; Kurle, Croll et al. 2008; Robley, Short et al. 2001). Increased agricultural and pastoral activity has resulted in a loss of vegetation through habitat destruction by land clearing (Asase, Ofori-Frimpong et al. 2010; Bartzen, Dufour et al. 2010) and overgrazing worldwide (Anjum, Wang et al. 2010; Centeri, Herczeg et al. 2009; Kashaigili and Majaliwa 2010), including in Australia (Bird, Bicknell et al. 1992; Fischer, Sherren et al. 2010). In Australia there has also been a dramatic loss of native fauna (Brown, Bennett et al. 2008; Driscoll 2004; Walker, Landis et al. 2001), including some kangaroo species (Pople and
Grigg 1999). Even today, vegetative species are under threat in the rangelands on mainland Australia by introduced grazing herbivores (Brown 1985). For example, the Western Myall (*Acacia papyrocarpa*) is disappearing from the open rangelands due to grazing pressures of both native and introduced herbivores (Bosworth 2005). Unfortunately, the consequence for this semi-arid and arid region on mainland Australia is that the vegetation community is being irreversibly altered (Auld 1993). Kangaroo Island has also seen large scale land clearance since the end of World War II, even though it is of high conservational significance (Anon 2004).

Kangaroo Island has an area of 440,000 hectares (Anon 2001b; Jennings, Clarke *et al.* 1989) with the highest proportion of native vegetation remaining of all agricultural regions in South Australia (Anon 2001b). Native vegetation on the island covers 207,161 ha (47%) with 132,665 ha (30%) protected, while the remaining vegetation is highly fragmented into small areas less than 20 ha each that survived because they were deemed less suitable for agriculture (Anon 2001b). The recent expansion of agriculture and pastoralism on Kangaroo Island has introduced cattle, sheep, goats and pigs, with the latter two species escaping and establishing feral populations, increasing the total grazing pressure on native vegetation of the island. Kangaroo Island has only two native herbivores, the western grey kangaroo and tammar wallaby. Wallabies have exploited the increase in agriculture/pastoralism which has resulted in many large areas left with natural vegetation as its diurnal habitat to exploit pastures at night (Anon 2001b). The diet of tammar wallabies and western grey kangaroos comprises mainly grasses (Strathan 1995) with unsustainable grazing pressures being imposed on some Kangaroo Island areas containing threatened plant species (Anon 2004). Wallabies are currently culled in large numbers under pest destruction permits, with the carcasses wasted as they cannot be utilised for any other purpose (Wright and Stott 1999). National interest in providing an
environmentally sustainable Australia would be better served if the wallabies were integrated into the farming system (Wilson 2004). However, the biological basis for a wallaby management plan must be established before the legal requirements for use of wallaby products can be met under the South Australian National Parks and Wildlife Act. Therefore, understanding competition between mammalian herbivores on Kangaroo Island is critical for effective management of both the environment and the future of agriculture in a significant biodiversity ‘hotspot’.

In the current study, competitive inter-specific interactions of four herbivores were investigated in the context of the Hutchinson Theory of Inter-specific Competition. Hutchinson (1959) examined the physical size of animals of different species and noted that an increase in flora diversification corresponded to increases in fauna diversity near the tropics. Questions arose as to the differences required between two competing species in the same ecological niche to prevent further interspecific competition. Morphological measurements of coexisting species utilising the same resources were recorded, revealing that the culmen in birds and the skulls in some mammals differed in a mean ratio of 1.28 from the larger to the smaller form (Hutchinson 1959). The length ratio of the morphological features is 1.28 and can be extrapolated to a weight ratio of 2.1 since weight varies to the third power of length $1.28^3 \approx 2.1$ (Eadie, Broekhoven et al. 1987). However, there is still a debate on the use of the Hutchinson ratio as a basis for the size difference needed for a competitor to avoid interspecific competition.

On Kangaroo Island, three of the four mammalian grazing herbivores (sheep, goat and kangaroo) are similar in adult body size, but the wallaby is very much smaller. There have been no studies of the competitive interactions between the grazers of Kangaroo Island. Hutchinson’s theory predicts that the three large grazers will be in direct competition, but
the wallaby will escape competition with all three of the larger species because of its size. In this chapter, I examine these two hypotheses: firstly, the three larger herbivores were in direct competition for resources and secondly, the wallaby escapes direct competition for resources due to its size, being greater than 2.1 x smaller in weight compared to the larger herbivores.

### 7.2 Methods

There were two experimental trials that were similar in nature and that were testing interspecific competition. The experiment was an interspecific comparison of the grazing of three large species of mammalian grazers (western grey kangaroo *Macropus fuliginosus*; Sheep *Ovis aries*; Goat *Capra hircus*) and one small species of grazer (tammar wallaby *Macropus eugenii*) on seven plant species. It was conducted simultaneously in two sections: one section compared plant consumption by the three large herbivore species penned as mixed species groups with and without wallabies, with plant consumption of all four grazing species penned together, and the other section compared plant consumption by each species of grazer penned separately. The plants available to the animals were Lucerne (*Medicago sativa*), Rye grass (*Lolium rigidum*), Oat grass and grain (*Avena sativa*), Caltrop (*Tribulus terrestris*), Potato weed (*Heliotropium europaeum*), Wire weed (*Polygonum aviculare*) and Marsh mallow (*Althaea officinalis*).

The common name of the above plant and weed species will be used from this section onwards in this chapter.

### 7.2.1 Site
The pen trial was located at the University of Adelaide’s Roseworthy Campus (latitude -34.51 S, longitude 138.68 E and altitude, 65 m above sea level which is located in a cropping and grazing area approximately 50 km north of the city of Adelaide and 10 km from the town of Gawler. The long term average rainfall for Roseworthy is 440 mm per year (BOM 2008). The average rainfall is usually received from autumn through winter and into spring; summers are usually hot to very hot and dry.

### 7.2.2 Trial Pens

The ten trial pens each measured 38m x 132m which is 5016 m² (0.5 ha) running east west with a 14 m wide ungrazed control pen in the centre, running north south (fig. 7.1). The area had a slight gradient running from NE to SE but was otherwise generally level. Although the pens were of the same size, the area of the plant cover in the three-species pens was reduced to 0.75 of the area in the four-species pens to balance the biomass of grazing herbivores to the biomass of the available plants across the pens.

<table>
<thead>
<tr>
<th>Mixed 4 spp</th>
<th>Mixed 3 spp</th>
<th>Sheep</th>
<th>Mixed 4 spp</th>
<th>Kangaroo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wallabies</td>
<td>Mixed 3 spp</td>
<td>Goats</td>
<td>Mixed 4 spp</td>
<td>Mixed 3 spp</td>
</tr>
</tbody>
</table>

Figure 7.1 Diagram of pen layout. Each single species pen had 4 animals except for wallaby pen that had 16 animals and had approximately similar grazing pressure to the 3 and 4 species pens. Mixed 4 spp. pens contained 1 kangaroo, 1 goat, 1 sheep and 4 tammar wallabies while the mixed 3 spp. pens contained 1 kangaroo, 1 goat and 1 sheep.
7.2.3 Capture and transportation of all herbivore species

All four species required for these experiments were captured and transported as previously described in Chapter 3.

7.2.4 Sowing of Trial Pens

The pen area was sprayed a week before sowing to kill any residual plants and weeds that had germinated since rain to reduce any possible contamination or extra plant species in the trial.

The trial pens were sown on May 9th 2007; Roseworthy recorded 17.6º C at 3 pm just prior to sowing of the pens, and had recorded 76.8mm of rainfall over a five day period at the end of the previous month (April).

All the seeds from each species were thoroughly mixed before being placed into one bin on the air seeder for sowing. This was achieved by placing seeds into a clean cement mixer to let them mix thoroughly before emptying into clean bags. The mixed seeds were placed into one holding bin while another separate holding bin contained Mono Ammonia Phosphate (MAP), a fertilizer that was delivered at the same time as sowing.

The pasture seed mixture was:

1. Lucerne cv Rosillo
2. Annual Rye grass cv Tetila gold
3. Oats cv Winteroo

On farms in the Mediterranean climate zone of Australia, annual crops and pastures are prevalent due to the extreme heat and aridity of a typical summer. The study site had no crops or pasture species present before the current trial. The fallow paddock, as
previously discussed, had been sprayed with herbicide prior to sowing of the trial pasture species. As the trial pasture species germinated, four weed species (caltrop, potato weed, wire weed and marsh mallow) also germinated from the soil seed bank. Therefore, the weed species became part of the trial.

7.2.5 Plant Survey

A plant survey was conducted in all ten trial pens and in the ungrazed control pen on Nov 25th 2007. The stratified survey was undertaken with fourteen, 1 m² quadrants laid out in fixed positions in the same grid pattern in each pen. Plants were counted and removed for each species, including weed species present in each quadrant. The plants were cut at the ground surface level and placed into a paper bag identified by pen and quadrant. In the laboratory, the wet weight of each sample was recorded, the plants were then sorted out into separate species and each species was weighed separately for each quadrant.

7.2.6 Analysis of Data

The plant species wet weights and plants present were analysed by one way ANOVA using GenStat 11th Edition package (Lawes Agricultural Trust, VSN International Ltd., Wilkinson House, Jordan Hill Road, Oxford OX2 8DR, UK). The data were tested to determine any significant differences between all control pens, and three versus four species pens, by utilising a one-way ANOVA with significance denoted by P<0.05. Post hoc testing utilised the Tukey multiple comparison test.

7.3 Results

7.3.1 Plant survey: Mixed species grazing trial

7.3.1.1 Plant by number in mixed grazer pens
In the presence of wallabies, there were not any significant differences detected in the mean number of the different plant species tested, between the 3 species and 4 species pens. However the trend for rye grass plants (fig. 7.2, $P = 0.578$), young oat grass plants (fig. 7.3, $P = 0.929$), and caltrop plants (fig. 7.4, $P = 0.82$) was for greater number of plants present in the 4 species pens. Furthermore, the trend for lucerne plants (fig. 7.5, $P = 0.681$), marsh mallow plants (fig. 7.6, $P = 0.23$), potato weed plants (fig. 7.7, $P = 0.46$), and wire weed plants (fig. 7.8, $P = 0.282$) was for fewer number of plants present in the 4 species pens.

Figure 7.2 Mean rye grass plant numbers present (m²) between 3 species and 4 species pens ($P = 0.578$ at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.3 Mean young Oat grass plant numbers present (m²) between 3 species and 4 species pens ($P = 0.929$ at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.
Figure 7.4 Mean caltrop plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.82 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.5 Mean lucerne plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.681 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.6 Mean marsh mallow plant numbers present (m$^2$) between 3 species and 4 species pens (P = 0.23 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.
7.3.1.2 Plant by biomass in mixed grazer pens

In the presence of wallabies, there was only one significant result detected in the mean weight of the different plant species tested, between the 3 species and 4 species pens. The trend for young oat grass biomass (fig. 7.9, P = 0.8) and potato weed biomass (fig. 7.10, P = 0.161) was greater in the 4 species pens. Furthermore, the trend for lucerne biomass (fig. 7.11, P = 0.111), rye grass biomass (fig. 7.12, P = 0.11), caltrop biomass (fig. 7.13, P = 0.207), and marsh mallow biomass (fig. 7.14, P = 0.32) was smaller in the 4 species pens.
The biomass of wire weed was significantly lower in the pens grazed by wallabies (fig. 7.15, P= 0.002). However, for the other plant species, none of the differences between plant biomasses were significant at P<0.05, but at P≈0.1, there appears to be selective consumption of lucerne and rye grass by the wallabies.

Figure 7.9 Young Oat grass plant mean weight (g) between 3 species and 4 species pens (P = 0.8 at 0.05 significance level, means + SEM, df = 5) there was no significant difference between species pens.

Figure 7.10 Potato weed mean weight (g) between 3 species and 4 species pens (P = 0.161 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.
Figure 7.11 Lucerne plant mean wet weight (g) between 3 species and 4 species pens (P = 0.111 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.12 Rye grass plant mean weight (g) between 3 species and 4 species pens (P = 0.11 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.13 Caltrop mean weight (g) between 3 species and 4 species pens (P = 0.207 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.
Figure 7.14 Marsh Mallow mean weight (g) between 3 species and 4 species pens (P = 0.32 at 0.05 significance level, means + SEM, df = 5). No significant difference was detected between species pens.

Figure 7.15 Wire weed mean weight (g) between 3 species and 4 species pens (P = 0.002 at 0.05 significance level, means + SEM, df = 5). A significant difference was detected between species pens indicated by different alphabetical characters.

7.3.2 Plant survey: Single species grazing trial

7.3.2.1 Plant by number in single grazer pens

There were significantly fewer lucerne plants in the grazed pens compared to the ungrazed control plot, demonstrating that all of the grazing species ate lucerne (fig. 7.16, P<0.001). There were significantly fewer lucerne plants in the wallaby pen than in the goat pen, demonstrating that the wallaby was more efficient at foraging for lucerne. No other significant differences were detected at P<0.05.
There were significantly fewer rye grass plants in the grazed pens compared to the ungrazed control plot, demonstrating that all of the grazing species consumed rye grass (fig. 7.17, P<0.001). There were significantly fewer rye grass plants in the wallaby pen than there were in the kangaroo pen, demonstrating that the wallaby was more efficient at foraging for rye grass. No other significant differences were detected at P<0.05.
There were no significant differences among the trial pens for young oat grass (fig. 7.18, P = 0.259). The data trend indicated all species were successful in foraging for the young oats grass with no mammal species having any advantage.

![Graph showing mean number of young oat grass present (m²) in all single species and control pens. Graph legend: Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.](image)

Figure 7.18 Mean number of young Oat grass present (m²) in all single species and control pens (P = 0.259 at 0.05 significance level, means ± SEM, df = 69). Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.

There were significantly fewer caltrop plants in the goat pen compared to the sheep pen (fig. 7.19, P = 0.024) demonstrating the goat had a foraging advantage against the sheep but not against the other grazing species. No other significant differences were detected at P<0.05.

![Graph showing mean number of Caltrop plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P = 0.024 at 0.05 significance level, means ± SEM, df = 69) among single species pens. Graph legend: Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.](image)

Figure 7.19 Mean number of Caltrop plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P = 0.024 at 0.05 significance level, means ± SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.
There were significantly fewer marsh mallow plants in both kangaroo and sheep pens compared to the wallaby pen (fig. 7.20, \( P = 0.013 \)), although there were not significantly fewer marsh mallow plants in both the kangaroo and sheep pens compared to the other pen types. The result demonstrates that both the kangaroo and sheep have a foraging advantage with respect to marsh mallow over wallabies but not over goats. No other significant differences were detected at \( P<0.05 \).

Figure 7.20 Mean number of Marsh mallow plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences \( (P = 0.013 \text{ at } 0.05 \text{ significance level, means } + \text{ SEM, } df = 69) \) among single species pens. Graph legend Wallaby – \( W \), Kangaroo – \( K \), Goat – \( G \), Sheep – \( S \) and Ungrazed Control – \( UGC \).

There were significantly fewer potato weed plants in the three larger herbivore pens compared to the wallaby pen (fig. 7.21, \( P<0.001 \)). No other significant differences were detected at \( P<0.05 \). This result indicated that the larger herbivores found this plant more palatable and were more successful in foraging for this weed species than the wallaby.
There were significantly fewer wire weed plants in the grazed pens compared to the ungrazed control plot, demonstrating that all of the grazing species ate wire weed (fig. 7.22, P<0.001). No other significant differences were detected at P<0.05.
7.3.2.2  Plant by biomass in single grazer pens

There were significantly less lucerne biomass in the grazed pens than in the ungrazed control plot, demonstrating that all of the grazing species consumed lucerne (fig. 7.23, P<0.001). No other significant differences were detected at P<0.05.

Figure 7.23 Mean weight (g) of Lucerne plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means ± SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.

There was significantly less rye grass biomass in the grazed pens than in the ungrazed control plot, demonstrating that all of the grazing species consumed lucerne (fig. 7.24, P<0.001). No other significant differences were detected at P<0.05.

Figure 7.24 Mean weight (g) of Rye grass plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means ± SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.
There were no significant differences among the test pens for young oat grass biomass (fig. 7.25, P = 0.379).

![Graph of young oat plants biomass](image)

Figure 7.25 Mean weight (g) of young Oat plants present (m^2) in all single species and control pens. No significant differences (P = 0.379 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.

There were no significant differences among the test pens for caltrop biomass (fig. 7.26, P = 0.67).

![Graph of caltrop plants biomass](image)

Figure 7.26 Mean weight (g) of Caltrop plants present (m^2) in all single species and control pens. No significant differences (P = 0.67 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.

There were no significant differences among the test pens for marsh mallow biomass (fig. 7.27, P = 0.92).
Figure 7.27 Mean weight (g) of Marsh mallow plants present (m²) in all single species and control pens. No significant differences (P = 0.92 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.

There was significantly less potato weed biomass in the three larger herbivore pens and the ungrazed control plot compared to the wallaby pen (fig. 7.28, P<0.001). No other significant differences were detected at P<0.05.

Figure 7.28 Mean weight (g) of Potato weed plants present (m²) in all single species and control pens. Different alphabetical characters indicate significant differences (P<0.001 at 0.05 significance level, means + SEM, df = 69) among single species pens. Graph legend Wallaby – W, Kangaroo – K, Goat – G, Sheep – S and Ungrazed Control – UGC.

There was significantly less wire weed biomass in the grazed pens than in the ungrazed control plot, demonstrating that all of the grazing species ate wire weed (fig. 7.29, P<0.001). No other significant differences were detected at P<0.05.
7.4 Discussion

Only a proportion of the competitive interactions between the mammalian grazing herbivores of Kangaroo Island are consistent with the predictions of the Hutchinson Theory. The results of the current study produced some instances in which the smallest animal was the more effective forager, several instances in which no differences were detected and two instances (marsh mallow and potato weed) in which two of the larger grazers were more effective than the wallaby. Also there was an instance in which one large herbivore had an advantage over another large herbivore for caltrop weeds.

The first experiment was the replicated trial between pens which contained the three larger herbivores and pens that had all four species. There were no significant differences between all of the plant numbers and plant biomass for each plant species tested, in the presence or absence of wallabies, except for wire weed. Wire weed biomass was significantly different in the presence of wallabies (fig. 7.15) but not significantly different in wire weed plant numbers (fig. 7.8). The data suggest that there may have been similar differences between the numbers and biomass for each of lucerne and rye grass.
Thus, for wire weed, lucerne and rye grass it appeared that the individual plants were smaller in the presence of wallabies, indicating the wallabies had been more successful in foraging for those species. There is no indication from the data as to whether the wallabies were more successful than the larger grazer in finding theses plants, or more successful inprehending these plants. Furthermore, there is no indication that the wallabies were more successful in foraging for oat plants. Therefore, the results of this part of the trial are only partially consistent with the predictions of the Hutchinson Theory.

The second experiment was the pseudo-replicated single species pen trial. This was necessary due to the costs and logistics associated with large scale experimentation. Pseudo replication is accepted by many biological scientists (Oksanen 2001) because limitation in scientific resources sometimes necessitates sacrificing true replication in the interests of particular questions (Hodges and Sinclair 2003). Full replication on a large scale in ecology has economical and logistical constraints (Oksanen 2001) in some instances. It is therefore prohibitive. The choice is a trade-off between pseudo-replication or no experimentation in ecology/wildlife research (Cottenie and De Meester 2003). This part of the trial has resulted in instances that provide weak support for the Hutchinson theory and instances that counter Hutchinson.

There were four tests that indicated all test species had been successful in foraging for pasture species; lucerne and ryegrass with respect to plant numbers and biomass. However, the wallaby pen had significantly less lucerne plants present than the goat pen (fig.7.16) providing weak support for Hutchinson, but the biomasses of those plants were not significantly different between the pens (fig 7.23). Also, the wallaby pen had significantly fewer rye grass plants present than the kangaroo pen (fig 7.17). This also
provided weak support for the Hutchinson theory, but the biomasses of those plants were not significantly different between pens (fig. 7.24).

Another test also indicated all species were successful in foraging for a weed species; wire weed with respect to plant numbers present (fig. 7.22) and not biomass (fig. 7.29). However, weed species, marsh mallow presence was significantly fewer in both large herbivore pens of kangaroo and sheep compared to the wallaby pen (fig. 7.20); which counters the Hutchinson theory of size displacement, while there was not any significant difference amongst all pen plant biomasses (fig. 7.27). Potato weed results are an anomaly with respect to there being significantly more plant numbers present in the wallaby pen compared to all other pens (fig. 7.21). However, the biomass of potato weed in the wallaby pen was significantly greater than all other pens, including the control pen (fig. 7.21). Possible reasons for the large amount of potato weed seed in the seed bank of the wallaby pen; could be due to the area before sowing and erection of test pen was a sheep camp with a greater concentration of sheep dung with potato weed seeds than the remaining trial area. Another possibility is that the plants were larger because the greater numbers of wallabies evenly distribute urine around the pen (moisture and nitrogen). There were significantly fewer caltrop plants present in the goat pen compared to the sheep pen, indicating the goat ate caltrop weeds more than the sheep (fig. 7.19), which also counters Hutchinson’s theory.

Weed species have greater chemical defences compared to domesticated pasture species that are toxic to herbivores (Aslani, Movassaghi et al. 2004; Aslani, Movassaghi et al. 2003; Bourke 1983; Bourke, Stevens et al. 1992). This toxicity is not the same for all herbivores and usually can be tolerated at low concentrations. The toxicity of the plant is directly related to the environmental conditions where it is growing (Dinchev, Janda et al.)
The goats in the current study ate more caltrop than the sheep even though a previous study indicated the steroidal saponins caused weight loss, depression, and pathological changes to liver and kidneys (Aslani, Movassaghi et al. 2004) in a short period of time.

The suite of resources in this trial was only part of each animal’s natural realised niche resources. Therefore, direct competition was evident. The forced competition had negated strategies that may have evolved, as suggested by Elmhagen et al. (2002), to reduce the effect of direct competition. Even though the animals had a wide range of weights and size differences, competition for the resources was documented (Hutchinson 1959).

Kangaroo and wallaby species are nocturnal and usually exploit the habitat between sunset and dawn, while the sheep and goat are diurnal, exploiting the habitat during the day, thereby reducing direct competition for the same resources (Harrington and MacDonald 2008; Neale and Sacks 2001). All species were observed grazing during daylight hours. Therefore, competition was greater than the temporal separation. The dietary overlap during this trial was evident in the results of all species.

There was some evidence that the dietary overlap in this trial was not complete. There was an abundant standing oat crop which was not tested as to whether all species were able to exploit the abundance of oat grain. The results are clear the animals could not avoid the competition by reducing the dietary overlap, as suggested as a strategy to avoid direct competition (Homolka 1987; Robley, Short et al. 2001). All species experienced competition for the available resources with only significant differences between the wallaby and kangaroo (fig. 7.17), wallaby and goat (fig. 7.16) for some of the plant species tested, which suggested there was not total dietary overlap for these species.
However, there was total dietary overlap between the smallest animal (wallaby) and the largest (sheep) with no animal able to avoid direct competition. All animals exploited the total pen area searching for food.

Sheep are known to systematically search for palatable plants, even if the plants are very small (Bosworth 2005; Lange and Willcocks 1980). Search patterns could explain differences in consumption between herbivore species therefore; sheep consumed more of the pasture plant species than the other larger herbivore species but did not out compete in the weed species (section 7.3.2). The sheep and wallaby appeared to have the same ability to systematically search and locate palatable plants due to there being no significant differences between them for the pasture plants.

The animals in this trial had a greater body size displacement than described by Hutchinson (1959) to avoid direct competition. Most studies that support the Hutchinson theory have length ratios that are similar to the 1.3 rule (Millien 2004). The 1.3 rule (for either linear measurements or extrapolated to 2.1 for weight measurements) for this study centre on weight measurements. The average weight of all test animal species in the current study were; wallaby the smallest species with the adult female weight averaging 6.1 kg, the female kangaroo adult weight averaging 21.2 kg, the female goat adult weight averaging 24.8 kg and the sheep adult weight averaging 44.3 kg. Therefore, the kangaroo was 3.5 x larger than the wallaby, the goat was 4.1 x larger than the wallaby, and the sheep was 7.3 x larger than the wallaby. Therefore, according to Hutchinson the wallaby should not have been indirect competition with the larger herbivores tested. However, there is only weak support for this theory. The ratios in the current study were greater than the predicted ratios of Hutchinson with the wallaby in direct competition for resources.
In conclusion, this study has provided evidence that the wallaby is in direct competition with the three larger herbivores, which conflicts with the views of Hutchinson (1959) and Millien (2004) that support Hutchinson theory 1.3 rule. The current study findings supports the many authors that state the Hutchinson theory 1.3 rule is invalid as a mechanism for animals to avoid interspecific competition in the same habitat (Parra, Loreau et al. 1999; Roth 1981).
Chapter 8

Food preference of four Kangaroo Island herbivores

8.1 Introduction

Food preferences are a function of the relationship between taste and digestibility (Provenza, Scott et al. 1996; Robertson, Gordon et al. 2006; Villalba and Provenza 2000). Animals use different senses, such as taste and smell, to forage for palatable plants while grazing, (Arnold 1966; Launchbaugh and Provenza 1993; Provenza, Scott et al. 1996). Smell, taste and defences may vary with the age of the plant (Ahmadi 2009; Franck, Christian et al. 2011). Plants also have physical defences such as thorns (Gowda, Albrectsen et al. 2003; Gowda and Palo 2003), silica induction (Massey, Ennos et al. 2007; Massey and Hartley 2006; Vicari and Bazely 1993) and chemical defences that reduce the effects of grazing animals (Provenza 1995). The height of palatable vegetation also determines which plant is selected during grazing (Ginane and Dumont 2010). Grazing animals have the ability to actively and methodically find the sought after plant once they acquire a taste for a particular species (Bosworth 2005). Many palatability trials have been conducted to investigate the preference of domesticated animals such as sheep and goat for different food sources (Catanese, Distel et al. 2009; Favreau, Baumont et al. 2010; Ginane and Dumont 2010; Provenza, Scott et al. 1996; Robertson, Gordon et al. 2006).

Food preferences alter seasonally when often highly palatable plants are not available; therefore, less palatable plants are foraged (Ahmadi 2009; Duncan, Reid et al. 2005;
Sayers, Norconk *et al.* 2010). Sheep are selective when choosing plant species to ingest. If sheep have not been introduced to a specific variety of plant at an early age, then they are less likely to consume that plant, even if the plant has high nutritional value (Ahmadi 2009). Sheep also have the ability to remember the spacial location of preferred food patches, which also enables them to exploit the available resources (Dumont and Petit 1998; Edwards, Newman *et al.* 1996a; Edwards, Newman *et al.* 1997).

The focus of this chapter is on the relative palatability of the pasture species that dominated the plant structure in the trial pens (*Chapter 7*) for each herbivore species used for the grazing experiment. This work was conducted to more fully understand the results found during the experimental trials (*Chapter 7*), to determine if the differences in the results of either the inability to locate the plants or alternatively, palatability preference of each species.

**8.2 Methods**

**8.2.1 Palatability Trial**

Five animals of each species were tested as individuals; all animals had been fed the previous day and were moderately hungry prior to testing. Each animal was presented with four food options (each in triplicate) in 180 mm diameter pots randomly placed around the perimeter of a circular arena six metres in diameter. Food options matched the main food sources available in the pens used for the experiment described in *Chapter 7*. They were foods commonly available to sheep in areas of South Australia: lucerne (*Medicago sativa*) plants, ryegrass (*Lolium rigidum*) plants, oatgrass (*Avena sativa*) plants and oat seed.
The observers were individuals with whom the animals were familiar and *vice versa*, and the distance from which the observations were made was increased if the behaviour of the animal under testing suggested that it was disturbed by the proximity of the observer. The sheep not under testing remained immediately outside the test arena and therefore, close to the animal under testing, to cater for the flocking behaviour of the species. The other species, whilst social, are not known to be perturbed if they are alone. For each animal, the test began when it began to eat, or after five minutes in the test arena. Observations continued for 10 minutes.

8.2.1.1 Trial sites

The trials were undertaken in animal holding facilities located at the University of Adelaide’s Roseworthy campus. All animals had a minimum of four weeks to become accustomed to the area, and the test arena within that area. All animals had prior exposure to the test arena and potted test fodder for two days immediately prior to the third consecutive day, the trial day.

8.2.1.2 Data collection and Analysis

The sequence of pot visitation was ranked for each animal, up until no new pots were visited, after which all subsequent pots were ranked equally. Time spent; number of bites and number of steps taken to each pot were recorded. The recorded data of time, bites and steps were standardised. For example the total time of each species at all food varieties was divided into the time taken at lucerne, multiplied by 100 to provide the percentage time for lucerne for that animal species. Data analysis of time spent, bites and steps taken was analysed by ANOVA using a computer program Genstat, 11th edition (Lawes Agricultural Trust, VSN International Ltd., Wilkinson House, Jordan Hill Road, Oxford OX2 8DR, UK).
8.2.2 Oat grain trial

8.2.2.1 Trial site

The site of the oat trial was the same test pen used for the palatability trial of the wallabies. The test pen was in the wallaby pen in the fauna yard at Roseworthy Campus, University of Adelaide.

8.2.2.2 Capturing of Wallabies

Six wallabies were herded into the trial pen and captured using hand-held nets as described in Chapter 3. The wallabies were identified by ear tags and weighed. Four 2.2 litre pots were filled with oat seeds and pegged down in random positions in the test arena, and checked daily and to ensure that the oats were available ad lib. The wallabies were weighed at the commencement of the trial and on days four, nine, and 14, and body condition was assessed on each occasion. The wallabies were then returned to the general population once the trial had concluded.

8.2.2.3 Data analysis

Data were analysed using paired t test recorded as proportions and arcsin transformed before ANOVA analysis using Genstat 11th ed. (Lawes Agricultural Trust, VSN International Ltd., Wilkinson House, Jordan Hill Road, Oxford OX2 8DR, UK).

8.3 Results

8.3.1 Palatability trial Ranked visits

Wallabies ranked the food on offer from lucerne (most preferred) to oat seed (least preferred) table 8.1. Kangaroos ranked oat grass most preferred to lucerne and oat seed being equally least preferred. Goats had the narrowest ranking values from least to most preferred compared to the other three species, oat grass was most preferred to oat seed
being least preferred. Sheep recorded the largest rank value recorded for any food variety, with lucerne recording a value of 24.6. Sheep ranked oat seed most preferred and lucerne least preferred (Table 8.1).

Table 8.1 Averaged rank value of five test mammals for each species, the lower the ranked value indicated a preference for that food variety.

<table>
<thead>
<tr>
<th>Species</th>
<th>Wallaby</th>
<th>Kangaroo</th>
<th>Goat</th>
<th>Sheep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucerne</td>
<td>9.2</td>
<td>17.2</td>
<td>9</td>
<td>24.6</td>
</tr>
<tr>
<td>Rye Grass</td>
<td>9.8</td>
<td>12.4</td>
<td>8.6</td>
<td>13.2</td>
</tr>
<tr>
<td>Oat Grass</td>
<td>11.6</td>
<td>11.2</td>
<td>8.4</td>
<td>19.2</td>
</tr>
<tr>
<td>Oat Seed</td>
<td>13.2</td>
<td>17.2</td>
<td>10.6</td>
<td>10.6</td>
</tr>
</tbody>
</table>

8.3.1.1 Wallaby

Wallabies did not spend time at all fodder varieties on offer during the trial. Wallabies allocated the majority of foraging time (61% of total foraging time) at rye grass plants which was significantly different to the amount of time at the other fodder on offer, except for lucerne. Time spent at lucerne was 31% of total foraging time and was not significantly different to rye grass. Wallabies allocated only 8% of total foraging time at oat grass and did not allocate any foraging time at oat grain, indicating oat grass and in particular oat grain was unpalatable to the wallaby (fig. 8.1).

Figure 8.1 Mean time spent in seconds by wallabies (n=5, df = 19) at the food range available (P = 0.01 ± SEM). The different alphabetical characters indicate significant differences (P<0.05) among the fodder varieties.
Figure 8.2 Mean number of bites taken by wallabies at each variety of the food range offered ($P = 0.01 \pm SEM, n=5, df = 19$). The different alphabetical characters indicate significant differences ($P<0.05$) among the fodder varieties.

The results for the mean number of bite taken were identical to the time spent with most bites taken at rye grass (61%), lucerne (31%), oat grass (8%) and no bites taken at oat grain (figs. 8.1 & 8.2).

Figure 8.3 Mean number of steps taken by wallabies to reach each variety of the fodder range offered ($P = 0.13, n=5, df = 19$).

The wallaby took almost the same mean number of steps to reach both lucerne (43% of total steps) and rye grass (42% of total steps) during the trial, and only 15% of total steps to oat grass with no steps taken to oat grain (fig. 8.3).
Wallaby data indicated the preference order of the fodder on offer was firstly rye grass, followed by lucerne and oat grass with oat grain not even considered as a food source in the presence of the other food or fodder varieties.

8.3.1.2 Kangaroo

Kangaroos spent time at all fodder varieties on offer during the trial. Oat grass (41% of total time) and rye grass (39% of total time) which were both significantly different to lucerne (1% of total time) (fig.8.4). Oat grain (19% of total time) was not significantly different to lucerne (1% of total time) (fig.8.4). These results indicated that kangaroos tested in this trial found oat grass and rye grass to be most palatable, followed by oat grain and lucerne.

8.3.1.2 Kangaroo

Kangaroos spent time at all fodder varieties on offer during the trial. Oat grass (41% of total time) and rye grass (39% of total time) which were both significantly different to lucerne (1% of total time) (fig.8.4). Oat grain (19% of total time) was not significantly different to lucerne (1% of total time) (fig.8.4). These results indicated that kangaroos tested in this trial found oat grass and rye grass to be most palatable, followed by oat grain and lucerne.

Figure 8.4 Mean time spent in seconds by kangaroos at the food range available (P = 0.003 ± SEM, n=5, df = 19). The different alphabetical characters indicate significant differences (P<0.05) among the fodder varieties.
Oat grass had the greatest percentage of total bites taken (54%) followed by rye grass (22%), oat grain (21%) and lucerne (3%) (fig. 8.5). The mean number of bites at rye grass appeared to be rather low compared to oat grass considering the time spent for each fodder type was almost the same, with just over one minute difference between rye and oat grass (fig. 8.4).

The mean number of steps taken by kangaroos in this trial to reach oat grass was the greatest, 7.4 steps, of all fodder on offer (46% of total steps) which was significantly
different to lucerne mean steps 0.6 (4% of total steps) but not significantly different to rye grass mean steps 5.4 (34% of total steps) and oat grain mean steps 2.6 (16% of total steps) (fig 8.6). However, rye grass and oat grain mean number of steps were not significantly different to lucerne.

The kangaroo data indicated the preference order of the fodder on offer was firstly oat grass, followed by rye grass and oat grain with lucerne least favoured of the fodder varieties. Lucerne fodder was barely considered as a food source in the presence of the other fodder varieties. However, the kangaroo did spend time consuming lucerne, indicating it would eat lucerne when foraging.

8.3.1.3 Goat

Goats in this trial ate all fodder varieties on offer, although not equally, even though there were not any significant differences among fodder varieties (fig 8.7). Rye grass (34% of total time) and oat grass (33% of total time) were the fodder varieties the goat spent the greatest amount of time, followed by oat grain (23% of total time) and lucerne (10% of total time).

Figure 8.7 Mean time spent in seconds by goats at the fodder range available (P = 0.251 ± SEM, n=5, df = 19).
Figure 8.8 Mean number of bites taken by goats at each variety of the food range offered (P = 0.403 ± SEM, n=5, df = 19).

The greatest number of bites of a fodder variety by goats was at oat grass (50 % of total bites) followed by rye grass (35 % of total bites), then oat grain (10 % of total bites) and lastly lucerne with only 4% of total bites taken, even though there were no significant differences among all fodder varieties (fig.8.8).

Figure 8.9 Mean number of steps taken by goats to reach each variety of the food range offered (P = 0.537 ± SEM, n=5, df = 19).
There were no significant differences among all fodder varieties for steps taken to reach each fodder variety taken by goats (fig. 8.9). The greatest number of steps taken was to rye grass (40% of total steps) closely followed by oat grass (38% of total steps), then lucerne (14% of total steps) and lastly, oat grain, with 8% of total steps by goats to reach each fodder variety (fig. 8.9).

The goat data suggests there might be some degree of preference among the food or fodder provided, firstly rye grass, followed by oat grass and oat grain with lucerne least favoured of the fodder varieties. Therefore, the goat spent time consuming all fodder varieties indicating it would consume all varieties when foraging.

8.3.1.4 Sheep

Sheep during this trial did spend time at all fodder varieties presented with significant differences between fodder varieties (fig.8.10). Sheep clearly indicated oat grain was very palatable by spending 80% of the total time in this trial at that fodder variety. Oat grain was significantly different to the remaining three fodder varieties, which were not significantly different to each other. Oat grass total time was only 8%, with rye grass, 7% and lucerne, 5%.
Figure 8.10 Mean time spent in seconds by sheep at the selection of fodder available (P < 0.001 ± SEM, n=5, df = 19). The different alphabetical characters indicate significant differences (P<0.05) amongst the fodder varieties.

Figure 8.11 Mean number of bites taken by sheep at each variety of the food range offered (P < 0.001 ± SEM, n=5, df = 19). The different alphabetical characters indicate significant differences (P<0.05) among the fodder varieties.

The most bites taken by sheep was at the fodder variety oat grain (74% of total bites) which was significantly different to the other fodder varieties, followed by oat grass (13% of total bites), then lucerne (7% of total bites) and lastly rye grass (6% of total bites).
The greatest number of steps taken to all fodder varieties was to oat grain (44% of total steps) which was significantly different to all the other fodder varieties, followed by rye grass (24%), then oat grass (19%) and lastly lucerne (13%) (fig. 8.12). Lucerne, rye and oat grasses were not significantly different to each other.

The sheep data has clearly highlighted the palatability preference of oat grain by sheep, with no preferences indicated among the three plant species on offer.

8.3.1.5 Food Varieties

Wallabies spent more time consuming lucerne than any other species, while kangaroos spent the least time consuming lucerne (fig. 8.13). The wallaby allocated just under one third of the total time during the trial at lucerne. The remaining herbivore species allocated less than 10% of their total time consuming lucerne plants.
Figure 8.13 Standardised time percentage each of the four herbivore species spent consuming the pasture plant Lucerne.

Wallabies again have devoted the most time consuming rye grass with 60.6% of their total time allocated for the trial. The remaining three species increased the percentage of time spent consuming rye grass (fig 8.14) compared to lucerne (fig. 8.14).
Figure 8.15 Standardised time percentage each of the four herbivore species spent consuming the pasture plant Oat grass.

Kangaroos allocated 40.8% of their allocated time in the trial consuming oat grass with goats not far behind with 33.5% of their allocated trial time devoted to consuming oat grass (fig. 8.15). However the wallaby and sheep only allocated 8% of their allocated trial time consuming oat grass.

Figure 8.16 Standardised time percentage each of the four herbivore species spent consuming Oat seeds.
Sheep clearly devoted most of their allocated trial time to consuming oat grain (80%) (fig. 8.16). At the other end of the spectrum it was clear that the wallaby avoided the unpalatable oat grain completely, which needs further investigation. Both the goat (23%) and the kangaroo (18.7%) allocated approximately one fifth of their time to the consumption of oat grain.

8.3.1.6 Summary

The palatability trial provided important information on each species’ preference for the fodder variety tested, which was sown in the pens of the Hutchinson trial (Chapter 7). The investigation assists in the understanding of how the larger species chose not to eat small pasture plants in the presence of abundant oat grain, or whether they did not find those plants.

There are clear differences between the palatability of the various food types for the tested grazing species. The goats ate all of the food varieties tested, and there were not any significant differences amongst the foods samples in all categories tested. Sheep results were completely opposite to the goat, with oat seed being significantly greater to the other food varieties test for all the different categories. The kangaroo results indicated that they preferred green grass and oat seed in preference to lucerne. This result suggested greater direct competition with the goat for rye and oat grass and to a lesser extent, with the sheep. The kangaroo would also be in direct competition with the goat and the sheep for the oat seed. This result has implications for farmers on Kangaroo Island and mainland Australia during drought condition when hand feeding oat seed for sheep. Wallabies have clearly shown that oat seeds are highly unpalatable and that they are not interested in consuming oat seed, even when they are in abundance. The wallaby would not be competing against sheep for this valuable hand feeding fodder. The
results indicate that the kangaroo and the feral goat would be in greater competition with the sheep for oat seed during hand feeding in drought conditions, even when the oat seed was disbursed during the day.

The palatability trial demonstrated that rye grass and oat grass were palatable to goats and western grey kangaroos, which in turn indicated that any relatively lower consumption of plants of these plant species compared with the tammar wallaby was due to lower foraging efficiency. The design of the trial, however, did not enable the abilities of the animal to find plants or the abilities to prehend plants to be distinguished. The trial also demonstrated the high palatability of oat grain to sheep, and the low palatability of oat grain to wallabies, in the presence of growing pasture plants. It demonstrated that sheep would eat growing pasture plants if available, but it did not demonstrate that wallabies would eat oat grain.

8.3.2 Oat grain trial

The wallabies lost weight during the trial (fig. 8.17 & Table 8.2), weight loss was significant at each weighing period (fig. 8.18), with the average weight loss of 0.55 kg over 14 days.
Figure 8.17 Wallaby weight in kg at each weighing period for the oat trial.

Table 8.2 Identification number and weights of each wallaby in the oat seed trial from 24th November to 7th December 2008 inclusive.

<table>
<thead>
<tr>
<th>#</th>
<th>Wallaby ID</th>
<th>Initial W</th>
<th>Day 4</th>
<th>Day 9</th>
<th>Day 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A 077-078</td>
<td>6.466</td>
<td>6.070</td>
<td>5.921</td>
<td>5.837</td>
</tr>
<tr>
<td>2</td>
<td>A 071-072</td>
<td>6.531</td>
<td>6.274</td>
<td>6.122</td>
<td>6.038</td>
</tr>
<tr>
<td>3</td>
<td>A 101-102</td>
<td>5.355</td>
<td>4.990</td>
<td>4.960</td>
<td>4.915</td>
</tr>
<tr>
<td>4</td>
<td>A 098-099</td>
<td>6.386</td>
<td>6.053</td>
<td>5.967</td>
<td>5.863</td>
</tr>
<tr>
<td>5</td>
<td>A 059-060</td>
<td>5.323</td>
<td>4.923</td>
<td>4.783</td>
<td>4.708</td>
</tr>
<tr>
<td>6</td>
<td>A 067-068</td>
<td>5.494</td>
<td>5.073</td>
<td>4.916</td>
<td>4.922</td>
</tr>
</tbody>
</table>

Figure 8.18 Mean weight (kg) loss of wallabies (n = 6) at the data collection days compared to the mean of initial weight. Each weighing day recorded significant weight loss. The different alphabetical characters indicate significant differences (P <0.001 at the 0.05 significance level, means ± SEM, df = 5) among weighting times.
The mean weight loss was significant at each weighing day of the trial. At each data collection day, wallabies lost significant weight compared to the previous weighing day (fig 8.18). The greatest weight loss was from the beginning of the trial until day four. This indicated the wallabies ate the oat grain when no other food sources were available.

![Bar chart showing change in wallaby condition score over the duration of the oat seed trial.](image)

Figure 8.19 Change in wallaby condition score over the duration of the oat seed trial. Numbers on the X axis represent the wallaby while numbers on the Y axis represent Condition Scores (CS).

Four of the six wallabies in this trial lost enough weight to reduce the body condition score by one level (fig. 8.19). One wallaby which was in the highest CS at the peak of fitness had been reduced to CS 4, while the other three wallabies had been reduced from CS 4 to CS 3 which is the minimum CS at which locomotionary performance is maintained (Chapter 6). The remaining two wallabies remained at CS 4, even though they had lost weight during the trial.
The percentage weight loss of the six wallabies over the 14 days of the trial ranged from 7.5 to 11.6 (fig. 8.20). The wallaby that lost the least weight was the one in CS 5 while the wallaby that lost the greatest was in CS 4. The two wallabies (#’s 1 and 4, fig 8.19) that did not lose enough weight to reduce their CS level lost 9.7 and 8.2% of their body weight.

8.3.3 Summary

It was clear that wallabies would eat oat seed if there were no other source of food available. However, on an oat grain diet, significant weight loss occurred. The lower weight loss after the first four days of the trial suggested that the wallaby adapts over time (to some extent) to an oat seed diet. Whether they are able to adapt sufficiently to indefinitely maintain body weight at a lower level of body condition is not known. The condition score (CS) (Chapter 6) of each animal was calculated for the initial body weight and at the end of the trial, with 66% of the wallabies losing enough weight to reduce their CS by 1 level (fig 8.19) even though the average weight loss had been 9.3% (fig.8.19). The CS level of 3 was the lowest level where the wallaby is considered fit and
has not lost muscle condition (Chapter 6). Therefore, the loss of condition of the wallabies in this trial did not occur to the extent that it reduced the animals’ ability to find food in the wild or to compromise its ability to function normally.

### 8.4 Discussion

The aim of this study was to investigate whether all the pasture plants and the oat grain were palatable to all of the test herbivore species. As discussed earlier in this chapter, palatability/preference is determined by the relationship between taste and digestibility. In this study none of the animals reached the point where any of the food on offer was eaten to satiety which would skew the trial results, forcing the animals to choose other less favourable food varieties (Provenza 1996; Provenza, Scott et al. 1996).

The age of the plants determines the level of defences, taste and palatability (Elger, Lemoine et al. 2009; Gowda and Palo 2003; Trager and Bruna 2006). Trial plants were young, not fully matured to simulate the age of the plants in the Hutchinson trial (Chapter 7) therefore if there were any chemical defences to protect the plant from herbivores, they would be minimal. All animal species consumed the young pasture species suggesting any defences against herbivory attack were nonexistent. The height of each plant variety was similar to avoid any possible preference for a plant at a certain height (Arsenault and Owen-Smith 2008). The height of a plant has been shown as a deterrent for sheep with sheep preferring short rye grass (Ginane and Dumont 2010).

The three large herbivores consumed all fodder varieties on offer, with the goat (a browser) having the narrowest range of ranked values for the fodder varieties (table 8.1). The results for time spent (fig. 8.7), bites (fig.8.8) and steps (fig.8.9) also reflected there was not any preference for each variety and found all fodder palatable.
Kangaroos consumed all fodder varieties on offer, which had a wider range of ranked values compared to the goat and wallaby, and a smaller range than the sheep (table 8.1). The kangaroos preferred to consume the pasture plants of rye and oat grass equally over oat grain and lucerne.

Sheep spent time and consumed all fodder on offer, but had the widest of ranked values of the four herbivores in the trial (table 8.1). Sheep clearly preferred oat grain, with significant results for time spent (fig. 8.10), bites (fig. 8.11) and steps (fig. 8.12) even though the sheep were familiar with the other fodder and were of consistent heights (Ginane and Dumont 2010).

The plant and grain variety on offer indicated the wallaby (a browser) found the oat grain unpalatable when compared to the green young pasture plants on offer. Lucerne and rye grass were clearly the most palatable of all the fodder on offer (table 8.1). Further investigation into whether wallabies eat oat grain has found the wallaby will eat the unpalatable oat grain when there is not any other fodder present. Wallabies lost significant weight at first, when compared to their initial weight, but continued to lose weight until their weights stabilised (fig 8.18). The weight loss was enough to reduce the body condition of all animals, although only two thirds of the test animals had a reduction in their respective condition scores (fig. 8.19). The reduction was not of a drastic nature at a time in captivity when feed on high quality food and the animal was in almost optimal body condition. However, if the animal in the natural habitat and in drought conditions, the loss of a condition scores level could have drastic ramifications for the animal. As discussed in Chapter 6, the condition score (CS) boundary between CS2 and CS3 is
where the Gastrocnemius and Deep Digital Flexor muscles are compromised and the locomotional performance of the animal is reduced.

The fact that wallabies found the oat grain unpalatable has ramification for the farmers on Kangaroo Island during drought condition when hand feeding oat grain to sheep. The wallaby is culled by farmers, especially in drought conditions, by obtaining destruction permits. The wallaby, due to their high numbers on Kangaroo Island, are considered a pest species, and in supposed competition for resources with sheep especially when hand feeding. This study has shown that the wallaby does not prefer oat grain and would prefer to find other fodder to eat. Also, the wallaby does lose body condition eating oat grain. In drought conditions, the wallaby would already be in the lower body condition score levels and would prefer to browse other food resources on offer to the oat grain.

This study has validated the Hutchinson trial results by providing evidence that the large herbivores would have eaten the plants in the trial, if they were able to find them or prehend them, compared to the wallaby.
Chapter 9

Alternative explanation

9.1 Introduction

Competition between animals which share the same environment and resources is complicated. Despite this, the Hutchinson theory focused on only one explanation for the avoidance of interspecific competition. Avoidance of interspecific competition can result from both temporal and spatial separations, and some competitors have evolved different features that provide an advantage to one competitor to out-compete another competitor for the same resources in the same time and space.

Herbivores graze constantly, except when sleeping, therefore, many thousands of bites are taken daily from the forage on offer (Shipley 2007). Bite size is firstly dependent on herbivore size, and secondly by the size and abundance of vegetation, which each influence harvesting rates (Searle, Hobbs et al. 2005; Shipley 2007). Larger herbivores require greater dietary intake, and thus have larger morphological features to remove and chew larger quantities of herbage, thereby increasing efficiency compared to smaller bites (Maguire, Ramp et al. 2006; Searle, Hobbs et al. 2005). For these larger animals, a consequence of smaller bites would be longer foraging time. The larger bite size provides greater efficiency and reduces harvesting time for the larger herbivore, suggesting larger herbivores have an advantage over smaller herbivores when competing for the same resources. However, size difference of the bite is not the only reason for longer or shorter foraging and harvesting times.

Herbivores have evolved different mouth anatomy, which allows greater bite sizes and has shaped the different structure of grazers and browsers (Shipley 2007). Browsers have
narrow muzzles and incisors, longer tongues and lips that can help wrap around the herbage being browsed, compared to grazers with wider muzzles and incisors, allowing for greater bite width (Shipley 2007).

Many other anatomical and morphological features could influence the distribution, and avoidance of interspecific competition. Several of these features include eyesight (Clarke, Jones et al. 1995; Howland, Merola et al. 2004), metabolic weight and surface area (Garland 1983b), speed of the animal and body size (Garland 1983a) and reaching height of animals (Jiang, Ma et al. 2010). Along with the above mentioned features that could allow animals in the same environment to escape interspecific competition, is the preference of each animal to the height of the vegetation chosen (Arsenault and Owen-Smith 2008). Shipley (2007) concluded that ecologists need to research the effects of bite size of herbivores when measuring and predicting competition amongst herbivores for plants.

9.2 Methods

Mouth measurements were recorded from the four species of interest; tammar wallaby, western grey kangaroo, goat and sheep within 30 minutes of euthanasia. The lower jaw dental arcade width, lip coverage, tongue length and upper incisor/pad length were measured to the nearest mm. All body weights were recorded.

The most common measurement for dietary intake is bite width, which is associated with head width (Kurihara and Oda 2009) and bite force (Vanhooydonck, Cruz et al. 2010), while other studies have utilised mouth width (Arsenault and Owen-Smith 2008) as measurements involved with dietary intake. The animal species in this study had two different bite actions. The macropod (Lentle, Stafford et al. 1998b) action is different to
the domestic species therefore, the combination of lower dental arcade width and upper incisor/pad length were utilised to provide data for bite width comparisons of the four herbivore species.

9.2.1 Lower dental arcade width
The measurement to the nearest mm was taken of the lower jaw width across the dental arcade at its widest point.

9.2.2 Tongue length
Tongue was measured from the point of reflection of the base of the organ on the floor of the oral cavity to the tip of the mid line of the free end (un-stretched).

9.2.3 Lip length
Lip length was measured from the point of reflection of the mid line of the upper lip and gum, to the free edge of the lip (un-stretched).

9.2.4 Incisor/Pad length
The incisor length was measured just to the left side of the philtrum of the wallabies and kangaroos and in an equivalent position of the lips of sheep and goats.

9.2.5 Data Analysis
The linear data for lip length, incisor row width, tongue length and width of dental arcade were corrected for scaling purposes (x³) before being expressed as a proportion of body weight. The standardised data were then multiplied by 10 to provide data for a one way ANOVA. Data were analysed to investigate differences among the test species utilising a one-way ANOVA with significance denoted by P<0.05. The software program used was
9.3 Results

Sheep weight was significantly greater than that of the kangaroo and goat, with the wallaby significantly smaller than all three larger herbivores. Sheep mean weight was 8.75 x greater than wallaby weight. Also, kangaroo and goat mean weights were more than 4 x the wallaby mean weight. Sheep mean weight was almost double the weight of the kangaroo and goat (fig. 9.1).

Figure 9.1 Comparison of the four test species’ mean body weight (kg). Different alphabetical characters indicate significant differences (P <0.001 at 0.05 significance level, means + SEM, n=20, df = 19) among species.
Figure 9.2 Average lip length (mm) of the four species (P < 0.001, means ± SEM, n=20, df = 19). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species.

Figure 9.3 Standardised lip length (mm) to body weight (kg) (P = 0.036, mean ± SEM, n=20, df = 19). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species.

Even though the sheep was double the weight of the kangaroo and goat, the absolute lip length of the kangaroo was not significantly greater than the sheep, although the goat absolute lip length was significantly lower to the kangaroo (P<0.001, fig 9.2). The relative lip length of the wallaby was not significantly shorter compared with the lips of all of the larger herbivores (P<0.036, fig 9.3). The longer the absolute lip length the greater ability the lips have at grasping and manipulating the food items.
Figure 9.4 Mean left incisor/pad row length (mm) ($P < 0.001$, means + SEM, $n=20$, $df = 19$). Different alphabetical characters indicate significant differences ($P < 0.001$ at 0.05 significance level) among species.

The mean absolute left incisor/pad row length was significantly lower for the wallaby compared to each of the larger herbivores ($P < 0.001$, fig. 9.4). The sheep and wallaby both had significantly lower relative incisor/pad row length compared to the goat and kangaroo ($P < 0.001$, fig. 9.5).

Figure 9.5 Standardised incisor row length (mm) to body weight (kg) of the four test species ($P < 0.001$, mean + SEM, $n=20$, $df = 19$). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species.
Figure 9.6 Mean tongue length (mm), n=20, df = 19. Different alphabetical characters indicate significant differences (P <0.001 at 0.05 significance level, means + SEM) among species.

Kangaroo mean absolute tongue length was significantly longer than the goat and wallaby, but not significantly longer than the sheep. Sheep and goat mean absolute tongue lengths were not significantly different (P<0.001, fig. 9.6). The wallaby relative tongue length was not significantly longer than the kangaroo and goat. However, the relative tongue length of the wallaby and kangaroo was significantly different to the sheep (P<0.001, fig. 9.7).

Figure 9.7 Standardised tongue length to body weight of the four test species (P<0.001, mean + SEM). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species.
Figure 9.8 Mean lower jaw width (mm) (P<0.001, means + SEM), n=20, df = 19. Different alphabetical characters indicate significant differences (at 0.05 significance level) among species.

Figure 9.9 Standardised width of dental arcade to body weight of the four test species (P<0.008, mean + SEM). Different alphabetical characters indicate significant differences (at 0.05 significance level) among species.

Sheep had the absolute widest lower jaw of all the four herbivore species, which was significantly wider compared to kangaroo, goat and wallaby (P<0.001, fig.9.8). Furthermore, the relative lower jaw width of the wallaby was significantly wider to the sheep and goat species but not significantly wider to the kangaroo species (P<0.008, fig 9.9).
Table 9.1 A visual summary diagram of absolute morphological features that was significantly different among the four herbivore species. Colour differences across rows signify features that are significantly different between species.

<table>
<thead>
<tr>
<th></th>
<th>Wallaby</th>
<th>Kangaroo</th>
<th>Goat</th>
<th>Sheep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lip L</td>
<td>[Red]</td>
<td>[Yellow]</td>
<td>[Green]</td>
<td>[Yellow]</td>
</tr>
<tr>
<td>Incisor L</td>
<td>[Red]</td>
<td>[Yellow]</td>
<td>[Green]</td>
<td>[Yellow]</td>
</tr>
<tr>
<td>Tongue L</td>
<td>[Red]</td>
<td>[Yellow]</td>
<td>[Green]</td>
<td>[Yellow]</td>
</tr>
<tr>
<td>Jaw W</td>
<td>[Red]</td>
<td>[Green]</td>
<td>[Green]</td>
<td>[Yellow]</td>
</tr>
</tbody>
</table>

Table 9.2 A visual summary diagram of standardised morphological features that was significantly different among the four herbivore species. Colour differences across rows signify features that are significantly different between species.

<table>
<thead>
<tr>
<th></th>
<th>Wallaby</th>
<th>Kangaroo</th>
<th>Goat</th>
<th>Sheep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lip L</td>
<td>[Green]</td>
<td>[Yellow]</td>
<td>[Green]</td>
<td>[Yellow]</td>
</tr>
<tr>
<td>Incisor L</td>
<td>[Green]</td>
<td>[Yellow]</td>
<td>[Green]</td>
<td>[Yellow]</td>
</tr>
<tr>
<td>Tongue L</td>
<td>[Green]</td>
<td>[Yellow]</td>
<td>[Green]</td>
<td>[Yellow]</td>
</tr>
<tr>
<td>Jaw W</td>
<td>[Yellow]</td>
<td>[Green]</td>
<td>[Green]</td>
<td>[Green]</td>
</tr>
</tbody>
</table>

Summary

The wallaby, being significantly smaller in body weight, also had significantly smaller absolute morphological facial features (Table 9.1) of all measured features of lip coverage, incisor length, tongue length and lower jaw width compared to the three larger herbivores. Kangaroos, despite having a lower body weight than the sheep, did not differ significantly in absolute facial characteristics of lip coverage, incisor/pad length and tongue length; although the lower jaw width was significantly different. However, the goat was significantly smaller than the kangaroo and sheep with respect to absolute lip coverage only, but not significantly different to the sheep in absolute incisor length and
tongue length. The goat was significantly different to the kangaroo in absolute tongue length and lower jaw width. When the morphological facial characteristics were standardised to body weight (table 9.2), the wallaby, the smallest competitor, had relative sized features (lip coverage) not significantly different to the three larger herbivores. However, some features were both significantly smaller (incisor row length) and larger (tongue length and jaw width) than some of the larger herbivores.

9.4 Discussion

Comparison of the four species revealed differences between the three larger species and the smaller species which was to be expected in response to the difference in size. However, when analysed to include relative body weights, the results shifted with the smaller animal having significantly longer features to some of the larger herbivores.

Sheep are grazers and have larger mouth width compared to the kangaroo and goat which are browsers (Shipley 2007). Grazers take larger bites and which more efficient than small bites. Sheep are known to methodically and actively search for palatable fodder (Bosworth 2005; Dumont and Petit 1998; Edwards, Newman et al. 1996b; Edwards, Newman et al. 1997) with bite size influencing the patches of fodder selected. With larger mouth widths, the intake of fodder is greater, regardless of palatability and digestibility. Sheep have higher metabolic rates compared to the kangaroo (Mc Nab 2005; Nagy 2005; Nagy, Sanson et al. 1990) and require greater intake of digestible matter to be viable in times of restricted availability of resources. Mouth size influences bite size, and bite size is also influenced by body size dimorphism within a species, with significant differences between sexes (Perez-Barberia and Gordon 1999).
Small herbivores are disadvantaged by having smaller bite size when compared to larger herbivores. Smaller herbivores take a large bite size relative to their body size (Shipley 2007). The current study has shown the smallest animal had only a significantly smaller mouth width, relative to body size, to one larger herbivore. Also, an African study has shown that a large herbivore can have a competitive advantage to a smaller herbivore when there is a difference in vegetation height (Arsenault and Owen-Smith 2008). For example the zebra has a significant advantage over the white rhino with respect to grass height although the white rhino has a significantly larger muzzle width. However the larger muzzle width allows a competitive advantage for the rhino on short grasses.

The height of the grazed vegetation preference has separated species that coexist in the same habitat (Arsenault and Owen-Smith 2008; Durant, Fritz et al. 2003). An African ungulate community of impala, wildebeest, zebra and white rhino was able to coexistence in the same habitat, thereby escaping interspecific competition, irrespective of the size of the competitors (Arsenault and Owen-Smith 2008). These animals have certain plant height preferences when consuming the same vegetation. The South African study had a suite of herbivores that, according to the Hutchinson theory, should not have been in direct interspecific competition for resources, just by their size. However, the rhino is in competition with the smaller herbivores, the impala and wildebeest, with overlapping vegetation height grazed (no significant difference) (Arsenault and Owen-Smith 2008). The impala weight is six times less than the rhino and the wildebeest is approximately two and a half times less than the rhino. The zebra is just within the Hutchinson ratio of 2.1 x body weight ratio and should be in direct interspecific competition with the rhino, but the zebra has significantly smaller relative muzzle width and grazes on significantly longer grasses (Arsenault and Owen-Smith 2008). The smaller muzzle width of the zebra
allows for greater selectivity for removal of desired swords or seeds from a patch of vegetation.

Browsers, in general, have longer tongues and supple lips compared to grazers (Shipley 2007). This was only weakly supported in the current study. The kangaroo had the absolute longest tongue of all species tested. However, the goat, which is a browser, had a shorter tongue than the kangaroo and sheep. Browsers have longer narrower muzzles to be able to exploit thorned plants with their longer tongues (Shipley 2007), also supple lips to assist with removal of vegetation. Kangaroos and wallabies have a cleft upper lip which aides in protruding the teeth to allow selection of vegetation (Hongo, Toukura et al. 2007). Sheep and goat do not have a cleft upper lip.

Nutritional requirements are a function of body weight to the power of 0.7 (Garland 1983b). That exponent is in turn determined by the animal’s surface area to body weight ratio. There is also the difference between placentals and marsupials that have different metabolic rate. The marsupial has a lower metabolic rate and therefore requires less good quality food to survive compared to the placentals. Heat loss is also a function that varies between animals of various sizes. A small animal will lose greater heat due to the small surface area of the animal; the larger animal has a larger surface area and has less heat loss. The smaller animal requires higher yielding quality food to maintain heat. Due to the body weight power function and the surface area/heat loss, smaller herbivores have trouble getting enough quality food through their digestive system to maintain homeostasis (Uden and Van Soest 1982).

Eyesight of each animal is dependent on the absolute size of the eye and therefore the size of the animal (Howland, Merola et al. 2004). If an animal relies on sight to find food, the
larger animal will have better eyesight, which may well be sufficient to counter the fact that its eyes are further from the plant. The resolving power of the eye increases with absolute eye size (Howland, Merola et al. 2004). The test animals were of varying heights and weights with the wallaby the smallest in respect to height and weight, to the kangaroo, the tallest with the sheep weighing the greatest. Therefore, kangaroos and sheep should have the largest eyes and resolving power to see the smaller plants. The goat and sheep were of similar heights but not weights, and should have similar size eyes and resolving power. Along with the larger eye with the larger animal, there is a further advantage with increasing height.

Animals that are taller have greater reach (Jiang, Ma et al. 2010), but presumably also reach down to graze on the ground if needed. The height advantage means the larger herbivore has access to more food reserves in the same area, if that area has trees and shrubs. The suite of animals tested (Chapter 7) co-exist on Kangaroo Island, where there is much more browse that is within reach of the larger herbivores that is not available to the tammar wallaby due to their height.
Chapter 10

General Conclusion

The Hutchinson Theory of Interspecific Competition (Hutchinson 1959) predicts that two animals will be able to avoid direct competition if the size of the body weight ratio is greater or lesser than $2.1x$. The broad aim of this research was to better understand interspecific competition among the 4 terrestrial mammalian herbivore species on Kangaroo Island, South Australia, one of which has a smaller adult body size than the others, in the context of the Hutchinson Theory. The specific objectives of this research were to investigate:

- To test whether the removal of sheep from the suite of competing grazers influenced the composition of the pastures on either side of a boundary fence;
- Interspecific competition in situ at the north-western end of Kangaroo Island, where all four herbivore species co-exist. This investigation included dietary overlap among species via cuticle analysis from faecal deposits;
- A method to determine the physical fitness of macropod species for inclusion in scientific trials;
- Predictions arising from the Hutchinson Theory via two trials: a replicated mixed species trial; and a pseudoreplicated single species trial.
- The palatability of the pasture plant species to validate the results obtained in the Hutchinson Trial;
- The palatability of oat grain for the tammar wallaby;
- Alternatives to the Hutchinson Theory.

Prior to the start of the competition trials all animals required assessment of their physical fitness for either inclusion or rejection. Condition score systems were available for the
sheep and goat species with nothing comparable for the macropod species. Therefore, to validate the use of each individual macropod in the trials of the current study, a body condition scoring system (Chapter 6) was required to determine body condition of each animal. The sole purpose was to either exclude or include the macropod in the grazing trial. Wallabies were deemed to be the macropod with the greatest need for validation. An identical system of determining body condition of the wallabies was utilised for the kangaroos. The system revealed the wallabies to be in a range of condition scores (CS). The crus muscle index assessed the degree of muscle wasting of crucial locomotory muscles and hence whether the individual animal was unfit for use in any trial that involved normal locomotive performance. It revealed that animals with a condition score below CS 3 had been, therefore, only wallabies with a score greater than CS 2 were included in the experimental trials.

The Hutchinson hypothesis was supported by the evidence that wallabies in the pen trials were more able than the larger herbivores to find small palatable plants (Chapter 7) and the wallabies appeared to be more able to access germinating Allocasuarina verticillata following rain on Kangaroo Island (Chapter 5). However, there were 28 tests (Chapter 7) in total for the competition trials. Although some of the tests revealed support for the Hutchinson hypothesis, many more tests showed either no significant competitive advantage by the smaller wallaby or evidence of a competitive advantage by a larger-bodied species over the wallaby.

Examples of tests that failed to reveal a competitive advantage on the basis of size included all plant present tests (7) and plant biomass tests (7) for the 3 versus 4 species replicated trial, except for the biomass for Polygonum aviculare.
Examples of a competitive advantage of a larger species were obtained in the pseudo replicated trial include the goat, having an advantage over the sheep, but not the wallaby and kangaroo, with respect to the number of plants present for *Tribulus terrestris*. Also the kangaroo and sheep had an advantage over the wallaby with significantly fewer *Althaea officinalis* weeds present in their pens.

Pseudo replication in ecology is acceptable for gaining greater understanding of natural systems. Full replication of all experimental work is not always possible due to financial and logistical constraints. As previously discussed, much enlightenment and understanding of natural systems would be missed if full replication was the only accepted experimental design, provided that the interpretations of the results are appropriately guarded.

The current study showed morphological differences in lip and dental morphology between the test species, both in absolute terms, and when corrected for size and scale *(Chapter 9)*, suggesting that morphology has a potential influence on competitive interactions. The importance of morphology has been demonstrated by Arsenault and Owen-Smith (2008), who showed that the largest-bodied grazing herbivore in existence, the white rhinoceros, is afforded a competitive advantage over its smaller competitors attributed to the square shape of its lip, negating any disadvantage of size attributable to the Hutchinson hypothesis.

The pasture at all three sites on Kangaroo Island *(Chapter 4)*, High, Chris’s and Duncan’s paddocks varied with seasonal conditions. Duncan’s paddock was the only site that did not have any bryophytes present throughout the study period. The pasture on both sides of a recently erected boundary fence at High and Chris’s paddocks fluctuated and
varied with seasonal conditions. However, there were indications at Chris’s and High paddock that sheep facilitated the growth of *Trifolium subterraneum* and *Arctotheca calendula* in the pasture within the boundary fence.

The dietary overlap results on Kangaroo Island (Chapter 5), indicated a low level of dietary overlap across all four herbivores which in itself does preclude high levels of inferred competition. However, the greatest dietary overlap result was between pairs of herbivores, which occurred in spring, when plant growth was at its greatest. This was presumably due to the coincidence of warmth and rain in the Kangaroo Island environment. However, the high dietary overlap could also indicate a lack of assumed direct competition due to increased resource supplies. In summer and autumn, the dietary overlap decreased slightly due to diversification of plant species eaten with the increase of native browse vegetation in the diet. The increase in diversification and decrease in dietary overlap were contrary to many other dietary overlap studies that indicated dietary overlap increases when resources are in short supply during summer and drought conditions. The wallaby, the smallest competitor, appeared to be in direct competition with the three larger competitors, with the greatest implied competition for resources occurring between the wallaby and the kangaroo throughout the seasons. However, the high precipitation events, which occurred in late April 2007, and the resulting germination of *Allocasuarina verticillata*, provided an opportunity that was exploited providing an advantage to the wallaby due to its size. The wallaby had significantly greater amounts of this plant species in its diet than the larger herbivores in Spring 2007. There was no escaping the assumed interspecific competition against the larger species, for the wallaby on Kangaroo Island. During drought conditions, body condition is lost, especially if the drought is persistent for any lengthy period.
Kangaroo Island native herbivores are subjected to the same ramifications as mainland native herbivores with respect to loss of body condition during drought, which was evident when the wallabies were captured in 2006 (Chapter 6).

The palatability trial (Chapter 8) was important with respect to the plant structure and results of the two Hutchinson trials. There was no aversion to any of the plants or grain by the larger herbivores in the trial. However, the wallaby demonstrated a complete aversion to *Avena sativa* grain. Subsequently, another trial (Chapter 8) was required to explore the aversion of *Avena sativa* grain by wallabies. Wallabies will eat *Avena sativa* grain if there is no other fodder available. However, the wallaby had significant weight loss and loss of body condition. This aversion has important management implications for both the wallaby and the farmer on Kangaroo Island.

The management of native and introduced herbivores on Kangaroo Island is crucial for the survival of both the conservation of native vegetation and agricultural/pastoral activities with respect to two animals in this study. Firstly, wallaby numbers are managed by allocation of destruction permits to farmers to cull wallabies, an attempt to reduce assumed direct competition with the introduced sheep. The work in this study (Chapter 5) has shown the wallaby could be in alleged competition with the sheep, with the exception of one aspect. Wallabies find *Avena sativa* grain unpalatable and prefer other sources of food. This has very important implications for wildlife and farm management during drought conditions. Wallaby numbers are drastically reduced naturally in severe drought conditions, and at a time when farmers are hand feeding the sheep *Avena sativa* grain. Wallabies already suffering weight loss and reduced body condition may eat the *Avena sativa* grain, but they are not able to maintain body weight and hence body condition to survive prolonged drought conditions by solely eating *Avena sativa* grain.
Therefore, if farmers are permitted to continue culling the wallaby during this period of hand feeding sheep to reduce perceived competition with the sheep, the wallaby population may be severely impacted. If the population has been reduced by a combination of natural circumstances and culling, the wallaby’s long term viability may be jeopardised on Kangaroo Island.

Secondly, the feral goat population effect on the native vegetation. The goat diet in this study consisted in great proportion of native vegetation (Chapter 5). There were three native plant species that the goat consumed in greater proportions than the native herbivores; *Acacia leiophylla*, *Allocasuarina verticillata* and *Astroloma conostephoides*. The extent of the intake of *Acacia leiophylla* reduced dietary overlap with the other herbivores due to the apparent aversion of this plant species by the native herbivores. As discussed previously (Chapter 5) the goats’ preference for native vegetation is of great concern, especially for any vulnerable native tree or shrub species.

In conclusion, this study found some evidence in support of the Hutchinson theory of interspecific competition, but found more instances in which the theory was not supported. Because many factors other than size influence competition, the Hutchinson theory of interspecific competition is simplistic. It is only one means by which an animal can escape interspecific competition. There are many other explanations as to how animals are able to co-exist in the same habitat, utilising the same resources. These are not accounted for by the Hutchinson theory. This study of Kangaroo Island herbivores has raised concerns and management issues in relation to farmers hand feeding sheep, the culling of wallabies during drought conditions, and the impact of goats on native vegetation.
Appendix 1

Drug use and methods

Two methods were used at sequential stages to catch kangaroos for relocation to different sites throughout the current study; alpha-chloralose first, followed by darting with Zoletil (1:1 Zolazepam and Tileta-mine; Virbac, Peakhurst, New South Wales, Australia) if necessary.

1.1 Alpha-chloralose application for both in fodder and water supply

1.1.1 Fodder application

The use of alpha-chloralose in fodder has been discussed in Chapter 3.

1.1.2 Water supply application

Capturing kangaroos in Hutchinson trial pens to be transported back to the fauna yards involved a different approach to sedate the kangaroos. Alpha-chloralose on this occasion was dissolved in the water supply for each pen due to the abundant feed in the pens. The alpha-chloralose/water was produced by dissolving 9.5g of powdered alpha-chloralose in five litres of water (Arnold, Steven et al. 1986). The water was heated (Nelson 1994), not boiled, to avoid problems in dissolving the alpha-chloralose unlike the previous attempt using cold water. Some of the kangaroos were very hesitant at first to drink from the only watering point in each pen. The water was left and topped up daily; affected kangaroos were captured at dawn each day and placed into wool bags and transported to the fauna yard as described previously. The remaining kangaroos in the Hutchinson pens and in the fauna yard were monitored closely (daily) until no kangaroos exhibited any signs of having ingested the drugged water. The remaining kangaroos in the Hutchinson pens were very stubborn and just looked at the drugged water each day for seven days, with no signs
that they had drank any of the water. On the afternoon of the seventh day the drugged water was replaced with clean (non-drugged) water. The remaining kangaroos were shot with Zoletil drugged darts and transported to the fauna yard holding pen.

1.2 Zoletil application and materials

After unsuccessful attempts with food and water dosed with alpha-chloralose kangaroos on Roseworthy campus were captured by shooting the animal with a dart syringe. The dart was filled with Zoletil 100, an intramuscular anaesthetic, used as a sedative for dogs, cats, zoo captive animals and wild animals. The darts were purchased from Paxarms in New Zealand. Dart was assembled (figures Ap 1.1 & Ap 1.2) and tested with water to ensure smooth operation with no leakage of fluid or air. Darts were capable of holding 5 ml of the Zoletil/water mixture. Each dart mixture was obtained from inserting 3 ml of distilled water into the Zoletil container to dissolve the entire powdered drug. Therefore the concentration of the drug was 166 mg/ml with a total amount of 500 mgs in the dart. The mixture was removed by using a syringe and needle. Average weight of the kangaroos was estimated to be 30 kg therefore the dose rate was 17 mg/kg, which is within the safe working limits of the drug (Stott 1990). The mixed solution of Zoletil was pushed from a syringe to the dart via the needle at the front of the dart similar to figure Ap1.3. Once all the sedative was placed into the dart a plastic seal has been placed over the needle opening. Each dart was pressurised with compressed air from a hand pump device that is attached to the plastic feathers structure (fig. Ap1.3). The feather structure contains a valve that prevents the air from escaping once the pump is removed. The pressure at the rear of the dart was utilised to push the sedative into the animal once the dart had penetrated its hide (fig. Ap1.3). Dart for delivery of anaesthetic drugs is common practice for wild animals and has been utilised by many cultures throughout the world (Jones 1976; Wentges 1975)
Figure Ap 1.1 The components of the dart, the filling device and the hand pumping unit to pressurise the dart once the liquid drugs had been inserted into the dart.
PAXARMS
DART ASSEMBLY INSTRUCTIONS

1. Fit the valve gasket to tail.

2. Lubricate rubber piston between flanges with silicone lubricant.
   Using the plunger from the filling unit, push the black rubber piston all the way into the body.

3. Fit the gas check over the end of the dart body.
   (For accuracy, use the same gas check as more than twice.)

4. Screw needle into body with tube spanner provided, or pliers, until flange on needle comes firmly against gas check.
   Do not overtighten.

5. Withdraw plunger of filling unit from body 25mm.
   Insert filling unit into dart body until white rubber piston touches black rubber piston already in dart body.
   Then push the central plunger of the filling unit home firmly.

6. Recruit the filling unit for the amount of units of drug required in step 5 of filling instructions.

Figure AP 1.2 Dart assembly.
Figure AP 1.3 Method for filling the dart; firstly with the liquid drug and secondly the pressurising of the dart with the hand pump.

1.3  Wallaby capture and materials

Wallabies in the holding pen were captured with nets and placed into hessian bags and transported as previously described in chapter three. A fence was erected in the holding yard that divided the pen. The fence was constructed from star droppers with padding half way up the dropper, the droppers were covered in shade cloth that was suspended by wire stretching between the droppers. Shade cloth was attached to the droppers and pinned to the ground. An apron of shade cloth was on the ground on the side of the fence that the wallabies would be herded. This apron was also pinned to the ground. The padding was to
give the wallaby a level of protection against injuring itself if it ran into the dropper while trying to evade capture. The remainder of the dividing fence was made up of portable fencing panels secured by wiring to droppers. The dividing fence was connected to the boundary fence at one end, while the other end was stopped short of the boundary fence by 1.5 metres. This gap was the location where the wallabies were netted as they tried to escape. Several people would be herding the wallabies in the direction of the gap in the dividing fence. Once all the wallabies in the capturing half (area A) of the pen had either been caught, or had evaded capture another sweep of the pen was conducted to herd the wallabies that had evaded capture into the area A. Once all the wallabies had been caught, they were weighed; pes length was measured and they were checked for pouch young. The wallabies were suspended from the frame in the vehicle and transported to the Hutchinson pens where they were released into their allocated pens. The same procedure was followed once the Hutchinson trial had ended and the animals were transferred back to the holding pen,
Appendix 2

Cuticle pictures and Pant Identification

All of the cuticle pictures are at 10 times magnification.

Abbreviation key

1. Paddock locations
   - CPBV – Chris’s Paddock Borda Vale
   - HPBV – High paddock Borda Vale
   - DPCP – Duncan’s Paddock Correll Property

2. Pasture location, side of boundary fence
   - P – Paddock
   - C - Coast

Dicotyledon

![CPBV 01 Sept 06 P, Trifolium subterraneum](image1)

![CPBV 03 Sept 06 P & C Arctotheca calendula](image2)
CPBV 06 Sept 06 C, *Lepidosperma viscidum*

CPBV 07 Sept 06 C *Acacia paradoxa*

CPBV 08 Sept 06 C, *Allocasuarina verticillata*

HPBV 01 Sept 06, *Dodonaea viscosa*

HPBV 02 Sept 06 C, *Hibbertia riparia*

HPBV 03 Sept 06 C, *Astroloma conostephiodies*

HPBV 04 Sept 06 C, *Pultenea villifera*

HPBV 05 Sept 06 C, *Stackhousia aspericocca*
HPBV 06 Sept 06 C, *Acacia leiophylla*

HPBV 02 Oct 06 P, *Juncus pallidus*

DPCP 08 Sept 06 W, *Hibbertia aspera*

DPCP 09 Sept 06 *Euromyntus ramosissima*

DPCP 10 Sept 06 W, *Lepidosperma canescens*

DPCP 11 Sept 06 W, *Tetratheca halmaturina*
Monocotyledon

CPBV 05 Sept 06 P, *Vulpia myuros*

BV Grasses Sept 06 P, *Bromus hordeaceus*

BV Grasses Sept 06 P, *Vulpia bromoides*

DPCP 02 Sept 06 P, unidentified

DPCP 04 Sept 06 P, *Ehrharta*

DPCP 06 Sept 06 W, *Bromus*

DPCP 07 Sept 06 W, *Lolium rigidum*

CPBV 03 Oct 06 P, *Bromus madritensis*
<table>
<thead>
<tr>
<th>Sample Field Identification</th>
<th>Family</th>
<th>Genus</th>
<th>Species</th>
<th>Sub species</th>
<th>Common name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CPBV 01 Sept 06 P</td>
<td>Leguminosae</td>
<td>Trifolium</td>
<td>subterraneum</td>
<td></td>
<td>Sub clover</td>
</tr>
<tr>
<td>2 CPBV 02 Sept 06 P</td>
<td>could not be Identified</td>
<td>Arctotheca</td>
<td>calendula</td>
<td></td>
<td>Grass</td>
</tr>
<tr>
<td>3 CPBV 03 Sept 06 P &amp; C</td>
<td>Compositae</td>
<td>Arctotheca</td>
<td>calendula</td>
<td></td>
<td>Daisy/Capeweed</td>
</tr>
<tr>
<td>4 CPBV 04 Sept 06 P &amp; C</td>
<td>could not be Identified</td>
<td></td>
<td></td>
<td></td>
<td>Grass</td>
</tr>
<tr>
<td>5 CPBV 05 Sept 06 P</td>
<td>Gramineae</td>
<td>Vulpia</td>
<td>myuros</td>
<td></td>
<td>Annual Grass</td>
</tr>
<tr>
<td>6 CPBV 06 Sept 06 C</td>
<td>Cyperaceae</td>
<td>Lepidoperma</td>
<td>viscidum</td>
<td></td>
<td>Sticky sword-edge</td>
</tr>
<tr>
<td>7 CPBV 07 Sept 06 C</td>
<td>Leguminosae</td>
<td>Acacia</td>
<td>paradoxa</td>
<td></td>
<td>Kangaroo thorn</td>
</tr>
<tr>
<td>8 CPBV 08 Sept 06 C</td>
<td>Casuarinaceae</td>
<td>Allocasuarina</td>
<td>verticillata</td>
<td></td>
<td>Drooping sheoak</td>
</tr>
<tr>
<td>9 CPBV 09 Sept 06 C</td>
<td>Casuarinaceae</td>
<td>Allocasuarina</td>
<td>verticillata</td>
<td></td>
<td>Drooping sheoak</td>
</tr>
<tr>
<td>10 HPBV 01 Sept 06 C</td>
<td>Sapindaceae</td>
<td>Dodonaea</td>
<td>viscosa</td>
<td>ssp spatulata</td>
<td>Sticky hop-bush</td>
</tr>
<tr>
<td>11 HPBV 02 Sept 06 C</td>
<td>Dilleniaceae</td>
<td>Hibbertia</td>
<td>riparia</td>
<td></td>
<td>Erect guinea-flower</td>
</tr>
<tr>
<td>12 HPBV 03 Sept 06 C</td>
<td>Epacridaceae</td>
<td>Astroloma</td>
<td>conostephodies</td>
<td></td>
<td>Flame heath</td>
</tr>
<tr>
<td>13 HPBV 04 Sept 06 C</td>
<td>Leguminosae</td>
<td>Pultenea</td>
<td>villifera</td>
<td>var. glabrescens</td>
<td>Yellow bush-pea</td>
</tr>
<tr>
<td>14 HPBV 05 Sept 06 C</td>
<td>Stockhousiaceae</td>
<td>Stackhousia</td>
<td>aspericocca</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 HPBV 06 Sept 06 C</td>
<td>Leguminosae</td>
<td>Acacia</td>
<td>leiophylla</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 BV Grasses Sept 06 P</td>
<td>Gramineae</td>
<td>Bromus</td>
<td>hordeaceus</td>
<td>ssp hordeaceus</td>
<td>Soft brome</td>
</tr>
<tr>
<td>16a BV Grasses Sept 06 P</td>
<td>Gramineae</td>
<td>Vulia</td>
<td>bromoides</td>
<td></td>
<td>Squirrel-tail fescue</td>
</tr>
<tr>
<td>17 DPCP 01 Sept 06 P</td>
<td>Leguminosae</td>
<td>Trifolium</td>
<td>subterraneum</td>
<td></td>
<td>Sub clover</td>
</tr>
<tr>
<td>18 DPCP 02 Sept 06 P</td>
<td>Gramineae</td>
<td></td>
<td></td>
<td></td>
<td>Annual/perennials</td>
</tr>
<tr>
<td>19 DPCP 03 Sept 06 P</td>
<td>Compositae</td>
<td>Arctotheca</td>
<td>calendula</td>
<td></td>
<td>Daisy/Capeweed</td>
</tr>
<tr>
<td>20 DPCP 04 Sept 06 P</td>
<td>Gramineae</td>
<td>Ehrharta</td>
<td></td>
<td></td>
<td>Annual/perennials</td>
</tr>
<tr>
<td>21 DPCP 05 Sept 06 P</td>
<td>Gramineae</td>
<td></td>
<td></td>
<td></td>
<td>Annual/perennials</td>
</tr>
<tr>
<td>22 DPCP 06 Sept 06 W</td>
<td>Gramineae</td>
<td>Bromus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23 DPCP 07 Sept 06 W</td>
<td>Gramineae</td>
<td>Lolium</td>
<td>rigidum</td>
<td></td>
<td>Wimmera ryegrass</td>
</tr>
<tr>
<td>24 DPCP 08 Sept 06 W</td>
<td>Dilleniaceae</td>
<td>Hibbertia</td>
<td>aspera</td>
<td></td>
<td>guinea-flower</td>
</tr>
<tr>
<td>25 DPCP 09 Sept 06 W</td>
<td>Myrtaceae</td>
<td>Baeckea</td>
<td>ramosissima</td>
<td></td>
<td>Rosy baeckea</td>
</tr>
<tr>
<td>26 New Name</td>
<td>Myrtaceae</td>
<td>Euromyntus</td>
<td>ramosissima</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27 DPCP 10 Sept 06 W</td>
<td>Cyperaceae</td>
<td>Lepidoperma</td>
<td>canescens</td>
<td></td>
<td>Hoary rapier-sedge</td>
</tr>
<tr>
<td>28 DPCP 11 Sept 06 W</td>
<td>Tremandraceae</td>
<td>Tetraheca</td>
<td>halmaturina</td>
<td></td>
<td>Curly pink-bells</td>
</tr>
<tr>
<td>29 HPBV 01 Oct 06 P</td>
<td>Gramineae</td>
<td>Holcus</td>
<td>lanatus</td>
<td></td>
<td>Yorkshire fog</td>
</tr>
<tr>
<td>30 HPBV 02 Oct 06 P</td>
<td>Juncaceae</td>
<td>Juncus</td>
<td>palidius</td>
<td></td>
<td>Pale rush</td>
</tr>
<tr>
<td>31 CPBV 01 Oct 06 P</td>
<td>Gramineae</td>
<td>Bromus</td>
<td>hordeaceus</td>
<td>ssp hordeaceus</td>
<td>Soft brome</td>
</tr>
<tr>
<td>32 CPBV 03 Oct 06 P</td>
<td>Gramineae</td>
<td>Bromus</td>
<td>hordeaceus</td>
<td>ssp hordeaceus</td>
<td>Soft brome</td>
</tr>
</tbody>
</table>
References


Archer M, Flannery TE, Grigg GC (1985) 'The Kangaroo.' (Weldons)


Black JM (Ed.) (1986) 'Flora of South Australia.' (Government Printer: Adelaide)


Charry AA, Kemp DR, Lawrie JW Alpacas and ecosystem management. In '14th Congress of International Farm Management Association', 2003, Perth,


Harris LE (1970) Nutrition research techniques for domestic and wild animals. In. ’ (Utah State University: Logan)


Hutchinson GE (1959) Homage to Santa Rosalia, or why are there so many animals. American Naturalist 93, 145-159.


McLaren C (1997) Agriculture notes, Dry Sheep Equivalents for comparing different classes of livestock. In. ' (Department of Primary Industries, Victoria)


Morrison RGB (1981) 'A field guide to the tracks and traces of Australian animals.' (Rigby Publishers Limited)


Pople AR, Phinn SR, Menke N, Grigg G, Possingham HP, McAlpine C (2007) Spatial patterns of kangaroo density across the South Australian pastoral zone over 26 years:


Strathan R (Ed.) (1995) 'The Mammals of Australia.' (Reed Books)


Zeuner FE (1963) 'A History of Domesticated Animals.' (Hutchinson: London)